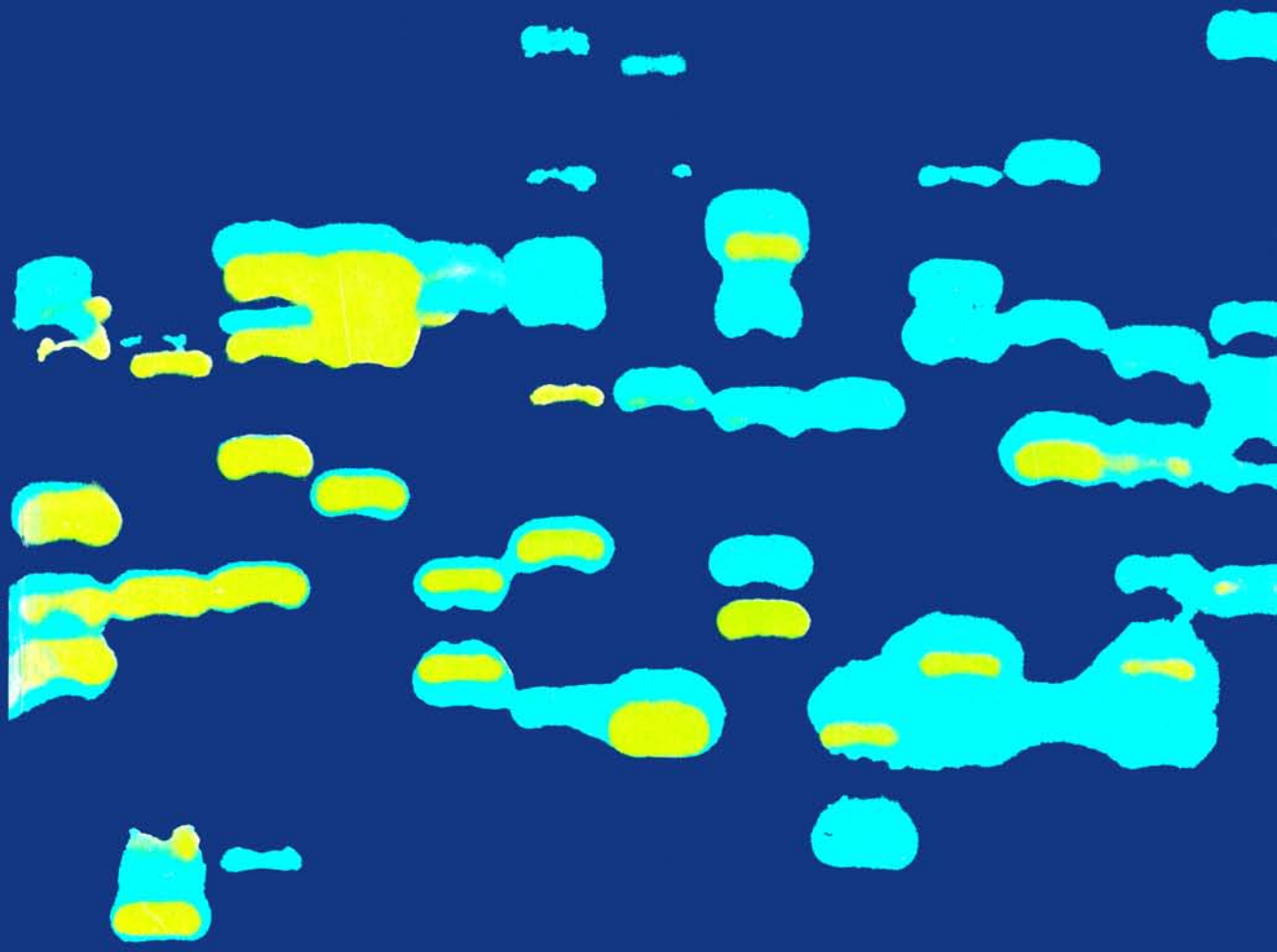
International Rice Research Institute

Annual Report for 1988



International Rice Research Institute

Annual Report for 1988

1989
INTERNATIONAL RICE RESEARCH INSTITUTE
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Foreword

Early in 1988, a 15-member IRRI Strategic Planning Unit was constituted to mobilize internal and external resources to produce a Strategic Plan for the Institute. This became the starting point of an institute-wide process that yielded the first draft of ***IRRI Toward 2000 and Beyond*** in August.

A second draft of the Strategic Plan was prepared, incorporating the comments and suggestions of various reviewers including two Strategy Review Panels of distinguished scientists from both industrialized countries and major rice-growing countries. Based on comments from the IRRI Board of Trustees, a third draft was prepared and reviewed by the Technical Advisory Committee (TAC) and a third Strategy Review Panel composed of distinguished scientists from governmental and nongovernmental agencies of our host country, the Philippines. A final draft was then prepared at year's end.

With the Strategic Plan well under way, in early December several Task Forces of IRRI staff were constituted to prepare the Five-Year Work Plan for the implementation of the strategy.

In designing our strategy for the year 2000 and beyond, we considered ongoing changes in the world of rice—from the physical environments to the people involved, and from demand and supply situations to new research tools—and how best IRRI could and should respond to them.

Our goal is the

improved well-being of present and future generations of rice farmers and consumers, particularly those with low incomes.

Our objectives are

to generate and disseminate rice-related knowledge and technology of short- and long-term environmental, social, and economic benefit and to help enhance national rice research systems.

Many of the issues related to rice are interdependent. The range of possible entry points for research is extensive, and difficult decisions must be made. Our policies are guided by the following considerations:

- research relevance,
- environmental and production sustainability,
- efficiency and equity, and
- disciplinary strength and interdisciplinary focus.

Our strategy aims at striking an optimum balance of efforts devoted to several alternatives, the most important of which are

- four rice ecosystems (irrigated, rainfed lowland, upland, deepwater and tidal wetland),
- three regions (Asia, Africa, Latin America),
- conducting research and helping to enhance national rice research systems,
- levels of research (adaptive, applied, strategic, basic), and
- securing previous yield gains and seeking new yield potentials.

IRRI programs will be oriented to the major rice ecosystems and to the farming communities and consumers that depend on them. Collaborative research on the less favorable rice ecosystems will increase. Consistent with environmental enhancement

and sustainability, IRRI will direct its efforts toward securing yield gains in favorable ecosystems while concurrently seeking new yield potentials in all ecosystems. Our research efforts will move toward strengthening our scientific base, using results and techniques emerging from the frontiers of scientific discovery.

During 1988, IRRI's research made progress on several fronts. We developed integrated pest management tools for rice leaffolder and yellow stem borer that will help determine action thresholds for pest managers. To increase the efficiency of nitrogen use, we found ways to reduce ammonia volatilization losses and continued to explore the potential of biological nitrogen fixation for rice production. From results of plant physiological and agronomic studies, we identified an improved plant type for direct seeding, a rapidly spreading crop establishment technique. We made significant progress in finding a stable cytoplasmic male sterile rice line and in evaluating the potential of gametophytes for the production of hybrid rice seed under humid tropical conditions. We continued to strengthen our capabilities in rice biotechnology in the areas of tissue culture, the preparation of genetic and molecular maps of the rice genome, and the isolation of desirable genes from wild rices through wide hybridization and embryo rescue techniques.

During 1988, we likewise pursued our commitment to help strengthen national rice research programs, and we will increase collaborative work and knowledge sharing with all of our partners. We look toward a mutually supportive global rice research system.

While IRRI will continue to focus on Asia, its worldwide responsibilities cover all regions. We will contribute to research and to strengthening national programs in Africa and Latin America in the context of the activities of other international agricultural research centers.

A recurring dilemma in research management is how to integrate the strengths of various scientific disciplines in seeking solutions to complex problems. Our strategy calls for a new program and management structure to facilitate the pursuit of excellence in both disciplinary and interdisciplinary research.

Both quantitative and qualitative changes will occur as IRRI's new strategy is implemented. Scientific disciplines will be grouped into divisions. Carefully designed interdisciplinary projects will be implemented through IRRI's research and international programs. The strategy calls for increasing the range and degree of collaboration with different types of research organizations and systems. All IRRI's work will continue to relate directly to its two primary objectives: conducting research and helping to enhance national rice research systems, so as to achieve the common goal of improved well-being of present and future generations of rice farmers and consumers, particularly those with low incomes.

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[4]Joined during the year.
[5]Cooperative research staff.
[6]On project appointment.
[7]Died during the year.
[8]Transferred from Soils to Water Management.
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[10]Transferred from Rice Farming Systems Program to Plant Breeding.
[11]Transferred from Human Resource Department to Communication and Publications.

About this report

This *Annual report* reviews research conducted by IRRI staff during 1988. Some experiments are summarized completely. Others are ongoing, and interim results are reported. In all cases, further information can be obtained from the appropriate units at IRRI. Institute scientists also report their results in *IRRI highlights*, the *International rice research newsletter* (IRRN), the *IRRI research paper series* (IRPS), conference proceedings, monographs, and technical journals.

Each year, the Institute intensifies its cooperative work with national and international agencies, based on priorities expressed at work plan meetings. Although almost every section of this report mentions these activities, they are featured in the International Collaboration section. Three programs that are based on international cooperation—the International Rice Testing Program (IRTP), the International Network on Soil Fertility and Sustainable Rice Farming (INSURF), and the Asian Rice Farming Systems Network (ARFSN)—are discussed there. Other sections that include a particularly strong international focus are Engineering Technologies and Training Programs.

The abbreviations and acronyms used in this report are listed on the following pages. In addition, we have spelled out all names and terms on first use in each subsection and have used abbreviations thereafter.

The report refers to four fundamental types of rice culture. Upland culture means rice grown in rainfed, naturally well-drained soils with bunded or unbunded fields without surface water accumulation. Rainfed lowland culture means rice grown in fields that are usually bunded and in which the crop is not irrigated, but the soil is flooded for a portion of the crop cycle to a depth of 1-50 cm. Irrigated culture means rice grown with irrigation in bunded fields. Deepwater culture means rice grown in unbunded fields that become submerged under 50 cm or more of water. The adjectives upland and lowland describe rice and rice-growing soils.

The report uses the International System of Units (SI), with a few exceptions. Monetary units are usually in U.S. dollars ($); if not, exchange rates are provided. Control or check normally means an untreated control. Grain yield is calculated as rough rice, and protein content as a percentage of brown rice, at 14% moisture content. Yield refers to grain yield unless otherwise noted. Fertilizer amounts are given in terms of the elements (N, P, K, Zn, etc.) and not in the older conventional oxide formulations (P_2O_5, K_2O, etc.).

Pedigrees are indicated by a slant bar (/) rather than by a multiplication sign (×). For example, PTB33×IR30 is written PTB33/IR30. The sequence of crosses is illustrated by the number of slant bars: (PTB33×IR30)×IR36 is written PTB33/IR30//IR36. Fourth and further crosses are designated /4/, /5/, and so on. Backcrosses are designated by an asterisk (*) and a number indicating the dosage of the recurrent parent. The asterisk and the number are placed adjacent to the crossing symbol, which divides the recurrent and donor parents.

Unless otherwise noted, scoring of morphological characters and of damage attributed to rice pests and physiochemical stresses is based on scales in *Standard evaluation system for rice* (SES), 2d edition, 1980. Copies are available from the International Rice Testing Program, IRRI.

In tables, a single asterisk (*) means a difference at the 5% level of significance, and a double asterisk (**) means a significant difference at the 1% level; ns means not significant. Unless otherwise stated, separation of means in table columns is by Duncan's multiple range test at the 5% level.

This report normally uses generic names for chemicals. Use of a commercial or brand name does not constitute endorsement.

A thumb index on the back cover provides access to each section. To use it, bend the book slightly and follow the margin index to the page with the black edge marker.

Abbreviations and acronyms

AARD = Agency for Agricultural Research and Development, Indonesia
AAT = accelerated aging treatment
AC = amylose content, anther culture
ADPC = area under disease progress curve
ads = air-dried soil
ai = active ingredient
AIDAB = Australian International Development Assistance Bureau
AIRAT = African Irrigated Rice Advanced Trial
AIRON = African Irrigated Rice Observational Nursery
AIRPSS = African Irrigated Rice Preliminary Screening Set
ARA = acetylene-reducing activity
ARFSN = Asian Rice Farming Systems Network
AS = ammonium sulfate
ASL = Analytical Service Laboratories
asl = above sea level
ASV = alkali spreading value
ATR = apparent translocation rate
AURAT = African Upland Rice Advanced Trial
AURON = African Upland Rice Observational Nursery
AURPSS = African Upland Rice Preliminary Screening Set
AVRDC = Asian Vegetable Research and Development Center
AYT = advanced yield trial

B&I = broadcast and incorporated
BA-ELISA = biotin-avidin enzyme-linked immunosorbent assay
BB = bacterial blight
BB&I = basal broadcast and incorporated
BC = backcross
BEST = Bicol Experiment Station
BGA = blue-green algae
BI = blast
BLS = bacterial leaf streak
BNF = biological nitrogen fixation
BPH = brown planthopper
BPI = Bureau of Plant Industry, Philippines
BRP = brown rice protein
BRRI = Bangladesh Rice Research Institute
BS = best split
BSFR = broadcast seeded flooded rice
BShR = brown sheath rot
BSR = broadcast seeded rice

CABI = Commonwealth Agricultural Bureaux International
CARRDI = Cambodian Rice Research and Development Institute
CEC = cation exchange capacity
CEDIA = Rice Research Center, Dominican Republic
CF = crude fiber
CFU = colony-forming unit
CGIAR = Consultative Group on International Agricultural Research
CGR = crop growth rate
CHO = carbohydrates
CIAT = Centro Internacional de Agricultura Tropical
CIMMYT = International Maize and Wheat Improvement Center
CM = commercial model
CMS = cytoplasmic male sterile
CNPAF = Centro Nacional de Pesquisa-Arroz, Feijão
COM = compaction
CP = cowpea, crude protein
CPD = Communication and Publications Department
CRIFC = Central Research Institute for Food Crops, Indonesia
CRIN = Caribbean Rice Improvement Network
CW = caseworm
CY = crop year

D = duration of treatment
DAA = days after anthesis
DAD = days after draining
DAF = days after flowering
DAI = days after infestation, days after inoculation
DAP = days after planting
DAPE = days after panicle emergence
DAPI = days after panicle initiation
DAS = days after seeding, days after sowing
DASA = days after straw application
DAS-ELISA = double antibody sandwich enzyme-linked immunosorbent assay
DBH = days before harvest, days before heading
DBPE = days before panicle emergence
DBPI = days before panicle initiation
DBT = days before transplanting
DE = days after emergence
DH = deadheart
DIA = diaphorase
DLA = diseased leaf area
DM = dry matter
DMRT = Duncan's multiple range test
DMS = dry matter solubles
DS = dry season
DSR = direct seeded rice
DT = days after transplanting
dw = dry weight
DWR = deepwater rice

EC = electrical conductivity
EE = ether extract
ELISA = enzyme-linked immunosorbent assay
Epan = class A pan evaporation
EPC = engineered pest control
EST = esterase
Et = actual evapotranspiration
ETL = economic threshold level

F = fertile
FAO = Food and Agriculture Organization
fb = followed by
FC = free choice screening test
FDC = spikelet fertility depression coefficient
FDP = fructose 1,6 - diphosphatase

FE = field emergence
FOFIFA = Centre National de la Recherche Appliquée au Rural Developpement, Madagascar
FRT = floating rototiller
FS = false smut
FSR = farming systems research
fw = fresh weight
FYM = farmyard manure

GA_3 = gibberellic acid
GB = germplasm bank
GC = gel consistency, germination in cold
GD = growth duration
GEU = Genetic Evaluation and Utilization
GF = grain filling
GFD = grain filling duration
GFR = grain filling rate
GHC = green hairy caterpillar
GLH = green leafhopper
GLM = green leaf manure
GM = green manure
GMi = mild stunting and yellowing, slightly profuse tillering, erect growth habit
GMo = moderate stunting and yellowing, profuse tillering, spreading growth habit
GP = germination percentage, germination in polyethylene glycol solution
GSe = severe stunting and yellowing, reduced tillering, premature death
GSV = grassy stunt virus
GT = gelatinization temperature
GW = grain weight

HD = high density
HDI = high density index
HI = harvest index
HPLC = high performance liquid chromatography
HW = hand weeding
HWT = hot-water treatment

I = indica, intermediate
IARC = international agricultural research center
IBPGR = International Board for Plant Genetic Resources
ICIPE = International Centre of Insect Physiology and Ecology
ICRISAT = International Crops Research Institute for the Semi-Arid Tropics
IDH = isocitric dehydrogenase
IDP = intensive data ricefield
IDRC = International Development Research Centre, Canada
IFDC = International Fertilizer Development Center
IFRON = International Floating Rice Observational Nursery
IgG = specific immunoglobulin
IITA = International Institute of Tropical Agriculture
IJ = indica-japonica
INSURF = International Network on Soil Fertility and Sustainable Rice Farming
IPB = Institute of Plant Breeding, Philippines
IPM = integrated pest management
IRAT = Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières, France
IRBBN = International Rice Bacterial Blight Nursery
IRBN = International Rice Blast Nursery
IRBPHN = International Rice Brown Planthopper Nursery
IRC = interrow cultivation
IRCTN = International Rice Cold Tolerance Nursery
IRDSN = International Rice Drought Screening Nursery
IRDWON = International Rice Deepwater Observational Nursery
IRGC = International Rice Germplasm Center
IRON = International Rice Observational Nursery
IRRI = International Rice Research Institute
IRRSWON = International Rice Rainfed Shallow Water Observational Nursery
IRRSWYN-E = International Rice Rainfed Shallow Water Yield Nursery-Early
IRRSWYN-M = International Rice Rainfed Shallow Water Yield Nursery-Medium
IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery
IRSBN = International Rice Stem Borer Nursery
IRSGON = International Rice Slender Grain Observational Nursery
IRTN = International Rice Tungro Nursery
IRTP = International Rice Testing Program
IRUSS = International Rice Ufra Screening Set
IRWBPHN = International Rice Whitebacked Planthopper Nursery
IRYN-E = International Rice Yield Nursery-Early
IRYN-M = International Rice Yield Nursery-Medium
IRYN-VE = International Rice Yield Nursery-Very Early
ITPRON = International Tide-Prone Rice Observational Nursery
IURON = International Upland Rice Observational Nursery
IURYN-E = International Upland Rice Yield Nursery-Early
IURYN-M = International Upland Rice Yield Nursery-Medium
IVB = inner vascular bundle
IVOMD = in vitro organic matter digestibility
IVTDMD = in vitro total dry matter digestibility

J = japonica

LAI = leaf area index
LAR = leaf area ratio
LD = low density
LER = land equivalent ratio
LF = leaffolder
Lr = leaf rolling
LRP = less reactive phosphate
LSc = leaf scald
LSD = least significant difference
L:W = length-to-width ratio
LWP = leaf water potential

MBCR = marginal benefit-cost ratio
MCA = monoclonal antibodies
MCD = Multiple Cropping Department
MIFS = Myanmar-IRRI Farming Systems Project
MITS = multicrop inverted-T seeder
MORIF = Maros Research Institute for Food Crops, Indonesia
MR = moderately resistant
MRRTC = Maligaya Rice Research and Training Center, Philippines
MS = moderately susceptible
MSST = modified seedbox screening test
MT = maximum tillering
MTCB = minimum temperature for chloroplast biogenesis
MV = modern variety
MVP = mean viability period

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NA = nonanoic acid
NARS = national agricultural research systems
NBLS = narrow brown leaf spot
NBPT = N-(n-butyl) thiophosphoric triamide
NBS = narrow brown spot
NC = no-choice screening test
NCPR = North Carolina phosphate rock
NFE = nitrogen-free extract
NHI = nitrogen harvest index
NLB = neem leaf bitters
NMC = nonmorphogenic calli
NoET = number of effective tillers/hill
NoFG = number of filled grains/panicle
NSB = neem seed bitters
NSKE = neem seed kernel extract
NT = nontilled, no tillage
NUE = nitrogen utilization efficiency

Od = orange discoloration
ODNRI = Overseas Development Natural Resources Institute, United Kingdom
OMS = organic matter solubles
ON = observational nursery
ORSTOM = Office de la Recherche Scientifique et Technique Outre-Mer
OVB = outer vascular bundle
OYT = observational yield trial

P = primary tillers
PAB = photosynthetic aquatic biomass
PAGE = polyacrylamide gel electrophoresis
PAPR = partially acidulated phosphate rock
PAR = photosynthetically active irradiance
PB = primary branches
PEG = polyethylene glycol
PEt = potential evapotranspiration
PF = partially fertile
Pg' = gross photosynthesis
PGR = plant growth regulator
P+H = plow and harrow
PhilRice = Philippine Rice Research Institute
PI = panicle initiation
PPD = plant population density
PR = partial resistance, phosphate rock
PRF = pulse repetition frequency
PS = partially sterile, potential sink size
PSS = preliminary screening set
PTR = Prosperity Through Rice
PU = prilled urea
PVC = polyvinyl chloride

R = resistant, restorer line, dark respiration
RAVC = return above variable costs
RB = relay broadcast, rice bug
RCBD = randomized complete block design
RDA = Rural Development Administration, Korea
RFLP = restriction fragment length polymorphism
RFSP = Rice Farming Systems Program
RG = rate of germination
RH = relative humidity
RI = ragged leaves
RL = root length
RLCU = reactive layer coated urea
RLH = relative lesion height
RMD = relay, manual, delayed
RMP = relay, manual, prompt
RRTC = Rice Research and Training Center, Egypt
RS = researcher's split, simple random sampling
RSHT = routine seed health test
RSR = row seeded rice
RSV = ragged stunt virus
RTBV = rice tungro bacilliform virus
RTSV = rice tungro spherical virus
RTV = rice tungro virus, tungro
RWM = rice whorl maggot
RYMV = rice yellow mottle virus
RYT = replicated yield trial

S = secondary tillers, sink size, sterile, susceptible
SAWAH = Simulation Algorithm for Waterflow in Aqueous Habitats
SB = secondary branches, soybean, stem borer
SCSFA = short-chain saturated fatty acids
SCU = sulfur-coated urea
SD = standard deviation
SDI = stress day index
SDM = shoot dry matter
SDS = sodium dodecylsulfate
SDW = seedling dry weight
SES = *Standard evaluation system for rice*
SG = standard germination
ShB = sheath blight
ShR = sheath rot
ShS = sheath spot
SL = shoot length
SMT = soil moisture tension
S&P = seepage and percolation
SR = stem rot
SRS = stratified random sampling
SS = systematic sampling
SSB = striped stem borer
SSST = standard seedbox screening test
SWCB = Southwestern corn borer
SWRI = surface water retention index

T = temperature, tertiary tillers
TARC = Tropical Agriculture Research Center, Japan
TDMY = total dry matter yield
TPR = transplanted rice
TSP = triple superphosphate
TTTD = Training and Technology Transfer Department
TV = traditional variety
TVC = total variable cost

UAF = University of Agriculture and Forestry, Vietnam
UC = University of Cantho, Vietnam
UG = unfilled grain
UPLB = University of the Philippines at Los Baños
UR = upland rice
URRC = Ubon Rice Research Center, Thailand
URYT = Upland Rice Yield Trial
USDA = United States Department of Agriculture
USG = urea supergranules
UTRIS = Upper Talavera River Irrigation System, Philippines

VAM = vesicular-arbuscular mycorrhizal fungi
VRBL = variable

WA = wild abortive
WAI = weeks after incubation, weeks after inoculation
WARDA = West Africa Rice Development Association

WAS = weeks after seeding
WBPH = whitebacked planthopper
WC = wide compatibility
WE = weeks after emergence
WH = whitehead
WIRFS = Women in Rice Farming Systems
WI = wrinkled leaves
WLS = white leaf streak
WS = wet season
WSB = white stem borer
WSR = wet seeded rice
WSRP = wild-specific repeated probe
WT = weeks after transplanting
WTD = water table depth

Xco = bacterial blight caused by *Xanthomonas campestris* pv. *oryzae*
XDH = xanthine dehydrogenase

Yd = yellow discoloration
YSB = yellow stem borer

Genetic evaluation and utilization (GEU) program

Genetic resources

International Rice Germplasm Center, Statistics Department, and Seed Health Unit

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FIELD COLLECTION

International Rice Germplasm Center

For the second year, field collecting activities concentrated on the wild relatives of rice. Seven countries were visited (Table 1). Of the wild germplasm collected, 85% have the same genome (AA) as cultivated rice and can be readily used in breeding programs. The other 15% of the species have the CC or BBCC genome. These are difficult to cross with rice but are likely to be used in rice breeding in the near future, when advances are made in biotechnology.

Of special interest among the germplasm sampled were populations from peat soils in western Sri Lanka, wild germplasm from flood-devastated areas of Bangladesh, high-altitude germplasm from Nepal, and male sterile populations from Thailand.

The new collections offer valuable materials for studies on genetic diversity and evolution. In response to a specific request, *Hygroryza aristata* populations—from a genus related to *Oryza*—were sampled for evolutionary studies.

Our efforts are directed toward ex situ conservation of rice and wild rice germplasm. During the year, however, wild species of *Oryza* were found growing in protected areas that serve as reservoirs for their continued protection and evolution in natural habitats. These sites of in situ conservation (Table 2) allow a valuable additional form of long-term conservation for wild rice germplasm.

During the year, herbaria in Bangkok (Thailand), Bogor (Indonesia), Coimbatore (India), Godawari (Nepal), Singapore, and Peradeniya (Sri Lanka) were visited. The information obtained from 362 herbarium sheets of *Oryza* species and related genera provided a clearer picture of species distribution, ecology, and habitat.

SEED DEPOSITS AND INVENTORY

International Rice Germplasm Center

During 1988, the International Rice Germplasm Center (IRGC) received 863 seed samples either through donation or exchange. The major donors were

- China: 500 samples from Guangxi Provincial Academy of Agricultural Sciences via the Chinese Academy of Agricultural Sciences; 30 samples from the China National Rice Research Institute, Hangzhou, Zhejiang; 13 improved varieties and lines from the Taichung District Agricultural Improvement Station, Changhua, Taiwan Province
- International Board for Plant Genetic Resources via its Seed Exchange Unit at the Royal Botanic Gardens, Kew at Wakehurst Place, United Kingdom: 233 samples collected from Madagascar and 4 samples from Burundi

Table 1. Species collected and collection areas. IRRI, 1988.

Species	Species (no.)								
	Bangladesh	Tamil Nadu, India	Java, Indonesia	Kampuchea	Nepal	Sri Lanka	Thailand		Total
							Northeast	South	
Oryza sativa	25	22	11		4				62
"O. spontanea"	28			6	4		25	21	84
O. nivara	1	4		22	9	28	66		130
O. rufipogon	29	1	30	1	4	12	41	12	130
O. officinalis			12				2		14
O. eichingeri						22			22
O. granulata		3	2		3	2			10
O. ridleyi							1	1	2
Hygroryza aristata	4				2	2			8
Leersia spp.					4		1		5
Total	87	30	55	29	30	66	136	34	467

Table 2. Sites where wild rice germplasm is conserved in situ, 1988.

Country	Conserved area	Species
India	Parambikulam Game Reserve, Kerala	*Oryza officinalis* *O. granulata*
	Karulai Range Teak Plantation and Forest Reserve, Kerala	*O. nivara* *O. granulata* *O. officinalis* (tetraploid form)
Thailand	Pukai Botanic Garden, Mae Sai Valley Forest Reserve and Botanic Garden near Chiang Mai	*O. granulata*
	Tong Nga Chang Park near Haadyai	*O. ridleyi*
Sri Lanka	Yala National Park	*O. nivara* *O. eichingeri*
	Ruhuna Wildlife Sanctuary	*O. nivara* *O. eichingeri* *Hygroryza aristata*
Indonesia	Ujung Kulon National Park	*O. officinalis*

- Japan: 58 samples from the Hokkaido Prefectural Agricultural Experiment Station in Kitami, and 5 improved varieties from the National Institute of Agrobiological Resources in Tsukuba
- International Rice Testing Program: 124 promising entries from its nurseries
- Thailand: 54 samples from the Pathum Thani Rice Research Center
- USA: Rice Experiment Station of Louisiana State University at Crowley: 69 wild rices collected from South America
- Small donations from a large number of rice scientists: 90 samples

When field collections with IRRI participation were included, 1,138 *Oryza sativa* cultivars and 343 wild taxa were received in 1988.

The total holdings of IRGC at year's end stood at

- 76,297 registered accessions of *O. sativa*,
- 2,375 populations of wild species,
- 2,983 strains of *O. glaberrima*,
- 695 genetic testers and mutants, and
- 958 newly received and unplanted samples.

SEED INCREASE AND DISSEMINATION

International Rice Germplasm Center and Seed Health Unit

Field plantings for seed increase, characterization, and regeneration were divided equally between the IRRI farm and a rented field in Dayap, Laguna, Philippines. Seed production in the wet season (WS) was affected by unusually cloudy weather associated with three typhoons.

Seed dissemination to IRRI researchers and rice scientists abroad remained at a high level of about 46,550 samples, but the number of requests (549) was one of the highest on record. A strong demand from cellular and molecular biologists continued (Table 3).

Seed-related information and data were also freely supplied to rice researchers.

Table 3. Progress of the International Rice Germplasm Center in disseminating seed of *Oryza* cultigens and wild species, 1982-88.[a]

Year	*O. sativa* samples (no.) distributed		*O. glaberrima*, genetic testers, and wild rices (no.) distributed	
	Within IRRI	To national programs	Within IRRI	To national programs
1982	33,975 (279)	11,075 (154)	378 (26)	438 (20)
1983	28,443 (287)	3,756 (150)	342 (20)	972 (38)
1984	28,170 (277)	6,619 (146)	83 (17)	448 (29)
1985	30,709 (306)	4,736 (172)	1,138 (24)	1,174 (36)
1986	39,135 (327)	9,897 (187)	2,253 (13)	595 (28)
1987	35,212 (297)	8,714 (214)	1,758 (53)	618 (47)
1988	35,846 (257)	7,288 (202)	2,478 (41)	941 (49)

[a] Number of requests in parentheses.

CHARACTERIZATION, REGENERATION, AND SEED PRESERVATION

International Rice Germplasm Center

The long process of channeling fresh seed into the preservation phase was slowed down by the varying quality of seed produced in different seasons, which necessitated rigorous selection of seed prior to storage. During the year, 4,217 accessions of *O. sativa* were selected, dried, and canned for preservation. The total number of canned accessions was 36,552 at year's end. These amounted to about 45% of the IRGC holdings of rice cultivars.

A batch of 4,503 seed samples was sent to the National Seed Storage Laboratory in Ft. Collins, Colorado, USA, for duplicate storage.

For initial seed increase, 1,748 plots were grown; for field characterization, 2,500. Field and laboratory characterization were completed for about 1,000 *O. sativa* accessions, resulting in 64,047 accessions completely characterized for 45 morphoagronomic traits. For the process of preservation, 17,621 plots of aged seed were planted for rejuvenation and canning.

COMPUTERIZATION OF OPERATIONS

International Rice Germplasm Center and Statistics Department

Computerization of the germplasm bank (GB) operations accelerated during the year. With the completion of the microbased IRRIGEN data system in early 1988, the management of the GB Mini File—presently consisting of 72,482 accessions, with information on accession number, name, country of origin, and seed source—is now done on microcomputers at IRGC, resulting in a more efficient system for the printing of fieldbooks and data sheets for characterization. The ability of the microbased system to be linked to the mainframe GEU system allows a speedy updating of the GB Mini File and data on morphoagronomic characteristics on the mainframe GB files.

The Seed Inventory System, which was developed earlier as an independent microbased system, has been integrated with IRRIGEN; it is now possible to computerize selection of planting materials for seed increase and rejuvenation.

FUNGAL ACTIVITY ON SEED STORED FOR 20 YR

International Rice Germplasm Center and Seed Health Unit

The presence of storage fungi such as *Rhizopus, Penicillium*, and *Aspergillus* is deleterious to rice seed viability because their mycelia penetrate the seed and damage the embryo. Other fungi like *Trichoconiella, Curvularia, Fusarium*, and *Drechslera* infect rice seedlings. Both types are commonly found on rice seed.

A preliminary experiment was conducted to detect fungi on rice seed in IRGC storage rooms. Indica varieties with 8-9% moisture content—Siam 29 (Acc. 5473) and Peta (Acc. 3634)—that had been stored for 20 yr at 2 °C and 40% relative humidity in the medium-term storage room were studied. Eight replications of 25 seeds each per variety were tested using the blotter technique. *Trichoconiella* and *Curvularia* were common on both varieties, but *Fusarium* (10%), *Drechslera* (14.5%), and *Phyllosticta* (23.5%) were common only on Peta, maybe because of varietal differences. The higher germination percentage of Siam 29 (78% vs Peta's 45.5%) could be due to its lower infection.

On other seed stock stored for 2-20 yr, *Trichoconiella* was the most frequently detected fungal genus, followed by *Rhizopus, Penicillium, Aspergillus*, and *Fusarium*.

Probably because of the higher incidence of fungal infection in this batch of seed, Siam 29 and Peta showed lower germinability than their 25-yr-old seed stocks harvested in 1963 and stored under identical conditions: 96 and 94%, respectively.

DATABASE MANAGEMENT TRAINING COURSE

Statistics Department and International Rice Germplasm Center

The 10-wk Database Management for Genetic Resources Training Course was offered for the first time, from April to June, to national rice germplasm workers. The nine participants came from six countries: China (3), India (2), Indonesia (1), Philippines (1), Sri Lanka (1), and Thailand (1). The course, coordinated jointly by the Statistics Department and IRGC, was designed to enable

the data managers of national genebanks to fully exploit microcomputers in data processing and seed-related genebank operations. The course also familiarized participants with the biological background of genetic conservation, evaluation, and breeding, and with statistical and analytical procedures for analyzing genetic resources data, so that they can become effective partners in the team approach to rice improvement.

IRRIGEN, a microbased system to computerize and streamline genebank operations, developed by staff of the Statistics Department and IRGC, was introduced to the participants, who tested its applicability to their needs and constraints. The system aims specifically to assist national workers in the following genebank activities:

- processing of incoming seed,
- selection of planting materials,
- field operations,
- seed inventory,
- postharvest operations,
- information retrieval, and
- printing of reports, catalogs, and documents.

The ability of the system to manage not only data but also the various operations that form the data source was considered to be the unique feature of the system and was greatly appreciated by the participants. All participants received software programs and the user's manual.

The system was subsequently revised to improve its versatility, user-friendliness, and efficiency. It will be used as a core training material in the second Genetic Resources Conservation and Management Training Course from October 1988 to June 1989.

RETURN OF TRADITIONAL RICES TO NATIONAL AND STATE COLLECTIONS

International Rice Germplasm Center

Rice collections were returned to one national center and one state center for restocking or research purposes: 1) 517 accessions to Senegal, and 2) 119 accessions to the Rice Experiment Station of Karnataka State, India.

A special seed increase of the major upland rice varieties of the Philippines was made in the dry season. Sizable quantities of 29 varieties were supplied to the Philippine Rice Research Institute for further multiplication in WS before distribution to interested rice farmers. A number of Filipino farmers were interested in planting traditional rices and had asked IRGC for seed supply in WS.

Complete sets of GB data files for their countries were provided to national centers in Sri Lanka, Indonesia, Pakistan, and the Philippines so that germplasm workers could make comparative studies and further exchanges.

TECHNICAL ASSISTANCE TO NATIONAL GENEBANKS

International Rice Germplasm Center

The head of IRGC continued to provide advice and assistance to several genebanks in the areas of building design, refrigeration, machinery and setup, laboratory equipment, management, and staff training. Such assistance was extended to the China National Rice Research Institute in Hangzhou and to the expansion project of the United States National Seed Storage Laboratory in Ft. Collins.

Genetic evaluation and utilization (GEU) program

Agronomic and physiological characteristics

Agronomy, Plant Breeding, and Plant Physiology Departments

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APICAL DEVELOPMENT OF RICE

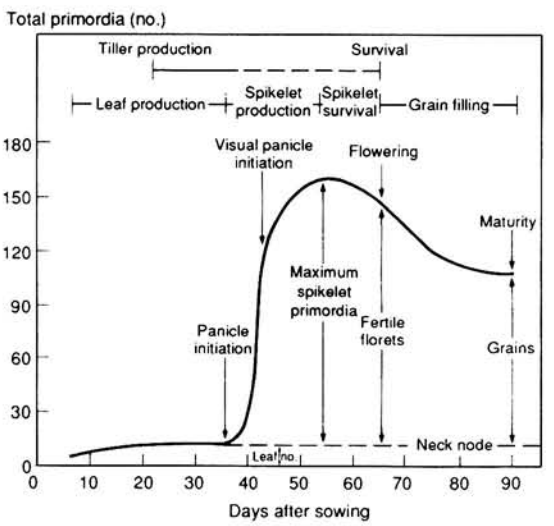
Agronomy Department

Apical development and potential yield loss. In the 1987 wet season (WS), greenhouse experiments monitored the apical development of rice to identify panicle development stages and yield loss periods for efficient fertilizer N application. IR42 (120-d maturity in the greenhouse) and IR50 (90-d maturity in the greenhouse) were the test varieties used with standard fertilizer practice.

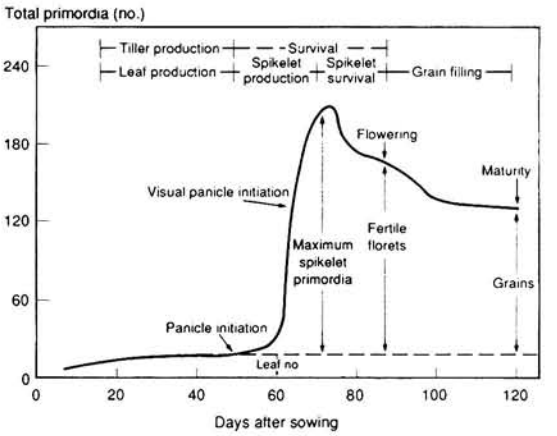
In both varieties, potential grain loss was due to spikelet abortion at preflowering, followed by that at postflowering (Fig. 1, 2). Preflowering spikelet abortion was higher in IR42 than in IR50. N topdressing at 7 d before panicle initiation (DBPI) coincided with panicle initiation (PI) in IR50 but not in IR42. Panicle and spikelet development took 15-18 d in IR50 and 24-31 d in IR42.

Nitrogen timing during vegetative phase of IR42. In 1987 WS, a greenhouse experiment determined the effect of N fertilizer application timing during the vegetative phase on reserve carbohydrate contribution to grain yield and spikelet development.

Reserve carbohydrate contribution did not significantly differ among treatments (Table 1). N application at 31 and 46 d after seeding (DAS), and kinetin application at 30 DAS increased the



1. Primordium production at different ages of IR50. IRRI, 1987.



2. Primordium production at different ages of IR42. IRRI, 1987.

number of spikelets differentiated through increased secondary branches and secondary branch spikelets. However, the survival of differentiated spikelets was lower than with standard fertilizer management. Experiments are in progress to find out the most efficient N timing.

Comparison of extreme rice types. In the 1988 dry season (DS), a greenhouse study was conducted using 6 varieties with 3 character extremes: culm length, 100-seed weight, and leaf senescence. Varieties with the same growth duration were selected based on data from the IRRI Germplasm Bank. They were managed similarly with fertilizer NPK at 120-60-60 kg/ha (2/3 N, total P, and total K applied basally; 1/3 N at 5-7 DBPI).

The time (25-47 d) it took to reach the reproductive phase (PI to flowering) depended on crop duration and hence varied greatly (Table 2). Spikelet differentiation and survival also varied among varieties, with smaller seed types having more spikelets differentiated than the large-seeded varieties. Spikelet survival was low in small-seeded and early senescence varieties.

MAXIMUM YIELD EXPERIMENT

Agronomy Department

IRRI. The potential yields of 10 early- and medium-maturing rices were evaluated further at 2 IRRI sites in DS and at 1 site in WS. Urea supergranules were deep-placed at 4 d after transplanting (DT) at 29, 58, and 87 kg N/ha, followed by

Table 1. Effect of N application on spikelet differentiation and survival during vegetative phase of IR42.[a] IRRI, 1987 WS.

Fertilizer treatment	Spikelets (no.)		Spikelet survival (%)	Secondary branches (no.)	Secondary branch spikelets (no.)
	At 73 DAS (maximum)	At flowering			
Standard N application (120 kg N/ha, 2/3 basal + 1/3 at 5-7 DBPI)	287	202 ab	70.6	38.7 ab	135 ab
Standard N application + 10 kg N/ha					
21 DAS	242	171 c-e	70.6	31.5 cd	106 c-e
26 DAS	282	176 b-e	62.1	32.6 bcd	113 b-e
31 DAS	316	198 abc	62.7	38.8 ab	120 abc
36 DAS	282	187 a-d	66.3	36.3 abc	125 a-d
41 DAS	282	193 abc	68.4	36.8 abc	125 a-d
46 DAS	327	209 a	63.9	39.9 a	141 a
51 DAS	308	194 abc	62.9	36.3 abc	129 abc
56 DAS	272	194 abc	71.4	36.8 abc	127 a-d
10 ppm kinetin application at 30 DAS	337	164 de	48.6	30.6 cd	100 de
Deep placement of 87.5 kg N/ha	289	198 abc	68.5	38.3 ab	135 ab
No fertilizer	223	149 de	66.5	26.8 d	89 e

[a]DAS = d after seeding, DBPI = d before panicle initiation.

Table 2. Growth and development of extreme character rice types. IRRI, 1988 DS.

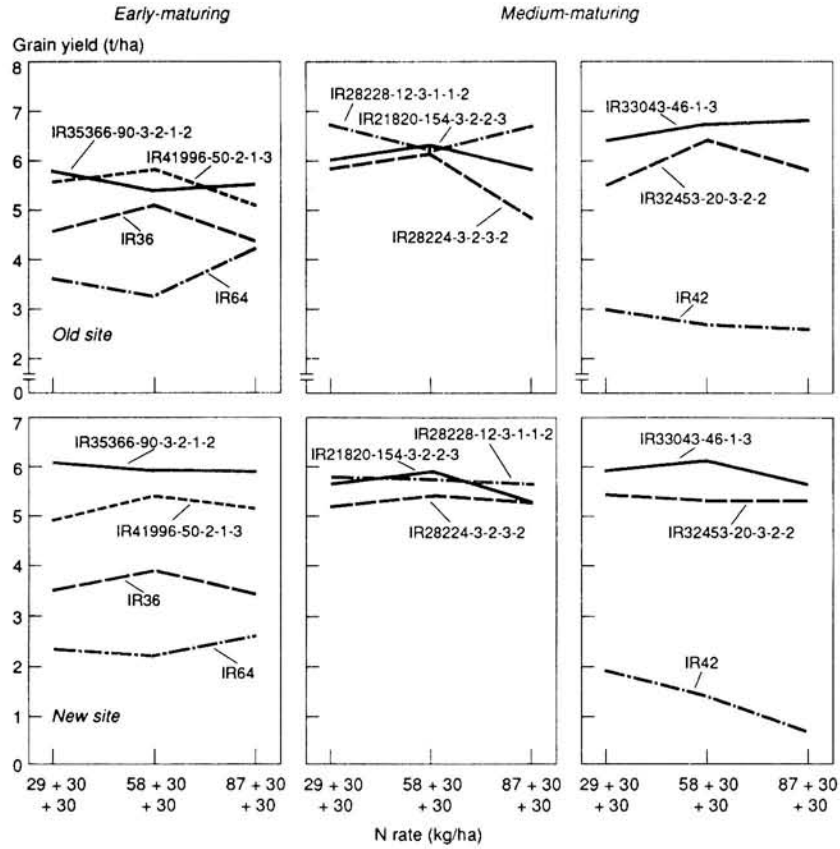
Character	Rice variety					
	CI 2471-1	Macunting	Neo-Dunghan I	Jirasar 280	ABB	B581-A6-458
Growth duration (d)	139	128	87	87	92	119
Leaf senescence	Late	Late	Late	Early	Late	Late
100-seed weight (g)	3.1	1.0	3.2	3.1	4.2	1.9
Culm length (cm)	131	86	92	110	76	80
Growth phases (d)						
Vegetative	0-65	0-49	0-21	0-21	0-35	0-42
Reproductive	65-105	49-96	21-48	21-52	35-60	42-85
Maturity	105-139	96-128	48-87	52-87	60-92	85-119
Spikelet differentiation and survival (no. spikelets/panicle)						
Maximum differentiation	211	548	120	153	115	338
At flowering	157	276	92	85	89	214
Grain at maturity	114	220	56	44	61	162

prilled urea topdressed during desired growth stages. Planting dates were staggered for uniform ripening.

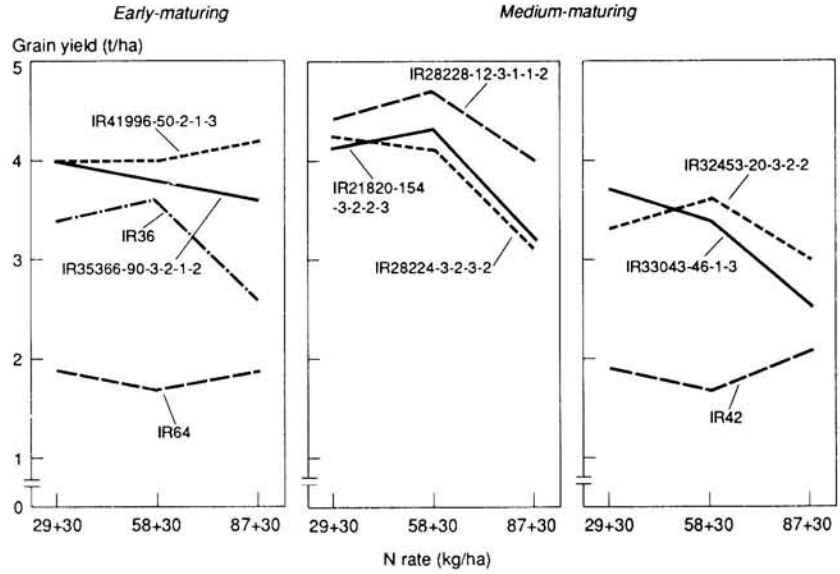
Dry season. At the old site in DS, IR33043-46-1-3 yielded highest (6.8 t/ha) among the medium-maturing rices (Fig. 3). Early-maturing IR35366-90-3-2-1-2 with 89 kg N/ha and IR41996-50-2-1-3 with 118 kg N/ha produced the maximum yield of 5.8 t/ha. Medium-maturing rices produced maximum yields ranging from 6.1 to 6.7 t/ha at 118 kg N/ha. Further increasing the N rate produced excessive vegetative growth that caused yields to decline.

At the new site, early-maturing IR35366-90-3-2-1-2 yielded highest (6.1 t/ha) with 89 kg N/ha (Fig. 3). A similar yield was obtained from medium-maturing IR33043-46-1-3 with 118 kg N/ha.

Yields of IR36, IR64, and IR42 at both sites



3. Effect of N application rate on rice yields in maximum yield trials at 2 sites. IRRI, 1988 DS. IR36, IR42, and IR64 were damaged by tungro.



4. Effect of N application rate on rice yields in maximum yield trials. IRRI, 1988 WS. IR36, IR42, and IR64 were damaged by tungro.

Table 3. Grain yield of hybrids, inbred lines, and IR varieties at 3 N rates and 3 N fertilizer management practices. IRRI, 1988 DS.

Nitrogen management[a]	Grain yield[b] (t/ha)					
	IR54752A/IR46R[c]	IR54752A/IR64R[c]	IR47067-B-B-12[c]	IR47067-B-B-94[c]	IR72	IR74
			100 kg N/ha			
M1	2.9 c	1.5 d	4.2 b	3.0 c	4.3 b	5.0 a
M2	2.6 d	1.8 e	3.8 c	3.1 d	4.4 b	5.0 a
M3	2.8 c	1.6 d	4.3 ab	2.5 c	4.0 b	4.8 a
			150 kg N/ha			
M1	3.1 c	1.6 d	3.1 c	2.7 c	3.7 b	4.7 a
M2	2.4 d	2.0 d	3.6 b	3.0 c	3.9 b	5.1 a
M3	2.8 c	1.6 d	3.4 b	3.2 bc	3.6 b	4.6 a
			200 kg N/ha			
M1	2.3 b	1.6 c	3.4 a	2.8 b	3.8 a	3.5 a
M2	2.6 c	1.5 d	3.3 b	2.1 c	3.5 b	4.6 a
M3	3.3 a	1.4 c	3.2 a	2.3 b	3.6 a	3.8 a

[a]M1 = 2/3 B&I + 1/3 at 5-7 DBPI, M2 = 2/3 B&I + 1/3 at 10 DAPI, M3 = 1/3 B&I + 1/3 at 30 DT + 1/3 at 10 DAPI. [b]Av of 4 replications. In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. CV = 21%. [c]Damaged by RTV.

were low and variable because of tungro (RTV) infestation. Stem borers and stem rot also caused low yields.

Wet season. The highest yield (4.7 t/ha) in WS was obtained with medium-maturing IR28228-12-3-1-1-2 at 88 kg N/ha (Fig. 4). Among the early-maturing rices, IR41996-50-2-1-3 gave the highest yield (4.2 t/ha) when 117 kg N/ha was applied.

Yields were low and tended to decrease with increasing N rate because of severe lodging, particularly among tall, medium-maturing rices. As in DS, low WS yields with IR36, IR64, and IR42 were caused by RTV infestation.

YIELD PERFORMANCE OF HYBRID RICE

Agronomy Department

During DS, 2 hybrid rices, 2 inbred lines, and 2 IR varieties were evaluated at 4 N rates (0, 100, 150, 200 kg N/ha) and 3 N management practices: 2/3 broadcast and incorporated (B&I) + 1/3 at 5-7 DBPI (M1), 2/3 B&I + 1/3 at 10 d after panicle initiation (DAPI) (M2), and 1/3 B&I + 1/3 at 30 DT + 1/3 at 10 DAPI (M3). Total N uptake was determined at 10 and 40 DT, 15 DAPI, flowering, and harvest.

Except at the high N rate in M3, IR72 and IR74 significantly outyielded the hybrid rices at all N rates and N management practices (Table 3). RTV infection and high spikelet sterility caused low yields of hybrid rices. Without N, IR74 yielded the highest, at 4.0 t/ha (Table 4). Increasing the N rate decreased the yields of all test varieties.

Increasing the N rate significantly increased the N uptake of rices at 40 DT, 15 DAPI, and flowering (Table 5). Application of 150 kg N/ha was sufficient to increase N uptake at harvest.

The total N uptake of IR54752A/IR46R was similar to that of IR74 at 10 and 40 DT and at flowering, and to that of IR72 at 40 DT, flowering, and harvest (Table 6). On the other hand, IR54752A/IR64R had lower N uptake than IR72 at flowering, and lower than IR74 at 15 DAPI, flowering, and harvest.

Table 4. Grain yield of hybrid rices, inbred lines, and IR varieties at varying N rates. IRRI, 1988 DS.

Rice entry	Grain yield[a] (t/ha)			
	0 N	100 N	150 N	200 N
IR54752A/IR46R[bc]	2.7	2.8 a	2.8 a	2.7 a
IR54752A/IR64R[bc]	1.4	1.6 a	1.7 a	1.5 a
IR47067-B-B-12[b]	2.7	4.1 a	3.4 b	3.3 b
IR47067-B-B-94[b]	2.9	2.9 a	3.0 a	2.4 b
IR72	2.8	4.2 a	3.7 b	3.6 b
IR74	4.0	4.9 a	4.8 a	4.0 b

[a]Av of 4 replications. In a row, means followed by a common letter are not significantly different at the 5% level by DMRT. CV = 9%. [b]Damaged by RTV. [c]High spikelet sterility.

Table 5. N uptake of hybrid rices, inbred lines, and IR varieties as affected by 3 N rates.[a] IRRI, 1988 DS.

Fertilizer level (kg N/ha)	N uptake (kg N/ha) at				
	10 DT	40 DT	15 DAPI	Flowering	Harvest
100	2.2 a	51.2 c	112.6 c	106.8 c	112.7 b
150	2.0 a	57.1 b	124.3 b	128.9 b	124.7 a
200	1.9 a	69.2 a	154.4 a	150.6 a	137.5 a

[a] Av of 6 rices and 4 replications.

N management practice affected total N uptake at maximum tillering and harvest. N uptake with M1 and M3 was higher than with M2 (Table 7).

YIELD OF EXPERIMENTAL RICE HYBRIDS IN KOREA

Plant Breeding Department

During 1988, seven experimental rice hybrids, involving CMS line IR54756A and Korean restorer lines, were evaluated in comparison with the male parents, which included the best available check varieties, in replicated yield trials in Milyang, Korea. Fertilizer application rates (kg NPK/ha) were 220-90-110 in Suweon, 180-110-130 in Iri, and 120 -90-110 in Milyang. The mean yield of the hybrids was 10.1 t/ha, that of the inbreds was 8.3 t/ha. Detailed results are given in the section Cooperative Country Projects.

YIELD PERFORMANCE AND NITROGEN RESPONSE OF VARIETIES AND BREEDING LINES

Agronomy Department

Irrigated rice. The yield performance of check varieties and promising breeding lines was evaluated at five N levels at IRRI, at four N levels in a farmer's field, and at six N rates at three Philippine Bureau of Plant Industry (BPI) research stations. N rates were higher during DS than during WS.

IRRI. At IRRI in DS, IR72 yielded highest (6.4 t/ha) with 150 kg N/ha, followed by IR37873-16-2-3-3-3-1 (6.2 t/ha) at 120 kg N/ha (Fig. 5). Without N, early-maturing lines IR41996-12-2-2-3 and IR37873-16-2-3-3-3-1 yielded more than 4.0 t/ha. Of the 28 rices tested, 3 did not reach their maximum yield potential even with 150 kg N/ha. Most test cultivars gave the maximum yield at interme-

Table 6. N uptake of hybrid rices, inbred lines, and IR varieties as affected by sampling period. IRRI, 1988 DS.[a]

Fertilizer level (kg N/ha)	N uptake (kg N/ha) at				
	10 DT	40 DT	15 DAPI	Flowering	Harvest
IR54752A/IR46R	2.3 a	58.6 a	165.1 a	142.1 a	136.5 a
IR54752A/IR64R	2.1 ab	59.6 a	135.5 b	112.4 b	134.6 a
IR47067-B-B-12	1.8 b	55.4 a	114.3 c	135.2 a	133.4 a
IR47067-B-B-94	1.8 b	59.1 a	131.6 b	112.5 b	117.6 b
IR72	1.8 b	59.2 a	131.5 b	134.0 a	132.2 a
IR74	2.2 ab	63.0 a	104.5 c	136.3 a	115.4 b

[a] Av of 3 N management practices, 3 N rates, and 4 replications.

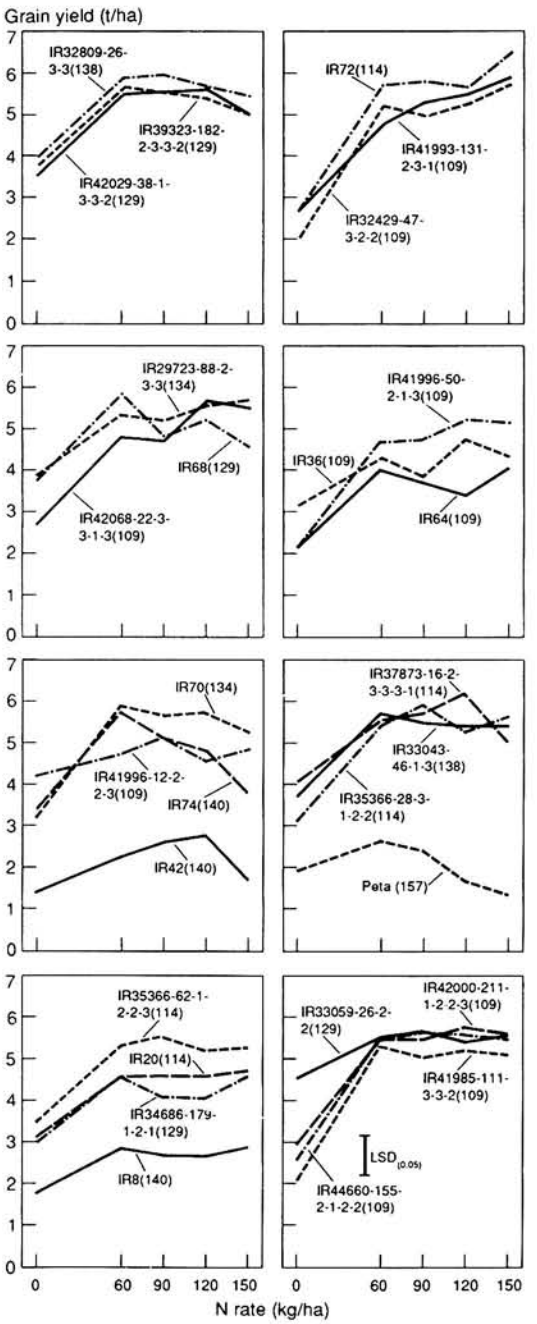
Table 7. N uptake of hybrid rices, inbred lines, and IR varieties as affected by 3 N management practices.[a] IRRI, 1988 DS.

N management[b]	N uptake (kg N/ha) at				
	10 DT	40 DT	15 DAPI	Flowering	Harvest
M1	2.0 a	58.3 ab	128.6 a	124.6 a	123.8 ab
M2	2.0 a	57.2 b	129.7 a	129.0 a	122.6 b
M3	2.0 a	62.0 a	133.0 a	132.6 a	128.5 a

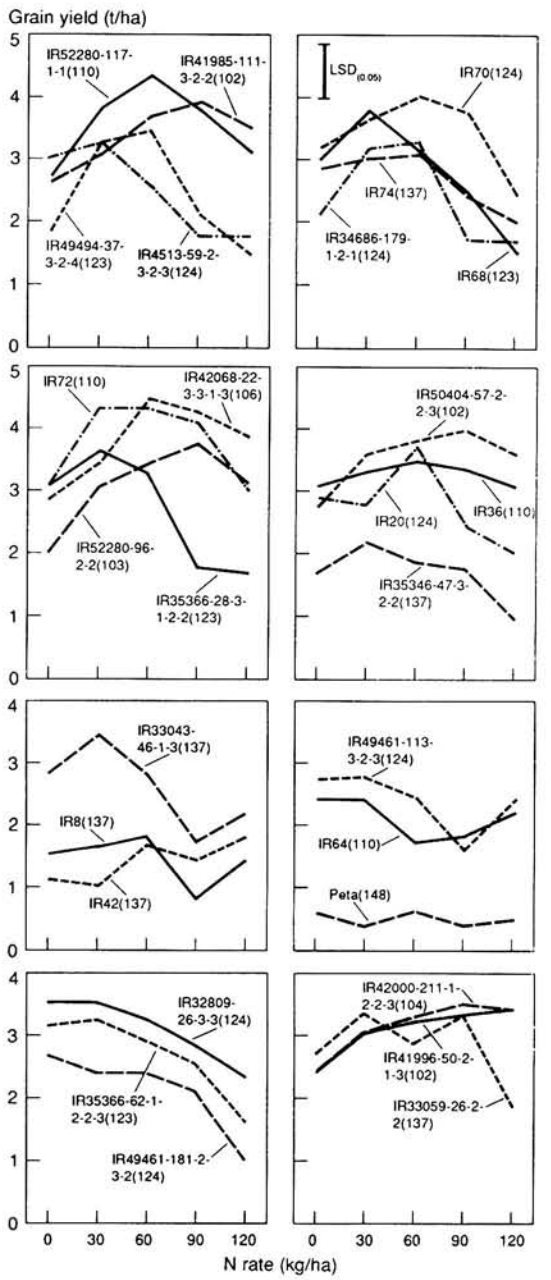
[a] Av of 3 N rates and 4 replications. [b] M1 = 2/3 B&I + 1/3 at 5-7 DBPI, M2 = 2/3 B&I + 1/3 at 10 DAPI, M3 = 1/3 B&I + 1/3 at 30 DT + 1/3 at 10 DAPI.

diate N rates (60-120 kg/ha). IR8, IR36, IR42, and IR64 were infected with RTV. The highest yield of traditional variety Peta was only 2.6 t/ha.

In WS, heavy rains and a storm during the rice maturity stage greatly damaged those rices maturing in 120 d or longer. Early-maturing IR42068-22-3-3-1-3 and IR52280-117-1-1 gave highest yields (4.5 and 4.4 t/ha, respectively) at 60 kg N/ha (Fig. 6). Without N, 4 varieties and 4 other breeding lines yielded at least 3.0 t/ha. As in DS, IR8, IR36, IR42, and IR64 were severely infected with RTV. Most yields declined at high N rates.



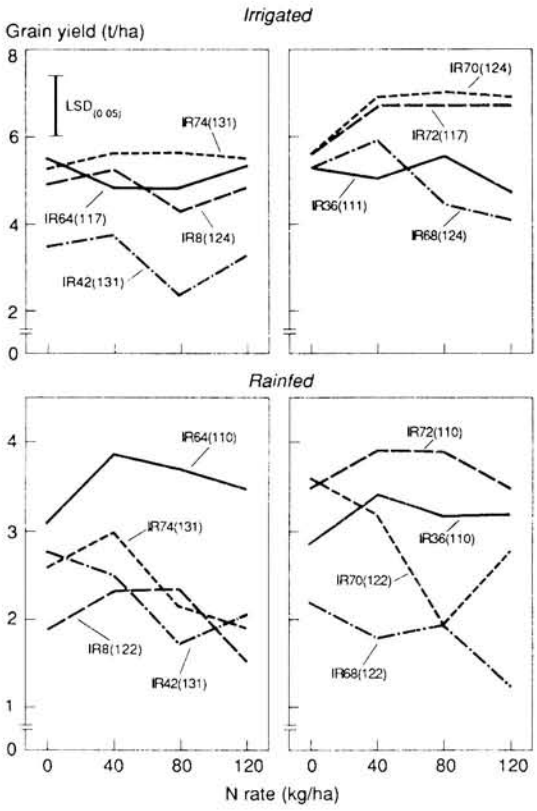
5. Yield of rices at 6 N rates. IRRI, 1988 DS. Numbers in parentheses indicate growth duration.



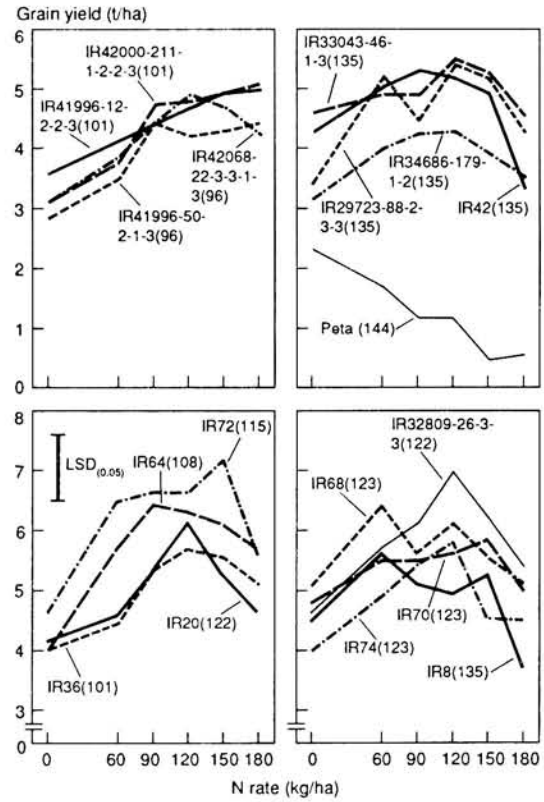
6. Yield of rices at 5 N rates, IRRI, 1988 WS. Numbers in parentheses indicate growth duration.

Farmer's field. IR8, IR36, IR42, and IR64 gave low yields in farmers' fields in both seasons because of RTV infection. Without applied N in DS, IR8 yielded highest with 4.0 t/ha, while IR70 yielded 3.9 t/ha. With applied N, IR74 gave the highest yield of 5.1 t/ha. Without N in WS, all test varieties except IR42 yielded 5.0 t/ha or better (Fig. 7). Heavy rains caused lodging in IR68, IR70, and IR74. Despite lodging at maturity, IR70 yielded 7.0 t/ha at 80 kg N/ha.

BPI stations. Among the 17 IRRI-developed rices tested in DS at the Maligaya Rice Research and Training Center (MRRTC), Nueva Ecija, only early-maturing breeding lines IR41996-12-2-2-3 and IR42000-211-1-2-2-3 failed to reach their maximum yield (Fig. 8). The highest yield increases due to applied N were obtained from two early-maturing varieties, IR64 and IR72, and from a promising medium-maturing breeding line,



7. Yield of rices at 4 N rates in irrigated and rainfed farmers' fields, Cabuyao, Laguna, Philippines, 1988 WS. Numbers in parentheses indicate growth duration.

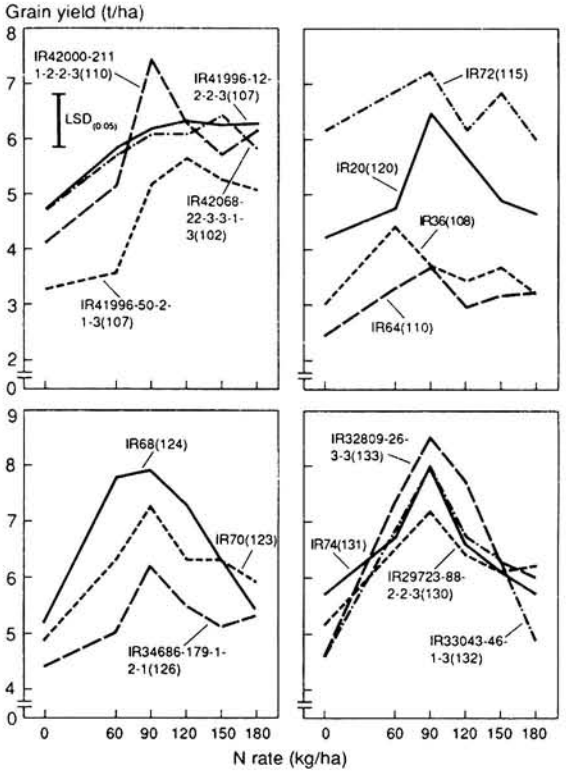


8. Yield of rices at 6 N rates, Maligaya Rice Research and Training Center, Nueva Ecija, Philippines, 1988 DS. Numbers in parentheses indicate growth duration.

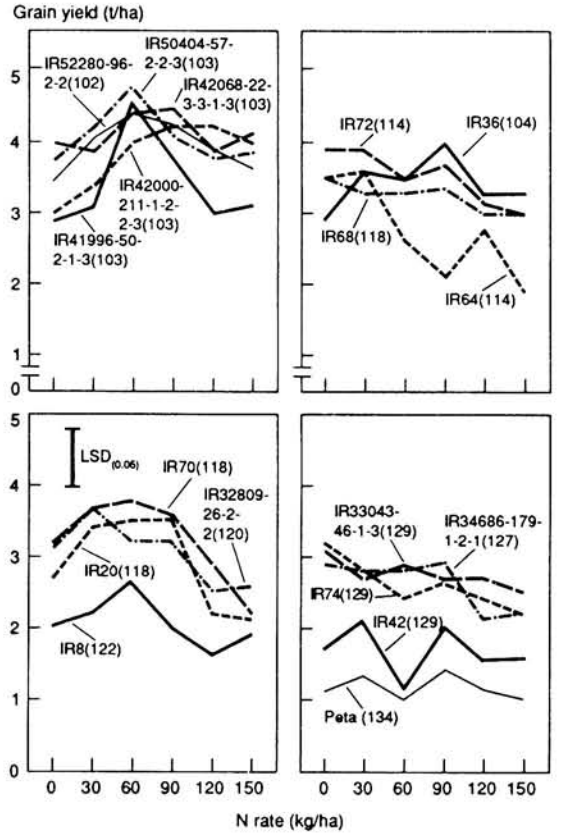
IR32809-26-3-3. Only 2 rices yielded 7.0 t/ha or more: IR72 (7.2 t/ha) at 150 kg N/ha and IR32809-26-3-3 (7.0 t/ha) at 120 kg N/ha. Without N applied, the recently named variety, IR68, outyielded all test rices. Yields of 3.0 t/ha or more were common among test rices in plots without N. Modern rices outyielded the traditional variety Peta at all N rates. Rice response to N application was generally low, as poor tillering was observed during the early vegetative phase.

The WS crop was damaged by three successive typhoons that occurred during either flowering or the early dough stage, hence the low and erratic yields obtained.

At the Bicol Experiment Station (BEST) during DS, IR32809-26-3-3 yielded highest at 90 kg N/ha (Fig. 9). Rices with maturity longer than 120 d from seeding, except IR34686-179-1-2-1, gave maximum yields of more than 7.0 t/ha. Among the



9. Yield of rices at 6 N rates, Bicol Experiment Station (BEST), Pili, Camarines Sur, Philippines, 1988 DS. Numbers in parentheses indicate growth duration.



10. Yield of rices at 6 N rates, BEST, Pili, Camarines Sur, Philippines, 1988 WS. Numbers in parentheses indicate growth duration.

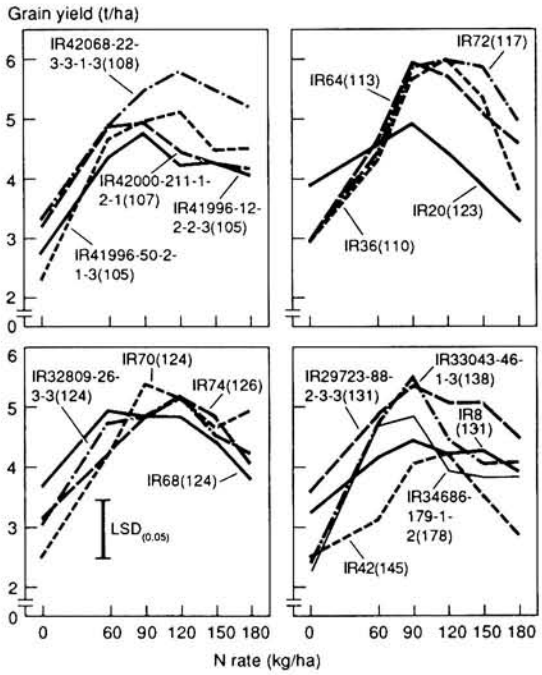
early-maturing cultivars, only IR42000-211-1-2-2-3 and IR72 produced yields of more than 7.0 t/ha. IR8, IR42, and Peta were seriously infected with RTV and are therefore not included in this report. Without applied N, a yield of at least 4.0 t/ha was common. IR72 yielded 6.0 t/ha. Continuous P and K fertilizer application in zero-N plots helped achieve considerable grain yields.

In WS, yields were lower than in DS. Early-maturing rices (≤ 103 d) showed higher response to applied N than did those maturing later (Fig. 10). As at MRRTC, Peta was outyielded by modern rices at all N levels.

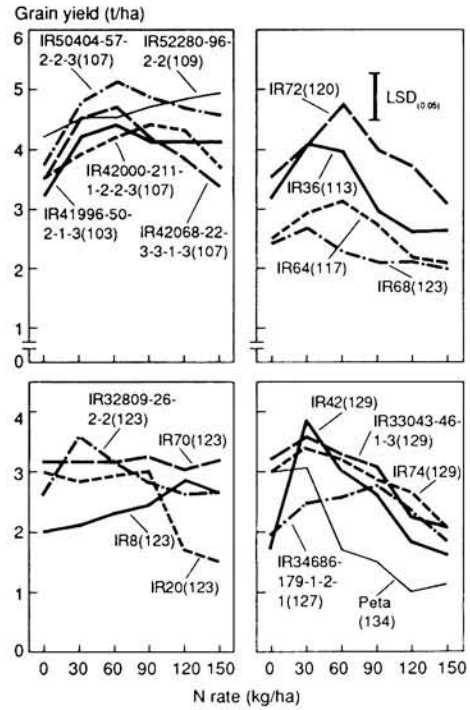
At the Visayas Experiment Station in DS, all test cultivars gave their maximum yields. These, however, were lower than those at MRRTC and BEST, primarily because of limited irrigation water supply (Fig. 11). Irrigation water was not enough to sustain Peta, the latest cultivar to mature, up to maturity. Most early-maturing cultivars yielded more than 5.0 t/ha. IR36 and IR72 gave the highest yields of 5.9 t/ha at 120 kg N/ha. The optimum N fertilizer application was 90-120 kg N/ha for most test cultivars. Of 17 rices, 10 yielded at least 3.0 t/ha without N application.

In WS, 30-60 kg N/ha was the optimum N fertilizer application rate (Fig. 12). IR50404-57-2-2-3 consistently gave higher yields at intermediate N levels, while IR52280-96-2-2 increased yield response as N rate was increased.

Rainfed rice. *IRRI.* Yields of eight varieties and four promising lines were evaluated at five N rates. IR42 and IR64 were infected with RTV, while IR46 was damaged by sheath rot disease. A strong storm that occurred at rice maturity caused lodging in rices maturing at 120 d or longer. IR70 and IR72 yielded highest on plots without applied N.



11. Yield of rices at 6 N rates, Visayas Experiment Station, Iloilo, Philippines, 1988 DS. Numbers in parentheses indicate growth duration.



12. Yield of rices at 6 N rates, Visayas Experiment Station, Iloilo, Philippines, 1988 WS. Numbers in parentheses indicate growth duration.

Farmer's field. Yields of all test varieties were lower in rainfed farmers' fields than in the irrigated field (Fig. 7). IR72 yielded 3.9 t/ha at the intermediate N rate. IR8 and IR42 were infected with RTV. Low yields of other test rices were due to flash floods during maturity and a storm that caused flooding at harvest.

PHOTOPERIOD SENSITIVITY

Plant Breeding Department

Near-isogenic F_6 sister lines differing in photoperiod sensitivity were developed from crosses with GEB24, a tall photoperiod-sensitive cultivar, and three semidwarf lines insensitive to photoperiod. Photoperiod-sensitive plants were identified as those that flowered in October or later when seeded on 10 May. Linkage between a major gene for photoperiod sensitivity and the isozyme allele *Pgi-2* was calculated using a cross between two of the lines. The sensitive sister line (IR38699-53-3-3-2) possessed *Pgi-2*^{1} from GEB24, and the insensitive line (IR38699-53-3-3-1) possessed *Pgi-2*^{2} from IR13146-179. Data showed that the gene for sensitivity was linked with *Pgi-2* (Table 8). The recombination value for the 2 genes was estimated as 23 map units based on the maximum likelihood method. *Pgi-2* has been shown to be closely linked to the major photoperiod sensitivity gene *Se-1*.

Three pairs of sister lines differing in the gene for photoperiod sensitivity were studied for morphological and agronomic characteristics under three seeding dates (10 Jun, 1 Jul, and 22 Jul) in 1987 WS. The photoperiod-sensitive lines showed a marked reduction in growth duration at later seeding dates. Similar reductions were seen in plant height, internode number, length of flag leaf, panicle length, and grains per panicle (Table 9). Weight of 100 grains, grain yield per plant, and length of last internode were independent of seeding date or growth duration. The number of panicles per plant and spikelet sterility increased in the last seeding date. Date of planting did not appreciably affect any of the traits measured for the photo-

Table 8. Segregation for a photoperiod-sensitive gene and the isozyme gene phosphogluco-isomerase-2 (*Pgi-2*) in the F_2 of a cross between the 2 sister lines IR38699-53-3-3-2 (photoperiod sensitive) and IR38699-53-3-3-1 (insensitive). IRRI, 1987.

Sensitivity	Plants (no.) in each *Pgi-2* allele class[a]				Test of significance[b]	
	1/1	1/2	2/2	Total	Trait	χ^2
Sensitive	21	43	8	72	Sensitive (3:1)	0.17
Insensitive	3	8	16	27	*Pgi-2* (1:2:1)	0.09
Total	24	51	24	99	Independence	24.85**

[a] 1/1 = homozygous for allele $Pgi\text{-}2^1$, 2/2 = homozygous for allele $Pgi\text{-}2^2$, 1/2 = heterozygous. [b] ** = significant at the 1% level.

Table 9. Percent change in plant characters of 3 isogenic lines compared with cultivar GEB24 (in parentheses) at later seeding dates compared with the first seeding date.

Plant character	Value for 10 Jun seeding	Percent change from 10 Jun seeding	
		1 Jul seeding	22 Jul seeding
Days to flowering	139 (136)	−7 (−7)	−19 (15)
Plant height (cm)	127 (158)	−11 (−8)	−14 (−13)
Internodes (no.)	9 (8)	−11 (0)	−22 (−13)
Length (cm) of last internode	35 (36)	−9 (2)	−10 (−5)
Flag leaf length (cm)	36 (40)	−10 (−13)	−24 (−22)
Panicles (no./plant)	14 (19)	21 (−8)	29 (−5)
Panicle length (cm)	29 (29)	−5 (−1)	−16 (−8)
Grains (no./panicle)	179 (131)	−7 (−5)	−17 (−12)
Spikelet sterility (%)	27 (13)	2 (4)	25 (28)
100-grain weight (g)	2 (2)	−3 (2)	−3 (2)
Grain yield (g/plant)	20 (17)	6 (10)	2 (5)

period-insensitive lines. However, changes in growth duration in photoperiod-sensitive genotypes had significant effects on morphological characters.

VARIABILITY AND INHERITANCE OF RATE AND DURATION OF GRAIN FILLING

Plant Breeding Department

We conducted two consecutive experiments to determine the variability and inheritance of two important traits that determine yield potential: rate and duration of grain filling. Experiments were begun in 1987 DS and completed in March 1988.

In experiment 1, conducted in 1987 DS on the IRRI farm, 21 cultivars representing a diversity of agronomic characters were used to identify variability in rate and duration of grain filling. Seeds were sown using the wetbed technique, and 1-mo-old seedlings were transplanted at 1 plant/hill in plots (7.2 × 0.9 m^2) with 4 rows spaced 30 cm between rows and 20 cm within a row in a randomized complete block design (RCBD) with 3 replications. Spacing between blocks was 1 m, and space between plots within a block was 60 cm to facilitate sampling. Just before transplanting, fertilizer was applied at 60-40-40 kg NPK/ha. Weeds were controlled with occasional hand weeding. Insecticides were applied as often as necessary. Panicles were tagged when approximately 5% of the spikelets had dehisced anthers. Ten tagged panicles were taken at random from the day of tagging to 40 d after tagging at 4-d intervals. The panicles were oven-dried at 48 °C for 3 d. Thereafter, grains—filled or unfilled—of each panicle were removed by hand, counted, and weighed. The weight obtained was denoted as panicle weight. The increase in panicle weight of cultivars was calculated adopting Richard's func-

tion, and the grain-filling duration (GFD) and grain filling rate (GFR) were determined.

Six cultivars—BG276-5, BG267-4, BG90-2, BG573, BG11-11, and Remadja—selected from experiment 1 on the basis of grain size, duration, GFR, and GFD were used in experiment 2, designed to determine the mode of inheritance. The six cultivars were crossed in a half diallel manner by making only one of the two possible crosses between any pair of varieties. The resulting F_1 and parents were divided into three groups according to days to flowering (F_1 was estimated as the average of the two parents). The three groups were sown at 20-d intervals, with the latest flowering group sown first and the earliest flowering group sown last to obtain flowering of all entries at the same time. One-month-old seedlings were planted in a RCBD with three replications in 1987 WS on the IRRI farm. Each plot had 2 rows with 30 cm between rows and 30 cm between hills. Unlike in experiment 1, only ammonium sulfate at 60 kg N/ha was applied to the field at the time of each transplanting, since the field used had adequate soil P and K. Crop management and panicle sampling were the same as in experiment 1. Days to 50% heading and growth duration of all varieties were recorded. Grain number per panicle, unfilled grains, and 100-grain weight were determined from data on panicle weight. The mode of inheritance was determined on the basis of genetic component and genetic parameters obtained from F_1 data, and the variance and covariance graph. An analysis of variance of the diallel table was also carried out. The relationship of the order of dominance to GFD and GFR was analyzed by a standardized deviation graph of the parental measurement and the order of dominance of the parents.

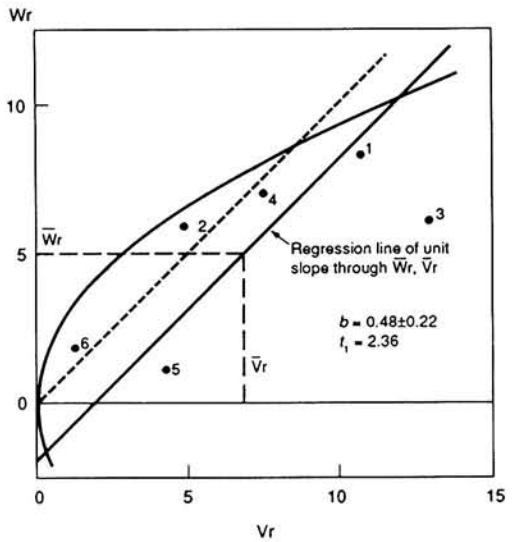
Highly significant differences for both GFR and GFD were found among the 21 varieties. PP2462/11 ranked fastest in GFR at 129.7 mg/panicle per d, and BG11-11 ranked lowest at 27.8 mg/panicle per d. BG90-2 ranked longest in GFD with 40 d, and PP2462/11 ranked shortest with 16 d (Table 10).

GFR and GFD in the parents and F_1 hybrids of experiment 2 showed highly significant differences among genotypes, so further analyses were done to estimate the genetic components and

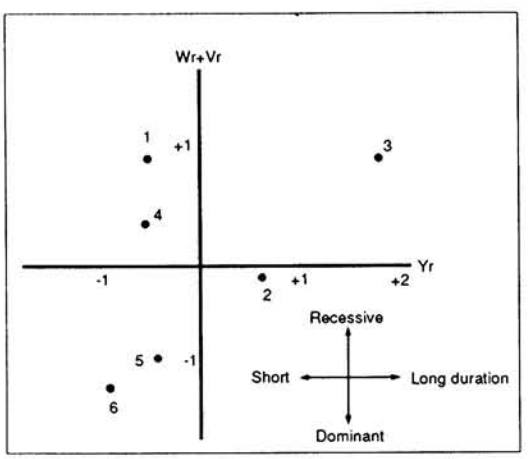
Table 10. Rate and duration of grain filling of 21 rice cultivars. IRRI, 1987 DS.

Cultivar	Grain filling rate (mg/panicle per d)	Grain filling duration (d)
SSD106	98.1 b	18 h
BG750	121.9 a	17 h
PP2462/11	129.7 a	16 h
Seeraga Samba	34.1 hi	26 def
BG276-5	90.8 bc	19 gh
BG367-4	75.3 cd	23 fg
IR50	65.1 de	24 fg
IR36	78.6 cd	23 fg
BG34-8	59.1 ef	27 cdef
BG90-2	42.1 fghi	40 a
BG380	44.4 fghi	38 a
IR64	85.7 bc	24 fg
IR54	47.1 fgh	33 b
BG573	35.9 ghi	25 ef
IR42	50.8 efgh	29 bcde
IR48	95.7 b	24 fg
BG11-11	27.8 i	31 bc
BG400-1	56.3 ef	30 bcd
Remadja	86.2 bc	24 fg
H4	53.1 efg	32 b
IR26	46.0 fgh	33 b

their effects on the two characteristics. The variance and covariance graph of the GFD is shown in Figure 13. Overdominance is indicated by the relative proportion of dominant and recessive genes in the parents. BG90-2, with the longest GFD, is located farthest away from the point of origin, indicating relative abundance of recessive genes. The Yr, Wr + Vr graph (Fig. 14) confirmed the above results. BG90-2, located in the first quadrant indicating predominance of recessive genes, gave relatively long GFD. BG276-5 and BG573, located in the second quadrant, although controlled by a larger portion of recessive genes, had shorter GFD, indicating a complicated genic effect involved in controlling this trait. Remadja and BG11-11 are in the third quadrant, suggesting short GFD by dominant genes. BG367-4, located in the fourth quadrant, although possessing more dominant genes, had a longer GFD, again indicating a complicated gene interaction. Estimated genetic components for GFD revealed a large influence of environment on the character. A relatively larger portion of dominant gene effects and unequal mean allelic frequencies at the loci influencing the trait were also detected. The parents used appeared to have more recessive



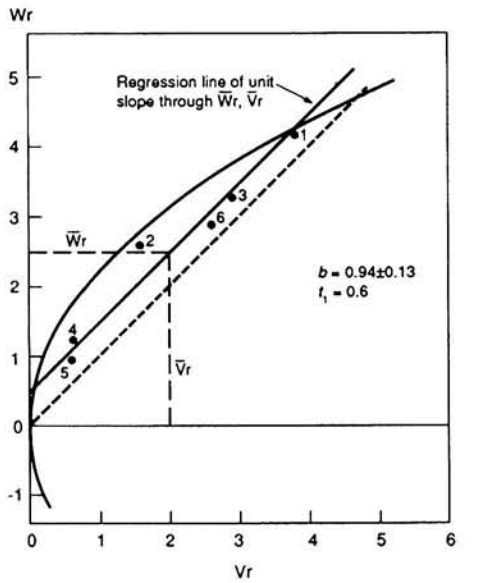
13. Duration of grain filling—Wr, Vr graph. Array 1 = Bg 276-5, 2 = Bg 367-4, 3 = Bg 90-2, 4 = Bg 573, 5 = Bg 11-11, 6 = Remadja. IRRI, 1987 WS.



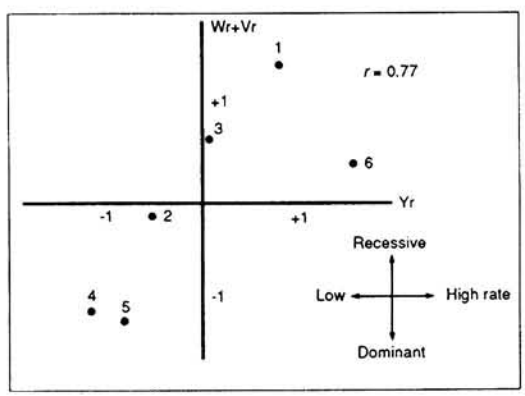
14. Standardized deviation—Yr, Wr + Vr graph for duration of grain filling. Array 1 = Bg 276-5, 2 = Bg 367-4, 3 = Bg 90-2, 4 = Bg 573, 5 = Bg 11-11, 6 = Remadja. IRRI, 1987 WS.

alleles than dominant ones for GFD. Broad- and narrow-sense heritability estimates were 73.3 and 61.6%, respectively.

The variance and covariance (Vr, Wr) graph of GFR is shown in Figure 15. The regression line of unit slope indicates the influence of partial dominance in the inheritance of GFR. BG11-11, having the slowest GFR with the smallest Wr + Vr value, has the greatest excess of dominant alleles. Ascending the line are parents having increasing proportions of recessive alleles. BG276-5, farthest away from the origin, indicates a predominance of recessive genes. BG90-2 and Remadja have a higher proportion of recessive genes, while BG367-4 seems to have a higher proportion of dominant genes. The Wr + Vr graph (Fig. 16)



15. Rate of grain filling—Wr, Vr graph. Array 1 = Bg 276-5, 2 = Bg 367-4, 3 = Bg 90-2, 4 = Bg 573, 5 = Bg 11-11, 6 = Remadja. IRRI, 1987 WS.



16. Standardized deviation—Yr, Wr + Vr graph for rate of grain filling. Array 1 = Bg 276-5, 2 = Bg 367-4, 3 = Bg 90-2, 4 = Bg 573, 5 = Bg 11-11, 6 = Remadja. IRRI, 1987 WS.

provides a direct examination of the above relation. The relation of quadrants to recessiveness and dominance and to high and low GFR is indicated in Figure 16. The distribution of coordinated points and the correlation coefficient show positive associations between high GFR and an excess of recessive alleles, and between low GFR and an excess of dominant genes.

The estimated genetic components of variation for GFR revealed that variations due to additive dominance and environmental effects were all highly significant, indicating that all of the components play an important role in controlling the character. GFR, unlike GFD, appears to be controlled mainly by additive gene effects. However, there are also unequal mean allelic frequencies influencing it, like those in GFD. The ratio of dominant to recessive alleles also indicated that there are more recessive alleles controlling GFR in the parents used in the study. The broad-sense heritability (91.5%) was very high, indicating a small environmental effect in influencing the trait compared with that of additive and dominance allelic effects. The high narrow-sense heritability (81.1%) revealed the major role of additive gene effects relative to dominant gene effects.

The associations between the grain filling parameters and agronomic traits measured are presented in Table 11. Panicle weights were correlated with mean GFR. The correlation between GFR and 100-grain weight was high ($r = 0.86^{**}$). Grain number per panicle was significantly negatively correlated ($r = -0.59^{**}$) with 100-grain weight. This negative correlation appears to be universal in small-grain crops like rice. So does the significant negative correlation between mean GFR and grain number per panicle ($r = -0.46^{*}$). GFD showed no significant correlation with any of the other traits measured.

The fact that GFR is controlled mainly by additive gene effects and has high heritability points to the possibility of large genetic gain through recurrent selection. However, direct selection for the trait would be very difficult because of the complicated procedure involved in measuring GFR. The close association between GFR and 100-grain weight in these genotypes made it possible to select for high GFR through selection for larger grain size. There appears to be no genetic barrier to hinder the development of genotypes with high GFR combined with any GFD.

INCREASING YIELD POTENTIAL

Plant Physiology Department

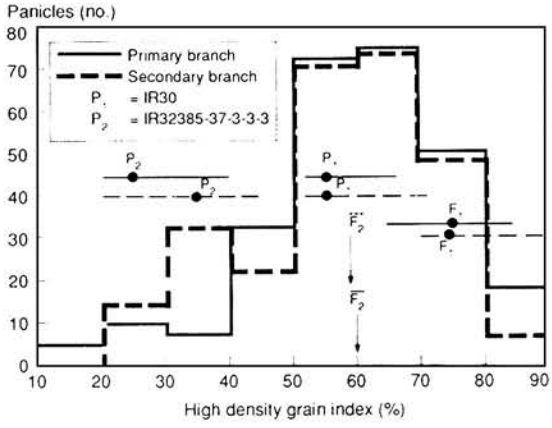
Genetics of high-density rice grain. High-density (HD) grains (specific gravity > 1.20) have higher test weight and head rice recovery. An increase in the number of HD grains may possibly increase the yield potential further. The genetics of HD grain was studied in 6 crosses from 6 parents—IR32307-75-1-3, IR30, IR34615-75-1-1, IR29725-135-2-2, IR29692-117-1-2, and IR35337-61-2-2—having at least 30% HD grains and in 2 low-density (LD)-grain parents—IR32419-102-3-2 and IR32385-37-3-3—having less than 30% HD grains. The HD grain index (HDI) was calculated by dividing the number of HD grains by the total number of spikelets per panicle on both primary branches (PB) and secondary branches (SB).

Table 11. Correlation coefficients among grain-filling parameters and some yield components of selected rice genotypes and their 15 half-diallel crosses.[a] IRRI, 1987 WS.

Parameter	Seeding to 50% heading	Grain filling duration	Mean grain filling rate	Percentage of unfilled grains	100-grain weight	Grain number per panicle	Panicle weight
Growth duration	.94**	.22	−.10	−.21	.02	.28	.36
Panicle weight	.36	−.01	.44*	−.25	.47*	.43*	
Grain number per panicle	.31	−.21	−.46*	−.05	−.59**		
100-grain weight	.01	.17	.86**	−.19			
Percentage of unfilled grains	−.27	.04	−.16				
Grain filling rate	.05	−.35					

[a] Significant at the 5% (*) and 1% (**) levels.

The HDI distribution and means of parents, F_1, and F_2 plants of one of the crosses are presented in Figure 17. Cross IR30/IR32385-37-3-3-3 (HD/LD) had an F_1 population with a large range of HDI variation, a mean HDI of 76% for spikelets on the PB, and 75% for spikelets on the SB, which markedly exceeded the high parent value (56%). The mean HDI for the low parent was 29%. The F_2 population was distributed continuously, ranging from 10 to 90% on PB and from 20 to 90% on SB. The F_2 mean was 60% for PB and 59% for SB, which was 16% lower than that of the F_1, indicating inbreeding depression. The curve was unimodal but slightly negatively skewed (Fig. 17). Only a few plants scored below the lower parental limit, but 20% of the population exceeded the upper limit of IR30, indicating that multiple genes with opposing effects were operating.



17. Distribution and means of parents, F_1, and F_2 plants by high density grain index in IR30/IR32385-37-3-3-3 cross. IRRI, 1987 WS.

The dominance effect (PB = -34.0, SB = -34.2) was 2 to 3 times higher than the additive effect (PB = -16.4, SB = -12.0). The potence ratio was more than 2 (PB = -2.2, SB = -2.6), indicating overdominance of genes governing this trait. The effective factor pairs estimate was 0.58 for PB and 1.26 for SB, indicating that the trait is controlled by a few polymeric genes. The positive degrees of heterosis were 86.8 (PB) and 70.0% (SB), and the positive degrees of heterobeltiosis were 33.2 (PB) and 33.9% (SB). The heritability estimate was very high at more than 80%, and thus selection for higher HD grain may be effective in early generations like the F_3 or F_4.

Gene action varied in other crosses, ranging from no dominance to partial dominance to complete dominance to overdominance. Multiple genes with both dominance and additive effects controlled HDI on PB and SB, although dominance effects were greater. Heterosis and heterobeltiosis for PB were also positive in another cross, IR29692-117-1-2-2-2/IR30 (HD/HD). The heritability estimates were high to moderate. The number of effective factor pairs did not exceed two for any cross.

The phenotypic correlation coefficients among nine characters of the two nonsegregating generations (parents and F_1) and one segregating generation (F_2) were estimated (Table 12). The relationship between any pair of characters differed among the generations. Number of PB was significantly and positively associated with spikelets on PB, HDI on PB, and SB in all generations. Strong significant positive correlation was noted between HDI on PB and number of PB, spikelets on PB, and HDI on SB. HDI on PB had a significant negative association with sterility on PB. Higher HDI on SB depends more on number of PB and spikelets on the PB but had no correlation with SB and spikelets on SB in the F_1 and F_2. This suggests that the number of PB and the number of spikelets on PB are most important in increasing HD grains in both PB and SB.

The direct and indirect influences of different panicle characters on HDI on PB was assessed by path coefficient analysis. The number of PB and spikelets on PB had a strong positive association with HDI on PB in all generations (Table 13), indicating they are probably controlled by additive genes. HDI on SB had a strong positive correlation and direct effects on HDI on PB in both segregating (Fig. 18) and nonsegregating generations. In most cases, negative correlation and direct and indirect effects were noted between HDI on SB and sterility on PB and SB. As a result, higher HDI depends on higher number of PB and spikelets on PB but not on number of spikelets on SB. The plant type for enhanced yield should have more PB and spikelets on PB with few SB and spikelets on SB.

Table 12. Phenotypic correlation coefficients among 9 characters in parents (P), F_1, and F_2.[a] IRRI, 1987 WS.

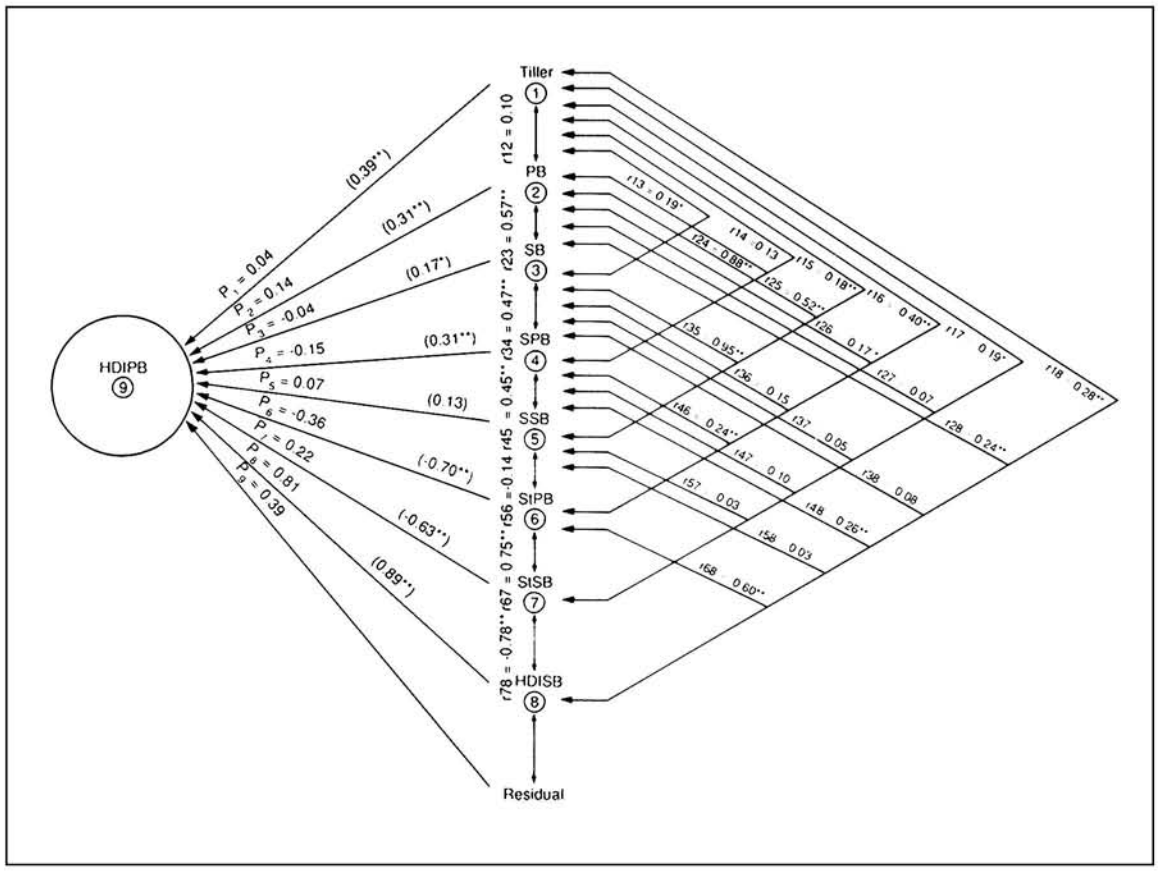
Trait	Generation	Tillers (no.)	PB (no.)	SB (no.)	Spikelets on PB (no.)	Spikelets on SB (no.)	Sterility on PB (%)	Sterility on SB (%)	HDI on PB (%)
PB (no.)	P	0.18							
	F_1	0.26							
	F_2	0.10							
SB (no.)	P	0.02	0.68**						
	F_1	0.02	0.06						
	F_2	0.19*	0.57**						
Spikelets on PB (no.)	P	−0.02	0.82**	0.72**					
	F_1	0.29	0.73**	0.07					
	F_2	0.13	0.88**	0.47**					
Spikelets on SB (no.)	P	−0.04	0.63**	0.88**	0.72**				
	F_1	0.04	0.01	0.74**	0.01				
	F_2	0.18**	0.52**	0.95**	0.45**				
Sterility on PB (%)	P	0.09	−0.05	0.15	−0.26	0.16			
	F_1	0.01	−0.03	0.32	−0.09	0.34			
	F_2	−0.40**	−0.17*	−0.15	−0.24**	−0.14			
Sterility on SB (%)	P	0.05	0.24	0.49**	0.24	0.49**	0.75**		
	F_1	−0.05	−0.16	0.36	−0.14	0.25	0.89**		
	F_2	−0.19*	−0.07	−0.05	−0.10	−0.03	0.75**		
HDI on PB (%)	P	0.40*	0.44**	0.34*	0.54**	0.43*	−0.39*	−0.13	
	F_1	0.65**	0.49**	−0.07	0.56**	−0.07	−0.49**	−0.56**	
	F_2	0.39**	0.31**	0.17*	0.31**	0.13	−0.70**	−0.63**	
HDI on SB (%)	P	0.69**	0.42**	0.36*	0.43**	0.44**	−0.09	0.16	0.81**
	F_1	0.55**	0.43**	−0.25	0.49**	−0.31	−0.52**	−0.60**	0.89**
	F_2	0.28**	0.24**	0.08	0.26**	0.03	−0.60**	−0.70**	0.89**

[a] PB = primary branches, SB = secondary branches, HDI = high-density grain index. * = significant at the 5% level, ** = 1% level.

Table 13. Direct (underscored) and indirect effects of associated traits on high-density grain index on primary branch (HDIPB).[a] IRRI, 1987 WS.

Trait	Generation	Tiller	PB	SB	SPB	SSB	StPB	StSB	HDISB	*r*
Tiller	P	−0.19	−0.02	–	−0.01	–	0.01	−0.02	0.64	0.40*
	F_1	0.26	0.02	–	0.03	0.01	–	–	0.34	0.65**
	F_2	0.04	0.01	−0.01	−0.01	0.01	0.01	−0.04	0.23	0.39**
Primary branch (PB)	P	−0.03	−0.14	0.04	0.28	–	−0.01	−0.11	0.38	0.44**
	F_1	0.07	0.08	–	0.07	–	0.01	–	0.26	0.49**
	F_2	–	0.14	−0.02	−0.10	0.03	0.06	−0.02	0.20	0.31**
Secondary branch (SB)	P	–	−0.09	0.06	0.24	0.01	0.02	−0.22	0.33	0.34*
	F_1	0.01	–	–	0.01	0.13	−0.07	–	−0.15	−0.07
	F_2	0.01	0.08	−0.04	−0.05	0.06	0.05	−0.01	0.06	0.17*
Spikelets on PB (SPB)	P	–	−0.11	0.04	0.34	–	−0.03	−0.11	0.39	0.54**
	F_1	0.07	0.06	–	0.11	–	0.02	–	0.31	0.56**
	F_2	–	0.13	−0.02	−0.15	0.03	0.09	−0.02	0.21	0.31**
Spikelets on SB (SSB)	P	0.01	−0.09	0.05	0.24	0.01	0.02	−0.22	0.40	0.43**
	F_1	0.01	–	–	–	0.18	−0.08	–	−0.19	−0.17
	F_2	0.01	0.07	0.04	0.05	0.07	0.05	−0.01	0.03	0.13
Sterility on PB (StPB)	P	−0.02	0.01	0.01	−0.09	–	0.11	−0.33	0.08	−0.39*
	F_1	–	–	–	−0.01	0.06	−0.23	0.01	−0.32	−0.49**
	F_2	−0.01	−0.02	0.01	0.03	−0.01	−0.36	0.16	−0.48	−0.70**
Sterility on SB (StSB)	P	−0.01	−0.03	0.03	0.08	–	0.09	−0.44	0.15	−0.13
	F_1	−0.01	−0.01	–	−0.01	0.05	−0.20	0.01	−0.37	−0.56**
	F_2	−0.01	−0.01	–	0.01	–	−0.28	0.22	−0.56	−0.63**
HDI on SB (HDISB)	P	−0.13	−0.06	0.02	0.14	–	−0.01	−0.07	0.91	0.81**
	F_1	0.14	0.03	–	0.05	−0.06	0.12	–	0.61	0.90**
	F_2	0.01	0.03	–	−0.03	–	0.22	−0.15	0.81	0.89**

[a] – = very low value, almost equal to zero. Residual effects: (P) = 0.41, (F_1) = 0.31, (F_2) = 0.39.



18. A path diagram and coefficients of factors influencing high density grain index on primary branch (HDIPB) in the F_2. IRRI, 1987.

Among the crosses studied, IR30/IR32385-37-3-3-3 was most promising. It had the highest mean value for HDI in both the F_1 and F_2. The cross showed positive heterosis and heterobeltiosis for this trait. As the heritability estimates were high, the progenies are expected to offer higher HD grain genotypes. Among the parents, IR30 was found to be promising in increasing HD grains.

Prebreeding for panicle structure improvement. In a prebreeding program, the panicle structure of 80 rice cultivars and lines was studied. Table 14 shows four distinct panicle types. The IR varieties and Rewa type (PAU125-1-2/Lalco 14) have similar panicle structure, except that Rewa has more spikelets on SB. The *glaberrima* type has more PB and spikelets on PB, with few SB and spikelets on SB. The upland type, derived from an anther-cultured cross Moroberekan/Palawan, is intermediate, having almost the same number of spikelets on both PB and SB. The PB/SB ratio is high in the *glaberrima* type and low in the Rewa type.

Several crosses were made between these groups in an attempt to improve panicle structure. The total spikelet number increased up to 279 in Rewa 353-3/IR47705-AC4 compared with around 150 spikelets in IR entries (Table 15). PB numbered 17.3 in IR47705-AC5/Ch IR87-3-1, 16.1 in Acc. 103995/IR47705-AC4, and around 10 in the IR varieties.

Heterosis (over midparent), heterobeltiosis (over better parent), and standard heterosis (over IR36) were estimated for PB, SB, spikelets on PB, spikelets on SB, and total spikelets. The estimates of overall degree and direction of heterosis (F_1-P) were significantly positive for all the characters, indicating dominance of the higher values.

The values for individual F_1 families, however, differed from the overall estimates for different

characters in showing positive, negative, or no heterosis. The F_1 means conspicuously deviated from the respective parental and midparental values, indicating nonadditive gene action in expression observed for most characters.

Substantial heterosis in the desirable direction

Table 14. Panicle characteristics[a] of parental material.

Parent	Number					
	PB	SB	PB/SB	SpPB	SpSB	TSp
Glaberrima type						
Acc. 103995	12.3	7.3	1.7	98	16	114
Acc. 103350	15.4	4.0	3.8	123	9	132
Acc. 104003	16.3	18.7	0.9	126	56	182
IR cultivars or lines						
IR30	9.1	22.2	0.4	46	69	115
IR34615-75-1-1	12.1	32.2	0.4	67	113	180
IR29725-135-2-2-3	10.3	19.8	0.5	65	59	123
IR32307-75-1-3-1	8.3	23.8	0.3	45	79	124
IR28211-43-1-1-2	10.4	26.1	0.4	68	92	160
IR36 (check)	9.2	22.8	0.4	50	72	122
Upland type						
IR47705-AC1	13.0	30.0	0.4	80	92	173
IR47705-AC3-2	14.0	35.5	0.4	82	109	190
IR47705-AC4	12.4	39.0	0.3	77	131	208
IR47705-AC4-1	12.5	36.5	0.3	78	116	193
IR47705-AC5	14.0	17.7	0.8	81	54	135
IR47705-AC5-1	14.7	30.7	0.5	91	97	189
Indica type						
Rewa 353-2	10.1	35.2	0.3	61	131	192
Rewa 353-3	10.0	34.4	0.3	61	129	191
Rewa 353-4	10.5	36.4	0.3	64	137	202
Rewa 353-7	10.3	31.0	0.3	63	114	177
Ch IR87-3-1	12.3	24.4	0.5	80	72	152
LSD (0.05)	1.2	3.9		14	15	12

[a] PB = primary branches, SB = secondary branches, SpPB = spikelets on PB, SpSB = spikelets on SB, TSp = total spikelets.

Table 15. Panicle characteristics of F_1 hybrids.

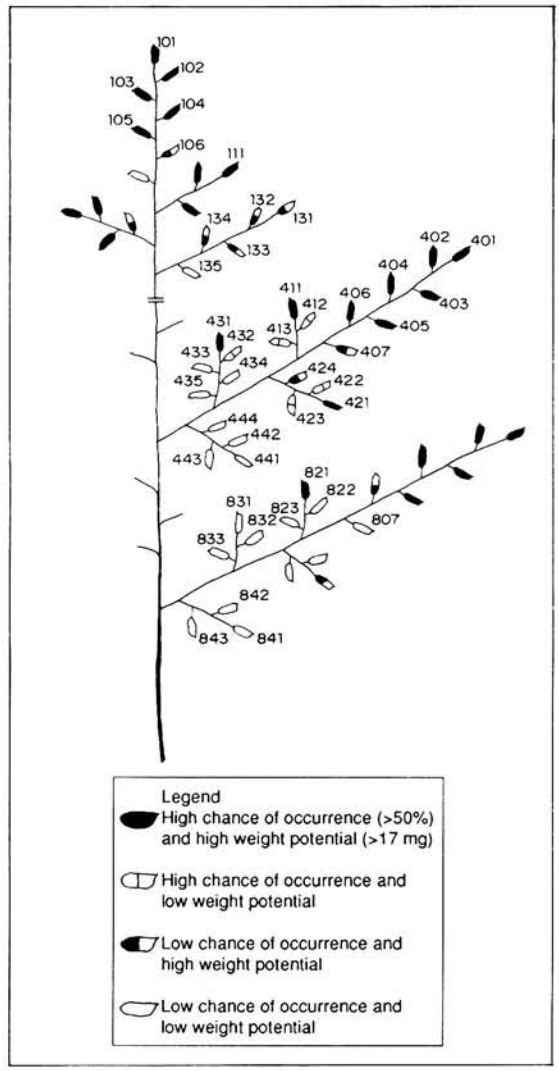
Hybrid	Number					
	PB	SB	PB/SB	SpPB	SpSB	TSp
Rewa 353-3/IR47705-AC4	14.1	50.4	0.3	91	187	279
Rewa 353-2/IR30	12.0	43.3	0.3	66	158	224
Rewa 353-4/IR28211-43-1-1-2	10.9	32.0	0.3	68	116	184
Rewa 353-7/IR32307-75-1-3-1	9.4	31.5	0.3	56	115	171
Acc. 103995/IR47705-AC4	16.1	36.8	0.4	119	111	230
Acc. 103350/IR47705-AC4	14.0	35.3	0.4	101	115	217
Acc. 103350/IR47705-AC4-1	14.2	45.3	0.3	117	150	267
Acc. 104003/IR47705-AC4-1	14.9	35.2	0.4	100	109	208
IR47705-AC1/IR29725-135-2-2-3	13.6	35.2	0.4	91	119	210
IR47705-AC3-2/IR34615-75-1-1	14.7	47.4	0.3	85	168	253
IR47705-AC5/Ch IR87-3-1	17.3	40.3	0.4	113	130	244
IR47705-AC5-1/IR28211-43-1-1-2	13.9	34.4	0.4	96	123	219
LSD (0.05)	1.3	3.8		12	16	19

was observed in characters like number of PB, spikelets on PB, and total spikelets that are related to higher grain yield potential. All the crosses exhibited positive heterosis, heterobeltiosis, and standard heterosis for number of PB and spikelets on PB except some *glaberrima* crosses, where heterobeltiosis was negative. This may be due to the already high number of PB and spikelets on PB in the *glaberrima* parents. Two Rewa crosses (Rewa 353-3/IR47705-AC4 and Rewa 353-2/IR30) and four crosses having an upland type as the female parent manifested positive heterosis, heterobeltiosis, and standard heterosis for all characters.

Spikelet occurrence in IR58 panicles. The development of spikelets within a panicle proceeds in a sequential manner. Spikelets on the lower panicle branches are initiated and developed first; development then proceeds acropetally within a panicle. At anthesis, however, development of grains among panicle branches starts from the top branch and moves downward; but within a branch, the topmost spikelet is the first to open, followed by the basal spikelet, proceeding acropetally.

An understanding of the occurrence of spikelets at a particular panicle position and of their chances of being filled can be used to improve panicle type. Tillers of IR58 were removed to maintain a uniculm. At heading, panicles that had just started to flower were tagged, and 10 tagged panicles were sampled at random, starting at heading and every 3 d thereafter for 30 d. Spikelets within each PB and SB were also numbered from top to bottom. A three-digit spikelet notation was used to denote PB number, SB number, and spikelet position. Spikelet occurrence in the top, middle, and bottom primary branches was determined by dividing the number of times a spikelet in a particular position occurred by the total number of panicles observed. Individual spikelets were weighed during the last four sampling dates.

For all three PBs studied, spikelets 1 to 4 (X01-X04) on the main axis had 100% occurrence (Fig. 19). Spikelet 5 (X05) had at least 98% chance of occurrence, while spikelet 6 (X06) on the PBs had 50-84% chance of occurring. Spikelet 7 (X07) had 10% or less chance of occurrence. The 3 spikelets (X11-X13) on the first SB of PB 1 and 2 have 78-100% chance of being formed.



19. Spikelet occurrence and weight within a panicle of IR58. Three-digit figures above spikelets refer to primary branch number, secondary branch number, and spikelet number, respectively.

However, the chances of spikelets being formed decreased basipetally with position in a SB, a PB, and a panicle. Thus, PB 8 had a low occurrence of spikelet 7 (807), and the lowest spikelet occurrence in SB, especially 84X.

Since spikelets on 44X, 83X, and 84X had small chances of occurring, they were relatively unimportant in grain yield determination.

Grain weight was heaviest for spikelets 1-6 on PB (Fig. 19). Spikelet 2 of PB was generally lighter than the other spikelets in the main axis of PB.

Spikelets 2, 3, and 4 of PB 4, SB 4, and spikelet 7 of PB 8 had very poor grain filling. On the other hand, spikelets of PB 8, SB 2, and all lower secondary branches had a very small chance of occurrence. Unfilled spikelets do not contribute to total grain yield and may actually have a negative effect, since the energy to initiate and develop them could have been used to develop other spikelets. Selection for nonoccurrence of these spikelets might improve grain yield potential.

Several spikelets on the SBs of PB 4 (412, 413, 422, 423, 432-434) and one on PB 8 (822) had >50% chance of occurrence but had low grain weight. These spikelets should be selected out in breeding for better panicle type.

Spikelets can be classified into four groups: A) high chance of occurrence (>50%) and high weight potential (>17 mg); B) high chance of occurrence and low weight potential; C) low chance of occurrence and high weight potential; and D) low chance of occurrence and low weight potential (Fig. 19). In the selection for better panicles for higher grain yield, high proportions of spikelet types A and C are needed. IR58 is composed of 43% type A, 13% type B, 16% type C, and 28% type D. Type D should be selected out in the breeding process to increase the proportion of types A and C. Type D spikelets generally occur on the SB, especially on PB 4/SB 4 and PB 8/SB 2 to PB 8/SB 4. The chances of spikelets on SB being formed and filled decreased basipetally within a SB, within a PB, and within a panicle; thus, fewer spikelets on SB and more spikelets on PB could improve grain yield potential.

Contribution of different tillers to grain yield. The yield contribution of different tillers was investigated in an effort to evaluate the number of tillers for a low-tillering rice ideotype to increase grain yield potential. The improved high-yielding cultivars are high tillering, but they produce many small or weak tillers at close spacing. These weak tillers may limit the potential grain yield. The low-tillering, large-panicle IR25588-7-3-1 was compared with the high-tillering, small-panicle IR58. Both have short growth durations (103 d) and similar plant height. Single plants were grown in pots, and the emergence of primary (P), secondary (S), and tertiary (T) tillers was recorded every 2 d. The tillers were labeled M (main culm), P1, P2, P3 (1st, 2d, 3d primary tillers); S1P1, S2P1, S3P1 (1st, 2d, 3d secondary tillers originating from P1, and so on); and T1, T2, T3 (1st, 2d, 3d tertiary tillers developing from the secondary tillers). The secondary tillers originating from the prophyll of P1 and P2 were labeled S0P1 and S0P2.

Yield contribution of different tiller orders. The contribution of different tiller orders to grain yield per plant in IR25588-7-3-1 was 9, 40, 46, and 5% for the M, P, S, and T tillers, respectively (Table 16). IR58 showed a similar trend, indicating no varietal difference in that character between low- and high-tillering cultivars.

Both cultivars had more P and S panicles than T panicles (Table 16). The grains from P and S tillers were the main component of the grain yield: 86% of the total yield in IR25588-7-3-1 and 88% in IR58. The T panicles contributed only 5% in both cultivars, which is low considering the number of T tillers.

Generally, panicles from P tillers were larger (heavier and more spikelets) than those from S and T tillers up to P5 in both cultivars. The panicles from T tillers weighed less and had fewer

Table 16. Contribution of different tiller orders to grain yield in a plant.[a] IRRI, 1987 DS.

Cultivar	Main culm	Primary	Secondary	Tertiary	Total
		Grain yield (g/plant)			
IR25588-7-3-1	4.46 ± .13	18.78 ± .45	21.94 ± .55	2.40 ± .44	47.58
IR58	3.18 ± .10	16.08 ± .39	21.73 ± .67	1.87 ± .42	42.86
		Tillers (no./plant)			
IR25588-7-3-1	1.0 ± 0	5.6 ± .2	9.6 ± .3	2.9 ± .4	19.1
IR58	1.0 ± 0	7.5 ± .1	17.7 ± .4	6.3 ± .7	32.5

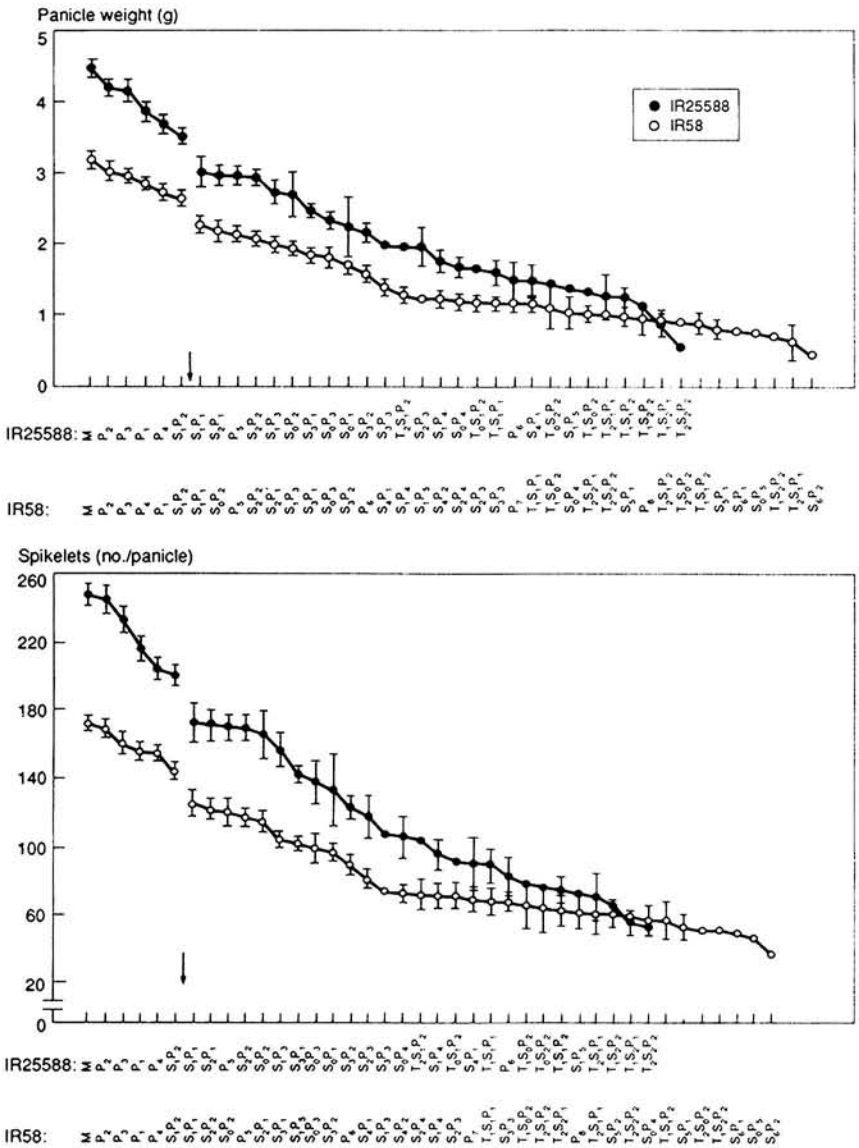
[a]Mean ± standard error.

spikelets per panicle. In developing cultural practices for higher yielding ability, T tillers should be avoided or minimized.

Low-tillering IR25588-7-3-1 had more and a higher proportion of large panicles (>100 spikelets/panicle) than IR58.

Critical panicle number. The panicle weight and number of spikelets per panicle of the six top panicles in both cultivars was significantly more than in the other panicles (Fig. 20). The top six panicles were M, P1, P2, P3, P4, and S1P2 in both cultivars. Their tillers had 100% probability of occurring; other tillers varied greatly in their chances of being initiated or producing a panicle. These observations suggest that a new rice ideotype having only six or fewer potential tillers or panicles may help increase grain yield potential.

Tillering behavior. In general, high-tillering IR58

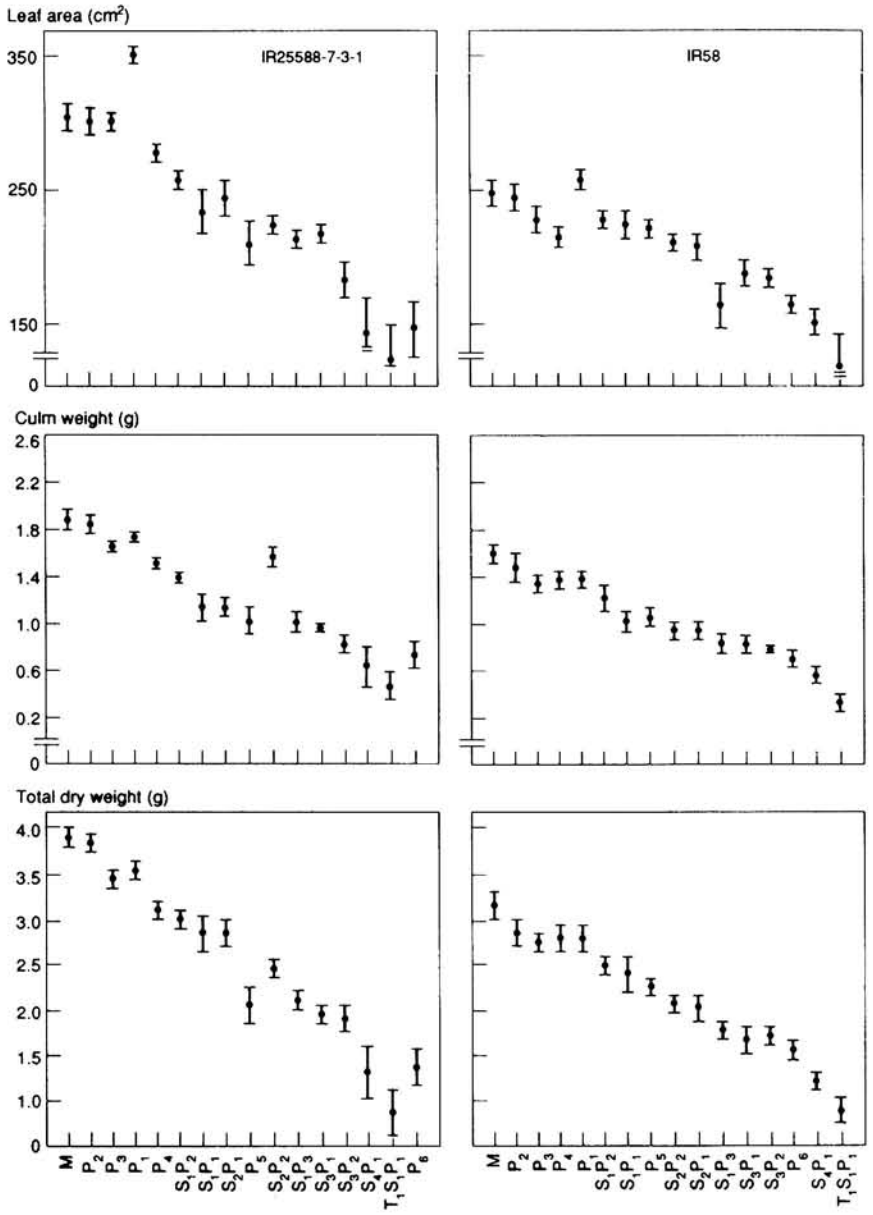


20. Weight and number of spikelets on panicles on different tillers in a plant. IRRI, 1987 DS.

had earlier tillering and a higher rate and longer period of tillering than low-tillering IR25588-7-3-1. The longer tillering period of IR58 is disadvantageous, since late tillers generally are small, mature late, or become nonbearing. Different tiller orders also had different tillering periods, being shortest in the tertiary tillers.

The main contributors to total tiller number in both cultivars were the secondary tillers, which produced 50-55% of the total tillers. The tillering ability of IR25588-7-3-1 was only 59% that of high-tillering IR58 in this pot experiment.

The percentage of effective tillers in IR25588-7-3-1 (85%) was higher than that in IR58 (67%).



21. Leaf area, culm weight, and total dry weight per tiller of representative tillers at heading in IR25588-7-3-1 and IR58.

The percentage of effective tillers among the secondary (87 vs 62%) and the tertiary (70 vs 30%) tillers was higher in IR25588-7-3-1 than in IR58.

Heading time of different tillers. Heading of the different tillers in a hill occurred in 6-11 d. No varietal difference was observed, although IR58 had more tillers than IR25588-7-3-1. Heading of P2 and P3 tillers on the main culm in IR25588-7-3-1 was earlier than that of the main culm.

Generally, the top six tillers flowered earlier than the others. Those that emerged earlier also flowered earlier, except the first primary tiller (P1), which was relatively late, and S1P2, which was relatively early. The top 6 tillers all headed in 3 d, while the interval within a hill was 6-11 d. Uniform flowering and maturity of the crop are more likely if only the top six tillers are considered in cultural management. Also, the top six tillers, which are initiated earlier, can probably accumulate more photosynthates than the tillers formed later because of their longer growth period.

Other characters of the different tillers. IR25588-7-3-1 had generally bigger leaf area, and higher culm weight and total dry weight per tiller than IR58 at heading (Fig. 21). The top six tillers had larger culms and leaves per tiller than the rest of the tillers in both cultivars. The larger culms and leaves could support the formation of many spikelets during spikelet differentiation and permit better grain filling after heading. Bigger culms would also be necessary to support heavy panicles.

IR25588-7-3-1 had more inner (IVB) and outer (OVB) vascular bundles just below the neck node than IR58 (Table 17). The main culm had the largest number of IVB followed by the P, S, and T tillers in both cultivars. In both cultivars, the number of IVB within a tiller order varied. In the primary tillers, P4 and P5 had fewer IVB than P1 and P2. Tillers that emerged later had fewer IVB than tillers that emerged earlier. The difference between the IVB of the main culm and that of the T tillers was around 6-7. The number of IVB generally decreased at the rate of two for each tiller order, and is probably controlled by tillering time and the origin of tillers.

The top six tillers had more IVB. The IVB was larger than the OVB. The number and distribution of OVB were similar to those of IVB.

The number of IVB is usually correlated with the number of primary branches. In this study, around two IVB (IVB/no. of primary branches) were connected to a primary branch of the panicle regardless of cultivar and tiller order.

In general, the culm diameter, culm thickness, and diameter of the medullary cavity of low-tillering IR25588-7-3-1 were larger than those of IR58. The top six tillers generally had greater culm diameter than the rest of the tillers in both cultivars. The bigger culms and more vascular bundles probably indicate a better delivery system. Translocation of metabolites depends on the development of an efficient vascular system. The medullary cavity tended to be bigger in the top six tillers, accounting for the bigger culm diameter rather than culm thickness.

The number of PB and SB on the panicle was highest in the main culm, followed by that in the P, S, and T tillers in both cultivars. However, IR25588-7-3-1 had more SB on the panicle than IR58.

Generally, the top six tillers had more PB on the panicle than the lower yielding tillers except in S1P2 of IR25588-7-3-1, which compensated with

Table 17. Number of inner and outer vascular bundles in different tillers in IR25588-7-3-1 and IR58.[a] IRRI, 1987 DS.

Tiller[b]	IR25588-7-3-1		IR58	
	Inner vascular bundles (no.)	Outer vascular bundles (no.)	Inner vascular bundles (no.)	Outer vascular bundles (no.)
M+	24.4 ± 0.7	23.0 ± 1.0	22.0 ± 0.6	22.0 ± 0.4
P1+	23.6 ± 0.7	24.2 ± 1.1	22.1 ± 0.7	21.8 ± 1.1
P2+	23.2 ± 0.4	24.6 ± 1.2	22.2 ± 0.8	21.2 ± 0.7
P3+	22.0 ± 0.4	23.8 ± 1.2	21.4 ± 0.4	20.2 ± 0.8
P4+	21.2 ± 0.5	23.8 ± 1.0	21.0 ± 0.4	20.6 ± 0.7
P5+	21.3 ± 0.5	21.0 ± 1.1	19.2 ± 1.0	19.6 ± 1.3
P6	18.0 ± 0.6	21.0 ± 1.2	18.2 ± 0.2	17.3 ± 1.1
S1P1	21.2 ± 0.7	22.8 ± 1.0	19.0 ± 0.7	18.8 ± 1.4
S2P1	20.4 ± 0.5	23.0 ± 1.0	18.6 ± 0.8	17.6 ± 1.1
S3P1	20.4 ± 0.7	20.8 ± 1.2	17.0 ± 0.8	18.0 ± 1.0
S1P2+	21.2 ± 0.4	23.2 ± 0.9	20.4 ± 0.7	19.8 ± 0.4
S2P2	20.8 ± 0.5	22.2 ± 1.2	18.6 ± 0.9	18.6 ± 0.8
S3P2	20.0 ± 0.9	20.0 ± 1.1	18.0 ± 1.1	17.3 ± 1.7
S1P3	20.3 ± 0.7	20.3 ± 0.9	18.2 ± 1.0	18.2 ± 1.2
T1S1P1	18.6 ± 0.8	18.8 ± 0.5	15.0 ± 0.7	15.0 ± 0.6
T2S1P1	18.2 ± 0.9	18.7 ± 0.7	15.5 ± 0.3	15.0 ± 1.2

[a] Mean ± standard error. [b] + = top six tillers.

Table 18. Yield and yield components of tillers in IR25588-7-3-1 and IR58.[a] IRRI, 1987 DS.

	IR25588-7-3-1					IR58				
Tiller[b]	Grain weight (g/panicle)	Spikelets (no./panicle)	Fertility (%)	1,000-grain weight (g)	HD grains with specific gravity ≥1.18 (no.)	Grain weight (g/panicle)	Spikelets (no./panicle)	Fertility (%)	1,000-grain weight (g)	HD grains with specific gravity ≥1.12 (no.)
M+	4.5 ± .1	247 ± 7	82 ± 1	22 ± 0.2	135 ± 7	3.2 ± 0.1[a]	172 ± 4	84 ± 2	22 ± 0.2	129 ± 4
P1+	3.8 ± .1	216 ± 8	82 ± 2	22 ± 0.2	119 ± 10	2.7 ± 0.1	155 ± 4	80 ± 2	22 ± 0.2	106 ± 5
P2+	4.2 ± .1	245 ± 7	81 ± 1	22 ± 0.2	124 ± 9	3.0 ± 0.1	169 ± 5	84 ± 2	22 ± 0.2	128 ± 4
P3+	4.2 ± .1	233 ± 7	81 ± 1	22 ± 0.2	121 ± 9	3.0 ± 0.1	160 ± 5	85 ± 2	22 ± 0.2	122 ± 4
P4+	3.7 ± .1	204 ± 6	82 ± 2	22 ± 0.2	111 ± 8	2.9 ± 0.1	155 ± 4	85 ± 2	22 ± 0.2	119 ± 4
P5+	3.0 ± .1	169 ± 8	80 ± 2	22 ± 0.2	87 ± 8	2.2 ± 0.1	117 ± 4	85 ± 2	22 ± 0.2	90 ± 4
P6	2.0 ± .3	82 ± 13	82 ± 4	21 ± 0.5	42 ± 12	1.6 ± 0.1	89 ± 5	84 ± 2	22 ± 0.3	63 ± 3
S1P1	3.0 ± .2	172 ± 11	82 ± 2	22 ± 0.2	95 ± 8	2.3 ± 0.1	125 ± 5	84 ± 2	22 ± 0.3	89 ± 5
S2P1	3.0 ± .1	171 ± 9	81 ± 2	22 ± 0.3	95 ± 8	2.0 ± 0.1	115 ± 5	83 ± 2	22 ± 0.2	85 ± 4
S3P1	2.5 ± .1	142 ± 5	81 ± 2	22 ± 0.3	85 ± 5	1.9 ± 0.1	104 ± 4	83 ± 2	22 ± 0.3	77 ± 4
S4P1	2.0 ± .3	90 ± 18	78 ± 4	22 ± 0.4	49 ± 8	1.4 ± 0.1	81 ± 4	81 ± 3	21 ± 0.3	57 ± 4
S1P2+	4.0 ± .1	200 ± 5	81 ± 1	22 ± 0.3	110 ± 7	2.7 ± 0.1	144 ± 5	86 ± 2	22 ± 0.2	108 ± 4
S2P2	3.0 ± .1	169 ± 6	80 ± 1	22 ± 0.2	89 ± 6	2.1 ± 0.1	121 ± 5	82 ± 2	21 ± 0.2	86 ± 6
S3P2	2.2 ± .1	123 ± 6	80 ± 2	22 ± 0.3	72 ± 5	1.7 ± 0.1	97 ± 4	86 ± 2	21 ± 0.6	73 ± 3
S1P3	2.7 ± .2	157 ± 9	80 ± 2	22 ± 0.2	86 ± 6	1.9 ± 0.1	102 ± 4	88 ± 1	22 ± 0.3	77 ± 4
T1S1P1	1.6 ± .2	90 ± 11	86 ± 2	22 ± 5.5	57 ± 7	1.2 ± 0.1	68 ± 7	83 ± 4	21 ± 0.2	45 ± 4
T2S1P1	1.3 ± .3	70 ± 16	83 ± 7	22 ± 0.6	43 ± 16	0.7 ± 0.2	61 ± 11	61 ± 10	17 ± 2.5	29 ± 13

[a] Mean ± standard error. [b] + = top six tillers.

more SB. The top six tillers similarly had generally more SB than the rest of the tillers. Thus, the total number of branches on the panicle was higher for the top six tillers.

Yield components of top tillers. IR25588-7-3-1 had more spikelets per panicle than IR58. The top six tillers had more spikelets per panicle than the rest of the tillers in both cultivars. Grains on the SB were the main contributors to the grain yield in IR25588-7-3-1. This low-tillering cultivar has many SB to compensate for its low panicle number per unit area compared to the high-tillering cultivar.

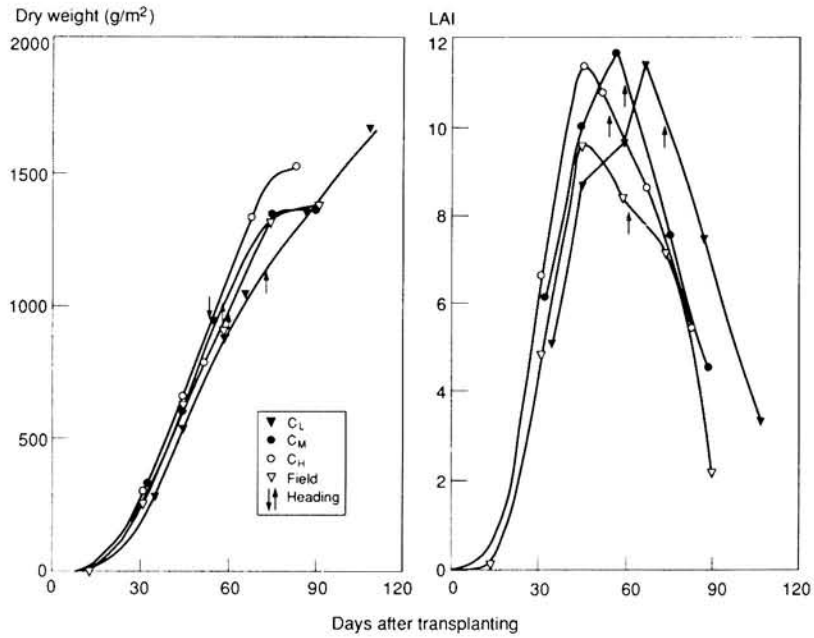
The higher grain weight of the top six tillers was the result mainly of more spikelets per panicle (Table 18). Among tillers within a plant, differences in 1,000-grain weight and fertility percentage of all spikelets in a panicle were relatively small. However, fertility percentage and 1,000-grain weight of PB in both cultivars tended to be higher than those of SB.

The top six tillers have the extra quality of having significantly more HD grains than the rest of the tillers. HD grains have higher milling and head rice yield. Many S and T tillers, however, had relatively high percentage of HD grains based on total spikelets per panicle.

Production of T tillers and even of late P and S tillers (P6, S4P1, and S1P4) should be prevented, as they contribute little to grain yield and may actually have a negative effect. Their total spikelets were low and headed late. Selection of breeding lines without late tillers would be useful in increasing yield potential in rice.

Growth and energy balance of rice canopy in temperature-controlled and field conditions. To understand the effect of temperature on the growth, N content, and energy balance of a rice canopy, IR58 was grown from 23 Jan to 10 May both in the field and in culture boxes in phytotron glasshouses with different day/night temperature (°C) combinations: 31/25 (C_H = high), 27/23 (C_M = medium), and 24/20 (C_L = low).

Except under C_L conditions, IR58 grown in the phytotron showed a growth pattern similar to that of field-grown plants (Fig. 22). At C_L initial growth was slower, growth duration was longer, and total biomass produced per crop was highest. Daily biomass production, however, was highest with C_H. Leaf area increased faster and senescence was easily defined in C_H. At any temperature, the maximum leaf area index (LAI) was achieved before heading time. The highest values of crop

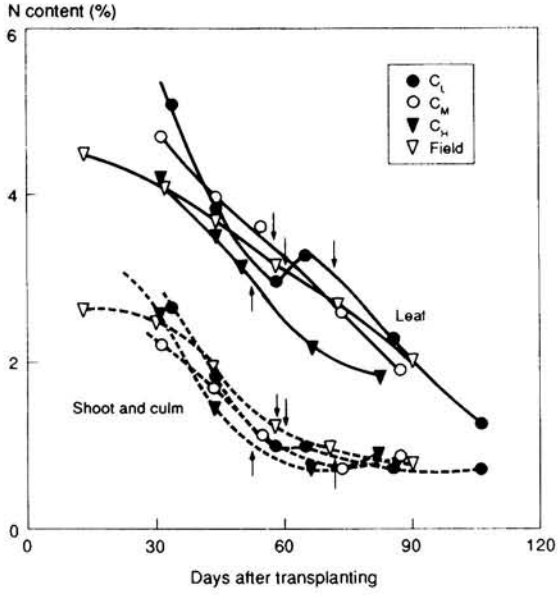


22. Dry matter production and leaf area index (LAI) of IR58 under various temperature conditions. IRRI phytotron, 1988 DS.

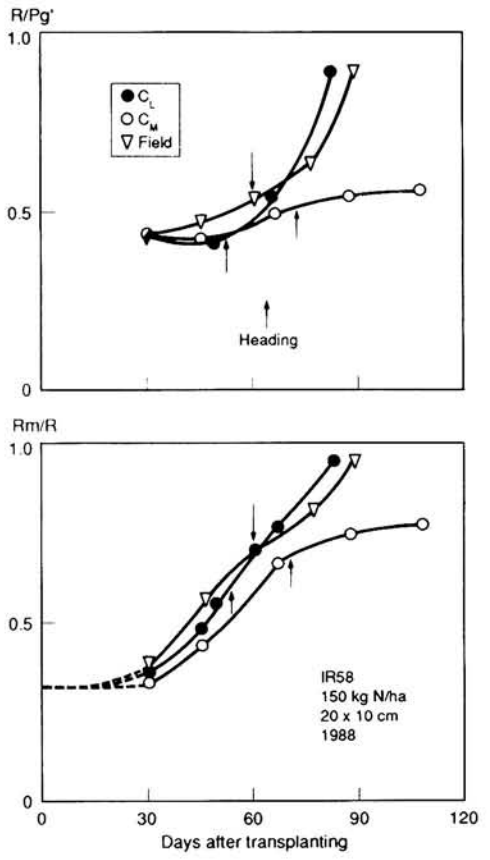
growth rate (CGR) and LAI were 34.8 g/m^2 per d and 11.1, respectively, both obtained with C_H.

N content varied with growth stage and was inversely related to temperature (Fig. 23). N content was high in the early growth stages up to PI, sharply decreased up to heading in the case of shoot and culm, but remained high until maturity in the leaf. Plants grown at C_L showed much lower leaf N at maturity. Shoot N was closely related to dark respiration rate ($r = 0.86^{**}$).

In evaluating CGR, the ratio of respiratory energy loss to gross photosynthesis (R/Pg4') has often been used. As indicated in Figure 24, R/Pg' after heading depended on temperature. At C_L this ratio remained low up to maturity. At C_H or in the field, R/Pg' increased sharply from about 10 d after heading to maturity. This difference in R/Pg' after heading may account for the difference in dry matter production between plants grown at C_L and those grown at C_H during ripening. Likewise, the ratio of maintenance respiration rate to total dark respiration (Rm/R), an estimate of energy loss by maintenance in the rice canopy, varied with temperature. At all stages, IR58 at C_L showed lower Rm/R than at C_H or under field conditions. The difference in Rm/R was bigger during ripening. Low maintenance cost at lower temperatures



23. N content of organs of IR58 grown at different temperatures. IRRI phytotron, 1988 DS.



24. Ratios of total dark respiration rate and gross photosynthesis (R/Pg') and maintenance respiration to total dark respiration (Rm/R) of IR58 grown under different temperature conditions. IRRI phytotron, 1988 DS.

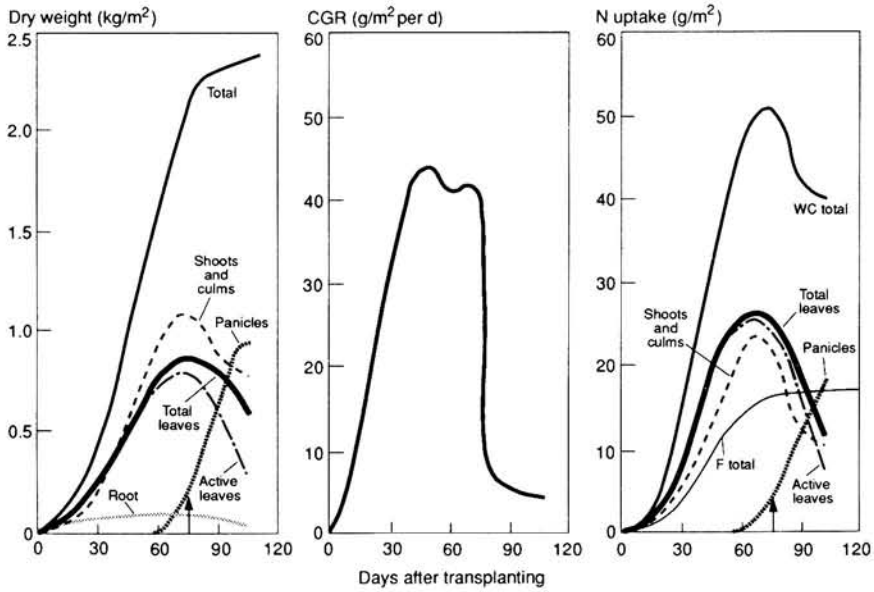
at later growth stages coupled with high spikelet formation capacity would result in higher grain yield. For the tropics, it is desirable to find cultivars with low maintenance respiration after heading. With low leaf senescence, such a trait would be beneficial in improving yield potential.

Bioenergetics of IR cultivars in high-nitrogen water culture. The expression of the potential productivity of improved rice cultivars in the tropics has often been thwarted by soil constraints and available N. To override these limitations, a field water culture study was conducted in 1988 DS. Water culture provided a convenient means to control plant growth and development through the amount and time of supply of essential nutrients.

The potential biomass and grain yield of IR46830A/IR9761-19-1R, IR58, and IR29723-143-3-2 were evaluated using a high level of N. N was initially supplied at 40 ppm, then increased to 60 ppm at 3 wk after transplanting. This level was maintained until maturity. The nutrient solution was renewed weekly, and pH was adjusted to about 5.0. Fifteen-day-old seedlings were transplanted at a spacing of 10 × 20 cm with one seedling per hill. The culture tanks contained lecaton pebbles to provide plant support as well as cation exchange sites for the available nutrients. The gaps between hills were covered by panels of white styrofoam to minimize temperature change in the rooting medium until a canopy cover was established.

The most striking observation was the luxuriant vegetative growth. The initial total biomass curve was steep, and the pattern was similar in all cultivars tested (Fig. 25). The high N supply promoted vigorous leaf as well as sheath and culm growth. The highest biomass was 2.42 kg/m^2 in IR29723-143-3-2. This biomass may approach the upper limit of potential biomass production for current improved cultivars under tropical conditions. CGR increased rapidly and remained high during the reproductive phase. A maximum CGR of 45 g dry weight/m^2 per d was obtained in IR29723-143-3-2 with a very high LAI of 17. The total N uptake reached a maximum of 52 g/m^2, almost twice that of field-grown plants under favorable conditions (Fig. 25). N uptake after heading varied widely, depending on the balance among the sink and the N mobilized from the leaves and sheaths to the panicles.

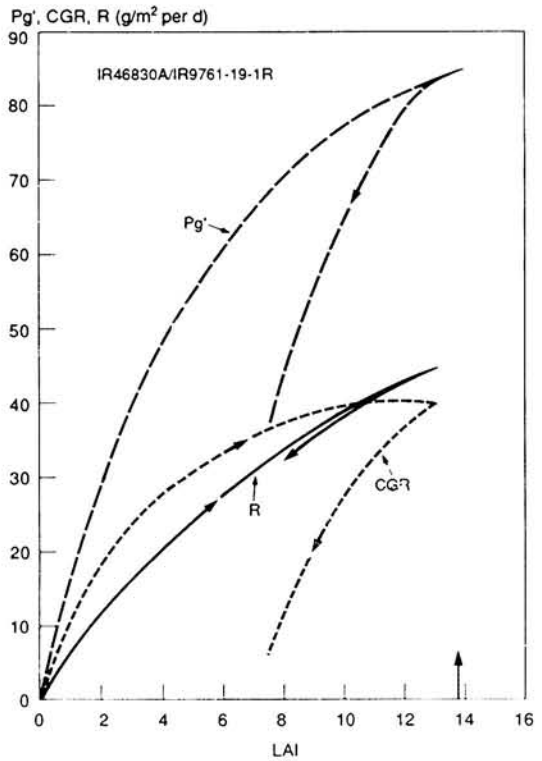
Maximum yield was 1.32 kg/m^2 in IR46830A/IR9761-19-1R (Table 19), resulting from higher panicle number and better grain filling. Such high yield is possible only if optimum interaction occurs between increased net canopy photosynthesis and efficient energy partitioning to the grain. High energy fixation was facilitated by the high leaf area development. Gross photosynthesis (Pg'), which is the sum of dark respiration (R) and CGR, increased up to LAI of 15 or higher (Fig. 26). After heading, the association between Pg' and LAI showed hysteresis. The decline in Pg' indicates it is greatly affected by leaf erectness, leaf senescence coupled with N remobilization, and maintenance respiration. Maximum Pg' was 85 g dry weight/m^2 per d. The equivalent photosynthetic CO_2 fixation rate, assuming an ash content of 20% and the R/Pg' as 0.45, was 51 μmol CO_2/m^2 per s. This photosynthetic rate was about



25. Total and partial dry weight, crop growth rate (CGR), and total N uptake of IR29723-143-3-2-1 in high N water culture (WC) and field (F) conditions. IRRI, 1988 DS.

Table 19. Maximum tiller, yield components, yield, and harvest index of 3 IR cultivars with varying growth duration. IRRI water culture, 1988 DS.

Cultivar	Grain yield at 14% moisture (kg/m^2)	Growth duration (d)	Panicles ($no./m^2$)	Spikelets (no./panicle)	Filled grains (%)	1,000-grain weight (g)
IR46830A/IR9761-19-1R	1.3	98	880	73	84	21.5
IR58	1.0	100	725	79	76	19.4
IR29723-143-3-2-1	1.1	119	630	98	73	20.7



26. Relationship of gross photosynthesis (Pg'), crop growth rate (CGR), and dark respiration (R) to leaf area index (LAI) of IR46830A/IR9761-19-1R in high N water culture. IRRI, 1988 DS.

25% higher than in field-grown materials. The dark respiration rate of the vegetative parts declined after PI except in IR29723-143-3-2-1 (Table 20). Since respiration rate is a function of N content and, usually, a 1% reduction in N content brings about a 10% decline in growth respiration, low dark respiration rate implies low N content in vegetative organs. This condition allows more energy for panicle formation. The significance of N content in the vegetative organs was placed in a clearer perspective when viewed through the energy balance analysis. Regulating the N level at various stages of growth appears to be a promising avenue for improving grain yield.

Response to planting season of promising IR cultivars differing in maturity. The yield of WS rice is generally low because of low and erratic irradiance.

The performance under varying climates of three IR entries differing in maturity was evaluated through a monthly planting field experiment from 1 Mar 1987 to 1 Feb 1988.

The best grain yield of early-duration IR58 and IR64 was obtained from the January planting, and the lowest yield from the October planting. IR29723-143-3-2, a medium-duration line, gave the highest yield in the December planting and the lowest in the September planting. In general, early December to early February is an ideal period to transplant in Los Baños.

The responses of the three cultivars under the best (December and January) and worst (September and October) plantings were compared, from which a change index to measure stability of a variety under varying climatic conditions was calculated (Table 21). A change in transplanting month from December or January to September or October resulted in a reduction of 21-31% in irradiance in the reproductive phase and 38-46% during ripening. Only a slight change was noted in daily mean temperature. Between the best and worst crops, significant changes were likewise observed in grain yield, spikelet number per square meter, percentage of filled grains, total dry weight, harvest index, and percentage decrease of N content of the shoot from heading to harvest. Growth duration (GD) and maximum number of tillers were stable.

Table 20. Difference in dark respiration rate at night per absorbed N among cultivars and organs at panicle initiation and at heading in water culture. IRRI, 1988 DS.

Cultivar	Dark respiration rate (mg CO_2/g N per h)					
	Panicle initiation			Heading		
	Leaf	Shoot and culm	Panicle	Leaf	Shoot and culm	Panicle
IR46830/IR9761-19-1	49	67	–	41	76[a]	–
IR58	52	103	–	46	68	114
IR64	69	60	–	53	58	132
IR29723-143-3-2-1	32	46	–	52	72	188

[a] Includes panicle.

Table 21. Response to season of high-yielding IR cultivars differing in maturity. IRRI, 1987-88.

Cultivar	Growth duration (d)	Grain yield (t/ha)	Spikelets (no. X $10^3/m^2$)	Filled grains (%)	1,000-grain weight (g)	Total dry weight (g/m^2)	Harvest index	Maximum tillers ($no./m^2$)	Decrease in shoot N(%) from heading to harvest	Environment			
										Reproductive phase		Ripening phase	
										Solar radiation (cal/cm^2 per d)	Temperature (°C)	Solar radiation (cal/cm^2 per d)	Temperature (°C)
Best crop (BC)													
IR58	104	7.15	34.5	82.6	22.0	1200	0.52	555	32	436	26.7	472	26.8
IR64	112	8.12	34.7	85.9	23.9	1452	0.49	695	31	440	26.6	485	27.1
IR29723-143-3-2	127	8.47	39.0	84.9	22.5	1803	0.41	536	22	423	26.7	449	26.6
Worst crop (WC)													
IR58	103	3.22	25.9	56.1	19.5	702	0.4	616	17	335	27.3	256	25.6
IR64	113	2.36	19.3	46.2	23.2	750	0.28	632	22	302	26.5	300	26.8
IR29723-143-3-2	133	4.30	30.5	60.5	20.4	1130	0.33	561	18	335	27.3	256	25.6
Change index[a]													
IR58	0.1	55	25	32	11	42	23	-10	47	23	2.0	46	4
IR64	0.1	71	44	46	3	48	43	9	29	31	0.4	38	11
IR29723-143-3-2	4.0	49	22	29	9	37	20	-5	18	21	-2	42	3

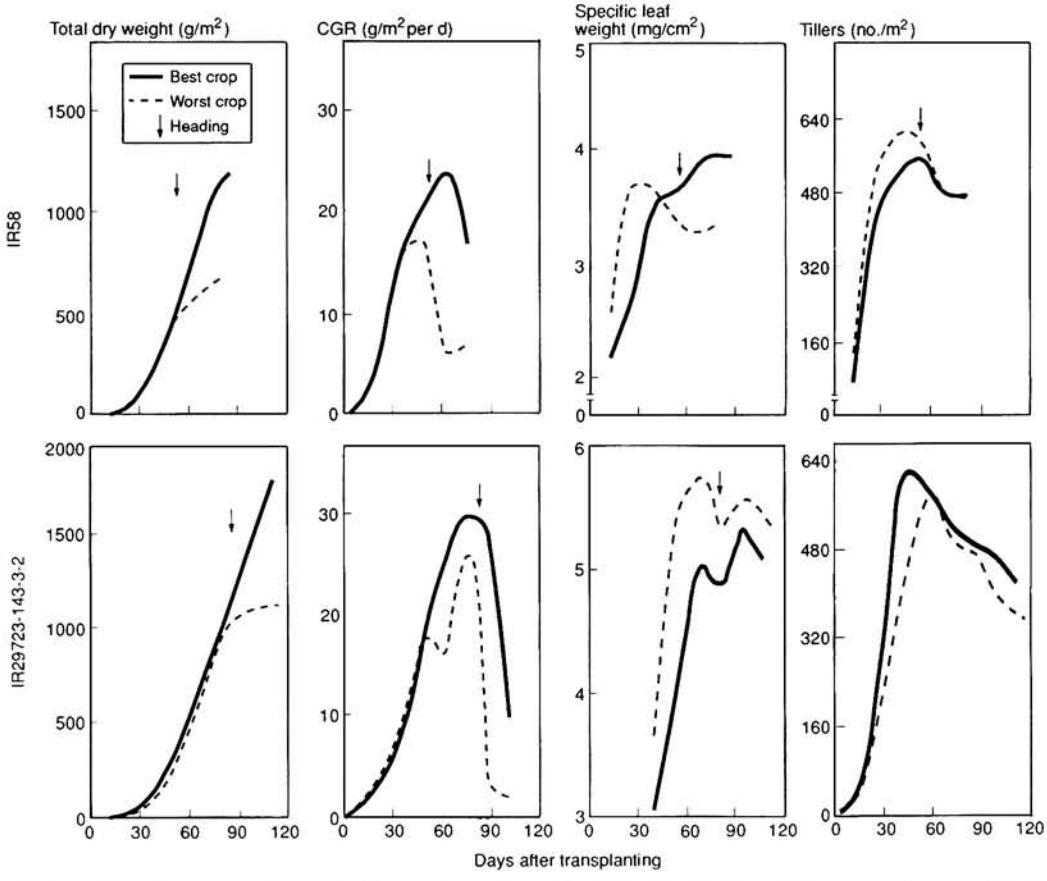
[a] $\frac{BC - WC}{BC} \times 100$.

Similarities and differences were observed in cultivars differing in maturity. In both IR58 and IR29723-143-3-2, the best and worst crops showed almost identical linear growth patterns from transplanting to heading (Fig. 27); thereafter, there was a significant difference in total dry weight accumulation. CGR started to differ at about PI in both cultivars. Thereafter, the CGR of the best crop consistently remained higher than that of the worst crop at all growth stages.

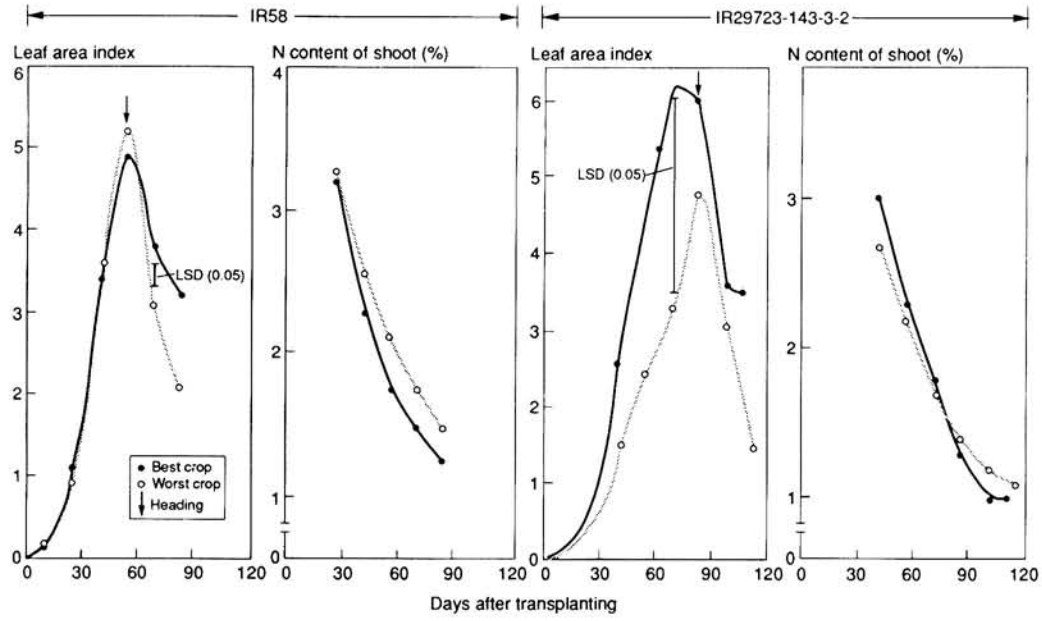
Tiller number per square meter in the best and worst IR58 crops differed from 25 DT to heading; thereafter, their tiller numbers were comparable. In IR29723-143-3-2, tillering varied from 20 to 50 DT (before PI) and became comparable until heading; then more tillers died in the worst crop. The significance of the mortality of ineffective tillers to the quality of productive tillers between rice cultivars differing in maturity must be clarified.

The best IR58 crop showed thicker leaves (specific leaf weight) after heading than the worst crop, while the best crop of IR29723-143-3-2 had thinner leaves than the worst crop throughout its growth. This trait may be related to greater sensitivity of short-duration lines to low light regime (Table 21).

The LAI of the best IR29723-143-3-2 crop from 40 DT to heading and at harvest was significantly different from that at its worst planting (Fig. 28). In IR58, LAIs of the best and worst crops differed only from 15 d after heading to harvest. It appears that the relevance of LAI to organ development from transplanting to heading differs in the two cultivars. But extended leaf area duration was noted in the best crop of both



27. Total dry weight and crop growth rate and tiller number and specific leaf weight (SLW) at different growth stages of IR58 and IR29723-143-3-2 in their best and worst planting seasons. IRRI, 1987-88.



28. Leaf area index (LAI) and N content in the shoot at different growth stages of IR58 and IR29723-143-3-2 in their best and worst seasons of planting, IRRI, 1987-88.

cultivars after heading, suggesting the importance of leaf senescence to high dry matter production after heading, irrespective of GD.

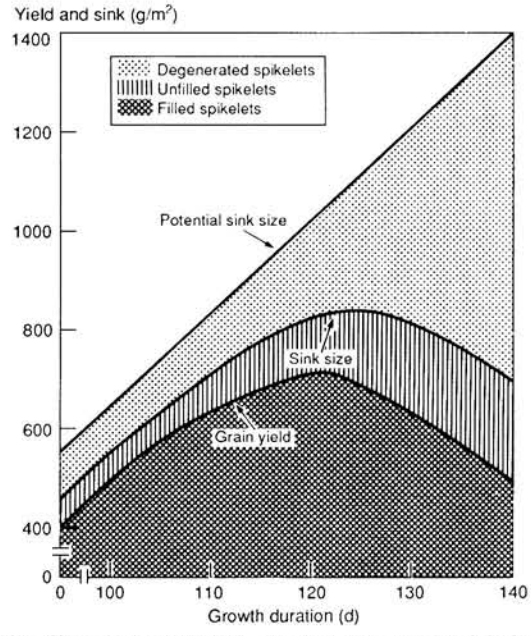
N of the shoot in the best crop tended to be lower at all growth stages in early-maturing IR58 and only after heading in medium-maturing IR29723-143-3-2, apparently indicating a varietal difference in respiratory or partitioning activity at different growth stages.

NITROGEN RESPONSE OF RICE VARIETIES: REFERENCE TO NITROGEN ABSORPTION ABILITY

Plant Physiology Department

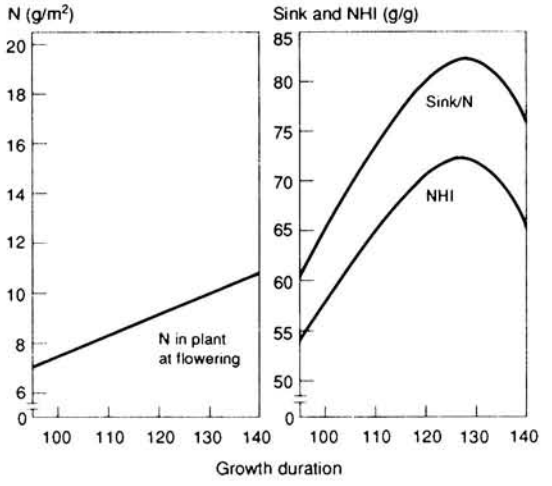
Sixty IR varieties and advanced lines grouped according to GD were planted in 1987 DS and WS to evaluate varietal differences in N absorption ability and some N use efficiency parameters. Likewise, the effect of spacing on N absorption as a function of N level and spacing on N use efficiency was studied.

Yield, sink size, and potential sink size were generally correlated with N in the plant at critical growth stages. Potential sink size increased with GD, while yield and sink size were quadratic functions of GD (Fig. 29). The amount of N in the

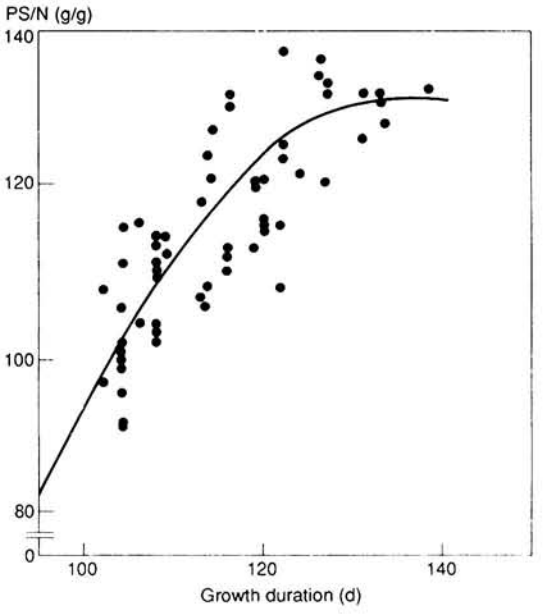


29. Differences in grain yield, sink size, and potential sink size of IR varieties and lines with varying growth duration. IRRI, 1987 DS and WS.

plant increased with GD at critical growth stages (Fig. 30). The contribution of N to potential sink size (PS/N) increased with GD up to 125 d and



30. Difference in amount of N in the plant, contribution of N in the plant to sink size, and nitrogen harvest index (NHI) of IR varieties and lines with varying growth duration. IRRI, 1987 DS and WS.



31. Effect of growth duration on the contribution of plant N to potential sink size (PS). IRRI, 1987 DS and WS.

leveled off with further increase in GD (Fig. 31). On the other hand, contribution of N to sink (S/N) and N harvest index (NHI) were quadratic functions of GD (Fig. 30). Maximum N use efficiency in terms of PS/N, S/N, and NHI were observed at optimum GD (Fig. 30).

Varietal differences in N absorption ability were observed at tillering and were highly correlated with yield and yield components. Sink size was highly correlated with N absorption ability of varieties with GD of 102-127 d in DS and 104-122 d in WS. Likewise, varieties with high N absorption ability have high S/N. This was noted in 102- to 116-d varieties during DS and in 104- to 122-d varieties during WS. N absorption ability was significantly correlated with potential sink and PS/N in all GD groups during the two seasons. Spikelet degeneration was highly affected by N absorption ability in long-duration varieties (DS and WS). Grain yield was also affected by N absorption ability, particularly varieties with GD of 102-116 d in DS and those with 104-122 d in WS. Similarly, NHI was highly correlated with N absorption ability in 102- to 122-d varieties (Table 22). Therefore, N absorption ability is an important characteristic of short- and short- to medium-duration varieties in increasing yield.

Different N levels and spacings affected N absorption, PS/N, S/N, and NHI (Table 23). Narrow spacing increased N absorption at different N levels such that N absorption at low N level was compensated by narrow spacing. In a short-duration variety, S/N, PS/N, and NHI were lower under wider spacing. In a long-duration variety, however, small variations were observed. These observations could be explained by the relationship between GD and N absorption patterns in rice plants. Hence, aside from high N absorption ability due to variety, N absorption at early growth stages could be increased by narrow spacing and high basal N level.

PHYSIOLOGICAL ASPECT OF DIRECT SEEDED RICE CULTIVATION

Plant Physiology Department

The growth performance and yield-determining process of transplanted and broadcast direct seeded rice were evaluated using 10-15 IR varieties and advanced lines with varying GD and different plant types. The plant density with broadcast direct seeding (DS_1) at the rate of 100 kg/ha at 50% crop establishment was equivalent to 200 plants/m² at 10- × 5-cm spacing; that of transplanting (TP) and dibbled direct seeding (DS_2)

Table 22. Relationship of N absorption ability to yield and yield components.[a]

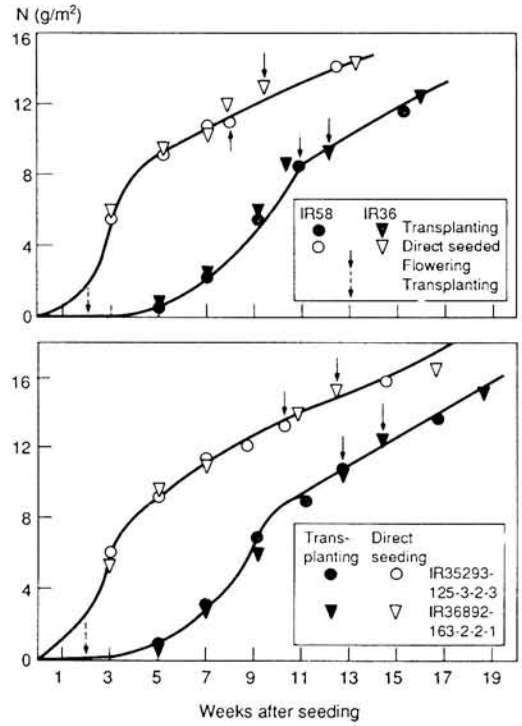
Growth duration (d)	S	PS	S/N	P/N	DEG	Y	NHI	R
				Dry season				
102-106	0.872**	0.847**	0.723**	0.839**	0.820**	0.576**	0.836**	−0.343ns
108-109	0.857**	0.873**	0.819**	0.741**	0.322ns	0.593*	0.829**	−0.326ns
113-116	0.841**	0.828**	0.862**	0.684*	0.390ns	0.600*	0.972**	−0.438ns
119-122	0.728*	0.879**	0.593ns	0.637ns	0.290ns	0.600ns	0.972**	−0.271ns
124-127	0.948**	0.936**	0.637ns	0.833**	0.814**	0.708*	0.581ns	−0.271ns
131-138	0.644ns	0.944**	0	0	0.911**	0.528ns	0.265ns	−0.362ns
				Wet season				
104	0.850**	0.863**	0.760**	0.778**	0.440ns	0.727**	0.838**	−0.374ns
111-118	0.946**	0.889**	0.821**	0.746**	0.298ns	0.680*	0.854**	−0.545ns
117-122	0.974**	0.802**	0.859**	0.820**	0.179ns	0.677*	0.906**	−0.431ns
125-127	0.348ns	0.749*	0	0.875**	0.775*	0.127ns	0.762*	−0.523ns
131-138	0.645ns	0.843*	0	0	0.858*	0.526ns	0.427ns	0.364ns

[a]S = sink, PS = potential sink, DEG = degenerated sink, Y = yield, NHI = nitrogen harvest index, R = percentage of ripened grains, N = amount of N in plant at flowering, N absorption ability = amount of N absorbed by plant from transplanting to 3 wk after transplanting.

Table 23. Effect of spacing and N level on the contribution of N to sink, potential sink, and NHI.[a] IRRI, 1987 DS.

N level (g/m²)	Spacing (cm)	Amount (g/m²) of N		PS/N (g/g)	S/N (g/g)	NHI
		3 WT	5 WT			
		IR64				
0	20 × 10	1.8	3.7	79.8	65.2	60.6
	20 × 30	0.6	2.7	72.8	57.8	57.7
6	20 × 10	2.4	5.2	84.8	64.5	63.7
	20 × 30	0.7	3.2	78.8	62.6	59.0
12	20 × 10	3.0	8.4	93.2	76.3	70.2
	20 × 30	0.9	5.0	82.2	63.7	63.0
		IR36892-163-1-2-2-1				
0	20 × 10	1.8	3.9	124.4	83.4	57.4
	20 × 30	0.7	2.4	124.7	81.8	57.8
6	20 × 10	2.2	6.1	128.3	79.4	64.0
	20 × 30	0.6	3.2	125.6	76.4	62.0
12	20 × 10	3.3	8.6	129.1	79.9	64.0
	20 × 30	1.0	5.2	124.7	77.6	62.3

[a]WT = weeks after transplanting, S/N = contribution of N to sink size, PS/N = contribution of N to potential sink size, NHI = N harvest index.



32. Difference in N absorption pattern between direct seeded and transplanted rice plants. IRRI, 1987 WS.

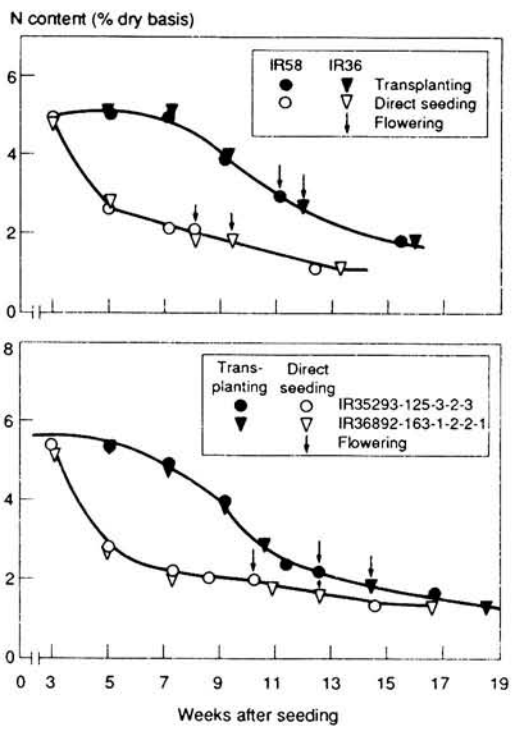
was 50 plants/m² (20- × 20-cm spacing and 2 plants/hill).

The N absorption pattern was completely different for DS_1 and TP (Fig. 32). The amount of N in the plant at early growth stages was higher in DS_1 than in TP. However, the difference in plant N between DS_1 and TP plants decreased with plant growth and became very small at flowering.

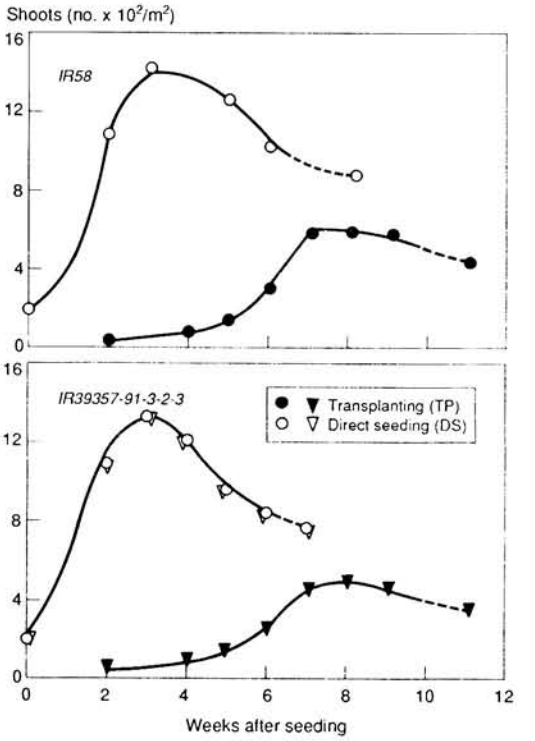
The N content (dry basis) in the laminae of DS_1 plants decreased rapidly 3-5 wk after seeding (WAS) and slowly after 7 WAS (Fig. 33). In TP plants, it decreased rapidly at 7-11 WAS and slowly after 11 WAS. These observations reflect the behavior of NH_4^+ in the plow layer.

The tillering pattern of DS_1 and TP plants reflected the N absorption pattern (Fig. 34). The number of nonbearing tillers was much higher in DS_1 than in TP, especially in medium-duration varieties. Flowering occurred 10-25 d earlier in WS and 4-11 d earlier in DS for DS_1 plants (Table 24).

In WS, DS_1 short-duration varieties yielded more than TP short-duration varieties. For short- to medium-duration varieties, yields of the two types of rice cultivation were more or less the same. The yields of DS_1 medium-duration varieties, however, were lower with TP. This can be explained by the relationship between the potential sink size and GD of DS_1 and TP plants. A correlation between potential sink size and GD of



33. Difference in N content in laminae between direct seeded and transplanted rice plants. IRRI, 1987 WS.



34. Difference in tillering pattern between direct seeded and transplanted rice plants. IRRI, 1987 WS.

TP plants existed; none was observed for DS_1 plants (Fig. 35). The degenerated sink size of TP was likewise related to GD, but there was no relationship between degenerated sink and GD of DS_1 plants.

The broadcast plants had a longer vegetative lag phase and possessed a larger number of nonbearing tillers than TP plants. An extremely long vegetative lag phase was observed in DS_1 medium-duration plants. It can thus be assumed that these plants have a large number of degenerated spikelets, which are impossible to count because they degenerate together with the nonbearing tillers.

In DS, DS_1 plants had a higher yield than TP regardless of GD. However, the yield ratio of DS_1 to TP was higher in shorter duration varieties than in longer duration ones. Nevertheless, in the case of identical plant density, there was little difference in yield between DS_2 and TP. Therefore, the difference in yield between broadcast direct seeded rice and TP depends on plant density.

Table 24. Yield and yield components.[a] IRRI, 1987-88.

Cultivar	Growth duration (d)				Vegetative lag phase (d)				Sink (g/m^2)				Sink degeneration (%)				Yield (g/m^2)			
	1987 WS		1988 DS		1986 WS		1987 DS		1987 WS		1988 DS		1987 WS		1988 DS		1987 WS		1988 DS	
	DS_1	TP	DS_1	DS_2	TP	DS_1	TP	DS_1	DS_2	TP	DS_1	TP	DS_1	DS_2	TP	DS_1	TP	DS_1	TP	DS_1	DS_2	TP
IR58	87	108	96	98	102	11	4	10	−2	5	772	584		800	737	26.0	19.2	25.8	13.4	9.9	672	508			660	671
IR39347-91-3-2-3	87	108	96	97	102	11	4	10	−3	5	798	618	1159	722	653	29.1	26.5	24.7	25.4	23.9	694	507	1056	642	603
IR32419-81-2-3-3			98	101	102			12	1	5			1066	874	810			29.4	23.2	22.4			908	744	689
IR36	94	110	98	104	109	18	6	12	4	12	789	764	1083	933	771	26.9	28.0	22.8	20.6	19.2	655	634	928	814	711
IR25588-7-7-1	94	108	96	101	103	18	4	10	1	6	794	705	1099	802	839	29.6	32.3	23.2	24.6	23.1	683	571	942	657	749
IR24632-34-2			109		104			23		7			905		650			31.9		21.6			715		619
IR39323-110-5-2-2	107	121	111	115	117	31	17	25	15	20	909	935	1043	995	850	35.4	30.7	24.6	26.3	20.4	727	729	887	820	715
IR31293-125-3-2-3	101	116	101	109	109	25	12	15	9	12	783	928	1165	922	806	33.5	21.0	17.1	23.8	16.3	642	780	897	672	686
IR31868-64-2-3-3-3			98		109			12		12			1010		651			18.6	23.6	14.7			840		591
IR21850-84-3-3-2	107	128	117	126	117	31	24	31	26	20	692	862	1216	809	835	21.6	20.7	18.6		16.2	554	741	900	687	716
IR28228-96-3-2-1-3	107	128	109	115	117	31	24	23	15	20	772	1108	1046	855	807	32.7	32.5	32.6	33.0	27.3	556	806	835	684	651
IR36892-163-1-2-2-1	116	130	125	126	121	40	26	39	26	24	776	1113	873	1040	955	29.9	35.3	30.9	30.8	24.7	543	846	724	757	751
IR29723-143-3-2-1	116	130	117	130	121	40	26	31	30	24	789	1077	1273	1107	1024	28.9	36.7	32.1	32.1	25.4	663	883	978	835	744
IR324530-20-3-2-2				126	121				26	24				911	920				32.6	25.5				591	663

[a] DS_1 = direct seeded (10 × 5 cm), DS_2 = direct seeded (20 × 20 cm), TP = transplanting (20 × 20 cm).

35. Relationship between growth duration and sink size. IRRI, 1987-88.

The optimum GD for yield was observed to be 95 d for DS_1 and 125 d for TP in WS, and 96 d for DS_1 and 120 d for TP in DS. From these results, the yield potential of varieties under varying plant densities must be reevaluated.

EFFECT OF SEEDLING AGE AND PLANT DENSITY ON GROWTH AND YIELD OF RICE VARIETIES

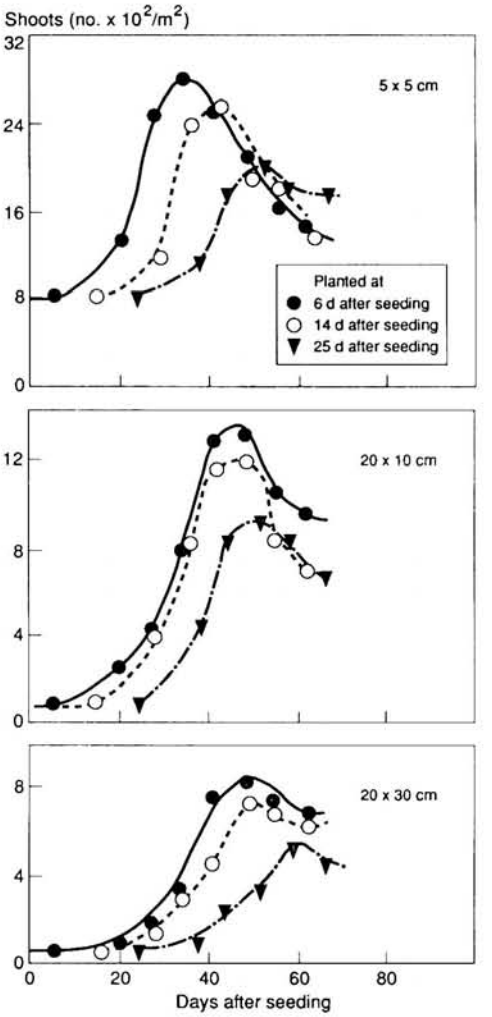
Plant Physiology Department

Differences in growth performance and yield-determining processes of short (IR66)- and medium (IR36892-163-1-2-2-1)- duration varieties grown under different cultural practices, plant densities (5 × 5, 20 × 10, and 20 × 30 cm spacing, 2 plants/hill), and seedling ages at planting time (coleoptile, 3- and 6-leaf stage or 6-, 14-, and 25-d-old seedlings) were studied to obtain basic information on direct seeded plants. The effects of seedling age at planting time (coleoptile, 1- to 7-leaf stage) on the number of days from seeding to flowering and on the number of leaves emerging on the main culm were also studied.

The two varieties, grown under the same cultural practices, showed no varietal difference in the number of days to maximum tiller number stage. Seedling age and spacing affected the tillering pattern and the tiller number per unit area (Fig. 36). In young seedling and narrow spacing treatments, tillering was promoted, resulting in the early occurrence of the maximum tiller number stage; relatively more tillers were produced than in the old seedling and wide spacing treatments. Furthermore, PI came a few days earlier with young seedlings and narrow spacing. However, the effect of seedling age and spacing was much more on the tillering habits than on the occurrence of PI. Therefore, narrow spacing and young seedlings lengthened the vegetative lag phase (Table 25). The proportion of bearing tillers to total tillers was higher in old seedlings and wide spacing than in young seedlings in the medium-duration variety. This observation can be explained by the duration of the vegetative lag phase.

The effect of seedling age at planting time on the flowering stage and on the number of leaves that emerged from the main culm was more apparent in WS.

With younger seedlings at planting time, plants flowered earlier and fewer leaves emerged from the main culm in WS (long day condition). However, the number of days to flowering and number of leaves on the main culm did not differ in DS (short day condition). Premature flowering occurred in the older seedlings, 7-leaf stage for IR66 (Table 26), in DS.



36. Difference in tillering pattern among treatments. IRRI, 1988 DS.

Narrow spacing increased yield in both varieties; the effect was higher in the short-duration than in the medium-duration variety. Seedling age at planting affected the yield, particularly under extremely narrow spacing, where young seedlings decreased yield. There was a small difference in ripening among treatments within the same variety; hence, the yield was governed by sink size.

Under extremely narrow spacing, young seedlings reduced sink size by increasing degenerated

Table 25. Effect of seedling age and spacing on the growth and yield of rice plants. IRRI, 1988 DS.

Spacing (cm)	Seedling age (d)	Days from seeding to flowering	Vegetative lag phase (d)	Panicles (no./m²)	Sink (g/m²)	Potential sink (g/m²)	Yield (g/m²)
			IR66				
5 X 5	6	75	20	1507	1360	1865	1202 b
	14	79	14	1160	1528	2031	1293 b
	25	79	4	1240	1549	1991	1366 a
20 X 10	6	75	15	548	903	1248	770 d
	14	79	11	547	901	1260	743 d
	25	79	4	565	848	1239	741 d
20 X 30	6	83	13	444	795	1136	660 de
	14	83	9	382	785	1110	645 de
	25	86	4	362	712	949	624 de
			IR36892-163-1-2-2-1				
5 X 5	6	104	49	933	1112	1769	740 de
	14	104	39	893	1216	1845	944 c
	25	104	29	880	1320	1943	1007 c
20 X 10	6	104	44	448	860	1301	646 de
	14	104	36	381	850	1246	660 de
	25	108	33	358	874	1289	624 de
20 X 30	6	112	38	331	747	1119	607 e
	14	108	34	294	773	1130	624 de
	25	108	26	260	772	1151	618 e

Table 26. Effect of seedling age on growth duration.[a]

Leaf stage	1987 wet season				1988 dry season			
	IR66		IR36892-163-1-2-2-1		IR66		IR36892-163-1-2-2-1	
	FLW	Leaf stage at flowering (no.)	FLW	Leaf stage at flowering (no.)	FLW	Leaf stage at flowering (no.)	FLW	Leaf stage at flowering (no.)
0	73	13.2	97	15.9	68	12.6	94	15.9
1	73	13.6	96	15.6	72	12.2	94	15.3
2	74	14.3	97	15.7	72	11.9	94	14.2
3	74	14.2	102	16.9	73	12.8	95	15.0
4	78	14.0	103	17.1	74	12.7	95	14.7
5	85	15.8	–	–	74	13.0	96	14.8
6	88	16.7	109	17.2	75	12.8	96	14.6
7	97	18.5	109	19.4	75	9.0	97	14.1

[a] FLW = days (no.) from seeding to flowering. (–) = data not available.

spikelets and nonbearing tillers, especially on the medium-duration variety. The large number of degenerated spikelets and nonbearing tillers is caused by a long vegetative lag phase and low N content (dry basis) in the plant. In relating potential sink to sink degeneration, 4-14 d of vegetative lag phase favor increased yields. The sink size of a short-duration variety can be easily increased by narrow spacing compared with a medium-duration variety, and the reduction of sink size and yield due to an increase in vegetative lag phase is smaller in short-duration than in long-duration varieties. Short-duration varieties are preferred for broadcast direct seeding.

Genetic evaluation and utilization (GEU) program

Grain quality and nutritional value

Cereal Chemistry, Plant Breeding, Agricultural Economics, and Statistics Departments; International Rice Testing Program; Centro Internacional de Agricultura Tropical; National Food Research Institute, Japan; Chiang Mai University, Thailand; University of Agriculture, Faisalabad, Pakistan; Osaka Shoin Women's College, Japan; Kagoshima University, Japan; Food Science Department, University of Manitoba, Canada; United States Department of Agriculture; Overseas Development Natural Resources Institute, United Kingdom; and University of the Philippines at Los Baños, Philippines

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BREEDING PROGRAM AND EVALUATION

Cereal Chemistry and Plant Breeding Departments, International Rice Testing Program, and Centro Internacional de Agricultura Tropical

Irrigated rice elite lines (*Cereal Chemistry and Plant Breeding*). The presence of different gel consistency (GC) types, particularly among elite, high apparent amylose content (AC) lines, justified a study of the relative merits of the GC methods with and without ice bath cooling (Annual report for 1987). Among 23 dry season (DS) elite lines (26.6-28.8% AC, alkali spreading value [ASV] 4.6-7.0), standard GC values using standard small (13 × 100 mm) tubes were 28-86 mm with 5-min ice bath cooling and 74-100 mm with room temperature cooling. Using 16- × 150-mm tubes and cooling at room temperature, GC values were 47-103 mm. Values by the three GC methods correlated with each other ($r = 0.77^{**}$ - 0.87^{**}), but GC in the standard tubes cooled at room temperature correlated only with ASV ($r = -0.52^{**}$) and not with AC ($r = 0.24$). With all 50 DS elite lines, the standard GC value correlated better with AC ($r = -0.37^{**}$) than with ASV ($r = -0.24^{*}$), but GC value with room temperature cooling correlated significantly only with ASV ($r = -0.41^{**}$). Only the standard GC values correlated significantly with cooked rice Instron hardness ($r = -0.42^{**}$).

Among the 51 wet season (WS) samples, standard GC values did not correlate significantly with AC and ASV but correlated with cooked rice Instron hardness ($r = -0.36^{**}$). Again, GC value with cooling at room temperature correlated with ASV ($r = -0.35^{**}$) and not with AC. Thus, with diverse samples, the modified GC method of cooling at room temperature instead of in an ice bath has no advantage over the standard method in distinguishing rices differing in AC, particularly if the standard method is run unreplicated at 90 mg and 100 mg flour, instead of with duplicate 100-mg flour samples, in 2 ml 0.2 N KOH.

Intermediate (24%)-AC rices have been observed to have higher Instron hardness values than high (25%)-AC rices because of differences in water:rice ratio for the 2 AC types: 1.9 for intermediate AC and 2.1 for high AC. To obtain more comparable screening results, all nonwaxy elite samples were cooked at the same water:rice ratio of 2.1 in 1988. With this revised cooking method, cooked rice Instron hardness correlated significantly with AC and ASV in the 50 DS samples ($r = 0.85^{**}$, 0.47^{**}) and in the 51 WS samples ($r = 0.78^{**}$, 0.38^{**}). Cooked rice hardness also correlated with GC values ($r = -0.42^{**}$ in DS and -0.36^{**} in WS). Raw milled rice translucency (24-100%) also correlated positively with AC ($r = 0.55^{**}$, 0.40^{**}) and cooked rice Instron hardness ($r = 0.62^{**}$, 0.47^{**}) in both sets of samples.

Intermediate-AC lines. Sixteen intermediate-AC lines and 1 low-AC line were represented in the 1988 DS samples (17.6-24.5% AC), and 14 intermediate-AC and 2 low-AC lines in the WS samples (18.5-24.8%). AC, ASV, and GC were significantly correlated in the DS samples only. Cooked rice Instron hardness correlated positively with AC ($r = 0.78^{**}$) and raw rice translucency ($r = 0.65^{**}$), and negatively with GC ($r = -0.52^{*}$) in the DS samples. In the WS samples, cooked rice Instron hardness correlated positively with AC ($r = 0.51^{*}$), raw rice translucency ($r = 0.58^{*}$), and milled rice protein ($r = 0.54^{*}$), and negatively with GC ($r = -0.60^{*}$). Two low-gelatinization temperature (GT) entries, IR34686-179-1-2-1 and IR42015-83-3-2-2-2, overlapped in cooked rice hardness with the intermediate-GT lines (Table 1), suggesting the feasibility of obtaining low-GT, intermediate-AC rices with softer cooked texture than IR48, and approaching that of IR64. Low-GT rices would have shorter cooking time and would conserve fuel, provided no decrease in grain quality accompanies the decrease in GT. Reducing AC to 18-20% would further soften the cooked rice texture without unduly increasing cooked rice stickiness.

High-AC lines. All GC types were represented among high-AC samples in the elite lines except for soft-GC, low-GT rice (Table 2). However, some medium-GC, low-GT samples such as IR33043-46-1-3 had cooked rice as soft as intermediate-GT rices such as IR35366-28-3-1-2-2 with soft GC. The hard-GC samples were not necessarily the hardest cooked rices. Some variation occurred even at the same GC type, such as IR74 being softer than IR68, and IR50 being harder than IR41996-118-2-1-3. AC, ASV, and GC were not significantly correlated in the DS samples, but

Table 1. Milled rice properties of selected intermediate-AC elite lines with intermediate and low GT as compared with low-AC and waxy entries.[a] IRRI, 1988.

Variety or line	Protein (%)	AC (%)	Alkali spreading value	GC (mm)		Cooked rice[b] Instron hardness (kg/7 cm²)
				100 mg	90 mg	
			Intermediate AC			
IR64	8.2	21.7	3.2	70	88	6.0
IR10447-113-5-1-1-5	8.3	20.4	3.0	48	70	6.6
	10.4	20.3	3.0	44	68	6.1
IR26957-86-2	5.7	21.1	3.1	75	88	5.4
	7.0	22.4	3.2	54	72	5.6
IR34686-179-1-2-1	6.9	23.8	7.0	37	52	6.2
	6.4	23.6	7.0	35	53	6.4
IR41996-50-2-1-3	10.5	20.2	4.9	48	66	5.9
	8.2	22.6	4.8	48	64	5.8
IR41999-139-1-1-2-3	9.4	20.5	4.2	48	66	5.6
	8.2	21.4	3.2	45	61	6.1
IR42015-83-3-2-2-2	10.6	20.8	7.0	42	52	6.1
	10.1	22.6	6.8	33	46	7.2
IR42029-38-1-3-3-2	8.4	22.4	3.4	53	72	5.8
	7.0	23.2	4.5	52	72	5.8
			Low AC and waxy			
IR13754-6-3	7.1	17.6	5.6	66	80	4.6
IR27069-B53-B-B-1-2	7.5	18.5	7.0	65	82	5.1
IR43485-40-2-42-3	8.4	19.0	5.8	56	79	6.0
IR39368-31-1-2	9.0	5.5	6.6	98	100	3.0
	9.2	4.8	6.9	99	100	3.0

[a] AC = amylose content, GT = gelatinization temperature, GC = gel consistency. [b] Water:rice ratio = 2.1.

Table 2. Milled rice properties of selected high-AC elite lines with low and intermediate GT. IRRI, 1988.

Variety or line	Protein (%, wet basis)	AC (%, dry basis)	Alkali spreading value	GC (mm)		Cooked rice Instron hardness (kg/7 cm²)
				100 mg	90 mg	
			Low GT			
IR33043-46-1-3	8.0	26.8	7.0	51	89	8.0
	7.5	27.4	7.0	48	86	8.1
IR39323-182-2-3-3-2	7.4	27.4	6.8	56	86	9.0
IR39357-133-3-2-2-2	8.5	27.6	7.0	51	76	9.9
	7.7	28.2	7.0	46	84	9.5
IR68	7.9	27.6	7.0	27	32	10.3
IR74	9.1	25.7	7.0	28	33	8.4
	7.9	26.2	7.0	27	34	9.6
			Intermediate GT			
IR35366-28-3-1-2-2	7.6	27.4	4.6	54	91	7.9
	6.2	28.3	5.0	76	99	8.3
IR42068-22-3-3-1-3	11.9	25.6	4.9	65	88	8.7
	7.9	27.6	5.0	76	94	8.8
IR72	7.6	28.2	5.0	50	92	8.5
	10.6	26.6	5.8	50	83	9.1
IR50	9.4	28.7	5.0	41	76	10.3
	9.8	27.3	5.0	31	48	9.3
IR41996-118-2-1-3	10.8	25.3	4.8	36	46	8.7
	8.9	26.4	5.1	31	50	8.8

they were correlated in the WS samples. Cooked rice Instron hardness was correlated with ASV (r = 0.51**) and GC (r = -0.33*) in the 32 DS samples. It also correlated with ASV (r = 0.46*), protein (r = 0.36*), and GC (r = -0.36*) in the 34 WS samples. However, the high protein samples did not necessarily produce harder cooked rice. The relatively poor correlations among these properties suggest that faster-cooking high-AC rices with soft cooked rice texture may be obtained by screening low-GT elite lines. Among high-AC milled rices, translucency percentage correlated positively with cooked rice Instron hardness only in the DS samples (r = 0.50**).

Protein screening (*Cereal Chemistry, Plant Breeding, and IRTP*). *Shikimate dehydrogenase as a marker for brown rice protein* (*IRTP*). Seed scientists reported a positive association of the higher mobility shikimate dehydrogenase isozyme band (Sdh-1^2) of rice coleoptiles with higher protein per seed in genetic and associated studies on seed protein content in rice (Annual report for 1986). Analysis of 300 F_2 plants from a cross between low-brown rice protein (BRP) genotype IR36 (with Sdh-1^1 or SKDH-low mobility allele) and a high-BRP genotype IR480-5-9-3 (with Sdh-1^2 or SKDH-high mobility allele) indicated a monogenic Mendelian segregation at the locus Sdh-1 (Table 3). The segregants homozygous for the Sdh-1^1 allele accumulated the least BRP, the homozygotes for Sdh-1^2 accumulated the most BRP, and the heterozygotes (Sdh-1^1/Sdh-1^2) had intermediary BRP in their grains. Out of 35 F_2 plants having more than 12% BRP, 78% were homozygous for Sdh-1^2, and the remaining 22% were heterozygous (Sdh-1^1/Sdh-1^2). There were 153 segregants in the range of 10-12% BRP, out of which 71% were heterozygous, 24% had only Sdh-1^2, and the remaining 5% had Sdh-1^1. Of the 112 segregants with BRP content less than 10%, 67% were Sdh-1^1 and the rest were heterozygous. Thus, the occurrence of Sdh-1^2 allele in the plants enhanced BRP content of the grains.

Application of shikimate dehydrogenase to replicated yield trials (*Cereal Chemistry and Plant Breeding*). The feasibility of using this method was tried on the 1987 WS and 1988 DS crops of replicated yield trial (RYT) entries. Coleoptiles from 5-d-old seedlings were analyzed for SDH in 10% polyacrylamide gel electrophoresis (PAGE), with IR480-5-9 as the check for Sdh-1^2. Of the 800 entries in 2 seasons, only 4 lines – IR39357-133-3, IR44530-41-1, IR44536-43-1, and IR47741-19-2 – showed the Sdh-1^2 band in both crops (Table 4). These four lines with the Sdh-1^2 band were no higher in BRP than either IR36 or IR42 (Sdh-1^1 allele). Only IR45912-9-1 and IR48555-63-1 had higher BRP than IR36 and IR42 among these 15 lines with the Sdh-1^2 band. IR47741-19-2 showed the highest mobility Sdh-1^3 band only in the 1987 WS crop. Residual heterozygosity was shown by some lines. Eight lines, although grown in both seasons, exhibited the Sdh-1^2 isozyme in only one season, showing that this property is not yet fixed in them. The residual heterozygosity of lines at the Sdh-1^2 locus raises uncertainty about the usefulness of this screening method for BRP in RYTs.

In the 1987 WS RYT, BRP correlated signifi-

Table 3. Mean and range of brown rice protein (BRP) percentage in parents, F_1, and F_2 segregants in a cross between parents with Sdh-1^1 and Sdh-1^2 alleles. IRRI, 1988.

Plant generation	Sdh genotype of plants	Samples (no.)	BRP (%) in the grains			
			Mean	Min	Max	CV (%)
Parent 1 (IR36)	Sdh-1^1/Sdh-1^1	20	10.04±0.12	7.91	13.45	11.49
Parent 2 (IR480-5-9-3)	Sdh-1^2/Sdh-1^2	20	12.43±0.11	10.06	16.60	8.72
F_1 (IR36/IR480-5-9-3)	Sdh-1^1/Sdh-1^2	25	13.02±0.22	11.19	15.59	8.47
F_2	Sdh-1^1, Sdh-1^1/Sdh-1^2, Sdh-1^2	300	10.52±0.07	7.68	14.93	11.84
	Homozygous Sdh-1^1	82[a]	9.19±0.07 a	7.68	10.77	7.28
	Heterozygous Sdh-1^1/Sdh-1^2	154[a]	10.60±0.06 b	8.99	12.73	7.06
	Homozygous Sdh-1^2	64[a]	12.03±0.11 c	10.06	14.93	7.48

[a] Chi-square for 1 Sdh-1^1 : 2 Sdh-1^1/Sdh-1^2 : 1 Sdh-1^2 = 2.37 (probability 0.31).

Table 4. BRP and shikimate dehydrogenase allele banding pattern of 15 selected entries exhibiting the faster mobility band in 1987 WS and 1988 DS replicated yield trials as compared with BRP of IR36 and IR42. IRRI, 1988.

Line	Season	Runs (no.)	Sdh-1 allele			BRP (%)		
			1	2	3	Line	IR36	IR42
IR34686-138-3[a]	1987 WS	5	2	5	0	8.6	11.1	9.2
IR35346-47-3[a]	1988 DS	2	1	2	0	7.3	8.9	7.9
!R37712-90-3[a]	1988 DS	2	1	2	0	7.4	8.9	7.9
IR37721-9-2[a]	1987 WS	5	0	5	0	8.3	11.2	9.1
IR37721-16-3[a]	1987 WS	5	0	5	0	8.6	11.2	9.1
IR39357-133-3	1987 WS	5	0	5	0	8.7	13.6	9.4
IR39357-133-3	1988 DS	3	0	3	0	8.1	11.8	10.4
IR39474-104-3	1988 DS	2	0	2	0	8.7	11.8	10.4
IR42029-38-1[b]	1988 DS	2	0	2	0	7.7	9.0	7.1
IR44530-41-1	1987 WS	5	0	5	0	8.4	9.6	7.1
IR44530-41-1	1988 DS	2	0	2	0	8.2	9.0	7.1
IR44536-43-1	1987 WS	6	0	6	0	9.4	9.6	9.0
IR44536-43-1	1988 DS	2	0	2	0	7.6	9.0	7.1
IR45138-139-2	1987 WS	6	3	6	0	9.0	10.1	9.9
IR45912-9-1[a]	1988 DS	2	0	2	0	10.9	8.6	8.4
IR47741-19-2	1987 WS	4	0	4	3	8.6	9.7	8.4
IR47741-19-2	1988 DS	2	0	2	0	8.7	8.2	7.2
IR48555-63-1	1987 WS	5	2	3	0	11.5	10.3	9.5
IR54745-2-10[a]	1988 DS	2	1	1	0	7.0	8.0	7.3

[a]Showed only Sdh-1^1 band in the other season sample. [b]Showed both Sdh-1^1 and Sdh-1^2 bands in the 1987 WS sample.

cantly with duration (r = -0.40**) but not with yield (r = -0.01) for the 370 entries. Yield and duration were not correlated (r = 0.04). BRP was analyzed for 1988 DS only on samples showing the Sdh-1^2 band.

Screening for stable head rice yield (*Cereal Chemistry and Plant Breeding*). IR rices from 1987 WS were further evaluated for stable head rice yield. Head rice yields of oven-dried (28-63%) and shade-dried (19-61%) rough rice were also correlated (r = 0.85** n = 28). In brown rice soaked for 10 min, the percentages of cracked grains in the 2 sets of samples (22-96% for oven-dried and 9-61% for shade-dried) were correlated (r = 0.80**). Brown rice translucency ranged from 22 to 62% and correlated again with head rice yield (r = 0.67** for oven-dried and 0.58** for shade-dried samples). Waxy rices had low translucency values but high head rice yield: IR29, 16-18% translucency and 53-60% head rice; IR65, 22-23% translucency and 44-52% head rice.

For the 27 nonwaxy rices (IR5 to IR64) shade-dried in 1987 DS and WS, the percentage of cracked brown rice after 10 min soaking was correlated in the 2 crops (r = 0.71**), as was translucency (r = 0.77**) and head rice yield (r = 0.50**). The percentage of cracked brown rice in the 2 crops was not significantly correlated at either 0 or 5 min soaking, thus confirming earlier indications that 10 min soaking is optimum for screening purposes.

Rough rice of IR36, IR42, IR44, IR58, IR60, and IR66 from 1987 WS was fractionated by sieving through 2.5-, 2.1-, and 1.6-mm slots to obtain 4 thickness fractions. The brown rices were subjected to a micromilling test and to cracking during soaking. Fraction 2 (2.1-2.5 mm) was the major fraction (42-71% by weight), followed by fraction 3 (1.6-2.1 mm, 6-36%) except fraction 1 (>2.5 mm, 12-38%) for IR44. Fraction 4 (<1.6 mm, 2-10%) was mainly immature grains and was highest for IR42. Fraction 3 had a lower density (1.29-1.38) than fractions 1 and 2 (1.36-1.39). Head rice yields tended to be higher in fraction 2 (31-66%) and fraction 1 (28-64%) than in fraction 3 (21-55%), although the cracking test on soaked brown rice did not differentiate the 3 fractions as well. Both tests showed IR58 and IR60 as most resistant, and IR44 and IR42 as most susceptible to cracking during soaking or milling.

Two additional sets (II and III) of samples of rough rices differing in cracking susceptibility

were obtained from the Centro Internacional de Agricultura Tropical (CIAT). Set II was six varieties harvested 20 Jan and 1 and 5 Feb 1988. The head rice of unstressed grain (42-66%) correlated with brown rice translucency (59-80%, $r = 0.87^{**}$), and with percentage of cracked brown rice after soaking for 10 min (0-60%, $r = -0.71^{**}$) and 15 min (18-91%, $r = -0.60^{**}$). IRGA409 and IR22 were among the resistant samples, and IR36 was the most susceptible based on head rice yield. IRGA409 was most resistant to cracking of soaked brown rice. IR36 was the least translucent sample (59-61%).

More samples were available from set III to run rough rice stressing by soaking for 3 h, airdrying, and milling the brown rice both in the Kett mill (5 g) and the Satake mill (120 g). Head rice tended to be higher in the standard mill, except for IR36 (Table 5). Head rice yield by the two mills correlated in both unstressed ($r = 0.84^{**}$) and stressed ($r = 0.94^{**}$) rough rice. IR58 and IR60 grown in Colombia had poor head rice yield after stressing, whereas at IRRI they were the best IR varieties. The IR58 samples were quite chalky, as evident from low translucency values. IR22 had high head rice unstressed but was as susceptible to stress as IR60. IRGA409 and Anayansi showed the best cracking resistance, although Anayansi was quite chalky. In this set of samples, brown rice translucency did not correlate with head rice yield of unstressed grain using either mill. IR varieties grown in Colombia showed different performance from those grown at IRRI. IR36 had low GT instead of intermediate GT, as did all the other nine rices.

GRAIN QUALITY AND NUTRITIONAL FACTORS

Cereal Chemistry, Plant Breeding, and Agricultural Economics Departments, and International Rice Testing Program

Country samples (*Cereal Chemistry*). Samples of nine varieties from the Ivory Coast grown under irrigated and upland conditions were analyzed together with one variety grown only under irrigated conditions. Rough rice Chroma meter L* (whiteness) and brown rice translucency values were higher for irrigated than for upland rice in eight of the nine samples. Hull phenolics were higher in seven upland rices but lower in two other samples. Grain weight was higher under irrigated conditions in seven of the samples. Brown rice phenolics were higher in the three red-pericarped rices Bg 141, Bg 187, and Zakpale 3 (4-5 mg tannic acid/g) than in nonpigmented brown rices (0.5-1.2 mg/g), and phenolics were higher in upland-grown grains in 6 varieties. The red pigmentation was darker in upland-grown brown rice as evidenced by higher Chroma meter a* values (7.4-10.2 vs 6.1-8.2) than in irrigated-grown grains. Water regime had little effect on GC, ASV, or cooked rice Instron hardness and had a

Table 5. Selected properties of 3 sets of rice samples from CIAT differing in crack resistance. CIAT-IRRI, 1987-88.

Variety	Cracked brown rice after soaking 10 min (%)		Head rice yield[a] in (% of rough rice) set III				Brown rice translucency (%)	Milled rice amylose content[b] (%)
	Set I	Set II	Micro mill		Standard mill			
			U	S	U	S		
IRGA409	10	2	64	56	69	63	74-80	28
Anayansi	30	–	63	59	68	66	49-52	29
Sinaloa A80	8	–	55	51	62	55	70-74	30
Juma 58	27	–	60	29	65	41	68-72	28
Inti	40	–	62	41	64	52	74	16
CICA8	34	–	65	27	66	36	66-70	28
IR22	26	14	65	31	67	41	61-72	26
IR36	–	38	42	28	22	23	59-61	28
IR58	–	–	43	15	52	26	44-47[c]	28
IR60	–	–	56	31	64	35	59-60	28

[a] U = unstressed, S = stressed by presoaking for 3 h in water, then airdrying. [b] All low GT (ASV 6-7). [c] Very chalky.

Table 6. Range of milled rice properties of national variety samples. IRRI, 1988.

Country	Samples (no.)	Amylose content[a]	Gelatinization temperature[b]	Gel consistency[c]	Protein (%)	Cooked rice Instron hardness (kg/7 cm²)	Length-width ratio
Ivory Coast	10 irrigated	H, I, L	I>L	M, S>H	6.3-9.1	6.4-8.8	2.1-2.7
	9 upland	H>I, L	I	S, H	6.5-8.4	6.2-8.8	2.0-2.9
Japan	29 irrigated	L	L>HI, I	S	6.0-8.8	5.4-8.8	1.6-2.2 2.5, 2.8
Philippines	9 UPL varieties	H, I>Wx	I, L>HI	M, H>S	7.6-10.2	6.3-9.8	2.7-3.1

[a]Wx = waxy (0-2%), L = low (10-20%), I = intermediate (20-25%), H = high (>25%). [b]Based on alkali spreading value: L = low (6-7), I = intermediate (4-5), HI = high-intermediate (3). [c]S = soft (61-100 mm), M = medium (41-60 mm), H = hard (27-40 mm).

variable effect on AC and milled rice protein content (Table 6). Length-to-width ratios were similar in the two crops.

Japanese rices from the 1986 crop were homogeneous in AC (low) and GC (soft), but all had low GT except three samples: two Akenohoshi samples, and one Chugoku 102, with intermediate and high-intermediate values. The 29 rices represented 23 varieties grown at 5 agricultural experiment stations in Japan. Three were considered high-protein and one was low-protein.

The nine Philippine rices represented varieties produced by the University of the Philippines at Los Baños (UPLB) other than C4-63G. The samples had high or intermediate AC except for one waxy sample (Table 6). GT was mainly either intermediate or low, and GC mainly either medium or hard. All were long-grain but either slender or bold.

Cooked rice hardness and stickiness (*Cereal Chemistry*). A comparison of texture measurements of cooked rice was undertaken with a Texturometer at the National Food Research Institute, Tsukuba, Japan, and with an Instron Food Tester at IRRI on the 1986 crop of 29 Japanese rices. Texturometer hardness, but not adhesiveness, of cooked rice correlated with AC, but both Instron hardness and stickiness correlated with AC (Table 7). The premium variety Koshihikari had low hardness and high stickiness values and markedly low hardness/stickiness ratio with both the Instron and the Texturometer methods. Both values of stickiness and hardness/stickiness ratio by the Instron method and of adhesiveness and

Table 7. Range of values of Texturometer and Instron hardness and adhesiveness or stickiness of bulk-cooked rice prepared by cooker method in 1.7 times by weight of water of 29 Japanese rices grown at 5 locations[a] in 1986 and their correlation with AC and with iodine blue value of cooking liquid. Japan National Food Research Institute and IRRI, 1988.

Property	Range	Correlation with Amylose content	Correlation with Iodine blue value
AC (%)	13.3 - 16.4	–	0.65**
Iodine blue value of cooking liquid (A_{600})	0.15- 0.31	0.65**	–
Texturometer hardness	5.4 - 8.8	0.38	0.02
Instron hardness (kg/7 cm²)	4.7 - 7.3	0.53**	0.50**
Texturometer adhesiveness	6.3 - 59.4	-0.33	-0.34
Instron stickiness (g·cm²)	87 -121	-0.48**	-0.63**
Texturometer hardness /stickiness	10 - 91	0.43*	0.32
Instron hardness/ stickiness (cm^{-4})	5.6 - 11.0	0.60**	0.70**

[a]Agricultural experiment stations in Tohoku, Hokuriku, Tsukuba, Chugoku, and Kyushu.

hardness/adhesiveness ratio by the Texturometer cooker method correlated significantly with water uptake ratio and expanded volume on cooking. Only the Instron values correlated with the iodine blue values of the cooking liquid. Cooking time correlated negatively with ASV (r = -0.68**). Texturometer values differentiated among the samples better for adhesiveness than for hard-

ness, but the reverse was true for Instron values. Similar Texturometer results were obtained using three-grain samples of rice cooked in a cooker, and similar samples cooked in excess water to optimum cooking time.

International market samples (*Cereal Chemistry and Agricultural Economics*). Retail market samples obtained by a collaborating agricultural economist from Hong Kong in November 1987, from Rome (Italy) in May 1988, and from Bonn (Germany) in June 1988, were analyzed for grain quality at IRRI in connection with a project on consumer demand for rice grain quality in the export market. The study was done in cooperation with Chiang Mai University, Thailand.

Hong Kong markets were partial to raw long, slender grains with low GT and somewhat low AC (Table 8). Major exporters were Thailand, China, Australia, and the United States. Grain translucency and whiteness were excellent. The raw rices in the Bonn retail markets were mainly long, slender-grained, with low-intermediate GT and intermediate AC. Parboiled rices were also long, slender-grained, with intermediate AC. Their low GT may have resulted from parboiling of intermediate GT rices from the U.S. The five short-grained processed rices were mainly quick-cooking rices. The extra long-grained samples were probably Surinam rices.

The Rome market rices had long-medium, medium-shaped grain, with low GT and low-intermediate AC. Only nine were labeled as imported rice. Processed rices were mainly parboiled rices, 10 of which were the Italian variety Ribe.

As expected, the parboiled rices had lower whiteness values by Kett meter and Minolta Chroma

Table 8. Classification of selected properties of raw and processed rices in retail markets in Hong Kong, Bonn (Germany), and Rome (Italy).[a] Chiang Mai University, Thailand, and IRRI, 1987-88.

Property	Hong Kong (93)	Bonn		Rome	
		Raw (64)	Processed (42)	Raw (83)	Processed (18)
		Samples (no.)			
Length[b]					
Extra long	0	22	6	0	0
Long	60	27	31	39	10
Medium	17	1	0	28	8
Short	16	14	5	16	0
Length/width ratio[c]					
Slender	62	49	37	4	4
Medium	27	0	0	54	14
Bold	4	15	5	25	0
Gelatinization temperature[d]					
Low	85	30	42	81	18
Intermediate	6	34	0	2	0
High-intermediate	2	0	0	0	0
Apparent amylose content[e]					
Low	38	5	2	57	14
Intermediate	29	54	40	23	4
High	26	5	0	3	0
Crude protein (%)					
Range	5.9-9.5	5.4- 9.0	5.8- 8.6	5.5- 8.8	5.9- 8.6
Mean	6.8	7.5	7.8	6.9	7.1
Milled rice					
Kett whiteness (%)	40-46	34-44	18 -53	18 -23	
Chroma meter L*	73-76	72-76	58 -66[f]	70 -80	61 -65[f]
Chroma meter b*	–	13-18	23 -26[f]	11 -15	24 -28[f]

[a] Figures in parentheses indicate total number of samples. [b] Extra long, >7.50 cm; long, 6.61-7.50 mm; medium, 5.51-6.60 mm; short, ≤5.50 mm. [c] Slender, >3.0; medium, 2.1-3.0; bold, 1.1-2.0. [d] Based on alkali spreading value: low, 6-7; intermediate, 4-5; high-intermediate, 3. [e] Low, 10-20%; intermediate, 20-25%; high, >25%. [f] Parboiled milled rice only, excluding 7 precooked rices in Bonn samples.

meter L* (whiteness) and higher Minolta Chroma meter b* (red) values (Table 8). Mean protein content was close to the reported mean value of 7%.

Philippine market samples (*Cereal Chemistry and Agricultural Economics*). Philippine retail market samples obtained in the 1987 DS and WS cooperative study on consumer demand for rice grain quality were classified based on Philippine milled rice standards. The market labels of identification differed widely, particularly in the chemical properties GT and AC, since variety identification in the market is based on grain size and shape (Table 9). Traditional variety names such as C4, Intan, Wagwag, and Dinorado were more common in sampled urban markets, particularly Metro Manila, than in the sampled rural markets. The IR rices, particularly IR64, were predominantly typical of the actual variety type. Since production of C4, Intan, and Wagwag is already minimal, samples labeled C4 looked predominantly like IR36 and other high-AC IR varieties such as IR60, with low GT (other than the smaller grained IR42). The increase in intermediate-AC C4 samples with intermediate GT in 1987 WS may imply IR64. The same holds true for Intan. Wagwag (fine-grained) was mainly IR42 but since larger grain samples predominate, other IR varieties were also being traded as Wagwag. Dinorado has red pericarp and remains a traditional variety. Being an upland variety may explain Dinorado's predominantly low GT compared with the IRRI crop with intermediate GT.

Among 110 waxy nonpigmented market samples, very few (4) were the short, bold-grained traditional Malagkit Sungsong based on grain size and shape. The common name for waxy rice is Malagkit or Pilit. Most samples were contaminated by nonwaxy grains, and only 1 had less than the 2% AC characteristic of pure waxy rice. The majority of the samples had >5% AC. The majority of the nonpigmented waxy rices were of the modern, longer grained type with low GT. In contrast, 19 samples of Tapol were still the traditional purple pericarped waxy rice with high-intermediate GT, but they were also contaminated with nonwaxy grains. Pigmented rices were not mixed with nonpigmented IR rices.

The analysis of the market samples verified that variety names used, particularly in urban retail markets, were more for grading purposes rather than a true reflection of variety identification.

Effect of saline soil on grain quality (*Cereal Chemistry and International Rice Testing Program*). Four selected saline soil-grown rices (CSR-1

Table 9. Summary of selected physicochemical properties of some nonwaxy rices from selected Philippine retail markets in 1987.[a] IRRI, 1987-88.

Name	1987 season	Samples (no.)	Length[b]			Length-to-width ratio[c]		Gelatinization temperature[d]			Apparent amylose content[e]		
			L	M	S	S	B	L	I	HI	L	I	H
C4	DS	65	49*	15	0	47*	18	50	15*	0*	0	13*	52
	WS	94	92*	2	0	72*	22	23	66*	5*	0	34*	60
Dinorado	DS	10	1	7*	2	0	10*	10	0*	0	1	9*	0
	WS	19	9	10*	0	8	11*	12	7*	0	2	15*	2
Intan	DS	12	8*	4	0	7*	5	9	3*	0	0	3*	9
	WS	24	24*	0	0	22*	2	7	15*	2	0	11*	13
Wagwag	DS	35	23	11*	1	28	7*	29	6*	0	0	6	29*
	WS	84	63	21*	0	46	38*	42	41*	1	0	17	67*
IR36	DS	37	31*	6	0	33*	4	18	18*	1	0	5	32*
	WS	59	55*	4	0	45*	14	13	46*	0	0	27	32*
IR42	DS	18	4	14*	0	4	14*	16*	2	0	0	1	17*
	WS	53	17	36*	0	11	42*	45*	7	1	1	5	47*
IR60	DS	22	14*	8	0	17*	5	22*	0	0	0	1	16*
	WS	31	28*	3	0	21*	10	19*	12	0	1	8	22*
IR64	DS	75	69*	6	0	70*	5	9	60*	6	0	57*	18
	WS	163	162*	1	0	154*	9	9	136*	18	2	146*	15

[a] * = values for authentic variety samples grown at IRRI. [b] L = long, ≥6.0 mm; M = medium, 5.0-5.9 mm; S = short, <5.0 mm. [c] S = slender, >3.0; B = bold, 2.0-3.0. [d] Based on alkali spreading value: L = low, 6-7; I = intermediate, 4-5; HI = high-intermediate, 3. [e] L = low, 10-20%; I = intermediate, 20-25%; H = high, >25%.

[Damodar], resistant; Mehran 69 [IR6-156-2] and IR64, medium resistant; and IR36, susceptible) from the Agricultural Research Substation, Sadhoke, Punjab, Pakistan (soil electrical conductivity 5-6 dS/m) had lighter grains (16 vs 18 mg) and higher Na content (117 vs 26 ppm) than the control samples. Milled rice ash content was higher only in saline-grown Mehran 69. Three out of four saline-grown grains had higher BRP (12.3 vs 9.6%), less translucent grain (38 vs 43%), lower starch (72 vs 76%) and amylose (24 vs 26%) content, or lower K (0.21 vs 0.22%) than the control samples. ASV and GC were not affected by saline soil. No consistent reduction in grain length, width, or breadth was observed in the four varieties. The study was done in cooperation with the University of Agriculture, Faisalabad, Pakistan.

Rices with similar starch properties (*Cereal Chemistry*). Cooked rice Instron hardness could not readily distinguish texture among rices of similar AC and GT. The shear rate-stress relationship of 8, 10, and 12.5% slurries of these cooked rices was determined using a Wells Brookfield cone-plate microviscometer model RVT with 2.4 cm diameter 1.565° cone. Differences in the regression curves were evident using the power law model $\tau = m\gamma^n$ where τ is shear stress in mPa, γ is the shear rate in s, m is the consistency coefficient, and n is the flow behavior index. The nonwaxy samples showed significant differences in n and m but not the waxy rices (Table 10). Apparent viscosities at 10 r/min and 20 r/min may be used to differentiate nonwaxy rices, since they can differentiate as well as m and n.

At Osaka Shoin Women's College, Japan, a new Tensipresser multibite test on 6% cooked-rice slurry from rices cooked for 20 min at 94 and 98 °C differentiated the IR64 and C4-63G and the Akibare-Milyang 23 pairs. IR64 had higher hardness (A) and stickiness (-A) values than C4-63G at both cooking temperatures. Milyang 23 also had higher values than Akibare, and the highest values of the four nonwaxy rices. The -A/A ratios were similar for each pair. With the waxy rices, 17-min cooking at 90 °C gave better differentiation than 20-min cooking, probably because of their high percentage of brokens. Malagkit Sungsong had lower A and higher -A and -A/A than IR65. Hardness and stickiness values of cooked whole-grain samples were also negatively correlated.

Systematic analysis of molecular structure of starch (*Cereal Chemistry*). In collaborative studies with starch chemists at Kagoshima University, Japan, on 5 IR (IR32, IR36, IR42, IR48, and IR64) and 3 Japanese rice starches, the increase in iodine affinity of starch over 16-18% apparent AC was verified to be due to an increase in iodine affinity of amylopectin rather than an increase in

Table 10. Viscosity and flow parameters using the power law model $\tau = m\ \gamma^{n}$ and apparent viscosity at 10 and 20 r/min of boiled milled-rice slurry in a cone-plate microviscometer.[a] IRRI, 1988.

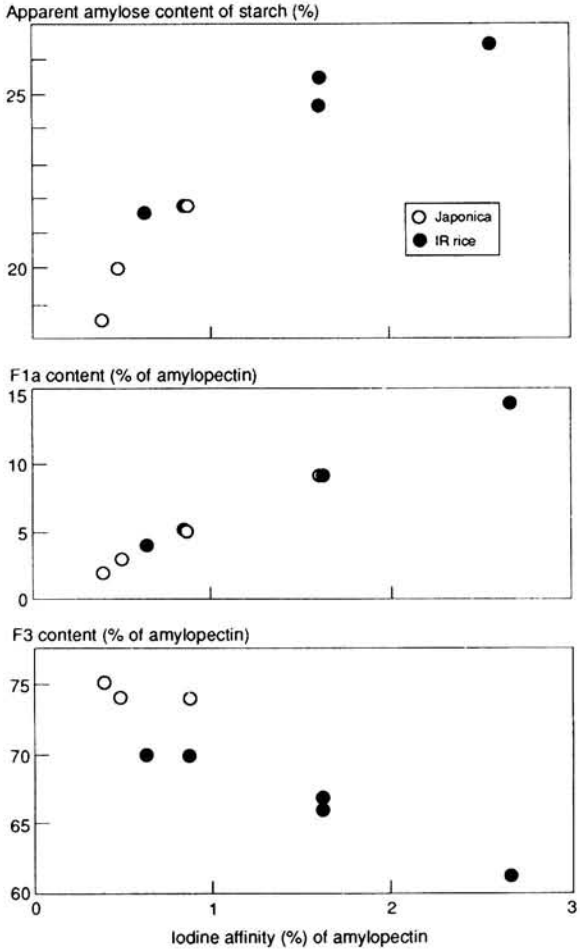
Sample	Amylose class	Flow behavior index n	Consistency coefficient m ($mPas^n$)	Apparent viscosity (mPa·s) at	
				10 r/min	20 r/min
		10% slurry			
IR36	High	0.456 a	3370 b	1540 b	1060 b
IR42	High	0.480 b	2940 b	1510 b	1040 b
IR62	High	0.506 c	1880 a	1030 a	730 a
		12.5% slurry			
IR64	Intermediate	0.562 b	3000 a	2040 a	1530 a
C4-63G	Intermediate	0.456 a	6200 b	2840 b	2020 b
Akibare	Low	0.543 a	3450 b	2190 b	1600 b
Milyang 23	Low	0.565 b	2510 a	1720 a	1270 a
Malagkit Sungsong	Waxy	0.656 a	30 a	858 a	674 a
IR65	Waxy	0.710 a	23 a	815 a	653 a
IR29	Waxy	0.694 a	27 a	900 a	713 a

[a]Mean of 3-4 replications. In a column for each pair or group, means followed by a common letter are not significantly different at the 5% level by DMRT.

AC (Fig. 1). Intermediate-AC starches IR48 and IR64 overlapped with Japanese rice starch in amylopectin properties and had true AC similar to that of high-apparent-AC rice starches IR32, IR36, and IR42.

The iodine affinity of amylopectin also predicted the content of the longest chain (F1a, DP >100 glucose units) and the shortest chain (F3, DP 13) components on gel filtration of isoamylase-debranched amylopectin (Fig. 1).

Among the 7 amyloses, the ß-amylolysis limit of the branched fraction of amylose was estimated to be 39% from the relationship between the ß-amylolysis limit of amylose and the percentage by number of branched molecules. This 39% value is lower than that of amylopectin (55-60%). The predicted ß-amylolysis limit of the linear fraction of amylose was 102%. Branched amylose ß-limit dextrin had about twice as many chains per molecule (5.6-9.0) as the parent amylose (2.5-4.3). The molecular size of branched amylose was 1.4-2.2 times that of linear amylose. Branched amylose comprised 25-49% (mean 36%) by number and 33-60% (mean 48%) by weight of amylose.



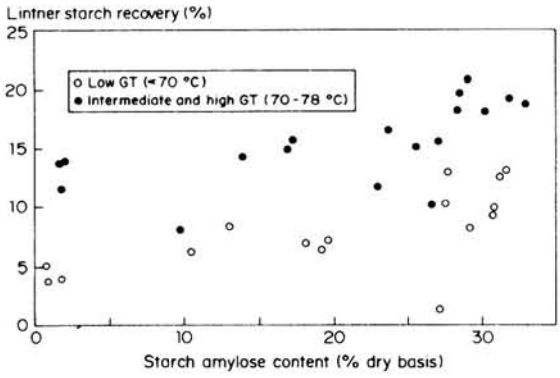
1. Relationship between iodine affinity of 8 amylopectins with apparent amylose content of starting starch, and the longest-chain (F1a) and shortest-chain (F3) components on gel filtration of isoamylase-debranched amylopectin. Kagoshima University (Japan)-IRRI, 1988.

Limit viscosities in 1 M KOH at 22.5 °C were 180-249 ml/g for 7 amyloses and 134-170 ml/g for 8 amylopectins. In both amylopectins and amyloses, limit viscosity was not significantly correlated with molecular size, but rather with the proportion of linear and branched fractions. Higher linear fraction resulted in higher limit viscosity.

Amylopectins were prepared from additional high-AC samples. Those from the 3 low-GT samples had higher iodine affinity (2.3-2.7%) than amylopectins from 4 intermediate-GT starches (1.7-1.8%). Amylopectins from IR48 and IR64 had iodine affinities of 0.8-0.9%. These results support earlier studies showing that low-GT, high-AC amylopectins had higher iodine affinity than intermediate-GT, high-AC amylopectins.

Crystallinity of starch granules (*Cereal Chemistry*). The crystallinity of 34 rice starch granule samples was indexed from the recovery of lintner starch obtained by treating starch granules at 35 ±1 °C in 2.2 N HCl for 15 d. Lintner starch recovery correlated positively with AC ($r = 0.44^{**}$) and final GT ($r = 0.69^{**}$) (Fig. 2) despite the fact that amylopectin is the established crystalline fraction of the starch granule. Highest lintner starch recoveries (18-20%) were obtained for high-GT, intermediate-AC starches from Ganagala and Yilan-chu-tze. Corrosion of the amorphous fraction was confirmed to be completed within 7-8 d and was faster for low-GT than for intermediate-GT starches. Starch granules of high-AC rices differing in GC–IR42 (hard), IR36 (medium), and IR32 (soft)–had similar X-ray diffractograms, suggestive of similar degrees of crystallinity, despite differences in lintner starch recoveries (10, 18, and 19%, respectively).

The crystallinity of gelatinized and retrograded starch granules was also indexed by lintner starch and digestibility with ß-amylase-pullulanase.



2. Scattergram of granule crystallinity indexed by lintner starch recovery of 34 rice starch granules differing in apparent amylose content and final gelatinization temperature (GT). IRRI. 1988.

Cooked granules were retrograded three times by cooling for 4 h or overnight at 4 °C, followed by heating for 4 h each time at 42 °C at 80% relative humidity. Lintnerization was complete within 3-5 d in contrast to 7-8 d for raw granules. However, the corrosion-resistant residue was higher in cooked rice, representing retrograded starch, both amylose and amylopectin (Table 11). The degree of gelatinization using ß-amylase-pullulanase showed IR42 as most susceptible, and IR8 as least susceptible. Defatting with butanol prior to cooking increased lintnerization of all except IR42 and increased the degree of gelatinization only of IR8. Methanol defatting reduced the degree of corrosion except for the action of ß-amylase-pullulanase on IR8. Butanol-defatted waxy IR29 had 48% lintnerization and 77% gelatinization.

Japanese researchers reported that HCl attacks mainly retrograded amylose but not amylose-lipid complex and retrograded amylopectin in gelatinized granules, whereas ß-amylase-pullulanase attacks mainly retrograded amylopectin but not amylose-lipid complex and retrograded amylose. Our data on cooked retrograded rice starch granules show that HCl also attacks amylopectin, as in IR29. ß-amylase-pullulanase also attacks amylose, since the 77% hydrolysis for IR29 is close to the values of IR42 and IR32 (Table 11).

Waxy alleles of starch granules (*Cereal Chemistry and Plant Breeding*). Japanese scientists have discovered two waxy alleles in nonwaxy rice starch

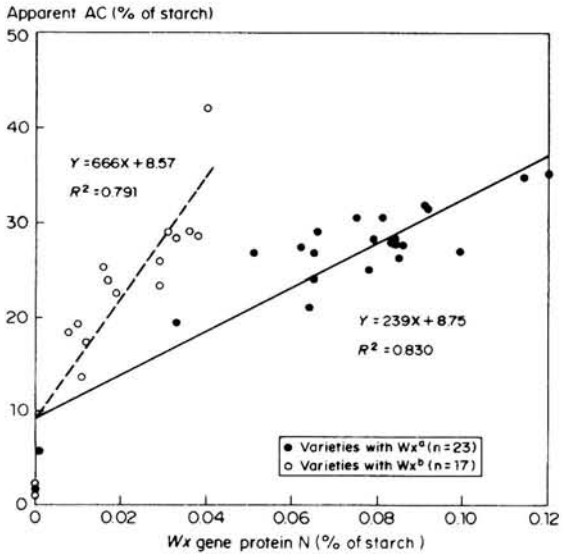
Table 11. Effect of cooking and prior defatting with hot water-saturated butanol at 92 °C or with refluxing 85% methanol on the susceptibility to HCl and β-amylase-pullulanase corrosion of retrograded starch granules of 4 high-AC rices differing in starch GT. IRRI, 1988.

Treatment	Low GT		Intermediate GT	
	IR8	IR42	IR32	IR36
Degree of lintnerization[a] (%)				
Raw granules	88	90	81	82
Cooked retrograded[b]				
Undefatted	60	65	58	63
Predefatted with hot water-saturated butanol	68	66	68	70
Predefatted with 85% methanol	46	47	46	47
Degree of "gelatinization"[c] (%)				
Cooked retrograded[b]				
Undefatted	51	75	70	59
Predefatted with hot water-saturated butanol	69	74	62	56
Predefatted with 85% methanol	56	64	60	55

[a] 15-d lintnerization for raw granules and 5 d for gelatinized granules in 2.2 N HCl at 35 °C. [b] One cycle of retrogradation for all, except 3 cycles for methanol-defatted samples. [c] 4-h hydrolysis with β-amylase-pullulanase.

granules: Wx^a in indica and Wx^b in japonica. Wx^a is presumably responsible for more waxy gene protein (60-kD polypeptide) and higher AC than Wx^b. At IRRI, the predominant waxy allele of 40 rice varieties from different ecosystems was identified through their waxy gene protein. Regression analysis of their AC and amount of waxy gene protein gave two distinct regression equations (Fig. 3) instead of one, as reported by the Japanese scientists. With the same AC, varieties with the Wx^a allele had about three times as much waxy gene protein in their endosperm starch as varieties with the Wx^b allele.

This method may be used as an additional means to classify nonwaxy rices into indica and japonica starch types. Indica/japonica, bulu, and basmati types showed selection for either Wx^a or Wx^b (Table 12). Upland rices showed selection for Wx^a allele. U.S. long-grain rices had the Wx^b allele. Two amylose extender mutants showed preference for the waxy allele of their parent varieties Kinmaze and IR36. The waxy allele classification did not always coincide with the classification based on isozyme patterns.



3. Relationship between waxy gene protein and apparent amylose content (AC) of starch with Wx^a and Wx^b alleles. IRRI, 1988.

Table 12. Correspondence between isozyme classification of rice embryos and waxy allele classification of endosperm starch of selected rices. IRRI, 1988.

Type	Samples (no.)	Distribution based on Isozyme classification[a]			Waxy allele	
		1	5	6	Wx^a	Wx^b
Japonica	6	0	0	6	0	6
Indica	5	5	0	0	4	1
Samba	2	2	0	0	2	0
Indica/japonica	4	2	0	2	2	2
Upland, tropical	11	1	0	10	11	0
Bulu (javanica)	2	0	0	2	1	1
U.S. long grain	3	0	0	3	0	3
Basmati	3	0	3	0	1	2
Amylose extender mutants	2	1	0	1	1	1

[a] 1 = indica, 5 = basmati, 6 = japonica.

Grain properties of IR36-based starch mutants (*Cereal Chemistry and Plant Breeding*). The properties of brown rice (1987 WS) of 12 starch mutants with IR36 background were compared with those of IR36. All rices had lighter and less dense grain than IR36 (Table 13). Sugary and shrunken mutants had the lowest starch content, but the sugary mutant had the highest content of total free sugars (9 vs 2%). About 50% of the measured starch content of the sugary mutant was actually phytoglycogen. Fat content was higher (5-6%) in the grains of sugary and shrunken mutants than in the others (1.3-2.2%). Protein contents were high. Protein per seed was lowest in the sugary mutant and highest in the dull EM47. Lysine content was highest in the amylose extender mutant, but highest in the dull 2035 on a per seed basis.

All mutants except the amylose extender had lower AC in defatted brown rice than IR36. The GTs of the samples were intermediate except for that of the dull EM47 and the amylose extender. The extremely high GT in the sugary mutant may have been due to the effect of its high sucrose level on GT. Actually, a few granules gelatinized between 57 and 62 °C. ASV estimated the GT of most mutants but underestimated the GT of the amylose extender and floury-2 mutants. Corresponding starch mutants based on Kinmaze have been reported to show similar trends in starch properties.

A sample of the amylose extender mutant EM129 based on Kinmaze and IR36-based amylose extender mutant were fractionated into amylose and amylopectin. Their amylopectins had iodine affinities similar to those of high-AC starches, suggesting that the higher AC of these mutants is due to increased true AC rather than more linear amylopectin with higher iodine affinity. The milled rice of amylose extender M16, IR36-based mutant, when cooked to 75% water content, had higher cooked rice Instron hardness than IR36 rice.

Starch properties related to plasma glucose response (*Cereal Chemistry*). Amylose content and processing such as parboiling are known to reduce the rate of glucose increase in blood plasma within 3 h of rice ingestion. The plasma glucose response of two cooked rices and six types of cooked noodles in eight noninsulin-dependent diabetics at the Ramathibodi Hospital (Bangkok, Thailand) correlated positively with the in vitro starch digestibility of food slurry using ß-amylase-pullulanase, and negatively with AC and Amylograph consistency (Table 14). Waxy (glutinous) rice had the highest value, and mungbean noodles the lowest. The poorly digested starch fraction

Table 13. Brown rice properties of IR36-based starch mutants. IRRI, 1988.

Entry	Mutant description	100-grain weight (g)	Density (g/cm³)	Composition (% wet basis)		Lysine (g/16.8 g N)	Apparent amylose content[a] (% dry basis)	Alkali spreading value	Gelatinization temperature (°C)
				Starch + free sugars	BRP				
IR36	(Control)	1.8	1.54	73	11	3.9	22 (26)	4.0	73.5
82GF	Sugary	0.6	1.29	57	16	4.1	0 (0)	3.0	>80
EM20	Shrunken	1.1	1.22	61	16	4.2	15 (22)	4.6	73.5
2064	Amylose extender	1.8	1.38	68	10	4.7	34 (44)	6.6	77
EM36	Floury-2	1.5	1.36	68	12	4.1	10 (13)	6.0	72.5
ESD7-3 (0)	Floury-1	1.8	1.28	71	10	4.1	19 (23)	4.8	74
2035	Dull	1.7	1.40	68	13	4.3	6 (8)	3.0	73
2057	Dull	1.3	1.40	71	12	3.9	5 (7)	3.2	73
2077	Dull	1.5	1.40	70	14	4.1	7 (8)	3.0	72
2120	Dull	1.4	1.38	69	12	3.8	6 (8)	3.2	74
EM12	Dull	1.4	1.39	65	13	3.9	6 (8)	3.4	74.5
EM47	Dull	1.7	1.39	70	14	3.6	5 (6)	6.0	66
EM98	Dull	1.5	1.40	73	11	3.7	6 (7)	3.2	72.5

[a] AC on starch basis in parentheses.

Table 14. Properties of Thai foods differing in plasma glucose response in noninsulin-dependent diabetics. Ramathibodi Hospital, Bangkok-IRRI, 1988.

Food	Plasma glucose response[a] (%)	In vitro starch digestibility[b] (%)	Apparent amylose content (%)	Amylograph setback (Brabender units)
Waxy milled rice	75	99 f	2.3 g	−295
Nonwaxy milled rice	71	85 e	15.8 f	−200
Flat rice noodles	54	80 de	27.0 d	375
Extruded fine rice noodles	53	82 de	28.3 c	50
Extruded fermented rice noodles	55	75 c	27.0 d	−10
Wheat (egg) noodles	57	71 b	19.2 e	45
Imitation mungbean noodles (with cassava)	51	69 b	39.6 b	520
Mungbean noodles	45	62 a	46.4 a	375
r with glucose response (n = 8)		0.87**	−0.93**	−0.85**

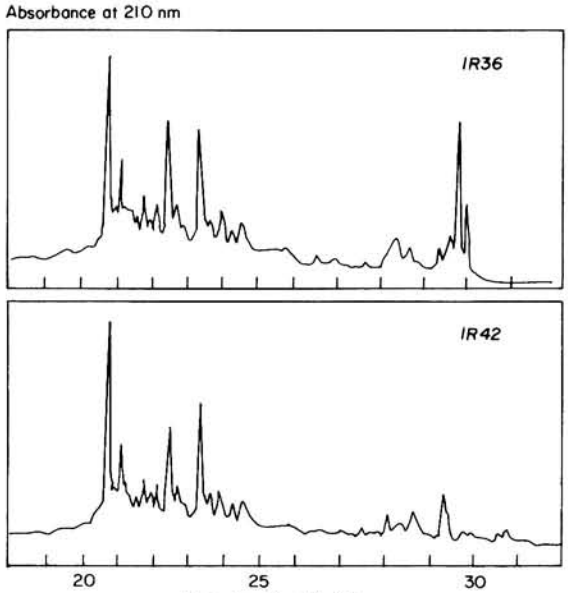
[a] Based on 3-h area response of 8 patients on 50 g carbohydrate and 1674 kJ diet, and on a glucose drink as 100%. [b] By β-amylase-pullulanase method.

must be retrograded amylose, not amylose-lipid complex, since legume (mungbean) starch is not rich in lipids. Researchers at the Flour Milling and Baking Research Association, Chorleywood, UK, recently identified the fraction of cooked wheat starch resistant to digestion to be retrograded amylose with mean DP 60.

Earlier collaborative studies with nutritionists at the University of Toronto showed that after hot-plate cooking with a fixed water:starch ratio of 3.4, low-GT IR42 showed higher glycemic index and greater in vitro salivary α-amylase digestibility than intermediate-GT IR36 and IR62 (Annual report for 1986). The water:rice ratio in cooked rice was 1.77 for IR42, 1.64 for IR36, and 1.78 for IR62. Recent studies wherein intermediate-GT rices were cooked in excess water for optimum cooking time (>20 min) revealed similar glycemic indexes and digestibilities for the 3 cooked high-AC samples. Evidently the longer cooking

time allowed the intermediate-GT samples to achieve the same high degree of cooking as low-GT IR42.

Methods of variety identification (*Cereal Chemistry and Plant Breeding*). In collaboration with scientists at the Food Science Department, University of Manitoba, Canada, 10 rice varieties and 1 advanced line were used to develop methods of soluble protein fingerprinting for variety identification. Brown rice flour proteins were extracted with 5 M acetic acid containing 10% sucrose, and the extract was centrifuged and filtered. Proteins were separated by PAGE in pH 3.1 aluminum lactate buffer and by reversed-phase high-performance liquid chromatography (HPLC) using acetonitrile:water solvent gradient elution. All 11 samples were differentiated by both methods. Sister line varieties IR36 and IR42 showed similar electrophoregrams except for minor differences in the 23 mm region. Storage of the extracts at 4 °C up to 4 wk did not affect the PAGE patterns. In HPLC, the 2 had similar elution patterns of extracted proteins in the 18- to 25-min regions but differed in the 26- to 30-min regions (Fig. 4).



4. Reversed-phase high performance liquid chromatograms of 5 M acetic acid protein extract of brown rice of sister line varieties IR36 and IR42 showing similarity in elution patterns at 18-25 min and differences at 26-30 min. Food Science Department, University of Manitoba, Canada-IRRI, 1988.

Location was shown to affect particularly the minor HPLC peaks of prolamin extracts of IR36 and IR42 in a cooperative study with chemists at the United States Department of Agriculture (USDA) U.S. Grain Marketing Research Laboratory, Manhattan, Kansas. Samples grown in Beaumont, Texas, have more minor peaks than those grown elsewhere, including the Philippines. Propanol (60%) was verified to be a better prolamin extractant than 70% ethanol. Brown rice extracts gave sharper HPLC peaks than milled rice extracts.

In collaborative studies with protein chemists at the USDA Northern Regional Research Center, Peoria, Illinois, milled rice flour (150 mg) was extracted in sequence by 4 ml butanol:ethanol (1:1) to defat, 1.5 ml 60% 1-propanol to extract prolamin, 1 M NaCl in pH 7.5 phosphate buffer to extract albumin-globulin, and 3% sodium dodecylsulfate (SDS)-0.5% dithiothreitol in pH 8 Tris buffer to extract glutelin. Milled rice proteins were 5-18% prolamin, 4-10% albumin-globulin, and 77-90% glutelin. Reversed-phase HPLC in acetonitrile-water revealed that glutelin was the best fraction for variety identification of 27 U.S. rices and 6 samples from IRRI.

Poorly digested cooked rice protein bodies (*Cereal Chemistry*). Poorly digested cooked rice protein bodies representing the core of large spherical protein bodies were prepared by destarching cooked IR58 milled rice (9.8% protein) with *Aspergillus oryzae* α-amylase and incubating the protein body preparation in pepsin. The protein content was 52%, and protein recovery was 23%. The crude preparation was purified by gel filtration on a Bio Gel A-5m column, resulting in 2 protein peaks eluted with 0.5% SDS-0.6% ß-mercaptoethanol, with V/Vo ratios of 1.9 and 2.4. The second and major peak (V/Vo 2.4) showed on SDS-gradient (10-20%) PAGE mainly the 16-kD polypeptide plus one minor band corresponding to 17 kD and diffused staining below 16 kD. Fecal protein particles from a human fed cooked rice gave an identical SDS-PAGE pattern. Milled rice prolamin also gave mainly the 16-kD subunit but showed no staining below 16 kD. Isoelectric focusing (pH 3-10) separated this purified fraction into at least four bands with much trailing.

BY-PRODUCTS AND RESIDUES

Cereal Chemistry, Plant Breeding, and Statistics Departments

Variability in nutritional value of harvest straw. A collaborative study was undertaken with chemists at the Overseas Development Natural Resources Institute (ODNRI), UK, and nutritionists at the Institute of Animal Science, UPLB, to assess the sources of variation in nutritional value of harvest straw, since variety rankings of nutritional value of harvest straw, such as IR36 and IR58, vary with season. Five semidwarf and 5 tall varieties were grown in 1987 WS and 1988 DS at IRRI with 0 and 90 kg N/ha. Straw samples were collected and analyzed at ODNRI, and harvest straw was assayed for in vitro dry matter digestibility (IVDMD) at UPLB using rumen fluid from fistulated carabaos. Dry matter solubles (DMS) and organic matter solubles (OMS) at ODNRI utilized commercial cellulase enzymes instead of rumen fluid. Harvest straw was the upper portion of the harvest plant down to 40 cm below the panicle base that was cut, hauled, and threshed.

The DMS, OMS, IVDMD, and crude protein values of the harvest straw of tall and semidwarf rices overlapped (Table 15). Semidwarf rices had somewhat higher DMS, OMS, and crude protein than tall rices in WS only. Among the component tissues of harvest straw, DMS and OMS were highest for the stem, followed by the blade and sheath, and then the rachis. Protein content was less than 6% even at 90 kg N/ha but was lower in WS for tall rices only. Peta harvest straw had the lowest ash content (16-18%) among the samples (20-22%), and Gam Pai the highest (24%). The harvest straw of IR36 was no more nutritious than that of IR58, in contrast to earlier data.

For semidwarf rices, variety was a more important source of variation in DMS and OMS of harvest straw than environment (Table 16). The reverse was true for tall rices. Season, but not N

Table 15. Range of nutritional value parameters of harvest straw of 5 tall and 5 semidwarf rices grown at 0 and 90 kg N/ha for 2 seasons. ODNRI, London-Institute of Animal Science, UPLB-IRRI, 1987-88.

Harvest straw property[a]	1987 WS		1988 DS	
	Tall	Semidwarf	Tall	Semidwarf
DMS (% of total)	20-26	22-30	24-33	24-31
OMS (% of total)	26-33	28-38	31-40	32-39
IVDMD (% of total)	31-44	34-41	33-40	35-41
Crude protein (%)	3.1-4.9	3.6-5.4	3.9-5.9	3.6-5.9

[a]OMS = organic matter solubles, IVDMD = in vitro dry matter digestibility, DMS = dry matter solubles.

Table 16. Estimates of variance components for 4 indexes of nutritional value of harvest straw of 5 semidwarf and 5 tall rices grown at 0 and 90 kg N/ha in 1987 WS and 1988 DS.[a] ODNRI, London-Institute of Animal Science, UPLB-IRRI, 1988.

Property and rice type	Estimates of variance components (% of total)					
	Environment (E)	Replications within E	Variety (V)	E X V	Error	Sampling error
Degrees of freedom	3	12	4	12	48	80
DMS semidwarf	12**	0	42**	14**	0	32
DMS tall	40**	0	15**	11**	0	34
OMS semidwarf	16**	0	39**	12**	0	33
OMS tall	44**	0	14**	11**	0	31
IVDMD semidwarf	4*	0	12**	14**	7	63
IVDMD tall	1	0	14**	10**	0	75
Protein semidwarf	9	30	10**	17**	0	34
Protein tall	23**	5	26**	3	0	43

[a]Significant at the 5% (*) and 1% (**) levels by the *t*-test.

level, contributed significantly to the environment effect. Sampling error was the second major source of variation in DMS and OMS of harvest straw.

Variation in IVDMD was due mainly to sampling error (Table 16). Variety contributed more to IVDMD variation than did environment, and the effect of environment was significant only for semidwarf rices. Only N level and not season significantly contributed to environment effect on IVDMD for both semidwarf and tall rices. Sampling error was the major source of variation for crude protein of harvest straw. Environment–specifically season followed by N–contributed to variation in crude protein only in tall rices. N also contributed significantly to variation in protein content of harvest straw of semidwarf rices.

DMS and OMS were significantly correlated in the two crops since the range in ash content was narrow (Table 17). Both properties correlated with IVDMD in both crops. Crude protein was not consistently correlated with the four other nutritional value indexes except with DMS and OMS in WS.

Table 17. Correlation coefficients between indexes of nutritional value of harvest straw of 5 semidwarf and 5 tall rices at 0 and 90 kg N/ha in 2 seasons (n = 20). ODNRI-IAS UPLB-IRRI, 1988.

Property	Season	OMS	IVDMD	Crude protein
DMS	1987 WS	0.98**	0.64**	0.52*
	1988 DS	0.96**	0.72**	0.08
OMS	1987 WS		0.59**	0.45*
	1988 DS		0.57**	0.03
IVDMD	1987 WS			0.20
	1988 DS			0.10

The relatively poor contribution of variety to variation in nutritional value of harvest straw at IRRI, particularly of IVDMD (Table 17), cannot justify breeding for improved nutritional value of harvest straw, even in semidwarf rices.

Genetic evaluation and utilization (GEU) program

Disease resistance

Plant Pathology and Plant Breeding Departments; International Rice Germplasm Center; International Rice Testing Program; and Wageningen Agricultural University, Netherlands

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IRTP DISEASE RESISTANCE TRIALS

International Rice Testing Program

Disease evaluation results obtained from the 1987 International Rice Testing Program (IRTP) disease screening nurseries were analyzed in 1988. The best performing entries across locations are indicated in Table 1. Entries that were rated resistant to specific diseases at certain locations are given in Table 2. More detailed information on IRTP disease nursery results is given in the IRTP section of this report.

Table 1. Best performing entries in the 1987 disease nurseries. IRRI, 1988.

Nursery	Trials (no.)	Entries
International Rice Bacterial Blight Nursery	26	AC19-1-1, Camor, IR29341-85-3-1-3, Kachamota, RP2151-173-1-8, RP2151-21-22, RP2151-40-1
International Rice Blast Nursery	20	Kataktara DA2, IR24632-34-2, IR29506-60-3-3-2, IR32307-12-2-1-2, IR32720-138-2-1-1-2, IR328533-185-3-2-2, IR37721-3-3-3-3-1, IR39326-9-2-2-3
International Rice Tungro Nursery	3	ARC11554
International Rice Ufra Nursery	2	BR539-17-4-3-3-1, Rayada 16-06, Sada Pankaich, CNL 319, NC492, Dalbao

Table 2. 1987 IRTP yield nursery entries rated resistant to or tolerant of various diseases at sites with high disease pressure (location average ≥5.0). IRRI, 1988.

Disease	Nursery[a]	Location	Entries
Leaf blast	IRYN-VE	Los Baños, Philippines	IR31785-58-1-2-3-3, IR32429-47-3-2-2, IR39357-133-3-2-2-2, IR39422-75-3-3-3-2, IR41985-111-3-2-2, IR41996-118-2-1-3, IR42015-83-3-2-2
	IRYN-M	Los Baños	Nanjing 80-2143
		Mtwango, Zanzibar	BW293-2, IR27316-32-3-2, IR31809-83-3-2-2, IR42
	IRSSWYN-E	Los Baños	CR213-1002, IR21573-2-1-2-2-2-1, IR4563-1-1-3-6-1E-P1
	IRRSWYN-M	Los Baños	SPT7106-2-3-3-1
	IURYN-M	Los Baños	IRAT110, ITA212
	IRON	Los Baños	IR42015-83-3-2-2, Suweon 341, IR39323-110-5-2-2, IR39334-7-3-3-3, P2016F4-116-1B-B, P3059F4-25-3, P3059F4-105-1B
	IURON	Los Baños	AUS257, Burik, TOX1010-21-5-12-4, TOX955-202-2-101-1-1, Gu Meuang Luang, ITA256, P1264-6-11M-1-3M-4, P2056F4-59-2, Addey, IR27078-11-6, UPLRi-5, Salumpikit, 7 Canuto
	IRRSWON	Los Baños	Rohyb15-WAR-3-3-B-2, Rohyb15-WAR-3-3-B-3, IRAT116, IR21178-43-1-2-2-2, IR28384-21-2, ITA231, ITA249, Leuang Yai 148, SPT7149-598-3, Xiang Chou V
Neck blast	IURYN-E	Los Baños	ADT31, ADT36, IR25588-7-3-1, TNAU6464
		Santo Tomas, Philippines	ADT36, RAU4028-2, RP1899-1689-98, IET1444
		Huimanguillo, Mexico	ADT31, ADT36, BG367-4, IR25588-7-3-1, NDR83, NDR97, UPR103-80-1-2, IET1444
	IURYN-M	Ibadan, Nigeria	B3906d-14-ST-16-48-3, B3906F-13-13-ST-47, B3913F-16-5-ST-42, IAC220/79, IRAT110, IRAT141, IR27078-11-2, IR8997-4-4-2

continued on next page

Table 2 continued.

Disease	Nursery[a]	Location	Entries
	IURON	Hawalbagh, India	IAC118/81, IAC150/76, RR20-5
		Huimanguillo	CR222-MW10, Rajendra, Tella Hamsa, TOX1010-21-5-12-4, UPR238-42-2-3-TCA1, Gu Meuang Luang, IAC233/79, Kabra, RR20-5
	IRCTN	Cyabayaga, Rwanda	No. 11, B4574b-Sr-4, IR13045-104-1
Bacterial blight	IRYN-VE	Los Baños	BG731-2, IR32429-47-3-2-2
		Suphanburi, Thailand	IR39357-133-3-2-2-2
		Van Dien, Vietnam	C1158-7, IR29692-117-1-2-2, IR31779-19-3-3-2-2, IR31787-16-1-2-3-2, IR31787-85-3-3-3-2, IR39357-133-3-2-2-2, IR50
		R. S. Pura, India	IR66, IR39357-133-3-2-2-2, IR41996-118-2-1-3
		Kankai, Nepal	C1158-7, IR66, IR39357-133-3-2-2-2
	IRYN-E	Nanjing, China	IR31802-48-2-2-2, S818b-10-2
		Bumbong Lima, Malaysia	Chianung sen yu 26, SPRLR76102-26-1-1
		Jhapa, Nepal	Chianung sen yu 26, C711097, IR32843-92-2-2-3
	IRYN-M	Bumbong Lima	BG380-2, B4183b-Si-33-6-1-2, DR31, IR19661-150-2-2-2-1, IR25604-99-1-3-2-2, IR27316-32-3-2, IR68, IR31809-83-3-2-2, IR42, OR447-20, Seberang, S499b-28
		Los Baños	C1333-4, RNR3070
		Van Dien	C1333-4, C1359-8, DR31, IR42, Seberang
		Kankai	IR19661-150-2-2-2-1, IR70, UPR254-85-1-TCA3
	IRRSWYN-E	Parwanipur, Nepal	IR31429-18-4-2, IR31429-20-2-3, IR4563-1-1-3-6-1E-P1, KKN7205-35-1-SKN-1-1
	IRRSWYN-M	Los Baños	IR29337-36-3
		Phrae, Thailand	BRB34-74-3, IR14497-15-2, IR29337-36-3
		Patna, India	IR29337-36-3
	IURYN-M	Los Baños	IAC220/79, IRAT110, IR26957-86-2
		Cuenca, Philippines	B3622e-Tb-5-4-4, B3906F-13-13-ST-37, IAC220/79
	IRON	Los Baños	KK9-6-B, AC1182, IR24632-206-3-2-2, B4354g-Pn-4, IR48, B4356F-Mr-13-1, IR28154-101-3-2, RP2136-43-2
		Raipur, India	IR32429-115-3-2-6, IR58, IR39385-20-1-2-1-1, IR50, AC1182, AC800, B3894-40d-Pn-5-1, B4403-F-Mr-17-1, B5322b-Pn-1-Sm-83, IR24632-206-3-2-2, Suweon 341, BG951, B4070d-Pn-199-43, B4354g-Pn-75, B4356F-Mr-13-1, B4368F-Mr-13-3, B5183d-56-Mr-2-3, IR28154-101-3-2, IR32720-138-2-1-1-2, IR32829-5-2-2, IR34686-179-1-2-3, IR35353-94-2-1-3, IR39323-110-5-2-2, KK15-23-C, P2025F4-159-3-1B, RP967-4-7-2-7, S499b-28
	IURON	Joydebpur, Bangladesh	BG367-7, TOX1010-21-5-12-4, TOX955-202-2-101-1-1, BG621-9, 30-TV, Singkarak, S431b-5-1, 7 Canuto
	IRDWON	Patna	IR29159-16-2-1-3, IR31338-30-2-1, IR38787-26-6-1-3, IR38787-26-6-4-2, IR38787-26-6-6-1, IR39536-1-3-5-1-1-1
Sheath blight	IRYN-VE	Los Baños	IR41985-111-3-2-2
		Van Dien	BAU148-27, BG731-2, IR39357-133-3-2-2-2
	IURYN-M	Los Baños	B3622e-Tb-5-4-4, B3906F-13-13-ST-37, IR26957-86-2, RP1674-4038-78-4
		Vinh, Vietnam	B3622F-Tb-14-2, RP1674-4038-78-4
	IRON	Los Baños	IR29725-117-2-3-3, IR39357-133-3-2-2-2, RP1669-1529-4254, RP18987-3790-30-1, IR39357-91-3-2-3, L201, B4354g-Pn-75, RP825-45-1
	IURON	Los Baños	Gu Meuang Luang, 30-TV, BR160-2B-4-8-HR-8, IR13754-12-3, IR26957-86-2, IR27078-11-6, IR29429-B-3-B-2-7

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Table 2 continued.

Disease	Nursery[a]	Location	Entries
Rice tungro virus	IRYN-VE	Los Baños	IR32429-47-3-2-2
	IRYN-E	Los Baños	C711097, IR25861-153-1, IR31805-20-1-3-3, IR34615-4-2-3, SPRLR76102-26-1-1, S818b-10-2, Taichung sen yu 223
	IRYN-M	Bumbong Lima	C1333-4, C1359-8, IR19661-150-2-2-2-1, IR25604-99-1-3-2-2, IR68, IR70, IR42, S992b-Pn-8-2
		Los Baños	IR19661-150-2-2-2-1
	IRRSWYN-E	Los Baños	BRB11-461-1
	IRRSWYN-M	Los Baños	IR31432-8-6
	IRRSWON	Los Baños	CN834-1-2-1-9, IR18272-27-3-1, IR31429-14-2-3, IR31429-20-2-3, MRC8009-3536, BR51-291-3-22, IRAT116, IR13146-45-2-3, IR13149-71-3-2-3, IR21064-48-2-1E-P1, IR26933-16-2-3, IR28384-21-2, IR28526-44-1-1, IR31432-1-2, IR31432-2-3, IR33238-25-2-3-2, IR33356-22-3-1-2, IR9217-6-2-2-2-3, ITA231, RP1486-846-1, RP1579-1863-73-32-53, SPR7419-203-3-1, SPT7106-2-3-3-1, 177D, 3000
Brown spot	IRYN-E	Ebano, Mexico	Chianung sen yu 26, C711097, DR32, IR35366-40-3-3-2-2
	IRON	Rewa, India	Suweon 339
	IURON	Rewa	BG367-7, KMP34, Rajendra, Tella Hamsa, TOX1010-21-5-12-4, TOX955-202-2-101-1-1, IAC118/81, IAC150/76, IRAT112
Sheath rot	IRYN-E	Comilla, Bangladesh	IR35366-40-3-3-2-2, Lei Zhong 124, SPRLR76102-26-1-1
	IURYN-E	Cuenca	B3622e-Tb-5-4-4, B3622F-Tb-14-2, IR26957-86-2, IR27078-11-2, Pankaj, IR43
	IURYN-M	Cuenca	ADT31, BG367-4, CR222-MW10, IR10198-66-2, TNAU6464
		Santo Tomas	ADT31, CR222-MW10, IET1444
	IURON	Los Baños	Tella Hamsa, TOX1010-21-5-12-4, Rangpur, Addey, BR160-2B-4-8-HR8, IR26957-86-2, IR29429-B-3-B-2-7, UPLRi-5, Salumpikit
		Santo Tomas	AUS257, ITA256, 30-TV, BR111-140-1-1, B3906d-14-ST-16-48-3, CICA8, GH319, IR12979-24-3-4, IR13754-12-3, IR29429-B-3-B-1-4, IR29429-B-3-B-2-7, PR206, Tondano, 7 Canuto
		Hawalbagh	VRS129-1-1
Bacterial leaf streak	IURYN-E	Los Baños	IRAT133, IR10198-66-2, RP1899-1689-98, TNAU6464
		Cuenca	IR25588-7-3-1, IR9729-67-3, RP1140-28-3-3-6, RP1899-1689-98, TNAU6464
	IURYN-M	Los Baños	Bala Late Mutant, IAC220/79, IRAT110, IRAT141
Glume discoloration	IURYN-E	Pounichak, India	ADT36, IRAT133, IR10198-66-2, IR25588-7-3-1, IR9729-67-3, IET1444
		Ibadan	IR10198-66-2
	IURYN-M	Ibadan	B3622F-Tb-14-2, IR26957-86-2

[a] IRYN-VE = International Rice Yield Nursery-Very Early, IRYN-E = International Rice Yield Nursery-Early, IRYN-M = International Rice Yield Nursery-Medium, IRRSWYN-E = International Rice Rainfed Shallow Water Yield Nursery-Early, IRRSWYN-M = International Rice Rainfed Shallow Water Yield Nursery-Medium, IURYN-E = International Upland Rice Yield Nursery-Early, IURYN-M = International Upland Rice Yield Nursery-Medium, IRON = International Rice Observational Nursery, IRRSWON = International Rice Rainfed Shallow Water Observational Nursery, IURON = International Upland Rice Observational Nursery, IRDWON = International Rice Deepwater Observational Nursery, IRCTN = International Rice Cold Tolerance Nursery.

BACTERIAL DISEASES

Plant Pathology and Plant Breeding Departments, International Rice Germplasm Center (IRGC); and International Rice Testing Program

Bacterial blight (*Plant Pathology, Plant Breeding, IRGC, and IRTP*). *Screening (Plant Pathology, Plant Breeding, IRGC, and IRTP*). In 1988, we tested and screened 77,546 entries for resistance to races 1 and 2 of the bacterial blight (BB) pathogen. These materials composed the bulk of the pedigree nurseries and replicated yield trials for the various ecosystems in both wet season (WS) and dry season (DS) (Table 3).

Resistance of GEU elite lines (Plant Pathology). Reactions of 51 WS elite lines (1988) were compared with those of differential varieties against four races of the BB pathogen. Test plants were clip-inoculated at maximum tillering with a suspension of *Xanthomonas campestris* pv. *oryzae* (Xco) at a concentration of 10^9 cells/ml.

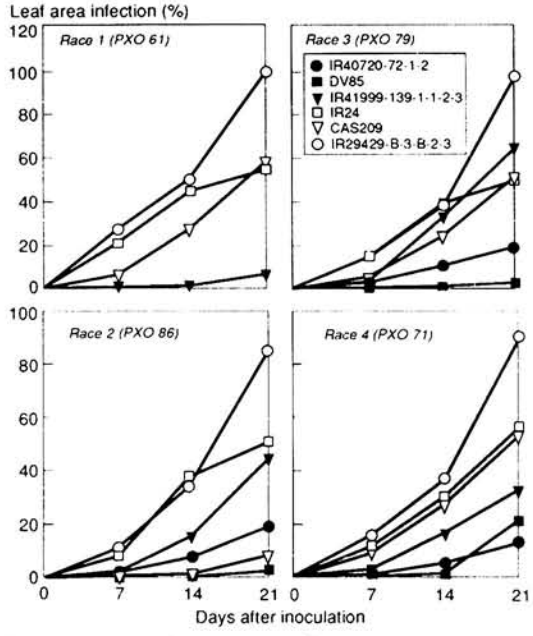
Table 3. Summary of screening for resistance to BB races 1 and 2 in the Philippines. IRRI, 1988.

Nursery	Entries (no.) tested against	
	Race 1	Race 2
Hybridization block (DS)	273	272
Hybridization block (WS)	302	304
Irrigated replicated yield trial	400	400
Irrigated observational yield trial (DS)	656	656
Irrigated observational yield trial (WS)	549	564
Rainfed lowland replicated yield trial (DS)	400	400
Rainfed lowland replicated yield trial (WS)	100	100
Rainfed lowland observational yield trial (DS)	884	884
Rainfed lowland observational yield trial (WS)	953	930
Deepwater observational yield trial (DS)	235	235
Deepwater observational yield trial (WS)	660	661
Germplasm bank	2,400	–
Tissue culture plants	58	–
Chinese varieties and lines	2,962	–
IRTP nurseries	590	–
Pedigree nurseries	49,748	10,970
Total	61,170	16,376

The percentage of leaf area infection was recorded at 7, 14, and 21 d after inoculation (DAI) (Fig. 1). For the analyses, the area under the disease progress curve (ADPC) was calculated. The relative area under the disease progress curve (RADPC) was also taken to normalize the ADPC.

None of the elite lines possessed resistance similar to that of DV85 against the four races (Table 4). Only IR40720-72-1-2 was more resistant than DV85 to PXO 71 at 21 DAI. Compared with susceptible check IR24, some entries were more susceptible to the 4 races at 21 DAI, namely, IR32453-20-3-2-2, IR27069-B-53-B-B-1-2-1, and IR29429-B-3-B-2-3. The resistances of entries with similar disease ratings at 21 DAI were differentiated using ADPC and RADPC.

Genetic resistance of selected IR varieties to bacterial blight races (Plant Pathology). Many IR varieties carry the *Xa-4* gene for resistance to race 1 of the BB pathogen but are moderately susceptible to race 2, the prevalent race in the Philippines. Initial analysis showed that these varieties appear to have background resistance (Annual report for 1987). Three widely planted IR varieties – IR60, IR54, and IR36–were used for genetic study



1. Lesion progression in selected GEU elite lines—compared with that in DV85, CAS209, and IR24—infected with 4 races of *Xanthomonas campestris* pv. *oryzae*. IRRI, 1988.

Table 4. Reaction of selected elite lines and differential varieties to 4 races of BB.[a] IRRI, 1988.

Entry	PXO 61				PXO 86				PXO 79				PXO 71			
	LAI		ADPC	RADPC	LAI		ADPC	RADPC	LAI		ADPC	RADPC	LAI		ADPC	RADPC
	14 DAI	21 DAI			14 DAI	21 DAI			14 DAI	21 DAI			14 DAI	21 DAI		
DV85	1.0	6.2	32.2	1.5	1.0	2.8	20.3	1.0	1.0	3.4	22.4	1.1	1.9	21.5	92.0	4.4
IR40720-72-1-2	1.4	6.5	36.5	1.7	7.9	19.0	128.1	6.1	11.5	19.5	161.3	7.7	5.0	13.0	84.0	4.0
IR1545	1.6	6.5	39.5	1.9	3.2	9.4	59.5	2.8	1.4	5.1	31.8	1.5	26.0	42.0	344.8	16.4
IR41999-139-1-1-2-3	1.7	6.4	39.2	1.9	15.0	44.5	269.1	12.0	33.5	66.0	480.2	22.9	16.0	31.5	232.8	11.1
IR41985-98-3-1-3-2	3.0	6.0	45.5	2.2	15.7	26.0	215.6	10.3	23.5	33.0	296.8	14.1	11.9	20.5	191.8	9.1
IR34686-179-1-2-1	3.0	9.0	95.7	4.5	24.5	63.5	408.1	19.4	28.0	61.0	451.5	21.5	10.4	20.5	183.0	8.7
IR33059-26-2-2	3.6	5.3	47.3	2.3	4.7	13.5	134.8	6.4	16.0	29.0	248.5	11.8	7.2	12.5	108.8	5.2
IR32809-26-3-3	4.0	6.4	53.9	2.6	26.5	50.0	395.1	18.8	27.0	36.0	355.3	16.9	13.0	27.5	210.4	10.0
IR32453-20-3-2-2	22.5	56.5	407.8	19.4	18.5	63.5	368.2	17.5	26.5	80.0	519.8	24.8	26.0	85.0	533.0	25.4
CAS209	27.5	57.0	412.3	19.6	1.3	6.7	36.0	1.7	25.5	50.5	376.9	17.9	26.0	52.5	397.6	18.9
IR27069-B-53-B-B-1-2-1	28.0	78.0	542.5	25.8	22.5	75.0	431.9	20.6	25.5	67.0	456.8	21.8	30.5	64.0	483.0	23.0
IR24	45.0	55.0	582.8	27.8	38.7	51.0	474.3	22.6	40.0	49.5	507.5	24.2	30.0	56.5	446.3	21.3
IR29429-B-3-B-2-3	49.5	100.0	791.0	37.7	34.5	85.5	579.3	27.6	38.5	99.5	670.3	31.9	35.5	90.5	619.5	29.5

[a] LAI = leaf area infection, DAI = days after inoculation, ADPC = area under the disease progress curve, RADPC = relative area under the disease progress curve.

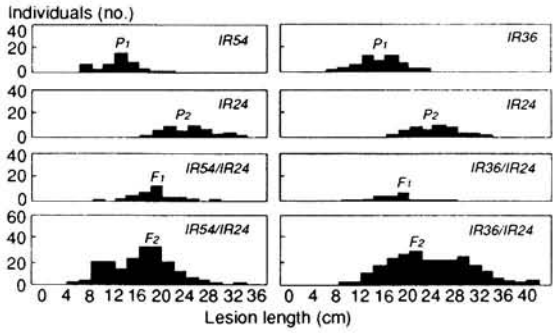
of the two races. Using IR24 as the susceptible (S) parent, segregation for resistance in F_2 populations from the crosses IR60/IR24, IR54/IR24, and IR36/IR24 showed discrete bimodal distribution against race 1 (Fig. 2). As the F_1 plants were resistant (R), the reaction of the F_2 fitted a 3R:1S segregation ratio, indicating that resistance to race 1 (PXO 61) is qualitatively inherited through a single dominant gene (Table 5). Against race 2 (PXO 86), however, the F_1 plants were intermediate in reaction. The progenies of the F_2 populations did not show a discrete distribution pattern, but rather a continuous variation in susceptibility (Fig. 3). The genotypes could not be classified into small qualitative groups. The data suggest that the moderate susceptibility to race 2 in IR60, IR54, and IR36 is quantitative and polygenic. The broad sense heritability was estimated in the range of 40-625. IR36/IR24 had the highest percentage, while IR60/IR24 had the lowest (Table 6).

2. Frequency distribution of lesion lengths of P_1, P_2, F_1, and F_2 populations from crosses IR60/IR24 and IR54/IR24 with PXO 61 (race 1) of *Xanthomonas campestris* pv. *oryzae*. IRRI, 1988.

Table 5. Reactions of plants in F_1 and F_2 populations from crosses between resistant (R) and susceptible (S) IR cultivars for resistance to isolate PXO 61 of Xco.[a] IRRI, 1988 WS.

Cross	F_1			F_2		
	n	Reaction (cm)	R (n)	S (n)	χ^2 (3:1)	P-value (3:1)
IR60/IR24	38	R (1.5)	165	66	1.39	0.25-0.10
IR54/IR24	34	R (4.8)	139	60	2.55	0.25-0.10
IR36/IR24	21	R (2.2)	164	72	3.52	0.10-0.05

[a] n = number of individuals.



3. Frequency distribution of lesion lengths of P_1, P_2, F_1, and F_2 populations from crosses IR54/IR24 and IR36/IR24 with PXO 86 (race 2) of *Xanthomonas campestris* pv. *oryzae*. IRRI, 1988.

Table 6. Heritability estimates of moderate susceptibility to Philippine isolate PXO 86 of Xco for the crosses between moderately susceptible and highly susceptible cultivars. IRRI, 1988 WS.

Cross	h^2 (%)
IR60/IR24	40.0
IR54/IR24	59.5
IR36/IR24	62.4

Evaluation of resistance of near-isogenic lines to races of Xanthomonas campestris pv. oryzae (Plant Pathology). The IRRI-Ministry of Agriculture, Forestry, and Fisheries (Japan) collaboration has produced near-isogenic lines with monogenic resistance to BB. IR24, Tohonishiki, and Milyang 23 were used as recurrent parents. Tests at maximum tillering (43 d after seeding [DAS]) and booting (74 DAS) in the screenhouse indicated clearcut differentiation and specificity among lines and races (Table 7). The line carrying the adult plant resistance gene (*Xa-3*) showed resistance to all races except race 6 at booting. The interactions between the near-isogenic lines and races were comparable to those of BB differential varieties and races.

Bacterial leaf streak (*Plant Pathology*). *Resistance evaluation*. The levels of resistance and susceptibility of some rice cultivars at the seedling stage to isolate BLS 335 were studied in the greenhouse. The cultivars were inoculated at 30 DAS with the bacterium at a concentration of 10^7 cells/ml.

The reaction based on percentage of leaf area infection at 3, 6, and 9 DAI showed varietal differences, with CNA4206 having no infection by the isolate (Table 8). IR66 and IR52 showed the most severe reaction at 3 DAI but were not statistically different from IR48 and IR50 at 9 DAI. Only CNA4206 was statistically different from the rest of the test entries based on incubation period and latent period.

At maximum tillering, selected cultivars were screened with BLS 335 at a concentration of 10^7 cells/ml (Table 9). CNA4206 had no infection; IR52 and IR48 gave the highest leaf area infection at 14 and 21 DAI.

Table 7. Interaction of isolines for BB at maximum tillering (MT) and booting (B) with races of *Xanthomonas campestris* pv. *oryzae* in the Philippines. IRRI, 1988 DS.

Isoline	Lesion length[a] (cm)											
	Race 1		Race 2		Race 3		Race 4		Race 5		Race 6	
	MT	B	MT	B	MT	B	MT	B	MT	B	MT	B
IR24[b]	33.0	23.5	33.4	16.8	25.5	19.6	32.7	29.3	14.5	8.38	42.3	31.0
Xa-4	4.8	4.9	31.3	16.5	23.8	18.9	13.2	11.7	4.8	1.9	39.4	24.0
Xa-10	33.0	21.4	2.0	0.6	25.7	16.7	33.0	27.7	1.4	0.6	40.5	27.9
xa-5	4.3	1.3	5.8	1.5	4.2	1.5	19.2	10.9	4.1	1.5	31.6	14.4
Xa-7	14.6	0.5	2.7	0.4	1.1	0.6	32.8	25.0	3.2	0.5	33.0	26.9
Xa-3	28.8	4.9	24.0	3.6	16.0	1.2	22.3	3.6	9.5	2.6	44.8	31.1
xa-8	20.8	12.9	24.6	9.4	22.3	12.6	28.6	24.6	6.9	6.5	27.0	10.8

[a] Mean of 15 leaves per line. [b] Recurrent parent.

Table 8. Percentage of leaf area infection on selected varieties against BLS 335 inoculated at the seedling stage at 10^7 cells/ml. IRRI, 1988.

Variety	Leaf area infection (%)			Incubation period (d)	Latent period (d)
	3 DAI	6 DAI	9 DAI		
IR66	68.8 a	72.0 a	83.8 a	2 a	3 a
IR52	68.2 a	81.5 a	82.5 a	2 a	3 a
IR48	59.3 b	75.3 a	74.6 ab	2 a	3 a
IR50	58.0 b	73.7 a	75.6 ab	2 a	3 a
IR46	51.8 c	74.7 a	67.7 b	2 a	3 a
IRAT177	12.8 d	29.2 b	28.5 c	2 a	3 a
IRAT104	11.2 d	22.8 b	20.7 c	2 a	3 a
CNA4206	0.0 e	0.0 c	0.0 d	0 b	0 b

Table 9. Percentage of leaf area infection on selected varieties against BLS 335 at 10^7 cells/ml at maximum tillering. IRRI, 1988.

Variety	Leaf area infection (%)		
	7 DAI	14 DAI	21 DAI
IR48	12.0	17.9	23.0
Agulinha	11.0	17.8	22.9
IR52	10.6	18.1	23.7
IR66	9.6	8.1	17.7
IR46	8.7	16.3	20.5
IR60	4.5	8.2	9.8
Palawan	3.8	13.0	21.8
Agulhao	3.4	6.4	7.9
IR64	2.7	3.8	6.6
IR54	2.6	4.1	3.4
IR50	2.6	7.8	6.4
IR56	2.5	3.7	2.8
AUS196	2.4	6.1	6.9
UPLRi-7	1.3	3.5	4.8
IR62	1.3	4.7	4.9
IR58	0.9	2.3	3.1
CNA4217	0.3	0.9	0.5
IRAT104	0.2	0.5	0.5
IRAT13	0.1	0.1	0.3
IRAT177	0	0.1	0.4
CNA4206	0	0	0

FUNGAL DISEASES

Plant Pathology and Plant Breeding Departments; International Rice Testing Program; and Wageningen Agricultural University, Netherlands

Blast (*Plant Pathology and Plant Breeding*). *Screening* (*Plant Pathology and Plant Breeding*). During 1988, 120,386 materials from the GEU program, national programs, the International Rice Germplasm Center (IRGC), and IRTP were tested for blast (Bl) resistance in the IRRI nursery (Table 10).

Table 10. Source and number of materials tested in the IRRI blast nursery, 1988.

Source		Entries (no.)
F_2		21,330
Pedigree nurseries		88,139
Irrigated lowland	52,431	
Rainfed lowland	19,400	
Deepwater	16,308	
Yield trials, elite lines, hybridization block, and tissue culture-derived plants		6,182
National programs		2,445
IRGC accessions		1,171
IRTP nurseries		1,119
Total		120,386

As in the previous years, populations of diverse races of the Bl fungus *Pyricularia oryzae* virulent on Carreon, UPLRi-5, and IR442-2-58 were being maintained in the nursery to enhance the effectiveness of resistance screening.

Evaluation of GEU elite lines (Plant Pathology and Plant Breeding). Using an upland nursery miniplot technique, DS elite lines were evaluated for Bl resistance relative to the partially resistant check IR36 and the susceptible check IR50. The RADPC and percentage of diseased leaf area (DLA) at the final scoring were used as measures of resistance. Eight of the elite lines and IR42 showed slow disease progress similar to that of IR36, probably indicating similar levels of partial resistance to Bl (Table 11). Lines with resistance similar to that of IR36 will likely have sufficient resistance in lowland fields. Unlike in some previous tests, IR66 showed high susceptibility.

Table 11. Relative area under disease progress curve (RADPC) and percentage of diseased leaf area (DLA) of GEU elite lines and IR varieties evaluated for resistance to Bl in upland nursery miniplots.[a] IRRI, 1988.

Line or variety	RADPC	DLA (%)
IR39323-182-2-3-3-2	0.01	0.04
IR44530-41-1-2-1	0.03	0.07
IR44660-115-2-1-2-2	0.04	0.07
IR37721-9-2-1-3	0.05	0.10
IR42015-83-3-2-2-2	0.05	0.10
IR44526-47-3-2-2	0.05	0.10
IR42068-22-3-3-1-3	0.12	0.30
IR41993-131-2-3-1	0.20	0.50
IR39357-133-3-2-2-2	0.22	0.67
IR48566-147-3-1-3	0.22	0.67
IR10147-113-5-1-1-5	0.33	0.57
IR33043-46-1-3	0.36	1.33
IR5931-113-1	0.40	0.83
IR41996-163-2-1-2	0.42	1.00
IR41999-139-1-1-2-3	0.42	0.90
IR32429-47-3-2-2	0.45	1.33
IR32453-20-3-2-2	0.63	2.67
IR39368-31-1-2	0.71	2.00
IR33059-26-2-2	1.02	4.67
IR41985-111-3-2-2	1.43	4.67
IR54	1.53	6.00
IR41996-118-2-1-3	1.56	6.00
IR35366-28-3-1-2-2	1.60	7.33
IR41985-98-3-1-3-2	1.79	5.33
IR41985-77-3-3-3	2.25	8.00
IR29723-88-2-3-3	2.37	6.00
IR29429-B3-B-2-3	2.55	10.67
IR33238-25-2-3-2	2.86 PR	13.33 PR
IR46323-26-1-3	2.93 PR	12.33 PR
IR42028-50-2-1-3-2-2	3.29 PR	13.00 PR
IR26957-86-2	3.37 PR	15.67 PR
IR40720-72-1-2	3.47 PR	15.00 PR
IR36 (partially resistant check)	4.19 PR	20.00 PR
B4259-48-1-1-3	4.23 PR	21.33 PR
IR37873-16-2-3-3-3-1	4.75 PR	18.33 PR
IR42	4.84 PR	24.00 PR
IR39357-71-1-1-2-2	5.64 PR	30.33
IR64	5.91	28.33 PR
IR13754-5-2	6.48	26.00 PR
IR41996-12-2-2-3	6.59	26.00 PR
IR35366-90-3-2-1-2	7.09	33.33
IR34686-179-1-2-1	7.56	35.67
IR41996-50-2-1-3	8.18	40.33 S
IR35366-62-1-2-2-3	8.63	33.33
IR42029-38-1-3-3-2	8.98	34.67
IR42000-211-1-2-2-3	9.10	33.33
IR50 (susceptible check)	12.89 S	61.67 S
IR40931-33-1-3-2	14.74 S	57.67 S
IR19431-72-2	17.68 S	75.00 S
IR35346-47-3-2-2	18.16 S	70.67 S
IR32809-26-3-3	21.73	82.00 S
IR66	25.55	90.00 S

[a]Mean of 3 replications. Figures followed by PR are not significantly different from the partially resistant IR36; those followed by S are not significantly different from the susceptible check IR50.

Agronomic value of partial resistance (Plant Pathology). It is uncertain to what degree partial resistance (PR) to Bl can prevent yield loss under field conditions favoring the disease. The objective of this series of experiments was to determine if PR could prevent high grain yield loss in temperate and tropical rice environments. This study was part of the IRRI-Rural Development Administration collaborative roject and was done at irrigated sites in Incheon, Korea, and Magdalena, Laguna, Philippines, in 1987 and 1988.

In 1987 in Korea, the partially resistant variety Seomjin and the susceptible varieties Chuchcong and Daechang were evaluated at 2 N levels (110 and 220 kg N/ha) in 2.0- × 3.0-m field plots. In the Philippines, the partially resistant IR36, the moderately susceptible IR66, and the susceptible IR50 were tested in 4.0- × 9.0-m plots.

Another partially resistant variety, Bonggwang, was added to the Korean trial in 1988, and the test was conducted in larger plots (2.7 × 8.0 m) and with 240 kg N/ha. In all experiments, both fungicide-protected and unprotected plots were included so that effects of Bl on yield could be measured. Bl was allowed to develop naturally in the unprotected plots in Korea in 1987. In 1988, the plots were inoculated with an isolate of *P. oryzae* that was virulent to all of the test varieties. The field plots in the Philippines were inoculated by placing infected seedlings of IR442-2-58 in plastic trays at the center of the plot. After the first lesions appeared in the plots, the trays were removed.

Leaf Bl was scored by making visual estimates of the percentage of DLA. Panicle Bl evaluation in Korea was based on spikelet and panicle branch symptoms, since these are easier to score than neck node infection under Korean conditions. In the Philippines, only panicles with severe infection at the panicle neck node were included for computing the incidence of infection, because spikelet infection is difficult to score under Philippine conditions.

At the peak of epidemic development in 1987, variety Chucheong showed 4.0% DLA and Daechang 4.5% at the 220 N level in unprotected plots (Table 12). Seomjin had only a few sporulating lesions in 1987, but showed more lesions in 1988 (Table 12). High panicle Bl infection occurred in the unprotected plots in both years at

Table 12. Percentage of diseased leaf area (% DLA) due to Bl and relative area under the disease progress curve (RADPC) of Korean varieties in protected and unprotected plots.[a] 1987-88.

Variety	Protected		Unprotected	
	RADPC	Highest % DLA	RADPC	Highest % DLA
	1987, 110 kg N/ha			
Seomjin	0.01 a	0.1 a	0.02 b	0.1 b
Daechang	0.03 a	0.1 a	0.13 a	0.5 a
Chucheong	0.03 a	0.1 a	0.14 a	0.6 a
	1987, 220 kg N/ha			
Seomjin	0.01 c	0.0 c	0.02 b	0.0 c
Daechang	0.23 a	1.6 a	0.63 a	4.5 a
Chucheong	0.17 b	0.9 b	0.67 a	4.0 b
	1988, 240 kg N/ha			
Seomjin	0.02 a	0.1 a	0.10 a	0.2 a
Bonggwang	0.04 a	0.1 a	0.40 a	1.5 a
Daechang	0.04 a	0.2 a	0.51 a	0.8 a
Chucheong	0.05 a	0.2 a	0.41 a	1.7 a

[a] In a column within a treatment, means having a common letter are not significantly different at the 5% level by DMRT (1987) or LSD (1988). Maximum possible RADPC value = 100.

high N levels (Table 13). Application of fungicide lowered the disease incidence and consequently increased yield.

In the Philippines, IR50 exhibited much higher panicle Bl than did IR36 or IR66 in the unprotected plots in 1987, but the disease was low in all the treatments in the 1988 trial (Table 14). Yield loss was observed only on IR50 in 1987.

Thus, under conditions where the susceptible variety IR50 exhibited only moderate disease, such as in the 1987 Philippine trial, the resistance of IR36 and IR66 was sufficient to prevent yield loss. Conditions in Korea were much more favorable for Bl, and only the partially resistant variety Seomjin did not show high grain yield losses. The partially resistant Bonggwang showed higher losses, and future experiments will focus on understanding in detail how the PR of Bonggwang and Seomjin differ.

Effects of leaf age on partial resistance (Plant Pathology and Wageningen Agricultural University, Netherlands). Bl appears to be a disease of young plant parts, since plant tissues become increasingly resistant when they grow older. This resistance seems to be generally present in rice and differs in mechanism from the resistance controlled by major genes. PR is being studied in detail through a collaborative project with the Institute of Plant Breeding, Wageningen Agricultural University, Netherlands.

Although leaves become more resistant with age, it is not known if the time during which newly formed leaves remain susceptible varies with genotype.

Table 13. Percentage of severe panicle Bl infection and grain yield of Korean varieties in the protected and unprotected plots.[a]

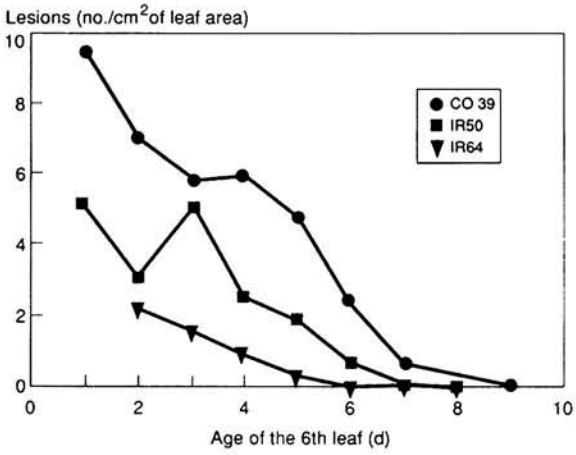
Variety	Protected		Unprotected		Yield loss (%)
	Panicle Bl (%)	Yield (t/ha)	Panicle Bl (%)	Yield (t/ha)	
		1987, 110 kg N/ha			
Seomjin	0.0 b	6.6 a	0.0 c	6.9 a	–4.5
Daechang	11.7 a	6.2 a	64.8 a	5.4 b	12.9
Chucheong	4.6 ab	6.1 a	50.1 b	5.4 b	11.5
		1987, 220 kg N/ha			
Seomjin	0.0 c	6.5 a	0.0 b	6.6 a	–1.5
Daechang	49.6 a	4.7 c	98.2 a	2.4 c	48.9
Chucheong	14.6 b	5.8 b	90.2 a	3.7 b	36.2
		1988, 240 kg N/ha			
Seomjin	0.0 c	6.6 a	0.0 d	6.2 a	6.1
Bonggwang	4.6 b	6.0 a	43.1 c	4.2 b	30.0
Daechang	14.8 a	6.6 a	99.8 a	3.3 b	50.0
Chucheong	1.2 bc	6.1 a	75.8 b	4.0 b	34.4

[a] In a column within a treatment, means having a common letter are not significantly different at the 5% level by DMRT or LSD (1988 neck Bl).

Table 14. Percentage of severe panicle BI infection and grain yield of 3 IR varieties in inoculated and protected plots.[a] Magdalena, Laguna, Philippines, 1987-88.

Variety	Protected		Inoculated		Yield loss (%)
	Panicle BI (%)	Yield (t/ha)	Panicle BI (%)	Yield (t/ha)	
		1987			
IR50	0.8 a	3.7 b	28.3 a	3.0 c	18.9
IR36	0 a	3.4 b	1.0 b	3.4 b	0
IR66	0 a	4.2 a	0.5 b	4.2 a	0
		1988			
IR50	0 a	3.8 a	2.5 a	3.7 a	2.6
IR36	0.2 a	4.3 a	0.4 b	4.4 a	-2.3
IR66	0.4 a	4.2 a	3.0 a	4.1 a	2.4

[a] In a column within a year, treatment means having a common letter are not significantly different at the 5% level by DMRT (1987) or LSD (1988).



4. BI susceptibility on the 6th leaves of 3 rice genotypes as a function of leaf age. IRRI, 1988.

To ascertain if genotypic differences exist in the development of leaf age-dependent resistance, 10 rice genotypes were grown in the greenhouse. Pure seed was obtained by controlled selfing of a single plant for three generations. The varieties and lines were planted 3 times during 5 d to obtain a series of plants that differed slightly in development stage. The plants were raised in pots with aerobic soil and were inoculated with a virulent isolate when most of them reached the 7-leaf stage. To know the age of each leaf more precisely, the date of emergence of the fifth, sixth, and seventh leaves on the main tiller was recorded. The age of a particular leaf at inoculation was defined as the number of days after the tip of the leaf became visible. The susceptibility of the leaves was measured as the number of lesions with greyish centers per square centimeter of leaf area.

Older leaves were more resistant than younger leaves, as shown for three varieties in Figure 4. Genotypic differences occurred in the period of leaf susceptibility. For example, the sixth leaves of IR64 were completely resistant after 6 d, whereas leaves of CO 39 remained susceptible for 9 d. The period during which a leaf can be infected seems to be related to the initial level of BI susceptibility.

Although genotypic differences exist for the period of susceptibility, it is not yet certain whether this trait could be useful for breeding.

Sheath blight (*Plant Pathology, Plant Breeding, and IRTP*). *Screening* (*Plant Pathology, Plant Breeding, and IRTP*). In 1988, we tested and screened 642 entries for sheath blight (ShB) resistance. The entries were from GEU elite lines, IRTP yield and observational nurseries, and previous IRTP nurseries (for confirmation) (Table 15).

Evaluation of GEU elite lines for resistance (Plant Pathology). Elite lines were tested for ShB resistance under two levels of N fertilization. Ammonium sulfate was applied in three equal splits: basal, at maximum tillering, and at booting. The test entries were inoculated at panicle initiation, and lesion height was measured weekly until maturity. Application of 120 kg N/ha resulted in higher disease severity based on lesion height.

Table 15. Summary of breeding materials and varieties screened for ShB resistance. IRRI, 1988.

Source	Entries (no.)
GEU elite lines	
Dry season	52
Wet season	52
IRTP nurseries	
IRYN	54
IRRSWYN	40
IURYN	28
IRRSWON	126
IURON	82
Confirmation tests	
1986 IRTP nurseries	72
1987 IRTP nurseries	136
Total	642

IR21573-2-1-2-2-2, IR29725-117-2-3-2, IR27316-6-2-2, M61B-132-3, and IR36 were less susceptible than IR62, the check for low ShB infection (Table 16). The disease developed faster with high N fertilization; however, these entries showed shorter lesions regardless of N level. Plant height and maturity had a significant negative correlation with lesion height.

Evaluation of resistance in wild rices (Plant Pathology and Plant Breeding). Since useful sources of ShB resistance are limited in existing rice germplasm, we evaluated a collection of wild rices for ShB resistance under field conditions. Seedlings were planted in two 50-cm rows with 5 hills/row and were spaced at 10 cm and 20 cm between hills and rows. IR58 was used as the susceptible check. Inoculum was prepared by inoculating rice hulls and grain (3:1 vol/vol) with a 7-d-old culture of *Rhizoctonia solani* grown on potato dextrose agar and incubated at room temperature for 10-14 d. At 45 and 65 DAS, about 6 ml of inoculum was placed at the center of a hill. The disease reaction was scored at 15-20 d after flowering. The lesion height in 5 randomly selected tillers per hill was measured, and the relative lesion height (RLH, lesion height/plant height × 100) was computed. Disease reaction was scored visually using a 0-9 scale as follows:

Scale	*RLH (%)*
0	0
1	1-20
3	21-30
5	31-45
7	46-65
9	>65

The reaction to *R. solani* of 110 entries from 76 wild rice accessions was tested (Table 17). Although all entries showed ShB symptoms, lesion height and RLH varied considerably among entries. Lesion height ranged from 17.9 cm (*O. minuta* 101089-1) to 75.1 cm (*O. nivara* 103840-2); RLH ranged from 18.7% (*O. minuta* 101089-1) to 85.3% (*O. barthii* 100119-4). Two entries were found to be resistant (*O. minuta* 101089-1, *O. rufipogon* 100907-2), and 34 were moderately resistant. Based on RLH, 32.7% (36/110) of the entries were considered more resistant than the susceptible check IR58. These might provide an additional source of ShB resistance for rice improvement.

Table 16. Reaction of varieties and lines to ShB at 2 N levels. IRRI, 1988.

Variety or line	Lesion height (cm)		
	120 kg N/ha	60 kg N/ha	Mean
IR21573-2-1-2-2-2	43.2 g	43.0 f-h	43.1 jk
IR29725-117-2-3-2	43.8 g	38.0 h	40.9 k
M61B-132-3	44.2 g	39.0 h	41.6 jk
IR27316-6-2-2	44.2 g	47.5 d-h	45.9 h-k
IR36	44.8 fg	42.5 gh	43.6 i-k
IR62	45.8 e-g	48.0 d-h	46.9 g-k
RP1897-3790-30-1	52.2 d-g	46.5 d-h	49.4 f-j
IR33383-23-3-3-3	53.8 c-g	50.8 c-g	52.2 d-h
IR18599-68-2-1	55.8 b-f	52.2 b-g	54.0 c-g
IR39357-91-3-2-3	56.8 b-e	54.5 a-f	55.6 c-f
IR41985-111-3-2-3	57.2 a-d	45.2 e-h	51.2 e-i
IR64	57.5 a-d	57.8 a-d	57.6 b-e
IR58	58.2 a-d	52.8 a-g	55.5 c-f
IR33356-14-3-1-3	58.2 a-d	52.5 b-g	55.4 c-f
P2030 F4-235-1B-1B	58.5 a-d	52.8 a-g	55.6 c-f
IR39357-133-3-2-2-2	63.0 a-d	60.5 a-c	61.8 a-c
L 201	63.0 a-d	54.8 a-f	58.9 a-e
IR31432-2-3	64.0 a-c	56.8 a-e	60.4 a-d
C1158-7	66.8 ab	62.5 ab	64.6 ab
P1288-1-4M-2-7B	68.8 a	64.2 a	66.5 a
Mean	54.99	51.1	53.0

VIRAL DISEASES

Plant Pathology and Plant Breeding Departments and International Rice Germplasm Center

Mass screening for tungro and grassy stunt (*Plant Pathology, Plant Breeding, and IRGC*). A total of 5,930 entries were tested by the mass screening method in the greenhouse. Of 2,362 rice accessions from the germplasm bank (GB), 6.9% showed

Table 17. Reaction of wild rices and some *Oryza sativa* varieties to the ShB pathogen *Rhizoctonia solani*.[a] IRRI, 1988.

Species and code number[b]	Plant height (cm)	Lesion height (cm)	Relative lesion height	Grade[c]
O. sativa				
IR36	82.2	42.8	52.2	7
IR31917-45-3-2	82.9	41.8	50.4	7
IR64R	70.8	35.3	49.2	7
IR58[d]	77.6	32.0	41.2	5
IR54R	80.2	23.4	28.8	3

continued on next page

Table 17 continued

Species and code number[b]	Plant height (cm)	Lesion height (cm)	Relative lesion height	Grade[c]
O. nivara				
103840-2	107.0	75.1	70.3	9
104691-1	67.4	43.2	63.6	7
104687-1	82.8	52.5	63.0	7
102174-2	67.8	42.8	62.3	7
102166-3	78.2	45.0	57.5	7
102169-1	97.5	55.6	56.4	7
102167-2	81.8	45.6	56.0	7
102167-3	80.7	45.3	55.8	7
103826-3	126.0	68.5	54.2	7
104691-2	71.4	38.7	53.6	7
102171-2	87.2	46.6	52.8	7
104705-2	99.6	51.4	51.2	7
102169-3	97.8	50.3	50.6	7
103826-2	139.2	70.4	50.4	7
103422-2	80.0	40.4	50.2	7
104697-1	70.2	35.4	50.0	7
102179-1	101.9	51.7	49.2	7
104443-1	86.3	42.8	48.7	7
103834-3	113.1	55.8	48.5	7
103834-1	120.6	59.1	48.4	7
104692-2	65.0	31.1	48.0	7
101973-2	114.1	52.2	46.3	7
103835-1	118.7	53.9	45.9	7
101994-2	102.3	45.8	43.9	5
102166-2	77.9	34.2	42.3	5
103830-1	146.3	59.8	40.7	5
103835-2	114.7	44.2	38.9	5
102174-1	71.9	27.9	38.3	5
101975-1	93.9	34.8	36.7	5
103826-1	124.0	45.6	36.5	5
104440-3	108.5	39.0	35.7	5
103422-1	86.4	31.3	35.6	5
103839-2	113.9	40.7	34.9	5
101973-3	118.0	41.2	34.8	5
104443-3	108.8	37.1	34.0	5
101975-3	95.3	32.5	33.8	5
104473-1	111.2	35.7	31.6	5
103407-1	144.2	45.2	31.0	5
103821-1	106.4	32.4	30.6	5
103422-3	127.8	39.4	30.2*	3
103835-3	119.6	36.4	30.1*	3
103840-3	126.7	36.3	29.3	3
101971-1	130.1	38.6	29.3	3
104444-1	113.9	34.1	29.3	3
104473-2	120.2	35.0	28.7*	3
101193-1	100.7	26.6	27.4*	3
103841-3	114.0	31.4	27.3** ?	3
103841-1	122.1	33.6	27.2*	3
103824-1	91.2	25.2	26.8*	3
104705-1	108.1	28.9	26.5	3
101967-1	120.4	32.2	26.5	3
101973-1	124.2	31.0	25.0*	3
100898-1	101.0	23.6	22.8**	3
O. barthii				
100119-4	63.3	54.5	85.3	9
100119-3	71.3	54.9	76.5	9
104293-2	79.0	59.4	74.5	9
101937-3	82.1	57.6	71.8	9
101248-4	68.0	47.1	68.8	9
101252a-1	91.4	56.2	61.6	7
100117-1	76.4	46.1	61.0	7
101317-2	101.5	61.6	60.6	7
101252a-2	88.2	50.6	57.8	7
101937-2	71.0	40.1	56.4	7
101317-4	80.3	44.8	56.3	7
104104-1	73.8	39.7	56.0	7
101252a-4	96.7	51.3	52.3	7
101380-3&4	79.8	39.8	51.2	7
104284-2	85.7	43.2	50.5	7
104288-1	79.1	33.7	42.5	5
100223-3	76.7	31.6	41.3	5
101381-4	111.3	44.4	39.3	5
101381-1	97.2	37.2	37.8	5
100117-2	75.6	27.3	36.8	5
100933-3	79.3	29.4	36.8	5
100933-4	74.3	25.8	35.2	5
104293-1	90.9	32.3	35.0	5
104104-2	82.5	28.9	34.5	5
104102-2	77.9	26.0	33.8	5
101317-1	98.4	31.2	32.2	5
101827-3	88.0	26.0	29.5	3
104304a-2	92.1	23.8	25.3*	3
104304a-1	95.2	22.5	23.0*	3
104304b-1	99.0	22.3	22.0**	3
101317-3	98.6	22.0	21.7**	3
O. perennis				
104765-3	94.6	65.9	69.0	9
104460-4	106.5	44.9	42.4	5
104482-4	121.2	43.3	35.5	5
100687-3	103.2	33.3	31.6	5
104765-2	172.3	34.8	30.0	3
104822-2	109.8	31.8	28.3*	3
104796-2	115.3	32.4	27.8*	3
100969-1	135.1	37.4	27.8*	3
103848-1	106.5	29.4	27.6*	3
100692-2	107.8	28.5	26.2*	3
104754-2	93.4	24.5	26.0*	3
104782-1	130.0	34.0	25.8**	3
104766a-3	124.9	31.6	24.4**	3
104642-2	86.2	19.3*	23.4*	3
104822-1	104.4	24.4	23.0*	3
O. rufipogon				
103817-1	71.9	50.8	70.0	9
100907-1	120.8	26.8	21.5*	3
100907-2	154.7	31.0	19.5*	1
O. latifolia				
100966-1	127.8	30.6	23.5*	3
100964-1	122.0	33.0	26.5	3
O. minuta				
101089-1	93.2	17.9	18.7**	1

[a] * and ** = significantly different from susceptible check IR58 at the 5% and 1% levels of significance, respectively, using the LSD test. [b] Among wild rices, the first number refers to the accession, and the second to the plant source. [c] 0 = highly resistant, 1 = resistant, 3 = moderately resistant, 5 = moderately susceptible, 7 = susceptible, 9 = highly susceptible. [d] Susceptible check.

severity scores below 4.5. These accessions will be further evaluated for their reactions to rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV).

A total of 3,056 entries were tested and screened for resistance to rice grassy stunt virus strain 2 (GSV 2) by the mass screening method. Thirty-three percent of entries showed an infection rate lower than 30%.

Tungro (*Plant Pathology, Plant Breeding, and IRGC*). We have screened more than 40,000 rice accessions from the IRGC for resistance to tungro in the last 20 yr. A total of 119 accessions that showed low levels of infection were selected for further evaluation. One-week-old seedlings were separately confined with 5 green leafhopper (GLH) adults that had fed for 3-4 d on plants infected with RTBV + RTSV or with RTSV alone. Three to four weeks after inoculation (WAI), seedlings were scored for symptom severity (Annual report for 1987). The severity score was 1 to 9 (1 = no symptoms, 3 = 1-10% height reduction with no leaf discoloration, 5 = 11-30% height reduction with no distinct discoloration, 7 = 31-50% height reduction and/or yellow orange discoloration, 9 = >50% height reduction and yellow orange discoloration). To indicate resistance levels of test cultivars, average scores were calculated.

Based on percentage of infection by RTBV + RTSV or RTSV, average severity score, and resistance score to GLH by the seedling bulk damage rating test, the accessions were divided into four groups: 1) resistant to tungro infection, 2) resistant to RTSV infection, 3) tolerant of RTBV, and 4) resistant to GLH (Tables 18-21).

Resistance to tungro infection. Six accessions had low overall infections with RTBV and/or RTSV (Table 18). Five of them had low or no RTSV infection, indicating strong resistance to RTSV. Three originated from Bangladesh, two from India, and one from Indonesia.

Resistance to RTSV. A total of 37 accessions had low RTSV infection, and 6 also had low RTBV infection (Table 18). Another 31 accessions had high RTBV infection (Table 19). Fifteen of them originated from India, 12 from Bangladesh, 4 from Indonesia, 4 from Pakistan, and 1 each from Iran and the Philippines.

Tolerance for RTBV. Nineteen cultivars had an average severity score of 4 or lower. Some of them had low scores because of low overall infection with RTBV and/or RTSV (Table 18), or low infection with RTSV (Table 19). RTSV-resistant cultivars that were also tolerant of RTBV were PI 184675-2, Habiganj DW8, ARC10312, Utri Merah, Utri Rajapan, ARC10963, ARC10980, ARC11554, ARC12596, Shuli 2, and Naria Bochi (Table 19). Five cultivars had low average severity scores but high overall infections with RTBV and/or RTSV (Table 20). Out of the 15 tolerant cultivars, 6 originated from Indonesia, 4 from India, 3 from Bangladesh, and 1 each from Iran and Thailand.

Resistance to green leafhopper. A total of 29 cultivars had GLH resistance scores of 3 or lower. Some of the GLH-resistant cultivars also had resistance to or tolerance for the tungro-associ-

Table 18. Reactions to GLH and infection with RTBV + RTSV or RTSV alone of cultivars resistant to tungro infection. IRRI, 1988.

Cultivar (accession no.)	GLH score[a]	Inoculation with RTBV + RTSV					Inoculation with RTSV	
		Plants tested (no.)	Average severity score	Plants infected (%)			Plants tested (no.)	Plants infected (%)
				RTBV+RTSV	RTBV	RTSV		
ARC10343 (12437)	9	38	3	0	3	0	30	0
Utri Merah (16680)	7	57	3	0	9	0	62	0
ARC5905 (19675)	9	39	4	0	0	0	38	0
Khoia Motor (26379)	5	40	5	0	15	0	36	11
Nedpasha (26515)	1	40	6	5	5	8	57	5
Gachia (26615)	5	39	5	0	23	0	40	0

[a] By seedling bulk damage rating test at IRRI.

Table 19. Reactions to GLH and infection with RTBV + RTSV or RTSV alone of cultivars resistant to RTSV infection. IRRI, 1988.

Cultivar (accession no.)	GLH score[a]	Inoculation with RTBV + RTSV					Inoculation with RTSV	
		Plants tested (no.)	Average severity score	Plants infected (%)			Plants tested (no.)	Plants infected (%)
				RTBV+RTSV	RTBV	RTSV		
Adday sel (177)	9	37	5	0	62	0	34	0
Binicol (4021)	1	40	6	0	73	0	32	0
Pankhari 203 (5999)	5	34	7	3	91	0	30	3
Mushkan 41 (6828)	9	34	7	0	88	0	36	0
PI 184675-2 (7366)	5	32	3	0	78	0	31	0
G378 (11062)	9	38	7	0	97	0	39	0
Habiganj DW8 (11751)	7	39	4	0	72	0	66	2
ARC6064 (12203)	5	34	5	0	94	0	36	0
ARC6080 (12207)	5	34	5	0	59	0	35	0
ARC7007 (12310)	5	37	5	0	41	0	31	0
ARC10312 (12428)	7	39	3	0	67	0	33	3
Utri Merah (16682)	7	35	4	3	54	0	61	3
Utri Rajapan (16684)	7	31	4	0	97	0	67	0
ARC10963 (19680)	9	31	3	0	97	0	36	0
ARC7140 (20533)	9	38	5	0	87	0	34	0
ARC10980 (21164)	9	37	4	3	92	0	53	0
ARC11554 (21473)	3	38	3	0	55	0	59	0
ARC12596 (22176)	5	37	3	0	89	0	40	0
Boron (26317)	7	34	5	0	97	0	33	0
Shuli 2 (26527)	9	37	4	5	95	0	37	0
Surjamukhi (26803)	3	34	6	0	56	0	38	7
Muktahar (27572)	9	37	7	0	73	0	40	0
Naria Bochi (27573)	9	37	4	0	35	0	37	3
Basmati (27782)	9	40	7	3	68	0	38	0
Basmati 375A (27827)	3	36	5	0	92	0	40	0
Basmati 376 (27828)	5	39	5	0	92	0	39	0
Gasmal 110-2 (29327)	7	31	6	3	90	0	38	0
Gasmal 735 (29349)	9	31	7	3	97	0	37	0
Cempo Obang (35588)	9	39	5	3	72	3	38	0
Kashiabinni (37488)	3	60	5	7	62	0	37	0
Ovarkondoh (49996)	9	40	7	3	83	0	40	0

[a] By seedling bulk damage rating test at IRRI.

Table 20. Reactions to GLH and infection with RTBV + RTSV or RTSV alone of cultivars tolerant of RTBV. IRRI, 1988.

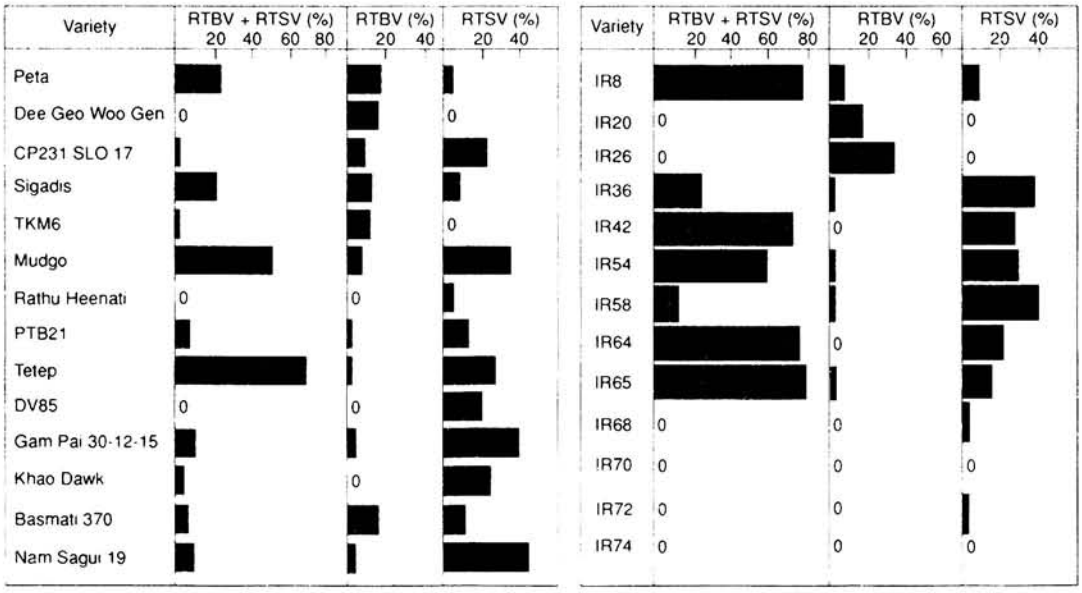
Cultivar (accession no.)	GLH score[a]	Inoculation with RTBV + RTSV					Inoculation with RTSV	
		Plants tested (no.)	Average severity score	Plants infected (%)			Plants tested (no.)	Plants infected (%)
				RTBV+RTSV	RTBV	RTSV		
Gam pai 30-12-15 (831)	1	33	4	6	42	0	64	6
Seratus Hari T36 (5346)	9	35	4	31	60	0	33	6
Tjempo Kijik (16602)	7	32	3	63	28	3	64	28
Balimau Putih (17204)	5	53	2	2	21	19	35	40
Bhoro Nepa (26311)	1	36	4	17	72	3	63	5

[a] By seedling bulk damage rating test at IRRI.

Table 21. Reactions to GLH and infection with RTBV + RTSV or RTSV alone of cultivars resistant to GLH. IRRI, 1988.

Cultivar (accession no.)	GLH score[a]	Inoculation with RTBV + RTSV					Inoculation with RTSV	
		Plants tested (no.)	Average severity score	Plants infected (%)			Plants tested (no.)	Plants infected (%)
				RTBV+RTSV	RTBV	RTSV		
Andi from n. pokhara (3707)	1	37	6	8	57	0	34	6
ASD7 (6303)	1	49	8	6	71	0	33	12
ASD8 (6393)	1	43	7	2	67	0	97	13
Su-Yai 20 (7299)	3	33	7	9	70	0	60	8
Ptb18 (11052)	1	34	7	32	47	6	37	16
ARC6608 (12293)	1	39	5	23	31	3	65	42
ARC10281 (12420)	3	39	6	28	13	28	34	18
Hathili (15195)	1	35	7	23	77	0	31	42
Hathili (15200)	1	34	6	41	59	0	31	52
RD5 (24141)	3	54	8	17	50	6	32	6
Bale Betor (26295)	1	36	5	8	19	0	68	10
Chingair (26322)	1	37	5	5	22	0	39	0
Dol Kochu 2 (26334)	1	39	6	15	13	0	36	6
Lal Amon (26498)	1	58	6	21	36	0	36	42
Nedpasha (26515)	1	40	6	5	5	8	57	5
Raj Bhawalia (26517)	1	36	5	31	61	3	34	3
Sungail (26529)	1	31	8	32	32	26	35	26
Sungwala (26530)	1	53	6	30	40	6	36	25
MK47-22 (26910)	1	30	8	43	53	0	36	69
D59-6 (33045)	3	51	7	25	25	10	37	35
Laki 1120 (37748)	3	47	8	32	56	0	30	30
TNAU736 (39855)	3	59	8	12	68	2	36	31

[a] By seedling bulk damage rating test at IRRI.



5. Field reaction of IR parents and IR varieties to RTBV and RTSV at 6 wk after transplanting. IRRI, 1988 WS.

ated viruses. GLH-resistant cultivars generally had high RTBV infection (Table 21). Of 29 cultivars, 12 originated from Bangladesh, 9 from India, 2 each from Sri Lanka and Thailand, and 1 each from Burma, China, Pakistan, and the Philippines.

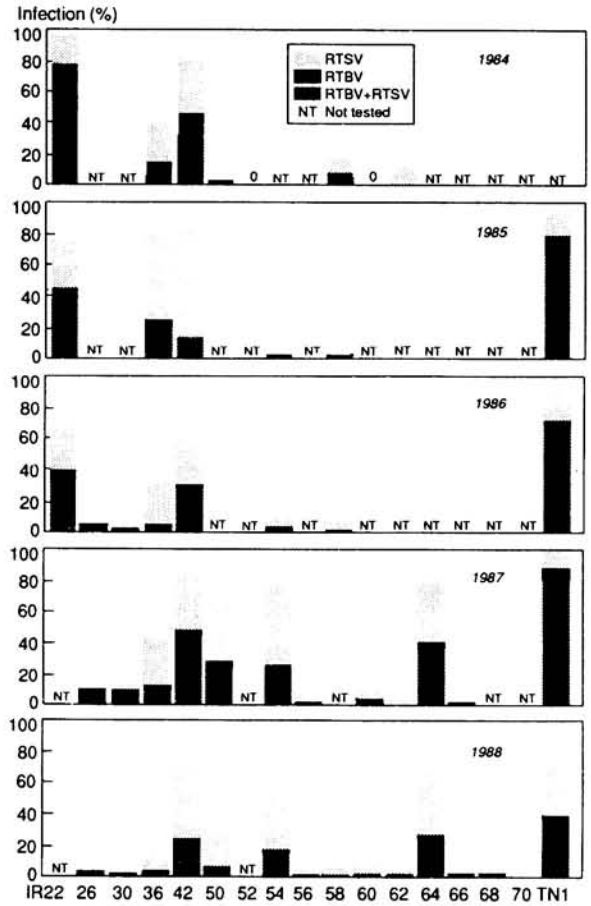
Field reactions of IR parents and progenies. In 1988 WS at IRRI, the reaction of some IR varieties and their parents to RTBV and RTSV in the field was tested. Six weeks after transplanting, leaves of 90 hills of each variety planted in 2.5- × 7.0-m plots at 20- × 20-cm spacing were randomly sampled and tested by enzyme-linked immunosorbent assay (ELISA) for the presence of RTBV and RTSV.

Dee Geo Woo Gen, TKM6, IR20, and IR26 showed no RTSV infection (Fig. 5). Rathu Heenati, DV85, and Khao Dawk showed no or very low percentage of infection with RTBV + RTSV and RTBV alone. IR68, IR70, IR72, and IR74 showed no or very low infection.

The field reaction of several IR varieties to RTBV and RTSV was determined in 1984-88 WS at IRRI. Three-week-old seedlings of the test varieties were transplanted at 20- × 20-cm distance in 2- × 2-m (1984-86) or 3- × 3-m (1987-88) plots arranged in a randomized complete block design with 4 replications. At 60 d after transplanting, leaf samples from 36-49 hills/plot were collected and indexed by serology for the presence of the tungro viruses.

In the 1984-86 trials, IR50, IR54, IR58, IR60, and IR62 showed no or low RTBV + RTSV infection. But in 1987 and 1988, IR50 and IR54 had high infection with either or both viruses. Infection of IR60 and IR62 remained low (Fig. 6). While other test varieties showed high RTSV infection, IR26 and IR30 showed none or very low infection. A change in the reaction to RTBV + RTSV of IR50 and IR54, both having Gam Pai 30-12-15 in their parentage, was observed. Similar results were obtained in South Cotabato, Philippines, and South Sulawesi, Indonesia, indicating the varieties' loss of field resistance to tungro.

Reaction of wild rices to tungro-associated viruses. Using the mass screening method, we evaluated 476 wild rice accessions from the GB for resistance to tungro. Thirty percent had average severity scores below 4.5.



6. Field reaction of IR varieties to RTBV and RTSV at 60 d after transplanting. IRRI, 1984-88 WS.

Those accessions that had low scores were further evaluated for their reactions to infection by RTBV and RTSV. Each seedling was inoculated in a test tube by 5 GLH that had fed on plants infected with RTBV + RTSV. At 3-4 WAI, all inoculated seedlings were indexed by ELISA.

Many accessions showed very low infection with RTBV and/or RTSV (Table 22). Some accessions had a high percentage of infection with RTBV and/or RTSV in the test tube inoculation but low severity scores in the mass screening method, indicating their tolerance for the RTBV + RTSV complex (Table 23).

These wild rices will also be evaluated for their resistance to RTSV by the test tube inoculation method using RTSV-infected TN1 as the virus source.

Table 22. Evaluation of wild rices for their reactions to tungro by the mass screening method and to infection with RTBV and/or RTSV in test tubes. IRRI, 1988.

Accession no.	Species or cross	Mass screening severity score	Test tube inoculation			
			Plants tested (no.)	Plants infected (%)		
				RTBV+RTSV	RTBV	RTSV
100161	*O. alta*	1.8	20	1	2	0
100168	*O. latifolia*	2.4	20	1	3	4
100169	*O. latifolia*	1.3	20	0	0	0
100877	*O. ridleyi*	1.4	20	0	1	0
100878	*O. officinalis*	3.0	20	1	1	0
100882	*O. australiensis*	1.9	20	2	0	0
100883	*O. officinalis*	2.0	19	1	2	0
100884	*O. punctata*	2.3	20	2	4	0
100886	*O. punctata*	2.1	20	2	0	1
100890	*O. latifolia*	2.0	20	1	1	3
100891	*O. latifolia*	0	20	0	0	1
100895	*O. latifolia*	1.6	20	0	2	2
100896	*O. officinalis*	3.4	20	4	0	1
100901	*O. nivara/O. sativa*	1.2	20	0	0	0
100905	*O. sativa/O. nivara*	1.9	20	1	0	1
100914	*O. latifolia*	1.2	20	0	0	5
100937	*O. punctata*	2.3	18	2	2	0
100957	*O. malampuzhaensis*	1.0	20	0	0	0
101074	*O. officinalis*	2.4	20	2	1	0
101112	*O. officinalis*	1.7	20	0	2	0
101144	*O. australiensis*	3.1	15	0	1	0
101155	*O. officinalis*	1.7	18	0	0	0
101233	*O. brachyantha*	0	20	0	0	0
101234	*O. brachyantha*	0	20	0	0	0
101235	*O. brachyantha*	0.5	20	1	0	0
101236	*O. brachyantha*	0	20	0	0	0
101399	*O. officinalis*	2.2	20	1	0	4
102169	*O. nivara*	1.0	20	0	0	4

Table 23. Evaluation of wild rices for their reactions to tungro by the mass screening method and to infection with RTBV and/or RTSV in test tubes. IRRI, 1988.

Accession no.	Species or cross	Mass screening severity score	Test tube inoculation			
			Plants tested (no.)	Plants infected (%) with		
				RTBV+RTSV	RTBV	RTSV
100187	*O. rufipogon/O. sativa*	3.5	20	16	3	0
100203	*O. rufipogon/O. sativa*	2.9	20	3	9	1
100211	*O. rufipogon*	2.9	20	0	19	0
100588	*O. rufipogon*	2.3	15	2	7	0
100900	*O. nivara/O. rufipogon*	1.9	16	15	0	0
100902	*O. nivara/O. rufipogon*	1.1	15	1	7	3
100952	*O. alta*	2.3	20	19	1	0
100963	*O. latifolia*	1.1	20	10	0	7
101960	*O. glumaepatula*	3.6	16	2	14	0
101993	*O. nivara/O. rufipogon*	3.1	18	17	1	0
103307	*O. rufipogon*	1.9	18	18	0	0
103790	*O. nivara/O. sativa*	1.4	19	7	9	1
103793	*O. sativa/O. rufipogon*	1.6	20	5	14	0
103808	*O. latifolia*	1.1	20	8	2	0
103888	*O. punctata*	2.8	20	8	5	1
103889	*O. punctata*	3.2	20	10	4	0
100582	*O. sativa/O. nivara*	2.8	17	10	6	0

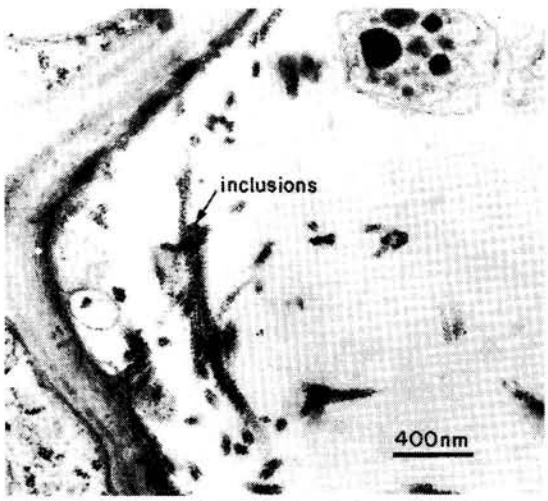
Grassy stunt (*Plant Pathology*). *Inclusions in grassy stunt-infected rice.* The association of fibrillar inclusions has been reported for GSV-infected TN1 plants. Another type of inclusion was observed in ultrathin sections of GSV-infected rice cells. The inclusions consisted of tubular structures associated with particles 18 nm in diameter (Fig. 7). The inclusions were observed in the phloem tube, but not in mesophyl cells of GSV-infected plants.

MOLECULAR GENETICS OF HOST-PATHOGEN INTERACTIONS

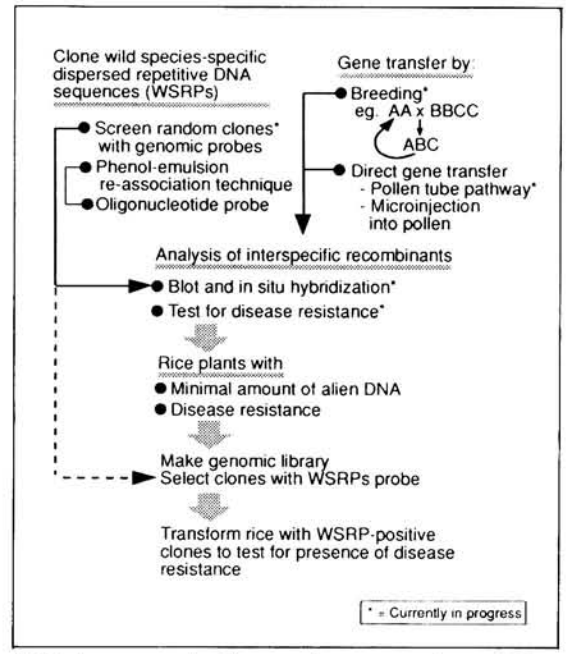
Plant Pathology and Plant Breeding Departments

Transfer and isolation of disease resistance genes from wild rices. We initiated a project directed toward the molecular cloning of disease resistance genes from wild rices. The cloning strategy (Fig. 8) is based on the fact that eukaryotic genomes are interspersed with DNA sequences with different degrees of repetitiveness. Because of genetic divergence between domesticated and wild rices, it is possible to isolate repetitive sequences present in the genomes of wild relatives of rice but absent (or present in only low copy numbers) in the rice genome. Since most of the moderately repetitive sequences are randomly interspersed between nonrepetitive sequences, unique classes of repeats might be linked to resistance genes. Our strategy is to produce interspecific recombinant plants, and, simultaneously, to clone wild species-specific dispersed repetitive DNA sequences to use as probes (wild-specific repeated probes, or WSRPs) for the analysis of the recombinants. Disease-resistant recombinants with minimal introgressed alien DNA will be selected by screening for resistance and by assessing the amount of alien DNA by blot and in situ hybridization using WSRPs. These plants will be used for constructing genomic libraries. Genomic clones will be screened with WSRPs for the presence of alien-specific repetitive sequences. Positive genomic clones will be used to transform susceptible varieties to identify clones that can restore resistance. This approach will reduce the number of clones that need to be screened by rice transformation, thus making it feasible to isolate resistance genes by complementation.

Another advantage of this approach is that it is not limited to a single target trait: the same strategy, and the same interspecific recombinants and wild species-specific probes can be used for cloning a wide range of useful genes from wild rices. For immediate application, alien-specific probes can be used to monitor the introgression of alien chromosomes in wide crosses and to reveal genomic relationships among rice relatives.



7. Tubular inclusions in GSV-infected plants. IRRI, 1988.



8. Cloning strategy for disease resistance genes from wild rice species. IRRI, 1988.

Transfer of disease resistance from wild rices. We have concentrated our efforts on three wild species—*O. minuta, O. longiglumis,* and *O. ridleyi. O. minuta* is a tetraploid wild relative of rice with the BBCC genome. It can be crossed with *O. sativa*, although the fertility is low. *O. longiglumis* and *O. ridleyi* are tetraploid species more divergent from rice. No genome designation has been given to these two species, and interspecific hybridization with rice has been unsuccessful.

Accessions of *O. minuta, O. longiglumis*, and *O. ridleyi* were tested for resistance to Bl and BB (Table 24). All accessions were highly resistant to both diseases, showing hypersensitive resistance to Bl and restricted BB lesion development.

Several methods were used to introduce DNA of wild rices into *O. sativa*. From an initial cross between *O. minuta* (accessions 101141 and 101089) and *O. sativa* (IR31917-45-3-2), we have advanced the F_1 to the BC_1 and BC_2. So far, five BC_1 and six BC_2 plants have been produced, and the chromosome number in each plant has been determined. Preliminary data show that five BC_1 plants and one BC_2 plant were resistant to BB (Table 25).

Since *O. longiglumis* and *O. ridleyi* are not sexually compatible with rice, we used the pollen-tube pathway transformation technique to introduce total genomic DNA from the two species in disease-susceptible varieties. To increase the efficiency of the screening of potential transformants derived from pollen-tube pathway transformation, we made a marker plasmid for use in cotransformation of rice with genomic DNA of the wild species. The marker plasmid contains a repetitive DNA sequence present at high levels in the rice genome and the *NPT II* gene cloned into the

Table 24. Disease reaction of *O. minuta, O. longiglumis*, and *O. ridleyi* to Bl and BB. IRRI, 1988.

Species	Accession no.	Reaction to Bl isolate PO-6-6[a]	Reaction to BB races[b]					
			1	2	3	4	5	6
O. minuta	101141	R	R	R	R	R	R	R
	101089	R	R	R	R	R	R	R
O. longiglumis	100974	R	R	R	R	R	R	R
	100913	R	R	R	R	R	R	R
O. ridleyi	101453	R	MR	R	R	R	R	R
	100821	R	R	R	R	R	R	R
	100820	R	R	R	R	R	R	R
	100877	R	R	R	R	R	R	R

[a]R = hypersensitive resistance to Bl. [b]R = resistant, lesion length less than 3 cm; MR = moderately resistant, lesion length 3.1-6 cm.

Table 25. Reaction of IR31917-45-3-2, *O. minuta* (101141), and their BC_1 and BC_2 progeny to 6 races of *Xanthomonas campestris* pv. *oryzae*. IRRI, 1988.

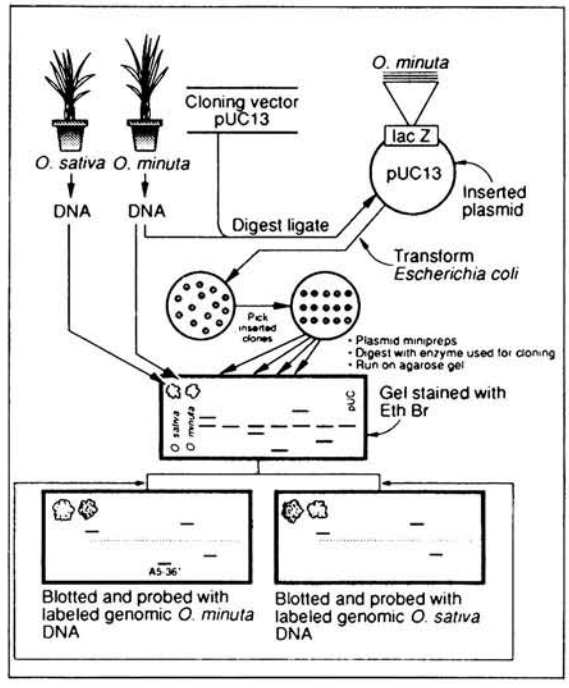
Plant or accession no.	Generation	Chromosomes (no.)	Reaction to bacterial blight races[a]					
			1	2	3	4	5	6
101141	Parental	48	R	R	R	R	R	R
IR31917-45-3-2	Parental	24	R	MS	MS	MS	R	MS
101141/IR31917-45-3-2	F_1	36	R	R	R	R	R	R
WHD50-1	BC_1	46	R	R	R	R	R	R
WHD51-1	BC_1	46	R	R	R	R	R	R
WHD203	BC_1	46	R	R	R	R	R	R
WHD233	BC_1	47	R	R	R	R	R	R
WHD57-1	BC_1	46 (?)	R	R	R	R	R	R
WHDIS52-1	BC_2	32	R	R	R	R	R	R
WHDIS53-1	BC_2	32	R	MS	MS	MS	R	MS
WHDIS54-1	BC_2	36	R	MS	MS	MS	R	MS
WHDIS55-1	BC_2	35	R	–	MS	MS	MR	MS

[a]R = resistant, lesion less than 3 cm; MR = moderately resistant, lesion 3.1-6 cm; MS = moderately susceptible, lesion 6.1-9 cm.

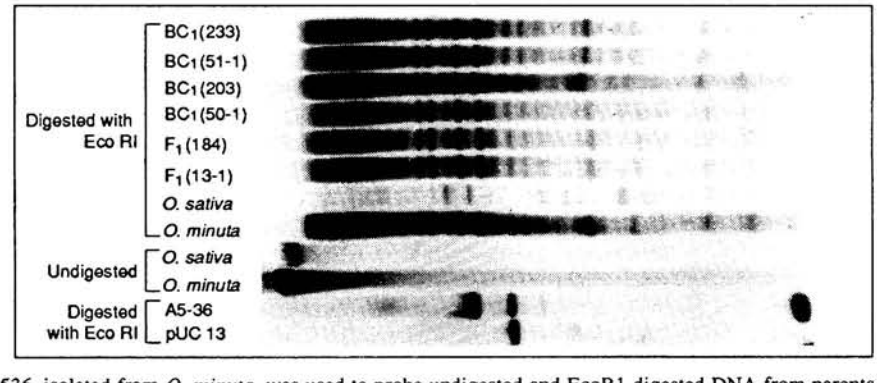
plasmic vector *pUC13*. The rice repeated DNA may increase the frequency of integration into the rice genome, and the *NPT II* gene is expected to confer resistance to the antibiotic kanamycin upon transformed plants.

Isolation of species-specific repetitive DNA sequences as linked markers for disease resistance. The procedure for isolating species-specific DNA sequences is illustrated in Figure 9. Genomic libraries of *O. minuta, O. longiglumis,* and *O. ridleyi* were constructed by ligation of *BamH1* or *BamH1/EcoRI* fragments of genomic DNA into *pUC13* vector. To screen for repetitive sequences, recombinant plasmids were probed with labeled total genomic DNA of the respective species. We found repetitive sequences in 32% (64/200), 24% (19/80), and 25% (24/88) of clones from *O. minuta, O. longiglumis,* and *O. ridleyi*, respectively. Sequences found to be repetitive in wild rice genomes were probed with *O. sativa* genomic DNA to allow selection of those showing low hybridization levels. Although the majority of repeats were present in both wild and domesticated rices, we were able to isolate one clone from each of the three species that showed strong hybridization to genomic DNAs from wild species but weak signals to *O. sativa* DNA.

A *minuta* clone, A5-36, was chosen for more detailed analysis. When the A5-36 probe was used to hybridize to genomic DNA from wild rices of different genomic designations only those with BB (*O. punctata*) and CC (*O. officinalis*) genomes gave strong hybridization signals, suggesting that the cloned sequence originated from the B or C genome. From the 3.3-kb *EcoRI* fragment present in *O. minuta* clone A5-36, a 0.4-kb Sau3A fragment was found to contain the repetitive sequence responsible for the differential hybridization with *minuta* genomic DNA. The 0.4-kb Sau3A fragment was subcloned and used to detect the introgression of *minuta* DNA in the F_1 and BC_1 of a cross between *O. minuta* and *O. sativa* (Fig. 10).



9. Procedure for isolating species-specific DNA sequences. IRRI, 1988.



10. Clone pA536, isolated from *O. minuta*, was used to probe undigested and EcoR1-digested DNA from parents, F_1 hybrids, and backcross generation 1 (BC_1) plants from the *O. sativa/O. minuta* cross. Similar near species-specific repeated sequences have been isolated from *O. ridleyi* and *O. longiglumis*.

Genetic evaluation and utilization (GEU) program

Insect resistance

Entomology, Plant Breeding, and Cereal Chemistry Departments; International Rice Germplasm Center; International Rice Testing Program; and International Centre of Insect Physiology and Ecology

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SOURCES OF RESISTANCE

Entomology and Plant Breeding Departments, International Rice Germplasm Center, and International Rice Testing Program

Evaluation of germplasm and other materials (*Entomology, Plant Breeding, and IRGC*). Materials from the GEU program, the International Rice Germplasm Center (IRGC), and national programs were screened for insect resistance. Similar IRGC accessions, breeding lines, or other test materials were screened against one or more of 11 rice insect pest species (Table 1). An average of 2.4% of the IRGC material was resistant (R) to brown planthopper (BPH) *Nilaparvata lugens*, whitebacked planthopper (WBPH) *Sogatella furcifera*, green leafhopper (GLH) *Nephotettix virescens*, and yellow stem borer (YSB) *Scirpophaga incertulas*. None was R to leaffolders (LF) *Cnaphalocrocis medinalis* and *Marasmia patnalis*, whorl maggot (RWM) *Hydrellia philippina*, caseworm (CW) *Nymphula depunctalis*, black bug *Scotinophara coarctata*, or green hairy caterpillar (GHC) *Rivula atimeta*. Most of the breeding lines and other materials exhibited resistance to BPH biotypes 1, 2, and 3, and to GLH. Breeding lines found R to LF and black bug in unreplicated field trials need to be retested. Information on the resistance status of breeding lines and other materials against BPH, GLH, WBPH, and YSB is summarized in Table 2.

IRTP insect resistance trials (*International Rice Testing Program and Entomology*). Insect resistance information was obtained from 1987 International Rice Testing Program (IRTP) trials (data received and analyzed in 1988). Entries in IRTP screening nurseries that performed well across locations are listed in Table 3. Entries in IRTP yield nurseries that were rated R to specific insects at certain locations are given in Table 4. Detailed results of IRTP trials appear in the IRTP section of this *Annual report*.

Resistance of GEU elite lines (*Entomology and Plant Breeding*). Sixty-seven elite lines were screened for resistance to BPH biotypes 1, 2, and 3; WBPH; GLH; YSB; LF; RWM; CW; and GHC (Table 5). About 16% expressed multiple resistance to the three BPH biotypes, WBPH, GLH, and YSB.

Resistance of wild rices to insect pests (*Entomology and IRGC*). To discover possible donors of durable and multiple resistance, we screened

Table 1. Screening of germplasm and breeding lines for resistance to insect pests. IRRI, 1988.

Insect	Germplasm collection			Lines and other materials		
	Tested (no.)	Resistant		Tested (no.)	Resistant	
		no.	%		no.	%
Brown planthopper (BPH) *Nilaparvata lugens*						
Biotype 1	1,725	380	22.0	26,253	21,143	80.5
Biotype 2	190	8	4.2	35,873	24,895	69.4
Biotype 3	463	114	24.6	25,902	19,169	74.0
Whitebacked planthopper (WBPH) *Sogatella furcifera*	470	3	0.6	1,810	96	5.3
Green leafhopper (GLH) *Nephotettix virescens*	697	53	7.6	78,362	43,670	55.7
Yellow stem borer (YSB) *Scirpophaga incertulas*	876	16	1.8	2,349	369	15.7
White stem borer (WSB) *S. innotata*	900	152[a]	16.9	47	39[a]	83.0
Leaffolder (LF) *Cnaphalocrocis medinalis* (greenhouse)	4,410	0	–	276	0	0
Leaffolder (LF) *C. medinalis* (field)	0	–	–	1,430	313[a]	21.9
Leaffolder (LF) *Marasmia patnalis*	5,047	0	–	276	0	–
Whorl maggot (RWM) *Hydrellia philippina*	2,300	0	–	276	24	8.7
Caseworm (CW) *Nymphula depunctalis*	750	0	–	276	3	1.1
Black bug *Scotinophara coarctata*	16	0	–	536	154[a]	28.7
Green hairy caterpillar (GHC) *Rivula atimeta*	6,959	0	–	226	0	–
Total or average	24,803	726	2.9	173,892	109,875	63.2

[a]Selected from unreplicated field trials in endemic areas for retesting.

Table 2. Summary of breeding lines and varieties screened for resistance to insect pests. IRRI, 1988.

Test material	Tested (no.)	Resistant no.	Resistant %
Nilaparvata lugens[a]			
Germplasm collection (GPC)	2,378	502	21.1
Hybridization block	1,284	722	56.2
Pedigree lines	69,653	53,262	76.5
Observational yield trials (OYTs)	7,401	5,128	69.3
Replicated yield trials (RYTs)	4,044	2,890	71.5
GEU elite lines	303	243	80.2
IRTP materials	2,010	993	49.4
Wide crosses	1,071	742	69.3
China,Korea,UPLB[b] materials,etc.	2,262	1,227	54.2
Total	90,406	65,709	72.7
Sogatella furcifera			
GPC	470	138	29.4
RYT 1988 dry season (DS)	386	120	31.1
RYT 1988 wet season (WS)	367	135	36.8
GEU elite lines 1988 DS	50	11	22.0
GEU elite lines 1988 WS	50	26	52.0
IRBPHN[c]	77	13	16.9
IRWBPHN[d]	56	13	23.2
OYT and RYT upland	489	175	35.8
Wild rices	185	140	75.7
Korean lines	130	29	22.3
Indian varieties	20	5	25.0
Total	2,280	805	35.3
Nephotettix virescens			
Germplasm collection	697	53[e]	7.6
Hybridization block DS	213	70	32.9
Hybridization block WS	217	85	39.2
Pedigree nurseries	73,076	41,049	56.2
OYT irrigated lowland DS	136	54	39.7
OYT irrigated lowland WS	175	145	82.9
OYT upland	379	6	1.6
OYT rainfed lowland DS	864	438	50.7
OYT rainfed lowland WS	720	434	60.3
OYT deepwater DS	143	139	97.2
OYT deepwater WS	664	411	61.9
RYT irrigated lowland DS	385	244	63.4
RYT irrigated lowland WS	363	264	72.7
RYT upland	100	6	6.0
RYT rainfed lowland	100	51	51.0
GEU elite lines DS	50	32	64.0
GEU elite lines WS	50	33	66.0
IRTP materials	524	128	24.4
Wild rices	184	68	36.9
Other materials	21	0	0.0
Total	79,061	43,710	55.3
Scirpophaga incertulas			
Germplasm collection	876	16[e]	1.8
Upland OYT	281	4	1.4
Upland RYT	200	7	3.5
RYT DS	356	78	21.9
RYT WS	346	24	6.9
GEU elite lines 1987 WS	62	11	17.7
GEU elite lines 1988 DS	49	6	12.2
GEU elite lines 1988 WS	50	5	10.0
IRTP materials	625	140	22.4
UPLB materials	78	45	57.7
Wild rices	302	49	16.2
Total	3,225	385	11.9

[a]Resistant to biotypes 1, 2, and 3. [b]University of the Philippines at Los Baños. [c]International Rice Brown Planthopper Nursery. [d]International Rice Whitebacked Planthopper Nursery. [e]For retesting.

Table 3. Best entries in 1987 IRTP insect screening nurseries, 1988.

Nursery	Trials (no.)	Entries
International Rice Brown Planthopper Nursery	15	IR13427-45-3-1-2-2-2, IR17494-32-2-2-1-3, IR27316-78-3-3, IR29725-109-1-2-1, IR31809-83-3-2-2, IR32822-2-2-3-2, IR32829-5-2-2, IR32830-23-2-2, IR35323-93-1-3-1
International Rice White-backed Planthopper Nursery	13	Bahbolon, Chemparan Pandi, IR13427-45-3-1-2-2-2, IR27316-6-2-2, IR64, Mushkan 41, Valsara Champara
International Rice Stem Borer Nursery		
Vegetative phase		
Greenhouse	2	Bahbolon, BPT1235, W1263, IR13427-40-2-3-3-3-3, IR13427-45-3-1-2-2-2
Field	4	W1263, IR28150-84-3-3-2, IR32307-107-3-2-2, IR32429-47-3-2-2, IR32429-68-3-3-3
Heading stage	4	CO 27, CH147 (M), 40 KRAD89, HTAFR77043-2, IR2035-117-3, IR28154-101-3-2

185 wild rice accessions against 9 insect pest species (Table 6). About 40% were R or moderately resistant (MR) to 1 or more BPH biotypes, 37% to GLH, 45% to WBPH, 23% to YSB, and 8% to RWM. None was R to CW, GHC, or LF. Thirteen accessions of eight species of wild rices expressed multiple resistance to the three BPH biotypes, WBPH, GLH, YSB, and RWM (Table 7).

Resistance of Korean lines (*Entomology and Plant Breeding*). We screened 130 Korean lines at IRRI for resistance to BPH biotypes and WBPH using the standard seedbox screening test (SSST). Fifteen lines were R to 1 or more of the BPH biotypes, and 29 were MR to WBPH (Table 8). The Korean lines with a certain degree of resistance to all the three BPH biotypes and WBPH were HR6615-15-1-1-1, HR6615-15-2-2-1, and HR6615-49-1-3-4.

Table 4. 1987 IRTP yield nursery entries rated resistant to various insects at certain locations. IRRI, 1988.

Nursery[a]	Location	Entries
		Brown planthopper
IRYN-VE	Los Baños, Philippines	C1158-7, IR31785-58-1-2-3-3, IR41996-118-2-1-3, IR50
IRYN-E	Los Baños	IR25840-83-3-2, IR31805-20-1-3-3, IR32419-81-2-3-3, IR32429-122-3-1-2, IR32843-92-2-2-3, IR34615-4-2-3, IR35366-40-3-3-2-2, S287b-39-1-3, S818b-10-2
IRYN-M	Los Baños	BW293-2, B4183b-Si-33-6-1-2, C1359-8, IR19661-150-2-2-2-1, IR25604-99-1-3-2-2, IR27316-32-3-2, IR68, IR70
	Bumbong Lima, Malaysia	IR19661-150-2-2-2-1, IR25604-99-1-3-2-2, IR68
IURYN-E	Los Baños	IR25588-7-3-1, IR9729-67-3, NDR84, NDR97
IURYN-M	Los Baños	B3913F-16-5-ST-42
IRRSWYN-E	Los Baños	IR31429-14-2-3, IR31429-18-4-2, IR31429-20-2-3, IR33380-60-1-2-2, IR33383-23-3-3-3
IRRSWYN-M	Los Baños	IR26707-78-2-1-1, IR31432-8-6, IR31432-9-3-2, IR31662-34-1-2
		Green leafhopper
IRYN-E	Los Baños	IR24632-206-3-2-2, IR25840-83-3-2, IR25861-153-1, IR31802-48-2-2-2, IR31805-20-1-3-3, IR32419-44-2-3-2, IR32419-81-2-3-3, IR32843-92-2-2-3, IR34615-4-2-3, IR35366-40-3-3-2-2, IR35546-17-3-1-3, IR64, S818b-10-2
IRYN-M	Los Baños	B4183b-Si-33-6-1-2, IR19661-150-2-2-2-1, IR25604-99-1-3-2-2, IR27316-32-3-2, IR68, IR70, IR31809-83-3-2-2
IRRSWYN-E	Los Baños	IR19274-26-2-3-1, IR21567-9-2-2-3-1-3, IR26933-16-2-3, IR31429-14-2-3, IR31429-18-4-2, IR31429-20-2-3, IR33380-60-1-2-2
IRRSWYN-M	Los Baños	IR13146-45-2, IR13610-72-2-2E-PI, IR19672-140-2-3-2-2, IR21037-2-1-2E-PI, IR31432-8-6, IR31432-9-3-2, IR31662-34-1-2, IR33421-110-1-3-1
		Stem borer
IURYN-E	Los Baños	IR25588-7-3-1, IR9729-6-7-3, NDR84, RAU4028-2, RP1158-85-1, UPR103-80-1-2, IET1444
IURYN-M	Los Baños	Bala Late Mutant, ITA212, RP1674-4038-78-4
		Rice bug
IRYN-M	An Khanh, Vietnam	C1333-4, C1359-8, IR19661-150-2-2-2-1, IR68, IR70

[a] IRYN-VE = International Rice Yield Nursery — Very Early, IRYN-E = International Rice Yield Nursery — Early, IRYN-M = International Rice Yield Nursery — Medium, IURYN-E = International Upland Rice Yield Nursery — Early, IURYN-M = International Upland Rice Yield Nursery — Medium, IRRSWYN-E = International Rice Rainfed Shallow Water Yield Nursery — Early, IRRSWYN-M = International Rice Rainfed Shallow Water Yield Nursery — Medium.

Table 5. GEU elite lines with multiple resistance to rice insect pests. IRRI, 1988.

Line or cross	Reaction[a] to					
	BPH biotype			WBPH	GLH	YSB
	1	2	3			
B4259-48-1-1-3	R	R	R	MR	R	MR
IR29723-88-2-3-3	R	R	R	MR	R	MR
IR32429-122-3-1-2	R	R	R	MR	R	MR
IR33380-60-1-2-2	R	R	MR	MR	R	R
IR35366-28-3-1-2-2	R	R	R	MR	R	MR
IR35366-62-1-2-2-3	R	R	R	MR	R	MR
IR37873-16-2-3-3-3-1	R	R	R	MR	R	MR
IR42015-83-3-2-2-2	R	MR	R	MR	R	R
IR45131-59-2-3-2-3	R	R	R	MR	MR	MR
IR49461-181-2-3-2	R	R	R	MR	MR	MR
IR50404-57-2-2-3	R	R	R	MR	R	R
TN1/Rexoro[b]	S	S	S	S	S	S

[a] R = resistant, MR = moderately R, S = susceptible. [b] YSB -susceptible check.

Table 6. Resistance of wild rices to insect pests. IRRI, 1988.

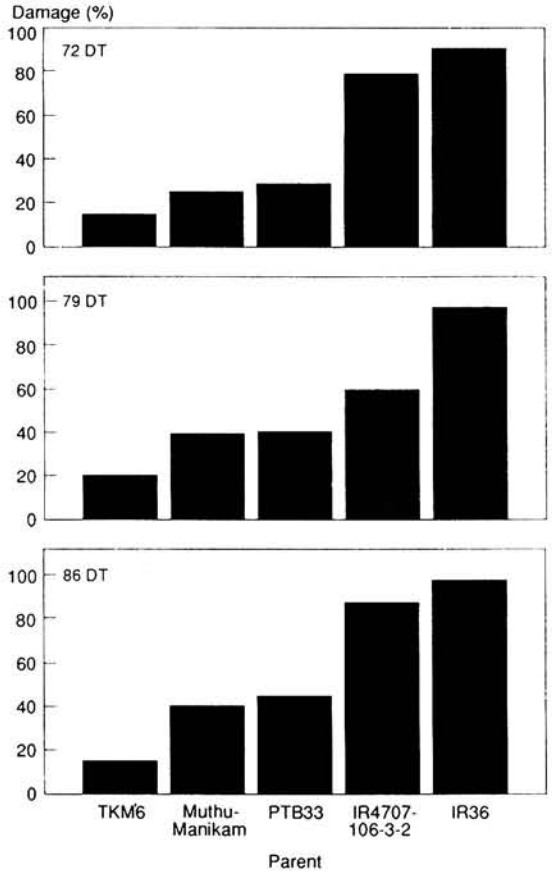
Insect	Tested (no.)	Resistant	
		no.	%
BPH			
Biotype 1	185	87	47.0
Biotype 2	185	66	35.7
Biotype 3	185	78	42.2
GLH	184	68	37.0
WBPH	185	83	44.9
YSB	177	41	23.2
Rice LF			
C. medinalis	176	0	0
M. patnalis	176	0	0
GHC	176	0	0
RWM	172	13	7.6
CW	172	0	0

Table 7. Wild rices resistant or moderately resistant to BPH biotypes 1, 2, and 3; GLH; WBPH; YSB; and RWM. IRRI, 1988.

Species	Acc. no.	Origin
Oryza alta	100111	Surinam
O. australiensis	105165	Australia
O. eichingeri	105159	Uganda
O. eichingeri	105163	Uganda
O. grandiglumis	105144	Brazil
O. latifolia	105142	Costa Rica
O. minuta	105126	Philippines
O. officinalis	100176	(unknown)
O. officinalis	105079	India
O. officinalis	105088	Malaysia
O. officinalis	105119	Philippines
O. punctata	100886	India
O. punctata	105158	Uganda

Table 8. Korean lines resistant or moderately resistant to BPH biotypes and WBPH. IRRI, 1988.

Insect	Lines (no.)		
	Resistant	Moderately resistant	Susceptible
BPH			
Biotype 1	15	69	46
Biotype 2	4	29	97
Biotype 3	11	25	94
WBPH	0	29	101



1. Leaffolder (LF) damage on parent materials at given days after transplanting (DT) in Laurel, Batangas, Philippines, 1988 WS.

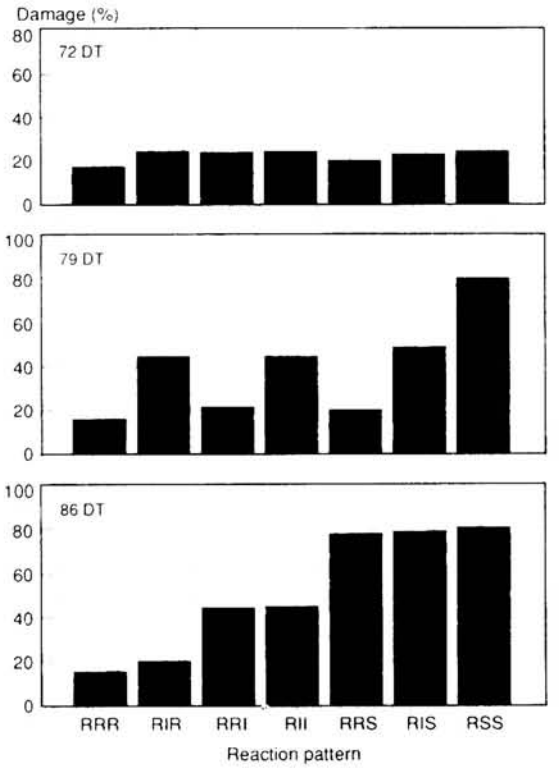
Resistance of new breeding lines to leaffolder (*Entomology and Plant Breeding*). In the greenhouse we screened F_2 and F_3 progenies of TKM6, Muthumanikam, and PTB33 with a common female parent IR4707-106-3-2 for LF resistance. In 1988 WS, the F_4 progenies of the greenhouse-selected F_3 lines and their parent materials were evaluated at a LF-endemic location (80 km southwest of IRRI) in Laurel, Batangas, Philippines. Heavy LF infestation at the experimental site was indicated by a high degree of LF damage on the susceptible (S) check variety IR36 and on IR4707-106-3-2 (Fig. 1).

Seven LF damage reaction patterns were recorded in 976 TKM6 lines: RRR, RIR, RRI, RII, RRS, RIS, and RSS (I = intermediate) (Fig. 2). The first, the second, and the third damage reactions were recorded at 72, 79, and 86 days after transplanting (DT). Categorized as RRR or highly R were 201 TKM6 lines including IR48645-65-15-1 to -10, IR48645-75-6-1 to -10, IR48645-225-29-2 to -10, and IR48645-232-5-1 to -9.

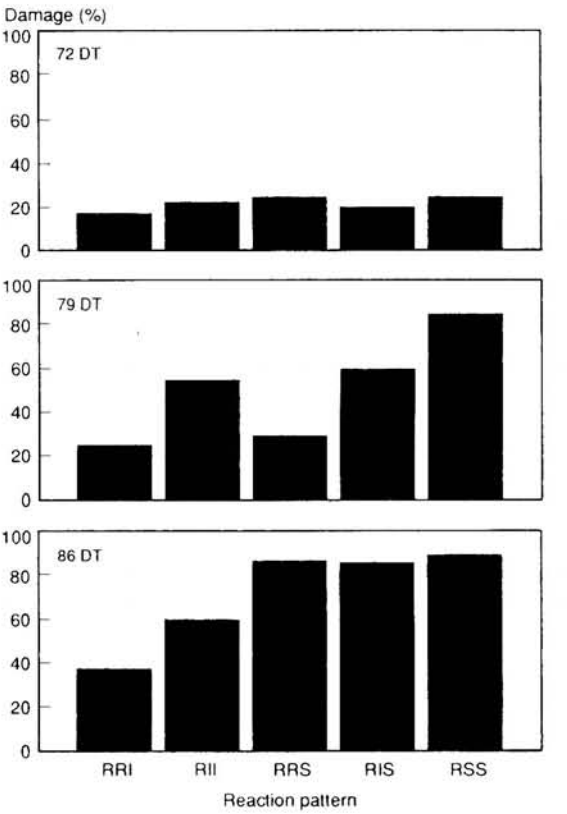
Of the 257 Muthumanikam lines, only IR48643-32-14-1 to -10 showed the RRR pattern.

PTB33 lines were R at 72 DT but became S at maturity (Fig. 3).

Whitebacked planthopper resistance in IR varieties (*Entomology*). IR varieties lack a high level of resistance to WBPH. Of the 30 IR varieties evaluated for WBPH resistance, 5 were MR by the SSST, and 10 exhibited R or MR reactions by the modified seedbox screening test (MSST) (Table 9). Data on WBPH growth indices and population buildup, together with plant reaction in the SSST or MSST, indicated that IR34, IR48, IR50, IR58, and IR65 might possess some tolerance for the pest, while IR44, IR52, IR60, IR62, and IR64 possess antibiosis as the resistance mechanism.



2. LF damage pattern on TKM6 lines at given days after transplanting (DT) in Laurel, Batangas, Philippines, 1988 WS.



3. LF damage pattern on PTB33 lines at given days after transplanting (DT) in Laurel, Batangas, Philippines, 1988 WS.

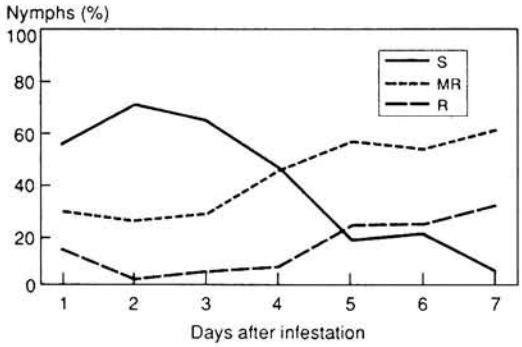
Free choice and no-choice screening tests for resistance to green leafhopper (*Entomology*). Twelve selected IR varieties were evaluated for GLH resistance using free choice (FC) and no-choice (NC) screening tests. For both tests, 20 seeds of each entry were sown in rows 10 cm long and 10 cm apart, and were replicated 3 times in seedboxes (60 × 45 × 10 cm). At 6 d after sowing (DAS), each row of test seedlings in the NC test was covered with a small mylar cage. For the FC test, the whole seedbox with seedlings was enclosed in a fiberglass cage. Each seedling was infested with four 3d-instar nymphs at 7 DAS. A separate seedbox of uninfested seedlings served as the control.

In the FC test, most of the nymphs initially settled on the S entries, then started to move away and transferred mostly to MR plants 3-5 d after infestation (DAI) (Fig. 4). The insects that fed first on S plants were vigorous and persistent, trying to damage R and MR plants. Damage was

Table 9. WBPH resistance in selected IR varieties. IRRI, 1988.

Variety	Plant reaction[a]		Insect response	
	SSST	MSST	Growth index	Population (no./cage)
IR34	S	MR	7.2 ab	573 a
IR44	S	MR	6.3 bcd	354 c
IR50	S	MR	5.8 cd	447 abc
IR58	S	MR	5.8 cd	516 ab
IR64	S	MR	6.6 abc	202 d
IR48	MR	MR	6.1 bcd	503 ab
IR52	MR	R	5.8 cd	388 bc
IR60	MR	R	5.0 de	153 de
IR62	MR	R	5.0 de	72 de
IR65	MR	MR	6.1 bcd	535 a
IR2035-117-3	R	R	4.0 e	40 e
TN1	S	S	7.6 a	582 a

[a]S = susceptible, MR = moderately resistant, R = resistant. SSST = standard seedbox screening test, MSST = modified seedbox screening test.



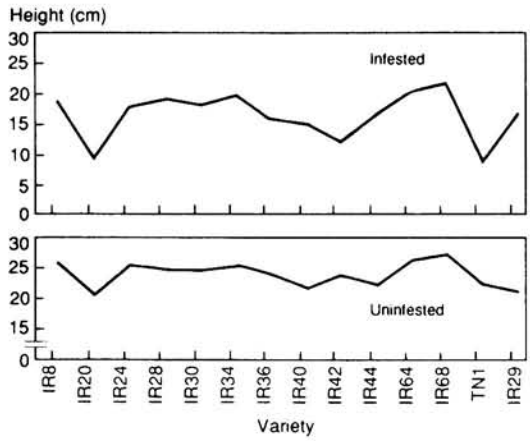
4. Green leafhopper (GLH) nymphs settling on resistant (R), moderately resistant (MR), and susceptible (S) varieties. IRRI, 1988.

recorded at 7 DAI, when the TN1 check (S) was killed. Although no significant difference between the FC and NC tests was recorded, the NC test ensured uniform infestation on all test seedlings for the duration of the test.

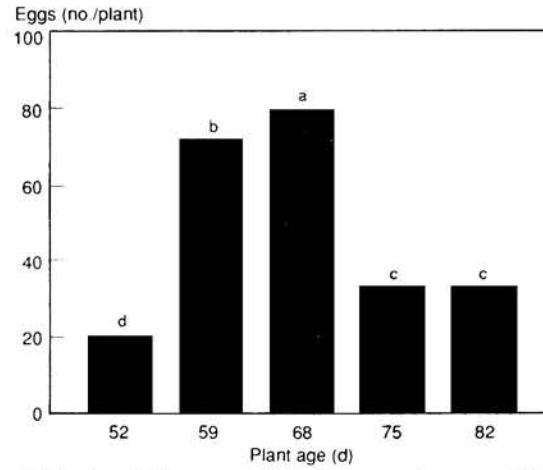
Plant heights of infested and uninfested seedlings of all test entries recorded at 2, 4, 6, and 8 DAI differed significantly (Fig. 5).

Screening methodology for rice bug resistance (*Entomology*). Breeding for rice bug (RB) resistance is needed because popular rice cultivars are S to this pest. Varietal maturity differences, the large greenhouse space requirements for growing plants, bulkiness of plants at the milky stage, and vulnerability of plants to diseases and insects because of prolonged exposure to infestation are some of the constraints in screening for RB resistance. We attempted to identify plant growth stages at which rice plants could be screened most efficiently against RB.

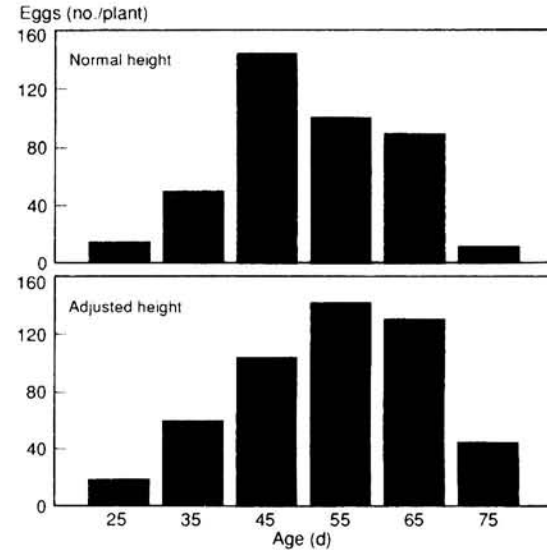
In an oviposition preference test, RB females laid significantly more eggs on IR36 plants at booting (59-68 DAS) than at panicle initiation (52 DAS) or flowering (75 DAS) (Fig. 6). In another test, potted plants with variable heights due to differences in plant age were raised to the same level as that of the tallest plants. The booting stage was still preferred for egg laying (Fig. 7).



5. Growth of GLH-infested and uninfested plants of IR varieties and TN1 (susceptible check). IRRI, 1988.



6. Rice bug (RB) eggs on IR36 plants at various ages. IRRI, 1988. Bars with the same letter are not significantly different at the 5% level by DMRT.



7. RB eggs on IR36 plants at various ages with normal and adjusted plant heights. IRRI, 1988.

In another study, 80% of RB females survived up to 20 DAI on 30-d-old IR70 plants (Fig. 8), but nymphs failed to become adults on these plants. The honeydew test showed that RB adults could derive partial nourishment from plants without exserted panicles. These observations suggest that RB probing (puncture) frequency on 7-d-old seedlings could be used as a possible parameter for evaluating RB resistance.

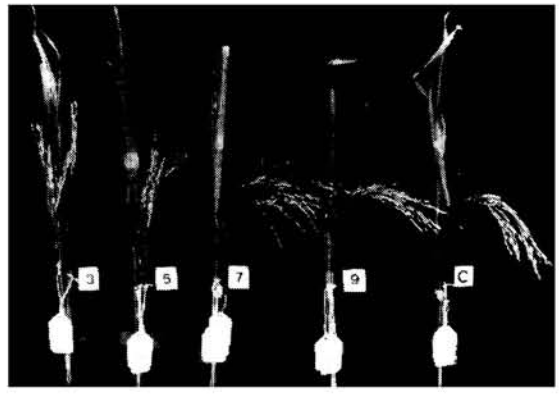
Panicle maturity variations on a hill and uneven grain maturity within a panicle are other problems in RB screening. We considered the floret opening stage (anthesis or pollination stage) as an index for specifying rice grain age. Floret opening time was designated as 0 d after anthesis (DAA). Grains infested at 3 DAA exhibited the highest grain weight loss, possibly because of RB proboscis damage on spikelet ovaries that failed to develop grains (Fig. 9). Grain weight loss was lower at 9 DAA than at 5 DAA or 7 DAA. RB excreted significantly more honeydew from grains at 7 DAA. RB resistance screening would require grains with uniform physiological development.

Tungro resistance screening using green leafhopper nymphs (*Entomology*). Previously we reported that viruliferous GLH nymphs could be used for rapid evaluation of rice varieties for resistance to rice tungro virus (RTV). In 1988, we found that 2d-, 3d-, and 4th-instar nymphs (causing 70-80% infection) were more efficient RTV transmitters than 5th-instars (48%) or 3-d-old adults (37%) when they all had an overnight acquisition period.

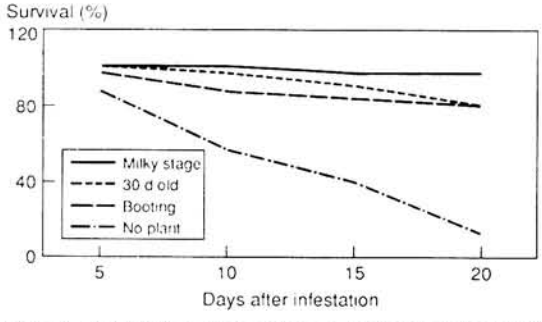
In a serial transmission test conducted at hourly intervals using eight seedlings, RTV infection tended to diminish after serial transmission through four seedlings (Table 10). A 1-, 2-, or 3-h midday reacquisition feeding was not necessary if the viruliferous nymphs were utilized only twice a day for RTV inoculation.

GLH nymphs used repeatedly in FC RTV resistance screening were likely to be stressed during alternated access to RTV-infected source plants and to the test materials. Such repeated stress reduced adult recovery to about 25%, but insect longevity and fecundity were not affected.

Regional monitoring of virulent green leafhopper and brown planthopper populations in the Philippines (*Entomology*). The observed vulnerability of some IR varieties to RTV in the Philippines could be attributed to selection of GLH biotypes capable of feeding on R plants. Similar shifts may also occur in BPH populations. We therefore evaluated a set of varieties with known genes for resistance to GLH and BPH pests in



9. Damage by RB females to panicles infested at 3, 5, 7, and 9 d after anthesis. IRRI, 1988.



8. Survival of RB females at various plant growth stages. IRRI, 1988.

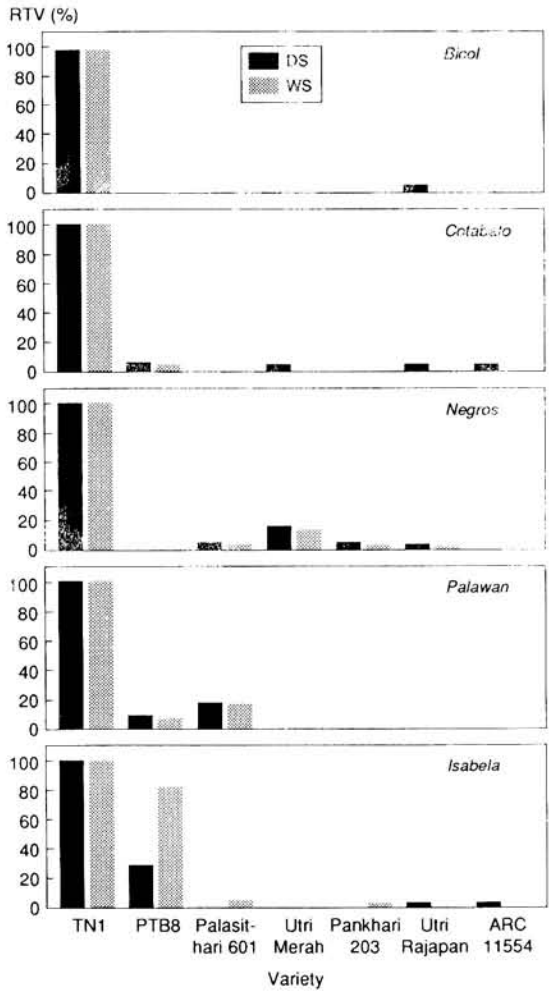
Table 10. TN1 seedlings infected by GLH nymphs with rice tungro virus at hourly intervals. IRRI, 1988.

Inoculation time	Infection[a] (%)
0700-0800	60 abc
0800-0900	68 ab
0900-1000	82 a
1000-1100	62 abc
1100-1200	54 bc
1200-1300	47 bcd
1300-1400	40 cd
1400-1500	26 d

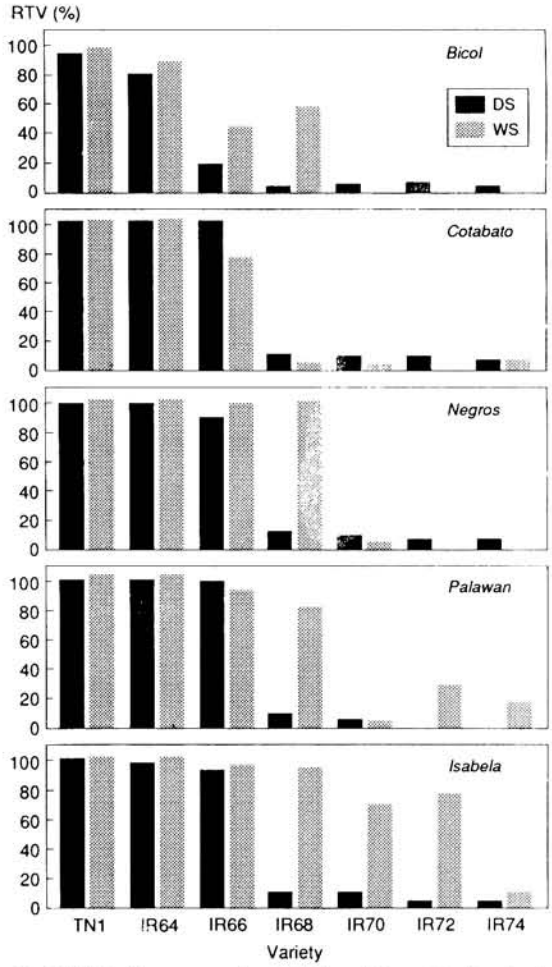
[a] Av of 3 replications, each consisting of 80 seedlings.

field plots in Isabela, Bicol, Negros, Palawan, and Cotabato Provinces. At all locations, Palasithari 601 (*Glh-2* gene), Utri Merah, Pankhari 203 (*Glh-1*), Utri Rajapan, and ARC11554 showed RTV resistance in 1988 DS and WS (Fig. 10). IR70, IR72, and IR74 were R to RTV at all locations in 1988 DS, but IR70 and IR72 became S in Isabela in 1988 WS (Fig. 11). Breeding lines such as IR32809-26-3-3, IR35366-28-3-1-2-2-3, IR39323-182-2-3-3-2, IR50404-57-2-2-3, IR52280-96-2-2, and IR52280-117-1-1 were also R to RTV except in Isabela in 1988 WS (Fig. 12).

Growth index and population buildup studies showed that the BPH population in Cotabato was



10. Rice tungro virus (RTV) incidence on selected traditional varieties at 5 sites in the Philippines. IRRI, 1988 DS and WS.



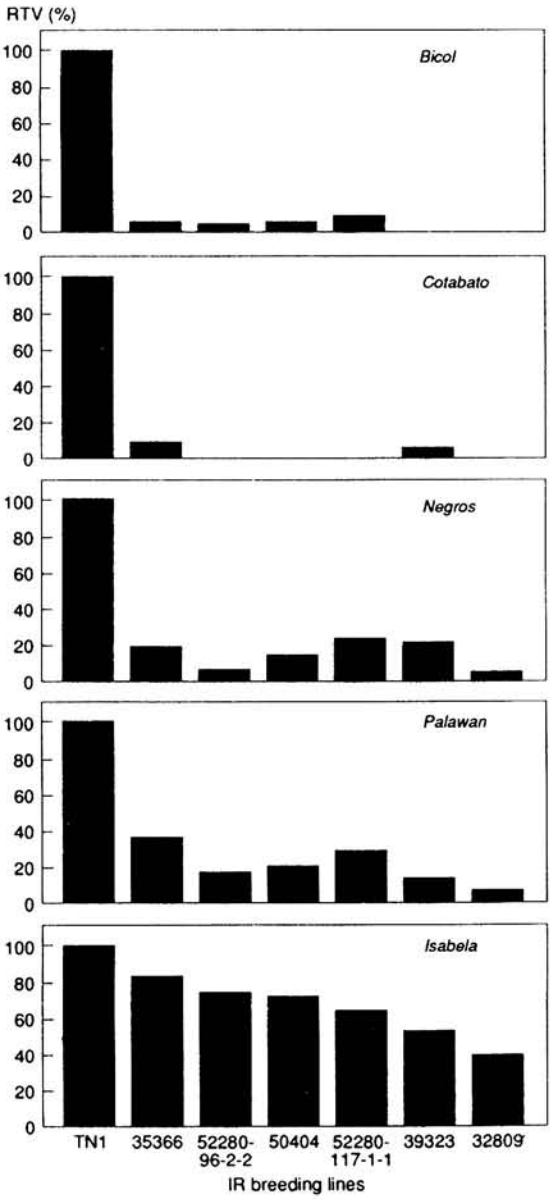
11. RTV incidence on selected IR varieties at 5 sites in the Philippines. IRRI, 1988 DS and WS.

more virulent than populations in Bicol and at other locations (Fig. 13).

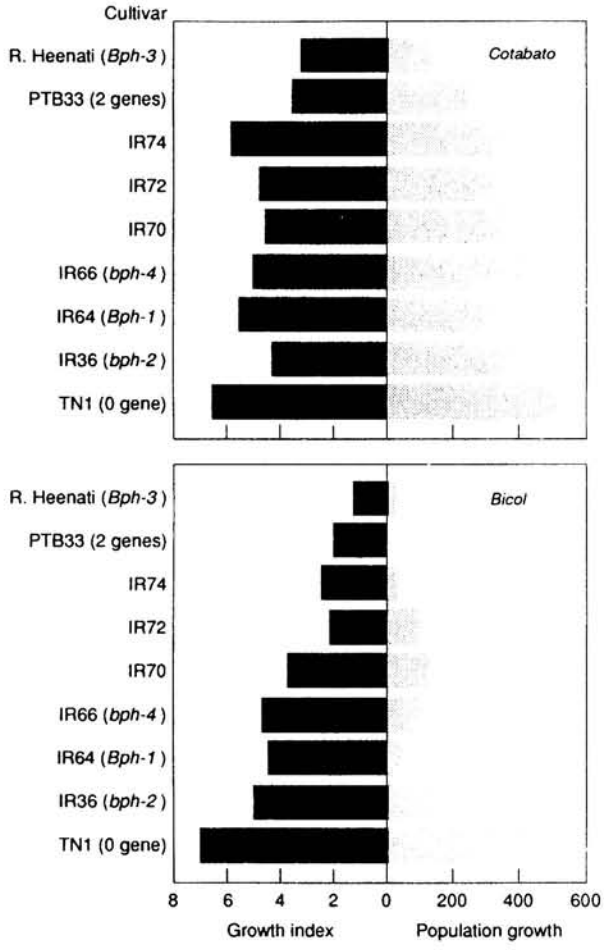
NATURE OF RESISTANCE

Entomology and Plant Breeding Departments, International Rice Germplasm Center, and International Centre of Insect Physiology and Ecology

Green leafhopper survival and population buildup on *Oryza officinalis* (*Entomology and IRGC*). *N. virescens* response was evaluated on 20 *O. officinalis* accessions. In the survival test, 30-d-old potted plants enclosed in mylar cages were infested with 1st-instar GLH nymphs. Total insects per cage were counted at 15 DAI. For population buildup studies, 30-d-old potted plants were infested with



12. RTV incidence on selected breeding lines at 5 sites in the Philippines. IRRI, 1988 WS.



13. Growth index and population buildup of BPH collected from Bicol and Cotabato, Philippines. IRRI, 1988 WS.

5 pairs of 3-d-old GLH males and females. One month later, total insects per cage were counted, and the insects were oven-dried at 50 °C for 24 h and weighed on a microbalance. GLH survival, population buildup, and insect weights were significantly lower on all *O. officinalis* accessions than on TN1 (S) (Table 11).

Feeding behavior of three green leafhopper species on rice, wild rice, and graminaceous weeds (*Entomology*). With an electronic monitoring device, the feeding behavior of *Nephotettix virescens, N. nigropictus*, and *N. malayanus* was studied on R rices Pankhari 203 and IR29, wild rice *O. officinalis* (Acc. 100896), and two weeds (*Leersia hexandra* and *Echinochloa glabrescens*). TN1 was the S check. All three GLH species could feed in the phloem tissue of all the test plants for varying durations (Table 12). Phloem feeding on different plants was positively correlated with the quantity of honeydew excreted that gave a basic reaction on bromocresol-treated filter paper. Phloem feed-

Table 11. Nymphal survival and population growth of *N. virescens* on selected *O. officinalis* accessions. IRRI, 1988.

Acc. no.	Survival (%)	Population (no./cage)	Weight (mg/insect)
100179	2.5 e	0.0 d	0.0 b
100180	0.0 f	1.2 bcd	0.2 b
101112	2.5 e	0.5 cd	0.1 b
101114	0.0 f	0.0 d	0.0 b
101115	0.0 f	0.0 d	0.0 b
101116	0.0 f	0.2 cd	0.1 b
101117	2.5 e	3.2 bcd	0.7 b
101121	0.0 f	0.0 d	0.0 b
101137	0.0 f	0.0 d	0.0 b
101139	0.0 f	0.0 d	0.0 b
101142	2.5 e	5.8 b	1.3 b
101149	0.0 f	1.0 cd	0.1 b
101150	0.0 f	0.0 d	0.0 b
101151	0.0 f	0.0 d	0.0 b
101152	0.0 f	3.5 bcd	1.2 b
101154	0.0 f	0.2 cd	0.0 b
101155	7.5 d	1.2 bcd	0.3 b
101166	0.0 f	0.0 d	0.0 b
102164	15.0 c	4.8 bc	2.2 b
IR29	55.0 b	2.2 bcd	2.5 b
TN1	100.0 a	52.5 a	27.9 a

ing was for shorter durations on R rices and on nonhost weeds than on TN1 plants. *N. malayanus* reared on *L. hexandra* fed for significantly longer durations on this weed than did the two other GLH species. Because *N. nigropictus* and *N. malayanus* can feed in the phloem of R cultivars, they can add to RTV transmission in the field. Having acquired RTV from rice plants, they, particularly *N. nigropictus*, can transmit RTV to weeds, which may serve as reservoirs of tungro viruses.

Brown planthopper, whitebacked planthopper, and stem borer resistance in wide crosses and parents of deepwater rice lines (*Entomology and Plant Breeding*). *O. minuta* and *O. brachyantha* hybrids showed high and moderate levels of resistance, respectively, to BPH biotype 2 and WBPH. *O. brachyantha* hybrids also expressed resistance to striped stem borer (SSB), but not at the same level as against YSB (Table 13). Tests showed that *O. rufipogon*, used in wide hybridization for deepwater lines, is R to both YSB and SSB (Table 14).

Rice bug response on Sathi (*Entomology*). Some Sathi accessions possess panicles that remain naturally enclosed within the leaf sheaths of flag

Table 12. Electronically recorded events during 180-min feeding access given to *Nephotettix virescens (Nv)*, *N. nigropictus (Nn)*, and *N. malayanus (Nm)* on selected graminaceous plants.[a] IRRI, 1988.

Plant	Probes (no.)			Salivation (min)			Xylem feeding (min)			Phloem feeding (min)		
	Nv	*Nn*	*Nm*	*Nv*	*Nn*	*Nm*	*Nv*	*Nn*	*Nm*	*Nv*	*Nn*	*Nm*
Pankhari 203	40 aX	44 dX	26 eX	14 cX	15 cX	8 bY	53 aX	36 aXY	25 abY	14 bY	42 bX	28 bcX
IR29	70 aXY	90 aX	51 bY	26 bY	43 aX	17 aY	34 abX	24 aX	43 aX	15 bX	10 dX	7 cdX
Oryza officinalis	66 aX	63 bX	64 aX	46 aX	18 cY	18 aY	16 cdY	26 aXY	46 aX	19 bXY	20 cX	4 dY
Leersia hexandra	37 aX	46 eX	16 fY	10 cX	23 bcX	5 cY	28 bcX	34 aX	6 cY	22 bY	50 abX	84 aX
Echinochloa glabrescens	53 aX	58 cX	33 dX	26 bX	26 bX	10 bY	18 cdY	36 aX	44 aX	20 bY	46 abX	27 bXY
TN1	19 bXY	15 fY	32 dX	7 dY	6 dY	12 abX	11 dXY	7 bY	22 bX	68 aX	92 aX	34 bY

[a]Means followed by a common letter in a column (a-f) or in a row (X-Y) are not significantly different at the 5% level by DMRT. Av of 7 replications.

Table 13. Resistance of *O. brachyantha* hybrids to BPH, WBPH, and stem borers. IRRI, 1988.

Entry	Population[a] (no./cage)		Survival[b] (%)	
	BPH	WBPH	YSB	SSB
Hybrids				
WHD452-1	304	238	0	32
WHD457-1	229	349	0	40
WHD636-1	562	393	3	28
WHD636-2	426	356	9	30
WHD685-1	340	290	3	36
WHD723-2	85	559	0	42
Checks				
IR62 (R to BPH)	11	–	–	–
IR2035-117-3 (R to WBPH)	–	22	–	–
TN1 (S to BPH, WBPH)	937	897	–	–
IR40 (R to YSB)	–	–	39	–
TKM6 (R to SSB)	–	–	–	56
Rexoro (S to YSB, SSB)	–	–	57	68

[a] Insect no./cage was recorded at 25 DAI with 3 pairs of adults/35-d-old potted plant enclosed in a mylar cage. [b] Survival was obtained at 10 DAI with 10 newly emerged 1st-instar larvae/30-d-old potted plant. YSB = yellow stem borer, SSB = striped stem borer.

Table 14. YSB and SSB larval survival on parents of deepwater rice lines. IRRI, 1988.

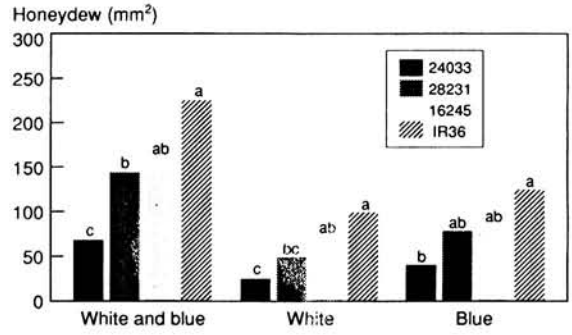
Entry	Survival[a] (%)	
	YSB	SSB
O. rufipogon	28.3	33.3
Rayada 16-6	48.3	48.3
RD19	50.0	62.0
Patnai 23	52.0	44.0
Jaganath	58.3	51.7
Baisbish	63.3	35.0
FR13A	56.7	56.7
IR42	61.7	53.3
IR11141-6-1-4	58.3	65.0
IR40 (YSB-R check)	46.7	–
TKM6 (SSB-R check)	–	35.0
Rexoro (S check)	61.7	66.7

[a] Percent survival was recorded at 11 DAI with 10 newly emerged 1st-instar larvae/35-d-old potted plant.

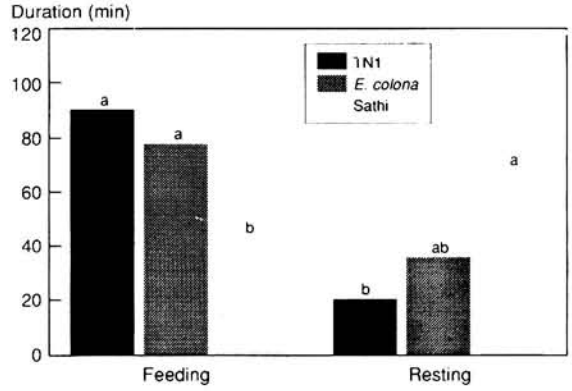
leaves from flowering to maturity. RB ovipositional preference on 12 Sathi accessions did not differ from that on S IR36 plants at booting. However, even when the panicles were forced open at the milky stage, the amount of honeydew excreted, nymphal survival, and nymphal weight were significantly less on Sathi Acc. 24033 than on IR36 (Fig. 14). Electronically recorded durations of RB feeding waveforms on Sathi Acc. 24033 were significantly shorter than even on *E. colona*, a gràminaceous weed host, or on S IR36 rice plants (Fig. 15).

Thrips settling response and leaf pubescence (*Entomology*). The lower preference of thrips for R pubescent Dahanala plants than for the same plants without their vestiture of hairs demonstrated that pubescence affects the insect's settling response (Table 15). However, the lower preference of thrips for Dahanala plants divested of hairs than for the glabrous S variety Nira indicated that Dahanala resistance is conferred by both morphological and biochemical factors.

Whorl maggot resistance of wild rices (*Entomology and IRGC*). Of 175 wild rice accessions screened at IRRI, 24 showed low damage levels. To confirm this resistance, ovipositional prefer-



14. RB honeydew excreted on 3 Sathi accessions and on IR36. IRRI, 1988.



15. Durations of electronically recorded events during RB feeding on panicles of TN1, Sathi, and *E. colona*. IRRI, 1988.

Table 15. Thrips settling on resistant Dahanala and susceptible Nira. IRRI, 1988.

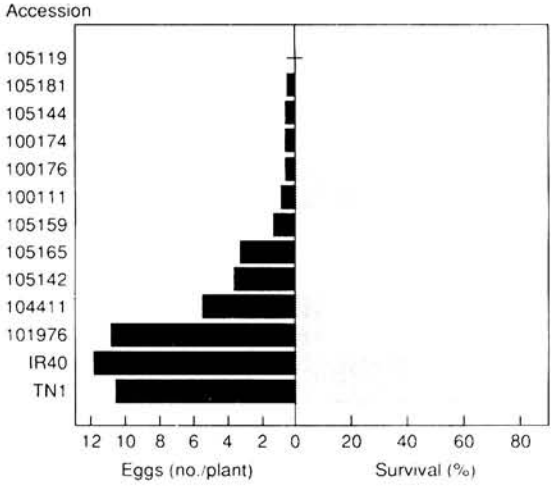
Treatment	Thrips settling[a] (no.) at given hours after release							
	1 h	Difference	5 h	Difference	18 h	Difference	24 h	Difference
Dahanala with hair	18.4		15.7		17.9		13.2	
Dahanala without hair	31.7	13.30**	26.1	10.40**	28.2	10.40**	22.8	9.60**
Nira	29.9		27.4		26.7		24.1	
Dahanala without hair	18.8	11.10**	17.9	9.50**	16.1	10.60**	15.8	8.30**
Nira	28.6		26.2		25.8		23.2	
Dahanala with hair	13.5	15.10**	12.8	13.40**	12.4	13.40**	11.9	11.30**

[a] ** = significant at the 1% level by *t*-test, av of 10 replications, 24 thrips/replication.

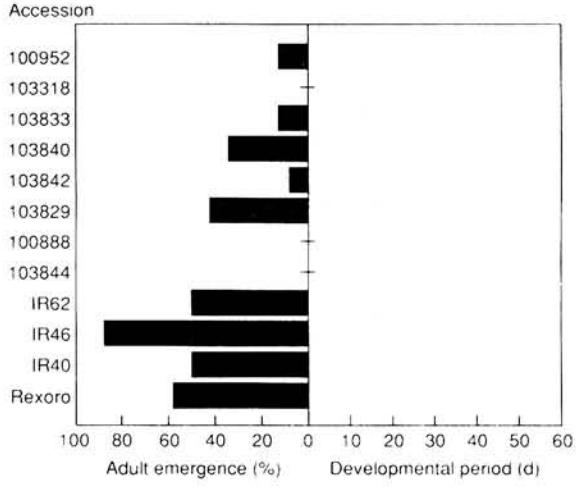
ence and larval survival tests were conducted in a greenhouse. Of the 24, 10 were less preferred for oviposition and had low larval survival (Fig. 16).

Yellow stem borer response on selected wild rices (*Entomology and IRGC*). Eight wild rice accessions and three IR varieties were infested at booting with 1st-instar YSB larvae at one larva per tiller. Plants were infested by making a 2.5-cm slit along the leaf sheath bulge below the flag leaf and introducing a larva into the growing panicle. No YSB adults were recovered from *O. australiensis* (Acc. 103318), *O. alta* (Acc. 100888), or *O. rufipogon* (Acc. 103844), while only a few emerged on *O. alta* (Acc. 100952), *O. sativa* f. *spontanea* (Acc. 103833), and *O. sativa*/*O. nivara* (Acc. 103842) (Fig. 17). YSB developmental period did not differ much.

Sensitivity of striped stem borer neonate larvae to handling (*Entomology*). We investigated whether handling of neonate larvae using a camel-hair brush stressed them. A 1-cm-thick layer of Southwestern corn borer (SWCB) diet in a rearing container (22.5 × 15 × 7.5 cm) was infested with 5 SSB egg masses at the blackhead stage. At 0.5, 1, 3, 5, 7, 12, 24, 48, 96, 240, and 360 h after eclosion, larvae were picked up individually with a moist camel-hair brush, weighed, and transferred to preweighed SWCB diet in small plastic rearing cups (4.5 cm high × 4 cm diam) later sealed with lids. In the control, handling was avoided, and the neonate larvae were allowed to crawl directly into the plastic cups containing the diet. Each treatment was replicated nine times, and each replication comprised six cups. Ten days



16. Whorl maggot eggs and larval survival on selected wild rices and TN1. IRRI, 1988.



17. YSB adult emergence and developmental period on wild rices and cultivars. IRRI, 1988.

later, the diet, the fecal pellets, and the larvae were removed from six cups and weighed separately. Then, 20 d later, the remaining larvae, the control larvae, their fecal pellets, and the unconsumed diet were weighed.

Handling of larvae from 0.5 h to 96 h adversely affected development and survival (Table 16). Larvae disturbed at 0.5 h weighed significantly less than undisturbed larvae. Nutritional indices were also compared between disturbed (0.5-360 h) and undisturbed (control) larvae. Physical disturbance decreased not only food intake but also the insect's efficiency in converting ingested food and in converting assimilated food into body substances (Table 17). Thus, stress caused by handling lowered insect growth rate.

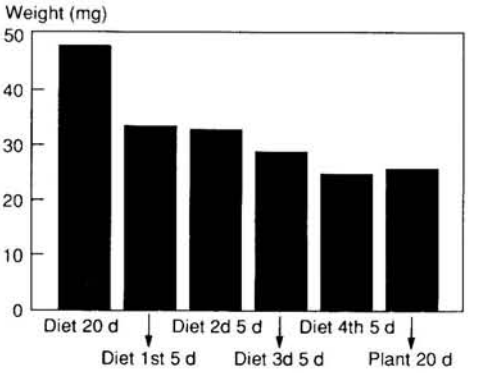
Growth and development of striped stem borer larvae on artificial diet and susceptible host (*Entomology*). We compared SSB larval development on Rexoro plants (S) and on SWCB diet devoid of any plant allelochemicals. A total of 200 rearing cups, each containing 6 ml of SWCB diet, were infested with two 1st-instar larvae/cup. Likewise, 80 potted Rexoro plants (30-d-old, 5 tillers/pot) were infested with 10 SSB larvae/pot. The cups and plants with larvae were kept in an iron tray for larval development at 27 ± 2 °C and 70 ± 5% relative humidity. In 1 treatment, larvae from the diet were removed after 5 d and transferred to Rexoro plants. In other treatments, larvae were removed from Rexoro plants after an initial infestation period of 5, 10, or 15 d and were transferred to SWCB diet for 5 d, then transferred back to Rexoro plants for 10, 5, or 0 d, respectively. After a total infestation period of 20 d on plants, on diet, or on plants and diet, the larvae were removed and weighed.

The larvae reared throughout on the diet weighed twice as much as those reared on Rexoro plants (Fig. 18). Also, a 5-d initial boost on SWCB diet helped the larvae to gain more weight than when

Table 16. Survival and growth of SSB larvae as affected by handling at different times after eclosion. IRRI, 1988.[a]

Transfer at given time (h) after eclosion	Survival (%)	Larval weight (mg)
0.5	18.8 ± 6.07 a	17.64 ± 6.56 a
1	19.4 ± 7.21 ab	20.87 ± 8.32 b
3	26.2 ± 7.45 b	33.38 ± 13.06 b
5	67.9 ± 7.78 c	41.29 ± 6.24 c
7	77.8 ± 14.43 d	44.87 ± 11.57 d
12	79.6 ± 13.16 d	51.84 ± 2.91 d
24	81.5 ± 13.01 d	51.26 ± 4.73 d
48	83.3 ± 10.21 d	62.16 ± 4.60 e
96	84.3 ± 10.58 d	70.52 ± 6.07 ef
240	97.3 ± 5.89 e	74.60 ± 6.13 f
360	100.0 ± 0.00 e	73.22 ± 7.96 f
480 (control)	100.0 ± 0.00 e	71.92 ± 5.14 f

[a] Av of 9 replications, each with 12 larvae.



18. Mean weights of SSB larvae fed Rexoro plants and given a "5-d boost" on an artificial diet at various times. IRRI, 1988.

Table 17. Performance of disturbed and undisturbed SSB larvae on Southwestern corn borer diet. IRRI, 1988.

Treatment	Growth indices[a]				
	Weight (mg) of diet eaten	Weight gain (mg)	Relative growth rate	ECI[b] (%)	ECD[c] (%)
Disturbed larvae	777.64 ± 96.85	44.48 ± 14.63	0.064 ± 0.30	5.47 ± 1.73	7.3 ± 0.029
Undisturbed larvae (control)	872.22 ± 119.23	64.83 ± 5.89	0.816 ± 0.26	7.59 ± 1.42	11.6 ± 3.58

[a] Av of 9 replications, each with 12 larvae. [b] Efficiency in converting ingested food. [c] Efficiency in converting digested food.

the boost was given later or when the larvae were reared exclusively on the S host. These results show that even a S host possesses some defense chemicals.

Mode of feeding of leaffolder larvae on selected wild rices (*Entomology and International Centre of Insect Physiology and Ecology*). In collaboration with the International Centre of Insect Physiology and Ecology (ICIPE), we measured the leaf area consumed and weight gain by larvae of *C. medinalis* and *M. patnalis* on wild rices *O. officinalis, O. perennis, O. punctata, O. nivara,* and *O. australiensis*. IR36 and TKM6 were the S and R checks, respectively.

C. medinalis larvae fed significantly more on IR36, *O. officinalis*, and *O. perennis* plants than on TKM6, *O. punctata, O. nivara*, and *O. australiensis* (Table 18). *M. patnalis* larvae fed less on all the wild rices and TKM6 than on IR36.

Larvae of both species gained weight on all test plants. *C. medinalis* larvae gained as much weight on wild rices as on IR36. *M. patnalis* gained less weight on *O. officinalis, O. nivara, O. australiensis,* and TKM6 than on IR36. Although *C. medinalis* larvae consumed more than *M. patnalis* larvae, the increase in percent weight gain was higher for *M. patnalis* on R TKM6 or *O. perennis* plants.

CHEMICAL BASES OF RESISTANCE

Cereal Chemistry and Entomology Departments and International Centre of Insect Physiology and Ecology

Phloem sap and susceptibility to brown planthopper (*Entomology and Cereal Chemistry*). BPH biotype 1 adults were allowed to feed on the basal leaf sheaths and at the base of panicles (milky stage) of IR8 (S) and IR26 (R). Bleeding sap from the base of cut panicles and diffusates from the cut leaf sheaths of IR8 and IR26 plants were collected and analyzed chemically. Females allowed to feed for 1 or 2 d at the panicle base excreted significantly more honeydew and weighed more on IR8 than on IR26 plants (Table 19). Similar but more dramatic differences were observed when BPH females were allowed to feed for 24 h on basal leaf sheaths. However, the longevities of adults feeding on the panicle base of IR8 and IR26 plants did not differ significantly. Nymphal development was similar on the two varieties. Although earlier analysis suggested higher levels of sugar and amino acids in bleeding sap of IR8 than in that of IR26, some 1988 samples showed higher levels in IR26 than in IR8 sap.

Levels of total sugars, free amino acids, silica,

Table 18. Leaf area consumed and percent weight gain by 1-d-old, 1st-instar LF larvae after 48 h on selected wild rices, 1988.[a]

Treatment	Leaffolder species		
	C. medinalis	*M. patnalis*	Difference[b]
	Leaf area consumed[c] *(cm²)*		
O. officinalis	0.92 + 0.21 ab	0.52 + 0.04 b	0.40**
O. perennis	0.90 + 0.35 abc	0.41 + 0.14 bc	0.49**
O. punctata	0.70 + 0.20 c	0.52 + 0.05 b	0.18*
O. nivara	0.31 + 0.11 d	0.34 + 0.04 cd	−0.03 ns
O. australiensis	0.73 + 0.20 bc	0.23 + 0.11 d	0.50**
IR36 (S check)	1.10 + 0.20 a	0.98 + 0.16 a	0.12 ns
TKM6 (R check)	0.68 + 0.15 c	0.38 + 0.14 c	0.30**
	Percent weight gain[d]		
O. officinalis	178 + 50 a	151 + 37 c	27 ns
O. perennis	155 + 38 ab	198 + 37 ab	−43**
O. punctata	134 + 41 bc	177 + 67 abc	−43 ns
O. nivara	160 + 52 ab	148 + 56 a	12 ns
O. australiensis	163 + 50 ab	168 + 34 bc	− 5 ns
IR36 (S check)	161 + 61 ab	203 + 49 a	−42 ns
TKM6 (R check)	102 + 46 c	166 + 42 bc	−64**

[a] For leaf area consumed and percent weight gain in a column, means (+SD) followed by a common letter are not significantly different at the 5% level by DMRT. [b] ns = not significant by *t*-test, ** = significant at the 1% level, * = 5% level. [c] Av of 9 replications, each with 10 larvae. [d] Av of 14 replications, each with 1 larva.

Table 19. Weight gain, honeydew excreted, longevity, and development of BPH biotype 1 on basal leaf sheaths and panicle stalks of S IR8 and R IR26 plants.[a] IRRI, 1988.

Insect response on	IR8	IR26
Leaf sheath		
Weight gain (mg/female per 24 h)	1.0 a	0.0 b
Honeydew (mg/female per 24 h)	36.9 a	1.7 b
Panicle		
Weight gain (mg/female per 24 h)	1.1 a	0.8 b
Weight gain (mg/female per 48 h)	1.5 a	1.1 b
Honeydew (mg/female per 24 h)	49.7 a	10.7 b
Honeydew (mg/female per 48 h)	69.7 a	38.4 b
Male longevity (d)	8.1 a	9.0 a
Female longevity (d)	9.1 a	11.9 a
Nymphs becoming adults (%)	84.3 a	78.1 a
Developmental period (d)	12.9 a	13.1 a

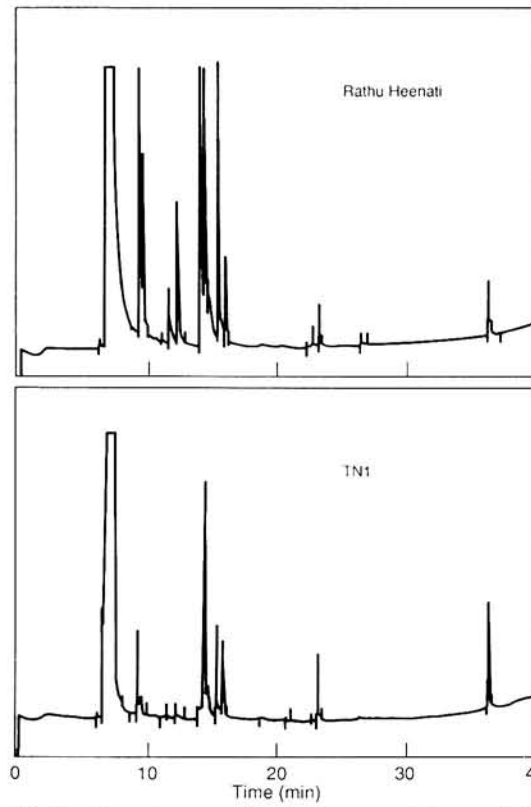
[a]Within a row, means followed by a common letter are not significantly different at the 5% level by *t*-test. Av of 11-18 replications.

and phenolics were assayed in 70% ethanol diffusates from stem segments of 2 batches of plants (45 DT) of 7 rices differing in BPH resistance genes. No consistent trends were obtained with the two crops of seedlings. Again, IR8 had higher free amino acid levels than IR26 in both leaf diffusate samples, but higher total sugars only in the second sample. The ethanol diffusate had low activity against BPH in the seedling-dip method. These results confirm that nutritional factors are minor determinants of varietal resistance to BPH.

Surface volatiles of rice plants (*Cereal Chemistry and Entomology*). Volatiles from 50 g of intact IR8 and IR26 leaves and leaf sheaths (45 DT) were collected by the low-pressure cold-trap (-70 °C) technique (Annual report for 1987). The volatiles were bioassayed for attractancy or repellency using a Y-shaped olfactometer and newly emerged BPH biotype 1 females. IR8 volatiles were preferred over IR26 volatiles by biotype 1 females.

In another test, intact leaf sheaths of IR8 and IR26 plants (45 DT) were dipped sequentially in solvents of increasing polarity to extract surface chemicals: 60 s in hexane and 2 s in diethyl ether, dichloromethane, methanol, and water; then the extracts were air-dried. The hexane and methanol extracts were the major fractions (0.1-0.3% of fresh weight). Solutions of the extracts (1,500 ppm) in acetone or acetone:water (4:1) were painted onto 25- to 30-d-old TN1 seedlings, which were later infested with 1st-instar nymphs for 24 h. The hexane fraction was the most biocidal, causing 91% insect mortality in IR26 and 46% in IR8. The other fractions were less active (0-9% mortality), and differences between IR8 and IR26 were not significant. These results support earlier data on steam distillates, showing high activity against BPH in the hexane-soluble fraction.

Chemical profiles of volatiles of whitebacked planthopper-resistant and -susceptible varieties (*Entomology and Cereal Chemistry*). We qualitatively evaluated volatiles from Rathu Heenati (R) and TN1 (S) plants. Leaves and leaf sheaths from 50-d-old plants were cut and their volatiles collected separately, using the low-pressure cold-trap technique. Gas chromatography showed that the number of peaks and their retention times differed between the volatiles of Rathu Heenati and TN1, indicating differences in their composition (Fig. 19).

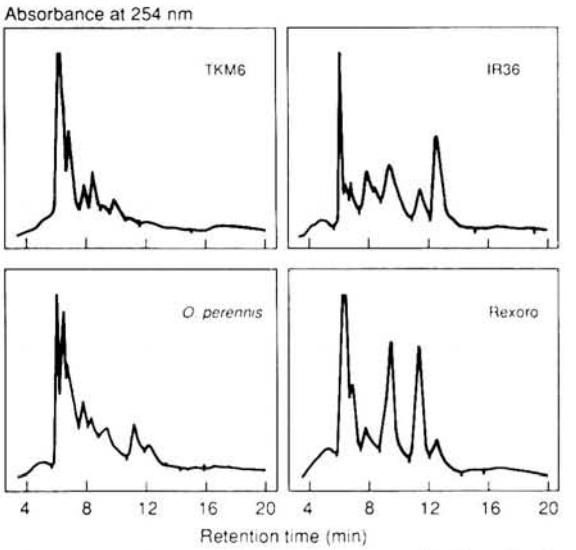


19. Gas chromatograms of molecular extracts from resistant Rathu Heenati and susceptible TN1 rice plants. IRRI, 1988.

Calli as media for screening leaffolder resistance (*Cereal Chemistry, Plant Breeding, and Entomology; and International Centre of Insect Physiology and Ecology*). Rice callus was used to demonstrate the chemical basis of resistance to LF *C. medinalis*. Calli from *O. ridleyi* (Acc. 100821) and Rexoro were obtained on Linsmaier and Skoog medium. PTB18 and IR5865-26-1 calli were obtained in Murashige and Skoog-3 medium. In a NC 20-d bioassay at 28 °C and 12:12-h photoperiod, neonate *C. medinalis* larvae developed to 5th instars on Rexoro (S) and PTB10 (S) calli, to 4th instars on IR5865-26-1 (MR) calli, and to 2d instars on *O. ridleyi* calli. Callus analysis for protein, total amino acids, starch, and free sugars suggested that nutritional factors were not involved.

Extraction and evaluation of antifeedants from rice plants (*Cereal Chemistry and Entomology, and International Centre of Insect Physiology and Ecology*). Antifeedants were extracted from dried rice foliage of IR36 and Rexoro (S) and TKM6 (R), and a R wild rice *O. perennis* (Acc. 100211) by successive extraction with petroleum ether, dichloromethane, methanol, and water. Crude extracts were bioassayed in a NC test against *C. medinalis*. Larval feeding decreased on IR36 leaf cuts impregnated with 5,000 ppm of methanol extracts of the test plants (Table 20). *O. perennis* and TKM6 extracts were most inhibitory. Distinct qualitative differences among the rices were observed when their methanol extracts were fractionated by high pressure liquid chromatography on a C18 reversed-phase column using a methanol-water gradient program from 50-100% methanol in 30 min (Fig. 20).

Collection and identification of rice plant volatiles (*Cereal Chemistry and Entomology, and International Centre of Insect Physiology and Ecology*). Volatiles from rice genotypes with different levels of LF resistance were collected using a dynamic head space collection device. Rice plants (45 DT), placed singly with roots immersed in water in 150-ml beakers, were introduced individually in a glass chamber (75 cm high, 10 cm diameter), through the bottom of which passed purified air at 80 ml/min. Volatiles were collected for 24 h at room temperature in a glass column (78 mm long, 4 mm I.D., 6 mm O.D.) containing 100 mg of Tenax TA 60-80 mesh. After collection, the trap was purged with purified N_2 to remove condensed water. The Tenax trap was then placed in the injector port of a gas chromatograph mass spectrometer at 40 °C in the splitless mode. Volatiles were desorbed by heating up the



20. Ultraviolet absorbance patterns by HPLC of methanol extracts of 4 rice varieties. IRRI, 1988.

Table 20. Feeding by *C. medinalis* larvae in a no-choice test on IR36 (S) leaf cuts treated with 5,000 ppm of extracts of powders of different rice plants sequentially extracted with solvents of increasing polarity. IRRI, 1988.

Plant	Area[a] (cm^2) scraped/d per larva on extract-treated IR36 leaf cuts			
	Petroleum ether	Dichloromethane	Methanol	Water
IR36	1.16 ab	1.28 b	1.27 c	1.04 a
Rexoro	1.63 ab	0.75 a	1.00 bc	1.16 a
TKM6	0.84 a	1.84 c	0.73 ab	1.32 a
O. perennis	1.30 ab	1.86 c	0.45 a	1.34 a
Control	1.88 b	1.07 ab	1.31 c	1.53 a

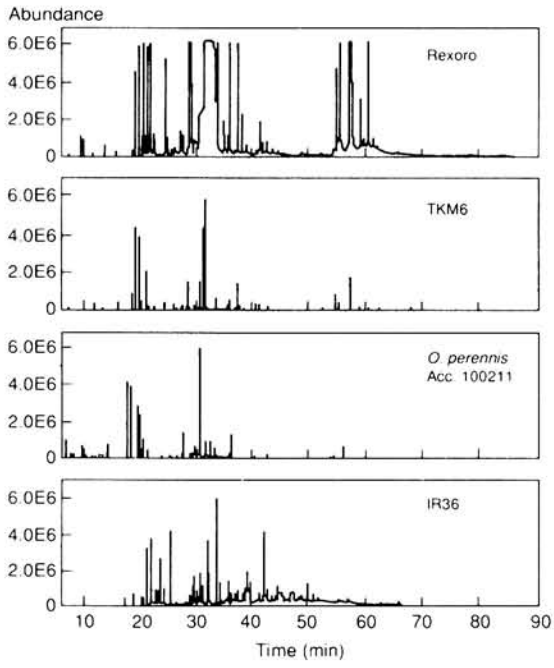
[a] Av of 15 replications.

injector port to 185 °C for 25 min and trapped in a 1-m capillary coil immersed in dry ice-acetone mixture. After desorption, the oven temperature was programmed from 2 min at 40 °C and heating to 240 °C at the rate of 2 °C/min. Identification was by mass spectral analysis and by comparison with authentic standards.

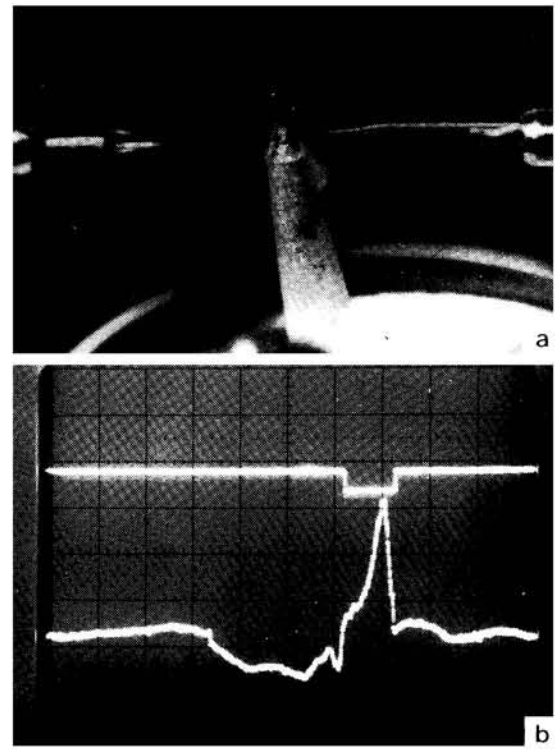
Rexoro variety (S) had more volatiles than TKM6 (R) or *O. perennis* (R). Although IR36 produced similar amounts of volatiles as R rices (Fig. 21), it is S to the pest. The major components of the extracts were low-molecular weight alcohol, aldehydes, ketones and hydrocarbons, monoterpenes, and sesquiterpenes. Among them, hexanal, cis-(3)-hexen-1-ol, cis-(3)-hexen-1-acetate, 1-hexanol, α-pinene, ß-myrcene, limonene, cineole, 1-nonanol, and trans-caryophyllene have been positively identified. Limonene formed the major component of Rexoro extract, and its level was about 100 times more than that in R genotypes.

Bioassays of volatiles from rice plants (*Cereal Chemistry and International Centre of Insect Physiology and Ecology*). Volatiles of IR36 and Rexoro (S to LF) and TKM6 (R) and *O. perennis* (R) rice plants were bioassayed for responses of *C. medinalis* moths using the electroantennogram (EAG) technique. EAG measures the drop in electrical potential across an insect's antenna in response to a stimulus. Compared with water, plant extracts evoked significantly higher EAG response (Fig. 22). The insects readily responded to the extract of S plants. Pure compounds hexanal, 1-hexanol, cis-(3)-hexen-1-ol, and ß-myrcene, which have been identified as volatilizing from rice plants, elicited a very high EAG response (Table 21).

Chemical basis of leaffolder resistance (*Cereal Chemistry and International Centre of Insect Physiology and Ecology*). Several chemicals showing qualitative and/or quantitative differences in R and S rice plants were assayed for orientational and settling responses and weight gain of 1st- and 3d-instar *C. medinalis* larvae. The oxidized form of trans-caryophyllene adversely affected the settling behavior of larvae (Fig. 23). Thus, this com-



21. GCMS profiles of volatiles of 4 rice genotypes. IRRI, 1988.

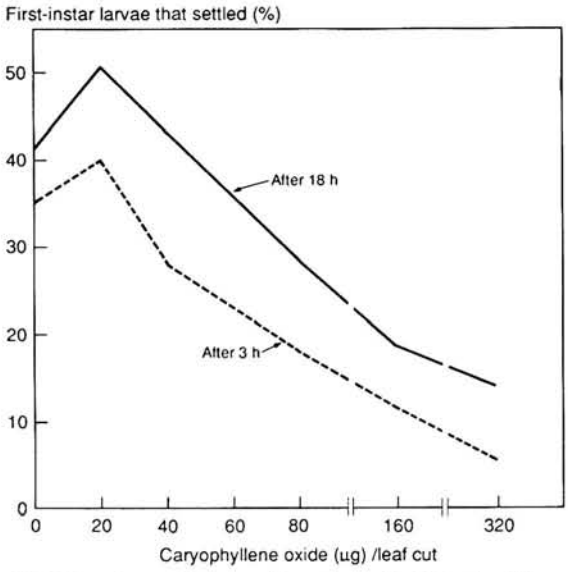


22. An antennal preparation of a female *C. medinalis* moth for electroantennogram response measurement (a), and a negative potential of -2.5 mV recorded for *C. medinalis* in response to hexanal (b). IRRI, 1988.

Table 21. Electroantennogram responses of *C. medinalis* moths to individual volatile compounds from rice plants. IRRI, 1988.

Compound[a]	Concentration in paraffin oil	
	10%	0.1%
Hexanal	907 ± 243	315 ± 38
1-hexanol	579 ± 102	277 ± 116
Cis-3-hexen-1-ol	730 ± 235	274 ± 59
β-myrcene	326 ± 109	181 ± 76
Limonene	213 ± 24	82 ± 23
Cineole	198 ± 56	70 ± 32
1-nonanol	232 ± 65	68 ± 20
Trans-caryophyllene	114 ± 32	74 ± 16
α-pinene	232 ± 62	73 ± 31
Paraffin oil (standard)	59 ± 18	

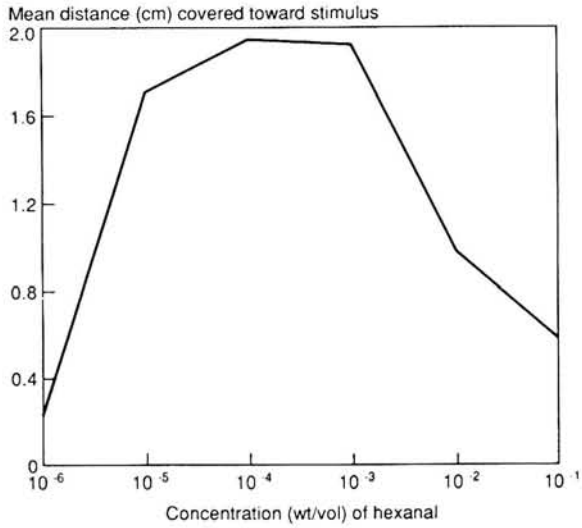
[a] Control = 25 μl water.



23. Effect of caryophyllene oxide on the settling behavior of 1st-instar *C. medinalis* larvae. IRRI, 1988.

pound may partly contribute to LF resistance in TKM6 and in some wild rices. Hexanal attracted 1st-instar larvae and may serve as a cue for larval orientation (Fig. 24).

Protease activity and protein patterns in leaffolder larvae reared on resistant and susceptible rice plants (*Entomology and International Centre of Insect Physiology and Ecology*). Protease activity was significantly higher in *C. medinalis* larvae reared on IR36 (S) than on TKM6 (R) or *O. perennis* (R) plants, indicating that digestive pro-



24. Effect of hexanal on the orientation of 1st-instar *C. medinalis* larvae. IRRI, 1988.

tease inhibitors possibly suppress larval growth and development on R plants (Table 22).

Protein bands also differed significantly in 3d-instar larvae reared on IR36 (S) and TKM6 (R) or *O. perennis* (R) plants (Table 23). Of 24 protein bands detected, 18 (both anodal and cathodal proteins) were present in larvae reared on S plants, while only 14 (mostly cathodal proteins) were present in larvae reared on R plants (Fig. 25). Width and color intensity of protein bands also varied. These differences in insect growth may be related to biochemical differences between S and R plants.

INSECT BIOTYPES

Entomology Department

Allozyme variations in brown planthopper and green leafhopper field populations. Allozyme

Table 22. Protease activity in *C. medinalis* 3d-instar larvae reared on S IR36 and R TKM6 and *Oryza perennis* plants.[a] IRRI, 1988.

Reared on	Protease (mg)/10 ml sample	Protein (mg)/ insect	Trypsin (mg)/ insect	Trypsin units/ mg protease per insect
IR36	12.93	69.51	0.136	0.272
TKM6	11.03	56.44	0.094	0.188
O. perennis	11.35	38.94	0.069	0.138

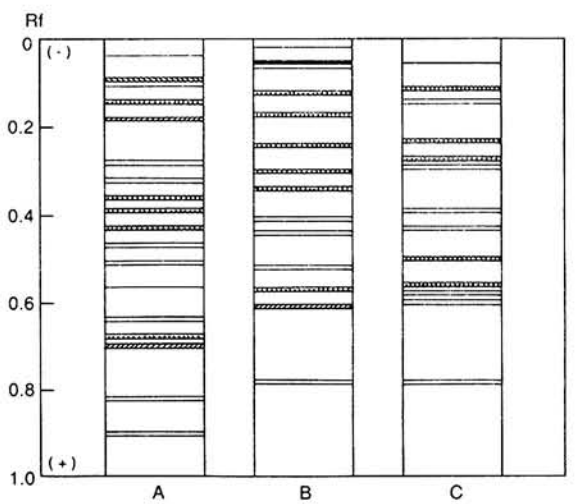
[a] Analysis was done with pooled samples of 100 larvae.

Table 23. Rf values, color intensity[a], and frequency of protein bands in 3d-instar larvae of *C. medinalis* reared on IR36, TKM6, and *O. perennis* plants. IRRI, 1988.

Band no.	IR36			TKM6			*O. perennis*		
	Rf range	Color intensity	Frequency (n=10)	Rf range	Color intensity	Frequency (n=10)	Rf range	Color intensity	Frequency (n=10)
1	0.04	2	7	0.02	3	10			
2				0.062-0.066	5	8	0.058-0.060	5	
3				0.07	2	6			
4	0.09-0.10	4	10						
5	0.11	3	4	0.12 -0.13	2	9	0.11 -0.12	2	5
6	0.14-0.15	2	1				0.14 -0.15	1	6
7	0.18-0.19	3	9	0.17 -0.18	2	8			
8				0.24 -0.25	2	9	0.23 -0.24	2	7
9	0.28-0.29	1	1				0.27 -0.28	2	7
10	0.32-0.33	1	9	0.30 -0.31	2	10	0.29 -0.30	1	8
11	0.36-0.37	2	9	0.34 -0.35	2	5			
12	0.39-0.40	2	1	0.41 -0.42	1	6	0.39 -0.40	1	1
13	0.43-0.44	2	1	0.44 -0.45	1	5	0.43 -0.44	1	1
14	0.47-0.48	1	8						
15	0.51-0.52	1	1	0.52 -0.53	1	7	0.50 -0.51	2	2
16	0.57-0.58	1	5	0.57 -0.58	2	9	0.56 -0.57	2	7
17							0.58		
18							0.58 -0.59		
19				0.61 -0.62	3	10	0.60 -0.61	1	9
20	0.64-0.65	1	4						
21	0.68-0.69	2	8						
22	0.70-0.71	5	10						
23	0.82-0.83	1	5	0.78 -0.79	1	6	0.78-0.79	1	6
24	0.90-0.91	1	7						

[a] 1 = very light, 2 = light, 3 = moderately dark, 4 = dark, 5 = very dark.

polymorphism at 26 gene loci in BPH and GLH revealed polymorphism at 11 and 14 loci, respectively. BPH populations from 10 locations in the Philippines differed significantly in allelic frequency at 4 polymorphic gene loci (Table 24). For GLH, heterogeneity of gene frequencies among seven local populations was detected at three loci (Table 25). Partitioning the total variation within and between local populations demonstrated that most of the genetic diversity exists as within-subdivision diversity (Table 26).



25. Summary of electrophoretogram for protein bands in 3d-instar larvae of *C. medinalis* reared on susceptible IR36 (A) and resistant TKM6 (B) and *O. perennis* (C) plants. IRRI, 1988.

Genetic variation in green leafhopper populations. Gene pools of GLH colonies reared on TN1 (no resistance gene), Pankhari 203 (*Glh-1*), and IR8 (*Glh-3*), and TAPL 796 (*Glh-6*) plants were analyzed. Genetic differences were observed in three of the five polymorphic gene loci (Table 27). Between TN1 vs IR8, and Pankhari 203 vs IR8, significant differences existed at three loci. TN1 vs Pankhari 203, TN1 vs TAPL 796, and Pankhari 203 vs TAPL 796 were significantly differentiated at two loci, while IR8 vs TAPL 796 differed at just one locus (Table 28).

Table 24. Chi-square[a] analysis of genetic structure of ten natural populations of *N. lugens*. IRRI, 1988.

Locality	Loci			
	ALKP	AK	IDH	MDH
Albay	0.020	1.99	51.170***	1.21
Camarines Sur	nt	0.07	0	0
Isabela	0.100	nt	0.02	0
Laguna	0	nt	0.02	
Mindoro	0.09	0.51	0.117	0.01
Negros Occidental	2.85	0.08	0.081	0.89
North Cotabato	0.030	0.02	61.69***	0
South Cotabato	0.020	0	21.04***	0
Palawan	0.38	0	0.16	0.010
Zamboanga del Sur	0	nt	0	0.14
χ^2[b]	47.84***	391.36***	386.65***	110.67***
	df=16	df=24	df=45	df=18

[a]Tests the goodness of fit of observed genotypic proportions to the proportion expected according to the Hardy-Weinberg Law. *** = $p \leq 0.001$, nt = not tested. [b]Tests the homogeneity of gene frequencies among *N. lugens* populations using the method of Workman and Niswander.

Table 25. Chi-square[a] analysis of genetic structure of seven natural populations of *N. virescens*. IRRI, 1988.

Locality	Loci			
	ALKP	EST	IDH	MDH
Camarines Sur	0.02	5.58*	0.02	0
Laguna (IRRI)	47.5***	24.45***	0.03	0.13
Laguna (Pila)	0.06	61.34***	2.5	5.73*
Isabela	0.02	0.46	0.02	0.02
North Cotabato	0.03	13.06***	1.04	0
Quezon	0.02	32.01***	0	32.52***
Zamboanga del Sur	0.05	38.10***	0.02	0
χ^2[b]	18.09[ns]	490.78***	173.47***	102.82***
	df=12	df=12	df=12	df=12

[a]Tests the goodness of fit of observed genotypic proportions to the proportion expected according to the Hardy-Weinberg Law. * = $p \leq 0.05$, *** = $p \leq 0.001$, ns = not significant. [b]Tests the homogeneity of gene frequencies among *N. virescens* populations using the method of Workman and Niswander.

Table 26. Partitioning of genetic variability in a population of *N. lugens* and *N. virescens* using the Shannon Information Index, H and Nei modification of F-statistics.[a] IRRI, 1988.

Locus	Shannon Index			Nei Method			
	$\bar{H}$ pop	$\bar{H}$ grp	% within groups	Ht	Hs	Dst	Gst
			N. lugens				
ALKP	0.14	0.12	98.2	0.05	0.05	0.001	0.02
AK	0.42	0.27	84.29	0.21	0.16	0.04	0.20
IDH	0.40	0.28	87.86	0.16	0.15	0.02	0.11
MDH	0.14	0.11	97.10	0.05	0.05	0.002	0.04
Mean	0.28	0.19	91.86	0.12	0.10	0.02	0.09
							% = 91.02
			N. virescens				
ALKP	0.09	0.09	99.3	0.03	0.03	0.0003	0.01
EST	0.74	0.65	90.4	0.41	0.48	0.07	0.14
IDH	0.16	0.12	96.2	0.06	0.06	0.005	0.08
MDH	0.16	0.13	96.8	0.06	0.03	0.003	0.05
Mean	0.29	0.25	95.68	0.14	0.16	0.02	0.07
							% = 93.2

[a]$\bar{H}$ pop = the H value for the whole population, $\bar{H}$ grp = the mean H of all groups, Ht = total gene diversity, Hs = gene diversity within populations, Dst = gene diversity among populations, Gst = differentiation among populations.

Table 27. Allele frequencies in 5 protein loci of *N. virescens* populations. IRRI, 1988.

Locus	Population	Genes (no.)	Allele frequencies			χ^{2a}	df
			1	2	3		
IDH	TN1	254	0.138	0.860	0.002	100.07**	6
	Pankhari 203	124	0.016	0.984			
	IR8	132	0	1.0	0		
	TAPL 796	124	0	1.0	0		
ALKP	TN1	237	0.007	0.989	0.004	57.78**	6
	Pankhari 203	124	0	1.0	0		
	IR8	198	0	0.940	0.060		
	TAPL 796	124	0	1.0	0		
MDH	TN1	175	–	0.994	0.006	4.57	3
	Pankhari 203	124	–	1.0	0		
	IR8	132	–	1.0	0		
	TAPL 796	124	–	1.0	0		
EST-A	TN1	176	–	0.396	0.604	97.10**	3
	Pankhari 203	93	–	0.597	0.403		
	IR8	81	–	0.759	0.241		
	TAPL 796	153	–	0.725	0.275		
AK	TN1	187	–	0.006	0.994	3.61	3
	Pankhari 203	100	–	–	1.0		
	IR8	100	–	–	1.0		
	TAPL 796	100	–	–	1.0		

[a] Tests the homogeneity of gene frequencies among GLH populations based on the method of Workman and Niswander. ** = significant at the 1% level.

Table 28. Results of homogeneity tests[a] of gene frequencies between *N. virescens* populations at 5 polymorphic loci, indicating level of significant heterogeneity. IRRI, 1988.

GLH colonies reared on	Enzyme loci				
	IDH	MDH	EST-A	ALKP	AK
TN1/Pankhari 203	28.66***	1.49	19.76***	2.75	1.21
TN1/IR8	40.71***	1.59	58.50***	26.25***	1.21
TN1/TAPL 796	38.23***	1.49	15.6 ***	2.75	1.21
Pankhari 203/IR8	4.26*	0	10.32***	15.45***	0
Pankhari 203/TAPL 796	4.00*	0	8.66***	0	0
IR8/TAPL 796	0	0	0.63	15.45***	0

[a] Based on comparison of allelic frequencies according to the method of Workman and Niswander. Values are significant at the 5% (*) and 0.1% (***) levels.

Table 29. Observed phenotypes and allelic frequencies at 7 loci of greenhouse-reared populations of WBPH *Sogatella furcifera* Horvath. IRRI, 1988.

Locus	Genotype					Allele frequency			H^a	N
	11	12	22	23	33	1	2	3		
IDH	4	20	298	–	–	0.044	0.956	–	0.06	322
MDH-1	–	–	122	2	3	–	0.968	0.031	0.02	127
MDH-2	–	–	120	3	3	–	0.964	0.036	0.02	126
ALKP	–	–	208	–	–	–	1.0	–	0	208
AK	–	5	55	–	–	0.042	0.958	–	0.09	60
PGI	4	7	128	–	–	0.053	0.946	–	0.05	139
PGD	–	–	54	–	–	–	1.0	–	0	54
EST[b]										
								$\bar{H}$ =	0.0405 ± 0.001	

[a] Heterozygosity values. [b] Not included in the computation of heterozygosity values but is appreciably polymorphic due to observations of 10 electrophoretic phenotypes.

Genetic variability in a greenhouse-reared whitebacked planthopper population. The genetic variation at seven loci of greenhouse-reared WBPH individuals was investigated. The mean heterozygosity value of 0.0405 ± 0.001 was on the low side of the mean values observed for other invertebrates, which is 0.146 (Table 29). The existence of low genetic variability in the greenhouse population can be attributed to genetic drift.

Genetic evaluation and utilization (GEU) program

Drought tolerance

International Rice Testing Program, International Rice Germplasm Center, and Agronomy and Plant Breeding Departments

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SCREENING AND FIELD TESTING

International Rice Testing Program, International Rice Germplasm Center, and Agronomy and Plant Breeding Departments

Drought-tolerant materials identified in IRTP trials (*International Rice Testing Program*). The rice varieties and breeding lines listed in Table 1 exhibited good drought tolerance in various rainfed trials of the 1987 International Rice Testing Program (IRTP) nurseries, the data for which were received and analyzed in 1988.

1988 dry season field drought screening (*Agronomy*). We field-tested for drought reaction during the vegetative growth phase 5,861 rice varieties and lines from the International Rice Germplasm Center (IRGC), IRTP, and IRRI rice breeding programs (Table 2). Seed was drilled into dry soil. The field was sprinkler-irrigated regularly to keep the soil at the 10-cm depth within 0-30 kPa soil moisture tension (SMT). Drought stress was imposed on the 30-d-old seedlings thereafter.

Table 1. Materials identified for drought tolerance in 1987 IRTP trials.

Nursery[a]	Entries
IURYN-E (3 sites)	ADT31[b], CR222-MW10, CR289-1208, IR9729-67-3
IURYN-M (2 sites)	B3016-Tb-260-3-2-1-1-3, B3622e-Tb-5-4-4, B3622F-Tb-14-2
IURON (8 sites)	AUS257, AUS463, IAC118/81, IAC150/76, IAC233/79, IRAT112[b], B3906d-14-ST-16-48-3, CNA762069,GH319, IAC39/79
IRRSWYN-E (1 site)	IR13240-39-3-3-3-P1, IR19274-26-2-3-1, IR21015-80-3-3-1-2[b], IR26933-16-2-3[b], IR31429-14-2-3, IR31429-20-2-3, IR4563-1-1-3-6-1E-P1, IR8073-65-6-1-1E-P2, KKN7205-35-1-SKN-1-1, Ratna
IRRSWYN-M (1 site)	IR21188-87-3-3-2-2
IRRSWON (3 sites)	MRC8009-3536, IR26933-16-2-3, IR31432-2-3, RP1579-1863-73-32-53

[a]IURYN-E and -M = International Upland Rice Yield Nursery - Early-maturing and - Medium-maturing, URON = International Upland Rice Observational Nursery, IRRSWYN-E and -M = International Rice Rainfed Shallow Water Yield Nursery - Early-maturing and - Medium-maturing, IRRSWON = International Rice Rainfed Shallow Water Observational Nursery. [b]Also rated good in 1986 trials (reported in 1987).

Table 2. Number of entries and drought-tolerant selections in vegetative phase drought screening. IRRI, 1988 DS.

Seed source	Entries (no.)	Drought selections[a] (no.)
Germplasm bank	1164	39
IRTP	543	10
Upland rice breeding	481	15
Deepwater rice breeding	531	6
Rainfed lowland rice breeding	1956	23
Breeding for adverse environments	149	8
Irrigated rice yield trial	649	2
Hybridization block	224	6
Elite lines	109	0
Miscellaneous sources	55	2
	5861	111

[a]Entries with better drought reaction than drought-tolerant checks Salumpikit and IR442-2-58.

Entries were scored for drought reaction when SMT at the 15-cm soil depth was at 0.1-0.2, 0.4-0.5, and 0.8-1.0 MPa. After drought scoring at 0.8-1.0 MPa SMT, the plants were reirrigated, then scored for drought recovery ability 15 d later.

The 0.1-0.2 MPa drought scoring was done 10 d after cessation of irrigation, and the 0.4-0.5 MPa scoring 9 d later. Rains totaling 92 mm on 3 consecutive days interrupted further development of drought stress and delayed the 0.8-1.0 MPa scoring to 26 d after the 0.4-0.5 MPa scoring. (In previous years, 0.8-1.0 MPa SMT was attained 6-11 d after the 0.4-0.5 MPa scoring, except in 1982, when it took 20 d.)

One hundred eleven entries exhibited better drought reaction than did the drought-tolerant checks Salumpikit and IR442-2-58, and showed similar recovery ability as well (Table 2). These rices had only up to 25% fully dried leaves at 0.8-1.0 MPa SMT, while the checks had up to 50% fully desiccated leaves. Fourteen rices showed outstanding drought tolerance as indicated by partial leaf drying (Table 3). All 111 rices and drought-tolerant checks had 90-100% stand recovery at 15 d after rewatering.

Five of the 10 drought-tolerant entries from IRTP originated from Thailand, 3 from India, and 1 each from Indonesia and Ivory Coast. The 39 drought-tolerant IRGC materials consisted of 24

Table 3. Outstanding rices in vegetative phase drought screening. IRRI, 1988 DS.

Designation	Source[a]	Origin	Drought reaction[b]			Recovery[c]
			0.1-0.2 MPa	0.4-0.5 MPa	0.8-1.0 MPa	
AUS34	Germplasm bank	Bangladesh	0	1	3	1
BKN6988-52-1-3	IRTP (IFRON)	Thailand	0	1	2	1
BKNFR76055-166-4-1	IRTP (IRDWON)	Thailand	0	1	3	1
Boro Sani	Germplasm bank	India	0	1	3	1
IRAT116	IRTP (IRRSWON)	Ivory Coast	0	1	3	1
IRAT130	IRRI—Rainfed	Ivory Coast	0	2	3	1
IR37025-R-R-R-5-1	IRRI—Deepwater		0	2	3	1
IR46274-53-21-3-3-1	IRRI—Rainfed		0	0	3	1
IR46332-CPA-11-2-1-2	IRRI—Rainfed		0	2	3	1
IR49702-19-2-2	IRRI—Rainfed		0	1	3	1
Khamu	IRRI—Rainfed	Thailand	0	1	3	1
RD19	IRTP (IRDWON)	Thailand	0	0	2	1
SPR7410-0-64-1	IRTP (IRDWON)	Thailand	0	0	3	1
TCA178	IRTP (IRDWON)	India	0	0	3	1
IR442-2-58 (tolerant check)			1	3	5	1
Salumpikit (tolerant check)			1	2	5	1
IR20 (susceptible check)			3	5	7	3
IRAT9 (susceptible check)			4	6	8	7

[a]IFRON = International Floating Rice Observational Nursery, IRDWON = International Rice Deepwater Observational Nursery, IRRSWON = International Rice Rainfed Shallow Water Observational Nursery. [b]At given soil moisture tension at 15-cm depth. 0 to 9 scale, where 0 = no visible effects of drought stress, and 9 = all plants fully desiccated. [c]1 to 9 scale, where 1 = 90-100% plants fully recovered, and 9 = 0-19% plants fully recovered.

accessions from Bangladesh, 14 from India, and 1 from Pakistan.

Since the tests started in 1975, 62,645 rices have been tested for drought reaction to 0.1-1.0 MPa drought stress (Table 4). Eight hundred eleven rices exhibited better drought reaction than the drought-tolerant checks.

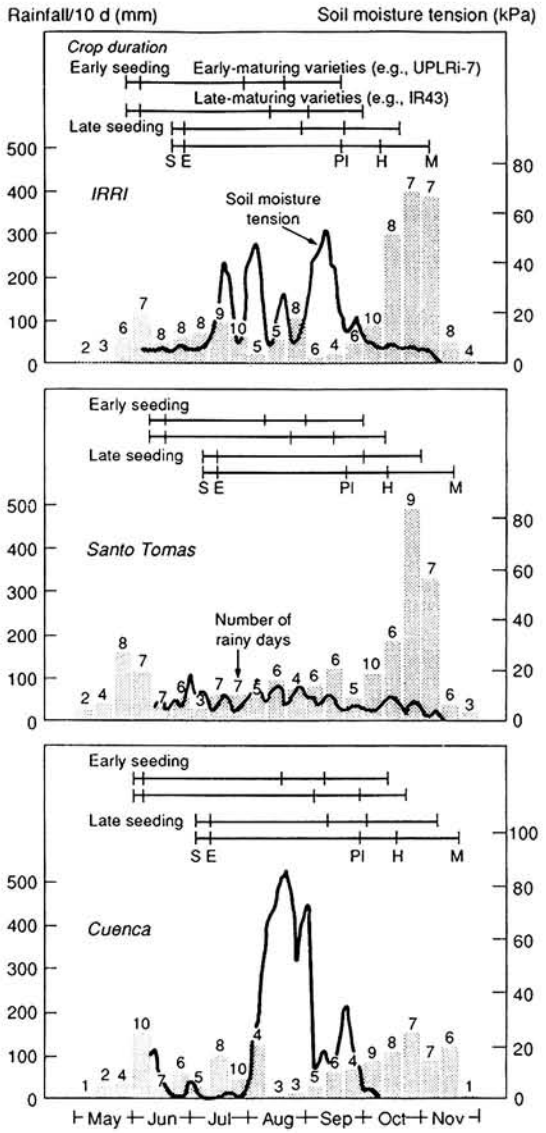
1988 wet season upland rice yield trials *(Agronomy)*. We tested three groups of varieties and lines for grain yield and other agronomic characters on the IRRI upland farm; in two farmers' fields in Santo Tomas and Cuenca, Batangas; and at two Philippine Bureau of Plant Industry (BPI) experiment stations in Ilagan, Isabela, and La Granja, Negros Occidental. The test consisted of the 20-entry International Upland Rice Yield Nursery - Early Maturing (IURYN-E) group and the 24-entry IURYN-M (medium-maturing) group from IRTP, plus the 36-entry upland rice yield trial (URYT) from IRRI's upland rice breeding and drought screening programs. Early and late seedings, 1 mo apart, were done at IRRI and the Batangas sites, whereas early seedings were done at the BPI stations.

Weather conditions during the 1988 wet season (WS) were unfavorable for rice growth at IRRI and the Cuenca and Ilagan sites (Fig. 1, 2). Rainfall was fairly adequate during the early part of the season at IRRI and in Cuenca. However, it

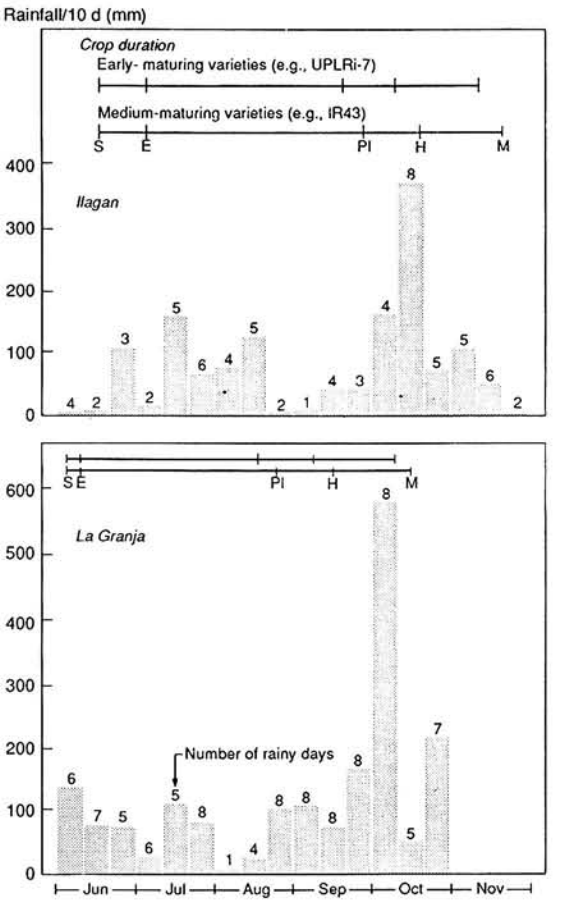
Table 4. Number of entries and outstanding selections in field screening for drought tolerance during the vegetative phase. IRRI, 1975-88 DS.

Year	Entries[a] (no.)	Outstanding selections[b] (no.)
1975	1,003	3
1976	1,016	6
1977	4,119	51
1978	4,772	56
1979	3,822	29
1980	4,540	166
1981	4,237	64
1982	3,750	26
1983	3,582	37
1984	5,978	38
1985	7,160	67
1986	6,224	21
1987	6,581	136
1988	5,861	111
Total	62,645	811

[a]Entries with good germination. [b]Entries with better drought tolerance scores than drought-tolerant checks IR442-2-58 and Salumpikit.



1. Decade rainfall, soil moisture tension, and crop duration at IRRI and Batangas, Philippines, upland rice experimental sites during 1988 WS performance trials. S = seeding, E = emergence, PI = panicle initiation, H = heading, M = maturity.



2. Decade rainfall and crop duration in Ilagan, Isabela, and La Granja, Negros Occidental, Philippines, during 1988 WS upland rice performance trials. S = seeding, E = emergence, PI = panicle initiation, H = heading, M = maturity.

was not sufficient for the medium- and late-maturing entries at IRRI or the early-maturing entries in Cuenca during the early reproductive phase–hence the zero to low yields of many entries. SMT at the 20-cm soil depth at IRRI went beyond 30 kPa three times, lasting for 5, 6, and 14 d from late July to early September (Fig. 1). The August-September drought stress in Cuenca caused SMT above 30 kPa to continue for 27 d (Fig. 1). An early dry spell in Ilagan delayed emergence until 15 d after seeding (DAS) and a late August to early September drought stress affected the early-maturing entries more adversely. Rainfall in Santo Tomas was adequate, as evidenced by a fairly stable SMT (Fig. 1).

At the La Granja site, the effect of low rainfall in early August was not manifested on the crop. However, the crop showed symptoms of Mn deficiency, interveinal chlorosis, dark brown streaks, and stunted growth, but tillered normally. Chemical analysis of 60-d-old plants revealed Mn contents below the critical level.

The early-seeded (9 Jun) 20-entry IURYN-E

Table 5. Grain yield of selected entries in upland rice performance trials at 5 Philippine sites.[a] 1988 WS.

Designation	Grain yield (t/ha)								
	IRRI		Santo Tomas		Cuenca		Ilagan	La Granja	Mean
	25 May	29 Jun	9 Jun[b]	6 Jul	1 Jun	5 Jul	15 Jun	6 Jun	
International Upland Rice Yield Nursery – Early-maturing group									
UPLRi-7 (check)	2.6 a	0.5 b	3.2 a	2.3 a	0.4 b	1.4 ab	0.8 bc	0.8 a	1.5
IR3646-9-3-1	1.2 c	1.1 a	3.4 a	1.8 ab	1.2 a	1.0 b	1.0 b	0.9 a	1.4
CR222-MW10	1.6 b	1.3 a	3.0 a	1.7 b	0.2 b	1.8 a	0.5 c	0.9 a	1.4
BG367-4	1.2 c	0.7 b	3.2 a	1.6 b	0.3 b	0.9 b	1.5 a	1.5 a	1.4
International Upland Rice Yield Nursery – Medium-maturing group									
IR43	0.9 bc	2.0 a	–	1.9 a	1.6 b	1.3 a	1.9 a	1.9 a	1.6
IR6023-10-1-1	1.4 b	1.2 c	–	1.9 a	1.7 b	1.3 a	1.2 b	1.9 a	1.5
UPLRi-5 (check)	1.2 b	1.4 bc	–	1.4 b	1.5 b	1.0 a	1.6 a	2.3 a	1.5
IR10147-113-5-1-1-5	2.0 a	1.6 b	–	1.5 ab	1.7 b	0.8 a	0.8 c	1.8 a	1.5
IR26957-86-2	0.5 c	1.6 b	–	1.6 ab	2.2 a	1.1 a	1.8 a	1.1 a	1.4
Upland Rice Yield Trial – Special group									
IR9560-2-6-3-1	1.4 cde	2.1 a	2.8 ab	1.7 ab	1.8 a	2.1 a	2.1 a	2.0 a	2.0
IR13754-12-3	0.9 def	1.6 b	3.2 a	1.7 ab	1.7 a	1.6 abc	2.0 a	2.0 a	1.8
IR49225-B-B-5-2	3.1 a	0.5 ef	3.8 a	2.0 a	0.7 cd	1.7 abc	1.1 c	1.8 a	1.8
IR13754-6-4	1.0 def	1.5 bc	3.4 a	1.3 bcd	1.6 ab	2.0 ab	1.6 abc	1.3 a	1.7
IR13754-6-3	0.5 ef	1.6 b	3.4 a	1.5 abc	2.0 a	1.6 abc	1.5 abc	1.5 a	1.7
IR49225-B-B-5-3	3.3 a	0.4 f	3.3 a	1.8 ab	0.7 cd	1.4 bcd	1.1 c	1.3 a	1.7
IR26957-86-2	0.1 f	1.2 cd	3.2 a	1.1 cd	1.8 a	1.6 abc	1.9 ab	2.0 a	1.6
BPIRi-6	2.1 bc	0.9 de	2.7 ab	1.3 bcd	1.0 bc	1.5 abc	1.2 c	2.0 a	1.6
UPLRi-5 (check)	1.6 bcd	1.3 bcd	2.9 ab	0.9 d	1.6 ab	0.9 de	1.6 abc	1.9 a	1.6
UPLRi-7 (check)	2.5 ab	0.5 ef	2.8 ab	1.8 ab	0.7 cd	1.2 cd	1.2 bc	1.1 a	1.5
Kinandang Patong (check)	1.0 def	0.5 ef	2.0 b	0.2 e	0.3 d	0.3 e	1.6 abc	1.3 a	0.9

[a]Within a nursery, values in a column followed by a common letter are not significantly different at the 5% level by DMRT. [b]Dashes indicate no observation.

and 36-entry URYT in Santo Tomas gave average yields of 2.5 and 2.7 t/ha, respectively (Table 5). The Santo Tomas late seeding (6 Jul) and tests at all other sites averaged way below 2.0 t/ha because of dry spells at the IRRI, Cuenca, and Ilagan sites and the suspected Mn deficiency at the La Granja site. IR49225-B-B-5-2, a product of the IRRI upland rice breeding program, yielded the highest, with 3.8 t/ha in the Santo Tomas early seeding (3 Jun) URYT (Table 5). A sister line, IR49225-B-B-5-3, yielded 3.3 t/ha with early seeding (25 May) at IRRI.

UPLRi-7, the check cultivar, had the best average yield performance in IURYN-E (Table 6), as in 1987 WS. IR3646-9-3-1 yielded higher than did UPLRi-7 with late seeding (29 Jun) at IRRI and with early seeding (1 Jun) at the Cuenca site, because the latter was severely affected by drought stress during the reproductive phase, although it had better drought reaction during the vegetative phase (Table 7).

In the IURYN-M group, semidwarf IR43, 3 intermediate-statured lines, and check cultivar UPLRi-5 yielded better among 7 semidwarf and 17 intermediate-statured entries (Table 6).

IR9560-2-6-3-1 gave the highest average yield over 5 sites in the URYT group (Table 6) and the highest yields in the late seeding (29 Jun) at IRRI, late seeding (5 Jul) in Cuenca, and mid-June seeding in Ilagan (Table 5). In previous years, IR9560-2-6-3-1 yielded better than did all test materials under drought stress.

Dry spells were more destructive to the early-maturing entries in all groups and at all test sites. Check cultivar UPLRi-7 and test entry IR49225-B-B-5-3, which headed in 83 and 84 d after seedling emergence (DE), respectively, were the earliest among the better yielding entries in the URYT

Table 6. Highest 3 replication mean yields in upland rice performance trials at 5 Philippine sites.[a] IRRI, 1988 WS.

Designation	Mean yield (t/ha)							
	IRRI		Santo Tomas		Cuenca		Ilagan	La Granja
	25 May	29 Jun	9 Jun[b]	6 Jul	1 Jun	5 Jul	15 Jun	6 Jun
			IURYN-E					
UPLRi-7 (check)	2.6	0.5	3.2	2.3	0.4	1.4	0.8	0.8
ADT31								2.3*
BG367-4							1.5*	
CR222-MW10		1.3*				1.8ns		
IR3646-9-3-1			3.4ns					
IR25588-7-3-1				2.3ns				
RAU4028-2					1.3*			
Group mean	1.2	0.4	2.5	1.5	0.4	0.8	0.5	1.3
			IURYN-M					
UPLRi-5 (check)	1.2	1.4	–	1.4	1.5	1.0	1.6	2.3
B3622F-TB-14-2	2.2*							
IAC220/79			–					2.9ns
IR43		2.0*	–	1.9*			1.9ns	
IR6023-10-1-1				1.9*				
IR26957-86-2					2.2*			
ITA212						1.4ns		
Group mean	1.1	0.8	–	1.1	0.9	0.8	0.8	1.7
			URYT-Special group					
UPLRi-5 (best check)	1.6	1.3	2.9	0.9	1.6	0.9	1.6	1.9
IR9560-2-6-3-1		2.1*				2.1*	2.1ns	
IR13754-6-3					2.0ns			
IR49225-B-B-5-2			3.8ns	2.0*				
IR49225-B-B-5-3	3.3*							
IR51388-B-B-B-1								2.4ns
Group mean	1.3	1.2	2.7	1.2	1.2	1.3	1.4	1.4

[a] * = better than group check at the 5% level by DMRT, ns = similar to group check at the 5% level by DMRT. [b] Dashes indicate no observation.

group (Table 7). Drought stress uniformly prolonged the growth duration of all entries in the early seeding (1 Jun) in Cuenca.

Neck blast was prevalent at IRRI and the Santo Tomas site (Table 7) while leaf blast was observed in Santo Tomas and Cuenca. Sheath rot was common at all three sites.

The suspected soil Mn deficiency in La Granja, which had been a problem for 3 yr and was most severe in 1988 WS, needs serious attention. The soil Mn content should be studied in relation to availability of other cations.

The destructive effect of drought stress that occurred toward the middle and later parts of the cropping season suggests a need for reproductive phase drought-tolerant cultivars. Crop management practices should be evaluated and improved to maximize use of limited water supply.

Screening for field resistance to drought (*International Rice Germplasm Center*). During the year, 6,494 cultivars and lines from the germplasm bank (GB) and the upland and lowland breeding nurseries, and from the introduced lines from Centro Nacional de Pesquisa-Arroz,. Feijão (CNPAF, Brazil), Centro Internacional de Agricultura Tropical (CIAT), and Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (IRAT) were screened for field resistance to drought (Table 8). Most of the upland traditional varieties from Sabah (Malaysia), Indonesia, and India were resistant to drought at the vegetative phase. Among the advanced breeding lines from the upland nursery, 70 to 80% also showed high levels of field resistance to drought, but among the early-generation breeding lines, only 45% were in the same category. The breed-

Table 7. Mean grain yield and other agronomic characters of selected entries in upland rice performance trials at 5 Philippine sites. IRRI, 1988 WS.

Designation	Mean grain yield (t/ha)	Days to heading (DE)[a]	Plant height (cm)	Panicles (no./m²)	Drought reaction[b]			Important diseases[c]				
					IRRI at 13 d	Cuenca at 30 d	Ilagan at 28 d	IRRI	Santo Tomas	Cuenca	Ilagan	La Granja
IURYN-E												
UPLRi-7 (check)	1.5	87 (76-100)	93	208	0	3	5	NBI	NBI	ShR	–	BSp
IR3646-9-3-1	1.4	91 (83-107)	109	176	3	4	5	BLS, ShR	NBI, ShR	ShR	–	–
CR222-MW10	1.4	85 (68-102)	81	208	1	3	5	BLS, ShR	NBI, ShR	ShR	NBLS	ShB
BG367-4	1.4	85 (73-99)	78	220	3	5	5	BLS, NBLS, ShR	LSm, ShR	ShR	–	ShB
IURYN-M												
IR43	1.6	100 (89-114)	76	232	1	3	5	ShR	ShR	LSc, ShB, ShR	–	–
IR6023-10-1-1	1.5	100 (90-113)	107	224	3	3	5	BLS, ShR	ShR	LSc, ShR	–	–
UPLRi-5 (check)	1.5	99 (91-112)	104	197	1	3	5	ShR	ShR	LSc, ShR	–	–
IR10147-113-5-1-1-5	1.5	97 (87-108)	107	190	1	3	6	BLS, ShR	–	LSc, ShR	–	–
IR26957-86-2	1.4	102 (96-117)	113	226	1	2	6	ShR	ShR	ShR	–	–
URYT-Special group												
IR9560-2-6-3-1	2.0	102 (93-114)	80	245	1	1	5	ShR	LSm, ShR	BB, LSc, ShR	–	ShB
IR13754-12-3	1.8	101 (89-111)	105	233	0	2	6	NBI, NBLS ShR	ShR	ShR	–	–
IR49225-B-B-5-2	1.8	86 (74-107)	95	198	0	2	7	NBI	ShR	ShR	–	–
IR13754-6-4	1.7	100 (88-115)	104	249	1	2	5	NBI, ShR	ShR	ShR	–	–
IR13754-6-3	1.7	99 (89-111)	105	244	1	2	5	ShR	ShR	BB, ShR	–	–
IR49225-B-B-5-3	1.7	84 (75-103)	94	194	0	3	6	NBI, ShR	NBI, ShR	LSc, ShR	–	–
IR26957-86-2	1.6	101 (92-114)	114	206	1	2	6	ShR	ShR	BB, ShR	–	–
BPIRi-6	1.6	96 (85-110)	96	200	1	3	5	NBI	NBI, ShR	NBI, ShR	–	–
UPLRi-5 (check)	1.6	97 (87-112)	106	174	1	4	6	NBI, ShR	NBI, ShR	NBI, ShR	–	–
UPLRi-7 (check)	1.5	83 (74-98)	96	189	0	2	4	NBI, ShR	NBI	ShR	–	–
Kinandang Patong (check)	0.9	92 (81-116)	125	115	1	2	6	BLS, ShR	LSm, ShR	ShR	–	–
IR20 (drought-susceptible)	1.0	98 (82-114)	78	197	5	5	7	NBI, ShR	NBI, ShR	NBLS, ShR	–	ShB

[a]DE = days after emergence. Numbers in parentheses indicate range obtained over 5 sites. [b]0-9 scale, where 1 = no visible effects of drought stress, and 9 = all plants fully desiccated. [c]NBI = neck blast, BLS = bacterial leaf streak, BB = bacterial blight, LSc = leaf scald, LSm = leaf smut, NBLS = narrow brown leaf spot, BSp = brown spot, ShB = sheath blight, ShR = sheath rot. Dashes indicate no observation.

Table 8. Plant reactions to field drought at the vegetative and reproductive growth phases. IRRI, 1988 DS.

Source[a]	Total no.	Plants (no.) showing a given reaction or score								
		1	2	3	4	5	6	7	8	9
				Vegetative phase						
Germplasm bank accessions	3675	27	6	160	124	1062	1654	612	2	28
Upland breeding nurseries										
URYT	100	13	1	38	28	18	1	1	0	0
UOYT	389	8	4	118	145	86	23	5	0	0
UPN	676	1	2	77	224	288	68	14	2	0
AUOYT	33			15	7	11				
Lowland breeding nurseries										
Rainfed lowland	779	1	0	26	66	342	265	78	0	1
Deepwater	587	3	0	51	110	268	94	59	1	1
GEU elite lines	50	0	0	0	2	30	13	5	0	0
Introduced lines										
CNA lines from Brazil	40			13	13	12	2			
CT lines from CIAT	27			5	3	11	5	3		
IRAT lines	79	1		11	25	30	10	2		
Traditional uplands	59	2		6	6	17	15	13		
				Reproductive phase						
Germplasm bank accessions	998	2		58		173		428		337
Upland breeding lines										
URYT	1	0		1						
UOYT	2			2						
UPN	42	0		12		21		9		
AUOYT	2					1		1		
Lowland breeding nurseries										
Rainfed lowland	12	1		0		9		2		0
GEU elite lines	5					2		3		
Introduced lines										
CNA lines from Brazil	34	13		16		5				
CT lines from CIAT	4			2		2				
IRAT lines	41			16		18		7		
Traditional uplands	12	4		2		6				

[a]URYT = Upland Rice Yield Trial, UOYT = Upland Observational Yield Trial, UPN = upland nurseries, AUOYT = Acid Upland Observational Yield Trial.

ing lines from the deepwater nursery showed a higher percentage (28%) with resistance to drought at the vegetative phase. Outstanding lines were IR46274-53-21-3-3-1, IR49645-16-2-2, and IR49702-8-1-2 with a score of 1. IR43552-80-3-1-3 from the rainfed-lowland nursery was highly resistant (score = 1), and about 26 other lines were moderately resistant (score = 3). Many lines from CNPAF, CIAT, and IRAT were also outstanding in field drought resistance at the vegetative phase.

Of the 3,675 GB accessions screened, only 998 flowered at the end of the test (Table 8). Of those, only 60 accessions had good grain filling. Some of the outstanding cultivars were Black Gora (Accessions 66255 and 66256), Sujan (Acc. 67537), and Rambhog (Acc. 67750) from India and Lal Ahu (Acc. 16121) from Nepal. Some cultivars from Korea also had good grain filling, namely Bando (Acc. 73043), Chilseong (Acc. 73047), and Jeonbukgungweonna (Acc. 73055). As these were early-maturing cultivars (90-118 DAS), it is probable that the escape mechanism (earliness) has contributed to field resistance at the reproductive phase.

Among the upland advanced breeding lines, IR32093-B-1-2-3, IR36269-B-B-B-1, and IR38547-B-B-B-15 were resistant (score of 3) at the reproductive phase. About 12 lines from the pedigree nurseries also showed promising field resistance

at the reproductive phase (Table 8). Many CNA lines from Brazil also showed good field resistance to drought at the reproductive phase. About 9 breeding lines from the rainfed-lowland nursery showed 50% grain filling, indicating an intermediate reaction to field drought. The reproductive phase is the time most sensitive to prolonged water stress.

Mass selection for drought resistance (*Agronomy and Plant Breeding*). To determine whether it is more efficient to improve genotypic drought tolerance through selection in early or late generations, we tested 7 IR11141-derived F_2 populations for survival under dryland conditions after initial supplemental irrigation by sprinklers up to 30 DE only. The populations had 25-75% drought-tolerant IR11141-6-1-4 in their ancestry. Some populations had an additional drought-tolerant ancestor, IR9782-111-2-1-2.

Large differences in number of panicles and seed weight per population were observed (Table 9), with the differences partly corresponding to percentage of IR11141-6-1-4 parentage. Comparisons with unselected populations from the same crosses will be made to estimate the progress from this type of selection.

SCREENING METHODS

Agronomy Department

Use of atrazine to screen rices for ability to remobilize and translocate assimilates during stress. The ability of rice to tolerate stress during flowering is related to its ability to store and remobilize assimilates. To develop screening methods to identify genotypes with superior ability to store and remobilize assimilates, field and greenhouse experiments were conducted in 1987 WS to determine dose response curves for atrazine, and the effects of atrazine on the growth, yield, and carbohydrate status of lowland rice.

Atrazine (0.05 kg active ingredient [ai]/ha) reduced the growth, yield, and yield components of rice under wet and drained lowland field conditions (Table 10). Effects of atrazine on growth and yield were related to reduced stomatal conductance (Fig. 3), leaf area, dry matter, and tiller production (Table 11).

Atrazine, like water deficit, reduced the photosynthetic surface and stomatal conductance and forced rice plants to depend more on stored assimilates from culms and leaf sheaths to set and grow grains as reflected by increased apparent translocation and apparent contribution rates (Table 12). Thus, anthesis stage drought tolerance in rice may be indirectly assessed by applying low concentrations of atrazine in a nonstress environment.

A chemical desiccant method for identifying rainfed lowland rices with postanthesis drought tolerance. Previous research has shown that tolerance for drought during flowering is related to storage and remobilization of assimilates. It is difficult to screen rices for drought tolerance at flowering because of asynchronous flowering. We hypothesized that reducing photosynthesis by using a chemical desiccant would force plants to depend on stored and remobilized assimilates, an effect similar to that of water deficit at flowering.

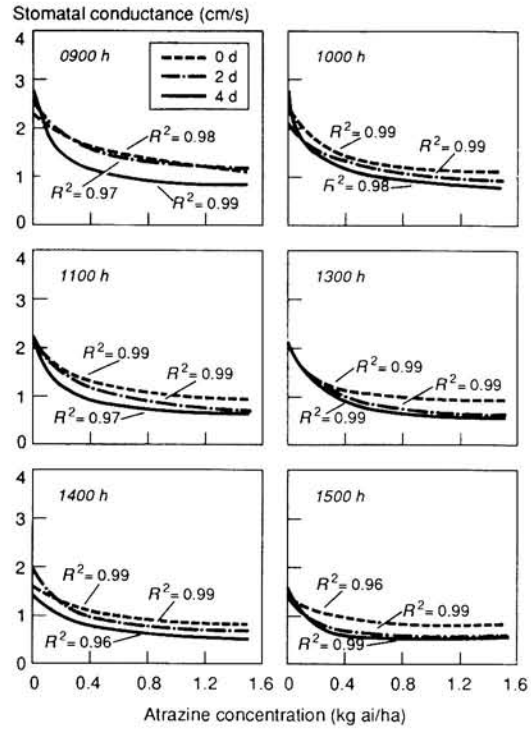
To test this hypothesis, we conducted a greenhouse experiment during 1988 DS using 2 pregerminated seedlings in pots containing about 8 kg

Table 9. Harvest from planting 100 g seed of each of 7 populations under dryland conditions. IRRI, 1988 DS.

Designation	Parentage	Percentage of IR11141-6-1-4	Panicles (no.)	Seed (g)
IR59087	IR64/IR11141-6-1-4//IR64	25	84	26
IR53590	IR42/IR11141-6-1-4	50	46	19
IR53592	IR11141-6-1-4/IR42	50	42	13
IR59101	IR9782-111-2-1-2/IR11141-6-1-4// IR11288-B-B-69-1	25	39	12
IR59098	IR9782-111-2-1-2/IR11141-6-1-4// IR7691-OT-4-2-2-1	25	187	100
IR53543	IR65/IR11141-6-1-4	50	198	42
IR59088	IR64/IR11141-6-1-4//IR11141-6-1-4	75	105	43

Table 10. Effect of atrazine on growth characters of IR64 at 20 d after panicle emergence, IRRI, 1987 WS.

Treatment	Tillers (no./m²)		Leaf area index		Dry weight of leaf blade (g/m²)		Dry weight of culm (g/m²)		Dry weight of leaf sheath (g/m²)		Total dry weight (g/m²)	
	Flooded	Drained	Flooded	Drained	Flooded	Drained	Flooded	Drained	Flooded	Drained	Flooded	Drained
Control (no spray)	399	343	3.43	2.20	160	146	161	141	65	66	757	617
Atrazine (0.05 kg ai/ha)	318	287	1.87	1.63	152	128	148	144	63	60	609	531
LSD (0.05) no spray vs. atrazine	53		0.29		28		25		14		66	
LSD (0.05) flooded vs. drained	17		0.13		8		7		6		20	



3. Dose response curve of atrazine on stomatal conductance. IRRI, 1987 WS.

dry soil. The desiccant (magnesium chlorate 4% ai) was applied to 6 rice cultivars at 2 growth stages: 10 d before panicle emergence (DBPE) and 5 d after panicle emergence (DAPE). Desiccant treatments were compared with water deficit treatments (80 kPa SMT) imposed at the same growth stages.

Water deficit and magnesium chlorate had similar effects on yield and yield components in all cultivars (Table 13). Magnesium chlorate had a slightly more detrimental effect on yield, presumably because the desiccant had a nearly instantaneous effect, whereas water deficit developed gradually over a 10-d period. Still, there were no significant differences between water deficit and the desiccation treatments. Relative yield reduction by drought and by the chemical desiccant were significantly correlated at 5 DAPE but not at 10 DBPE.

Thus, magnesium chlorate (4% ai) sprayed at 5 DAPE could be used for screening a large number of genotypes, because this method is faster than

Table 11. Effect of atrazine on yield and yield components of IR64. 1987 WS.

Treatment	Yield (mg/ha)		Panicles (no./m²)		Spikelets (no./panicle)		Grains (no./panicle)		Individual grain weight (mg)		Harvest index (%)		Tillers (no./m²)	
	Flooded	Drained	Flooded	Drained	Flooded	Drained	Flooded	Drained	Flooded	Drained	Flooded	Drained	Flooded	Drained
Control (no spray)	4.0	3.9	384	344	64	64	53	51	23.7	22.5	0.40	0.39	409	377
Atrazine (0.05 kg ai/ha)	3.2	3.0	286	268	55	45	37	28	19.7	17.7	0.34	0.36	320	283
LSD (0.05) no spray vs atrazine	0.1		18		3		2		0.8		0.03		17	
LSD (0.05) flooded vs drained	0.1		12		ns		2		0.7		0.10		17	

Table 12. Effect of atrazine on apparent translocation rate and apparent contribution rate of IR64. 1987 WS.

Treatment	Apparent translocation rate (%)		Apparent contribution rate (%)	
	Flooded	Drained	Flooded	Drained
Control (no spray)	0.05	0.16	0.20	0.20
Atrazine (0.05 kg ai/ha)	0.36	0.30	0.24	0.26
LSD (0.05) no spray vs atrazine	0.04		0.03	
LSD (0.05) flooded vs drained	0.07		0.02	

imposing drought conditions on individual cultivars having different flowering dates.

Water retention of excised rice leaves. Water retention of excised leaves has been used to characterize the drought resistance of wheat genotypes. A study was conducted to determine the water retention characteristics of excised rice leaves of six rice varieties and to assess the applicability of the method as a screening technique for drought resistance in rice.

Rices were grown in a greenhouse and subjected to 5 water treatments: continuously saturated, and no water applied at 25-35, 35-45, 50-60, or 85-90 DAS. At days 5 and 10 of each stress period, 3 fully expanded penultimate leaves (except during the 85-95 DAS stress period, when flag leaves were sampled) were excised and weighed. They were soaked in water for 2 h, then spread to dry. They were weighed after 1, 3, 5, and 7 h of drying and again after 24 h oven-drying at 80 °C. Water content was calculated from these weights.

Weighing leaf samples after 1-3 h of drying detected the greatest varietal differentiation. Differences in leaf water content were more pronounced in well-watered than in stressed plants. Kinandang Patong, a drought-resistant cultivar, almost always maintained higher leaf water content than IR20, a drought-susceptible cultivar. Water loss in Kinandang Patong also tended to slow down or level off at relatively higher water content than in IR20. Results suggest the possibility of using water retention capability to screen rices for drought tolerance under nonstressed conditions through repeated weighing of leaves after 1-3 h of drying.

Table 13. Effect of water deficit (80 kPa) and a chemical desiccant (magnesium chlorate 4% ai) on yield and yield components of rainfed lowland rice. IRRI, 1988 DS.

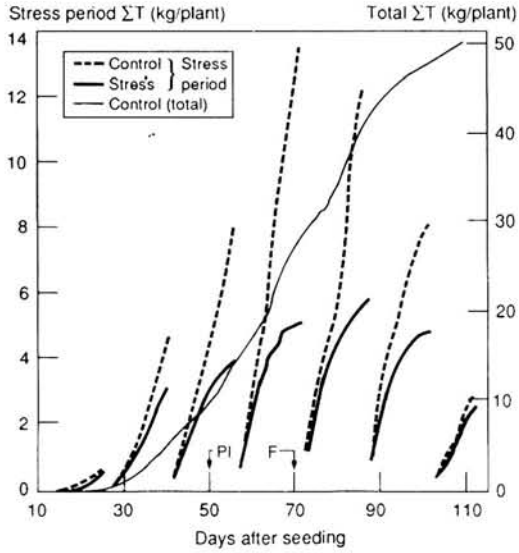
Treatment[a]	Grain yield (g/pot)	Panicles (no./pot)	Spikelets (no./panicle)	Panicle length (cm)	1000-grain weight (g)	Harvest index (%)	Unfilled grains (%)
			IR46				
Control	20.17	17.50	105.25	26.63	23.13	37.50	16.50
WD 10 DBPE	17.02	14.00	95.75	21.00	21.55	35.00	25.75
MC 10 DBPE	16.40	11.50	92.50	20.98	20.88	32.25	27.00
WD 5 DAPE	14.05	16.00	83.75	19.30	19.90	32.25	30.50
MC 5 DAPE	13.54	14.00	80.25	18.10	18.88	30.50	32.25
			IR32429-115-3-2-6				
Control	17.80	16.00	96.00	23.10	21.72	34.75	18.25
WD 10 DBPE	14.91	11.50	86.46	20.83	19.98	32.50	28.50
MC 10 DBPE	14.51	11.75	80.75	20.00	19.20	31.25	32.25
WD 5 DAPE	11.49	15.25	75.75	19.25	18.67	29.75	34.50
MC 5 DAPE	11.33	15.50	72.50	18.45	17.67	28.00	34.25
			N22				
Control	16.37	12.00	87.50	23.70	19.22	35.50	20.00
WD 10 DBPE	13.45	10.75	79.75	20.75	18.33	32.75	25.00
MC 10 DBPE	13.17	12.25	78.00	20.30	17.98	30.50	26.75
WD 5 DAPE	12.43	11.50	71.50	17.92	18.03	30.25	30.50
MC 5 DAPE	12.03	10.00	69.25	17.10	7.85	30.50	30.50
			IR43559-25-5-3-2				
Control	16.53	11.75	108.75	27.20	23.68	34.50	20.25
WD 10 DBPE	12.83	10.00	98.00	25.03	21.08	30.50	26.00
MC 10 DBPE	11.63	10.00	94.75	24.15	18.28	29.50	27.00
WD 5 DAPE	9.33	11.75	94.75	25.83	19.83	26.50	58.50
MC 5 DAPE	8.67	11.50	90.75	25.10	17.22	26.00	61.50
			IR52				
Control	18.15	14.00	107.00	29.08	24.40	37.50	19.75
WD 10 DBPE	14.05	11.50	100.75	27.30	22.95	35.75	21.50
MC 10 DBPE	13.82	11.50	94.50	26.18	22.75	32.75	23.00
WD 5 DAPE	9.01	13.00	87.00	26.43	19.30	30.25	63.75
MC 5 DAPE	8.67	13.50	85.25	25.10	17.88	27.75	67.25
			Salumpikit				
Control	12.80	11.00	86.96	24.00	26.55	36.00	19.00
WD 10 DBPE	10.44	8.75	74.75	21.10	25.60	33.00	27.00
WD 10 DBPE	9.75	8.00	71.75	20.15	24.95	31.75	26.50
WD 5 DAPE	7.92	10.75	71.75	18.63	21.10	30.50	35.00
MC 5 DAPE	7.85	10.75	68.00	18.60	20.38	29.50	35.75
LSD (0.05)	1.13	1.65	3.29	0.98	1.10	2.02	3.10

[a]WD = water deficit (80 kPa SMT), MC = magnesium chlorate (4% ai), DBPE = days before panicle emergence, DAPE = days after panicle emergence.

DROUGHT INDICES

Agronomy Department and International Rice Testing Program

Drought stress index for rice (*Agronomy*). In field trials on drought resistance at different locations and in different years, many factors in addition to water deficit affect yields. To identify that portion of a yield difference that results from differences in water deficit, a drought stress index is needed. A series of greenhouse experiments was begun in 1987 to quantify the effects of water deficit of different durations and at different growth stages on the transpiration and yield of rice. All experi-



4. Cumulative transpiration (ΣT) of IR64 stressed at different growth stages in experiment 1, IRRI, 1987. Left axis is for ΣT of control and stressed plants during stress period. Right axis is for total ΣT of control plants from 15 to 110 DAS. PI = panicle initiation, F = flowering.

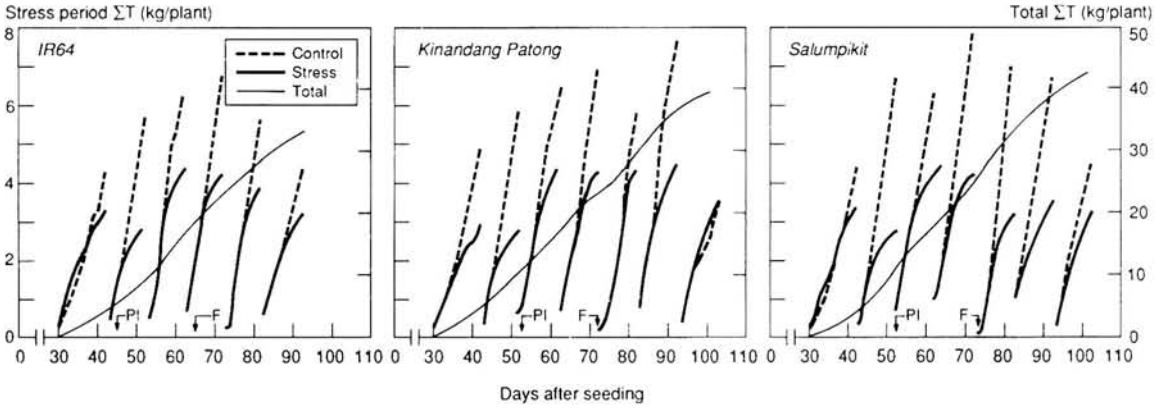
ments used plants grown in black polyvinyl chloride pots (20 cm diameter, 55 cm high) under aerobic soil conditions. Treatments were replicated 6 times with 1 plant/pot per replication, and pots were arranged in a randomized complete block design. Control pots were watered daily to maintain soil saturation. In experiment 1, only IR64 was grown, and water was withheld from stress treatment pots for 5, 10, or 15 d beginning at 10, 25, 40, 55, 70, 85, or 100 DAS. At the end of each stress period, pots were fully rewatered.

In experiment 2, IR64, Kinandang Patong, and Salumpikit were grown, and water was withheld from stress treatment pots from 30 to 43, 43 to 53, 53 to 63, 63 to 73, 73 to 83, 83 to 93, or 93 to 103 DAS. During stress periods, soil of control and of stress pots was covered with polyethylene lined with aluminum foil to minimize evaporation. Transpiration was determined by weighing the pots daily at 0700 h.

In experiment 1, the cumulative transpiration of IR64 stressed from 40 to 55, 55 to 70, and 70 to 85 DAS was 50, 38, and 47%, respectively, of that of control plants during the same periods. Control plants transpired about 50 kg of water from 14 DAS to maturity and produced about 50 g grain (Fig. 4).

In experiment 2, cumulative transpiration of control plants over a 10-d stress period was highest at flowering in all cultivars (Fig. 5). From 43 to 53 DAS, the ratio of cumulative transpiration of stressed to control plants, ΣTs/ΣTc, was 0.49 for IR64, 0.46 for Kinandang Patong, and 0.42 for Salumpikit. At flowering (63 to 73 DAS), ΣTs/ΣTc was 0.61 for IR64 and Kinandang Patong, and 0.54 for Salumpikit. Thus, young and mature plants were less severely stressed by withholding irrigation for a given duration than were plants stressed during reproductive growth.

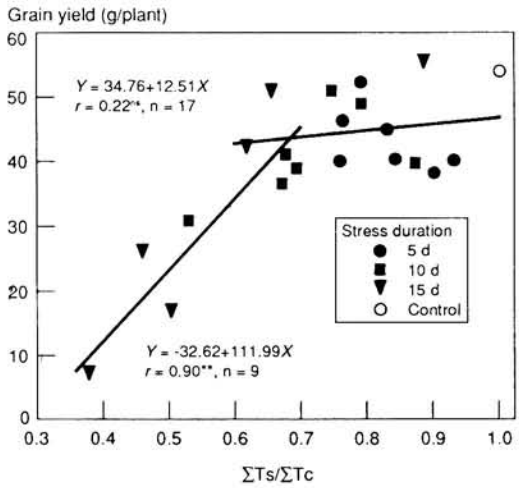
To determine the relationship between grain yield and transpiration, grain yield was plotted



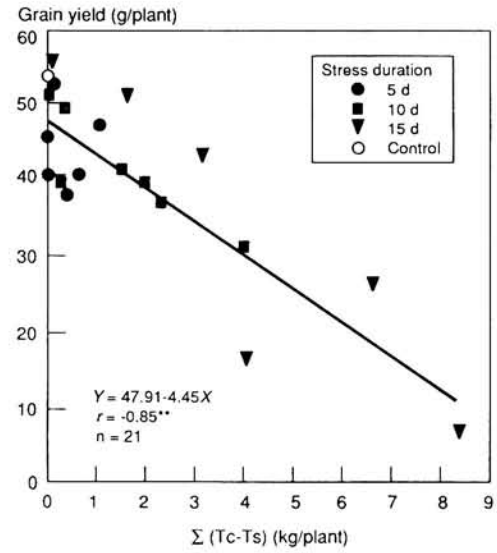
5. Cumulative transpiration (ΣT) of IR64, Kinandang Patong, and Salumpikit stressed for 10 d at different growth stages in experiment 2, IRRI, 1987. Left axis is for ΣT of control and stressed plants during stress period. Right axis is for total ΣT of control plants from 30 DAS to maturity.

against ΣTs/ΣTc and cumulative difference between transpiration of control and stressed plants, Σ(Tc-Ts). In experiment 1, the grain yield of IR64 decreased linearly with ΣTs/ΣTc when ΣTs/ΣTc was below 0.7 (Fig. 6). The grain yield of IR64 was inversely proportional to Σ(Tc-Ts) (Fig. 7). In experiment 2, the relationships between grain yield and ΣTs/ΣTc and Σ(Tc-Ts) for the three varieties were linear (Fig. 8, 9). However, for Kinandang Patong and Salumpikit, the relationship between transpiration and yield differed when plants were stressed at different growth stages. For Kinandang Patong, the point for plants stressed during flowering was separate from those during other growth stages. For Salumpikit, the points for plants stressed during flowering and panicle initiation were separate from those for plants stressed during the vegetative phase and the grain filling stage. More data are needed to give statistical accuracy to the relationships between transpiration and grain yield during reproductive phase water deficit, but the slopes of these relationships indicate that the reproductive growth phase of Kinandang Patong and Salumpikit is most sensitive to water deficit (Table 14). The sensitivity of IR64 to water deficit at different growth stages did not vary.

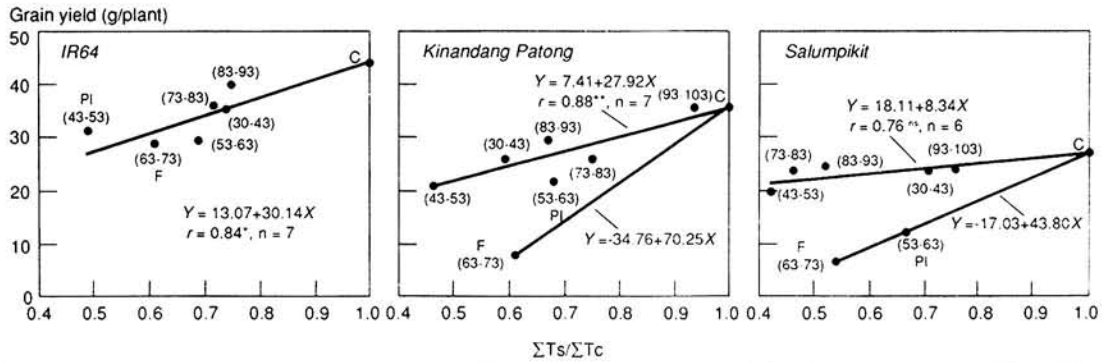
Screening for drought tolerance (*International Rice Testing Program*). To develop a drought tolerance index for rice, 30 genotypes belonging to the rainfed lowland, rainfed upland, and deepwater ecosystems showing different degrees of tolerance in IRTP multilocational trials were selected. They were subjected to laboratory tests: a) germination and seedling establishment over solutions of polyethylene glycol (PEG) maintained at -2 to -10 bar; b) desiccation injury (%) of fully expanded leaf segments under osmotic stress; c) reaction to 0.25% $KClO_3$ solution; d) tolerance for accelerated aging treatment (AAT, 100% relative humidity, 43 °C); and e) germination in the presence of nonanoic acid (5 mM, 3 ml). Isozyme patterns of esterase 2 (Est-2), maleate dehydrogenase (MDH), and peroxidase (POX) were also determined. Differences were observed with respect to drought tolerance reactions of the cultivars belonging to the indica and japonica ecogeographic races. While none of the abovementioned tests alone was adequate, a combination of three or more could identify most of the drought-tolerant genotypes. A drought tolerance index based on the combinations is being developed using germination over PEG, tolerance for AAT, and germination in the presence of nonanoic acid along with Est-2 isozyme patterns.



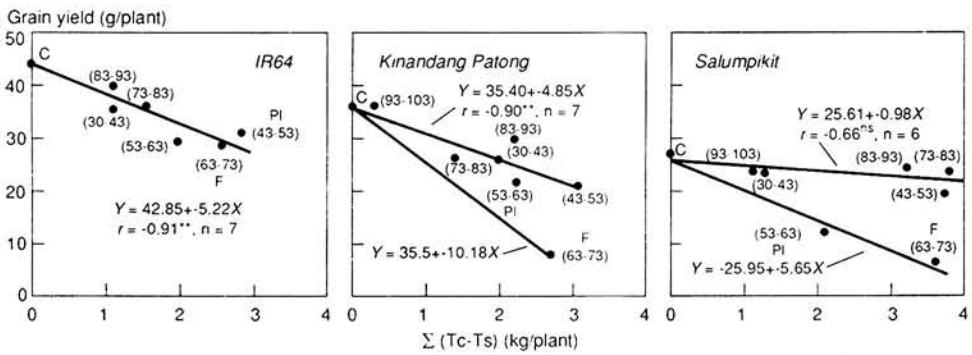
6. Relationship between cumulative transpiration ratio (ΣTs/ΣTc) and grain yield for IR64 in experiment 1, IRRI, 1987. Plants were stressed for 0, 5, 10, and 15 d at different growth stages.



7. Relationship between cumulative difference between daily transpiration of control and stressed plants Σ(Tc/Ts) and grain yield of IR64 in experiment 1, IRRI, 1987. Plants were stressed for 0, 5, 10, and 15 d at different growth stages.



8. Relationship between cumulative transpiration ratio (ΣTs/ΣTc) and grain yield of IR64, Kinandang Patong, and Salumpikit in experiment 2, IRRI, 1987. Plants were stressed for 10 d at different growth stages. C = control, F = flowering, PI = panicle initiation. Numbers in parentheses indicate the stress period in days after seeding.



9. Relationship between cumulative difference between daily transpiration of control and stressed plants Σ(Tc-Ts) and grain yield of IR64, Kinandang Patong, and Salumpikit in experiment 2, IRRI, 1987. Plants were stressed for 10 d at different growth stages. Numbers in parentheses indicate the stress period in days after seeding.

Table 14. Linear regression coefficient of the relationship of grain yield to cumulative transpiration ratio (ΣTs/ΣTc) and cumulative difference between daily transpiration of control and stressed plants Σ (Tc-Ts) at different growth stages in 3 rice varieties. IRRI, 1987.

Growth stage	Regression coefficient					
	IR64		Kinandang Patong[a]		Salumpikit	
	ΣTs/Tc	Σ (Tc–Ts)	ΣTs/Tc	Σ (Tc–Ts)	ΣTs/Tc	Σ (Tc–Ts)
Vegetative	30	–5	28	– 5	8	–1
Reproductive	30	–5	70 (F)	–10 (F)	44	–6
Grain filling	30	–5	28	– 5	8	–1

[a] F = flowering.

CARBOHYDRATE STORAGE AND REMOBILIZATION IN RELATION TO FLOWERING STAGE DROUGHT TOLERANCE

Agronomy Department

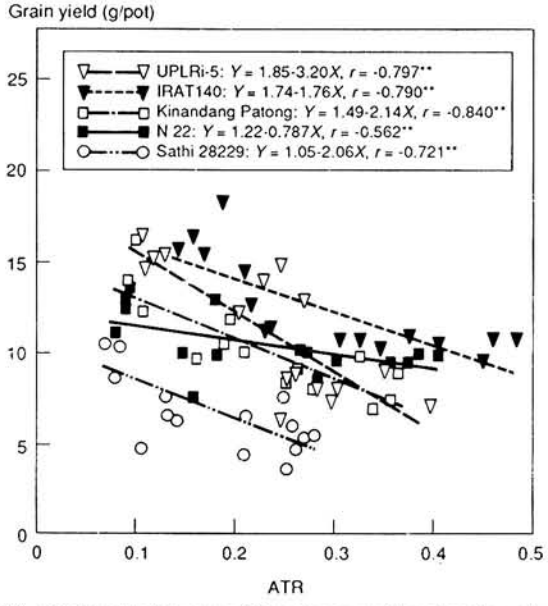
Substantial quantities of carbohydrates (CHO) are stored in different plant parts, and these reserve materials appear to be of paramount importance when rice experiences water deficit during flowering. A greenhouse experiment was conducted during 1987 DS to determine to what extent these reserve materials affect the drought tolerance of upland and lowland rices.

Table 15. Correlation (*r*) between grain yield and carbohydrate content in different plant parts for 5 upland and 5 lowland cultivars stressed at tillering, booting, and flowering. IRRI, 1987 DS.

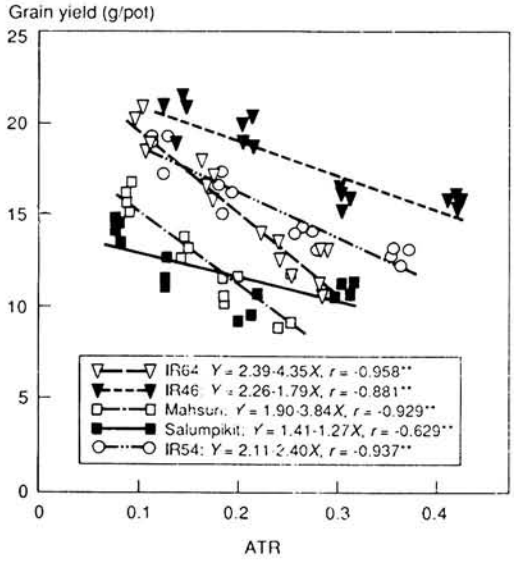
Plant part	Upland			Lowland		
	Tillering	Booting	Flowering	Tillering	Booting	Flowering
Leaf blade	.02ns	.50**	.80**	.21ns	.47**	.85**
Leaf sheath	.19ns	.51**	.82**	.20ns	.41**	.64**
Culm	.12ns	.45**	.77**	.20ns	.26ns	.52**

Five upland and five lowland rice cultivars were subjected to water deficit of 70-80 kPa SMT at tillering, booting, or flowering. Yield under stress at booting or flowering was positively correlated with level of tissue CHO, but yield under stress at tillering was not (Table 15). The apparent translocation rate (ATR) is the postanthesis decrease in dry weight of culm in relation to increase in panicle dry weight. Among different treatments of a single cultivar, yield was inversely correlated with ATR in both upland and lowland cultivars (Fig. 10, 11). Between different cultivars, yield was directly correlated with maximum ATR.

One goal of plant breeders is to produce germplasm with stable yields. One measure of yield stability is the slope of ATR vs yield



10. Relationship between yield and apparent translocation rate (ATR) in upland rices with water deficit at various developmental stages. IRRI, 1987 DS.



11. Relationship between yield and ATR in lowland rices with water deficit at various developmental stages. IRRI, 1987 DS.

regression – the smaller the slope, the more stable the yield. In this experiment, N22 had the most stable yield (Fig. 10) and IR64 the least (Fig. 11). Yield stability, while related to carbohydrate storage and remobilization, was also related to relatively low yields. A preferred cultivar would be one with high yield potential and moderate yield stability, such as IR46 for lowland and IRAT140 for upland conditions. These cultivars also have the greatest increase in ATR under stress conditions.

ROOT LESION NEMATODE IN UPLAND RICE

Agronomy Department

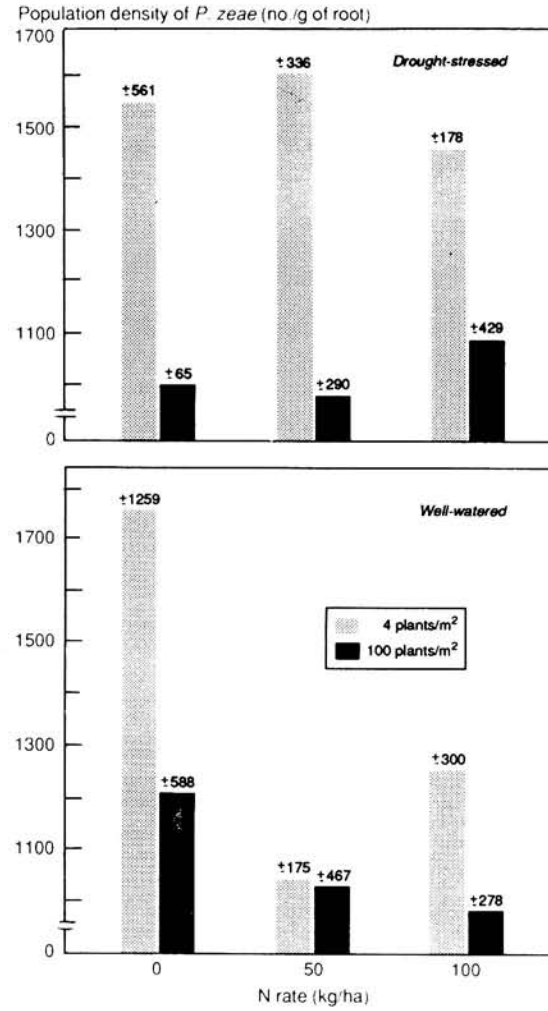
A 1985 survey reported 1,000 nematodes/g of rice roots in IRRI's experimental upland ricefields. *Pratylenchus zeae*, the root lesion nematode, was

the most common and potentially the most important parasitic nematode of upland rice. Its presence in experimental upland fields cannot be ignored, as it can affect experimental results, especially those on drought resistance. To determine whether nematode populations are affected by rice management practices, preliminary observations were made during 1987 DS. Experimental treatments were 2 irrigation levels (well-watered and drought-stressed [not watered for 12 d during maximum tillering]), 3 levels of N fertilization (0, 50, and 100 kg N/ha), and 2 plant population densities (PPD) (150 and 4 plants/m^2). Separate analyses of variance were done for drought-stressed and well-watered treatments.

Roots of UPLRi-5 were infested with up to 3,202 nematodes/g of roots, with an average of 1,246 nematodes/g of roots from different locations. Nematode counts were slightly higher under drought-stressed than under well-watered conditions (Fig. 12). At both irrigation levels, N fertilizer did not affect *P. zeae* population. Nematode infestation was generally higher in roots of plants under low than high PPD; but differences were significant only for drought-stressed plants. Thus, drought and low PPD favored *P. zeae* infestation of upland rice roots.

The association of yield with *P. zeae* density in roots was not clear, although it appeared that nematodes reduced yields of UPLRi-5.

More information is necessary to determine appropriate upland rice management practices that will reduce the effects of nematode populations.



12. *Pratylenchus zeae* population in roots of UPLRi-5, IRRI, 1987 DS. Numbers on bars represent standard deviation.

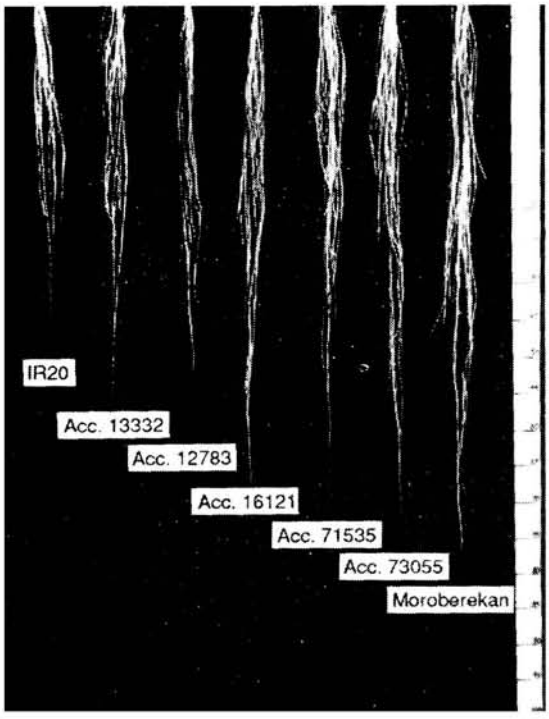
ROOT STUDIES IN AEROPONIC CULTURE

International Rice Germplasm Center

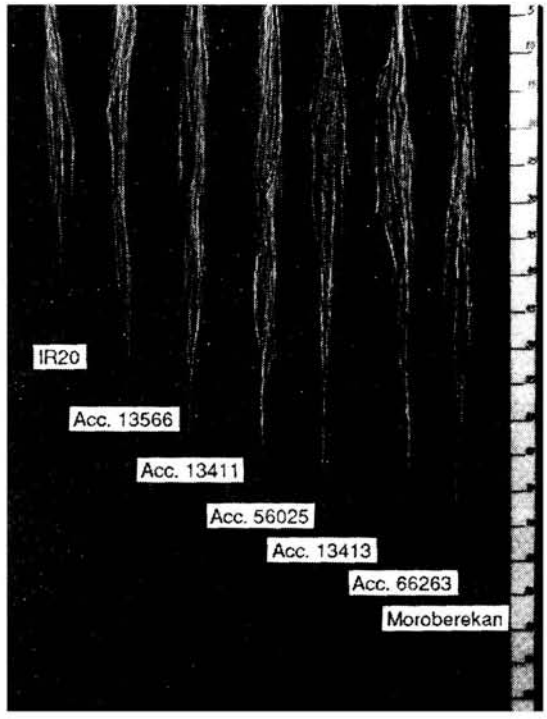
Recognizing the complex nature of the physiological mechanisms of field resistance to drought, we conducted a preliminary study to examine the roots of cultivars that headed and had good grain filling after a prolonged stress period in the drought screening field test in DS. Twenty-three varieties along with the traditional upland drought-resistant varieties Kinandang Patong and Moroberekan and the susceptible check IR20 were grown in aeroponic culture from June to July.

Analysis of variance showed highly significant differences in root length and root thickness among varieties. The coefficients of variation were 6.51% for root length and 11.83% for root thickness.

Two cultivars that produced highly fertile grains, Jeonbukgungweonna (Acc. 73055) from Korea and Sujan (Acc. 67537) from India, have moderately long and thick roots only (Fig. 13). However, both cultivars are early-maturing (96 and 118 d, respectively; Table 16). The moderately resistant cultivars Chawri Gora (Acc. 66263) and Kinandang Patong both have long and thick roots (Fig. 14) similar to those of Moroberekan, the resistant check. Early-maturing cultivars with long and moderately thick roots (Acc. 73047 and 73053) or moderately long and thick roots (Acc.



13. Roots of Jeonbukgungweonna (Acc. 73055) and other cultivars, compared with those of Moroberekan (resistant check) and IR20 (susceptible check) grown in aeroponic culture. IRRI, June-July 1988.



14. Roots of Chawri Gora (Acc. 66263), Boong Ngon (Acc. 56025), Moroberekan (resistant check), and IR20 (susceptible check) grown in aeroponic culture. IRRI, June-July 1988.

16121) also showed good grain filling during the DS test. In this particular set of varieties, the escape and avoidance mechanisms of field resistance to drought complemented each other.

Earliness alone does not guarantee that a cultivar can escape the serious effects of prolonged drought or water stress. Early-maturing cultivars Tauli (Acc. 16114) and Chalbyeo (Acc. 73046) have relatively shallow and thin roots similar to those of IR20. This could probably explain their highly susceptible reaction to prolonged drought (Table 16).

Similarly, thick roots alone, as demonstrated in drought-susceptible varieties Hong Do (Acc. 56075) and Abonga (Acc. 67542), cannot be taken as an index of drought avoidance (Table 16).

The preliminary results show the complex interaction of different physiological mechanisms. Earliness and reduction in evapotranspiration area via leaf rolling and slow drying of lower leaves may be a contributory factor to the conservation of water in plant tissues. An example is cultivar Boong Ngon (Acc. 56025), whose leaves remained green and unrolled (score = 1) during the stress period during the vegetative phase but produced only about 50% fertile grains (score = 5). In this particular variety, the roots were moderately long and thick (Fig. 14), and it is probable that the water extracted from the soil was not enough to support the evaporative demand of the shoot.

In general, the results again suggest that the avoidance mechanism via a combination of deep-and-thick root system enabled the plants to withstand the serious effects of water stress at the reproductive growth phase. Other avoidance mechanisms such as plasticity in leaf rolling contributed by the shoots should be thoroughly explored to further elucidate the complex mechanism of physiological resistance to field drought.

Table 16. Field drought score,[a] maturity, and length and thickness of roots of 25 test varieties grown in aeroponic culture. IRRI, 1988 WS.

Variety	Acc. no.	Drought score		Maturity (GB data) (d)	Root length (cm)	Root thickness (mm)
		Vegetative phase	Reproductive phase			
Jeonbukgungweonna	73055	3	1	96	67.94**,##	0.82**,##
Sujan	67537	5	1	118	65.08**,##	0.81**,##
Lal Ahu	16121	5	3	103	62.93**,##	1.01**,ns
Chapanj	16148	3	3	207	60.71**,##	0.82**,##
Dharia	64773	5	3	110	69.16**,#	0.89**,##
Chawri Gora	66263	3	3	118	73.79**,ns	1.04**,ns
Rambhog	67750	4	3	112	60.29**,##	0.93**,##
Chilseong	73047	4	3	103	71.05**,ns	0.85**,##
Jaeraeryudo	73053	3	3	102	75.28**,ns	0.89**,##
Oha	16140	5	5	103	63.54**,##	0.86**,##
Boong Ngon	56025	1	5	128	68.84**,#	0.87**,##
Karomok	71535	5	5	128	64.19**,##	0.91**,##
Rawal	71606	6	7	118	64.62**,##	0.97**,#
Waengchabyeo	73065	7	7	112	58.54**,##	0.83**,##
Indurok	71529	3	9	122	65.70**,##	0.87**,##
Tauli	16114	8	9	110	62.46**,##	0.63ns,##
Barkhe Tauli	16116	7	9	114	64.24**,##	0.83**,##
Hong Do	56075	7	9	130	69.54**,=	0.94**,##
Khau Lai La Cao Bang	60659	7	9	–	57.96**,##	0.67ns,##
Black Gora 5	66259	7	9	122	59.33**,##	0.71ns,##
Abonga	67542	6	9	134	56.75**,##	0.94**,##
Chalbyeo	73046	7	9	98	60.60**,##	0.70ns,##
Kinandang Patong (resistant check)	23364	3	3	125	73.89**,ns	0.96**,#
IR20 (susceptible check)	11355	7	–	124	46.05	0.60
Moroberekan (resistant check)	12048	5	2	135	74.82	1.10

LSD .01 = 6.53 0.1 = 0.16
.05 = 4.90 0.5 = 0.12

[a] Taken during 1988 DS. *, ** = significantly longer and thicker than IR20 at the 5% and 1% levels, respectively, by *t*-test. #, ## = significantly shorter and thinner than Moroberekan at the 5% and 1% levels, respectively, by *t*-test. ns = not significant.

Genetic evaluation and utilization (GEU) program

Adverse soils tolerance

Soils, Plant Breeding, and Plant Physiology Departments; International Rice Testing Program; and University of Sussex, United Kingdom

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This year 8,290 rices were tested for tolerance for salinity, alkalinity, Fe toxicity, peatiness, P deficiency, Zn deficiency, and acid upland conditions in the greenhouse and in the field in Pampanga, Pangasinan, Laguna, and Iloilo Provinces, Philippines. Outstanding rices among the 1,295 tolerant entries are listed in Table 1.

Multilocational results of the 1987 International Rice Testing Program (IRTP) screening for varietal tolerance for soil stresses were analyzed in 1988. The tests identified several promising entries (Table 2). Detailed information on IRTP trials is published in the IRTP annual nursery reports.

SALINITY

Soils, Plant Physiology, and Plant Breeding Departments; International Rice Testing Program; and University of Sussex, United Kingdom

Performance trials *(Soils)*. Varieties previously rated tolerant in mass screening tests were evaluated in salinized plots at IRRI and in farmers' fields in Pampanga, Pangasinan, and Iloilo during the dry season (DS) and the wet season (WS). These varieties are capable of producing more than 2 t/ha in spite of harsh conditions of high salinity compounded by acid sulfate conditions (Table 3).

In vivo chlorophyll fluorescence for screening *(Soils)*. In the search for more reliable screening methods, the potential of chlorophyll fluorescence was investigated. This method utilizes the changes in fluorescence when the photosynthetic mechanism of a green plant tissue is altered in response to a stress. The effect at solar radiation of 3.3 and 7.3 J/m^2 was studied. At the lower solar radiation, the visual scoring for salinity symptoms was sig-

Table 1. Entries found outstanding in greenhouse and field tests on adverse soils, 1988.

Stress	Location	Entries
Salinity	Greenhouse	Kalarata 1-24, Pokkali, IR42, IR36, IR48566-147-3-1-3, IR44526-47-3-2-27, IR44530-41-1-2-1, IR4595-4-1-13, IR43641-1-2-3-2-1, IR44670-168-2-3-1, IR39292-142-3-2-3
	Field	IR32809-26-3-3, IR19672-140-2-3-2-2, IR83360-5-1-3-1, IR4111-24-2-1-3, IR41431-11-2-1-3-3, IR43523-56-2-3-2, from advanced lines; IR9884-54-3-1E-P1, IR54742 from wide crosses; AC6519-31, AC6534-1, IR9884-54-3-1E-P1 from anther culture; IR37260-6-1-1-1-6-1, IR37263-6-1-3-3-1-2, IR46706 lines from tidal wetlands; Bhurarata 4-10, IR29337-36-3, Nona Bokra, IR36650-13-1-2-3, IR8236-B-B-57-2-1, IR13149-35-1 from IRSATON[a]
Alkalinity	Field	IR32809-26-3-3
Peatiness	Field	IR34686-179-1-2-1, IR33059-26-2-2, IR33238-25-2-3-2, IR41985-77-3-3-3, IR52280-96-2-2
P deficiency	Greenhouse	IR35366-28-3-1-2-2, IR37873-16-2-3-3-3-1, IR41985-32-2-2-3, IR44530-41-1-2-1, IR47441-B-B-B-33-B-B, IR47553-B-B-B-10-D-B, IR50134-B-B-9-B-D
Zn deficiency	Field	IR33059-26-2-2, IR40720-72-1-2
Inland Fe toxicity	Field	RP1486-842-1, RP1486-846-1, IR43053-31-42-1-1, IR15810-260-1-3-1-3, Yaya, Mahsuri, IR31375-5-2-1-1, IR43075-PM1-B-8-1-1, IR4414F-MR-6-3, CR213-1002, BRB32-52-1, IR43072-PM1-B-5-3-1, IR31363-1-1-3-3-2-1, Kankai-13-40-10-4, IR54741-3-47-4, IR54742-1-17-12, Pankaj, Pelita, Suakoko 8, IR34686-179-1-2-3
Acid upland soil conditions	Field	IAC272/78, Kalakari (Acc. 53347), AUS257, IAC118/81, IRAT141, Mahsuri, IRAT144

[a] International Rice Salinity and Alkalinity Tolerance Observational Nursery.

Table 2. Best performing entries in the 1987 IRTP soil stresses screening nurseries. IRRI, 1988.

Nursery	Trials (no.)	Entries
International Rice Salinity and Alkalinity Tolerance Observational Nursery		
Salinity	14	Bhurarata 4-10, BR51-282-8, B2433B-KN-10-1-1-1, Nona Bokra
Alkalinity	4	IR33238-25-2-3-2, IR22083-105-3-3-3-3
Acid Upland	2	Djoweh, IET1444, UPLRi-5, UPR103-80-1-2
Acid Lowland	5	IR9764-45-2-2, Kajalsail

nificantly related to the measurement parameters. This relationship was not confirmed at the higher solar radiation. Because reactions to salinity at high solar radiation become highly variable in the leaf, there was no correlation with scores.

Because of the high sensitivity of chlorophyll fluorescence to any stress affecting photosynthesis, it may be applicable only in highly controlled environments.

Reaction of Pokkali to salinity *(Soils)*. Pokkali is used as a parent in the salt tolerance hybridization program and as a resistant check in salinity mass screening tests. The germplasm bank has six Pokkali accessions from Sri Lanka, India, and elsewhere that are referred to as Pokkali.

In varietal tests on saline soils, inconsistent reactions of Pokkali have been observed. Differences in seed source may be the reason for the variability.

In 1988 DS and WS, the reactions of Pokkali accessions to salinity were examined, using the standard procedure for salinity greenhouse mass screening with six replications.

Accession 26869 was consistently the most tolerant during both seasons. In DS, when the electrical conductivity (EC) of the soil solution ranged from 8 to 10 dS/m, accession 26869 gave a mean score of 4 at 4 wk after transplanting, while the rest showed susceptibility (Fig. 1). In WS, when the EC of the soil solution was lower (5-8 dS/m), accession 26869 had a mean score of 5 but still emerged as the most tolerant (Table 4).

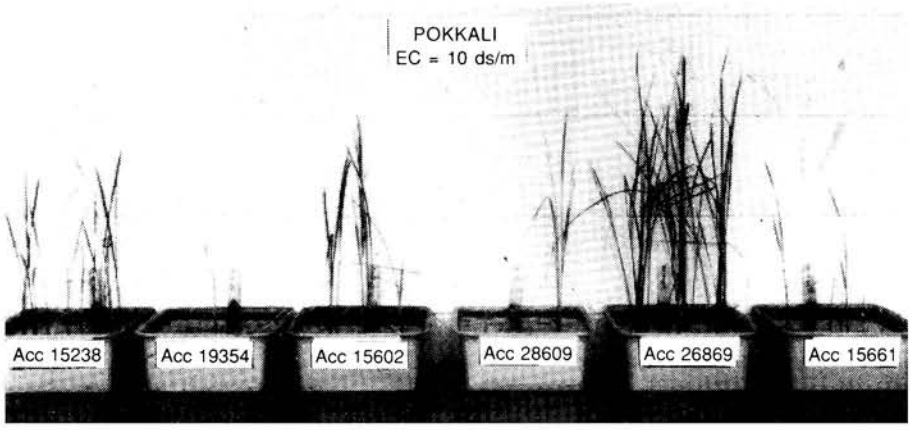
Salinity tolerance mechanism *(Soils)*. To understand salinity tolerance and to enable the formulation of simple screening tests, the characteristics of six varieties with known reactions to salinity were studied on salinized Maahas clay. Salt tolerance was related to the ability to absorb more nutrients; sustaining a balanced ratio; lower Na uptake (2-13 mmol/g dry weight in resistant rices against 30-130 mmol/g dry weight in susceptible rices); and restricting excessive salt entry into the younger leaves by maintaining Na in the culms and older leaves.

Aside from selective nutrient uptake by roots, rices minimize Na uptake by lowering transpiration with increasing salinity. Tolerant rices are able to regulate transpiration over a wider range of salinity (Fig. 2).

Physiology and genetics of salt tolerance *(Soils, Plant Breeding, and University of Sussex)*. Our collaborative research program with the University of Sussex, United Kingdom, on the physiology and genetics of salt tolerance mechanisms continued. Diallel analysis to determine mode of

Table 3. Yield of outstanding entries at 3 saline sites in the Philippines, 1988.

Soil	Cause of salinity	Entries (no.)	Outstanding entries	Grain yield (t/ha)
Maahas clay, Laguna	Salinized to EC_e= 6.6 dS/m	24	IR28228-12-3-1-1-1-2	>3
			IR34686-179-1-2-1, IR32307-107-3-2-2	
Bani, Pangasinan	Brackish water, EC_e = 12 dS/m	9	IR32809-26-3-3, IR28224-3-2-3-2	1.8
Iloilo	Tidal influence and acid sulfate soil conditions	78	ITA240 (Tox 711-2-6), ITA249 (Tox 711-17-9), Mahsuri	>2.5

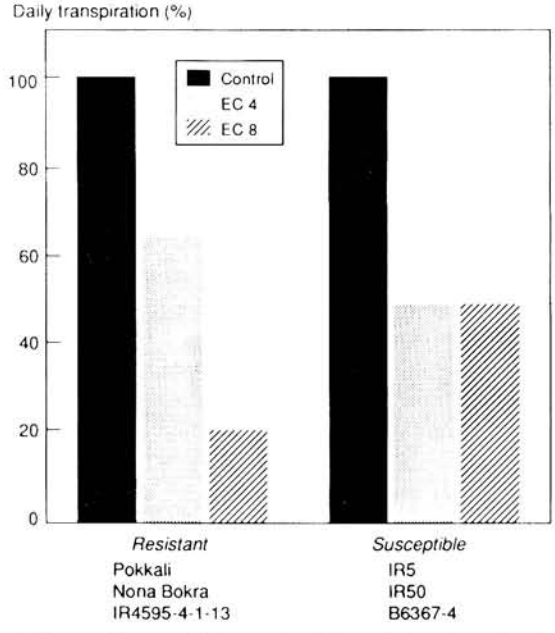


1. Reaction of Pokkali accessions to salinity (EC = 10 dS/m). IRRI, 1988.

Table 4. Reaction of Pokkali accessions to salinity at 4 wk after transplanting. IRRI, 1988.

Pokkali acc. no.	Country of origin	Score[a] DS	Score[a] WS
15238	Sri Lanka	7 a	7 b
15602	Sri Lanka	7 a	7 b
19354	Unknown	6 a	6 c
26869	Sri Lanka	4 b	5 d
28609	India	7 a	8 a

[a]Mean of 6 replications.



2. Mean daily transpiration (g H_2O/dry weight) of rice (2-wk-old seedlings) at different salinity levels. IRRI, 1988.

inheritance of different mechanisms identified and attempts to pyramid various mechanisms into one plant were still in progress. Preliminary observations indicate that the modern short-statured plant type of rice may be inconsistent with salinity tolerance. Any potential for increase in tolerance is lost by repeated selection in favor of the modern plant type. Obvious characteristics for tolerance appear to be seedling vigor, leaf longevity, intermediate to tall stature, and restricted Na uptake by roots.

Selection of potential donors for individual characteristics contributing to salt tolerance is done by physiological screening at Sussex before material is sent to IRRI for sequential pyramiding of genes. In collaborative screening tests at IRRI and Sussex, degree of submergence in the saline culture solution was a critical factor affecting plant reaction to salinity stress. Plants that were more submerged had better survival scores because of their lower transpiration. Salinity was also found to interfere with P transport to the shoots. In 8 rice varieties tested, salt at 50 mmol/liter decreased the P contents of the 3d, 4th, and 5th leaves. Data for one variety are shown in Table 5. As low as 0.004 mmol Na/g in the leaf decreased P uptake of the 5th leaf.

Relationship of embryo weight and salinity tolerance at seedling stage *(International Rice*

Table 5. P and Na content of CSR1 as affected by 50 mmol NaCl/liter.[a] IRRI, 1988.

Leaf	Control (mmol P/g)	With salt	
		P (mmol/g)	Na (mmol/g)
3d	0.382	0.267	0.166
4th	0.306	0.209	0.013
5th	0.176	0.128	0.004

[a]Mean of 15 leaf samples.

Testing Program). Nineteen indica and six japonica cultivars having a range of embryo weights were screened for salt tolerance using the water culture technique in the IRRI phytotron glasshouse at 29/21 °C (day/night) temperature with about 70% relative humidity under natural daylight. Seedling survival after 2 wk of salinization with 6,800 ppm (EC 12 dS/m) was taken as the criterion for salt tolerance. Salinity stress of 6,800 ppm was introduced by adding a 1:1 mixture of NaCl and $CaCl_2$ to the nutrient solution.

The embryo weight per 50 seeds of the cultivars evaluated ranged from 0.0140 g (Intan Gawri and Palman 46) to 0.0467 g (Rikuto Norin 15). The seedling survival percentage under salinity stress ranged from 2 (Palman 46) to 90 (IR51491-AC4-6). Rikuto Norin 15, Bombilla, Chang You Zae Rae, Thatnosubnet, and Jinbu 4—having higher embryo weights of 0.0467, 0.0454, 0.0450, 0.0440, and 0.0393 g, respectively—were susceptible to salinity, while Pokkali and Nona Bokra—having higher embryo weights of 0.0386 and 0.0358 g—were tolerant (Table 6). IR51491-AC4-6 and IR51491-AC4-7, having average embryo weights of 0.0309 and 0.0297 g, respectively, had better survival percentages than RNR1429 and IR31779-19-3-3-2-2 with the same range of embryo weight. Suweon 341, with a lower embryo weight of 0.0219 g, had 70% seedling survival, whereas Laxmi, IR28, IR36, NIAB6, and Duansan, having comparable embryo weights, recorded survival ranging from 8 to 42%. The association between embryo weight and salt tolerance among the cultivars studied was nonsignificant ($r = 0.2151$). This finding does not support the earlier report of such an association (Annual report for 1987).

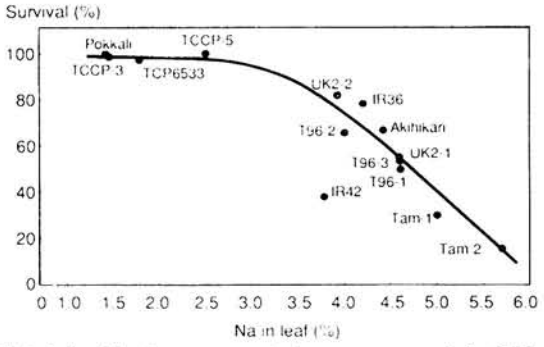
Physiological studies on salt tolerance *(Plant Physiology)*. Three semidwarf tissue culture lines of Pokkali—TCP6533-8-2, TCCP266-2-49-B-B-3, and TCCP266-2-49-B-B-5—were evaluated for their reaction to salinity together with IR36, IR42, and eight japonica cultivars and lines. TCP6533-8-2 was produced by anther culture of the F_1 of IR4630-22-2-5-1-3/Pokkali followed by conventional selection methods. The two other lines were somaclonal variants of Pokkali produced by the Tissue Culture for Crops Project, University of Colorado, USA, and later selected at IRRI. Six-day-old seedlings were salinized with NaCl of 8 and 15 dS/m for 6 and 12 d.

Table 6. Correlation[a] between embryo weight and seedling survival after 15 d of salinization (EC = 12 dS/m). IRRI, 1988.

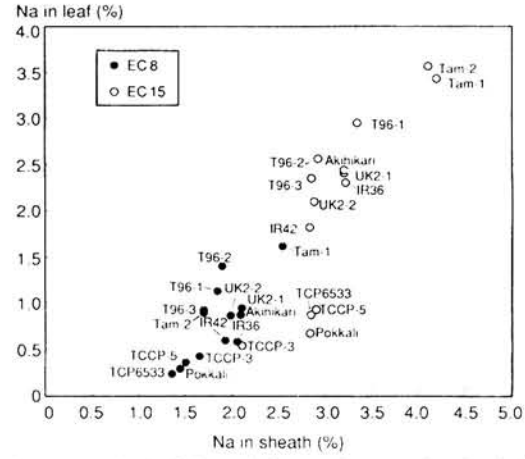
Cultivar	Embryo weight (g)	Survival (%)
Rikuto Norin 15	0.0467	7
Bombilla	0.0454	36
Chang You Zae Rae	0.0450	10
Thatnosubnet	0.0440	12
Jinbu 4	0.0393	45
Pokkali	0.0386	85
Nona Bokra	0.0358	89
IR51491-AC4-6	0.0309	90
IR31779-19-3-3-2-2	0.0302	10
RNR1429	0.0299	18
IR51491-AC4-7	0.0297	82
IR51500-AC9-8	0.0272	32
TNAU (AD) 103	0.0263	8
MI-48	0.0245	2
Khao youth	0.0237	22
IR25924-92-1-3	0.0236	5
Laxmi	0.0227	8
IR28	0.0226	20
Suweon 341	0.0219	70
IR36	0.0209	42
NIAB6	0.0208	25
Duansan	0.0202	18
Basmati 370	0.0195	20
Intan Gawri	0.0140	8
Palman 46	0.0140	2

[a]$r = 0.2151^{ns}$.

The three tissue culture lines showed tolerance comparable with that of parent Pokkali in terms of growth and survival under salinized conditions. Survival percentage was negatively correlated with Na content in the leaf after 12 d of salinization with NaCl of 15 dS/m (Fig. 3). The high survival of Pokkali and its variants can be attributed to low Na concentrations in the leaf. Among the japonica entries, UK2-2 had the highest survival, but the



3. Relationship between survival percentage and leaf Na content after 12 d of treatment with NaCl of 15 dS/m. IRRI, 1988.



4. Increase in leaf Na relative to increase in sheath Na concentration after 6 d of treatment with NaCl of 8 and 15 dS/m. IRRI, 1988.

amount of Na absorbed in the leaf was relatively high.

Since Na is first absorbed in the sheath, the amount of Na in the sheath is expected to be higher than that in the leaf. On the average, however, japonica and IR cultivars had almost equal concentrations of Na in the leaves and sheaths after 6 d of treatment with NaCl of 8 and 15 dS/m (Fig. 4). This can mean that in these cultivars, Na absorbed in the sheath is readily transported to the leaf, causing tissue death. On the other hand, the leaf Na concentration of Pokkali and its variants was only about 1/4 of sheath Na concentration. Whether this low leaf Na-sheath Na concentration ratio of Pokkali and its variants was due to dilution (high leaf area or leaf dry weight, Table 7) or to some other mechanism that prevents the entry of Na ions into the leaf will be the subject of further investigation.

These results show that with tissue culture, it is possible to improve the plant type of a traditional salt-tolerant cultivar without losing its desirable characteristics or to transfer the salt-tolerance genes of a traditional cultivar into a high-yielding line.

ALKALINITY

Soils Department

Performance trials. In alkalized (sodium absorption ratio = 34, pH = 8.4) plots at IRRI, the yields of 16 entries were evaluated. Top yielders were IR32307-107-3-2-2 (4 t/ha), IR32809-26-3-3 (3.8 t/ha), IR32809-26-3-3 (3.8 t/ha), IR28228-12-3-1-1-2 (3.7 t/ha), and IR37873-16-2-3-3-1 (3.7 t/ha).

PHOSPHORUS DEFICIENCY

Soils Department

Performance trials. In farmers' fields in Laguna, the performance of 32 rices of known reaction to P deficiency was evaluated in amended and unamended soils. Six (IR28222-9-2-2-2, IR28228-12-3-1-1-2, IR32453-20-3-2-2, IR35366-28-3-1-2-2, IR35366-90-3-2-1-2, and IR39357-133-3-2-2) were rated P efficient and highly responsive to P application, their response ranging from 1.1 to 2.5 t/ha.

The P-efficient rices recovered at late tillering. In unamended soils, the maturity of the P-efficient entries was delayed up to 3 wk compared with those in amended soils. When the P-efficient entries recovered, they produced more straw than those grown on amended soils, although grain yields were the same.

The entries found to be inefficient P users were also nonresponsive to P addition.

ZINC DEFICIENCY

Soils Department

Performance trials. The performance of 40 promising rices was evaluated in an unamended Zn-deficient (pH 6.8, available Zn 0.1 mg/kg) farmer's field (Table 8). The efficient entries produced 4 t/ha during both WS and DS, while the inefficient rices gave only 2.4 t/ha during DS and

Table 7. Effect of salinization on leaf area, dry weight, and leaf area ratio (LAR) of rice cultivars and lines. IRRI, 1988.

Cultivar or line	EC (dS/m)	Before treatment			After treatment		
		Leaf area (cm^2)	Dry weight (mg)	LAR (dm^2/g)	Leaf area (cm^2)	Dry weight (mg)	LAR (dm^2/g)
Pokkali	0	4.8	23	2.1	18.6	100	1.9
	8				21.2	107	2.0
	15				10.6	76	1.4
TCP6533-8-2	0	3.4	20	1.7	18.5	107	1.7
	8				14.0	106	1.3
	15				6.5	64	1.0
TCCP266-2-49-B-B-3	0	3.6	18	2.0	22.5	99	2.3
	8				17.1	82	2.1
	15				10.4	64	1.6
TCCP266-2-49-B-B-5	0	3.2	17	1.9	22.8	110	2.1
	8				18.2	88	2.1
	15				6.7	58	1.2
IR36	0	1.7	13	1.4	13.8	72	1.9
	8				7.4	53	1.4
	15				0.6	26	0.2
Akihikari	0	1.8	12	1.5	9.55	49	2.0
	8				4.01	35	1.1
	15				0.58	24	0.2

1.4 t/ha in WS. The efficient Zn users belonged to the intermediate plant types, which mature in 130 d; the inefficient rices were short and matured in 118 d. The moderately efficient entries had yields of 3.0-3.8 t/ha, were of intermediate plant type, and matured within 130 d.

The use of 2% ZnO seedling dip in a severely Zn-deficient soil produced a yield increase of up to 1.7 t/ha (Table 9) for both the resistant and susceptible entries.

Table 8. Grain yield of some rices in a Zn-deficient soil. IRRI, 1988.

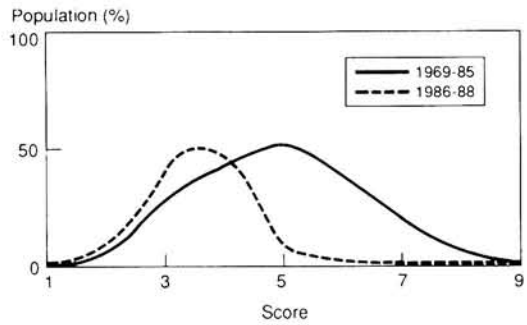
Entry	Plant type	Duration (d)	Grain yield (t/ha)	
			DS	WS
Zn-efficient				
IR13149-71-3-2-2	Intermediate	133	4.2	4.0
IR21567-18-3	Short	118	3.8	4.2
IR29723-2-3-3	Intermediate	133	4.0	3.8
IR33360-31-1-1-3	Intermediate	133	4.1	4.1
Zn-inefficient				
IR19743-25-2-2-3-1	Short	118	2.9	1.1
IR31802-48-2-2-2	Short	118	2.6	1.6
IR41985-111-3-2-2	Short	118	2.6	1.6
IR42905-83-3-2-2	Short	118	1.8	1.4

Increased zinc efficiency. The frequency of scores of rices screened since 1969 for tolerance for Zn deficiency revealed a normal distribution. Nine percent of all rices scored 3 or better on the *Standard evaluation system for rice* scale of 1-9. The significant shift toward higher frequency of tolerance of the 950 improved lines from 1986 to 1988 indicates the successful enhancement of tolerance for Zn deficiency in IRRI's breeding program (Fig. 5).

Table 9. Yield of some rices with and without Zn dip. IRRI, 1988.

Entry	Reaction[a]	Yield (t/ha)		Yield increase[b] (t/ha)
		Without Zn	With Zn	
IR9764-45-2	R	2.5	3.8	1.2*
IR64	MR	1.4	3.1	1.7*
IR66	MR	3.8	4.1	0.4
IR29692-78-2-2-1	MR	3.5	3.9	0.5
IR39423-124-3-3-1	S	2.9	3.8	0.9
IR31787-16-2-3-2	S	2.2	3.5	1.3*

[a] R = resistant, MR = moderately resistant, S = susceptible.
[b] * = significant at the 5% level by DMRT.



5. Distribution of scores of IRRI breeding lines for Zn utilization efficiency, 1988.

MULTIPLE STRESSES

Soils and Plant Breeding Departments

Peatiness *(Soils)*. In a peat soil (pH 6.2, organic C 19%, available Zn 0.47 mg/kg) in Calauan, Laguna, amended with 50-50-25 kg NPK/ha and ZnO seedling dip, the grain yields of 10 rices were compared during WS. IR36 performed best at 2.9 t/ha; IR42 was the poorest.

Inland iron-toxic soils *(Soils and Plant Breeding)*. In San Dionisio, Iloilo (pH 3.8, active Fe 2.3%), the highest yielding entries included BR51-91-7 and CR213-1002 (early maturity); BR51-282-8-HR83, IR31432-8-6, IR31432-9-3-2, IR31662-34-1-2, and IR142-99 (medium maturity); and CR1002, IR13610-72-2-2E-P2, IR21820-654-3-2-2-3, Matcandu, Pankaj, and Suakoko 8.

Acid upland soil conditions *(Soils)*. Three IR47686 lines gave an average yield of 1.7 t/ha under acid conditions, while Azucena yielded 0.8 t/ha under 2 acidity levels in farmers' fields in Laguna.

Sixty-one rices (40 from IRTP and 21 from the Multiple Cropping Department [MCD]) were tested at 2 sites in Bagacay, San Dionisio, and Fuentes, Banate, both in Iloilo. Mean grain yield of the IRTP entries was 1.1 t/ha. The highest yielders, with 1.6 t/ha each, were CR222-MW-10 and B3016B-TB-260-3-2-1-1-3 (Table 10). Three entries performed well at both sites: IR12979-24-3-4, AUS257, and IR27078-11-2.

The highest yield from the MCD entries was 1.5 t/ha (IR47686-6-1-1).

Multiple stress tolerance *(Soils)*. In Iloilo, eight rices were rated promising across all lowland key sites (inland Fe toxic and saline/acid sulfate soils): IR33360-5-1-3-1, IR41431-11-2-1-3-3, IR46706-49-3-1, IR46706-153-3-2, IR54742-43-35-15, IR54745-2-2-25, IR54745-2-21-11, and IR54746-2-5-14.

In concrete beds with problem soils, the multiple stress tolerance of IR66, IR68, IR9764-45-2, and IR32429-47 was confirmed during WS and DS. Those varieties are tolerant of salinity, alkalinity, saline-alkali soils, peatiness, acid sulfate soil condition, B toxicity, P deficiency, and Zn deficiency.

Table 10. Some promising upland rices selected in Iloilo, Philippines, 1988.

Nursery and entry	Phenotypic acceptability score	Days to flowering	Height (cm)	Panicles (no./m²)	Yield (t/ha)
International Upland Rice Yield Nursery (Early)					
CR222-MW-10	4	66	75	376	1.6
RPCB-28-849 (IET1444)	4	69	91	396	1.4
UPR103-80-1-2	4	65	78	360	1.4
International Upland Rice Yield Nursery (Medium)					
B3016B-TB-260-3-2-1-1-3	4	71	120	368	1.6
B3622E-TB-5-4-4	4	72	130	332	1.5
C894-7	4	82	95	360	1.5
BR319-1	4	78	98	352	1.4
B3622F-TB-14-2	4	80	125	332	1.4
IR12979-24-3-4	5	78	108	332	1.4

Genetic evaluation and utilization (GEU) program

Deepwater and flood tolerance

Agronomy, Soils, Plant Breeding, and Plant Physiology Departments; and Department of Agriculture, Thailand

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FIELD SCREENING OF DEEPWATER RICE

Soils and Plant Breeding Departments

At Tamis-ac, Concepcion, Iloilo, Philippines, 1,162 elongating rices including 699 from Cambodia were tested for elongating ability and deepwater tolerance in a farmer's field. They were sown in furrows with a spacing of 30 cm in dry soil before the onset of rains. After germination, the water depth in the field was gradually increased to 75 cm over 6 wk and was maintained at this level throughout the growth period. However, heavy rains at 30 days after sowing (DAS), 47 DAS, and 60 DAS raised the water level to more than 1.2 m. Taller varieties were submerged for 5-9 d, and shorter entries for longer periods during each flood.

Submergence tolerance was observed in 129 rices (104 from IRRI and 25 from Cambodia). Of these, 25 were outstanding (Table 1). They all had a plant height > 1.0 m and a flood tolerance score of 5 or better, and they produced grain yields of 200 g/m^2.

In addition, 72 F_2 and 222 F_3 populations were evaluated in a nearby field with similar soil and hydrological conditions. Of those, 23 F_2 and 27 F_3 populations were rated promising, and the surviving plants were harvested in bulk.

Table 1. Some promising rices from deepwater screening in Iloilo, Philippines, 1988.

Parentage and designation	Phenotypic acceptability score	Height (cm)	Lodging score	Yield (g/m^2)
IR42441 (IR11288-B-B-118-1//RD19/IR7835-28-2-3)				
IR42441-128-2-1-1-3	5	108	5	214
IR42441-128-2-1-3-2	5	103	5	286
IR42497 (BIET927/DWCT156-1//RP975-109-2/IR52)				
IR42497-118-3-2-1-2	5	130	5	260
IR42497-15-3-2-2-1	5	147	5	275
IR42508 (BKN7022-10-1-4/Chato Rayado//Chenab 64-117/ IR19661-131-1-3-1-3				
IR42508-1-1-3-2-1	5	170	9	262
IR42511 (BR118-3B-17/BKN7022-6-4//IR13259-153-5E-P2-2/ IR8234-OT-9-2)				
IR42511-24-1-3-1-1	5	160	9	249
IR42542 (IR13259-153-5E-P2-2/IR8234-OT-9-2//Chenab 64-117/ DWCT156-1)				
IR42542-25-3-3-3-1	5	120	5	268
IR42555 (Nam Sa-gui 19/IR11288-B-B-288-1//RD19/IR11288-B-B-445-1)				
IR42555-72-2-2-1-3	5	118	5	269
IR42555-72-2-2-2-1	5	122	5	235
IR42555-72-2-2-2-2	5	118	5	216
IR42571 (RD19/IR11288-B-B-288-1//RD19/IR15314-43-2-3-3)				
IR42571-179-3-1-2	5	115	7	214
IR42577 (RD19/IR19661-131-1-2//RD19/IR50)				
IR42577-21-1-2-2-2	5	150	7	268
IR42580 (RD19/IR19661-131-1-2//RD19/Khao Lo)				
IR42580-18-1-2-1-1	4	120	5	302
IR42580-18-1-3-3-1	4	102	5	324
IR42580-18-1-3-3-3	4	108	5	287
IR42580-18-3-1-1-2	4	103	5	336
IR42580-18-3-3-2-2	4	103	5	253
IR42580-23-2-1-1-1	4	143	5	207
IR42580-23-2-1-1-3	4	140	5	226
IR42582 (RD19/Murungakayan 101B//Nam Sa-gui 19/IR15314-43-2-3-3)				
IR42582-5-1-2-1-1	5	130	5	288
IR42582-5-1-2-1-3	5	116	5	249
IR42582-5-3-2-1-2	5	155	5	210
IR42582-5-3-2-2-3	5	150	5	223
IR42582-5-3-2-3-2	5	149	5	203
IR42583 (RD19/Murungakayan 101B//RD19/IR19661-131-1-2)				
IR42583-13-1-2-3-2	5	127	5	243

SCREENING FOR SUBMERGENCE TOLERANCE

Plant Physiology Department

The submergence tolerance of 22,893 entries was tested in concrete tanks in the greenhouse. Almost 60% of the entries were from deepwater pedigree nurseries (Table 2). Outstanding entries from pedigree nurseries were selected and transplanted in the field for further evaluation. Best entries from International Rice Testing Program (IRTP) nurseries are shown in Table 3.

SCREENING FOR ELONGATION ABILITY

Plant Physiology Department

Internode elongation tests were conducted in a deepwater tank on 308 entries from GEU elite lines, the hybridization block, and IRTP nurseries. All the outstanding entries–BR222-B-191-3-2, BR306-B-32-HR46, BR523-168-2, BR525-31-1, DWC-B-151-H1, DWC-B-14-1-X-6, DWC-B-283, DWC-167, Fulkari 715-X-3, HTAFR77012-3, and Kartiksail–were from the International Floating Rice Observational Nursery except IR40905-R-R-R-21, which came from the International Rice Deepwater Observational Nursery.

Table 2. Entries tested for submergence tolerance in the greenhouse. IRRI, 1988.

Source	Entries (no.)
Rainfed lowland pedigree nursery	5,633
Rainfed medium deepwater pedigree nursery	3,689
Deepwater pedigree nursery	12,893
Tidal swamp nurseries	179
IRTP nurseries	358
GEU elite lines	50
Hybridization block	91

Table 3. Entries from IRTP nurseries with submergence tolerance. IRRI, 1988.

Entry	Origin	Nurseries[a]
FRG7-BR1	Bangladesh	ITPRON, IRDWON
IR13149-71-3-2-3	IRRI	ITPRON
IR26702-25-1	IRRI	ITPRON
IR28985-X5-0-2-01	IRRI	ITPRON
IR31406-333-1	IRRI	ITPRON
IR40905-11-3-1-1-2	IRRI	IRDWON
IR40905-11-3-1-1-3	IRRI	IRDWON
Janki	India	IRRSWON
NC492	India	IRRSWON
NC493	India	IRRSWON
NC505	India	IRRSWON

[a] ITPRON = International Tide-Prone Rice Observational Nursery, IRDWON = International Rice Deepwater Observational Nursery, IRRSWON = International Rice Rainfed Shallow Water Observational Nursery.

EVALUATION OF EARLY SEEDLING ELONGATION ABILITY

Plant Breeding Department

We tested several elongating deepwater rices for their ability to elongate at a young seedling age. Single survival percentages for each line were obtained from average survival due to elongation at 14, 21, and 28 DAS to obtain average scores. These averages can then be converted to "seedling age at which elongation is possible" through linear interpolation between ideal reference types (Table 4).

The results clearly distinguished elongation parentage, among lines of Ashini, Badal, and BR516 with the best lines approaching a 14-DAS elongation ability.

ELONGATION OF DEEPWATER RICE AT LOW TEMPERATURE

Plant Physiology Department

Six-week-old rice cultivars were tested for internode elongation at constant water temperature of 15 and 25 °C and a water level of 85 cm for 8 d. Control plants did not receive any treatment. Before submergence, leaves were pruned to keep the plants below the water level. Most of the cultivars were from Bangladesh and had previously been rated as good elongators. Among those tested, 90% showed poor elongation at 15 °C (Table 5). Chanda Amon, Chota Bhawalia, Dal Katra, Dhal Pata, Digha, Goirol, Hasfal Borow, Hiruyal, and Ijol Digha showed good elongation at both temperatures.

YIELD POTENTIAL AND AGRONOMIC CHARACTERISTICS OF SOME PROMISING DEEPWATER RICES

Agronomy Department

A field trial was continued at IRRI to determine the yield potential and agronomic characteristics of promising deepwater rices. Eight promising rices, selected from seed-increase plots in dry

Table 4. Survival of deepwater rice lines in tests at 3 seedling ages.[a] IRRI, 1988.

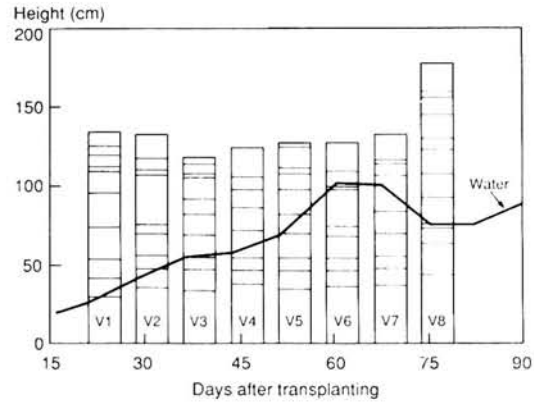
Designation	Average (%)	Surviving plants (no.)			Donor parent for elongation
		14 DAS	21 DAS	28 DAS	
Elongating at 28 DAS	33	0	0	10	*b*
IR28273-R-R-R-27-31-1	43	1	5	7	Ashini
IR28273-R-R-R-28-31-2-2-3	47	1	4	9	Ashini
Elongating at 24.5 DAS	50	0	5	10	*b*
IR28538-8-3-1-1	50	0	5	10	CNL 241
IR37025-R-R-R-59-1	50	0	5	10	RD19
IR28273-R-R-R-29-38-1-3-2	50	0	7	8	Ashini
IR28273-R-R-R-29-38-1-1-3	50	1	6	8	Ashini
IR28273-R-R-R-26-31-2	50	2	5	8	Ashini
IR28273-R-R-R-26-39-2	53	1	6	9	Ashini
IR39595-503-2-1-2	53	2	6	8	Baisbish
IR41415-15-1-2-3-1	53	2	6	8	BR516
IR28476-28-1-3-2	57	3	4	10	CNL 241
IR28273-R-R-R-29-38-1-3-3	60	1	7	10	Ashini
IR28273-R-R-R-28-31-2-2-1	60	1	7	10	Ashini
IR28273-R-R-R-29-38-2-3-3	60	1	8	9	Ashini
IR39610-507-1-1-1	60	3	6	9	Baisbish
IR40905-11-3-1-1-3	63	4	6	9	Badal 613
IR40905-11-3-2-3-2	63	5	4	10	Badal 613
Elongating at 21 DAS	67	0	10	10	*b*
IR40905-11-3-1-1-2	67	2	10	8	Badal 613
IR40905-11-3-5-2-1	70	2	9	10	Badal 613
IR43209-5-3-3	70	2	10	9	Badal 613
IR43209-5-3-2	70	3	9	9	Badal 613
IR40905-11-3-1-1-3	77	5	7	10	Badal 613
IR40966-5-4-1-3-1	77	6	9	8	BR516
IR43210-13-1-1	80	7	9	8	BR516
Elongating at 14 DAS	100	10	10	10	*b*

[a]DAS = days after seeding. [b]Reference type.

Table 5. Elongation of 270 varieties submerged in water at 15 and 25 °C for 8 d. IRRI, 1988.

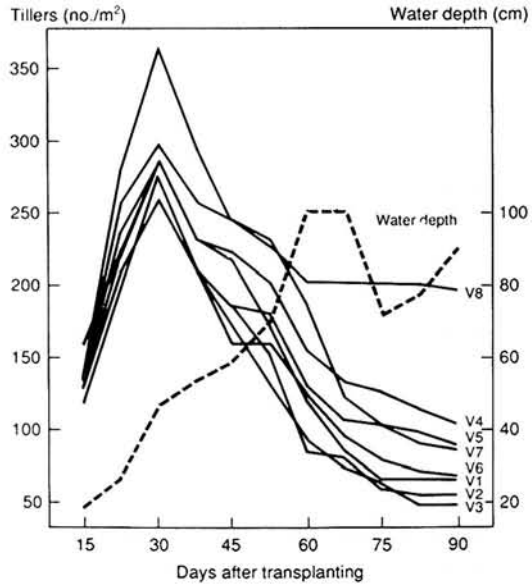
Elongation (cm)	Varieties (no.)		
	Control	15 °C	25 °C
0-10	225	251	26
10.1-20	42	18	40
20.1-30	8	1	107
30.1-40	0	0	72
40.1-50	0	0	23
50.1-60	0	0	2

season (DS), were transplanted in wet season (WS) in a replicated trial. Fertilizer rates of 0 and 58 kg N/ha as USG were used. Water in the deepwater rice pond gradually rose as early as 15 d after transplanting (DT) because of rainfall and seepage problems between ponds, before water depth was increased by 5 cm/d at 30 DT. Plant height and tiller production were recorded weekly to monitor changes in plant characters (Fig. 1, 2).



1. Plant height of 8 promising deepwater rice lines in relation to increasing water level at different rice growth stages. IRRI, 1988 WS.

Generally, tillers increased up to 30 DT, then gradually declined as water depth increased. IR28333-10-1-1 yielded highest at 2.3 t/ha, retained



2. Effect of increase in water level on tiller survival in 8 promising deepwater rice lines. IRRI, 1988 WS.

the most tillers, and was the tallest among the rices tested (Table 6). The low yield of some rices was due to disease problems and poor elongation ability.

NITROGEN FERTILIZER EFFICIENCY IN MEDIUM DEEPWATER AND DEEPWATER RICES

Agronomy Department

Studies on N fertilizer efficiency in medium deepwater (maximum depth 50 cm) and deepwater (maximum depth 100 cm) rices continued in deepwater ponds at IRRI. Prilled urea (PU), sulfur-coated urea (SCU), and urea supergranules (USG) at two N rates (29 and 58 kg N/ha) were applied using 3 methods: broadcasting and incorporation (B&I), 2/3 B&I + 1/3 foliar spray of urea solution at 5-7 d before panicle initiation, and deep placement of USG. Water depth was increased by 5 cm/d starting at 30 DT and was maintained at 50 and 100 cm until harvest.

Medium deepwater. Two photoperiod-insensitive rices were used: early-maturing (<120 d) IR38784-137-2-3-5 and late-maturing (>120 d) IR13149-3-2-2-P1. No yield difference was observed when the N rate was increased from 29 to 58 kg N/ha. IR38784-137-2-3-5 yield did not differ with N

Table 6. Grain yield, tiller number, and plant height of 8 promising deepwater rice lines. IRRI, 1988 WS.

Variety or line	Grain yield (t/ha)	Tillers (no./m²)	Height (cm)
V1: HTAFR77056-1-502-1-2	0.8	66	136
V2: IR38784-100-1-3-6-1-2	1.4	57	132
V3: IR21037-2-2-2E-P3-6	0.3	49	127
V4: IR38793-248-6-2-3-1	1.2	113	133
V5: IR38784-137-2-3-5	0.2	89	128
V6: BKN76026-3-2-2-2	[a]	62	127
V7: IR11288-B-B-69-1	1.8	88	137
V8: IR28333-10-1-1	2.3	138	179

[a] No yield because of a disease problem.

fertilizer application, source, or application method (Table 7). With IR13149-3-2-2-P1, however, 29 kg N/ha as PU B&I yielded higher than the nonfertilized control (Table 7), while USG deep placement, and PU and SCU B&I gave comparable yields at increased N rate.

Deepwater. Two photoperiod-insensitive rices were used: early-maturing (<120 d) HTAFR77056-1-502-1-2, a promising line from Thailand, and late-maturing (>120 d) IR38793-248-6-2-3-2. In HTAFR77056-1-502-1-2, yield was higher with increased N rate, while grain yield with 29 kg N/ha was similar to that of the no N treatment, indicating its low N-use efficiency. PU B&I at 58 kg N/ha increased HTAFR77056-1-502-1-2 grain yield by 700 kg/ha compared with the control, while PU and SCU B&I, and USG deep-placed gave comparable yields (Table 8). Foliar spraying of urea solution following B&I gave no advantage over a full dose B&I.

IR38793-248-6-2-3-2 gave no significant grain yield response to N treatment because a typhoon hit the crop during flowering and spikelet filling.

INTEGRATED USE OF ORGANIC AND INORGANIC NITROGEN APPLICATION IN MEDIUM DEEPWATER RICE

Agronomy Department

Experiments continued to evaluate the effect of inorganic N fertilizers, alone or in combination with organic N sources, on the yield of promising medium deepwater rices grown at 50-cm water level. Test crops were IR28932-9-3-3-2 in DS and IR37025-R-R-R-5-1 in WS. Both are photoperiod-

Table 7. Effects of source, rate, and application method of N fertilizer on rice grain yield at 50-cm water depth. IRRI, 1988 WS.

Treatment[a]	Yield (t/ha)	
	IR13149-3-2-2-P1	IR38784-137-2-3-5
No fertilizer N	1.6 c	1.7 ab
	29 kg N/ha	
PU B&I	2.4 ab	1.9 ab
2/3 PU B&I fb 1/3 foliar spray of urea solution at 5-7 DBPI	2.3 abc	1.2 b
SCU B&I	1.9 abc	1.5 ab
USG deep-placed at 10-12 cm	1.7 bc	2.1 a
	58 kg N/ha	
PU B&I	2.5 a	1.8 ab
2/3 PU B&I fb 1/3 foliar spray of urea solution at 5-7 DBPI	1.9 abc	1.7 ab
SCU B&I	2.4 ab	2.1 a
USG deep-placed at 10-12 cm	2.4 ab	1.9 ab
CV (%) = 24		

[a]PU = prilled urea, B&I = broadcast and incorporation, fb = followed by, DBPI = days before panicle initiation, SCU = sulfur-coated urea, USG = urea supergranule.

Table 8. Effects of source, rate, and application method of N fertilizer on rice grain yield at 100-cm water depth. IRRI, 1988 WS.

Treatment	Yield (t/ha)	
	IR38793-248-6-2-3-2	HTAFR77056-1-502-1-2
No fertilizer N	1.4 bc	1.4 b
	29 kg N/ha	
PU B&I	1.3 c	1.9 ab
2/3 PU B&I fb 1/3 foliar spray of urea solution at 5-7 DBPI	2.0 a	1.6 ab
SCU B&I	1.5 abc	1.9 ab
USG deep-placed at 10-12 cm	1.9 ab	1.7 ab
	58 kg N/ha	
PU B&I	1.7 abc	2.1 a
2/3 PU B&I fb 1/3 foliar spray of urea solution at 5-7 DBPI	1.5 abc	1.4 b
SCU B&I	1.9 ab	2.0 a
USG deep-placed at 10-12 cm	1.8 abc	1.8 ab
CV (%) = 20		

insensitive lines maturing in about 120 d. Nitrogen as PU or USG was applied at 58 kg/ha in a single dose. Green manure–*Azolla pinnata* and *Sesbania rostrata*–and chicken manure were used in combination with PU B&I onto mud at 1 d before transplanting.

Water depth was increased by 5 cm/d up to a maximum of 50 cm starting at 30 DT.

In DS, IR28932-9-3-3-2 yielded highest when azolla was combined with PU. USG and PU alone or in combination with sesbania or chicken manure gave similar grain yields in both seasons. The low yield obtained in WS with PU + azolla compared with the yield from PU alone was due to incorporation problems with azolla (Table 9).

N uptake pattern. In WS, plant samples were analyzed for total N to determine the N uptake pattern. Regardless of N source and fertilizer combination, N uptake of IR37025-R-R-R-5-1 was maximum at flowering and decreased during maturity because of senescence. Poor spikelet filling due to a typhoon contributed to low N

Table 9. Grain yield response of rices grown at 50-cm water depth to 58 kg N/ha applied as USG and PU alone or in combination with organic N source. IRRI, 1988 DS and WS.

Treatment	Grain yield (t/ha)	
	IR28932-9-3-3-2[a] in DS	IR37025-R-R-R-5-1[b] in WS
No fertilizer N	2.0 c	1.6 b
USG	2.3 b	1.8 ab
PU	2.4 b	2.1 a
PU + azolla	2.8 a	1.5 b
PU + sesbania	2.4 b	1.8 ab
PU + chicken manure	2.2 bc	2.2 a

[a]CV = 7%. [b]CV = 18%.

uptake at maturity. The N uptake pattern obtained from nonfertilized plants was similar to that with N application.

Changes in soil NH_4^+-N. The effect of N incorporation on soil NH_4^+-N concentration was analyzed during the rice growth period. At the 0- to 30-cm soil depth, NH_4^+-N rapidly decreased starting at 20 DT, slightly increased after 40 DT possibly because of N mineralization, then gradually decreased during crop maturity. No difference in NH_4^+-N concentration was observed with USG and PU alone or in combination with organic N.

Table 10. Yields of early-maturing rices grown under rainfed conditions at Prachinburi Rice Research Center, Thailand, and harvested before flooding, 1988 WS.

Designation	Mean grain yield (t/ha)
RD25	1.7 a
IR15429-268-1-2-1	1.2 ab
IR19743-25-2-2-3-1	1.2 ab
IR19735-5-2-3-2-1	1.0 bc
BKNGB80076-3-12-72	0.8 bc
CNLR79259-43-2-1-1	0.7 bc
BKNGB80076-1-5-8	0.6 c

EARLY-MATURING RICE FOR PREFLOOD PRODUCTION IN DEEPWATER RICE AREAS

Agronomy Department and Department of Agriculture, Thailand

Dry seed of modern varieties with expected maturities of <100 d was broadcast on 5- × 5-m plots at the Prachinburi Rice Research Center on 27 Apr 1988 for production under rainfed conditions. Seedlings emerged on 3 May. Growth was reduced by extremely wet conditions in the early part of WS. More than 200 mm of rain fell in 1 wk, near maturity, almost submerging plants. Consequently, yields were low (Table 10). The soil was acid sulfate with a pH of 4.

Genetic evaluation and utilization (GEU) program

Adverse temperature tolerance

Plant Breeding and Plant Physiology Departments; International Rice Testing Program; Rural Development Administration, Korea; Department of Agriculture, Philippines; and University of Hamburg, Germany

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KOREA-IRRI COLLABORATIVE PROJECT ON RICE COLD TOLERANCE

Plant Breeding and Plant Physiology Departments; International Rice Testing Program; and Rural Development Administration, Korea

Cold tolerance screening nursery *(Plant Physiology; Plant Breeding; and Rural Development Administration, Korea)*. Nine hundred sixty-nine entries from International Rice Testing Program nurseries and other national programs were screened in cooperation with the Rural Development Administration, Korea, using the same procedure as in previous years. Data for the individual entries are in the data bank.

Phenotypic acceptability. Fifty-three entries received a phenotypic acceptability score of 1 at maturity, a large number compared with previous years, indicating better breeding materials. Of these entries, 34 were from Korea, 4 from IRRI, 4 from China, 1 from Indonesia, 8 from India, and 2 from Japan. Most of the outstanding entries were japonicas.

Panicle number per hill. Although tillering rate is reduced at lower temperatures, tillering period at low temperature is prolonged, so that the final number of tillers at harvest generally increases at lower temperature. At present, there is a need to identify low-tillering, large-panicle types for direct seeding. The following entries had fewer than 8 tillers and more than 110 spikelets at the inlet: SR11452-T9, BG621-1, and Oryzella.

Spikelet fertility. Twenty-eight entries had spikelet fertility >80% at the point where the fertility of the check was 50% (Table 1). The fertile entries were mostly japonicas except indicas China 988, Bir-Ze-Goo, Fu-Men-Huan, IR20913-B-60, IR23325-R-R-B-7-2-2, Khonorulu, and Kasalath.

Spikelets per panicle. Low temperature during panicle differentiation and development may decrease the number of spikelets per panicle by degeneration of spikelets or panicle branches. Twenty entries had ≥150 spikelets/panicle at the inlet. Generally the entries had lower spikelet number per panicle at the inlet compared with the control plots. However, some entries had higher spikelet number at the inlet than in the control: B3619C-TB-8-1-4, BG367-7, GH305, H248-85, HPU741, Namyoungbyeo, Silewah, SR12234-8-1-4, Unbong 5, and YR6508-1-1.

Panicle exsertion. If the first internode below the panicle does not elongate sufficiently, the panicle may not exsert fully from the flagleaf sheath. The unexserted part of the panicle is generally sterile. Twenty-one entries had a score of 1 for panicle exsertion at the inlet.

Days to heading. Short-duration cultivars are advantageous in low-temperature areas because they are not affected by low temperature in the reproductive phase, and they allow ample time for land preparation for the next crop. Twenty-nine entries flowered in <100 d, with a delay of <10% at the inlet. Most of the early entries were from Hungary, Korea, and Kashmir, India.

Outstanding entries. Fu-Men-Huan, Bir-Ze-Goo, IR20913-B-60, SR11842-9-4-3, and Unbong 3 were the best entries in terms of fertility, phenotypic acceptability, and panicle exsertion under cold water. Fu-Men-Huan and Bir-Ze-Goo were identified as resistant in earlier screenings at IRRI of germplasm from China. Unbong 3 is from Unbong Substation of the Honam Crop Experiment Station, a high elevation station. IR20913-B-60 comes from the cross IR7149-51-1-3/IR36// Paro White.

Screening for cold tolerance in short rows *(Plant Physiology; IRTP; and Rural Development Administration, Korea)*. Many upland rice areas are affected by low temperatures, since upland rices are often planted on mountain slopes and in mountain valleys—thus the need to screen upland nurseries for cold tolerance to have a better knowledge of their reactions to low temperature.

The entries in the 1987 International Upland Rice Observational Nursery, those in the 1987 Acid Upland Soils Screening Set, and some materials from IRRI that were not accommodated in the main screening nursery were planted in 2-m rows and were irrigated with water at 17 °C as in the main nursery.

Only four entries performed well in this test: Rata 31-2 (Acc. 29388), RP1158-85-1, IR40085-6-1-3, and S431B-5-1. They had fertility ≥80% at the inlet. IR40085-6-1-3, Rata 31-2, and S431B-5-1 had good panicle exsertion and phenotypic acceptability. IR40085-6-1-3 also had good scores

Table 1. Physio-agronomic traits of elite entries at low water temperature in the cold tolerance screening nursery. IRRI, 1988.

Entry	Fertility (%)	Days to heading	Phenotypic acceptability (1-9)		Leaf discoloration (1-9)		Panicle exsertion (1-9)	Culm length (cm)	Panicles (no./hill)	Spikelets (no./panicle)
			Tillering	Maturity	Seedling	Tillering				
IR20913-B-60	96	120	7	1	7	7	1	79	11.3	126
Bir-Ze-Goo	93	124	3	1	7	5	1	67	12.7	124
Fu-Men-Huan	91	121	5	1	5	5	1	79	9.3	107
Z-Yah-Tsan	91	117	5	1	3	3	2	74	10.7	105
RP1848-216-3-2-1	90	114	5	2	5	5	3	63	13.0	91
SR13349-77-2	89	112	1	1	1	1	3	57	12.3	102
RP1158-85-1	89	120	5	1	5	5	5	52	16.7	107
Kasalath	88	121	3	2	1	5	5	76	16.7	87
Reimei	87	114	1	4	1	1	3	49	15.0	115
China 988	86	120	5	2	3	5	5	58	11.0	128
SR13925-14-1	85	110	1	2	1	1	3	56	12.0	107
B4190E-CW-B9-29-176	85	143	5	2	5	6	7	54	9.3	135
Jinbu 9	84	110	1	1	1	1	2	61	12.3	132
SR13925-13-1	84	110	1	1	1	1	2	68	12.7	111
SR13363-24-2	84	112	1	1	1	1	3	63	12.0	106
IR23325-R-R-B-7-2-2	84	150	7	1	7	8	6	63	9.0	126
HPU741	84	131	5	1	7	5	6	45	10.7	159
Khonorulu	84	144	7	1	5	5	5	81	12.0	157
Unbong 3	83	110	1	1	1	1	1	69	10.3	121
SR14859-8-1	83	107	1	1	1	1	2	57	12.0	125
HR7898-ACB15	82	136	1	3	1	1	7	42	14.7	95
Unbongbyeo	82	112	1	2	1	1	2	51	15.0	99
Chakula	82	108	5	6	5	3	5	57	15.0	59
NR10073-167-3-1-3	81	116	5	2	5	5	2	67	10.0	165
SR11842-91-4-3	80	112	1	1	1	1	1	56	11.3	109
SR10119-215-2-4-2-1	80	114	1	3	1	1	1	65	11.0	111
SR13363-19-2	80	113	1	1	1	1	2	56	11.7	87
Jinbu 2	80	104	1	1	1	1	3	62	15.3	129

for leaf discoloration. IR40085 came from IR50 and IR20654-R-R-R-1-2. The source of cold tolerance in this cross is Barkat, a parent of IR20654.

Screening for cold tolerance at anthesis (*Plant Physiology and Rural Development Administration, Korea*). Six plants of each entry were grown in small pots in the field until flowering. At panicle emergence, the plants were transferred to the greenhouse with an air temperature of 19 °C for 10 d and were then returned to normal conditions. At maturity, spikelet sterility was determined.

The screening procedure effectively induced sterility. Most of the entries had >70% sterility. Of the 132 entries that were screened, 14 had sterility <50%:

Designation	*Origin*
Barkat (K78-13)	India
Cheonmabyeo	Korea
China 1039	India
Dunghan Shali	Hungary
H231-85	Hungary
H404-85	Hungary
IR15579-135	IRRI
Karolina	Hungary
K39-96-1-1-1-2	India
Oryzella	Hungary
Sobaegbyeo	Korea
SR10255-2-1-1-1	Korea
SR11110-135-2-3-1	Korea
Zhong Hua 2	China

These materials came from countries where low temperature is a problem during the reproductive phase, like Kashmir, India; Hungary; China; and Korea. One entry from IRRI (IR15579-135) also had good fertility. This line came from the cross K78-76-B-1/2*Kn-1b-214-1-4-3.

Observational yield trial (*Plant Physiology and Rural Development Administration, Korea*). Thirty-five elite entries from the 1987 cold tolerance screening nursery were planted in field plots with 200 kg N/ha. Five entries yielded more than 7.0 t/ha: Pungsanbyeo, YR6488-ACP36, YR6488-ACP39, SR13618-9-3-2, and SR10649-B-285-2-2 (Table 2). The two lines of YR6488 are anther culture-derived plants; they are both panicle number types, having the least spikelets per panicle but having the most panicles per hill.

Salt tolerance for low-temperature areas (*Plant Breeding and Rural Development Administration, Korea*). We began a program to develop salt-tolerant varieties for low temperature areas. Variety Annapurna, which had been found to possess some salt tolerance and adaptability to low temperature conditions (because of its short duration), was crossed with 19 varieties and elite IR lines having high levels of either cold tolerance or salt tolerance. The 19 F_2 populations produced were evaluated in an artificial saline field in the dry season (DS) on the IRRI farm. Sixteen populations were mass selected, and F_3 seeds were sent to Korea for evaluation at the Coastal Lands Research Station in Ghewa. Twelve populations were promising and were mass selected and brought to IRRI for further advancement.

The indica-japonica hybridization program for producing salt-tolerant japonicas continued during the year. Three-way crosses were made with selected japonicas, salt-tolerant indicas, and three varieties (BPI-76, N22, and Moroberekan) with the wide compatibility gene. Moroberekan was the best among the three. F_2 populations of the 24 crosses made were established at IRRI at the end of the year for selection against grain sterility before being sent to Korea.

Table 2. Yield, yield components, and other agronomic characteristics of the high-yielding entries in the observational yield trial. Chuncheon, Korea, 1988.

Entry	Grain yield (t/ha)	Panicles (no./hill)	Spikelets (no./panicle)	Fertility (%)	1,000-grain weight (g)	Days to heading	Culm length (cm)	Total dry matter (t/ha)
Pungsanbyeo	7.26 a	13.0 b	118 a	86 a	26.05 a	119 ab	65 b	14.2 a
YR6488-ACP36	7.26 a	18.6 a	68 b	82 a	25.24 a	115 d	82 a	14.1 a
YR6488-ACP39	7.20 a	20.6 a	68 b	72 b	23.80 a	116 cd	83 a	14.3 a
SR13618-9-3-2	7.16 a	11.0 b	108 a	84 a	25.95 a	120 a	72 b	14.4 a
SR10649-B-285-2-2	7.02 a	13.0 b	113 a	88 a	24.35 a	117 bcd	66 b	13.3 a

IRTP COLD TOLERANCE TRIALS

International Rice Testing Program

Information on cold tolerance obtained from results of multilocational trials of the 1987 International Rice Cold Tolerance Nursery conducted at 28 sites in 15 countries was received and analyzed in 1988. The best performing entries across locations were JKAU(K)450-126-10, No. 11, Suweon 303, and Akiyudaka.

BULU IMPROVEMENT PROGRAM

Plant Breeding Department and Department of Agriculture, Philippines

We made 36 single and 18 multiple crosses. Crosses with indicas had varying degrees of fertility, ranging from normal to 90% sterility, with an average of 66%. Crosses with japonicas were all fertile. Tongil-type variety Milyang 54 was used in four crosses, of which one showed 50% sterility while the others were normal.

We disregarded the sterility barrier, and segregating populations produced in previous years were evaluated under low temperature conditions. Crosses with indicas showed sterility ranging from 0 to 100% in the F_2. We bulk-harvested fertile plants irrespective of their other characters. In the F_3, fertility was almost normal. When the F_4 pedigree of 1,034 plants was evaluated, sterility was not a problem, but only 14% expressed desirable plant characteristics. Abnormal sterility was not a barrier in crosses with japonicas. Good plant types could be selected even in the F_2. In the F_4 pedigree of these crosses, selection efficiency was about 50%. These observations reveal that high grain sterility of hybrids between bulus and indicas is not a drawback, since selection for sterility at subsequent segregating generations is effective. Crosses with japonicas do not show sterility problems, and a large number of desirable phenotypes could be obtained in early generations.

EFFICIENCY OF THE WIDE COMPATIBILITY GENE

Plant Breeding Department

In our breeding programs for low temperature tolerance and problem soils tolerance, we use several varieties having the wide compatibility gene with the objective of combining the good agronomic traits of japonica- and indica-type varieties.

In the 1987 wet season, we used three wide compatibility varieties—BPI-76 (indica), N22 (aus), and Moroberekan (japonica)—as male parents to make 66 single crosses involving a range of indicas and japonicas, and one Tongil (indica/japonica hybrid). Hybrid seeds were planted in the IRRI F_1 nursery in 1988 DS. At maturity, 10 main panicles were harvested at random, and spikelet fertility was determined for each cross. Of all crosses made, 45 were complete, i.e., all varieties crossed to all wide-compatibility types.

The spikelet fertility of crosses, calculated as the average of 10 panicles (Table 3) showed a wide range. BPI-76 showed normal fertility with indicas, the Tongil, and one japonica. Fertility with N22 was highly variable among japonicas and indicas. Fertility was normal in all crosses with Moroberekan.

It appears that the efficiency of the wide compatibility gene varies with variety. The gene of Moroberekan was found to be very effective; however, it may not be the best to use in common

Table 3. Spikelet fertility of hybrids between ordinary rices (female parent) and 3 with the wide compatibility gene (male parent). IRRI, 1988 DS.

Female parent	Spikelet fertility (%)		
	BPI-76	N22	Moroberekan
Indicas			
ARC6000	83.0	96.9	91.0
China 1039	90.7	86.2	87.4
IR4630-22-2-5-1-3	91.9	66.6	70.1
IR9884-54-3-1E-P1	84.4	72.3	86.0
IR31868-64-2-3-3-3	79.4	36.6	75.3
IR32843-92-2-2-3	95.0	79.4	71.6
IR44670-168-2-3-1	96.5	84.2	72.4
Nona Bokra	95.5	31.8	84.4
SR26B	92.3	76.9	72.3
Japonicas			
Akihikari	43.3	81.0	97.0
Barkat	30.3	59.3	90.9
Sasanishiki	23.6	69.8	95.5
Ta-Mao-Tao	33.1	59.6	89.6
Tatsumi Mochi	78.8	53.2	86.7
Tongil			
Milyang 54	92.1	40.8	93.0
Mean	74.0	66.3	84.2
SD	26.7	19.3	9.4

breeding programs because of its poor performance under lowland conditions. Acceptable varieties with an efficient wide compatibility gene need to be isolated or developed.

GENETICS OF COLD TOLERANCE

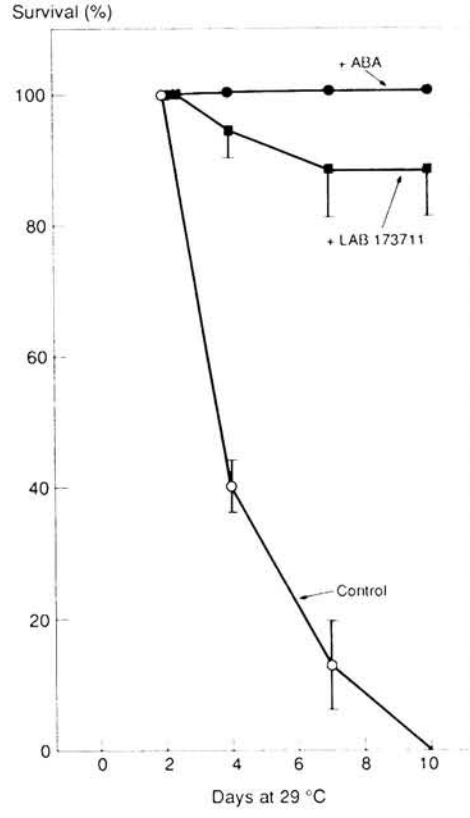
International Rice Testing Program

Gene action for minimum temperature for chloroplast biogenesis (MTCB) and spikelet fertility depression coefficient (FDC) as components of cold tolerance during the vegetative and reproductive phases, respectively, was investigated in 5 × 5 indica/indica (I/I), 5 × 5 japonica/japonica (J/J), and 7 × 7 indica/japonica (I/J) half diallel sets. In the I/I set, additive variance was predominant; in the J/J set, nonadditive variance was predominant; and in the I/J set, both variances were of similar magnitude, indicating that japonica cultivars were the primary source of nonadditive effects. The covariance (Wr), variance (Vr) analysis indicated persistent heterogeneity of Wr-Vr over the arrays in noninteracting sets for both MTCB and FDC in the I/J set and for FDC in the I/I set, indicating involvement of multiple alleles in the expression of the cold tolerance trait. There seem to be at least three alleles involved in cold tolerance, viz., T^+, conditioning high tolerance as in japonica cultivars; T, conditioning moderate tolerance as in indica cold-tolerant cultivars; and t, conditioning susceptibility to cold. In the reproductive phase, multiple alleles at the spikelet fertility locus S interfere with the alleles at the cold tolerance locus T, giving the impression that there is a reversal in gene action for cold tolerance.

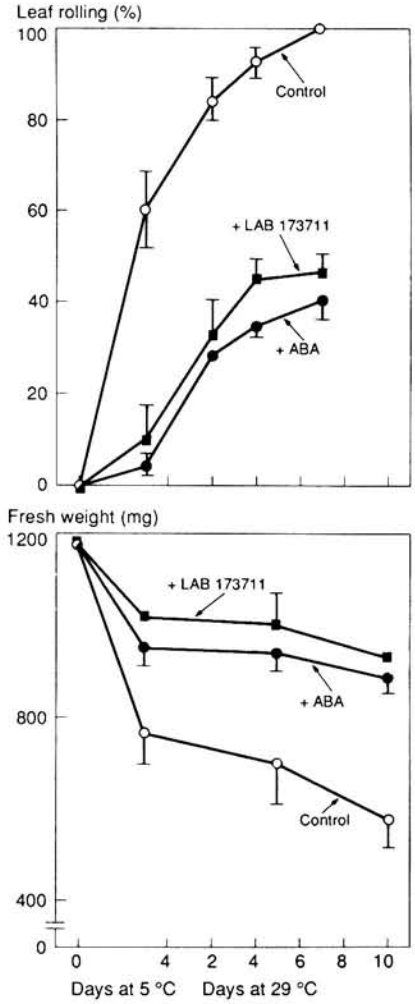
INCREASING COLD AND DROUGHT TOLERANCE IN RICE BY APPLICATION OF A NEW ABSCISIC ACID ANALOGUE

Plant Physiology Department and University of Hamburg, Germany

One of the factors limiting growth and yield in many rice-growing countries is chilling injury. Among the measures taken to minimize this problem is chemical treatment. In collaboration with the University of Hamburg, the protective effects of abscisic acid (ABA) and the synthetic ABA analogue LAB 173711 (BASF) against chilling and transplanting stress were studied. Seedlings were sprayed with LAB 173711 or ABA before chilling at 5 °C for 4 d. Plants were then kept at 29 °C for recovery. LAB 173711 and ABA both increased the plant's capacity for survival. No plant survived in the control, which was also subjected to low temperature (Fig. 1). Leaf rolling as a response to chilling was minimized in ABA- and LAB 173711-treated plants which showed only 4-10% rolling compared with about 60% in the control after 3 d at 5 °C. Leaf rolling reached 100% in the control and only less than ±40% in plants previously sprayed with ABA and LAB 173711 after recovery for 7 d at 29 °C (Fig. 2). A pronounced decrease in leaf fresh weight of the control compared with that of LAB 173711-treated plants was observed (Fig. 2). Likewise, the injured leaf area was markedly lower in LAB 173711-treated plants (Fig. 3). This effect may be due to the antitranspirant activity of the ABA analogue.

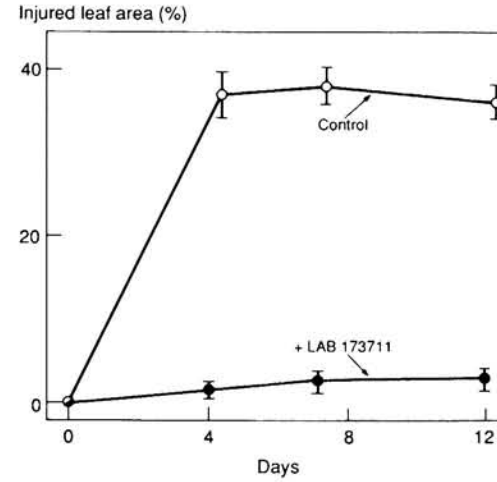


1. Survival rates of rice seedlings treated with ABA and LAB 173711 at 10^{-3} mol/liter and chilled, IRRI, 1988. Data are means ± SE of 5 parallel experiments with 10 plants each.



2. Effects of ABA and LAB 173711 on leaf rolling and leaf fresh weight of plants after chilling and recovery, IRRI, 1988. Data are means ± SE of 5 parallel experiments.

The analogue also protected the root system (Table 4). The number of adventitious roots, root length, and root weight were higher in treated plants. The stability of the root system may contribute to the increased survival rate in protected plants. LAB 173711 not only served as a cryoprotectant, but also prevented transplanting stress. As shown in Figure 4, dipping the roots of normal rice seedlings in LAB 173711 before subjecting them to a drought stress for 3 h prior to transplanting increased survival rate and speeded up crop establishment.

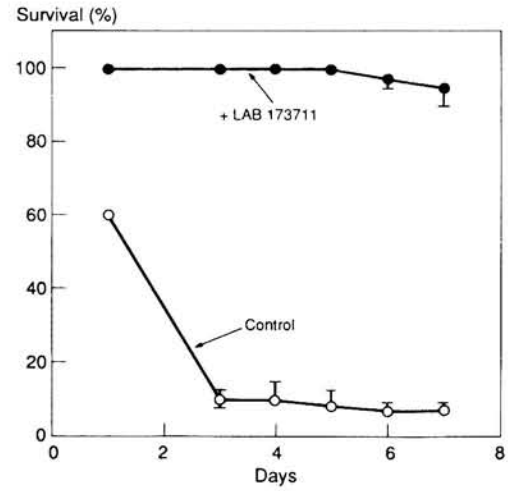


3. Percent leaf area injury in LAB 173711-treated rice seedlings chilled at 5 °C for 24 h, then transferred to 29 °C for recovery, IRRI, 1988. Data are means ± SE of 10 measurements.

Table 4. Root growth of rice plants treated with LAB 173711, chilled at 5 °C for 2 d, and returned to 29 °C for 7-d recovery. IRRI, 1988.

Treatment	Nodal roots[a] (no./plant)	Length[b] (cm)	Fresh weight[b] (mg)	Dry weight[b] (mg)
Control	17.0 ± 1.8	9.9 ± 1.2	205.8 ± 28.3	27.7 ± 7.0
173711	26.2 ± 1.7	14.7 ± 2.2	770.8 ± 28.0	69.2 ± 7.0

[a]Data are means ± SE of 5 measurements. [b]Data are means ± SE of 8 measurements.



4. Effect of LAB 173711 at 10^{-4} mol/liter on seedling survival after some days in the field, IRRI, 1988. The seedlings were dipped in LAB 173711 solution, subjected to drought stress, and then transplanted.

Genetic evaluation and utilization (GEU) program

Innovative breeding methods

Plant Breeding and Plant Physiology Departments

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HYBRID RICE

Plant Breeding and Plant Physiology Departments

Identification of heterotic combinations (*Plant Breeding*). During 1988 dry season (DS), 96 experimental hybrids were evaluated at IRRI against the best available inbred cultivars, viz., IR50 (very early), IR64, IR66, and IR72 (early), IR54 and IR68 (medium), and IR70 and IR32809-26-3-3 (late), in six groups. Hybrid combinations IR58055/IR19058-107-1 R, IR54752 A/IR64 R, IR54752 A/IR15324-13-3-3-2 R, and IR54752 A/IR13146-45-2-3 yielded significantly higher than the check inbred cultivars in their respective groups (Table 1). In group 1, IR50 yielded unusually low because of tungro infection. IR46830 A/IR97610-19-1 R, a very early-duration combination, yielded the same as IR66 and IR72, which were 10 d later in maturity. In the 1988 wet season (WS) this combination yielded well (3.2 t/ha) compared with IR50 (2.2 t/ha) and IR66 (2.4 t/ha). This combination had yielded significantly higher than the inbred cultivars of the same growth duration in 1986-87 trials (Annual report for 1987). From the results obtained so far, this hybrid appears to be promising enough to be tested in national coordinated trials in tropical countries, but its female parent IR46830 A has a very poor outcrossing rate, making large-scale seed production difficult. None of the 50 other experimental hybrids evaluated during 1988 WS showed a significant yield advantage over IR66, IR72, IR68, or IR74.

Table 1. Yield and growth duration of promising experimental rice hybrids and best available inbred varieties. IRRI, 1988 DS.

Hybrid or variety	Growth duration (d)	Yield (t/ha)	Percent of check
Group 1			
IR58055 A/IR19058-107-1 R	110	4.1	241[a]
IR50 (check)	110	1.7	100
LSD (5%)		0.7	
Group 2			
IR46830 A/IR97610-19-1 R	108	4.8	100
IR66 (check)	118	4.8	100
IR72 (check)	118	4.8	100
LSD (5%)		0.8	
Group 4			
IR54752 A/IR64 R	120	5.3	120
IR68 (check)	130	4.4	100
LSD (5%)		0.8	
Group 5			
IR54752 A/IR15324-13-3-3-2 R	122	5.9	116
IR68 (check)	130	5.1	100
LSD (5%)		0.8	
Group 6			
IR54752 A/IR13146-45-2-3	116	6.8	119
IR70 (check)	127	5.7	100
LSD (5%)		0.7	

[a] Increase was unusually high because of the severe incidence of tungro on IR50 check.

Critical yield assessment of rice cultivars on the IRRI farm is hampered by unusually high disease and insect pressure. It would be helpful if another site could be identified for the purpose.

Effect of sterile plants on yield of F_1 hybrids (*Plant Breeding*). A number of experimental rice hybrids derived from the cytoplasmic male sterile (CMS) line IR54752 A have shown inconsistent performance because of the occurrence of sterile to partially fertile plants in hybrid rice plots. During 1988 DS trials we evaluated seven such experimental hybrids derived from seed produced by controlled hand-pollination and natural cross-pollination. Seed produced through natural cross-pollination on IR54752 A resulted in F_1 populations containing 15-80% sterile or partially sterile plants, which reduced hybrid yield by 0.7-3 t/ha (Table 2). The occurrence of sterile or partially sterile plants in hybrid populations was attributed to unstable pollen sterility such that one or two of the six anthers in some spikelets of IR54752 A panicles showed some fertile pollen grains, causing partial selfing in the CMS line.

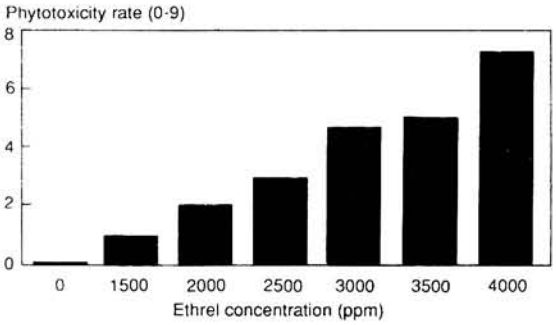
Use of ethrel to overcome unstable pollen sterility of IR54752 A (*Plant Breeding*). The gametocide ethrel (2-chloroethyl phosphonic acid) is known to induce pollen sterility in normal rice cultivars. We used this chemical to make partially sterile IR54752 A completely pollen sterile. Seven concentrations (0, 1,500, 2,000, 2,500, 3,000, 3,500, and 4,000 ppm) of ethrel were sprayed at 3 growth stages (panicle initiation [PI], flag leaf, and booting) of IR54752 A. Application at PI caused phytotoxicity (Fig. 1) and was not very effective in inducing complete pollen sterility. However, when the growth regulator was sprayed at 1,500-4,000 ppm at the flag leaf development to booting stages, complete pollen sterility occurred (Fig. 2).

Ethrel-treated and untreated plants of IR54752 A were also cross-pollinated artificially. Seed set

Table 2. Yield of F_1 rice hybrids derived from controlled hand-pollinated and natural cross-pollinated seeds in replicated yield trials. IRRI, 1988 DS.

Hybrid	Hybrid seed production[a]	Yield (t/ha)	S or PS[b] plants (%)
IR54752 A/IR19058-107-1 R	HP	4.5 a	0
	NCP	3.8 a	15
	Difference	0.7	
IR54752 A/IR64 R	HP	5.3 a	0
	NCP	2.9 b	37
	Difference	2.4*	
IR54752 A/IR15847-215-2-1 R	HP	4.6 a	0
	NCP	1.9 b	80
	Difference	2.7*	
IR54752 A/IR29512-63-2-2	HP	4.1 a	0
	NCP	2.1 b	80
	Difference	2.0*	
IR54752 A/IR46 R	HP	4.7 a	0
	NCP	3.0 b	52
	Difference	1.7*	
IR54752 A/IR21916-128-2-2-3	HP	3.6 a	0
	NCP	2.6 b	45
	Difference	1.0*	
IR54752 A/IR28118-138-2-3-3 R	HP	5.6 a	0
	NCP	2.6 b	77
	Difference	3.0	

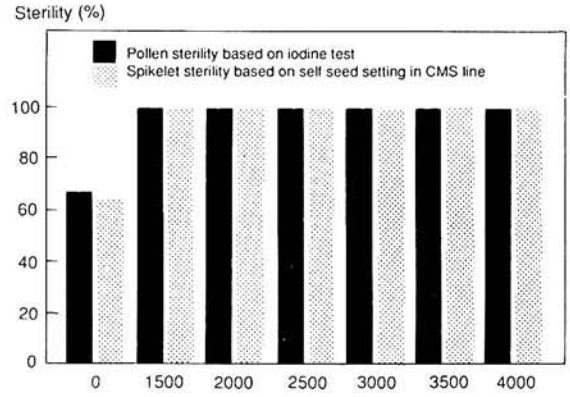
[a]HP = hand-pollinated seed, NCP = naturally cross-pollinated seed. [b]S = sterile, PS = partially sterile.



1. Phytotoxicity effect of ethrel sprayed at panicle initiation. IRRI, 1988.

on treated and untreated panicles was identical, indicating that the chemical did not reduce ovule fertility. We therefore recommend the use of 2,000 ppm ethrel at the flag leaf development stage (15-20 d after PI) to overcome the problem of unstable CMS lines such as IR54752 A.

Evaluation of new cytoplasmic male sterile lines (*Plant Breeding*). We continued to screen for maintainer lines among elite rice lines and cultivars developed at IRRI and in some national programs to convert these into CMS lines using recurrent backcrossing (BC). During the past 2 yr, we noticed a considerable reduction in the number of new maintainer lines identified among the elite lines screened at IRRI (Table 3). We also found that the CMS line conversion program is not giving completely male sterile backcross progenies even after 8-14 backcrosses with the prospective maintainer lines. A certain percentage of plants in the BC progenies continues to have pollen with 1-5% fertility. The hybrid rice breeding program cannot depend totally on the conven-



2. Effect of ethrel sprayed at flag leaf development stage on sterility percentage. IRRI, 1988.

Table 3. Number and frequency of maintainers identified in testcrosses made with stable CMS lines during 1981-88, IRRI.

Year	Test-crosses (no.)	Maintainers no.	Maintainers %	Male sterile lines used
1981	510	63	12.4	V20 A, 97 A
1982	649	39	6.0	V20 A, 97 A, V41 A, Erjiunan 1 A IR10154 A, IR10179 A
1983	320	27	8.4	IR19792 A, IR19807 A, IR10154 A, Jikoku Seranai A
1984	593	29	4.8	IR19756 A, IR19792 A
1985	594	26	4.4	IR46828 A, IR19657 A, IR46830 A
1986	267	14	5.2	IR46828 A, IR54753 A, IR54754 A
1987	243	7	2.9	IR46830 A
1988	929	5	0.005	IR46830 A, IR58025 A, IR58054 A, IR58055 A

tional breeding program to identify effective maintainers for developing stable CMS lines. We have therefore initiated a special breeding activity to develop effective maintainers and thereby stable CMS lines possessing good outcrossing potential and high general combining ability for the tropics and subtropics. We are also developing CMS lines possessing wide compatibility (WC) genes for use in developing indica/japonica hybrids.

Identification of cytoplasmic diversity among indica and japonica cytoplasmic male sterile lines (*Plant Breeding*). We testcrossed 4 indica CMS lines, viz., IR54753 A (CMS-WA), IR54755 A (CMS-ARC), Yar Ai Zhao A (CMS-GAM), and MS577 A (CMS-?), with 28 rice cultivars from IRRI, India, Indonesia, and Korea. Two of these cultivars originating from Korea were japonica types, while the others were indicas. Some of the testcrosses did not set seed. Testcross F_1 progenies of the available crosses were grown in 1-row plots of 10 plants along with the male parents. The testcross progenies were classified as fertile (>70% spikelet fertility), partially fertile (30-70% spikelet fertility), partially sterile (1-30% spikelet fertility), or sterile (0-1% spikelet fertility) (Table 4). IR54753 A and IR54755 A showed differential fertility reactions in 12 of 28 testcrosses; IR54753 A and Yar Ai Zhao A showed differential fertility reactions in 8 of 9 testcrosses; IR54755 A and Yar Ai Zhao A showed differential reactions in 8 of 9 testcrosses. MS577 A showed differential reaction from IR54753 A (in 13 of 16 crosses), from IR54755 A (in 7 of 16 crosses), and from Yar Ai Zhao A (in 8 of 8 crosses). These results indicate that cytoplasmic factors controlling male sterility in the four CMS lines are genetically different. Most of the IRRI-bred CMS lines developed so far possess wild abortive (WA) cytoplasm. We are

Table 4. Fertility or sterility reaction of 4 indica CMS lines in testcrosses with several rice cultivars from IRRI, India, Indonesia, and Korea. IRRI, 1988 DS.

Cultivar[a]	Origin	Fertility or sterility reaction[b] in testcross F_1 progenies involving			
		IR54753 A	IR54755 A	Yar Ai Zhao A	MS577 A
IR42	IRRI	F	F	–	S
IR58	IRRI	F	S	F	S
IR62	IRRI	PS	PS	F	S
IR64	IRRI	F/PF	PF	F	S
IR65	IRRI	F	F	F	S
AD9246	India	F	PF	–	–
ARC11353	India	F	F	–	–
CR314-5-10	India	PF/PS	S	F	S
IET2911	India	S	S	F	–
KAU1626-2	India	PF/S	S	F	S
KAU1722-2	India	PS	S	–	–
KAU1727	India	F	PF	–	S
PUSA167-120-3-2	India	S	S	–	–
PUSA367-4-2-1	India	PF	S	F	S
B4140C-PN-186-28-KP-2	Indonesia	F	S	–	–
B445-PH-MR3	Indonesia	F	F	–	–
B5323-8-PN-5-MS-60	Indonesia	PS	PF	–	–
Cimondiri	Indonesia	F	PF	–	–
Ketan Hitam	Indonesia	PS	S	–	–
S400-B-55-3	Indonesia	S	S	–	–
S431-B-25-1	Indonesia	PF	PS	–	–
S287-b-3p-1-3	Indonesia	F/PF	PS	–	S
Iri 377	Korea	F	F	–	S
Milyang 84 (J)	Korea	S	S	F	S
Milyang 85 (J)	Korea	S	S	–	S
Suweon 339	Korea	S	S	–	S
Suweon 340	Korea	F	F/PF	–	S
Suweon 341	Korea	F	F/PF	–	S

[a] (J) = japonica. [b] Spikelet fertility classification: F = >70%, PF = 30-70%, PS = 1-30%, S = 0-1%.

now transferring CMS-ARC cytoplasm to a number of improved breeding lines.

Two japonica CMS lines, Wu 10 A (CMS-bo cytoplasm) and Reimei A (CMS-ruf cytoplasm), were testcrossed with 23 cultivars from IRRI, India, and Korea. Only four of these testcrosses showed somewhat differential reactions (PS/PF vs S), thereby indicating that cytoplasmic factors inducing male sterility in these CMS lines possess only minor genetic differences.

***eui* gene for elongated uppermost internode transferred to indica rice** (*Plant Breeding*). The *eui* gene, a recessive gene controlling the uppermost internode in rice, nearly doubles the length of the uppermost internode, increases panicle length by 12%, and has little or no effect on other internodes or plant characters. It is considered equivalent to a recessive tall trait. If the gene were incorporated into the paternal parent of hybrid rice, this parent would be taller. A taller restorer parent would aid windblown pollen dispersal on the semidwarf male sterile female parent in hybrid seed production plots. The resulting F_1 hybrid would, however, be semidwarf. Additionally, a taller restorer parent would facilitate its removal before bulk harvest of the commercial hybrid seed borne on the male sterile plant.

This gene was originally identified in a japonica line having limited use in tropical hybrid rice breeding Original *eui* genetic stock obtained from the University of California at Davis in 1982 was crossed with the semidwarf indica restorer IR50. From the F_2 population of this cross, plants showing the uppermost elongated internode were backcrossed to IR50 three times. In every BCF_2, we selected plants possessing the *eui* trait and resembling IR50. The BC_3F_3 progenies homozygous for the *eui* gene were selected and designated IR50-*eui* (Fig. 3). Compared with IR50, IR50-*eui* is significantly taller, has 90% tillers with the *eui* trait, but has somewhat lower tillering (Table 5). Yields are not statistically different. Seeds of IR50-*eui* are available at IRRI.

Improved breeding lines possessing large anthers and/or exserted stigma (*Plant Breeding*). Large anthers generally possess more pollen grains, and exserted stigma have higher probability of cross-pollination. Both these traits, when present in the parental lines of hybrids, help increase natural outcrossing and therefore produce higher seed yields in hybrid seed production plots. Over the past 6 yr, we have been trying to transfer large anther size and/or exserted stigma from a genetic stock (6209-3) derived from wild rice *Oryza longistaminata* (Annual report for 1981) into improved rice cultivars. Over the years, we have performed several intermating cycles among plants in the segregating generations following the F_2 to transfer these traits from wild to cultivated rices. Forty-five lines were selected from a large number of F_4-



3. IR50-*eui* rice plant and IR50 at flowering. IRRI, 1988.

Table 5. Comparative performance of IR50-*eui* and IR50. IRRI, 1987 DS.

Trait	IR50-*eui*	IR50	Difference[a]
Days to flowering	84	83	
Height (cm)	110.7	64.3	+46.4**
Tillers (no./hill)	25	35	−10.0**
eui tillers (%)	91.0	0	+91.0**
Yield (g/plant)	18.1	22.3	−4.2ns

[a] ** = significant at the 1% level by *t*-test of mean values, ns = nonsignificant.

F_6 lines after several cycles of intermating and selection. These lines were evaluated during 1988 WS against IR54 and IR66 (cultivars) and C155-11 (a derivative of the genetic stock 6209-3) in a replicated trial. The promising lines possessing improved plant type, exserted stigma, and larger anther size are listed in Table 6.

Incorporation of large stigma size and high stigma exsertion into cultivated rice from wild rice was associated with very high spikelet sterility; this problem was relatively less acute when we selected for large anther size. We have not yet been able to develop lines possessing as large stigma and anthers and as high stigma exsertion as the wild rice genetic stock 6209-3 or its derivative C155-11. The promising lines possessing exserted stigma and large anthers are being used to transfer these traits into the CMS maintainer and restorer lines.

Identification of wide compatibility genes in rice (*Plant Breeding*). In 1987, we identified eight donor cultivars for the WC trait considered useful in exploiting heterosis in indica/japonica hybrids (Annual report for 1987). During 1988, we conducted studies to identify gene(s) present in five of the eight WC cultivars. We crossed the five—Dular, Palawan, Moroberekan, BPI 76, and N22 (Annual report for 1987)—in nine combinations (Table 7). Seven of these F_1s were testcrossed with the japonica tester Taichung 65. The three-way cross and single cross F_1 were analyzed, on an individual plant basis, for spikelet fertility from two primary panicles. Spikelet fertility ranged from 61 to 96.5% in the 2 single crosses involving WC cultivars. We therefore classified plants showing spikelet fertility >60% as fertile (F) and those below this fertility level as semisterile or partially fertile (PF). The three-way cross F_1 population showing all plants with spikelet fertility >60% was assumed to involve WC; however, those three-way crosses showing a segregation ratio of 3F:1PF were assumed to involve different WC genes in the WC donor parents. The three-way crosses involving Dular/Palawan, Moroberekan/Palawan, and BPI 76/Moroberekan showed no PF plants (Table 7), indicating that the WC genes in Dular and Palawan, Moroberekan and Palawan, and BPI 76 and Moroberekan were the same. The three-way crosses involving BPI 76/Palawan showed 33 F and 2 PF plants, which did not conform to a 3:1 segregation ratio. Perhaps the partial fertility of the two plants in this testcross might have been due to environmental factors. If we ignored these plants, results would also indicate that BPI 76 and Palawan possess the same WC gene. The other cross involving Dular/Moroberekan also showed 2 out of 23 plants as PF and would conform to a 3:1 ratio, indicating that Dular/Moroberekan possesses different WC genes; however, data from other crosses did not support this conclusion. Since the population of this three-way cross was small, we need to re-evaluate the cross before

Table 6. Floral and agronomic traits of promising lines developed to increase outcrossing potential in rice. IRRI, 1988 WS.

Line	Yield (g/plant)	Stigma exsertion (%)			Stigma size (mm)	Anther length (mm)	Filament length (mm)	Plant height (cm)	Panicles (no.)	Heading (d)
		Total	One side	Both sides						
SPN2827-2-7	19.1	17.5	16.1	1.4	1.3	2.9	5.0	116	10	96
SPN2870-12	18.3	55.1	43.4	11.7	1.2	2.9	4.5	106	10	79
SPN2901-11	17.9	39.7	35.2	4.5	1.6	2.8	5.2	111	11	87
SPN2804-1-10	16.8	57.9	44.9	13.0	1.4	2.8	5.3	120	9	89
SPN2803-2-12	15.8	10.6	10.2	0.4	1.2	2.8	5.3	116	10	96
SPN3313-1	15.4	59.5	47.5	12.0	1.6	2.8	4.5	109	11	88
SPN2840-2-12	13.7	68.2	52.8	15.4	1.3	2.6	4.6	120	7	89
SPN2916-11	13.4	37.5	28.0	9.5	1.2	2.9	4.4	99	11	77
SPN3016-1-3	13.2	49.5	42.4	7.1	1.5	2.8	5.7	104	7	81
IR54 (check)	15.6	37.9	34.4	3.5	1.5	2.2	5.2	108	9	94
IR66 (check)	12.5	42.8	36.5	6.3	1.3	2.2	5.4	101	10	92
C155-11 (check)	0.1	81.8	28.3	53.5	2.0	3.5	4.7	104	5	90
LSD (0.05)	8.9	14.3	–	–	0.3	0.3	ns	12.9	3	4

Table 7. Spikelet fertility of some 3-way crosses and single crosses involving 5 donors of wide compatibility gene(s) in rice. IRRI, 1988.

3-way/single cross	Plants (no.) showing spikelet fertility[a] of						Total (no.)	Mean spikelet fertility (%)	χ^2 3:1
	41-50 %	51-60 %	61-70 %	71-80 %	81-90 %	91-100 %			
Dular/Palawan//Taichung 65	–	–	5	9	29	7	50	81.8	–
Moroberekan/Palawan//Taichung 65	–	–	5	11	20	4	40	80.2	–
BPI 76/Moroberekan//Taichung 65	–	–	14	5	9	2	30	74.8	–
BPI 76/Palawan//Taichung 65	–	2	9	10	14	–	35	74.0	7.57**
Dular/Moroberekan//Taichung 65	–	2	6	5	10	–	23	73.4	3.25ns
N22/Dular//Taichung 65	1	11	18	19	18	3	70	71.3	2.3ns
BPI 76/N22//Taichung 65	7	15	22	13	7	–	64	62.4	3.0ns
BPI 76/Dular (check)	–	–	2	6	11	1	20	80.5	–
N22/Moroberekan (check)	–	–	1	10	7	7	25	82.4	–

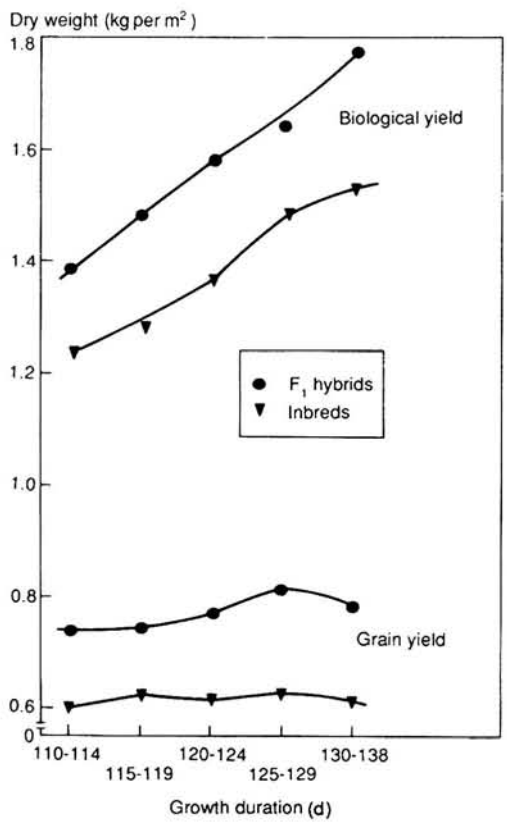
[a] Up to 60% = partially fertile, >60% = fertile.

drawing final conclusions. In the meantime, we conclude that the WC cultivars Dular, Palawan, Moroberekan, and BPI 76 possess the same WC gene. The remaining two three-way crosses involving N22/Dular and BPI 76/N22 conformed to a segregation ratio of 3F:1PF, indicating that N22 possesses a WC gene different from that of Dular and BPI 76. These results also indirectly confirm that BPI 76 and Dular possess the same WC gene.

We need to cross these cultivars with WC cultivars from Japan known to possess the S_5^n gene to determine if the gene(s) present in the above five cultivars analyzed at IRRI are the same as S_5^n or different.

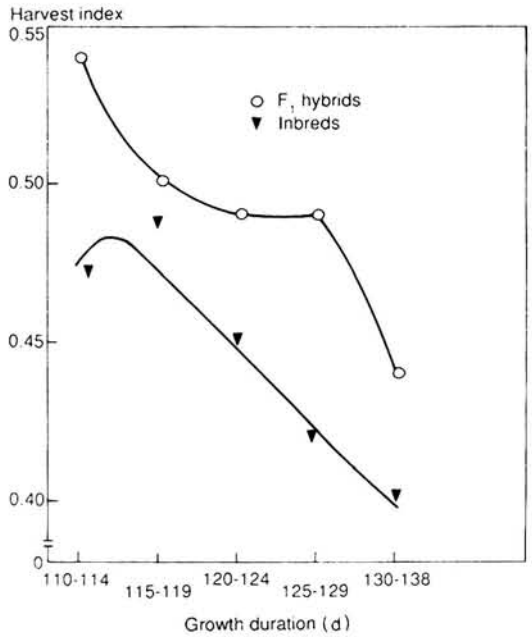
Biomass, grain yield, and harvest index of recent F_1 rice hybrids and inbreds (*Plant Physiology*). The biomass and grain yield of 100 rice cultivars from the observational yield trial (OYT), 57 F_1 hybrids and 43 inbreds, with growth durations ranging from 110 to 138 d, were evaluated. Growth duration of cultivars was grouped by 5-d intervals (Fig. 4). Biomass production increased with growth duration in both F_1 hybrids and inbreds. Heterosis was observed in biomass as well as in grain yield. F_1 hybrids showed an almost 10 and 20% advantage in biomass and grain yield, respectively, over the high-yielding inbreds. Grain yield was almost constant irrespective of growth duration of cultivars, except for a slightly lower yield of very short-duration cultivars. F_1 hybrids and inbreds with growth duration ranging from 125 to 129 d had the highest grain yield.

A decline of biomass with shorter growth duration and the almost constant level of grain yield



4. Biological yield and grain yield of 57 F_1 hybrids and 43 inbreds with different growth durations. IRRI, 1988 DS.

irrespective of growth duration resulted in a higher harvest index (HI) in short-duration cultivars (Fig. 5). A HI higher than 0.50 is often observed in very short-duration F_1 hybrids. F_1 hybrids showed an



5. Harvest index of F_1 hybrids and inbreds with different growth durations. IRRI, 1988 DS.

average of about 10% advantage in HI over inbreds.

WIDE HYBRIDIZATION

Plant Breeding Department

Identification of new sources of cytoplasmic male sterility. Thirty-two accessions of *Oryza perennis* and two accessions of *O. rufipogon* were crossed with two restorer lines (IR54 R and IR64 R) to identify possible new sources of cytoplasmic male sterility. In all crosses, the wild species was used as the female parent.

Fertile hybrids (pollen fertilities of 30% or higher) were obtained from *O. perennis* 100599, 100639, 100692, 104430, 104446, 104453, 104460, 104725, 104769a, 104833, 104870, 104754, and 104805; and from *O. rufipogon* 103817. These accessions were not pursued further.

Sterile hybrids (pollen fertilities of <30%) were obtained from 19 accessions (Table 8). The percentage of sterile hybrid plants varied with the cross combination, ranging from 14% for 103846/IR64 R and 104766a-3/IR54 R to 100% for 100969/IR54 R, 100969/IR64 R, 103846/IR54 R, 104800a/IR54 R, and 104859/IR54 R.

The sterile hybrids were selected and backcrossed to the appropriate restorer line. The pollen fertility of the BC_1 progenies was tested, and progeny with pollen fertilities of less than 10% were selected and are being backcrossed further, on a plant-to-plant basis.

In most cross combinations, sterile hybrids produced BC_1 progeny that segregated for fertility. There are two explanations for this: 1) sterility is under nuclear control and the progeny are segregating for factors conferring sterility; 2) sterility is under cytoplasmic control and the backcross progeny are segregating for nuclear restorer genes. As backcrossing proceeds, the frequency of fertile backcross progeny is expected to diminish, eventually producing stable sterile CMS lines.

Crosses of eight new accessions of *O. perennis* and *O. rufipogon* with IR54 R and IR64 R were made as a continuation of the search for new sources of cytoplasmic male sterility.

***Oryza brachyantha:* a source of yellow stem borer resistance.** *O. brachyantha,* a diploid species with an EE genomic composition, has been identified as a source of yellow stem borer (YSB) resistance. Reciprocal crosses were made between selected *O. sativa* cultivars and four accessions of *O. brachyantha* (101231, 101232, 101233, 105151).

O. sativa panicles were sprayed with gibberellic acid (GA_3 75 ppm) 1 d after pollination. Premature abscission of pollinated *O. brachyantha* spikelets was reduced by 5 post-pollination applications of a second hormonal solution (GA_3 100 mg/liter, naphthalene acetic acid 25 mg/liter, kinetin 5 mg/liter) twice a day beginning at 12 h after pollination.

Pollinations using *O. sativa* as the female parent gave 0.25% seed set (15 seeds from 6,012 spikelets pollinated), and those using *O. brachyantha* as the female parent gave 0.63% seed set (7 seeds from 1,104 spikelets pollinated).

Poor hybrid seed development made it necessary to remove the embryos 14 d after pollination and to place them on a 1/4-strength Murashige and Skoog medium.

More than 50% of the *O. sativa/O. brachyantha* hybrid embryos germinated to produce hybrid plants. Unfortunately, the *O. brachyantha/O. sativa* embryos did not germinate.

The diploid *O. sativa/O. brachyantha* (Acc. 101231, 101232) hybrids were totally sterile. A

Table 8. Frequency of sterile plants in hybrid and backcross generations derived from crosses of selected *O. perennis* and *O. rufipogon* accessions with 2 restorer lines (IR54 R, IR64 R). IRRI, 1988.

Accession	Origin	Restorer line	Generation[a]	Sterile plants[b] (%)
O. perennis				
100969	Surinam	IR54	F_1	100 (3)
			BC_1	100 (14), 66.6 (3), 100 (1)
100969	Surinam	IR64	F_1	100 (6)
			BC_1	50.0 (4), 64.3 (28), 65 (20), 69.8 (43), 75 (8), 100 (6)
103846	India	IR54	F_1	100 (1)
			BC_1	5.8 (17)
			BC_2	80.0 (5)
103846	India	IR64	F_1	14.3 (7)
			BC_1	8.3 (24)
			BC_2	0 (3)
103848	India	IR54	F_1	37.5 (8)
			BC_1	4 (25)
104440	Thailand	IR54	F_1	50 (2)
			BC_1	0 (5)
104447	Thailand	IR54	F_1	25 (4)
			BC_1	40 (5)
104491	Thailand	IR54	F_1	16.6 (6)
			BC_1	30.7 (13), 50 (2), 33.3 (6), 66.6 (12)
104714	Thailand	IR64	F_1	20 (5)
			BC_1	100 (5)
104764	Thailand	IR64	F_1	50 (4)
			BC_1	80 (5), 0 (1), 61.1 (18), 0 (2)
104765	Thailand	IR64	F_1	16.6 (6)
			BC_1	71.4 (14)
104766a-2	Thailand	IR54	F_1	50 (2)
			BC_1	24.4 (90)
104766a-3	Thailand	IR54	F_1	14.2 (7)
			BC_1	50 (14)
104778	Thailand	IR64	F_1	22.2 (9)
			BC_1	60 (10)
104800a	Thailand	IR54	F_1	100 (0)
			BC_1	0 (1)
104823	Thailand	IR64	F_1	33.3 (6)
			BC_1	100 (5), 100 (1)
104859	Thailand	IR54	F_1	100 (1)
			BC_1	33.3 (18)
104866	Thailand	IR64	F_1	25 (4)
			BC_1	15.4 (39)
104867	Thailand	IR64	F_1	5.9 (17)
			BC_1	5.3 (19)
O. rufipogon				
100907	Taiwan, China	IR54	F_1	20 (5)
			BC_1	0 (9)

[a] F_1 progeny considered sterile when pollen fertility is <30%, BC_1 and BC_2 progeny considered sterile when pollen fertility is <10%. [b] In many cases, progenies derived from more than one hybrid or BC_1 plant were observed, resulting in more than one value for percentage of sterile plants. Number of plants observed is in parentheses.

meiotic examination of these hybrids showed 24 univalents at metaphase I. The hybrids were backcrossed to the recurrent parent. The BC_1 seed also degenerated prematurely, making it necessary to rescue the embryos 8-10 d after pollination to improve embryo survival. Nevertheless, poor embryo differentiation, low percentage of embryo germination, and poor seedling survival are hindering the backcrossing process.

Tests of the hybrids for YSB resistance show levels of larval survival and larval weights comparable to those obtained with the parent species *O. brachyantha*. Apparently, the resistance shown by *O. brachyantha* is also expressed by the hybrids.

The resistance of subsequent backcross generations will also be tested to determine whether YSB resistance can be transferred from *O. brachyantha* into cultivated rice.

Gene transfer from *Oryza minuta*. Crosses between the *O. sativa* (AA) line IR31917-45-3-2 and *O. minuta* (BBCC) have been made in an attempt to transfer brown planthopper (BPH), whitebacked planthopper (WBPH), blast (Bl), and bacterial blight (BB) resistance from this wild species into cultivated rice.

The resultant F_1 hybrids are triploid (2n=36), with an ABC genomic composition. Meiotic analysis of the F_1 hybrids revealed a low frequency of chromosome pairing at pachytene, diakinesis, and metaphase I.

At pachytene, pollen mother cells from the 4 hybrids examined (WHD-17-4, 17-5, 19-1, and 20-3) showed a mean of 28.18 I + 3.80 II + 0.08 III. Tables 9 and 10 show the mean chromosome pairing frequencies of the individual hybrids examined at diakinesis and metaphase I, respectively. At diakinesis, the pairing frequencies observed ranged from 33.93 I + 0.86 II (rod) + 0.14 II (ring) + 0.02 III (mean of 1.19 chiasma/cell) in WHD-21-4 to 28.00 I + 2.60 II (rod) + 0.80 II (ring) + 0.40 III (mean of 5.00 chiasma/cell) in WHD-17-1 (Table 9). At metaphase I, the hybrids varied in their pairing frequencies, ranging from 34.53 I + 0.74 II (rod) (mean of 0.74 chiasma/cell) to 0.12 chromatids + 27.35 I + 3.94 II (rod) + 0.29 III (mean of 4.81 chiasma/cell) in WHD-19-1 and WHD-17-5, respectively (Table 10).

A comparison of chromosome pairing at pachytene, diakinesis, and metaphase I showed that, as meiosis progressed, the pairing level was reduced; the mean number of univalents at pachytene, diakinesis, and metaphase I was 28.18, 30.97, and 31.23, respectively; and the mean chiasma frequency per cell was reduced from 3.49 at diakinesis to 2.59 at metaphase I.

The low chromosome pairing level observed in these hybrids indicates that gene transfer from *O. minuta* to *O. sativa* should be possible by recombination. Presumably, chiasma that remain until metaphase I are more representative of crossover events that will lead to recombination than those observed at pachytene but not sustained until metaphase I.

A number of meiotic abnormalities were observed in these hybrids, such as complete desynapsis at metaphase I, multipolar spindles and

Table 9. Diakinesis chromosome pairing frequencies in IR31917-45-3-2/*O. minuta* hybrids. IRRI, 1988.[a]

Hybrid plant	I	II (rod)	II (ring)	III	IV	Cells examined (no.)	Mean chiasma frequency per cell
WHD-17-1	28.00 (25-32)	2.60 (2-4)	0.80 (0-2)	0.40 (0-1)	0	5	5.00
WHD-18-2	29.26 (21-36)	2.00 (0-5)	1.17 (0-4)	0.13 (0-1)	0	23	4.61
WHD-18-4	30.73 (21-36)	1.06 (0-5)	0.90 (0-5)	0.45 (0-3)	0	49	3.76
WHD-20-1	30.83 (26-36)	1.13 (0-3)	1.26 (0-3)	0.13 (0-1)	0	23	3.91
WHD-20-2	31.11 (22-36)	1.00 (0-5)	1.08 (0-5)	0.25 (0-1)	0	53	3.64
WHD-21-1	29.39 (19-36)	1.78 (0-5)	0.98 (0-6)	0.37 (0-2)	0	41	4.46
WHD-21-2	30.48 (25-36)	1.63 (0-4)	0.65 (0-3)	0.29 (0-2)	0.02 (0-1)	52	3.58
WHD-21-3	31.96 (25-36)	0.79 (0-3)	1.17 (0-3)	0.04 (0-1)	0	24	3.13
WHD-21-4	33.93 (30-36)	0.86 (0-3)	0.14 (0-1)	0.02 (0-1)	0	43	1.19
Mean	30.97 (19-36)	1.29 (0-5)	0.86 (0-6)	0.24 (0-3)	0.0001 (0-1)	313	3.49

[a]Numbers in parentheses are ranges.

Table 10. Metaphase I chromosome pairing frequencies in IR31917-45-3-2/*O. minuta* hybrids. IRRI, 1988.[a]

Hybrid plant	Half chromatid	Chromatid	I	II (rod)	II (ring)	III	IV	Cells examined (no.)	Mean chiasma frequency per cell
WHD-17-1	–	–	31.55 (20-36)	2.16 (0-8)	0.04 (0-1)	0.01 (0-1)	0	69	2.28
WHD-17-2	–	–	29.23 (18-36)	3.03 (0-9)	0.07 (0-2)	0.04 (0-1)	0	68	3.26
WHD-17-3	–	0.14 (0-4)	28.61 (20-36)	3.63 (0-8)	0	0.02 (0-1)	0	57	3.67
WHD-17-4	–	–	33.36 (26-36)	1.21 (0-5)	0.04 (0-1)	0.04 (0-1)	0	67	1.39
WHD-17-5	–	0.12 (0-2)	27.35 (18-36)	3.94 (0-9)	0	0.29 (0-3)	0	34	4.53
WHD-17-6	–	–	30.40 (17-36)	2.36 (0-7)	0.28 (0-2)	0.10 (0-2)	0	67	3.13
WHD-18-1	–	–	32.48 (22-36)	1.66 (0-7)	0.07 (0-1)	0.02 (0-1)	0	56	1.84
WHD-18-2	–	–	30.53 (20-36)	1.96 (0-7)	0.22 (0-3)	0.37 (0-2)	0	115	3.14
WHD-18-3	–	–	33.01 (26-36)	1.36 (0-4)	0.14 (0-2)	0	0	73	1.63
WHD-18-4	0.03 (0-2)	0.19 (0-4)	29.19 (20-36)	3.03 (0-7)	0.09 (0-1)	0.15 (0-3)	0	69	3.52
WHD-19-1	–	–	34.53 (30-36)	0.74 (0-3)	0	0	0	76	0.74
WHD-20-1	–	–	31.26 (24-36)	2.28 (0-6)	0.09 (0-1)	0	0	68	2.46
WHD-20-2	–	–	32.03 (20-36)	1.61 (0-6)	0.29 (0-2)	0.06 (0-1)	0	72	2.31
WHD-20-3	–	–	33.33 (22-36)	1.19 (0-6)	0.12 (0-1)	0.02 (0-1)	0	52	1.46
WHD-21-1	–	–	33.25 (26-36)	1.25 (0-5)	0.11 (0-2)	0.01 (0-1)	0	73	1.49
WHD-21-2	–	0.05 (0-4)	28.63 (18-36)	2.90 (0-9)	0.51 (0-4)	0.15 (0-2)	0.02 (0-2)	172	4.27
WHD-21-3	–	–	33.37 (25-36)	1.22 (0-4)	0.07 (0-2)	0.01 (0-1)	0	71	1.37
WHD-21-4	–	–	31.63 (26-36)	1.97 (0-5)	0.21 (0-3)	0	0	71	2.39
Mean	0.002 (0-2)	0.02 (0-4)	31.23 (17-36)	2.08 (0-9)	0.17 (0-4)	0.08 (0-3)	0.002 (0-2)	1330	2.59

[a]Numbers in parentheses are ranges.

laggards at telophase I, chromatin bridges between diads, asynchronous metaphase II, and an absence of cytokinesis in diads and tetrads. These abnormalities, together with the formation of hypotriploid gametes, are presumably the cause of the complete male sterility and high female sterility of these hybrids (Annual report for 1987).

A backcrossing program to advance these hybrids is under way. To date 18 BC_1, 25 BC_2, and 15 BC_3 plants have been produced. Chromosome numbers of the BC_1 progeny range from 2n=42 to 2n=48; and BC_2 progeny with chromosome numbers of 2n=32, 35, and 36 have been identified so far. We are continuing to backcross these progenies and to determine their chromosome number. All hybrids are resistant to BPH, WBPH, BI, and BB, and an analysis of the disease resistance of the backcross progeny is under way.

Incompatibility mechanisms operating in interspecific and intergeneric crosses with *Oryza sativa*. The seed sets obtained from crosses of cultivated rice with wild *Oryza* species or related genera vary, depending on the species used and its genomic composition (Table 11). Seed sets are

presumably limited by both prefertilization and postfertilization incompatibility barriers. A study was made of the types of prefertilization incompatibility barrier operating in selected interspecific and intergeneric crosses. *O. sativa* (AA), used as the female parent, was individually pollinated with *O. sativa*, *O. nivara* (AA), *O. minuta* (BBCC), *O. officinalis* (CC), *O. eichingeri* (CC), *O. alta* (CCDD), *O. brachyantha* (EE), *O. ridleyi* (genome unknown), and *Rhynchoryza subulata*, and fixed 24 h after pollination in 3 parts absolute alcohol: 1 part glacial acetic acid. The ovaries were macerated in 8 N NaOH for 2 h (*O. nivara*-pollinated ovaries were macerated for 1 h only), stained with 0.05% toluidine blue for 10 min, and then stained overnight with 0.1% aniline blue (water soluble) in 0.1 N K_3PO_4. The ovaries were examined under ultraviolet illumination using a 320-400 nm exciter filter and a 470 nm barrier filter.

In crosses with *O. nivara*, *O. minuta*, *O. officinalis*, *O. eichingeri*, and *O. alta*, pollen grain germination and pollen tube penetration of the stigma were successful. Inhibition of pollen tube growth within or at the base of the style was common, although pollen tube penetration of the ovary and the micropyle was observed. No consistent incompatibility barrier was detected in these crosses.

O. brachyantha, *O. ridleyi*, and *R. subulata* pollen showed good germination, but pollen tube penetration of the stigma was rare. When penetration did occur, the pollen tubes of *O. brachyantha* and *R. subulata* rarely grew past the base of the stigma. In the case of *O. ridleyi*, the pollen tubes grew as far as the ovary wall in 20% of the ovaries examined. This strong incompatibility mechanism is clearly responsible for the very low seed sets obtained from such crosses (Table 11). Experiments are under way to determine whether postpollination application of plant growth substances can overcome the incompatibility observed in such cross combinations.

Table 11. Variation in seed set obtained from crosses of *O. sativa* (AA) with selected *Oryza* species and related genera. IRRI, 1988.

Cross combination	Spikelets pollinated (no.)	Seeds set (no.)	Seed set (%)
O. sativa/O. nivara (AA) (Acc. 103839)	181	81	44.8
O. sativa/O. minuta (BBCC) (Acc. 101141)	1,553	66	4.2
O. sativa/O. officinalis (CC) (Acc. 100896)	352	37	10.5[a]
O. sativa/O. latifolia (CCDD) (Acc. 100966)	9,266	126	13.6
O. sativa/O. australiensis (EE) (Acc. 100882)	394	10	2.5[a]
O. sativa/O. brachyantha (FF) (Acc. 101231)	2,195	7	0.3
O. sativa/O. ridleyi (?) (Acc. 100821)	1,018	1	0.1
O. sativa/Rhynchoryza subulata (?) (Acc. 100913)	12,195	0	0

[a] Annual report for 1984.

Table 12. Detection of 3 new isozymes in rice. IRRI, 1988.

Isozyme	Electrophoretic system	Locus[a]	Allozyme	Marker accessions
Diaphorase (DIA)[b]	I	*Dia*-1 (t)	Slow	53950, 27642
	II		Fast	30416, 6304
Fructose 1,6-diphosphatase (FDP)[c]	I	*Fdp*-1	Absent (null)	41048, 27642
	II		Slow	23754
	VI		Fast	30416, 6304
Xanthine dehydrogenase (XDH)[c]	VI	*Xdh*-1 (t)	Slow	30416, 23754
			Fast	33

[a] t = tentative. [b] Emerging leaf (white and green portions). [c] 4- to 6-d-old germinating seed, excluding coleoptile.

BIOCHEMICAL MARKERS

Plant Breeding Department

Identification of new isozymes. In addition to the 24 isozyme loci known in *O. sativa*, 3 new isozymes, namely diaphorase (DIA), fructose 1,6-diphosphatase (FDP), and xanthine dehydrogenase (XDH), have been identified using starch and polyacrylamide gel electrophoresis (PAGE). These three enzymes were revealed in different electrophoretic systems and in different tissues of the rice plant (Table 12). The diaphorase *Dia*-1 (t) was detected in both white and green portions of emerging leaves and was absent from coleoptiles, whereas fructose 1,6-diphosphatase *Fdp*-1 and xanthine dehydrogenase *Xdh*-1 (t) could be found only in 4- to 6-d-old germinating seeds without any activity in coleoptiles or emerging leaves. The isozyme DIA was revealed using starch gel electrophoresis, while XDH was detected in PAGE using system 6. The isozyme FDP was revealed using starch gel electrophoresis as well as PAGE. The compositions of buffer systems and staining procedures are given in Table 13. Furthermore, polymorphism has been detected for these three isozymes (Table 12). Contrasting alleles have been identified between IR36 and marker accessions of the three isozymes (Fig. 6). Three variant alleles

Table 13. Buffer systems for electrophoresis and staining procedures of three isozymes (DIA, FDP, XDH).

Enzyme	Buffer system	Composition		
	Electrophoresis			
DIA	I *Gel*			
FDP	Tris (0.009 M) Histidine (0.005 M) pH 8.0 (diluted 20x)	Trizma base (Tris) Histidine mono HCl completed with H_2O		
	Electrode Tris (0.400 M) Citrate (0.105 M) pH 8.0	Trizma base (Tris) Citric acid, H_2O completed with H_2O		
	II *Gel* Tris (0.076 M) Citrate (0.006 M) pH 8.8 (diluted 10x)	Trizma base (Tris) Citric acid, H_2O completed with H_2O		
	Electrode Na-borate (0.30 M) pH 8.2	Sodium hydroxide (pellets) Boric acid completed with H_2O		
	Polyacrylamide gel, Laemmli, buffer systems			
XDH	VI Separating gel (0.0375 M Tris, pH 8.8)	7.5%		12.5%
	Acrylamide/Bis (30% T, 5% C)	25.0 ml		41.67 ml
	Tris-HCl (1.5 M) pH 8.8	25.0 ml		25.0 ml
	Deionized water	49.5 ml		32.78 ml
	10% APS	0.5 ml		0.5 ml
	TEMED (0.05%)	0.05 ml		0.05 ml
		100 ml		100 ml
	Stacking gel (4% Gel, 0.125 M Tris, pH 6.8)			
	Acrylamide/Bis		2.6 ml	
	Tris-HCl (0.5 M) pH 6.8		5.0 ml	
	Deionized water		12.28 ml	
	TEMED		0.02 ml	
	10% APS/freshly prepared (0.05%)		0.10 ml	
			20.00 ml	

continued on next page

Table 13 continued.

Staining

Diaphorase (DIA):

Solution A: H_2O – 29 ml
Agar – 0.5 g

Solution B:

Tris (0.1 M) pH 8.0	25 ml
DPIP (2 mg/ml)	1 ml
NADH (6 mg/ml)	1 ml

Incubate the gel with agar overlay at 30 °C for 15-20 min or until achromatic bands appear. Record the zymogram immediately as bands tend to diffuse and later fade away (negative staining).

Fructose 1,6-diphosphatase (FDP):

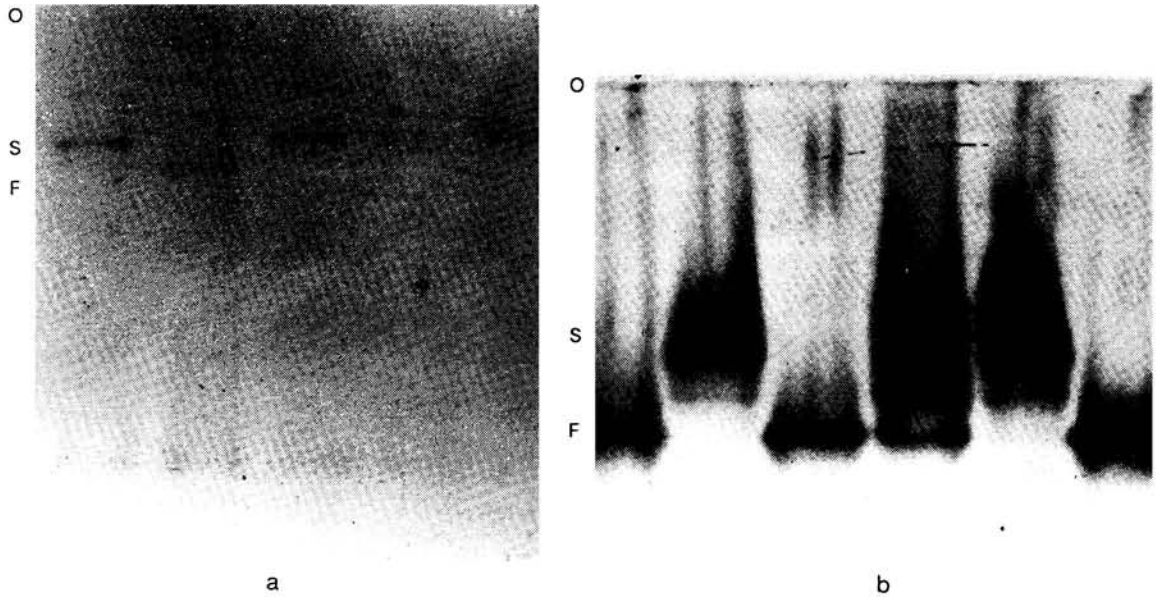
Fructose 1,6-diP	(50 mg/ml)	1.0 ml
PGI	(40 μ/ml)	2.5 ml
G6PDH	(40 μ/ml)	2.5 ml
NAD^+	(15 mg/ml)	1.0 ml
NBT	(1 mg/ml)	1.0 ml
PMS	(1 mg/ml)	1.0 ml
Tris (0.1 M) pH 8.0		41.0 ml

Incubate the gel in the dark at 30 °C for 30 min to 1 h or until the zones of enzyme activity appear in the gel. Discard the solution, rinse with tap water and fix.

Xanthine dehydrogenase (XDH):

Tris (0.05 M) pH 7.5	50.0 ml
Hypoxanthine	90.0 ml
NAD (15 mg/ml)	1.0 ml
NBT (10 mg/ml)	1.0 ml
PMS (2.0 mg/ml)	1.0 ml

Heat hypoxanthine in buffer until it dissolves. Bring the solution to room temperature and add other reagents. Incubate in the dark.

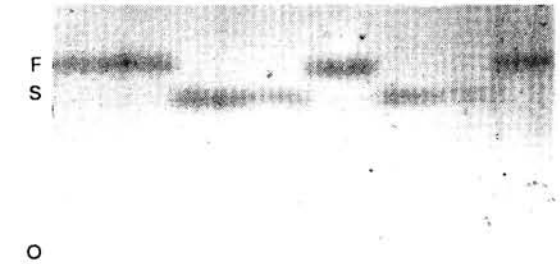


6. Polyacrylamide gel zymogram showing polymorphism for 2 new isozymes in cultivated rice, IRRI, 1988. a) Upper band- *Xdh-1*[1] (slow = IR36 and other accessions, fast = Acc.33); bottom band = unclassified. b) *Fdp-1* (slow band = Acc. 23754 and 43675, fast band = IR36 and other accessions).

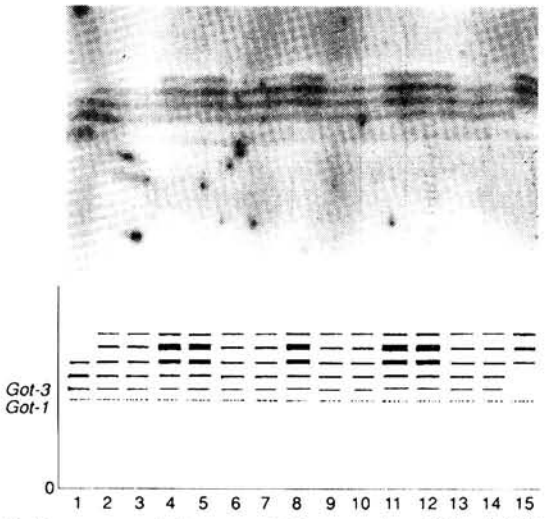
including the null allele were observed at *Fdp*-1, whereas two variant alleles have been identified each at *Dia*-1 (t) and *Xdh*-1 (t).

Chromosomal location of isozyme loci. To date, 18 isozyme loci have been located on 8 of the 12 rice chromosomes. To identify isozyme loci for the remaining four chromosomes, isozyme polymorphism was detected for four isozymes, namely *Got*-3, *Acp*-4, *Mal*-1, and *Pgd*-2, in IR36 and two other rice accessions (6304, 43394). The contrasting alleles between IR36 and these marker accessions were detected after screening more than 3,000 accessions each for *Got*-3 and *Pgd*-2, whereas about 1,000 entries were studied for *Acp*-4 and *Mal*-1. No contrasting alleles could be observed in the 25 isozyme tester stocks and IR varieties for *Mdh*-1, *Mdh*-2, *Mdh*-3, and *Enp*-1 isozyme loci. However, the wild species *O. nivara* (Acc. 101508) showed polymorphism for these four isozyme loci (Fig. 7). Analysis of eight F_1 trisomic progenies (primary trisomics/isozyme marker accessions) on the basis of gene dosage effect indicated that *Enp*-1 and *Got*-3 are located on chromosomes 3 and 2, respectively (Fig. 8). The segregation of *Got*-3 in F_2/BC_1 generations revealed trisomic 2 as the critical chromosome carrying *Got*-3 locus (Table 14). The gene dosage effect in the F_1 generation and segregation in the F_2/BC_1 generations for 12 isozyme loci involving *Got*-3, *Acp*-4, *Mal*-1, *Pgd*-2, *Mdh*-1, *Mdh*-2, *Mdh*-3, *Enp*-1, *Est*-1, *Dia*-1, *Fdp*-1, and *Xdh*-1 (t) are being analyzed to locate 12 loci on the specific rice chromosomes.

Isozyme polymorphism in rice genetic stocks possessing various morphological markers. Isozyme polymorphism was studied in rice genetic stocks representing 23 gene markers. Polymorphism was detected in these stocks for 15 isozyme loci (*Got*-1, *Icd*-1, *Est*-5, *Amp*-1, *Est*-2, *Amp*-3, *Cat*-1, *Pgi*-2, *Pox*-5, *Pgi*-1, *Sdh*-1, *Est*-9, *Amp*-2, *Adh*-1, and *Pgd*-1) located on 8 of the 12 rice chromosomes. In addition, polymorphism was also detected in these stocks for three isozyme loci (*Est*-1, *Mal*-1, *Pgd*-2) that have not been located on any of the chromosomes. The linkage relationships between the 23 gene markers and the 15 isozyme loci are being investigated.



7. Starch gel zymogram showing polymorphism for *Enp-1* in IR36 (fast band) and *O. nivara* (slow band). IRRI, 1988.



8. Zymogram and diagrammatic interpretation of *Got-3*, IRRI, 1988. Samples 1 and 16, IR36; sample 2, Acc. 6304; samples 3, 4, 7, 8, 10, 11, 14, 15, disomic F_1 progenies of IR36/Acc. 6304; samples 5, 6, 9, 12, 13, trisomic F_1 progenies of IR36/Acc. 6304.

Table 14. Segregation[a] for *Got*-3 isozyme in the F_2/BC_1 progenies of the crosses of 8 trisomics with Acc. 6304. IRRI, 1988.

Trisomic	Generation	Plants (no.) with designated genotype			χ^2
		11	112 122 12	22	
2	BC	0	40	12	15.076**
3	BC	0	53	51	0.038
5	F_2	8	17	8	0.030
6	F_2	7	18	5	1.466
7	F_2	11	26	9	0.955
8	F_2	10	12	6	1.715
9	F_2	27	54	28	0.010
11	F_2	10	17	9	0.167

[a] Mendelian segregations are 0:1:1 for BC and 1:2:1 for F_2. Trisomic segregations are 0:3.28:1 for BC and 4.86:7:1 for F_2, assuming a 30% female transmission of the extra chromosome.

Table 15. Comparison of segregations of heterozygous isozyme markers among anther-culture and selfed derivatives of 5 distant intervarietal rice F_1 hybrids.[a] IRRI, 1988.

	Isozyme locus[a]													
	Icd-1 1	*Amp*-3 3	*Est*-2 3	*Pgi*-2 3	*Cat*-1 3	*Pgi*-1 4	*Sdh*-1 6	*Acp*-1 6	*Acp*-2 6	*Est*-9 7	*Amp*-2 8	*Pgd*-1 11	*Est*-1 ?	*Mal*-1 ?
IRAT216					F	F	F	F	A	F	S		P	S
Eloni					S	S	S	S	P	S	F		A	F
NM calli					199:190	155:218■	146:249■	186:180	250:55■	184:189	243:152■		200:190	139:132
F_2 plants					48:68:27●	53:90:73	80:122:126▼	67:127:76	131:203■	54:84:43	84:136:67		59:148	32:74:60
IRAT216	F	F	S			F		F	A	F	S	S	P	S
IRAM31-8-5	S	S	F			S		S	P	S	F	F	A	F
NM calli	210:185	175:217	216:177			145:246■		122:160□	55:161■	153:240■	193:146□	164:228■	259:135■	124:45■
F_2 plants	100:133:87◇	62:90:35	67:145:77			51:99:40		32:82:61○	49:138	42:120:87○	64:80:41	58:83:38	188:133■	51:26:22▼
IR21567		S	P	S		S	S	S	P		F		A	
Ramjaewen		F	A	F		F	F	F	A		S		P	
NM calli		178:100■	154:130	135:147		148:134	189:95■	172:69■	67:112■		145:122		76:208■	
F_2 plants		83:67:88▼	47:81	51:94:57		63:102:36	121:66:17●	79:77:24●	30:155■		61:103:37		33:121	
Azucena					S	F		F	A	F	S	S	P	S
UPLRi-7					F	S		S	P	S	F	F	A	F
NM calli					151:103■	113:143		45:147■	128:66■	93:161■	85:135■	167:89■	147:106□	105:130
AC plants					38:34	44:84		18:27	46:32	40:36	31:47	29:42	43:30	24:28
F_2 plants					–	60:115:74		82:64:137●	167:204■	54:136:113●	50:93:69	85:53:55▼	178:128■	61:66:55◆
IR64		S	F	F	S	S	F	S	P	F	S		A	F
Azucena		F	S	S	F	F	S	F	A	S	F		P	S
NM calli		59:73	61:74	87:58■	77:61	69:70	78:61	52:80	76:24■	44:85■	57:78		72:67	44:42
AC plants		28:42	42:28	36:34	35:27	42:28	28:42	17:19	25:34	28:42	28:42		37:33	25:27
F_2 plants		96:145:90	78:126:72	101:157:106	37:77:46	101:186:75	67:122:72	61:97:58	114:245	67:140:79	47:146:67		116:181■	82:148:92

[a]Designation and chromosomal location of the isozyme loci. Parental allele designations adopted are fast (F) vs slow (S) when the parents differed in the migration speed of the allozymes, and absence (A) vs presence (P) when the parents differed in the presence of a band. Segregations following the sequence SS:SF:FF or AA:AP + PP for the F_2 progeny (F_2 plants) and SS:FF or AA:PP for the anther culture-derived callus (NM calli) or plant (AC plants) populations. Chi square values for a fixed ratio hypothesis significant at the 5% (□, ○, ◇) or at the 1% (■, ●, ▼, ◆) level indicating: (■, □): a departure of the observed segregations from the expected 1:1 ratio (NM calli and AC plants) or 1:3 ratio (F_2 plants), (●, ○, ▼, ◆, ◇): a departure from the expected 1:2:1 ratio of the segregations observed in the F_2 due to (●, ○) a significant disequilibrium in the calculated allelic frequencies, (◆, ◇) a significant non-random assortment of the alleles, or (▼) both causes.

Monitoring isozyme marker segregations among anther-culture derivatives of distant intervarietal crosses of rice. To know whether anther-culture (AC) derivatives represent a random recombinant array of the hybrid gametic population is important to assess the suitability of this innovative tool in improving the breeding efficiency of rice remote crosses. To test this question, segregations of heterozygous isozyme markers were surveyed among AC-derived populations (i.e., nonmorphogenic calli [NMC] and, when they reach a sufficient number, the plants [ACP]), and the F_2 progenies in four japonica/indica hybrids and one indica/indica hybrid.

The F_2 progenies of the hybrids involving tropical japonica upland (isozyme group 6) and indica (isozyme group 1) varieties (i.e., IR64/Azucena, IRAT216/Eloni, IRAT216/IRAM31-8-5, and Azucena/UPLRi-7) showed distorted segregations at 1, 3, 5, and 6 loci among the 12, 9, 11, and 8 heterozygous isozyme loci surveyed, respectively (Table 15). When departures from the expected segregation ratios were due to a distortion in the frequencies of the parental alleles, consistent deviations were generally noted among the NMC populations. Significant additional deviations from the expected 1:1 ratio at 3, 2, 4, and 1 loci were noticed only among the NMC derivatives of the 4 respective crosses, indicating that a slight in vitro gametic selection took place during callogenesis. The segregations at four of the nine loci surveyed among the F_2 and NMC of the intraindica cross between the rainfed lowland F_7 elite line IR21567-9-2-2-3-1-3 (isozyme group 1) and the high quality grain variety Ramjaewen (isozyme group 5) were also consistently distorted in the two populations. The anther-culture derivatives presented a further deviation from the expected 1:1 ratio at a fifth locus.

Segregations of 9 and 12 heterozygous isozyme markers were monitored among 78 and 70 ACPs derived from the hybrids Azucena/UPLRi-7 and IR64/Azucena, respectively, to know whether the gametic selections observed within the NMC were also found among the morphogenic callus population. Segregations fitting the expected 1:1 ratio were observed at all loci surveyed in the 2 ACP populations, suggesting that the nonmorphogenic and morphogenic callus populations were derived from distinct microspore pools. In Azucena/UPLRi-7, only the NMC population is affected by the in vivo selection known to occur during the subsequent steps of the microsporogenesis of rice distant F_1 hybrids and by in vitro deviations. This result contrasts with our previous report of consistent distortions observed in NMC and ACP populations derived from the cross IRAT177/Apura and must therefore be confirmed by surveying other ACP populations. Nevertheless, it clearly indicates that the morphogenetic pathway of androgenesis could act in some instance as a detour from the microsporogenesis in possibly avoiding the later in vivo pollen selection, which is known to hinder the conventional exploitation of rice F_1 distant hybrids.

TISSUE CULTURE

Plant Breeding Department

Anther culture. The influence of the physiological manipulations of donor plants on AC efficiency was studied using IR36 and IR43 (Table 16). The donor plants were grown under different temperature regimes. For IR36, the low temperature of 24/20 °C was superior to all other treatments, while for IR43, the high temperature stress of 31/31 °C was best. However, viewed together with the results of field experiments involving spacing and delayed transplanting, the response of IR43 was found to be better among field-grown plants. Plants transplanted at 35 d after sowing at a spacing of 30 × 30 cm gave the highest anther response of about 40%.

Table 16. Percentage of callus production of IR36 and IR43 in MSN and SK-7 media under different temperature regimes. IRRI, 1988.

Day/night temperature (°C)	Callus production (%)			
	IR36		IR43	
	MSN	SK-7	MSN	SK-7
Control I[a]	1.2	3.1	11.4	16.5
Control II[b]	0.6	1.2	4.7	5.9
31/31	3.4	4.8	15.7	8.5
29/29	3.1	3.4	3.6	2.5
24/24	2.2	2.1	7.0	8.0
31/25	2.0	2.2	7.7	9.7
29/25	4.4	3.4	14.6	10.0
24/20	6.7	3.9	11.1	6.1

[a]Plants were grown just outside the phytotron. [b]Plants were grown in the screenhouse.

The effect of various types of cereal flour/starch as gelling agents in rice AC was determined. The starch, aside from acting as a solidifying agent, acts as a C source upon hydrolysis. The callus induction response of Taipei 309 in medium gelled with 2.0% (wt/vol) of different cereal flours plus 0.2% agar was compared with that in medium solidified by 0.6% agar (Table 17). Rice flour improved the callus response in three varieties, although for the cross CAM14F4/Chiapas A84 the best medium was L8 (modified N_6) medium gelled with wheat flour. Nevertheless, addition of cereal flour improves rice AC response, as in barley AC.

The type and concentration of N source has been considered a critical factor in AC as well as in other tissue culture techniques. The effects of proline as an additional N source, and of high NH_4^+ concentration on callus induction and plant regeneration in Taipei 309 were determined (Table 18). The highest callus induction efficiency was observed in the treatment with 17.4 mM proline. However, plant regeneration from calli induced in medium containing proline was not significantly different from that in the control. The stimulatory effect of proline on callus induction was not carried over to the plant regeneration stage. A similar trend was observed in IR36, IR42, IR43, and RAC3. On the other hand, increased concentration of $(NH_4)_2SO_4$ from 1.01 to 25 mM in $E_{10}P_{20}N$ and addition of both proline and high concentration of $(NH_4)_2SO_4$ inhibited callus induction.

Residual heterozygosity always exists in conventionally bred lines in contrast to AC lines, which are presumably of 100% purity. Because of residual heterozygosity or possible outcrossing under natural growing conditions, some lines do not breed true-to-type after several generations. AC was therefore employed in the "purification" of some IR lines that were not of the desired stability. All of the 18, 15 of which were IR varieties, subjected to AC produced calli, and 27 plants were regenerated from 6 calli.

A combination of innovative breeding techniques may speed up work on rice improvement. Thus, AC of high heterotic F_1 (indica/indica) hybrids from the hybrid rice program was utilized for isolation of double haploid pure lines. From 4 crosses, more than 700 green plants were regenerated from more than 300 individual anther calli. The regenerated plants will be evaluated under field conditions and their performance compared with the F_1 progeny.

Table 17. Percentage of callus induction of 3 varieties in media gelled with different types of cereal flour.[a] IRRI, 1988.

Medium	Callus induction (%)		
	CAM14F4/ Chiapas A84	IR30716-1B-b-1-6/IAC165	Taipei 309
L8 (control)	28.5	9.7	40.8
L8 + rice flour	41.0	23.6**	63.9
L8 + wheat flour	62.5**	9.8	–
L8 + corn starch	28.5	–	7.4*

[a] – = no observation.

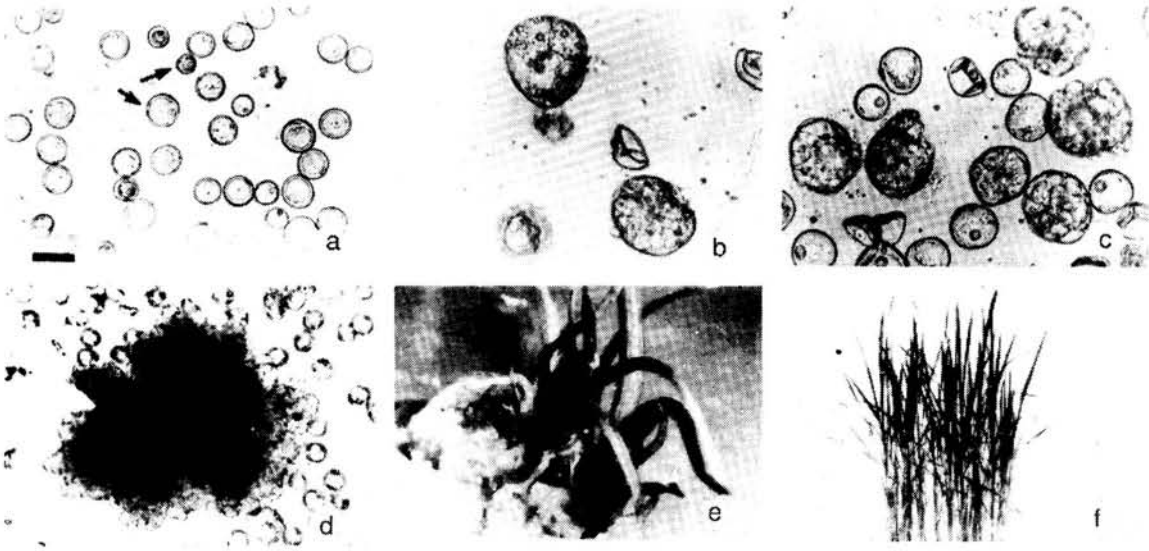
Table 18. Anther culture response of Taipei 309 in media containing different types and concentration of N source. IRRI, 1988.

Callus induction medium[a]	Anthers responding (%)	Calli producing green plants (%)[b]
$E_{10}P_{20}$ (control)	15.9 b	25.0 a
$E_{10}P_{20}L$	16.9 a	19.3 a
$E_{10}P_{20}N$	2.5 c	–
$E_{10}P_{20}LN$	4.2 c	12.0 b

[a] $E_{10}P_{20}$ = Gamborg's B5-medium with 20% potato extract, 1.0 mg 2,4-D/liter, 0.5 mg IAA/liter, 0.5 mg BAP/liter, and 5 g glucose/liter; L and N represent addition of 17.4 mM proline and 25 mM $(NH_4)_2SO_4$, respectively. [b] Values followed by a common letter are not significantly different at the 5% level by the χ^2-test for independence ratio. – = no data.

Isolated pollen culture. Plants of a japonica (Taipei 309) have been regenerated through isolated pollen culture (Fig. 9, Table 19). The protocol is still far from routine, since the plating and regeneration efficiencies are still low relative to AC. What is important is the demonstration of the possibility of this technique, which opens wide opportunities in transformation studies.

Several factors that significantly affect pollen culture efficiency have been identified: preculture prior to pollen isolation, the existence of pollen dimorphism (Fig. 9a), and pollen viability. Emphasis has been given to identifying factors



9. Callus formation and plant regeneration from isolated pollen culture of rice (*O. sativa* cultivar Taipei 309). (a) Fresh isolated pollen (x 200). Arrows indicate big and small grains. Bar = 60 μm. (b) Initiation of division (x 400). (c) Further division (x 400). (d) Callus formation from individual isolated pollen in culture (x 100). (e) Plant regeneration from pollen (x 6.6). (f) Plants grown in culture solution.

Table 19. Plating efficiency and plant regeneration in isolated pollen cultures from precultured anthers of Taipei 309.[a] IRRI, 1988.

Callus induction medium	Plating efficiency at day 17 after culturing (%)	Calli plated on regeneration medium (no.)	Plant regeneration efficiency (%)	
			Green	Albino
E_{10}	0.26 b	35	5.7	5.7
E_{10} + 1 mM alanine	0.35 b	16	6.3	12.5
E_{10} + 1 mM glutamine	2.71 a	89	21.3	12.4
E_{10} + 1 mM proline	3.50 a	111	31.5	18.0

[a] Based on 4 replications.

that increase the proportion of bigger pollen grains (50-58 μm diameter) with thin, light pink-colored cell walls—which were observed to be viable and have the capacity to divide (embryogenic pollen grains or P-grains)—compared with smaller grains, which have low viability and do not divide. Maintenance of pollen viability after isolation is also emphasized.

Protoplast culture. Cell suspensions from seed-derived and AC-derived calli of cultivars were established as possible sources of protoplasts. The growth parameters in terms of packed cell volume, fresh weight, and dry weight showed mostly cubic or quadratic patterns except for Kulu, which was linear.

Four varieties were used for protoplast culture—japonicas Taipei 177 and Taipei 309, and indicas Kulu and Tetep. The conditions for protoplast isolation and culture—the concentration of enzymes, type and concentration of osmoticum, gelling agent, and method of protoplast culture—were optimized. A total of 42 green plants from 3 varieties were regenerated (Table 20). The ability to regenerate plants from indicas was demonstrated.

Collaborative programs. Various collaborative programs, mainly for breeding rice for adverse conditions and soils tolerance with the use of AC for immediate attainment of homozygosity, were continued. The advantage of doing AC of F_1

Table 20. Performance of 4 rice genotypes in protoplast culture. IRRI, 1988.

Genotype	Protoplast yield (no. $\times 10^7$)/g fresh wt	Plating efficiency (%)	Green plants regenerated (no.)
Taipei 177 (japonica)	1.14	1.54	32
Taipei 309 (japonica)	1.89	0.81	9
Kulu (indica/japonica)	1.62	1.37	0
Tetep (indica)	0.65	1.77	1

crosses to shorten the breeding cycle is more pronounced in breeding for adverse conditions, since rice is grown in a single cropping season in a year under these conditions. The various projects were done in collaboration with IRRI scientists and national programs of several countries. The number of plants obtained in the different collaborative programs is shown in Table 21. More than 1,000 plants representing about 300 genotypes were produced. Seed of these regenerated plants is later sent to scientists and national programs for testing under the conditions for which they were bred.

More than 800 AC-derived lines from various collaborative projects were sent to various scientists and national programs for field testing. The bulk of these (540 AC-derived lines) were sent to Korea for cold tolerance testing. Around 30 and 40 lines were sent to Egypt and Peru, respectively. One hundred and seventy-six lines were given to

Table 21. Plant regeneration in anther culture of F_1 crosses in various collaborative projects for breeding for adverse conditions. IRRI, 1988.

Adverse condition or country	Crosses (no.)		Green plants produced (no.)
	Plated	Responding	
Salinity	18	16	53
Cold (in-house)	84	62	382
Cold (Korea)	16	13	277
Upland	14	12	111
Photoperiod sensitivity	26	25	13
Egypt	16	16	200
Mexico	22	18	22
Irrigated	15	11	53
Total	186	162	1111

IRRI's drought, salinity, and cold tolerance programs. Around 50 were sent to scientists elsewhere.

Five AC-derived lines were tested by the Rural Development Administration (RDA), Korea, in replicated yield trials. The lines were derived from F_1 crosses sent earlier by RDA to IRRI for AC. These lines were selected previously from observational yield trials. The pedigree SR12192-T8 has been nominated as Suweon 357. Another line, SR12192-T15, that outyielded the check is promising.

Eight AC-derived lines from four crosses bred for salt tolerance were planted in replicated yield trials in Iloilo, Philippines. Three of these lines were found to be comparable with or better than Pokkali or Nona Bokra.

Genetic evaluation and utilization (GEU) program

Computerized data management

International Rice Testing Program and Plant Breeding, Communication and Publications, and Computer Services Departments

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INTERNATIONAL RICE TESTING PROGRAM

International Rice Testing Program

A new nursery has been incorporated in the computerized systems for the International Rice Testing Program (IRTP): the International Rice Drought Screening Nursery (IRDSN).

The seed inventory system was developed in the DEC/VAX mainframe using ORACLE. The system will allow us to accurately keep track of the stock of seed in storage. It also aims to facilitate the production of reports to support related activities such as seed increase, nursery composition and preparation, and seed requests.

As of the end of 1988, the master inventory file contained 9,445 records for 23,831 kg of seed, of which 16,691 kg were for the 1989 nurseries, 4,730 kg of highlighted entries were for seed requests, and the rest were remnant seeds from nurseries of previous years.

Preliminary and final reports for 1987 were generated for 23 nurseries. Individual and master field books for 1988 nurseries were also generated. Entries for the 1988 nursery included 507 from IRRI and 812 from national programs.

Cooperators from 18 countries nominated 1,169 entries for the 1989 nurseries. The nominated entries, together with the highlighted and backlog entries, were increased in the IRTP fields. Seed increase field books for 1988 dry and wet seasons were printed for these entries planted in 3,932 plots.

By the end of the year, the IRTP master entry file had 12,625 entries, 9,615 of which had been tested in the nurseries.

EVALUATION OF BREEDING LINES

Plant Breeding Department

In 1988, the Deepwater Special Seed Increase Inventory System was developed on the IBM PC using ORACLE. This was done to keep accurate track of the stock of seed available for deepwater materials.

The generation of field books and data sheets for the use of plant breeders and other GEU scientists was continued. Information on the entries tested by the Plant Breeding Department was also provided to IRRI scientists and other research staff and to agricultural researchers on an ad hoc basis. Data on entries tested for the year were added to existing computer files.

At year end, 2,409 new F_1 crosses were added to the History-of-IRRI-Crosses file. Some 5,538 lines or varieties were tested in hybridization block, replicated yield trial, and observational yield trial nurseries.

INTERNATIONAL RICE GENETIC SURVEY

Communication and Publications Department

IRRI now has data from the International Rice Genetic Survey on 77,958 crosses made in national programs, plus genealogies of almost 1,000 post-IR8 varieties released by national programs, and of 1,600 pre-IR8 varieties that farmers still grow or that rice breeders use as parents in crosses (Table 1). Scientists everywhere may request genealogies of varieties and crosses.

Table 1. Sources of genealogical and hybridization data gathered through the International Rice Genetic Survey. IRRI, 1988.

Sources	no.		
Varieties			
Pre-IR8 varieties	1,587		
Post-IR8 varieties	923		
Elite breeding lines	219		
Progenitors	2,013		
Subtotal		4,742	
National crosses			
Argentina	118		
Australia	1,129		
Bangladesh	4,483		
Brazil	176		
Burma	1,318		
Dominican Republic	283		
India	11,775		
Indonesia	5,792		
International Institute of Tropical Agriculture	3,816		
Iran	353		
Japan	311		
Korea	29,679		
Nepal	817		
Pakistan	2,555		
Philippines	154		
Sri Lanka	1,617		
Thailand	11,196		
United Sates	2,409		
Subtotal		77,958	
Total			82,700

COMPUTER SERVICES FOR DATA MANAGEMENT

Computer Services Department

Central computer facilities in 1988 were increased by the addition of the VAX 8350 with three direct access storage devices, a tape drive, and two printers.

The ORACLE database management system was installed on the VAX 8350. By year end, central processing unit, main, and disk storage use increased significantly, indicating that additional data were being manipulated on the system.

User service and response time on the system remained at high levels (response average 0.12 s, resource availability index 76%, and system availability 98.7%). The total number of ports is 56 on the IBM 4361. On the VAX 8350, 16 ports are available, expandable to 64 directly and to 128 indirectly with additional equipment.

The microcomputer population grew to about 400 during the year. Many of these are also used for data storage and analysis, relieving the load on the mainframes.

Two channels have been assigned to data transmission on the new microwave system to facilitate the dissemination of information stored in IRRI databases.

Genetic evaluation and utilization (GEU) program

Seed science and technology

International Rice Testing Program, Cereal Chemistry Department, International Rice Germplasm Center, and Centre International de Recherche Agronomique pour le Développement-Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres

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SEED DORMANCY

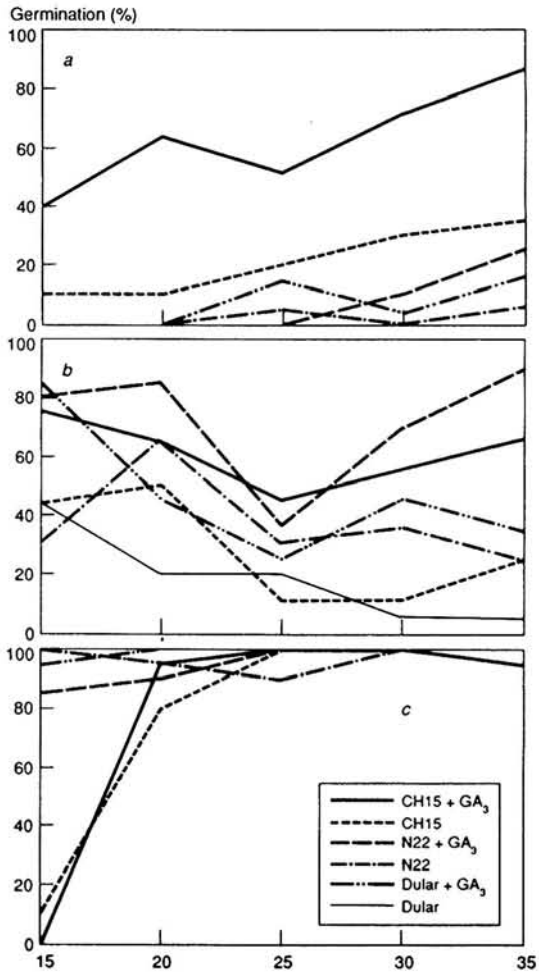
International Rice Testing Program

Development of natural dormancy and its alleviation. Ten rice cultivars were grown under natural light in the phytotron at 29/21 °C (day/night temperature), and the seeds were collected from 15 to 35 days after flowering (DAF) at 5-d intervals. Germination was tested at each interval in the presence or absence of gibberellic acid (GA_3 100 ppm), with or without the hull and the pericarp. One lot of seed samples was subjected to dry heat treatment at 50 °C for 5 d and another lot to moist heat treatment at 100% relative humidity (RH) and 43 °C for 3 d, prior to the germination test. Peroxidase activity and O_2 uptake at 5-d intervals from 15 to 35 DAF, and amylase activity at 35 DAF were measured in both intact and dehulled seeds.

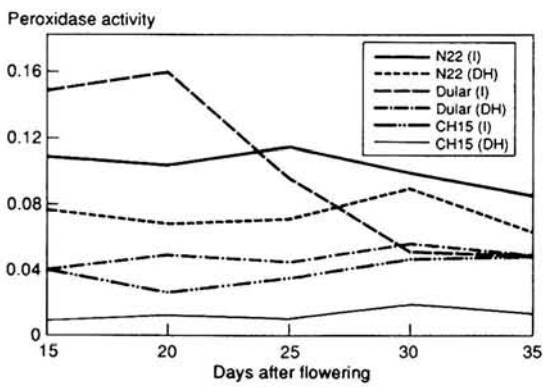
Germination of freshly harvested seeds of the 10 cultivars varied from 0 to 40%. Removal of the hull increased germination by 10-75%. Scraping the pericarp resulted in 75-100% germination in all cultivars at different DAF. Application of GA_3 had little effect on improving the germination of intact seed, but it increased the germination of dehulled seed up to 95% (Fig. 1).

In dormant cultivars with red kernels, such as Dular and Kataktara, the pericarp had a more inhibitory effect on germination. Dormant cultivars were characterized by higher peroxidase activity and higher O_2 uptake than nondormant cultivars (Fig. 2, 3). Peroxidase activity was higher in intact seed than in dehulled seed in all cultivars irrespective of dormancy level. The presence of the hull also showed an inhibitory effect on the amylase activity of freshly harvested mature seed (Fig. 4). Nondormant cultivars had higher amylase activity than did dormant ones.

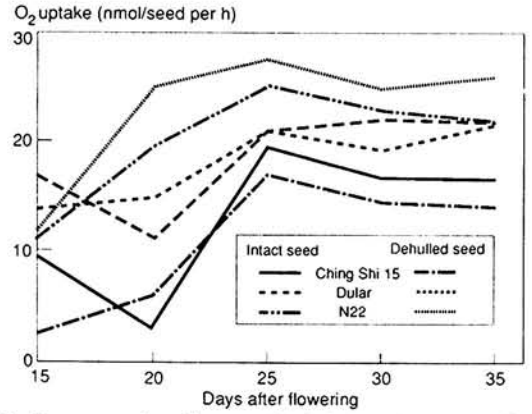
Dry heat treatment was not very effective in overcoming dormancy in freshly harvested seed. On the contrary, moist heat-treated seed showed up to 100% germination (Fig. 5). Thus, dehulling or heat treatment could only partially alleviate dormancy in freshly harvested seed, while removal of the pericarp or moist heat treatment could completely release dormancy. This suggests that in strongly dormant cultivars, the pericarp plays a major role in imposing dormancy.



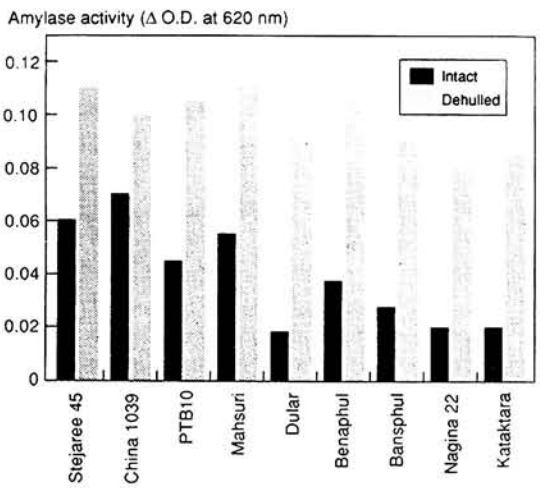
1. Effect of 100 ppm gibberellic acid (+GA_3) on germination percentage of intact (a), dehulled (b), and pericarp-removed (c) seeds harvested from 3 rice cultivars at various days after flowering. IRRI, 1988.



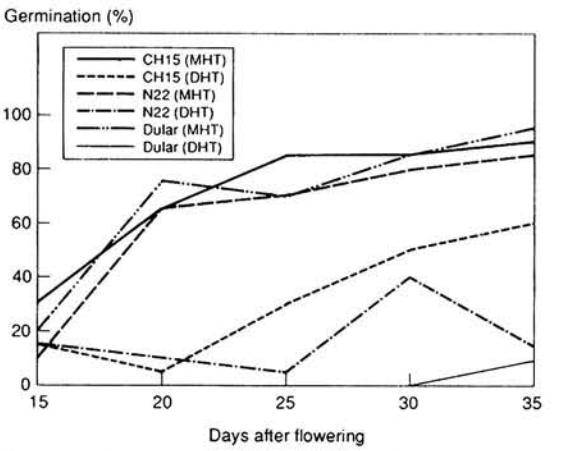
2. Peroxidase activity of intact (I) and dehulled (DH) seeds harvested from 3 rice cultivars at various days after flowering. IRRI, 1988.



3. Oxygen uptake of intact and dehulled seeds harvested from 3 rice cultivars at various days after flowering. IRRI, 1988.



4. Amylase activity of intact and dehulled seeds in 9 rice cultivars at 35 d after flowering. IRRI, 1988.



5. Germination percentage of seeds treated with dry heat (DHT: 50 °C, 5 d) and moist heat (MHT: 43 °C, 100% relative humidity, 2 d) and harvested from 3 rice cultivars at various days after flowering. IRRI, 1988.

Role of short-chain saturated fatty acids in imposing seed dormancy. Exogenous application of paired combinations (1:1) of four short-chain saturated fatty acids (SCSFAs), viz., hexanoic (C_6), heptanoic (C_7), octanoic (C_8), and nonanoic (NA, C_9) acids, at a combined concentration of 5 mM to nondormant seed of Ching-shi 15, IR8, and IR64 revealed that C_6 and C_7 acids were effective in reducing germination significantly only in combination with C_8 and C_9 Cultivars differed in response (Table 1). The actual germination, when compared with the expected by means of the contingency chi-square test, showed that combinations involving C_9 were all significantly

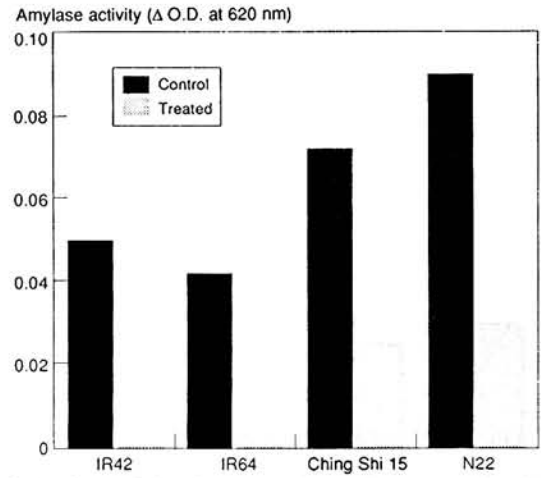
Table 1. Effect of paired combinations (1:1) of short-chain saturated fatty acids at a total concentration of 5 mM on germination of 3 rice cultivars.[a] IRRI, 1988.

	Germination (%)											
	C_6			C_7			C_8			C_9		
	IR8	IR64	Ching-shi 15	IR8	IR64	Ching-shi 15	IR8	IR64	Ching-shi 15	IR8	IR64	Ching-shi 15
C_6	100.0	100.0	100.0	96.6 (98.3)	100.0 (100.0)	100.0 (100.0)	80.0*[a] (65.0)	90.0** (66.7)	100.0** (91.7)	20.0** (50.0)	10.0* (50.0)	15.0** (94.0)
C_7				96.6	100.0	100.0	60.0 (63.3)	70.0 (66.7)	70.0** (91.7)	33.3* (48.3)	36.6 (50.0)	83.3* (94.0)
C_8							30.0	33.3	83.3	0.0** (15.0)	0.0** (16.7)	26.6** (85.7)
C_9										0.0	0.0	88.0
						Control	100.0					

[a] Expected value compared with observed value by contingency χ^2 test. Significant at the 5% (*) and 1% (**) probability levels. Figures in parentheses denote expected values derived as the mean of specific combinations.

more inhibitory than expected. Thus, NA was the most effective SCSFA in imposing dormancy, either alone or in combination with other SCSFAs.

Treatment of nondormant seed of China 1039, IR36, and N22 with 5 mM NA significantly reduced germination percentage, gain in fresh weight on soaking in water, electrical conductance of seed leachates, total dehydrogenase activity, and amylase activity (Table 2). However, NA treatment increased O_2 uptake in intact seed of IR36 (19.5% over the nontreated control). There was no increase in uptake in dehulled seed, and there was a decrease of 12.5% from the control in dehulled and pericarp-removed seeds. Reduction in amylase activity after NA treatment was also observed in seed of three other nondormant cultivars: Ching-shi 15, IR42, and IR64 (Fig. 6).



6. Amylase activity of untreated (control) and nonanoic acid-treated (5 nm, 3 ml) seeds in initially nondormant seed lots of 4 rice cultivars. IRRI, 1988.

SEED AND SEEDLING VIGOR

International Rice Testing Program

Tolerance for accelerated aging treatment. Two hundred and fifty-four rice cultivars from 14 International Rice Testing Program (IRTP) yield nurseries were screened for variation in seed vigor using an accelerated aging treatment (AAT) (50 °C, 100% relative humidity [RH], 24 h). Only 15% of the entries showed high tolerance (>80% germination after AAT), 10% showed moderate tolerance (60-80% germination after AAT), 12% moderate susceptibility (40-59% germination after AAT), and 63% susceptibility (<40% germination after AAT). Germination after AAT was correlated significantly with other seed vigor parameters like standard germination (r = 0.262), germination under cold (15 °C, r = 0.219) and salinity (5% NaCl, r = 0.414) stresses, and rate of emergence under field conditions (r = 0.295). IR13240-108, IR21178-39-P1, IR25588-7-3, IR29723-143-2, and IR39357-91-3 showed high tolerance for AAT and were among the best performers in the 1986 IRTP yield nurseries.

Genetic variation for embryo length and weight. Studies on genetic variation for embryo size and related traits on 132 rice cultivars representing 4 cultivar groups—indica (67), japonica (38), javanica (12), and hybrid derivatives (15)—and 2 cultivar types—traditional (70) and modern (62)—were carried out in seeds obtained from replicated experiments in the phytotron and field during 1988 dry season (DS). Analysis of variance indicated

Table 2. Effect of nonanoic acid (NA: 5 mM, 3 ml) treatment[a] on seed properties of 3 rice cultivars. IRRI, 1988.

Cultivar	Treatment	Germination (%)	Increase (%) in fresh weight by 24-h soaking in water	Increase (%) in seed leachate conductance on soaking in water for 24 h	Total dehydrogenase activity (O.D.)	Amylase activity (O.D.)
China 1039	Control	100.0	31.0	31.0	0.387	0.277
	NA	40.0	26.5	26.5	0.307	0.170
IR36	Control	100.0	23.6	25.1	0.203	0.237
	NA	31.7	22.6	22.6	0.157	0.162
N22	Control	93.3	21.8	21.8	0.180	0.175
	NA	13.3	20.5	20.5	0.157	0.077
CV (%)		11.47	6.27	8.57	9.75	6.86

[a]Mean of 3 replications. All values from NA treatment are significantly different from those of the respective controls at the 5% level of probability by t-test.

highly significant genotype differences in the traits evaluated within each cultivar group and type. Japonica rices had the maximum range and mean embryo length, 50-embryo weight, and embryo-endosperm weight ratio compared with indica rices (Table 3). Javanica rices recorded higher means but narrower ranges of variation than indicas. Traditional cultivars recorded larger embryo sizes than did modern cultivars.

Mean embryo length and weight differed slightly between field and phytotron conditions in indicas and traditional cultivars. A strong positive correlation between embryo length and weight (r' values ranging between 0.55 and 0.89) was evident across varietal groups and two production environments. The relationship between embryo weight and endosperm weight was moderate in indicas ($r = 0.58$ in phytotron and 0.61 in field) and javanicas ($r = 0.60$ in field), but was relatively low, though statistically significant at the 5% level in japonicas ($r = 0.35$ in phytotron and 0.38 in field). The embryo-endosperm weight ratio appeared to be a more stable trait than embryo weight or length.

Relationship of embryo length to seed quality and yield. Simple correlations of embryo length with seed vigor, seedling growth-related traits, and yield were studied in a replicated experiment during 1988 DS. The test material consisted of 117 cultivars: 67 indicas, 38 japonicas, and 12 javanicas. Embryo length ranged from 1.52 to 2.28 mm among the indicas, 1.78 to 3.35 mm among the japonicas, and 1.69 to 2.15 mm among the javanicas. Among the indicas, embryo length was found to be significantly correlated with germination percentage ($r = 0.25^*$), seedling dry matter ($r = 0.77^{**}$), seedling height ($r = 0.43^{**}$), leaf area per plant ($r = 0.36^{**}$), top dry weight:leaf area ratio ($r = 0.35^{**}$), leaf extension rate ($r = 0.36^{**}$), and seed yield per plant ($r = 0.42^{**}$). In the japonicas, the correlation was significant only with leaf area per plant ($r = -0.34^*$). Leaf extension rate was significantly correlated with embryo length in javanicas ($r = 0.71^{**}$).

Association of field emergence with laboratory-tested seed vigor parameters. Correlations between some laboratory-tested seed vigor parameters, viz., standard germination (SG), rate of germination (RG), germination in cold (GC

Table 3. Mean and range of variation for embryo size and related traits among 4 cultivar groups and 2 cultivar types in phytotron and field (in parentheses) environment conditions. IRRI, 1988.

Cultivar group or type	Entries (no.)		Embryo length (mm)	50-embryo weight (g)	50-endosperm weight (g)	Embryo-endosperm weight ratio	1000-seed weight (g)
Group							
Indica	67	Mean:	1.89 (1.93)	.026 (.024)	9.39 (9.41)	.003 (.003)	23.2 (23.3)
		Range:	1.52-2.28 (1.58-2.35)	.013-.048 (.013-.039)	1.85-14.97 (4.18-12.80)	.002-.011 (.002-.005)	5.3-37.0 (10.2-32.5)
Japonica	38	Mean:	2.10 (2.12)	.036 (.035)	10.60 (10.25)	.003 (.003)	26.0 (25.0)
		Range:	1.78-3.35 (1.74-3.24)	.020-.076 (.020-.082)	5.25-14.01 (5.03-13.21)	.002-.009 (.002-.009)	13.3-33.4 (13.0-31.2)
Javanica	10	Mean:	1.98 (1.99)	.028 (.028)	11.20 (10.66)	.002 (.003)	28.5 (26.5)
		Range:	1.69-2.15 (1.75-2.20)	.023-.033 (.019-.034)	9.83-12.97 (8.67-12.56)	.002-.003 (.002-.003)	23.5-32.9 (21.8-33.3)
Hybrid	15	Mean:	1.90 (1.94)	.024 (.025)	9.55 (9.97)	.002 (.003)	23.8 (24.6)
		Range:	1.63-2.14 (1.61-2.20)	.015-.036 (.017-.036)	7.75-11.74 (8.38-12.37)	.002-.003 (.002-.003)	18.9-28.5 (20.8-31.8)
Type							
Traditional	70	Mean:	1.97 (2.01)	.030 (.029)	10.21 (9.96)	.003 (.003)	25.3 (24.6)
		Range:	1.54-2.28 (1.58-2.38)	.013-.050 (.013-.045)	1.84-14.97 (4.18-13.21)	.002-.011 (.002-.004)	5.3-37.0 (10.2-33.3)
Modern	62	Mean:	1.96 (1.98)	.028 (.028)	9.66 (9.71)	.003 (.003)	23.9 (23.9)
		Range:	1.52-3.35 (1.61-3.24)	.015-.076 (.016-.082)	5.31-13.44 (5.27-12.37)	.002-.009 (.002-.009)	13.9-33.3 (13.3-31.8)

[15 °C]), germination in 5% NaCl solution, germination in 25% polyethylene glycol (PEG) solution (GPEG), germination after AAT, total dehydrogenase activity, and seedling dry weight (SDW) with field emergence (FE) in 58 rice cultivars selected from the 1988 IRTP yield nurseries showed that FE was significantly associated with SG (r = 0.522), RG (0.696), GC (0.505), GPEG (0.525), and SDW (0.271).

Partitioning of the correlations into direct and indirect effects by path analysis revealed that the direct effect of RG was greatest, followed by that of SG, SDW, GC, and GPEG (Table 4). The direct effect of SDW (0.221) being almost equal to its correlation coefficient (r = 0.271) with FE indicated that direct selection for SDW can improve FE. Though RG had the highest r = value with FE (0.696), its direct effect was only 0.441. The indirect effects of other parameters like GPEG and GC through RG were relatively higher. Thus, simultaneous selection for SDW and RG would be more effective in selecting for better FE. However, the parameters analyzed could explain only about 42% of the variability observed in FE, as the residual effect was 0.584.

Table 4. Contribution of certain laboratory-tested seed vigor parameters to field emergence (FE) in 58 rice cultivars. IRRI, 1988.

Total effect of standard germination (SG) on FE	0.522
Direct effect of SG on FE	0.277
Indirect effect of SG thru rate of germination (RG)	0.170
Indirect effect of SG thru germination in cold (GC)	0.063
Indirect effect of SG thru germination in PEG (GPEG)	0.021
Indirect effect of SG thru seedling dry weight (SDW)	−0.009
Total effect of RG on FE	0.696
Direct effect of RG on FE	0.441
Indirect effect of RG thru SG	0.107
Indirect effect of RG thru GC	0.077
Indirect effect of RG thru GPEG	0.055
Indirect effect of RG thru SDW	0.016
Total effect of GC on FE	0.505
Direct effect of GC on FE	0.192
Indirect effect of GC thru SC	0.091
Indirect effect of GC thru RG	0.176
Indirect effect of GC thru GPEG	0.028
Indirect effect of GC thru SDW	0.018
Total effect of GPEG on FE	0.525
Direct effect of GPEG on FE	0.094
Indirect effect of GPEG thru SG	0.083
Indirect effect of GPEG thru RG	0.256
Indirect effect of GPEG thru RC	0.059
Indirect effect of GPEG thru SDW	0.033
Total effect of SDW on FE	0.271
Direct effect of SDW on FE	0.221
Indirect effect of SDW thru SG	−0.011
Indirect effect of SDW thru RG	0.032
Indirect effect of SDW thru GC	0.015
Indirect effect of SDW thru GPEG	0.014
Residual effect	0.584

SEED VIABILITY

Cereal Chemistry Department, International Rice Germplasm Center, and Centre International de Recherche Agronomique pour le Dévéloppement-Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières

Varietal differences in longevity (*Cereal Chemistry and International Rice Germplasm Center*). A second longevity trial was undertaken on 13 rices from the 1986 wet season crop to investigate the effect of RH. The seed was stored at 28-30 °C in bottles containing silica gel (about 16% RH), and the control was kept in paper bags at ambient humidity conditions (60-80% RH). After more than 2 yr, all the samples stored in silica gel still had high viability (92-98% germination), while those at ambient humidity were only 0-2% viable. The mean viability period (MVP, 50% germination) was lowest (365 d) for low-gelatinization temperature (GT) waxy IR29 and highest (660 d) for low-amylose content (AC) IR2071-137-5 and high-AC IR62. IR2071-137-5 had also the longest MVP in the first trial, in which IR62 was not included (Annual report for 1986). Among the low-AC rices, IR42 stored better than IR58 and IR5. Intermediate-AC rices had similar MVP (560-563 d) for IR48 (low GT) and IR64 (intermediate GT). Dormancy was also not a major factor, although IR2071-137-5 and IR62 had some dormancy, as more dormant rices Adan and IR5 had shorter MVP (<500 d). Free (methanol-soluble) and bound (1% methanolic HCl-soluble) hull phenolics were higher in seed stored at high humidity than in that stored over silica gel.

Varietal resistance to storage pests (*Cereal Chemistry and Centre International de Recherche Agronomique pour le Développement-Institut de*

Recherches Agronomiques Tropicales et des Cultures Vivrières). Ivory Coast rices grown under irrigated and upland conditions were assayed for the resistance of rough rice and brown rice to the first generation of Angoumois grain moth *Sitotroga cerealella* by entomologists at the Centre International de Recherche Agronomique pour le Dévéloppement-Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières, Bouaké, Ivory Coast, and analyzed chemically at IRRI. The three red-pericarped brown rices (BG141, BG187, and Zakpale) had higher phenolics (3.7-5.3 mg tannic acid/g) than nonpigmented brown rices (0.5-1.2 mg/g). F_1 survival and index of susceptibility in rough rice correlated significantly with phenolic content of brown rice (r = -0.59**) and with milled rice AC (r = -0.67**, n = 19). F_1 survival in brown rice correlated with its phenolic content (r = -0.55*) and with milled rice AC (r = 0.46*). Crude protein, alkali spreading value, and hull phenolic content were not significantly correlated with the F_1 survival and index of susceptibility on rough rice. No consistent trend in susceptibility was observed between irrigated- and upland-derived grains.

SEED TREATMENT

International Rice Testing Program

Alginate coating. Seeds of 6 rice cultivars (Table 5) were coated with 0.5% sodium alginate, and then germinated in distilled water and 20% PEG-8000 solution. In all the cultivars, germination of the coated seed was significantly higher than that of the respective control, i.e., uncoated seed. Seedlings of the coated seed were more vigorous than those of uncoated seed both in water and PEG. Similar effects were observed for soil emergence and seedling establishment in the phytotron.

Table 5. Effect of sodium alginate coating on seed germination in 6 rice cultivars. IRRI, 1988.

Cultivar	Germination (%)			
	Water		PEG 20%	
	Uncoated	Coated	Uncoated	Coated
IR20	100	100	85	95
IR43	97	100	82	89
IR52	95	97	72	87
IRAT9	100	100	60	77
Kinandang Patong	100	100	90	94
Salumpikit	92	97	90	96
LSD (0.05)				
Treatment	3.3			
Moisture stress	3.3			
Cultivar	5.1			

Hot water treatment. Immersing seed in water at 40, 50, and 60 °C for 0, 15, 30, 45, or 60 min showed significant effects of temperature (T), duration of treatment (D), and T × D interaction on germination percentage (GP), shoot length (SL), and root length (RL) in IR64. Seedling dry weight was affected only by the temperature factor. All the treatments at 60 °C and the treatments at 50 °C for more than 30 min significantly reduced GP, SL, RL, and SDW. When subjected to hot water treatment at 58 °C for 0, 15, 30, 45, or 60 min, Barkat, Dharial, IR64, IR19743-140-2-3, and KAU1727 recorded significant effects of D, cultivar (C), and D × C interaction on GP, SL, RL, and SDW. Treatments of 30 min or longer significantly reduced GP and SDW, whereas SL was reduced and RL increased by 60-min treatment. IR19743-140-2-3 and KAU1727 withstood the 50-min treatment without any adverse influence on GP, SL, or RL.

Genetic evaluation and utilization (GEU) program

Integrated GEU program

Plant Breeding, Plant Pathology, Entomology, Multiple Cropping, Plant Physiology, Soils, and Agronomy Departments; International Rice Germplasm Center; Rice Farming Systems Program; Department of Agriculture and Bohol Agricultural Promotion Center, Philippines; Central Soil Salinity Research Institute, India; Bogor Research Institute for Food Crops and Banjarbaru Research Institute for Food Crops, Indonesia; Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico; Saline Agriculture Research Station, Pakistan; Regional Agricultural Research Center, Sri Lanka; and Pathum Thani and Phrae Rice Research Centers and Rice Research Institute, Thailand

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We made 2,409 crosses in 1988, grew F_2 populations from 3,097 crosses, evaluated 128,707 pedigree nursery rows, tested 988 breeding lines in replicated yield trials (RYTs), and sent 77,239 seed packets of IRRI breeding lines abroad; 37,005 seed packets filled 332 seed requests from 61 countries, and 40,234 packets went through International Rice Testing Program (IRTP) nurseries.

IRRIGATED RICE

Plant Breeding, Plant Pathology, and Entomology Departments

We made 529 crosses for irrigated rice in 1988. F_2 populations from 586 cross combinations were grown, and 70,386 pedigree nursery rows were evaluated. We also evaluated 800 advanced generation entries in RYTs.

In lowland rice performance trials of the Rice Varietal Improvement Group of the Philippine Seed Board conducted at 12 sites, 36 elite breeding lines were evaluated. About 220 elite breeding lines were evaluated internationally in IRTP nurseries. National rice improvement programs evaluated many other promising lines.

IRRI lines named varieties. In 1988, 20 IRRI lines from the irrigated breeding program were named varieties in 11 countries, bringing to 198 the number of IRRI breeding lines named as varieties worldwide.

- IR480-5-9-3-3, with long, slender grains, was released in Cuba. It has intermediate amylose content (AC) and somewhat elevated protein content. It was earlier named Ajral in Fiji.
- IR665-79-2-4, with long, slender, translucent grains and high yield potential, was named Araure 3 in Venezuela. It was earlier released as PR106 in India, where it is the most widely planted variety in Punjab and Haryana States.
- IR880-25, with long, slender, and translucent grains, was released in Cuba. It has excellent yield potential.
- IR2071-625-1-252 was released in Bhutan for cultivation in the mid-altitude valleys. It is the same line that has been released as IR36 in many countries.
- IR2153-276-1-10 was released in Vietnam for cultivation in low-pH (acid sulfate) soils. It has medium-long, slender grains and high yield potential.
- IR4570-83-3-3-2 was named PA-3 in Peru. This is the same line that was released as IR48 in the Philippines and Indonesia. It matures in 140 d and has intermediate stature.
- IR5853-118-5, with moderate drought tolerance, was released in Bolivia. It had been released earlier as IR52 in the Philippines and Indonesia.
- IR9224-73-2-2-3, an early-maturing line with long, slender grains, was released as OM33 for cultivation in the Mekong Delta of Vietnam.
- IR13240-108-2-2-3, with medium maturity, was released as TN108 for cultivation in the Mekong Delta of Vietnam, where it is now the most widely grown variety.
- IR13525-43-2-3-1-3-2, a high-yielding line with medium maturity, was named IR62 in Tamil Nadu State of India. This line has gene *Bph-3* for resistance to brown planthopper (BPH) and was earlier released as IR62 in the Philippines and in Andhra Pradesh State of India.
- IR15323-78 was named Sada Hayat in Sind Province of Pakistan. It has long, slender, translucent grains and is resistant to white-backed planthopper.
- IR18348-36-3-3 was released for cultivation in mid-altitude valleys of Bhutan. This high-yielding line with superior grain quality was earlier released as IR64 in the Philippines, Indonesia, and Vietnam.
- IR21015-80-3-3-1-2 was released as OM86 for cultivation in the Mekong Delta of Vietnam. It has excellent yield potential and long, slender, translucent grains. It was earlier released as N304 in Guangxi Province of China.
- IR25588-7-3-1, an early-maturing line with long, slender grains was named OM88 in the Mekong Delta of Vietnam.
- IR28224-3-2-3-2, a high-yielding line with multiple disease and insect resistance, was released as IR68 in the Philippines. It matures in 125 d.
- IR28228-12-3-1-1-2, a high-yielding line with multiple disease and insect resistance, was released as IR70 in the Philippines. It matures in 130 d.

- IR31802-48-2-2-2, a very early-maturing line with superior grain quality, was released as OM87-1 in the Mekong Delta of Vietnam.
- IR32429-47-3-2-2, an early-maturing line with superior grain quality, was named OM86-9 in Vietnam. It has excellent lodging resistance.
- IR32453-20-3-2-2 was named IR74 by the Philippine Seed Board. It matures in 130 d and has multiple resistance to diseases and insects.
- IR35366-90-3-2-1-2, an early-maturing line with multiple resistance to diseases and insects and with excellent yield potential, was released as IR72 by the Philippine Seed Board.

Elite breeding lines. Elite breeding lines were evaluated in RYTs during the dry season (DS) and wet season (WS). They were also evaluated for grain quality, disease and insect resistance, and tolerance for soil problems such as salinity and alkalinity. Eighteen of the most advanced lines were evaluated for yield in N response trials at Bureau of Plant Industry stations in the Philippines. Nine of the most promising elite lines are discussed below.

- IR32429-47-3-2-2, an early-maturing (105 d) line, has excellent grain quality with intermediate AC and intermediate gelatinization temperature (GT). It is resistant to blast (Bl), bacterial blight (BB), green leafhopper (GLH), and three biotypes of BPH and has field tolerance for tungro (RTV). It has excellent yield potential and has been released as a variety in Vietnam.
- IR35366-28-3-1-2-2, a sister line of IR72, matures in 115 d and has excellent yield potential. It has long, slender, translucent grains with high AC and intermediate GT. It is resistant to Bl, BB, GLH, and three biotypes of BPH and has field resistance to RTV.
- IR42015-83-3-2-2-2 is an early-maturing (105 d) line that has consistently outyielded other early-maturing lines in RYTs. It is resistant to Bl, BB, GLH, and three biotypes of BPH. It has medium-long and slender grains with intermediate AC and low GT.
- IR45912-9-1-2-2 is a very early-maturing (100 d) line with excellent yield potential. It has fine grains with intermediate AC and intermediate GT. It resists Bl, BB, GLH, and three biotypes of BPH.
- IR50363-61-1-2-2 is an early-maturing (105 d) line with excellent yield potential, and excellent long, slender grains with intermediate AC and intermediate GT. It resists Bl, BB, GLH, and three biotypes of BPH, and has field resistance to RTV.
- IR34686-179-1-2-1, a very high-yielding selection, matures in 135 d. It has excellent lodging resistance; and long, slender, translucent grains with intermediate AC and low GT. It is resistant to Bl, BB, GLH, three biotypes of BPH and has field resistance to RTV.
- IR39323-182-2-3-3-2 is a very sturdy line that matures in 135 d. It has long, slender grains with high AC and low GT. It is resistant to Bl, BB, GLH, and three biotypes of BPH. It resists RTV under field conditions.
- IR49461-113-3-2-3 matures in 125 d and has long, slender grains with high AC and intermediate GT. It resists BB, GLH, three biotypes of BPH, and RTV.
- IR44530-41-1-2-1 matures in 125 d. It has long, slender, translucent grains with high AC and low GT. It resists Bl, BB, GLH, and three biotypes of BPH and has field resistance to RTV.

COLD-TOLERANT RICE

Plant Breeding Department and Department of Agriculture, Philippines

Our restructured breeding program aims to generate advanced breeding materials for direct or indirect use by breeders of national programs. Breeding materials of four types are produced: 1) indica/indica, 2) indica/japonica (with or without the use of wide compatibility gene), 3) japonica/japonica for developing genotypes adapted to tropical conditions, and 4) indica/bulu or japonica/bulu types.

In our hybridization program, 159 single crosses and 114 multiple crosses were made during the year. These included 35 crosses we made at the request of breeders in Bhutan (16 crosses) and India (19). Other crosses belonged to the four types mentioned earlier.

In DS, 25 F_2 populations consisting of 16 japonica/bulu and 9 indica/indica crosses were

evaluated in Banaue, Philippines (about 1,000 m elevation). Twelve bulu crosses and four indica crosses were mass-selected. An F_4 pedigree nursery consisting of 774 lines from 23 indica/bulu crosses was also evaluated in Banaue. Though sterility was not a problem, very few lines expressed the desired plant characters. Plant selections were made from 67 lines derived from 15 crosses. At our other site in Tublay, Philippines (about 1,100 m elevation), F_3 bulks of 10 japonica/bulu and 17 indica/indica crosses were evaluated, and plant selections were made from 8 bulu crosses and 12 others. Because of limited space at our outreach sites, other breeding materials had to be advanced at IRRI. No selection except for high susceptibility to RTV was done. All 16 japonica/japonica F_2 bulks were mass-selected. Of the 48 indica/japonica F_2 bulks, 47 were selected. Among the 33 indica/indica F_2 populations, 25 were found suitable and advanced.

In WS, 25 F_2 bulks, all indica/indica, were established in Tublay and 14 were mass-selected. At IRRI, 25 japonica/bulu F_2 bulks were evaluated and 20 were selected for advancement. Of the 16 F_3 bulks (11 bulu/indica and 5 indica/indica), 10 were advanced. F_4 and F_5 plant selections made in DS, consisting of 343 indica/indica, 337 indica/japonica, and 366 indica/bulu or japonica/bulu types, were grown at IRRI in WS. Showing primarily pest and disease resistance, 305 lines were selected.

Twenty advanced lines produced in previous years were tested for adaptability at two locations in Tublay. At one location, where fungal diseases are very severe, only IR25976-12-2-2-2-1-1 could produce seed. At the other locations, low temperature was the main constraint. Seven lines were found promising: IR8866-30-3-1-4-2, IR13155-60-3-1-3, IR25976-12-2-2-2-1-1, IR29824-B-84-1-1, IR33988-11-4-3-2-1-2-2, IR40094-143, and IR40097-1-3-1.

Table 1. Characteristics of advanced rainfed lowland breeding lines with high grain yield and good phenotypic acceptability in the observational yield trial. IRRI, 1988 WS.

Line	Parentage	Plant height (cm)	Days to maturity	Reaction[a] to		Grain quality[b]				
				BI	RTV	AC	GT	L	S	C
IR48044-157-1-1-3-3	IR21848-65-3-2-2/5163 IR14753-49-3	138	130	1	5.3	23	I	3	5	9
IR48725-B-B-139-3[c]	BR10 IR21567-9-2-2-2-1-2-2-2	140	124	7	–	29	L	5	5	1
IR48725-B-B-38-1	BR10 IR21567-9-2-2-2-1-2-2-2	141	125	8	4.8	28	I	3	5	1
IR48725-B-B-86-2-2	BR10 IR21567-9-2-2-2-1-2-2-2	154	118	8	6.0	26	L	5	5	0
IR48749-B-B-40-1	Cisadane/IR52	116	120	8	5.4	27	I	3	1	0
IR48749-B-B-40-1	Cisadane/IR52	118	119	7	7.6	27	I	3	1	1
IR48783-8-2-3-3-3[d]	IR19431-72-2 IR26702-25-1	122	126	4	–	–	–	–	–	–
IR48799-61-3-2-2-3	IR21178-43-1-2-2-2 PM1121	112	111	1	5.6	24	L	5	5	1
IR48812-SRN-41-B-1-1	KDML 65-G4U-4-492 IR21567-16-2-2	111	128	4	5.7	24	I	3	1	9
IR49632-7-3-2	BR239-19-4-3-1/IR4829-89-2 IR31916-73-1-3-2	113	130	4	6.4	26	L	3	1	1
IR49727-4-3-3-2	Kartiksail/IR8192-166-2-2-3 IR28154-101-3-2	123	16 Nov[e]	8	5.0	26	I	5	5	5

[a] By the *Standard evaluation system for rice* (SES) scale. BI = blast, RTV = tungro. All entries had a score of 1 for bacterial blight (BB). [b] By SES. AC = amylose content, GT = gelatinization temperature, L = length, S = shape, C = chalkiness. [c] Some resistance to bacterial blight race 2. [d] Submergence tolerant. [e] Photoperiod sensitive.

RAINFED LOWLAND RICE

Plant Breeding, Plant Physiology, Multiple Cropping, and Agronomy Departments and Department of Agriculture, Philippines

In 1988, for drought-prone conditions 273 F_2 populations and 12,758 pedigree rows were grown; 408 breeding lines were evaluated in multilocation yield trials; and 48 lines were tested in RYTs. For medium deep/submergence-prone conditions we grew 132 F_2 populations and 16,810 pedigree rows; 209 entries were evaluated in a multilocation observational yield trial (OYT); and a RYT of 36 entries was grown at 2 sites.

The OYT grown under irrigated conditions had 864 entries in DS and 896 in WS. Some of the highest yielding new breeding lines evaluated in WS had useful characteristics (Table 1). More than 3,000 seed lots were sent to scientists working on rainfed lowland rice in Bangladesh, Burma, India, Cambodia, Laos, Malaysia, Nepal, Thailand, and Vietnam.

Submergence tolerance (*Plant Breeding and Plant Physiology*). All entries in the OYTs and RYTs are screened for submergence tolerance in greenhouse tanks. Several breeding lines have shown consistently strong submergence tolerance (Table 2).

Table 2. Characteristics of rainfed lowland breeding lines showing good phenotypic acceptability and high submergence tolerance in at least 3 tests at IRRI, 1988. Scores for submergence are in comparison with the tolerant check FR13A (= 1.0).

Variety or line	Parentage	Submergence tolerance		Plant height (cm)	Days to maturity	Reaction[a] to			Grain quality[a]					
		Mean	Tests (no.)			BI	BB	RTV	AC	GT	L	S	C	GEL[b]
IR40931-26-3-3-5	BKNFR76106-16-0-1-0/ IR19661-131-1-2	1.0	5	110	135	6	1		26	L	3	3	7	75
IR40931-33-1-3-2	BKNFR76106-16-0-1-0/ IR19661-131-1-2	1.3	6	105	125	7	1		25	L	3	2	3	63
IR42205-33-1-3 -3-2	IR4215-301-2-2-6// IR19382-42-3-3-2/BKNFR76106-16-0-1-0	2.2	5	110	140	6	1	5.6	25	L	3	1	6	100
IR43470-7-3-5-1	IR21841-81-3-3-2/BKNFR76106-13-2//IR21949-65-3-2	3.0	7	100	130	7	1	6.6	24	L	3	1	1	35
IR43559-25-5-3-2	IR13423-10-2-3/FR43B// MTU7029/IR19728-9-3-2-3-3	2.0	8	105	135	8	1		26	L	4	3	7	82
IR46292-24-2-2 -1-2	Chenab 64-117/IR60// CR1009	1.5	4	110	140	5	1		25	L	3	5	8	75
IR48788-4-3-4-2	IR28905-10-1-3 IR29012-4-1-3	3.0	3	120	140	3	1	4.7	25	I	3	1	1	–
IR49634-42-2-2-3	BR239-19-4-3-1/IR26702-25-1// IR28154-101-3-2	1.0	3	100	140	6	1	6.5	25	I	3	1	5	–
IR49830-1-3-2-6	IR4568-86-1-3-2/IR26702-111-1// IR20992-7-2-2-2-2-3/IR21567-9-2-2-2-1	1.0	3	105	140	6	7	5.8	25	L	3	1	5	–
IR49830-26-1-2-1	IR4568-86-1-3-2/IR26702-111-1// IR20992-7-2-2-2-2-3/IR21567-9-2-2-2-1	3.0	3	120	140	7	1		23	L	5	5	4	71
IR49830-7-1-2-2	IR4568-86-1-3-2/IR26702-111-1// IR20992-7-2-2-2-2-3/IR21567-9-2-2-2-1	2.3	3	110	140	7	1		25	L	3	4	4	42
IR54 (check)		9.0	7											
IR46 (check)		8.5	4											

[a] By SES. [b] Gel consistency.

An OYT was grown in the field under two water regimes. In trial 1, water depth was increased gradually up to 60 cm beginning at 45 d after seeding (DAS). This depth was maintained for 12 d and then gradually decreased to about 25 cm for the remainder of the season. In trial 2, conducted at the same time, water depth was increased suddenly up to 60 cm and held there for 8 d; then the field was drained to about 5 cm. In many cases lines performed differently in the different trials, but several lines had high survival ability in both trials (Table 3). Plant height was measured before and after submergence. Correlations between survival and plant height were low (r = 0.31 for both trials). The correlation between elongation during submergence was high for trial 1 (r = 0.71) and low and negative for trial 2 (r = -0.20). The negative correlation probably resulted from the fact that most of the lines with strong submergence tolerance incorporated from FR13A or other donors were shorter, and most of the tall checks included did not have good submergence tolerance.

Drought resistance (*Plant Breeding and Agronomy*). Almost 2,000 rainfed lowland breeding lines were screened for drought resistance in DS under direct seeded conditions. Several improved breeding lines performed better than the tolerant checks at 5 and 10 bars soil moisture tension (Table 4). IR42221-2-2-3-1 had submergence tolerance. IR50500-111-1-3-1 was photoperiod sensitive. These lines will be advanced to farmers' field trials at drought-prone sites, and some will be used as parents in the breeding program.

Collaborative programs (*Plant Breeding*). The collaborative Thai-IRRI breeding program in Northeast Thailand completed its sixth year. All progeny from selected plants in the F_2 and pedigree nursery will be grown at Bangkhen, Thailand, for generation advance. Plants harvested from the F_6 and OYTs were taken to IRRI for seed increase and screening. In general, growing conditions were favorable except for the farmers' field yield trial conducted in Ban Khu Kad, near Ubon.

Fourteen lines from the collaborative breeding program were grown in RYTs at four stations in Northeast Thailand. Three breeding lines outyielded the best check cultivar at all sites (Table 5). IR46375-CPA-16-3-1 was the highest yielding, but it is photoperiod insensitive and has slight grain chalkiness. Three breeding lines (IR43522-PMI-17-3-3-1, IR43570-SRN-535-3-1-1, and IR43506-UBN-520-2-1-1) combine strong photoperiod sensitivity, shorter plants, and grain yields comparable to those of the popular check cultivars Khao Dawk Mali 105 and RD6.

An OYT was conducted in Cambodia to identify high-yielding breeding lines for rainfed lowland conditions. Several IRRI breeding lines outyielded the local check cultivars (Table 6) and were moved to advanced trials. The highest yielding entry IR38699-49-3-1-2 is photoperiod sensitive with improved plant type. The second highest yielding line IR43559-25-5-3-2 has shown high submergence tolerance in screening at IRRI.

Table 3. Entries showing highest survival in 2 field tests for submergence. IRRI, 1988 WS.

Variety or line	Survival (%)			Submergence tolerance[a] (greenhouse)	Mature plant height[b] (cm)
	Trial 1	Trial 2	Mean		
IR49830-26-1-2-1	65	75	70	3.0	130
IR51052-2-3-1-6	70	68	69	9.0	140
IR6370-K23-1	85	58	69	9.0	120
IR51053-10-2-3-2	59	68	63	8.0	140
IR49830-29-1-3-3-2	58	65	61	1.0	140
IR43470-7-3-5-1	54	58	56	3.0	115
BKNFR76106-16-0-1-0 (resistant check)	11	89	50	6.6	105
IR43522-37-3-3-3	55	43	49	8.2	140
IR42 (check)	0	0	0	8.5	105

[a] Av scores for seedling stage in comparison with tolerant check FR13A. [b] Mature plant height under irrigated conditions.

Medium deepwater yield trials (*Multiple Cropping and Plant Breeding*). A RYT for medium deepwater conditions was conducted at four Philippine sites in 1987 WS. Conditions were variable over the sites. At San Vicente, Pangasinan, almost half of the entries produced no grain. At IRRI, many of the entries were heavily infected with RTV. Breeding line IR33360-5-1-3-1 gave an

Table 4. Rainfed lowland breeding lines showing high drought tolerance and recovery. IRRI, 1988 DS.

Variety or line	Parentage	Growth duration (d)	BI resistance[a]	Drought tolerance score[a]	
				5 bars	10 bars
IR42221-2-2-3-1	IR52/MTU7029//IR4215-301-2-2-6	125	6	1	4
IR46274-53-21-3-3-1	BKNFR76106-16-0-1-0/ IR21848-65-3-2//IR21313-36-2-2	130	7	0	3
IR47958-58-3-3-2	ARC11554/IR13564-95-1// IR19660-274-3-3-1-3	130	7	2	4
IR48749-B-B-87-1	Cisadane/IR29005-5-2-2-2	120	9	1	4
IR49692-44-2-3-3	IR11418-15-2/IR29385-2-2-3// IR21015-80-3-3-1-2	120	6	1	4
IR51130-SKN-24-B-1-1	Nam Sagui 19/KKN7409-SRN-501// IR33356-32-3-1-2	115	6	1	4
IR50500-111-1-3-1	BR265-81-2-4-2 IR21178-43-1-2-2-2	150	6	1	5
IR51130-SKN-31-B-1-1	Nam Sagui 19/KKN7409-SRN-501// IR33356-32-3-1-2	120	4	1	4
Salumpikit (tolerant check)				2	5
IR442-2-58 (tolerant check)				3	5

[a] By SES. All entries scored 1 (90-100% recovery) when drought stress was relieved.

Table 5. Mean plant height and grain yield of breeding lines and checks in the Inter-Station Yield Trial for the Thai-IRRI Collaborative Program. Northeast Thailand, 1987 WS.

Variety or line	Av plant height (cm)	Grain yield[a] (t/ha)					Endosperm type[b]
		UBN	SKN	SRN	CPA	Mean	
IR46375-CPA-16-3-1	149	2.9	3.7	4.8	3.6	3.8	NG
IR43069-UBN-514-1-3-2-1	115	2.3	4.0	4.5	3.3	3.5	G
IR43523-SRN-526-3-3-1	145	3.2	3.1	4.4	3.4	3.5	NG
RD15 (check)	144	2.7	3.7	4.0	3.0	3.3	NG
IR43074-PMI-B-28-2-1	146	2.3	3.5	3.9	3.3	3.2	NG
IR43522-PMI-17-3-3-1	155	2.9	3.0	3.8	3.1	3.2	NG
IR43570-SRN-535-3-1-1	116	2.9	3.0	3.6	3.3	3.2	NG
IR43506-UBN-520-2-1-1	116	2.0	3.2	3.9	3.1	3.1	G
RD6 (check)	163	2.9	3.7	2.7	3.2	3.1	G
KDML 105 (check)	152	2.7	3.8	3.5	2.3	3.1	NG
IR43075-PMI-B-8-11-1	156	2.7	3.5	3.2	2.4	3.0	NG
IR43570-SRN-504-2-2-3	110	2.2	2.8	2.7	3.2	2.7	NG
IR43490-PMI-19-1-2-1	149	2.0	1.8	2.6	2.6	2.3	NG
IR43523-SRN-504-2-2-3-2	147	1.9	2.1	2.1	2.4	2.1	NG
LSD (0.05)		0.6	0.8	0.9	0.6		

[a] UBN = Ubon Rice Research Center, SKN = Sakhon Nakhon Rice Experiment Station (RES), SRN = Surin RES, CPA = Chum Phae RES. [b] G = glutinous, NG = nonglutinous.

Table 6. Performance of the highest yielding entries and check cultivars in the observational yield trial conducted at the Prey Phdau Rice Experiment Station, Cambodia, 1987 WS.

Variety or line	Grain yield (t/ha)	Rank	Days to flowering	Plant height (cm)
IR38699-49-3-1-2	5.7	1	123	108
IR43559-25-5-3-2	5.6	2	108	105
Mahsuri	5.6	3	108	150
IR36974-13-3-3-3	5.4	4	115	104
IR33238-25-2-3-2	5.3	5	115	119
IR42 (check)	5.3	5	111	101
Traditional checks				
Srov Kong	4.7	22	137	130
Banla Phdau	4.6	24	122	155
Neang Noi	4.1	38	124	141
Pram Bei Knor	4.1	38	124	138
Srov Sor	3.8	43	126	146
Kramuon Sar	3.5	51	102	104
Changvay Phdau	3.3	52	101	123
Areth	2.5	56	101	129

average yield of 4.1 t/ha over all sites compared with 2.7 t/ha for the highest yielding check (Table 7). Breeding lines highlighted in past reports continued to perform well: IR13149-71-3-2-3, IR24705-11-3-2-3-3, and IR26760-27-1-3-2-1 have been among the highest yielders each year since the trial was started in 1983. IR13149-71-3-2-3 was approved for release as "IR1314" in the Philippines (in Palawan only because of its resistance to black bug).

Evaluation of medium deepwater rice cultivars in Central Luzon (*Multiple Cropping and Plant Breeding, and Department of Agriculture, Philippines*). Several sets of medium deepwater rice breeding lines were tested under field conditions at three Central Luzon sites in collaboration with field personnel of the Department of Agriculture, Philippines. The sites were located along the edges of swampy areas in Papaya, San Antonio, Nueva Ecija; San Vicente, Bayambang, Pangasinan; and Mabulitec, Malasiqui, Pangasinan. The hydrological dynamics of the sites were regularly monitored with depth gauges.

Adaptation trials. This experiment was composed of 10 lines (including 2 local photoperiod-sensitive varieties) laid out in a randomized complete block design with 3 replications in 2.5- × 4-m plots. The trial was established at two sites in Papaya, San Antonio, one having a slightly lower elevation than the other. Two sets were direct seeded 25 d apart, while a third set (one site only) was transplanted 45 d after seeding the second set.

The cultivars experienced shallow water conditions (<20 cm) during the first 2 1/2 mo, during which growth and tillering were normal. However, the floodwater rose to 130-160 cm in the 3d week of August, then gradually receded to

Table 7. Grain yield of the 10 highest yielding breeding lines and check cultivars in the medium deepwater replicated yield trial. Philippines, 1987 WS.

Variety or line	Grain yield (t/ha)				
	Bay, Laguna	IRRI	Solana, Cagayan	San Vicente, Pangasinan	Mean
IR33360-5-1-3-1	6.8	0.5	2.8	6.2	4.1
IR24705-11-3-2-3-3	5.8	0.6	3.2	5.2	3.7
IR41111-24-2-1-3	5.5	0.3	2.8	5.5	3.5
IR19319-5-3-3-2-1	5.9	0.8	2.6	4.4	3.4
IR26760-27-1-3-2-1	5.1	0.4	2.6	4.7	3.2
IR25077-KKN-38-PMI-2-1	4.4	1.2	1.6	5.5	3.2
IR26760-76-2-1-2-3	3.7	1.8	2.6	4.4	3.1
IR13149-71-3-2-3	3.3	1.0	2.5	5.5	3.1
IR29341-15-2-1-1	3.5	0.8	2.4	5.6	3.1
IR13149-43-2-P1	3.9	0.7	2.6	4.8	3.0
IR36974-13-3-3-3	4.2	0.3	2.6	4.8	3.0
Check cultivars					
IR48	3.4	0.7	2.7	3.8	2.7
IR54	3.6	1.2	2.0	3.5	2.6
Mahsuri	2.3	0.3	1.4	4.8	2.2
IR42	4.2	0.5	3.0	0.0	1.9

40-50 cm over a period of 2 wk, persisting until October. The flood killed nearly all the entries. A percentage survival assessment was made after submergence (Table 8). IR19319-5-3-3-2-1 showed a superior survival of 66.7% compared with the other entries, which had an average survival of <30%. Local varieties BE-3 and Wagwag Faire barely survived the deep flooding.

The surviving plants reached booting in October, when the site had begun to dry. Severe rat infestation completely destroyed all entries before harvest.

Cultivar × management trial. This trial was planted at two sites in San Antonio alongside the adaptation trials. Three cultivars were used: BE-3 (variety used by the farmers in the area), CR1009, and IR13146-45-2-3. A split split-plot design was followed, with 3 fertilizer levels (0, 30, and 90 kg N/ha) as main plots, 2 seeding rates (75 and 150 kg/ha) as subplots, and the 3 varieties as sub-subplots. $ZnSO_4$ was applied at 10 kg/ha before seeding.

The trial was dry seeded at the same time as the adaptation trials (28 May 1987) and likewise experienced no hydrological stress during the vegetative phase. The August flood caused considerable damage to the experiments at both sites. Damage at site 1 (higher elevation) was 22%, in contrast to 65% at site 2 (lower elevation). Table 9 summarizes the percentage survival assessment for site 1.

IR13146-45-2-3 showed the highest survival percentage (90%) across the fertilizer and seeding rate treatments. BE-3, however, survived almost as well, with 85%. The survival level of CR1009 was comparatively low at 58%.

Fertilizer level was not as consistent a factor on survival percentage as was seeding rate. All entries had increased survival percentage at 150 kg/ha over that established with 75 kg/ha. However, no grain yield was obtained from the study because of rat damage when the floodwater receded.

Diagnostic trials. A set (one replication) from the 1987 Medium Deepwater Yield Trial was transplanted at three locations: two sites in San Antonio and one each in San Vicente and Mabulitec. The trial was composed of 50 entries, including check cultivars IR42, IR46, IR48, IR54, and IR64 and local cultivars Wagwag, BE-3, Mahsuri, and Pankaj. The crop survived at only one of the two sites (site 1) in San Antonio after the August flood. Table 10 shows the entries that withstood submergence with 80% or higher survival rate. Of the 18 entries selected, IR37094-31-2-3-2 and IR38699-27-2-3-3 were superior, with 95% survival.

In Pangasinan, water level within the plots fluctuated to a maximum of 40-50 cm in August and September, after which the standing water remained mostly below 25 cm. Hydrological conditions were generally favorable, without significant hydrological stress for most of the entries. Table 11 shows the grain yield data of the cultivars harvested in San Vicente. Seven entries yielded more than 5 t/ha, among which IR33360-5-1-3-1 gave the highest (6.2 t/ha). IR64, one of the check varieties, performed poorly, giving only 1.5 t/ha.

Table 8. Survival of rice cultivars in the medium deepwater adaptation trial, Papaya, San Antonio, Nueva Ecija, Philippines, 1988 WS.

Cultivar	Survival[a] (%)
IR19319-5-3-3-2-1	66.7
B4259-39-2-3	29.3
IR24705-11-7-2-3-2	26.7
IR33461-39-1	26.3
IR36974-13-3-3-3	16.7
Wagwag Faire	12.7
BE-3	6.7
IR5	6.0
CR1009	3.0
IR14146-45	2.7

[a]Av of 3 replications. Based on a percentage survival assessment after the August flooding; data are for site 1 only (site 2 trial was completely killed).

Table 9. Survival percentage[a] in the medium deepwater cultivar × management yield trial. Papaya, San Antonio, Nueva Ecija, Philippines, 1987 WS.

Cultivar	Survival (%)					
	0 kg N/ha		30 kg N/ha		90 kg N/ha	
	75	150	75	150	75	150
BE-3	78	95	77	97	88	75
CR1009	44	70	23	91	40	83
IR13146-45-2-3	71	98	91	97	96	88
Mean	64	88	64	95	75	82

[a]Survival assessed after the August flood. Seeding rates were 75 and 150 kg/ha. Fertilizer N was at 0, 30, and 90 kg/ha.

Table 10. Entries with high survival percentage in the 1987 medium deepwater yield trial diagnostic set tested in Papaya, San Antonio, Nueva Ecija, Philippines, 1987 WS.[a]

Variety or line	Survival (%)
IR37094-31-2-3-2	95
IR38699-27-2-3-3	95
IR42205-33-1-3-3-2	92
IR33360-5-1-3-1	90
IR38699-49-3-1-2	90
IR43559-32-3-3-1	90
IR43581-57-3-3-6	88
IR48	87
IR64	85
B4258-39-2-3	85
IR42233-46-1-1-3	85
IR43559-39-2-6-3	85
IR25077-KKN-38-PMI-2-1	80
IR26708-4-2-1-3-3	80
IR54	80
BE-3	80
CR1009	80
Mahsuri	80

[a]The experiment was submerged during the August flood, approximately 60 d after transplanting.

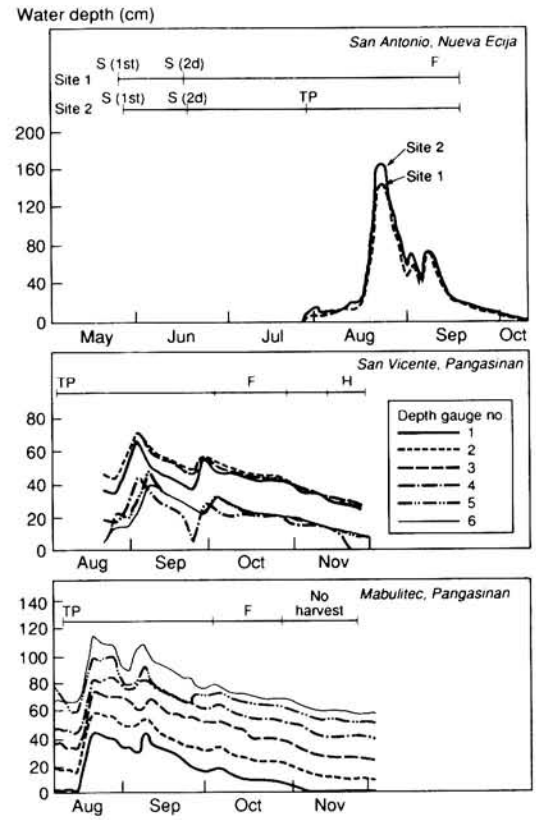
Table 11. Yield of selected entries from the 1987 medium deepwater yield trial diagnostic set. San Vicente, Bayambang, Pangasinan, Philippines, 1987 WS.

Variety or line	Plant height (cm)	Total dry matter (t/ha)	Grain yield (t/ha)
IR33360-5-1-3-1	123	10.7	6.2
IR43511-150-2-2-3-3	115	9.6	6.0
IR29341-15-2-1-1	118	9.0	5.6
IR13149-71-3-2-3	126	11.0	5.5
IR41111-24-2-1-3	112	8.3	5.5
IR25077-KKN-38-PMI-2-1	120	5.0	5.5
IR24705-11-3-2-3-3	122	8.1	5.2
IR33380-31-1-1-3	123	6.7	4.8
IR13149-43-2-P1	130	8.3	4.8
IR42205-33-1-3-3-2	125	9.1	4.8
IR36974-13-3-3-3	128	10.3	4.8
Mahsuri	136	9.4	4.8
IR26760-27-1-3-2-1	119	8.9	4.8
IR33380-7-2-1-3	120	10.9	4.5
IR19319-5-3-3-2-1	129	15.4	4.4
IR26760-76-2-1-2-3	126	7.1	4.4
IR21567-18-3	137	8.9	4.3
IR21567-9-2-2-2-1	133	7.9	4.1
IR19431-72-2	115	9.3	4.0
IR48 (check)	131	9.7	3.9
IR43582-176-3-2-2	117	7.2	3.8
IR38699-33-5-1-3-1	109	7.9	3.7
IR43581-57-3-3-6	122	7.4	3.6
IR43559-32-3-3-1	119	6.9	3.6
IR26708-4-2-1-3-3	113	9.2	3.6
IR54 (check)	108	6.5	3.5
IR43559-39-2-6-3	127	8.4	3.3
IR46343-26-2-3	125	8.0	3.2
IR33461-39-3	112	8.9	2.4
IR64 (check)	108	7.3	1.5

The set planted in Mabulitec performed almost as well as it did in San Vicente, partly because of comparable hydrology. However, most of the entries lodged at maturity and were subsequently destroyed by birds before harvest.

Hydrographs. Figure 1 shows hydrographs derived from monitoring depth gauge data. The two sites in San Antonio had practically the same hydrological trend, characterized by shallow (<25 cm) water conditions for the first 2 mo, interrupted by a flash flood, then somewhat stabilizing between 40 and 50 cm (medium deep) until the water disappeared in November. The flash flood in August caused greatest damage to the trials in the area.

The site in Mabulitec is a small depression where water accumulates during WS. The diagnostic trial was established at the edge of this small swamp (depth gauge 1). The other depth gauges



1. Hydrographs of the medium deepwater trial sites in Central Luzon, Philippines, 1987 WS. TP = transplanting, S = dry seeding, F = flowering, H = harvest.

were installed in a straight line across the swamp, where the water depth increased considerably away from the site.

San Vicente is located near the Agno River in Bayambang, and the site appears as an old meander scar (oxbow lake). The depth gauges were also installed across the swampy depression, with the trial located near the edge where flooding depth is expected to be shallower.

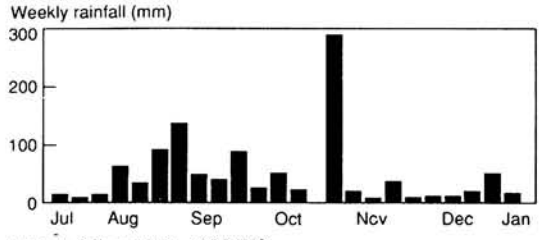
At both sites, the water level rose somewhat sharply to 40-50 cm depths in August and remained stable, but gradually receded until the end of the season. Although the sites typify a true medium deepwater hydrology, at least with respect to the 1987 season, farmers in the area said that water levels usually were higher in the depressions during most rainy seasons. It is clear, however, that portions of the sites exhibit medium deepwater conditions, particularly along the periphery, where cultivars can be tested.

Drought-prone areas yield trials (*Agronomy and Multiple Cropping*). To assess yield performance and reaction to drought under shallow rainfed lowland conditions, 46 genotypes were evaluated under transplanted culture in farmers' fields in Liloan, Cebu; Santa Rosa, Laguna; Solana, Cagayan; and under dry seeded culture at IRRI.

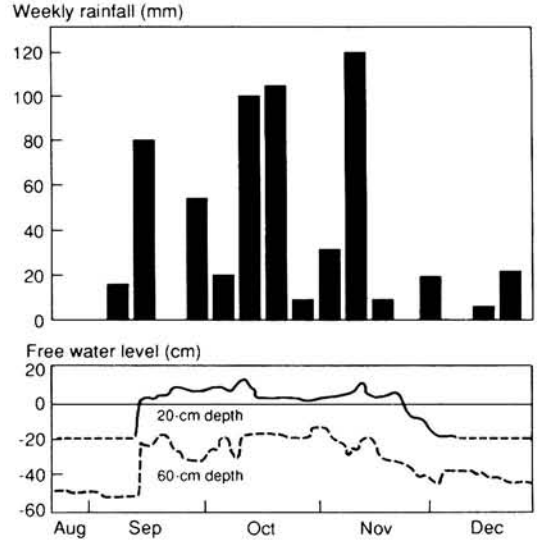
IRRI. Free water at IRRI remained below 60 cm soil depth for the entire crop duration. Drought from 23 to 31 Oct (Fig. 2) coincided with flowering of early-maturing genotypes, some of which had 100% unfilled spikelets. Because the drought was followed by a period of heavy rain, we tried to obtain a ratoon crop by cutting plants about 20 cm above ground level. Ratoon yields of 0.1 t/ha were obtained in IR64 and IR43518-66. Yields of very early and early genotypes ranged from 0.1 t/ha (IR64) to 0.5 t/ha (IR42247-1). Yields of late-maturing genotypes ranged from 0.3 t/ha (IR42266-11) to 1.3 t/ha (IR19319-1).

Liloan, Cebu. A short water deficit occurred from 20 Aug to 5 Sep in Liloan (Fig. 3). Yields of early-maturing genotypes ranged from 0.7 t/ha (IR29725-22) to 2.6 t/ha (IR43485-40). Yields of late-maturing genotypes ranged from 1.1 t/ha (IR43520-93) to 2.7 t/ha (IR42241-76).

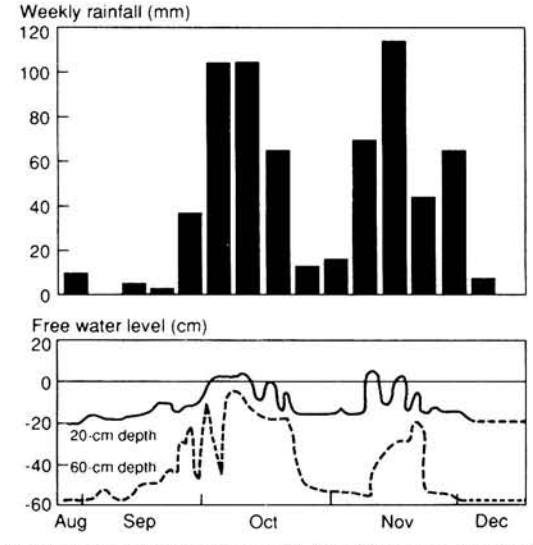
Santa Rosa, Laguna. In Santa Rosa, yields were lower than in Cebu because of erratic rainfall and a short water deficit during the vegetative phase (Fig. 4). Yields of early-maturing genotypes



2. Rainfall at IRRI, 1987 WS.



3. Water level (piezometers at 20- and 60-cm soil depth) and rainfall at Liloan, Cebu, Philippines, 1987 WS.



4. Water level (piezometers at 20- and 60-cm soil depth) and rainfall in Santa Rosa, Laguna, Philippines, 1987 WS.

ranged from 0.3 t/ha (IR43518-62) to 1.1 t/ha (IR29692-99). Yields of late-maturing genotypes ranged from 0.3 t/ha (IR43518-62) to 1.1 t/ha (IR29692-99). Yields of late-maturing genotypes ranged from 0.3 t/ha (IR33238-25) to 1.2 t/ha (IR43485-22).

Solana, Cagayan. Only the late set was grown in Solana. Because of early drought, test entries could not be transplanted until 82 DAS. Many of the improved breeding lines were able to yield as high as the local photoperiod-sensitive Wagwag cultivars. Yields ranged from 0.7 t/ha (IR43568-14) to 2.2 t/ha (IR43520-93).

1987 summary. Table 12 summarizes the yields of the 46 genotypes evaluated. Yields at IRRI illustrate the entries' responses under severe stress, those at Santa Rosa moderate stress, and those at Solana response to delayed transplanting. Highest yielding entries across the environments, presumably the most stable genotypes, were IR21567-9-2-2-3-1-3, IR42247-1-2-1-2-1, IR43485-40-2-42-2, and IR43491-133-3-42-2 among the early entries, and IR19319-1-2-2-2-2, IR29341-15-2-1-1, and IR42241-76-2-3-3 among the late entries.

UPLAND RICE

International Rice Germplasm Center; Plant Breeding and Multiple Cropping Departments; Rice Farming Systems Program; Bogor Research Institute for Food Crops, Indonesia; Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico; Phrae Rice Research Center, Thailand; and Bohol Agricultural Promotion Center, Philippines

Breeding operations (*International Rice Germplasm Center and Plant Breeding; Bogor Research Institute for Food Crops, Indonesia; Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico; and Phrae Rice Research Center, Thailand*). About 150 single and multiple crosses were made during the year to upgrade the Bl resistance, weed competitiveness, and grain quality of promising drought-resistant upland breeding lines. The aim is to combine the different traits that contribute to stable yield and farmer acceptance in upland rice cultivars.

Collaboration with national programs in Indonesia, Mexico, and Thailand was further strengthened. During the year, 141 single backcrosses and multiple crosses were made. Scientists in Mexico requested specific traits such as weed competitiveness, early maturity, good grain quality, and pleasing aroma to be incorporated into their drought- and Bl-resistant breeding lines. For Thailand and Indonesia, breeders specifically requested cold tolerance and good grain quality as donor traits.

During WS, 242 F_2-F_5 bulk populations were grown. The 2-wk drought spell during the reproductive phase at IRRI enabled us to select 57 populations with good grain filling and recovery ability. Most of the populations were early maturing (96-116 DAS).

Field evaluation of advanced breeding lines (*International Rice Germplasm Center; Plant Breeding; and Bohol Agricultural Promotion Center, Philippines*). Replicated yield trials were carried out in a farmer's field in Santo Tomas, Batangas, and at two sites on the IRRI farm (UZ and RF).

Leaf Bl and neck Bl remained the major constraints to yield in Santo Tomas. The total rainfall of 1,189 mm was evenly distributed throughout the crop growth period. The yield ranged from 1.3 to 3.9 t/ha. New entries in the upland RYT with field resistance to both leaf and neck Bl as well as high yield potential (3.1-3.5 t/ha) were IR40473-B-B-B-13-2-2, IR40473-B-B-B-13-2-3, IR27069 lines, IR36243-B-B-B-4, and IR36258-B-B-B-1. Most of the medium-late maturing lines (130 DAS) yielded from 3.0 to 3.9 t/ha. The highest yielder was IR13754-6-4 (136 d). Check varieties UPLRi-5 and IR43 yielded 3.4 and 3 3 t/ha, respectively. The early-maturing check UPLRi-7 gave a yield of only 1.3 t/ha because of severe neck Bl infection. The higher yields were positively correlated with the number of panicles per unit area ($r = 0.50^{**}$) and with maturity ($r = 0.23^{**}$). Plants having intermediate height (110-135 cm) generally gave higher grain yield ($r = -0.25^{**}$).

At IRRI, total rainfall was 1,386 mm, but a 2-wk drought occurred at the reproductive phase in early September. Only the IR27112 lines and IR27078-20-8-17 yielded more than 1 t/ha. Correlation analysis showed that the yield in field UZ was related to heavier grain weight ($r = 0.20^{*}$), higher number of panicles ($r = 0.36^{**}$),

Table 12. Grain yield and rank (in parentheses) of entries in integrated performance trials in rainfed shallow drought-prone environments, 1987 WS.

Variety or line	Grain yield (t/ha)			
	IRRI	Liloan, Cebu	Santa Rosa, Laguna	Solana, Cagayan
		Group A (early)		
IR13240-108-2-2-3	0.3 (6)	1.0 (17)	0.4 (18)	
IR21567-9-2-2-3-1-3	0.4 (4)	2.0 (4)	0.7 (6)	
IR26933-16-2-3	0.2 (9)	1.7 (10)	0.8 (15)	
IR29692-99-3-2-1	0.4 (5)	0.8 (18)	1.1 (1)	
IR29725-22-3-3-3	0.1 (15)	0.6 (20)	1.0 (3)	
IR36	0.2 (10)	1.1 (15)	0.4 (17)	
IR41054-81-2-3-2	0.2 (7)	1.3 (14)	0.6 (10)	
IR42247-1-2-1-2-1	0.5 (1)	1.9 (5)	0.5 (11)	
IR42253-63-1-2-3	0.4 (3)	0.8 (19)	0.5 (12)	
IR42273-72-1-1-2-3	0.2 (12)	1.0 (16)	0.5 (12)	
IR42342-40-3-3-2-3	0.2 (10)	1.3 (13)	0.6 (9)	
IR43485-15-3-42-3	0.2 (12)	1.6 (9)	0.5 (14)	
IR43485-40-2-42-2	0.4 (2)	2.6 (1)	0.6 (8)	
IR43491-133-3-42-2	0.1 (17)	2.1 (2)	0.8 (5)	
IR43518-62-2-2-1-3	0.1 (15)	1.7 (8)	0.3 (20)	
IR43518-66-2-3-2-3	0.1 (19)	1.8 (7)	1.0 (2)	
IR44915-356-2-1	0.2 (8)	2.0 (3)	0.4 (18)	
IR54	0.2 (12)	1.8 (6)	0.9 (4)	
IR64	0.1 (20)	1.4 (12)	0.7 (7)	
IR66	0.1 (17)	1.4 (11)	0.5 (16)	
		Group B (late)		
IR11346-45-2-3	0.4 (19)	2.1 (9)	0.6 (19)	1.2 (21)
IR19319-1-2-2-2-2	1.3 (1)	1.7 (20)	0.9 (12)	1.8 (8)
IR19319-5-3-3-2-1	0.6 (10)	2.0 (14)	1.1 (4)	1.9 (6)
IR19431-72-2	0.6 (7)	1.9 (15)	1.1 (5)	1.5 (15)
IR21188-15-2-2-3-3-3-1-1	0.4 (20)	1.6 (23)	0.8 (14)	1.6 (11)
IR28224-3-2-3-2	0.3 (24)	1.9 (16)	0.8 (13)	–
IR28526-44-1-1	0.3 (23)	1.3 (25)	0.7 (16)	1.5 (17)
IR29341-15-2-1-1	0.6 (6)	2.5 (2)	0.9 (8)	1.9 (6)
IR33238-25-2-3-2	0.7 (3)	1.8 (18)	0.3 (26)	1.6 (14)
IR33380-60-1-2-2	0.4 (22)	2.3 (7)	0.9 (9)	1.1 (23)
IR36974-13-3-3-3	0.4 (16)	2.1 (10)	0.4 (22)	1.6 (11)
IR37094-14-2-2-1-2	0.5 (12)	2.5 (4)	0.4 (22)	1.4 (19)
IR37096-49-1-3	0.3 (25)	2.0 (13)	0.6 (18)	0.8 (26)
IR38649-99-3-1-2	1.1 (2)	2.5 (5)	0.8 (14)	1.1 (23)
IR41111-113-1-2-1-2	0.7 (3)	1.8 (19)	0.6 (20)	1.5 (16)
IR42241-76-2-3-3	0.6 (9)	2.7 (1)	0.9 (11)	1.5 (18)
IR42253-14-1-3-2	0.5 (11)	1.7 (20)	1.0 (7)	1.7 (10)
IR42266-11-2-2-3	0.3 (26)	1.6 (12)	0.4 (24)	2.0 (4)
IR42266-73-1-2-2	0.4 (14)	2.2 (8)	0.9 (10)	2.0 (5)
IR43010-20-2-1-3	0.4 (13)	1.8 (17)	1.0 (6)	1.3 (20)
IR43485-22-2-2-2	0.4 (18)	2.1 (11)	1.2 (1)	0.9 (25)
IR43520-93-3-3-3	0.6 (8)	1.2 (26)	0.4 (24)	2.2 (1)
IR43568-14-1-1-2	0.4 (21)	1.5 (24)	0.4 (21)	0.7 (28)
IR43570-2-2-2-1	0.7 (5)	2.0 (12)	0.7 (17)	1.1 (22)
IR43582-119-1-1-2	0.4 (15)	2.5 (2)	1.1 (3)	0.7 (28)
IR48	0.4 (17)	2.4 (6)	1.2 (2)	0.8 (27)
Wagwag Ramsi				2.1 (2)
Wagwag Faire				2.1 (3)
Wagwag Saigon				1.8 (8)
Wagwag Tawataw				1.6 (13)
Mean	0.4	1.7	0.7	1.5
LSD (0.05)	0.2	0.5	0.3	1.1

intermediate plant height ($r = 0.22^*$), and medium-late maturity ($r = 0.45^{**}$). The final yields of most of the drought-resistant lines were rather low (0.3 t/ha) because they started to head when drought occurred, although the vegetative parts remained photosynthetic. Such lines produced lighter grains and showed high panicle sterility. Lines that headed after the stress period were able to produce 1 t/ha.

The check varieties also gave low yields of 0.1-0.2 t/ha except for UPLRi-7 (0.6 t/ha). The grains were heavier, as drought occurred at the early grain-filling stage. These observations once again indicated the importance of incorporating both drought resistance and recovery ability for stable yield in upland rice.

Yield in field UZ has been declining because of the growing severity of infestation by root nematode *Pratylenchus zeae*.

The crop in field RF matured in 115-130 d. Drought occurred just before heading in most of the entries. Only 35 entries yielded >1 t/ha, and the highest yield was 1.8 t/ha (IR29429-B-3-B-1-4). One of the promising lines in 1987, IR10147-113-5-1-1-5 yielded 1.5 t/ha, while IR43 yielded only 0.9 t/ha. Dinorado and Kinandang Patong yielded only 0.3 t/ha. The number of grains per panicle directly contributed to higher yield ($r = 0.33^{**}$), as did intermediate plant height ($r = 0.37^{**}$). The early-maturing lines and the check variety UPLRi-7 also gave higher yields ($r = -0.43^{**}$) than the late-maturing lines.

Across sites, the breeding lines generally showed higher and more stable yields than the traditional varieties.

The location specificity of upland rice was further demonstrated in the performance of observational nurseries at three locations. In a farmer's field in Santo Tomas, Batangas, the lines that showed good yield potential and Bl resistance were IR52222 lines, from the cross IR5420-1-1-2-3/Dawn, IR45222 lines from IR6023-10-1-1/BR201-193-1-1, and IR52812-CP128 lines from a composite made for Bl resistance.

At a poor soil fertility site in Cavinti, Laguna, leaf and neck Bl infections were more severe than in Santo Tomas. The IR52202 lines, progenies of Kinandang Tinambilok/Dawn, showed good field resistance to both leaf and neck Bl. They have a yield potential >2 t/ha, mature in 110 d, and are about 114 cm tall.

On the other hand, the best performers in an acid soil of moderate soil fertility in Bicao, Bohol, were IR52215-B-B-3 (SMGC80015/Dawn), IR52229-B-B-2 (IR12979-24-3-4/Dawn), and IR52188-B-B-3 (Dular/ITA235), with an average yield potential of 3.2 t/ha.

These results show the need for testing and selecting early-generation lines at a specific location representative of sites where upland rice would be widely grown.

Observational trials (*Plant Breeding and Rice Farming Systems*). *Cavinti, Laguna* (*Plant Breeding*). Table 13 lists upland rice entries yielding more than the mean of the trial plus the standard deviation, without lime.

Table 14 lists entries yielding more than the mean of the trial plus the standard deviation, with additional lime (3 t/ha in 1987).

Below are the major conclusions:

- The residual effect of lime is estimated as about 0.7 t rice/ha.
- Lime drastically reduces the coefficient of variation. Liming ensures better stability due to better nutrient balance in the soil.
- Liming has almost no effect on growth duration but reduces brown spot incidence.
- As in 1987, and more clearly because of heavy rains at the end of crop growth, early-maturing entries (100-110 d) show, with few exceptions, the best yields.
- Entries from West Africa (IRAT lines) and Latin America (CNA lines from Brazil and CT lines from Colombia) show good adaptation and yield potential under the serious constraints (low pH and low P content) at this site.
- Some entries from the Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT)-IRRI collaborative program, such as IR47686 lines rank well.
- Entries from Japan, India, and Thailand, all traditional upland types, have potential under these conditions. Examples are Sangoku and Oohata Wase from Japan; AUS196, Saita, Surjamkuhi, and Lakshmijata from India; and KU115 from Thailand.
- Some electrophoretically group 2 entries, such as AUS196 and Saita, show great potential because they are early and apparently stable, and have good yield potential. However, they lodge and are frequently susceptible to glume

discoloration (Gd) and leaf scald (LSc).

- Entries with * look particularly good in the field. The grains of CT6516-23-2-7 are exceptionally clean, without any Gd, while CT6516-06-4-1 (c) bulk and CNA4748 show excellent delayed leaf senescence.
- The best entries for brown spot resistance are B2997c-TB-4-2-1, IRAT239, CT6514-31-5-2, Arroz Dos Indios, IR47686-18-7-B, Sangoku, CT6516-24-16-2 (c) bulk, IAC165, Carijo, CT6516-06-4-1 (c) bulk, IRAT288, IRAT263, IRAT109, IRAT112 (A), IR47686-11-1-B-1, CT6516-23-2-7, CT6510-24-1-2 (B) gold, and Dular W-B.
- The best entries for LSc resistance are IRAT239, CNA4748, IR47686-06-02-2-1, Carijo, CT6516-06-4-1 (c) bulk, KU115, IR47686-18-1-1, IR47686-30-4-1, IR47691-27-7-2-1, CT6516-23-2-7, and Kele (West Bengal).
- Field evaluation was done by taking the average of six acceptability scores before maturity, while phenotypic acceptability was scored at harvest. For some entries, heavy rains between these two scores induced a serious impact on acceptability scoring, mostly because of serious Gd.
- The best entries for early vegetative vigor are AUS196, Saita, Surjamkuhi, Lakshmijata, N22 (Cuttack), Kele (West Bengal), and Dular (West Bengal) (group 2–aus) and IRAT160, IRAT224, and IRAT246 (group 6–tropical japonicas).

Group 2's earliness is an excellent trait conferring very high vigor at early stages and good weed competition ability. This group can be considered

Table 13. Results of observational trial without lime, Cavinti, Philippines, 1988.[a]

Variety	Yield (t/ha)	Yield (kg/d)	Days to maturity	Phenotypic acceptability		Early vegetative vigor	Neck blast	Glume discoloration	Brown spot	Leaf scald
				Av score	Single observation					
IRAT010	2.9	27.6	106	3	5	3	3	4	3	5
IRAT160	2.4	22.3	106	5	6	1	0	6	3	5
Lakshmijata[b]	2.1	20.6	103	5.7	7	1	0	6	3	6
KU115	2.0	16.0	122	3.3	5	4	0	0	3	1
CT6510-24-1-3 (A) straw	1.9	16.3	118	2.3	5	3	0	4	3	4
IRAT109	1.7	16.5	105	3.3	4	4	0	4	2	3
IRAT112 (HT)	1.7	16.7	103	4.3	4	3	3	3	3	5
Oohata Wase	1.7	16.4	103	4.3	6	2	0	4	3	5
Lung Sheng No. 1	1.6	13.9	115	5.7	6	3	4	5	3	7
CT6510-19-3-1 (B) gold	1.6	12.9	122	3	5	4	0	4	3	4
IR47686-18-1-1	1.5	12.5	123	2.7	5	4	0	4	3	2
CT6510-24-1-3 (B) gold	1.5	12.9	119	2.7	4	3	0	4	3	3
IRAT112 (A)	1.5	14.8	103	4.3	5	3	2	3	2	3
HD2.4	1.5	11.9	128	4.2	7	7	0	3	3	5
CT6510-19-3-1 (C) bulk	1.5	12.2	121	2.3	5	4	0	3	3	4
IR47686-30-4-1	1.4	11.3	124	3.3	4	4	0	4	3	2
IRAT134 (B)[b]	1.4	13.1	105	3.7	6	3	0	5	3	3
IR47691-27-7-2-1	1.3	11.1	119	3.4	4	4	0	3	3	2
IRAT215	1.3	10.9	118	2.3	5	2	0	6	3	3
IRAT224	1.3	10.9	118	3.3	7	1	0	6	3	3
IR42221-145-2-3-2	1.3	10.6	122	4.7	7	3	0	7	5	3
IR47686-11-1-B-1	1.3	10.5	122	2.6	5	4	0	5	2	3
CT6516-23-2-7[c]	1.2	10.4	118	3.7	3	3	0	3	2	2
IRAT078	1.2	10.2	118	3.7	7	3	0	7	6	3
IRAT246	1.2	11.4	105	5.3	6	1	0	6	3	6
IRAT238	1.2	11.0	105	3.7	4	2	0	3	3	6
Mean	0.6									
Standard deviation	0.5									
Coefficient of variation (%)	0.9									

[a]Scoring by SES. All entries scored 0 for leaf blast and 0-2 for sheath rot, sheath blight, and bacterial blight. [b]Had poor exsertion. [c]Clean.

Table 14. Results of observational trial with lime, Cavinti, Philippines, 1988.[a]

Variety	Yield (t/ha)	Yield (kg/d)	Days to maturity	Field evaluation	Phenotypic acceptability	Early vegetative vigor	Neck blast	Glume discoloration	Brown spot	Leaf scald	Sheath rot	Sheath blight	Bacterial blight	Drought resistance at vegetative stage
AUS196[b]	3.6	34.3	105	3.7	6	1	0	7	3	5	0-2	0-2	0-2	3
Saita[c]	3.2	30.5	105	5	7	1	0	5	3	5	0-2	0-2	0-2	3
Surjamkuhi[c]	3.2	30.8	103	5.3	6	1	0	3	3	5	0-2	0-2	0-2	3
B2997C-TB-4-2-1	2.5	22.3	111	3.4	3	3	0	2	1	4	0-2	0-2	0-2	3
IRAT239	2.4	23.4	103	2.7	3	3	0	3	2	2	0-2	0-2	0-2	3
CT6514-31-5-2	2.2	18.4	119	3.3	3	3	0	3	2	3	3	0-2	0-2	4
IRAT291	2.1	19.9	105	2.7	5	3	0	5	3	3	0-2	0-2	0-2	3
Arroz Dos Indios	2.1	19.6	106	3.7	4	3	0	2	2	6	3	3	3	3
CNA4173	2.1	19.6	106	4.7	4	4	0	3	3	5	0-2	0-2	0-2	3
CNA5628	2.1	19.6	106	4.7	4	4	0	3	3	6	5	0-2	0-2	3
CNA5626	2.1	17.6	118	5.3	7	2	0	6	6	6	6	0-2	0-2	3
IR47704-15-1-1[d,e]	2.1	17.5	119	3.3	5	3	0	4	4	5	0-2	0-2	0-2	3
CNA4748=Cuiabana[f]	2.0	16.6	119	3.7	3	3	0	2	3	2	0-2	0-2	0-2	3
IR47686-18-7-B	2.0	16.0	124	2.7	3	3	0	3	2	3	0-2	0-2	0-2	1
Sangoku	1.9	18.4	103	3	5	3	7	4	2	3	0-2	0-2	0-2	3
Arroz de Productor	1.9	17.7	106	3.7	3	3	0	3	3	5	3	3	3	3
IR47686-6-2-2-1	1.9	15.3	123	2.7	4	3	0	3	3	2	0-2	0-2	0-2	3
CT6516-20-1-2 (C) bulk[e]	1.9	15.6	119	2.3	4	3	0	4	4	6	4	5	0-2	3
BR319-1	1.8	15.5	119	5.7	7	3	2	7	6	4	0-2	0-2	0-2	3
CT6516-24-16-2 (C) bulk	1.8	15.5	119	3.8	3	2	0	2	2	3	0-2	3	0-2	3
GS529[b]	1.8	17.6	104	6.7	6	2	0	3	3	4	0-2	0-2	0-2	3
IAC165	1.8	17.3	106	3.3	4	3	0	3	2	5	0-2	0-2	0-2	5
CT6516-27-6-1[e]	1.8	14.8	124	3.7	4	4	3	4	3	4	0-2	4	0-2	3
IDSA6	1.8	15.2	119	1.7	2	2	0	2	3	3	2	3	0-2	2
Catetao Precoce	1.8	16.8	106	5.7	3	3	0	3	3	5	0-2	0-2	0-2	3
Carijo	1.8	13.5	119	4	4	5	1	3	2	2	0-2	0-2	0-2	3
CT6510-24-1-3 (C) bulk	1.8	14.8	119	4.3	6	2	0	6	5	6	6	0-2	0-2	4
Mean	1.2													
Standard deviation	0.5													
Coefficient of variation (%)	38													

[a] All entries scored 0 for leaf blast. [b] Lodging score = 9. [c] Lodging score = 7. [d] Long grain. [e] Looked particularly good in the field. [f] Low leaf senescence.

Table 15. Acid upland observational trial, Cavinti, Laguna, Philippines, 1988.

Variety	Yield (t/ha)	Yield (kg/d)	Days to maturity
CNA4121	2.3	25.1	93
HD 1.4	2.2	24.2	93
IRAT169 F 10/6	2.0	19.9	105
IR47686-12-5-B-1	2.0	18.6	105
AUS454	1.7	18.2	93
CNA4127	1.7	18.2	93
CNA4749	1.6	15.4	105
IRAT226	1.6	13.8	113
CT6514-34-2-2[a]	1.5	14.6	105
IR53234-27-4	1.5	16.0	93
CNA5626	1.4	13.5	105
IR47686-13-2-1	1.4	13.5	105
CNA4117	1.4	13.4	105
IR47691-17-1-B	1.4	13.1	105
CT6510-24-1-2	1.4	13.0	105
L 081-40	1.3	13.7	93
IDSA6	1.3	12.1	105
IRAT164[a]	1.2	11.9	105
Arroz Dos Indios	1.2	13.4	93
IR53236-292	1.2	13.4	93
CT6514-4-1-3	1.2	11.8	105
IR47686-1-4-B	1.2	11.7	105
IR47686-9-4-1[a]	1.2	11.7	105
CNA4130	1.2	12.7	93
IRAT166	1.2	11.2	105
IR53236-342	1.1	12.2	93
CT6514-34-2-3	1.1	10.8	105
CNA4206	1.1	10.8	105
Senshou Ibaraki 1	1.1	11.5	97
IR47691-27-7-2-2	1.1	10.6	105
IR53236-171	1.1	11.8	93
395C-IRAT	1.1	11.2	97
IR47686-1-1-B	1.1	9.4	113
Arroz de Productor	1.1	11.4	93
IR47684-5-1-B	1.1	10.0	105
IR47686-13-2-2	1.1	10.0	105
IR47686-1-4-1-1	1.0	9.9	105
CNA4143	1.0	9.9	105
IR55529-53	1.0	11.2	93
IR55539-33	1.0	9.8	105
A8-391	1.0	11.1	93
IR47686-13-3-2-2	1.0	8.9	113
Arroz de Aldeia Caulina	1.0	10.7	93
IRAT211	1.0	9.4	105
IRAT190	1.0	10.6	93
CT6510-24-1-1	1.0	9.4	105
IRAT169 F 10/6	1.0	9.3	105
AUS196	1.0	10.0	97
CT6516-23-1-5	1.0	9.2	105
IR47686-15-1-1	1.0	9.1	105
CT6516-27-6-1	1.0	9.0	105
Mean	0.5		
Standard deviation	0.4		
Coefficient of variation (%)	80		

[a] Looked particularly good in the field.

as a donor group for this trait, along with some early group 6 entries.

Cavinti, Laguna; and Claveria, Misamis Oriental (Plant Breeding and Rice Farming Systems). Summaries of two acid upland observational trials are given in Tables 15 and 16 for entries yielding more than the trial mean plus the standard deviation.

Table 16. Acid upland observational trial, Claveria, Misamis Oriental, Philippines, 1988.

Variety	Yield (t/ha)	Yield (kg/d)	Days to maturity
UPLRi-7	4.3	39.5	110
IR52222-B-B-8	4.1	39.4	105
IR38569-B-B-B-1-3-2	4.1	33.8	121
CT6516-18-1-2	4.1	38.5	105
IR47686-9-4-1[a]	4.0	37.9	105
IR38569-B-B-B-1-3-1	3.9	32.5	121
IR52197-B-B-B-8	3.9	39.0	100
IR48392-B-B-B-7-1	3.9	33.8	115
IR52812-CP128-C3-164-3-2	3.8	34.2	111
IR52222-B-B-2	3.8	34.4	109
IR47686-9-7-1	3.7	33.4	110
IR49253-B-B-8-5	3.7	32.1	114
IR52222-B-B-16	3.6	33.8	108
IR52214-B-B-3	3.6	34.0	107
IR47658-B-B-B-12-6	3.6	33.2	109
IR51414-B-B-B-20	3.6	34.1	105
IR52197-B-B-18	3.6	35.7	100
IR52222-B-B-15	3.5	32.6	108
IR52812-CP128-C3-1-5-5	3.5	28.9	121
IR52222-B-B-12	3.5	32.1	108
IR52812-CP128-C3-380-2-1	3.5	30.1	115
CT6636-27-1-1	3.4	34.3	100
IR52222-B-B-1	3.4	31.8	108
IR52222-B-B-6	3.4	31.8	108
Saita	3.4	33.3	102
IR38569-B-B-B-1-2-2	3.4	28.4	118
IR38535-B-B-B-2-2-3	3.3	31.4	104
IR52812-CP128-C3-31-1-3-4	3.3	28.2	116
IR52229-B-B-18	3.3	28.9	113
IR52229-B-B-11	3.2	28.8	113
IR52230-B-B-27	3.2	28.6	113
IR50199-B-B-4-1	3.2	31.8	102
B2997C-TB-4-2-1	3.2	30.5	106
IR49252-B-B-8-2	3.2	28.3	114
IR52230-B-B-10	3.2	30.3	106
IR52229-B-B-30	3.2	28.3	113
IR52188-B-B-9	3.2	31.7	101
IRAT164[a]	3.2	30.4	104
CT6514-34-2-2[a]	3.2	29.4	107
Mean	2.4		
Standard deviation	0.7		
Coefficient of variation (%)	28		

[a] Looked particularly good in the field.

Entries yielding more than the mean plus two standard deviations are in boldface in the tables.

The following are the major conclusions:

- The two sites are very different in potential. Cavinti, with pH 4.0 and very low P content, had a maximum yield of 2.3 t/ha. Claveria, with pH 5.2 and low P content, had a maximum yield of 4.3 t/ha. The more serious constraints in Cavinti induced the lowest yields, which were also reduced in 1988 because of heavy rains at the end of the growing season after the drought spells that prevailed at the beginning of the season. The maximum yields were 4.0 t/ha in Cavinti and 5.9 t/ha in Claveria in 1987, the difference at both sites being around 1.5 t/ha between 1988 and 1987. The potential in Cavinti is about 2 t/ha less than in Claveria, this difference being confirmed by yield trials (see below). Cavinti is thus a very good site for screening to select donors adapted to very unfavorable conditions. Claveria is a good site for upland rice cultivation, prevailing conditions being medium favorable.
- Only three entries appear in both lists: CT6514-34-2-2 from the Centro Internacional de Agricultura Tropical (CIAT) in Colombia, IR47686-09-4-1 from the IRAT-IRRI Collaborative Program, and IRAT164 from the Ivory Coast. These three entries can be an indication of the strategy used by CIAT, IRAT-IRRI, and IRAT. Selection was under very unfavorable conditions, to better detect donors that can be used under growing conditions varying from very unfavorable to moderately favorable.
- None of the IR or BB lines that ranked very well in Claveria were among the best entries in Cavinti, while one IR47686 and one CT6514 line that ranked well in Cavinti also ranked well in Claveria. This was due to differences in selection pressure applied during the early stages of selection of progenies for the three sets of materials. There was high selection pressure for both IR47686 and CT6514, and medium-low selection pressure for the others. This is a clear indication that different strategies are conducive to different results–confirmed by the presence of two IR47686 lines and three CT lines among the top ranking material in Claveria.
- Figures 5 and 6 report the polynomial (order 2) regression of days to maturity to yield in t/ha for both sites. The equations are d = maturity in days):

Cavinti:

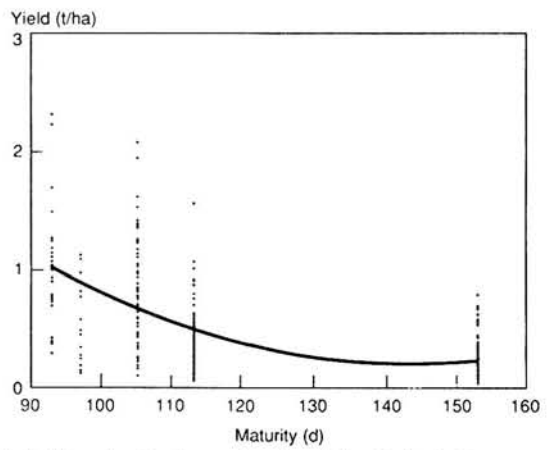
$$\text{Yield in t/ha} = 6.7489 - 0.0912d + 0.0003d^2$$
$$r = 0.59^{**}$$

Claveria:

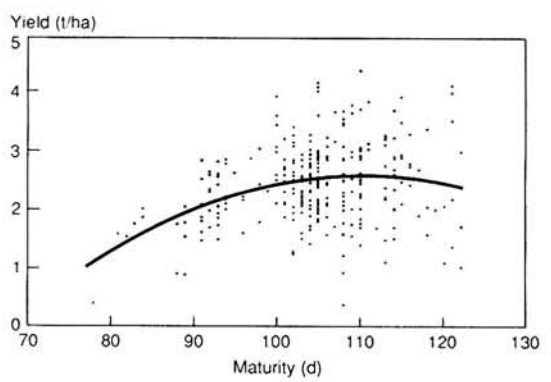
$$\text{Yield in t/ha} = 14.3657 + 0.3061d - 0.0014d^2$$
$$r = 0.31^{**}$$

Clearly, for both sites, where conditions are different, earliness is a major trait. The best yields are from entries maturing in 100-110 d.

Yield trials (*Plant Breeding and Multiple Cropping*). Three sites–Cavinti, Claveria, and Santo



5. Acid upland observational trial, Cavinti, Laguna, Philippines, 1988 WS.



6. Acid upland observational trial, Claveria, Misamis Oriental, Philippines, 1988 WS.

Tomas–were used for yield trials in 1988. From the Visayas State College of Agriculture, a few results concerning only the best entries are reported.

Without phosphorus. In these trials, the fertilizer was N only, at 30 kg/ha. The results are given in Table 17, where the entries yielding more than the trial mean plus the standard deviation for each site are given in boldface. The means indicate that when the yield is 0.5 t/ha in Cavinti, with its strongly acidic soil, it can be expected to be 1.2 t/ha in Santo Tomas and 2.6 t/ha in Claveria, where the pH is about 1.4 higher than in Cavinti.

The behavior of the entries contrasts when Cavinti and both Claveria and Santo Tomas are compared. Entries with top yields in Cavinti (given in boldface) were not top yielding in either Claveria or Santo Tomas. In fact, most of good yielders at these two sites were among the poorest yielders in Cavinti.

This result indicates the importance of the problems linked with stability as compared with yield potential. For a given entry, there is an evident linkage between response to environment and response to inputs. Most of the entries highly responsive to environment are unstable, the two characters being obviously strongly linked. However, some entries show a high intercept of their linear regression line with the yield axis when yield-environment regressions are studied. This is the case for HD1.4 and L081-40, which can be considered as stable under low inputs; IR30716 and IR49255 are unstable. Again, AUS196 is an indication of the potential and relative stability of AUS group 2 entries in adverse environments.

With phosphorus. Table 18 shows the best entries with the best mean yield.

Again, the results are contrasting for most entries between Cavinti and both Claveria and Santo Tomas, one variety (IRAT216) excepted.

Applied P showed no effect on mean yield in Santo Tomas, while its impact was 0.8 t/ha in Cavinti and 1.2 t/ha in Claveria. The best entry, IRAT216, showed 1 t/ha more than the best entry without P, viz., IR30716-B-1-B-1-2.

Table 17. Yields in acid upland yield trials at 4 Philippine sites, 1988.

Variety	Yield (t/ha)				
	Cavinti	Claveria	Santo Tomas	Mean, 3 sites	VISCA
IR30716-B-1-B-1-2[a]	0.7	**3.8**	**1.8**	2.1	
IR49255-B-B-5-3[a]	0.0	**3.8**	**2.0**	1.9	
HD1.4[a]	**1.7**	2.8	1.2	1.9	
L 081-40=CNA5366	**1.5**	2.9	1.2	1.9	
AUS196	0.5	**3.6**	1.5	1.9	
CNA4136[a]	**1.1**	3.2	1.3	1.9	
BR319-1	0.4	3.2	**1.9**	1.8	
IR10147-113-5-1-1-5[a]	0.2	**3.4**	**1.9**	1.8	
IR51388-B-B-B-15	0.1	**3.6**	**1.8**	1.8	1.3
IR49255-B-B-5-4[a]	0.1	**3.3**	**1.9**	1.8	
IR47686-5-10-B	**1.1**	2.7	1.3	1.7	
IR47686-31-1-1	**1.1**	3.1	0.9	1.7	0.9
IR23261-23-2-2	**1.1**	2.2	1.6	1.6	
IR49255-B-B-5-2[a]	0.0	3.0	1.7	1.6	0.5
IRAT216[a]	**1.6**	2.1	1.0	1.6	
IR23261-23-2-3[a]	0.0	2.3	**2.4**	1.6	
IRAT212	**1.8**	1.3	1.4	1.5	
IR48686-19-1-1 (B)	**1.5**	2.2	0.8	1.5	
IRAT291	**1.1**	2.2	1.1	1.4	
ITA130	0.5	2.1	1.7	1.4	
IR47686-4-4-B-1	1.0	2.9	0.3	1.4	
IR41716-B-B-B-6-2	0.1	2.1	1.7	1.3	
Mean	0.5	2.6	1.2	1.4	
Standard deviation	0.5	0.6	0.5		
Coefficient of variation (%)	91	25	38		

[a] Looked particularly good in the field.

Table 18. Yields in acid upland yield trials at 4 Philippine sites, 1988.

Variety	Yield (t/ha)				
	Cavinti	Claveria	Santo Tomas	Mean, 3 sites	VISCA
IRAT216[a]	**3.5**	**5.0**	1.2	3.2	
AUS257	**3.4**	3.9	1.1	2.8	
IR47686-9-1-B-1	**2.4**	4.4	1.6	2.8	
IR49255-B-B-5-4[a]	0.1	**5.2**	**2.7**	2.7	
IR49255-B-B-5-3[a]	0.0	**5.4**	**2.5**	2.6	
CNA4136[a]	**2.4**	4.2	1.2	2.6	
IR30716-B-1-B-1-2[a]	1.2	**4.6**	**2.1**	2.6	
IR49255-B-B-5-2[a]	0.2	**5.1**	**2.6**	2.6	1.1
AUS196	**2.9**	4.1	0.6	2.5	
HD1.4[a]	**2.8**	3.4	1.1	2.4	
CNA4121	**2.5**	3.5	1.2	2.4	
IR10120-7-2-1-4	1.0	4.4	1.8	2.4	
IAC165	**2.8**	3.7	0.6	2.4	
IR47686-6-2-2-1	**2.6**	3.3	1.2	2.4	1.4
IR47686-4-4-B-1	**2.5**	3.7	0.7	2.3	
IR47686-10-1-1-1	**2.4**	3.5	0.9	2.3	
IR10147-113-5-1-1-5[a]	0.7	4.0	**2.0**	2.2	
IR23261-23-2-3[a]	0.8	3.9	**1.9**	2.2	
Mean	1.4	3.7	1.3	2.1	
Standard deviation	0.9	0.7	0.5		
Coefficient of variation (%)	65	19	38		

[a] Looked particularly good in the field.

Only nine entries appear in both Tables 17 and 18: IRAT216, IR30716-B-1-B-1-2, IR49255-B-B-5-3, CNA4136, IR49255-B-B-5-4, HD1.4, IR49255-B-B-5-2, IR10147-113-5-1-1-5, and IR23261-23-2-3 (ranked according to the mean yield with and without P).

Estimate of phosphorus response. Table 19 provides an estimate of P response. Entries with very low yield in Cavinti without P were excepted, because the ratio is not reliable. The figures are the ratio of yield with P to yield without P. This ratio ranges from about 1.2 to 2.2, showing that variability exists among entries. IRAT and IR47686 entries at the top of the list will be further explored.

Two-year study of selected entries. Seventeen entries that have been studied during 2 yr at 2 sites under 2 P input levels (0 P and 20 P) are listed in Table 20.

We summarize the major results:

- Linear regression. The most stable entries were Azucena and Dinorado, traditional upland entries from the Philippines, along with progenies belonging to the IRAT-IRRI Collaborative Program: IR47686-06-02-2-1 and IR47686-10-1-1-1.

Table 19. Phosphorus response ratio of yields with and without P at 4 Philippine sites, 1988.

Variety	P response ratio			
	Cavinti	Claveria	Santo Tomas	Average
IRAT212	2.70	3.10	0.99	2.26
IAC165	1.84	3.11	1.54	2.16
IR47686-4-4-B-1	2.23	1.29	2.32	1.95
IR48686-19-1-1 (B)	2.58	1.47	1.75	1.93
IRAT216	1.93	2.35	1.25	1.84
IRAT291	2.62	1.58	0.99	1.73
CNA4121	2.24	1.29	1.59	1.71
ITA130	2.71	1.61	0.68	1.67
IR47686-9-1-B-1	2.28	1.46	1.13	1.62
IR47686-6-2-2-1	2.25	1.3	1.28	1.61
L 081-40=CNA5366	2.57	1.28	0.94	1.60
BR319-1	2.56	1.32	0.87	1.58
IR49255-B-B-5-2		1.68	1.48	1.58
IR30716-B-1-B-1-2	2.33	1.24	1.12	1.56
AUS257	2.02	1.52	0.94	1.49
IR49255-B-B-5-4		1.57	1.40	1.49
CNA4136	2.18	1.35	0.92	1.48
IR47686-10-1-1-1	2.20	1.14	0.93	1.42
HD1.4	1.90	1.19	0.94	1.34
IR49255-B-B-5-3		1.44	1.24	1.34
IR49255-B-B-5-3		1.44	1.24	1.34
AUS196	1.80	1.32	0.38	1.17

Table 20. Results of 2 yr acid upland yield trials, 1988.

Variety	Linear regression on mean (=m)	r	Comment	Phosphorus	Mean yield (t/ha)	Mean days to maturity	Mean yield (kg/d)	Surplus due to fertilizers (t/ha)	Cavinti			Claveria		
									Yield (t/ha)	Days to maturity	Yield (kg/d)	Yield (t/ha)	Days to maturity	Yield (kg/d)
AUS196	0.41+1.00 m	0.81**	Stable	Without	1.8	108	16.8		1.2	109	11.3	2.4	113	23.2
				With	3.2	103	31.3	1.4	2.7	104	26.4	3.7	102	36.7
Azucena	0.69+0.67 m	0.77*	Very	Without	1.6	121	13.5		1.1	126	8.4	2.1	115	18.5
			stable	With	2.6	119	22.2	1.0	2.5	120	20.9	2.7	117	23.5
CNA4136	0.56+0.91 m	0.85**	Stable	Without	1.9	105	17.9		1.6	107	14.5	2.2	102	22.5
				With	3.1	98	31.7	1.2	2.5	100	24.7	3.8	96	40.1
CNA5164	0.27+0.94 m	0.93**	Stable	Without	1.7	102	16.3		1.3	102	12.1	2.1	101	20.4
				With	2.8	95	30.4	1.2	2.1	96	22.0	3.6	94	38.8
Dinorado	0.28+0.69 m	0.71*	Very	Without	1.4	123	10.9		1.4	122	11.2	1.3	124	10.6
			stable	With	2.2	120	18.0	0.8	1.6	121	13.1	2.7	118	23.0
IR30716-B-1-B-1-2	−0.20+1.44 m	0.93**	Very	Without	2.5	110	22.8		1.1	112	9.9	3.8	107	35.7
			unstable	With	3.2	108	30.5	0.8	2.0	110	17.9	4.5	105	43.1
IR47686-4-4-B-1	0.82+0.83 m	0.90**	Stable	Without	2.0	118	16.8		1.5	117	12.5	2.5	119	21.1
				With	3.2	113	28.4	1.2	2.7	113	23.5	3.7	112	33.4
IR47686-6-2-2-1	0.99+0.70 m	0.79*	Very	Without	1.9	118	16.2		1.3	118	10.6	2.6	117	21.8
			stable	With	3.0	116	26.2	1.1	2.9	116	25.1	3.1	115	27.4
IR47686-8-4-3	0.32+0.83 m	0.77*	Stable	Without	1.7	124	13.6		1.5	122	12.1	1.9	124	15.2
				With	2.5	121	20.5	0.8	1.7	121	13.8	3.3	121	27.1
IR47686-9-2-B	−0.21+1.25 m	0.95**	Un-	Without	2.2	120	18.2		1.3	123	10.3	3.1	117	26.2
			stable	With	2.7	116	23.7	0.6	1.6	116	13.3	3.9	116	34.0
IR47686-10-1-1-1	0.79+0.75 m	0.88**	Very	Without	2.0	120	16.5		1.3	121	10.7	2.6	119	22.3
			stable	With	2.8	116	24.3	0.8	2.4	116	21.2	3.1	116	27.4
IR47686-13-1-1	0.25+1.01 m	0.89**	Fairly	Without	2.3	121	18.7		1.4	121	11.6	3.1	120	25.8
			stable	With	2.5	118	21.8	0.2	1.6	118	13.4	3.4	118	28.8
IR47686-13-2-2	−0.09+1.06 m	0.83**	Fairly	Without	1.4	116	11.7		1.0	115	8.6	1.8	117	14.8
			stable	With	2.9	113	25.9	1.6	2.1	111	18.6	3.8	114	33.2
IR47686-17-1-1-1	−0.07+1.04 m	0.90**	Fairly	Without	1.5	119	12.6		0.5	120	4.1	2.4	117	21.0
			stable	With	2.8	115	24.4	1.3	2.3	118	19.3	3.3	113	29.6
IRAT104	−0.45+1.14 m	0.91**	Un-	Without	1.6	123	13.3		1.0	123	8.2	2.2	122	19.5
			stable	With	2.3	120	19.8	0.7	1.5	120	12.5	3.2	119	27.2
IRAT144	0.07+1.07 m	0.96**	Fairly	Without	1.8	106	16.8		0.9	105	8.7	2.6	106	24.9
			stable	With	2.9	101	28.8	1.1	2.1	101	20.6	3.7	100	37.0
UPLRi-5	−1.01+1.43 m	0.98**	Very	Without	1.6	126	12.5		0.8	126	6.1	2.3	126	18.9
			stable	With	2.5	125	20.3	0.9	1.1	126	8.4	3.9	124	32.1
Selected entries average				Without	1.8				1.2			2.4		
				With	2.8			1.0	2.1			3.5		
Maximum yield				Without	3.1	112	27.3		2.3	111	20.4	3.8	112	34.2
				With	4.2	111	37.9	1.1	3.4	115	29.8	4.9	107	46.1
Trial average				Without	1.7	116	15.2		1.1	116	9.7	2.3	115	20.6
				With	2.5	112	22.1	0.8	1.7	113	15.2	3.4	111	31.1

IR47686-06-02-2-1 was the most stable entry, with a fairly good yield potential and good P response. Furthermore, previous results show that it has very good drought and Bl resistance. It has already been adopted by farmers in Iloilo, and is undergoing further evaluation in Leyte.

IR30716-B-1-B-1-2 and UPLRi-5 were very unstable. The first was the top yielding entry, while the second gave only moderate yield, and lower than that of Azucena.

This result confirms the potential of AUS196, the group 2 AUS entry. This group requires more attention; however, a careful choice of entries is necessary, because it exhibits highly variable tolerances and resistances.

- Elements on P response. Phosphorus applied to acidic (pH around 5) to strongly acidic (pH around 4) soils shows several important returns. The yield is drastically increased by about 1 t/ha; however, this effect varies, according to entries, from 0.6 to 1.6 t/ha. The seed-to-seed duration is reduced 1-7 d. And the daily yield is drastically increased.

Phosphorus also reduces brown spot incidence and, more generally, contributes to healthier and stronger plants.

DEEPWATER RICE

Plant Breeding Department and Rice Research Institute, Thailand

Hybridization (*Plant Breeding*). We made 435 single and multiple crosses for deepwater rice (DWR). The most frequently used parents representing donors for modern (MV) plant types combined with elongation ability or submergence tolerance, and donors for very rapid elongation ability are as follows:

- B 4259-48-1-1-1-2-2-2-1-3 (used 51 times). MV plant type resistant to BPH biotypes 1, 2, and 3; Bl and GLH; with good grain appearance and intermediate gelatinization temperature (GT).
- Bao Thai (34 times). Photoperiod-sensitive DWR for low-lying areas in the Red River Valley, Northern Vietnam, poor soils, and drought-prone conditions; resistant to BPH race 1 and GLH.
- BKNFR76106-16-0-1 Resel 2 (31 times). MV plant type with submergence tolerance as good as that of its parent FR13A, and resistant to BB race 1.
- BR118-3B-17 (44 times). Medium-tall DWR; resistant to Bl, GLH, and BB races 1 and 2; photoperiod sensitive with some elongation ability and submergence tolerance; drought tolerant.
- BR516-48-3 (40 times). Promising floating rice from Bangladesh; some resistance to GLH; good elongation; submergence tolerant.
- BR683-65-4-1-1 (44 times). Early-maturing, photoperiod-sensitive elongating dwarf from Bangladesh; good for 1 m water.
- IR11141-6-1-4 (95 times). MV type DWR with excellent elongation ability; resistant to BPH biotypes 1 and 3; drought tolerant.
- IR20992-7-2-2-2-2-3 (30 times). DWR resistant to BB race 1; BPH biotypes 1, 2, and 3; and GLH; drought tolerant; with high yield in deep water; adapted to acid soil.
- IR31406-333-1 (25 times). MV type with excellent submergence tolerance; resistant to BPH biotypes 1 and 3; BB race 1; tolerant of drought, salinity, and cold.
- IR37025-R-R-R-5-1 (73 times). MV type with moderate elongation ability, good drought tolerance, resistance to BPH biotypes 1 and 2.
- IR38446-4-1-3-1 (30 times). Good medium stature DWR.
- IR38446-4-1-3-2 (34 times). MV type, good for 1 m water; photoperiod sensitive; resistant to BB race 1; BPH biotypes 1, 2, and 3, and GLH; intermediate GT; good grain appearance.
- IR38784-100-1-3-1-2-1 (40 times). MV plant type with very good elongation ability; drought tolerant.
- IR38784-100-1-3-6-3 (56 times). MV plant type with very good elongation ability; resistant to BB race 1, BPH biotypes 1, 2, and 3, and GLH; good grain appearance and intermediate GT.
- IR40905-R-R-R-21 (34 times). Intermediate stature and very good and fast elongation ability; resistant to BB races 1 and 2, BPH biotypes 1, 2, and 3, and GLH.
- IR43641-1-2-3-2-1 (67 times). MV type; resistant to BB race 1, and GLH; good elongation; excellent tillering in 1 m deep water.
- Nam Sa-Gui 19 (30 times). Weakly photoperiod-sensitive, rainfed rice from northeast Thailand, tolerant of drought, resistant to Bl,

efficient in Zn utilization; with long, slender, clear grains.

Bulk handling of populations at IRRI (*Plant Breeding*). We grew 728 F_2s in elongation tests in 1988. Good survivors were harvested directly or transplanted first, then harvested, and 224 populations were identified as excellent.

For submergence tolerance, we grew 700 populations in simulated flash floods and transplanted surviving plants for further selection. We identified 320 superior populations. Frequently occurring parents responsible for the superior performance in deep water are listed in Table 21.

In the field, we grew 380 F_3 and 69 F_4 and later generation bulk populations, creating strong pressures for resistance to the RTV vector.

We grew 287 advanced-generation bulks that had been successfully tested in deepwater conditions in Prachinburi, Thailand. We found 25 populations able to withstand the disease pressure at IRRI.

Pedigree selection and preliminary observation (*Plant Breeding*). We grew 25,564 pedigree lines at IRRI. In observation trials, we grew 1,000 lines and found some outstanding entries (Table 22).

Combining superior submergence tolerance with improved plant types (*Plant Breeding*). We selected for submergence tolerance in several crosses having one or more proven submergence-tolerant parents. The parentage of these lines is indicated in Table 23.

Field testing of advanced lines and F_2 populations (*Plant Breeding*). We sent 630 advanced lines and 1,177 F_2 and F_3 bulk populations to interested DWR breeders in Asia and elsewhere. We observed, or received feedback from, various locations outside IRRI on the survival of materials sent in 1988 and before (including performance of lines tested through IRTP). Lines with superior survival noted in more than one country are listed in Table 24.

Incorporating superior elongation ability into floating rices (*Plant Breeding and Thailand Rice Research Institute*). Fast-elongating floating rices of the Indian subcontinent are distinct from the Southeast Asian types in that they can rapidly elongate in the early seedling stage and can emerge from flash floods that cause total submergence.

The Prachinburi Rice Research Center of the Rice Research Institute, Thailand, in collaboration with IRRI, has now developed lines with IR parentage that combine fast elongation ability with grain quality and maturity acceptable in Thailand. Several lines showed their superior elongation ability in a 2-m flood in a farmer's field near Prachantakam. The parentage of the better lines is given in Table 25.

Table 21. Salient parents in bulk populations superior in elongation ability or submergence tolerance at IRRI, and their ancestral donors, 1988.

Immediate donor	Ancestor
Elongation ability	
BR1118-3B-17	Habiganj Aman 7
BR311-B-5-4	Habiganj Aman 8
BR516-48-3[a]	Habiganj Aman 4
BR683-65-4-1-1[a]	Habiganj Aman 4
FRRS43-3	Indochine Blanc
HTAFR77022-14-157-6	Khao Nahng Nuey 11
IR11141-6-1-4	Leb Mue Nahng 111
IR11288-B-B-69-1	Leb Mue Nahng 111
IR11288-B-B-118-1	Leb Mue Nahng 111
IR37025-R-R-R-5-1	Pin Gaew 56
IR38446-4-1-3-1	Chenab 64-117, DWCT 156
IR38784-100-1-3-1-2-1	Pin Gaew 56
IR38784-100-1-3-6-3	Pin Gaew 56
IR40905-R-R-R-21	Leb Mue Nahng 111, Badal 613
IR43641-1-2-3-2-1[a]	Sarsari, DWCT 156
Karijawa	Karijawa
Leb Mue Nahng 111 mutant	Leb Mue Nahng 111
Rayada 16-6	Rayada 16
TCA4	TCA4
Submergence tolerance	
IR31406-333-1	Kurkaruppan
BKNFR76106-16-0-1	FR13A

[a] Capable of elongating rapidly.

TIDAL WETLAND AND PROBLEM SOILS RICE

Plant Breeding and Soils Departments; Central Soil Salinity Research Institute, India; Banjarbaru Research Institute for Food Crops, Indonesia; Saline Agriculture Research Station, Pakistan; Regional Agricultural Research Center, Sri Lanka; Pathum Thani Rice Research Center, Thailand; and Department of Agriculture, Philippines

This year, we concentrated on producing breeding materials for cooperating national programs to use in developing improved varieties for tidal wetlands and problem soils. Because handling of large numbers of early generation materials in target environments of national programs is

Table 22. Outstanding lines from observational trials at IRRI, 1988.

Designation	Parentage	Characteristics
IR37025	BKN6986-147-2/IR46	
IR37025-R-R-R-9-1		MV type elongating DWR, good in 1 m water, Assam
IR38446	KDM105/Chenab 64-117// NSPT/BKNFR78023	
IR38446-4-1-3-1		MV type elongating DWR, good in 1 m water, drought tolerant, Panay
IR38446-4-1-3-2		MV type elongating DWR, good in 1 m water, drought tolerant, Panay
IR40905	Badal 613/IR11288-B-B-118-1	
IR40905-11-3-1-5-2-22		Floating rice, rapid elongation ability, photoperiod sensitive, resistant to GLH
IR41364	RD19/IR19672-24-2-3	
IR41364-R-B-B-B-16-1		MV type elongating DWR, resistant to GLH, submergence tolerant
IR41364-R-B-B-B-16-2		MV type elongating DWR, resistant to GLH, good grain quality, submergence tolerant
IR42506	BKN7022-10-1-4/Cafuringa 1// IR19382-42-3-3-2/BKNFR76106-16-0-1	
IR42506-531-1-2-1		MV type elongating DWR; photoperiod sensitive; good for late transplanting; Solana, northern Luzon, and in severe flood regions on Panay
IR43846	BR232-2B-3-4-A/IR11288-B-B-118-1///Bhadoia/IR8//Habiganj Aman 1//IR11288-B-B-118-1	
IR43846-15-1-2-1		Medium-height elongating DWR, drought tolerant, resistant to BI and GLH, submergence tolerant
IR43846-15-1-2-2		Medium-height elongating DWR, drought tolerant, resistant to BI and GLH, good grain quality, submergence tolerant
IR43846-15-1-2-3		Medium-height elongating DWR, drought tolerant, resistant to BI and GLH, good grain quality, submergence tolerant
IR43846-15-1-3-2		Medium-height elongating DWR, drought tolerant, resistant to BI and GLH, good grain quality, submergence tolerant
IR43846-15-1-3-2-1		Medium-height elongating DWR, drought tolerant, resistant to BI and GLH, submergence tolerant
IR43846-15-1-3-2-2		Medium-height elongating DWR, drought tolerant, submergence tolerant
IR43846-15-1-3-2-3		Medium-height elongating DWR, resistant to GLH, submergence tolerant

difficult, we decided to evaluate, select, and advance segregating materials in problem soil sites in the Philippines up to about the F_6 as bulks before distributing to cooperators.

We made 276 single and 129 multiple crosses. Parents included newly identified sources for problem soils tolerance such as bulu type varieties. Elite IR lines with premium grain quality, and photoperiod-sensitive varieties with adaptability to problem soils were also used.

Breeding materials generated in previous years were advanced at seven Philippine sites, representing different problem soils. They were San Dionisio (P deficient and Fe toxic) and Lanjagan (saline acid sulfate), in Iloilo Province; Castuli (saline) and Santo Tomas (acid-saline) in Pampanga Province; and artificial saline and alkaline fields at IRRI.

We evaluated 550 populations ranging from the F_2 to the F_6. The site for evaluating each

Table 23. Advanced breeding lines with superior submergence tolerance and their parentage.[a] IRRI, 1988.

Breeding line	Parentage	Number
IR26708	**FR13A**/IR48//IR48	1
IR31114	**G. Heenati**/IR4422-98-3-6-1// IR13419-113-1	16
IR36449	Suweon 290/**FR43B**	4
IR37058	C168/**FR43B**	1
IR41009	**Chenab 64-117**/IR17494-32-3-1-1-3	3
IR41158	**IR31031-P/BKNFR76106-16-0-1**	5
IR41222	MTU7029/**IR6402-OT-7**	15
IR42551	Mahsuri/IR13146-45-2-3// **BKN7022-6-4/BKNFR76106-16-0-1**	3
IR43982	IR56/IR11288-B-B-118-1// **BKN7022-6-4**/IR17491-5-4-3-3	2
IR44160	**FR43B** /IR42//**IR26702-52-3**	2
IR46677	**BKNFR76106-29-0-1**/IR13423-10-2-3//TOX896/IR10110-23-1	6
IR46679	**BKNFR76106-29-0-1**/IR64// CR1010/TOX89	1
IR47420	HTAFR79130-1-2-1-2/**IR26702-25-1-1**	1
IR52607	IR28941-164-1-5// **IR31406-333-1**/IR31432-6-2-1-3	4
IR54207	IR64/**IR31406-333-1**//IR21567-9-2-2-2-1-2-2-2/IR9129-209-2-2-2-1	1

[a] Submergence-tolerant parents in boldface.

population was chosen on the basis of the objective of each cross combination. In DS, when some of our sites cannot be planted to rice, relevant populations were advanced in IRRI fields with poor

Table 25. Lines with superior elongation ability verified in a farmer's field near Prachantakam, Prachinburi, Thailand, 1988.

Designation	Parentage	Number
IR40905	Badal 613/IR11288-B-B-118-1	4
IR40939	BR222-B-263/IR11288-B-B-118-1	1
IR40942	BR223-B-55-H2-B/ IR11288-B-B-118-1	1
IR40951	BR232-2B-3-4-A/ IR11288-B-B-118-1	2
IR40960	BR314-B-4-6/IR11288-B-B-118-1	7
IR40961	BR314-B-4-6/RD19	4
IR40972	BR525-2-1/ IR11288-B-B-118-1	3
IR40993	Chamara/IR11288-B-B-118-1	1

Table 24. Deepwater rices outstanding in more than one country, 1988.

Designation	Parentage	Locations where observed
IR11185	IR40/LMN111	
IR11185-R-0-7		Prachinburi, Thailand[a]
		Uttar Pradesh, India
IR21038	BGD5-6-3PE-1/IR42//IR4683-54-2	
IR21038-77-P2-5-2-3-1-1		Prachinburi, Thailand
		Huntra, Thailand
		Assam, India
IR26708	FR13A/IR48//IR48	
IR26708-2-2-3-1-P5-208		Solana, Philippines
IR26708-2-2-3-1-P6		Uttar Pradesh, India
IR31442	Kurkaruppan/IR4422-98-3-6-1//IR13419-113-1	
IR31442-1-503-1-2-1		Prachinburi, Thailand
IR31442-1-503-1-2-1		Uttar Pradesh, India[a]
IR38787	RD19/IR7732-RGA-A96-1	
IR38787-27-2-3-2		Huntra, Thailand
IR38787-27-2-3-2		Uttar Pradesh, India
IR40555	BKN7022-6-4/IR25861-31-1-3	
IR40555-48-3-1-2-2-11		Prachinburi, Thailand
IR40555-48-3-1-2-21		Uttar Pradesh, India
IR42435	HTA7406-111-0-0-2//RD19/IR11288-B-B-288-1	
IR42435-35-6-3-3		Prachinburi, Thailand[a]
IR42435-35-6-3-3		Assam, India
IR42436	IR54//RD19/IR11288-B-B-288-1	
IR42436-266-3-2-3		Huntra, Thailand
IR42436-266-3-2-3		Assam, India
IR45466	Baisbish/BKNFR76014-1-9-2	
IR45466-B		Uttar Pradesh, India[a]
IR45466-B-PCR-B		Prachinburi, Thailand

[a] Abrupt flooding.

soil fertility. Selection among those populations was restricted to plant type and resistance to pests and diseases. Of the populations evaluated during both DS and WS, 274 early generation bulks were mass-selected, and 66 advanced-generation bulks were pedigreed.

A pedigree nursery was established at IRRI in DS with 156 single plant selections made in 1987 WS. They were in the F_6 to F_7 and were advanced under various problem soil conditions. Lines expressing some uniformity and appropriate plant type, and with field resistance to major pests and diseases were harvested to produce 130 advanced bulk populations. Variability within these populations was narrow, but that between populations was very wide–specifically for duration, plant height, and grain quality. These populations were distributed to cooperating national programs for evaluation in target environments.

In Indonesia, under acid peat soil conditions, 13 populations were superior to the local check and were retained for further testing. Five sites representing different acid sulfate conditions (moderate acidity, high acidity, potential, saline, and peaty) were used in Thailand to evaluate the advanced bulk populations. Performance varied from location to location. Four populations that showed wide adaptability and others that performed better than local varieties at each test site were selected. In Sri Lanka, tests at 2 sites with Fe-toxic soils showed 15 populations to be superior to local checks. For saline-sodicity, evaluation was done in Sadhoke, Pakistan. The stress was very severe, but 12 populations performed better than the local check. Sites representing different saline soil conditions were used in India. At one coastal saline site, only one population survived after a tidal flood; at the other site, where salinity was moderate, all populations expressed good adaptability. At all three inland saline sites, five populations consistently performed better than the local check.

Cooperating breeders of all national programs selected good populations for purification and inclusion in their national varietal evaluation trials.

At our Philippine sites that represent different tidal wetland and problem soil conditions, we tested for adaptability a series of traditional varieties and advanced lines of other breeding programs of the Institute.

The 20 bulu varieties tested performed well at all sites, including saline soils, indicating their value as good germplasm for problem soils tolerance. The upland varieties tested were good only for P-deficient soils. Their performance was poor under saline or Fe-toxic conditions. Of the 468 advanced lines, IR24637-38-2-2-1, IR29137-16-1-6, IR37255-21-3-3-2, IR37257-41-3-2-3, IR37260-1-1-1-6-1, IR38851-33-3-3-2-2-3, and IR39573-4-2-2-3 were promising for tidal wetlands. We also identified one F_1 anther-culture derivative, TCP6533-8 (IR4630-22-2-5-1-3/Pokkali), with good plant type, to have a level of salt tolerance equal to that of Pokkali. Laboratory tests conducted later confirmed this tolerance level.

The collaborative breeding program with the Republic of Korea to incorporate salt tolerance of indicas into japonicas continued during the year. See details in the section on Adverse Temperature Tolerance.

Management of rice pests

Diseases

Plant Pathology, Agronomy, Multiple Cropping, Soils, and Entomology Departments; University of Hawaii; Kansas State University; University of Wisconsin; Justus-Liebig University, Germany; Maros Research Institute for Food Crops, Indonesia; and Rural Development Administration, Korea

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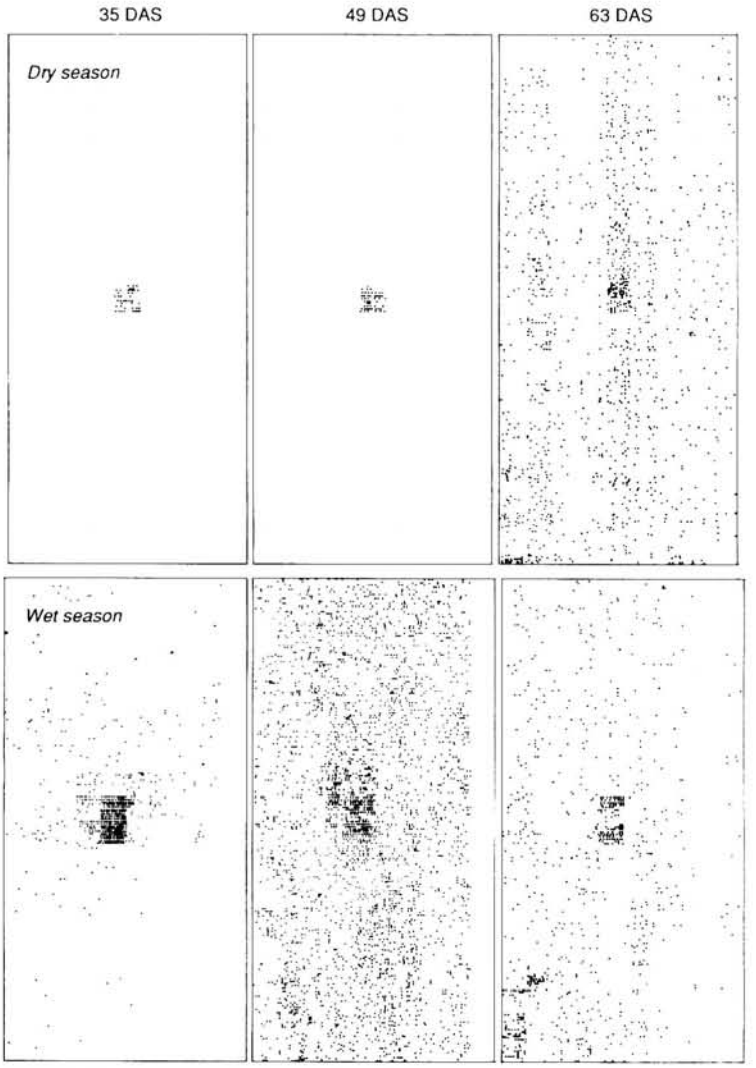
BIOLOGY, ECOLOGY, AND EPIDEMIOLOGY

Plant Pathology and Agronomy Departments, University of Hawaii, Kansas State University, and University of Wisconsin

Bacterial blight dissemination in transplanted and direct-seeded rice (*Plant Pathology*). In the field, bacterial blight (BB) infection varies from severe to mild. To determine BB dissemination from a given focus, the spread of the disease in direct seeded and that in transplanted rice were compared.

A plot size of 1,250 m^2 was used for both transplanting and direct seeding. IR56 was direct seeded at 100 kg seed/ha. Plants located at the 4-m^2 center of the plot were spray-inoculated with strain PXO 61 at 20 d after sowing (DAS). IR56 seedlings (21 d) were transplanted with a spacing of 0.2 m between hills. Plants in the 4 m^2 at the center of the plot had been inoculated with PXO 61 in the seedbed 1 d before transplanting. The inoculum concentration was adjusted to 10^9 cells/ml.

To follow the dissemination pattern, disease



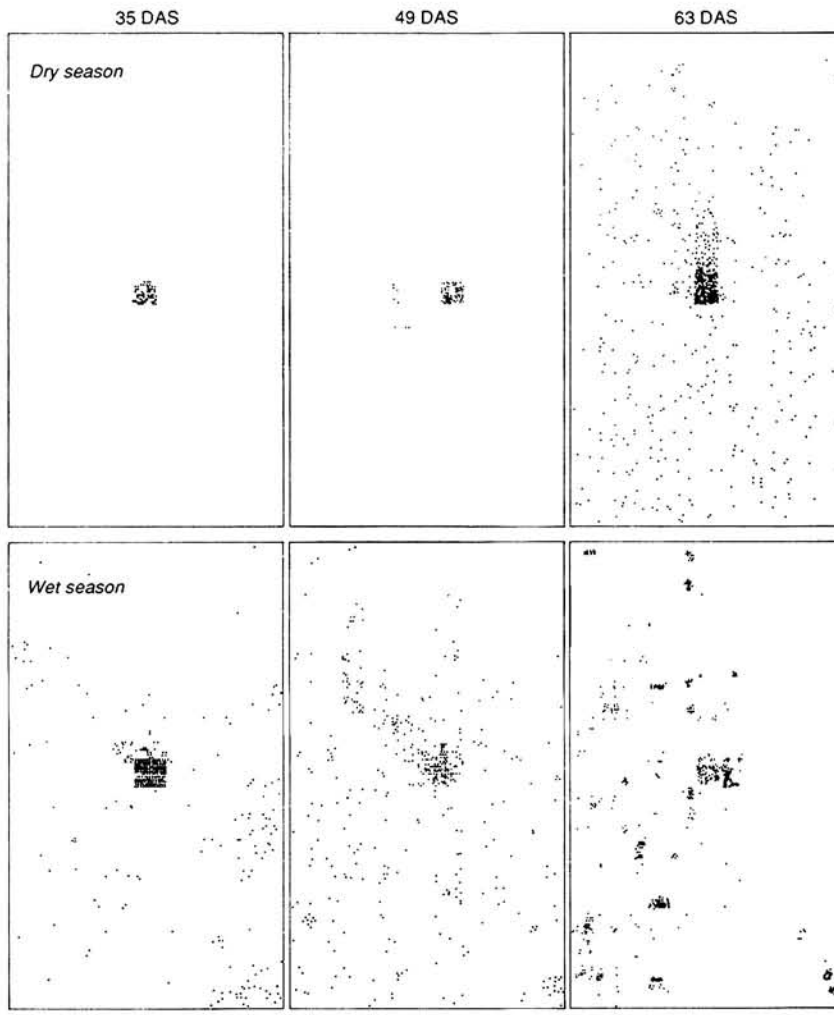
1. Distribution of bacterial blight (BB) on transplanted IR56 at 35, 49, and 63 d after sowing (DAS) during the dry and wet seasons. IRRI, 1988.

incidence was determined at 35, 49, and 63 DAS. Data were taken for both the dry (DS) and the wet (WS) seasons.

The distribution pattern of infected plants showed clumping at the focus during the early stages. The focal pattern disappeared at the later stages of the epidemic. Distribution was random in transplanted rice, whereas new focal points were observed in direct seeded rice (Fig. 1, 2). Compared with relative humidity, the amount of rainfall (mm/d) varied greatly in DS and WS.

Differences in the spread of BB between direct seeded and transplanted IR56 were evident. The disease spread faster in transplanted rice, especially during WS. The influence of plant density and environmental conditions, especially the microclimate and crop growth on the distribution of the disease, will be determined next.

Detection of bacterial blight pathogen with monoclonal antibodies (*Plant Pathology and University of Hawaii*). A United States Agency for International Development-supported collaborative project was developed between the University of Hawaii and IRRI to apply monoclonal antibodies (MCA) for the rapid detection of the BB pathogen. Four monoclonal antibodies were provided by the University of Hawaii: X_1, specific to the genus *Xanthomonas*; Xco-1, reacting



2. Distribution of BB on direct seeded IR56 at 35, 49, and 63 DAS during the dry and wet seasons. IRRI, 1988.

with all 178 strains of Xco from diverse geographical locations; Xco-2, reacting with most Xco strains from the Philippines; and Xco-5, reacting only with Xco strains from Texas and Louisiana, USA.

Experiments were conducted to demonstrate the usefulness of MCA in detecting Xco in artificially inoculated leaves. Taichung Native 1 plants (TN1) were inoculated with a range of inoculum concentrations of isolate PXO 86 or with water as the control. Leaves were sampled from each treatment 1 h after inoculation and then daily for 4 consecutive days. Leaf segments 1 cm long were cut, and bacteria were allowed to ooze for 2 h in 3 ml peptone sucrose broth. The bacteria were pelleted by centrifugation, washed 3 times with 0.85% saline, deposited onto Immulon II plates, and then dried at 37 °C. Plates were assayed by indirect enzyme-linked immunosorbent assay (ELISA) using MCA Xco-2 and commercially available alkaline phosphatase-conjugated goat antimouse antisera (1:1000). Results were read in a Microelisa Minireader II.

Positive signals were obtained from 3-leaf samples at 2 d after inoculation (DAI) and from single-leaf samples at 3 DAI (Table 1). Typical water-soaked lesions were observed only on leaves inoculated with 2.9×10^9 CFU/ml at 4 DAI. MCA could thus be used to detect Xco from leaves before symptoms appear.

To demonstrate the utility of MCA for detecting Xco in field specimens, 25 leaves showing atypical BB symptoms were collected from the field and the greenhouse. Visual scoring by 4 observers with 1-2 yr of research experience with BB indicated BB infection in 18 of the samples. Only 36% of the specimens showed positive reaction to MCA Xco-2, which was further confirmed by direct isolation of the bacteria (Table 2). This experiment showed that 1) visual diagnosis, especially at early stages of infection, could be unreliable, and 2) MCA could be used to diagnose BB infection accurately in the field.

Genetic diversity of the bacterial blight pathogen (*Plant Pathology and Kansas State University*). A repetitive element pJEL101 from Xco was used to determine the genetic diversity and population structure of Xco in the Philippines. Based on restriction fragment length polymorphism (RFLP) data provided by Kansas State University, a preliminary evolutionary tree of Xco races in the Philippines was constructed (Fig. 3). Race 3 was the most heterogeneous group, containing isolates related to many isolates from different races.

***Pythium* feeder-root necrosis** (*Plant Pathology*). The infection of rice roots by various species of *Pythium* is a serious problem in flooded soils in Louisiana, USA. Symptoms of *Pythium* feeder-root necrosis are cryptic, and the problem

Table 1. Detection of Xco with monoclonal antibodies in rice leaves inoculated with different concentrations of inocula. IRRI, 1988.

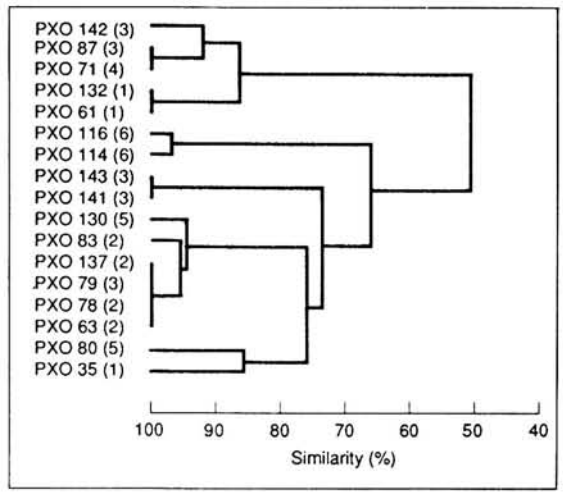
Time after inoculation	Leaves sampled[a] (no.)	Reaction in indirect ELISA[b] at given CFU/leaf at 1 h after inoculation						
		Control[c]	2.0×10^3	5.1×10^2	1.3×10^2	3.2×10^1	0.81×10^1	0.20×10^1
1 h	3	–	–	–	–	–	–	–
	1	–	–	–	–	–	–	–
1 d	3	–	–	–	–	–	–	–
	1	–	–	–	–	–	–	–
2 d	3	–	+	–	–	–	–	–
	1	–	–	–	–	–	–	–
3 d	3	–	+	+	+	–	–	–
	1	–	+	+	+	–	–	–
4 d	3	–	+[d]	+	+	+	–	–
	1	–	+[d]	+	+	+	–	–

[a] 1-cm segments of leaves. [b] Based on 2 replications. + and – = positive and negative diagnosis. [c] Leaves were clip-inoculated with water. [d] Water-soaked lesions were visible.

Table 2. Comparison of detection methods for *Xanthomonas campestris* pv. *oryzae* in leaves collected in field and greenhouse. IRRI, 1988.

Detection method	Presence or absence of disease in indicated sample[a]																								Accuracy of detection (%)
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
Visual score[b]	+	+	+	±	−	+	+	+	+	−	+	±	±	+	+	+	+	±	±	+	+	+	+	+	+	44
Indirect ELISA[c]	−	+	+	−	−	+	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	+	+	−	100
Direct isolation	−	+	+	−	−	+	+	+	+	−	+	−	−	−	−	−	−	−	−	−	−	−	+	+	−	100

[a] + and − mean positive and negative diagnosis, ± means uncertain. [b] Monoclonal antibody Xco-2 was used. [c] Score was based on data from 4 observers.



3. Dendrogram of 17 selected RFLP-types of *Xanthomonas campestris* pv. *oryzae* races in the Philippines. Five clusters of isolates are observed at 80% similarity level.

may be widespread but unrecognized. A project was begun in 1988 to determine if *Pythium* spp. can be isolated from rice roots and if these fungi are pathogenic to rice.

Soil samples were collected from 109 fields (mostly from Central Luzon). Rice seedlings were grown in each sample for 21 d before roots were sampled and plated on a selective medium. *Pythium* spp. were recovered from 65% of the samples.

Greenhouse pathogenicity tests were conducted throughout the year. *Pythium* spp. were grown on cornmeal-sand medium for 2 wk. The inoculum was blended (1:3 vol/vol) with steamed soil, and rice seeds previously soaked in water were sown after 3 d. Uninfested cornmeal-sand medium and autoclaved inoculum served as control treatments. The plants were maintained in the greenhouse under flooded conditions. The length and fresh weight of shoots and roots were recorded 3 wk after seeding. Root colonization by *Pythium* spp. was monitored by plating root segments on the selective medium. A plant was considered infected if any root segments yielded *Pythium*.

Tests during the cooler months of December-January generally gave better results. Some isolates such as B22-4 were pathogenic (Table 3).

Table 3. Effects of 2 *Pythium* isolates on root and shoot growth and percentage root infection of IR52 grown in flooded soil in a greenhouse.[a] IRRI, 1988.

Treatment[b]	Length (cm)		Weight (g)		Root infection (%)
	Root	Shoot	Root	Shoot	
Raw soil	16.3	53.9	2.4	6.6	12.5
Check A	13.5	53.1	3.1	9.3	0.0
Check B	12.8	54.1	3.1	8.6	0.0
N55-1	11.9	53.8	3.5	10.2	68.9
B22-4	9.4	47.0	1.1	3.6	99.3
LSD (0.05)	2.1	3.0	0.6	1.8	16.8

[a]Means of 4 replications. [b]Check A = steamed soil amended with cornmeal-sand substrate; check B = steamed soil amended with autoclaved inoculum grown on cornmeal-sand substrate; isolates were grown on cornmeal-sand before being used to amend soil.

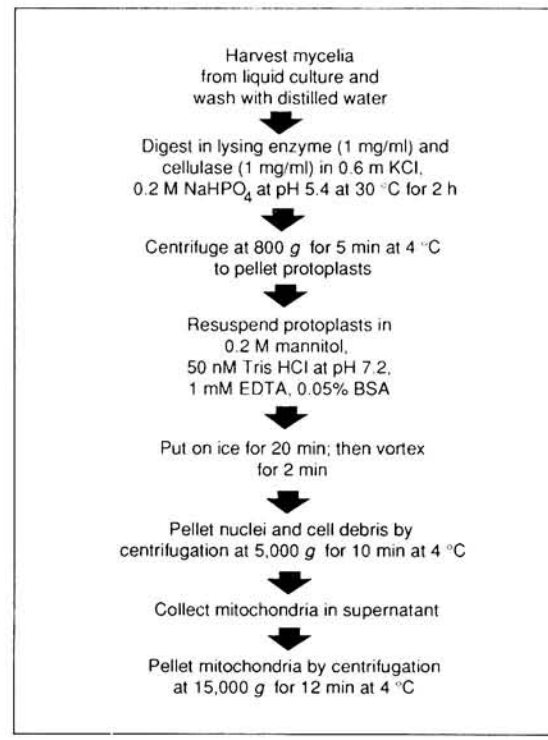
Other isolates such as N55-1 did not reduce plant growth even though root infection occurred (Table 3).

The results indicate that *Pythium* spp. are associated with rice roots under tropical conditions and that some isolates are pathogenic. Future work will seek to identify the species of *Pythium* present and more precisely assess their pathogenicity.

Genetic relationships among blast fungus isolates from different hosts (*Plant Pathology and University of Wisconsin*). Molecular techniques and pathogen-diagnostic probes enable us to examine epidemiological aspects of rice pathogens that were previously not amenable to analysis. Our objective is to understand the genetic diversity and population structure of pathogens to provide the basis for implementing an effective disease management strategy.

One unresolved problem in blast (Bl) epidemiology is whether *Pyricularia* populations on a variety of weed hosts are important sources of inocula for rice Bl epidemics. The practical questions are whether weed-infecting populations can cross-infect rice in the field and whether timely control of certain weed species surrounding ricefields is useful in reducing the epidemic potential. Previous studies on the relationship between weed and rice isolates were based primarily on pathogenicity tests. In most cases, weed isolates did not infect rice under artificial inoculation conditions. However, the pathogen population tested was small compared with the natural inocula in the field; hence it is unclear whether weed pathogens constitute a source of genetic variability for the pathogen population on rice.

We applied RFLP analysis to determine the genetic relationship between isolates from rice and weeds. The Bl fungus was collected from rice and surrounding weeds at upland and lowland sites. A differential centrifugation technique was developed for rapid isolation of mtDNA from a large number of samples (Fig. 4). With this technique, mtDNA was isolated from mitochondria after the separation of the organelles from nuclei, thus alleviating the need for isopycnic ultracentrifugation that is commonly used for mtDNA purification; mtDNA's were digested with restriction enzymes and analyzed by gel electrophoresis. Of 18 isolates from weeds and 12 isolates from rice examined, 4 mtDNA types were identified with 3 restriction enzymes (EcoRI, PstI, and HindIII) (Table 4). Most of the weed iso-



4. Isolation of mitochondria from *Pyricularia oryzae*. IRRI, 1988.

Table 4. Mitochondrial DNA restriction patterns of *Pyricularia oryzae* isolates collected from weeds and rice in different locations in the Philippines. IRRI, 1988.

Location	Isolate	Host	mtDNA restriction patterns based on 3 endonucleases			Unique mtDNA type
			EcoRI	HindIII	PstI	
Los Baños, Laguna	Dc275	*Digitaria ciliaris*	A	D	G	1
	Pd413	*Paspalum distichum*	B	E	H	2
	R515	*Oryza sativa*	B	E	H	2
	R518	*O. sativa*	B	E	H	2
	R522	*O. sativa*	B	E	H	2
	R525	*O. sativa*	B	E	H	2
	Ec4443	*Echinochloa colona*	B	E	H	2
	Ei448	*Eleusine indica*	B	E	H	2
Caliraya, Laguna	R476	*O. sativa*	B	E	H	2
	Dc466	*D. ciliaris*	A	D	G	1
Cabanatuan, Nueva Ecija	Lh504	*Leersia hexandra*	B	E	H	2
	R107	*O. sativa*	B	E	H	2
	Pr501	*Panicum repens*	B	E	H	2
	Pd24	*Paspalum distichum*	B	E	H	2
	Pd335	*P. distichum*	B	F	H	3
Santo Tomas, Batangas	Dc356	*D. ciliaris*	A	D	G	1
	Dc420	*D. ciliaris*	A	D	G	1
	Ei365	*E. indica*	B	E	H	2
	Ei424	*E. indica*	B	E	H	2
	R374	*O. sativa*	B	E	H	2
	R377	*O. sativa*	B	E	H	2
	R380	*O. sativa*	B	E	H	2
	Cr383	*Cyperus rotundus*	C	F	–	4
Tanauan, Batangas	Dc428	*D. ciliaris*	A	D	G	1
	R431	*O. sativa*	B	E	H	2
	Ei435	*E. indica*	B	E	H	2

lates had the same mtDNA type as the rice isolates, suggesting a common mitochondrial genome in the *Pyricularia* population. However, five isolates from *Digitaria ciliaris*, one from *Paspalum distichum*, and one from *Cyperus rotundus* had unique mtDNA patterns.

In collaboration with the University of Wisconsin, we obtained DNA probes as nuclear markers for the *Pyricularia* genome. Plasmid libraries of *P. oryzae* were constructed by ligation of restricted enzyme-digested fragments of *Pyricularia* genomic DNA into the pUC13 vector. Repetitive DNA probes were found to hybridize differentially with different *Pyricularia* isolates, both in number and intensity of hybridizing bands. Rice isolates showed large numbers of polymorphic, strongly hybridizing bands, whereas the weed isolates showed less hybridizing bands with weaker homology to the repeated sequences tested. With the available mtDNA and nuclear DNA markers, we are determining whether there is gene flow between weed and rice isolates at selected sites.

Analysis of blast effects on rice growth and yield (*Plant Pathology*). Three lowland field experiments were conducted from May 1987 to November 1988 to assess the effects of Bl on rice growth and yield. Eleven-day-old IR50 dapog seedlings were transplanted in 30 plots (4 × 8 m) in a randomized complete block design (RCBD) without replication. Each plot was separated from the others by 2-m alleys. One week after transplanting (WT), Bl epidemics were manipulated by covering some of the plots with plastic sheets at night, applying different amounts of inoculum in the form of chopped Bl-infected leaves, timing of inoculation, and spraying tricyclazole (3 g formulated product/16 liters water). Combinations of 5 leaf Bl severity levels and 5 panicle Bl incidence levels serving as treatments were randomly

assigned on 25 plots. The five other plots were replications of control (Bl-free) and other disease levels. Starting at 1 wk after the first inoculation, 24 mother tillers were sampled from each plot at weekly intervals until harvest. From those tillers, the lesion number per tiller, lesion size (length × width of 100 lesions, in mm^2), leaf area (cm^2), plant height (cm), and biomass of leaves, stems, and panicles were determined. At harvest, the panicle Bl severity score of each plot was determined, using a 0-5 scale (Table 5).

In the first trial, 3 sampling patterns for assessing panicle Bl were compared: 1) every other hill (70 hills), 2) zigzag pattern (24 hills), 3) four 2 × 2 hills (16 hills). Likewise, the effects of panicle Bl severity on yield components—number of effective tillers/hill (NoET), number of filled grains/panicle (NoFG), percentage of unfilled grains (%UG), 1,000-grain weight (1,000GW)—were determined from 800 panicles of each scale category. Grain yield (t/ha) was determined from the 6-m^2 center of each plot. Yield components were determined, and yield loss percentage was computed based on control plots. Blast severity (%) at each reading date was computed as [lesion number x (lesion size/100)/ leaf area] × 100. The area under the disease progress curve (ADPC) for each plot was computed using the formula:

$$ADPC = [(X_{i+1} + X_{i+n})/2]\,(t_{i+1} - t_{i+n})$$

where

x_i = proportion of tissue affected at the ith observation,

t_i = ith observation in time "t",

n = total number of observations.

Trial 1. Using the combinations of the different methods mentioned, varying leaf Bl severities—0 to 10%—were obtained. The maximum severity was obtained at 30 d after transplanting (DT). Weekly spraying of tricyclazole proved effective in controlling both leaf Bl and panicle Bl. This is evident from sprayed plots, which were almost completely free from Bl. An increase in panicle Bl severity resulted in an increase in %UG, a decrease in NoFG, and a decrease in 1,000GW (Table 6). The effects of Bl were felt starting from a score of 2 but were more obvious at a score of 3 or higher. The yield losses obtained were 0, 0-10, 13-19, 23-27, 50-54, and 78-79%, for scores of 0, 1, 2, 3, 4, and 5, respectively. Statistical analysis of three sampling patterns for panicle Bl scoring showed no significant difference. This suggests that a lot of time can be saved by scoring only 16 or 24 hills of predetermined patterns. Panicle Bl incidence (score 2-5) among plots ranged from 0 to 38.5%. The highest yield loss was 53.8%, recorded on the plot with leaf Bl severity of 8.1% at 38 DT and with 33.8% panicle Bl incidence. Correlation analysis showed that yield loss (%) was positively correlated with lesion no./tiller ($r = 0.56^{**}$), diseased leaf area (DLA, %) ($r = 0.61^{**}$), panicle Bl incidence ($r = 0.58^{**}$), NoET ($r = 0.56^{**}$), %UG ($r = 0.51^{**}$), and ADPC ($r = 0.50^{**}$); and was negatively cor-

Table 5. Scale for panicle blast (Bl) severity assessment. IRRI, 1988.

Score	Description
0	No symptom
1	Lesion(s) found only on tertiary branches; visually, unfilled grains are <10%
2	Lesion(s) found on secondary and tertiary branches; visually, unfilled grains are about 25%
3	Lesion(s) found on panicle neck node; visually, unfilled grains are about 50%
4	Same as scale 3; visually, unfilled grains are about 75%
5	Same as scale 3; visually, unfilled grains are >90%

Table 6. Effects of panicle Bl severity on yield components and percent yield loss. IRRI, 1988.

Panicle Bl severity scale	Unfilled grains (%)	Filled grains (no./panicle)	1,000-grain weight (g)	Yield loss (%)
0	23-30	57-72	18-20	–
1	33-35	75-79	17-21	0-10
2	30-49	59-64	14-19	13-19
3	34-35	58-60	14-17	24-28
4	51-53	39-40	13-16	51-54
5	61-75	14-18	12-13	78-80

related with yield (r =1.0**), plant height (r = -0.71**), NoFG (r = -0.70), 1,000GW (r = -0.51**), and panicle biomass at harvest (r = -0.45*). Leaf (r = -0.36ns) and stem (r = -0.35ns) biomass at harvest were not significantly correlated with yield loss. With a stepwise regression technique, percentage yield loss (Y) can be estimated by the equation

$$Y = 0.2101 + 1.0124X2 + 0.5102X3 \ (R = 0.80)$$

$X2$ = percent diseased leaf area (% DLA max), and

$X3$ = percent panicle Bl incidence.

Trial 2. Leaf Bl severity ranged from 0 to 8.3%, obtained at maximum tillering. Panicle Bl incidence was generally higher than in the first trial (0 to 90.3%). The highest yield loss (72.9%) was obtained on a plot with leaf Bl severity of 1.7% and panicle Bl incidence of 90.3%. Yield loss (%) was positively correlated with panicle Bl incidence (r = 0.83**), %UG (r = 0.71**), leaf biomass at harvest (r = 0.46**); and negatively correlated with yield (r = -0.99**), plant height (r = -0.56**), NoFG (r = -0.59**), %GW (r = -0.67**), and panicle biomass at harvest (r = -0.57**). Percentage yield loss was surprisingly not correlated with either lesion number/tiller, % DLA, ADPC, or stem biomass at harvest, probably because of lower leaf Bl levels in this trial. Stepwise regression for yield loss predictors arrived at the equation

$$Y = 13.2983 + 1.7717X2 + 0.4683X3 \ (R = 0.73)$$

Trial 3. More favorable conditions for Bl development in trial 3 promoted higher disease levels than in the first two trials. The leaf Bl severity ranged from 0 to 16.9%. The panicle Bl percentage incidence ranged from 0 to 98.0%. The highest yield loss (70.4%) was obtained in a plot with 11.5% DLA and 98.0% panicle Bl incidence. Yield loss (%) was positively correlated with lesion number/tiller (r = 0.77**), % DLA (r = 0.79**), panicle Bl (r = 0.92**), %UG (r = 0.80**), and ADPC (r = 0.84**); and negatively correlated with yield (r = -0.99**), plant height (r = -0.91**), NoFG (r = -0.90**), 1,000GW (r = -0.63**), leaf biomass (r = -0.48**), stem biomass (r = -0.76**), and panicle biomass (r = -0.90**). NoET was not correlated with yield loss. In this trial, the percent yield loss could be estimated by the equation

$$Y = -13.0959 + 1.6118X2 + 0.6767X3 \ (R = 0.88)$$

When results of the three trials were combined (Table 7), a single predictive equation

Table 7. Relationships among leaf Bl severity, panicle Bl incidence, and yield loss. IRRI, 1988.

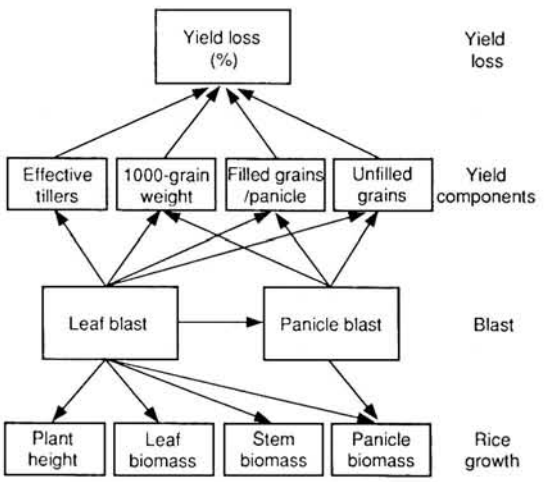
Leaf Bl severity (%)	Yield loss (%)																				
	Panicle Bl incidence (%)																				
	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
0	0	3	6	15	22	32	23		21		9		11		25		60				
1	0	9	15	22		21	17	28	15	16			59	44		48	52		73		
2		10				20	19		25						42						
3		26				27	21	21	27		27			30	42						
4			22																		
5			19	17					28						46		37				
6			32	19											35	61			64		
7		11												38				43	66		
8								54						40	28		49			67	
9					29										60		47		62		
10		20														59				70	
11																					
12																					
13																					
14																					
15																	67				

that could explain 75% of the variation in yield loss was derived:

$$\hat{Y} = 5.7909 + 1.3854X2 + 0.4740X3 \ (R^2 = 0.75)$$

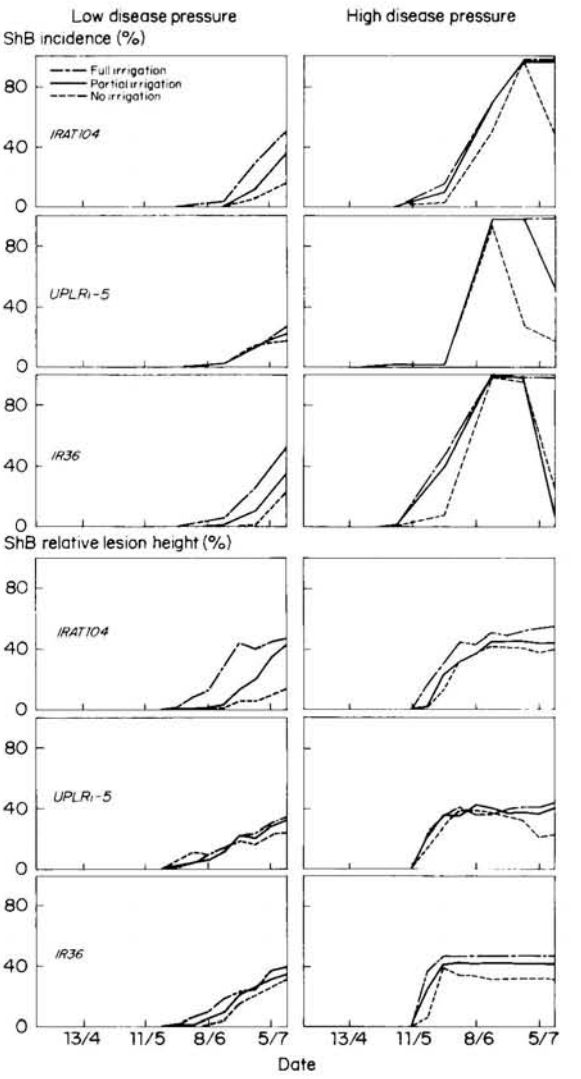
Path coefficient analysis of the effects of blast on rice growth, yield components, and yield loss. Figure 5 shows the possible path of influence of Bl on rice growth–plant height, leaf, stem, and panicle biomass–yield components, and yield loss. Path coefficient analysis showed that leaf Bl had a relatively stronger negative effect on plant height than on leaf, stem, and panicle biomass. Panicle Bl, on the other hand, had a stronger effect on panicle biomass than did leaf Bl. Among the yield components, NoFG and 1,000GW were the two most affected by leaf Bl. %UG was more affected by panicle Bl than by leaf Bl. NoFG had the highest negative effect on yield loss in the first trial, while %UG had the highest direct effect on yield loss during the second and third trials.

Relationship of rice plant growth to sheath blight severity (*Plant Pathology*). To relate the growth of rice plants to sheath blight (ShB) severity, cultivars IRAT104, UPLRi-5, and IR36 were planted under upland conditions at three irrigation levels (full, partial, and no irrigation) and two disease pressure levels (inoculated or high ShB pressure, and uninoculated or low ShB pressure).

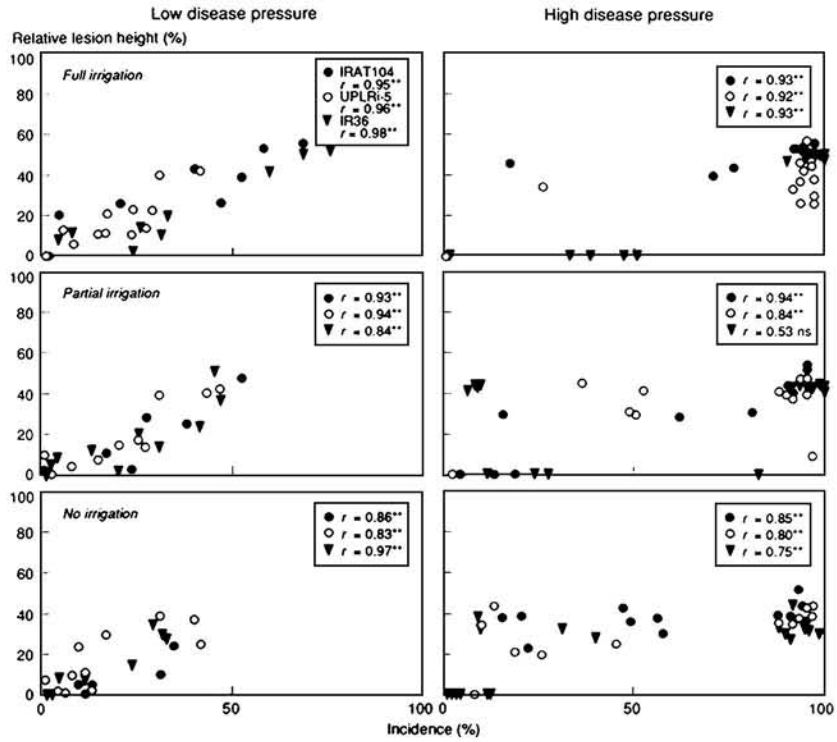


5. Path of influence of blast on rice growth, yield components, and yield loss. IRRI, 1988.

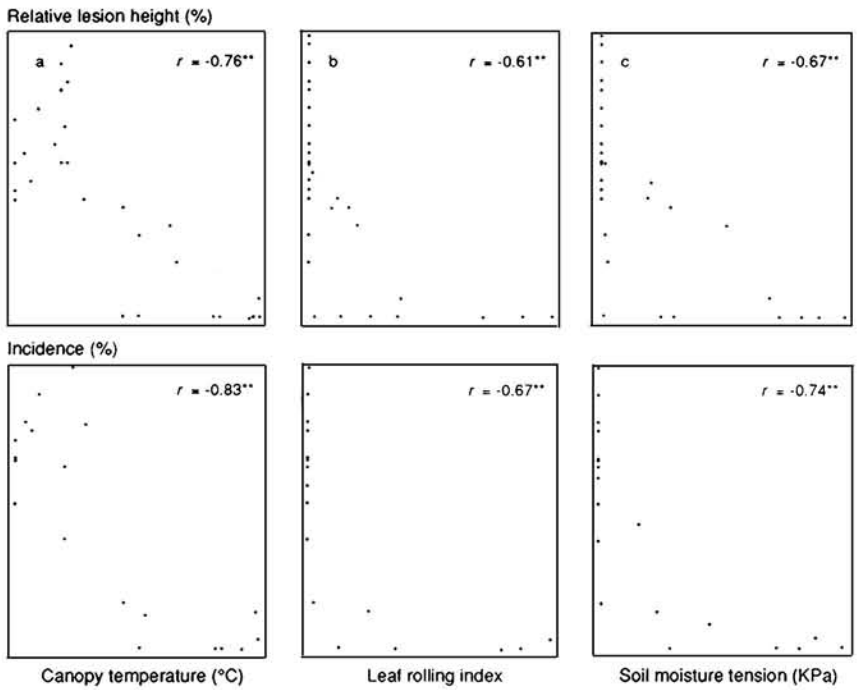
ShB level and development were significantly reduced in water-stressed plants under both high and low ShB pressure in all cultivars (Fig. 6). ShB relative lesion height was also highly correlated with ShB incidence under all of the above conditions (Fig. 7). Water-stressed rice plants, characterized by high soil moisture tension and high leaf rolling index, were likely to produce canopy temperature higher than the optimum temperature (30 °C) for ShB infection and development (Fig. 8). Moreover, water-stressed plants produced lower canopy density, which did not



6. Sheath blight (ShB) development in 3 rice cultivars grown under different conditions and disease pressures. IRRI, 1988.



7. Relationship between relative lesion height and ShB incidence in 3 rice cultivars grown under different conditions and disease pressures. IRRI, 1988.



8. Relationship between relative lesion height and ShB incidence, and canopy temperature, leaf rolling index, and soil moisture tension (all 3 varieties combined). IRRI, 1988.

Table 8. Possible occurrence of rice tungro bacilliform virus (RTBV) and rice tungro spherical virus (RTSV) in 8 weed species collected from 6 areas in different provinces in the Philippines.[a] IRRI, 1988.

Item	*Eleusine indica*	*Echinochloa crus-galli*	*E. glabrescens*	*E. colona*	*Leptochloa chinensis*	*Leersia hexandra*	*Panicum repens*	*Cyperus rotundus*	Total
				Lowland fields without tungro					
Plants tested (no.)	48	72	156	144	96	192	96	96	900
Plants (no.) giving positive ELISA to									
RTBV+RTSV	1	0	2	0	1	1	1	2	8
RTBV	0	0	4	2	1	8	2	1	18
RTSV	0	5	0	3	1	13	1	8	31
				Previously tungro-infected lowland ricefields[b]					
Plants tested (no.)	72	120	72	192	72	144	120	144	936
Plants (no.) giving positive ELISA to									
RTBV+RTSV	0	0	0	1	0	0	0	1	2
RTSV	0	0	0	2	0	0	0	0	2
				Lowland tungro-infected ricefields					
Plants tested (no.)	148	148	172	172	196	148	148	124	1256
Plants (no.) giving positive ELISA to									
RTBV+RTSV	0	0	1	2	0	0	0	0	3
RTBV	0	1	0	0	1	1	0	0	3
RTSV	0	1	3	6	3	5	4	0	22
				Lowland fallow fields					
Plants tested (no.)	24	24	48	72	36	24	48	72	348
Plants (no.) giving positive ELISA to									
RTBV+RTSV	0	0	1	1	0	0	0	1	3
RTBV	0	0	0	0	0	1	0	0	1
RTSV	2	0	0	0	0	2	0	0	4
				Upland ricefields					
Plants tested (no.)	132	72	132	132	96	24	48	96	732
Plants (no.) giving positive ELISA to									
RTBV+RTSV	3	2	3	4	0	0	1	0	13
RTBV	5	0	0	2	0	0	0	2	9
RTSV	8	0	2	9	2	0	0	6	27
				Upland fallow fields					
Plants tested (no.)	240	48	132	168	24	192	72	60	936
Plants (no.) giving positive ELISA to									
RTBV+RTSV	0	0	0	2	0	2	3	0	7
RTBV	0	0	0	3	0	0	1	0	4
RTSV	0	0	0	3	0	0	1	0	4

[a]Samples were indexed by ELISA. [b]No sample gave positive ELISA to RTBV.

create a microclimate favorable for ShB development. Therefore, ShB incidence and severity were lower in water-stressed plants.

Occurrence of rice tungro virus and grassy stunt virus in weeds (*Plant Pathology and Agronomy*). From April 1987 to June 1988, eight potential weed hosts were collected in fields under different agroclimatic conditions in the Philippines. Leaf samples were tested by ELISA for the presence of rice tungro bacilliform (RTBV) and spherical (RTSV) viruses. Healthy weed plants served as controls. Absorbance in ELISA of weed extracts greater than the mean of healthy extracts plus five times the standard deviation was considered positive.

Plants of all the weeds tested gave positive reactions to RTSV and/or RTBV. The percentage of plants that gave positive ELISA to RTSV and/or RTBV differed, depending on the weed species and the agroclimatic conditions of the fields where the weed samples were collected (Table 8). These results indicate occurrence of RTBV and RTSV in weeds not only in ricefields but also in fallow fields. Further tests to confirm the presence of the viruses in weed plants are required.

Nine weeds and rice plants were randomly collected in lowland and upland fields. At each location, about 100 leaf samples were collected for each plant species including rice. For annual weeds, collection was made at flowering. Extracts of leaf samples were tested by ELISA for the presence of grassy stunt virus (GSV). Plants grown from seeds of annual plants and kept in insect-proof cages served as healthy controls. Perennial weed species such as *Cyperus rotundus, Leersia hexandra*, and *Panicum repens* were collected from areas where rice is not grown. Leaves from these plants were indexed by ELISA, and plants with low absorbance value were selected and kept in insect-proof cages as healthy controls. Absorbance in ELISA from weed extracts with greater than the mean of healthy extracts plus five times the standard deviation was considered positive. Extracts of leaf samples from all the species gave positive ELISA results (Table 9). The percentage of plants that gave positive ELISA results was high when samples were collected from lowland fields. When samples were collected from upland fields, only *C. rotundus* gave positive ELISA.

Table 9. Possible occurrence of grassy stunt virus in 9 weeds and rice collected in lowland and upland fields in the Philippines. IRRI, 1988.

Host	Lowland		Upland	
	Plants tested (no.)	Plants (no.) with positive ELISA	Plants tested (no.)	Plants (no.) with positive ELISA
Cyperus rotundus	574	79	110	11
Echinochloa colona	288	9	18	0
E. crus-galli	78	1	[a]	–
Eleusine indica	380	17	36	0
Fimbristylis miliacea	368	56	20	0
Leptochloa chinensis	40	2	[a]	–
Leersia hexandra	294	27	[a]	–
Monochoria vaginalis	276	29	[a]	–
Panicum repens	268	20	20	0
Rice	180	6	20	0

[a] No samples collected.

Orange leaf symptoms on rice (*Plant Pathology*). We tested eight rice varieties for reaction to orange leaf disease. Third- or 4th-instar nymphs of *Recilia dorsalis* free of the orange leaf agent were allowed to feed on source plants for 2-3 d. Individual leafhoppers were used for serial daily inoculation feedings on 7- to 10-d-old seedlings in test tubes. Inoculated plants were grown in pots.

Symptoms appeared in IR36, IR50, and FK135 at 14-20 DAI. Symptoms included the orange discoloration and inward leaf rolling typical of orange leaf disease. Infected plants died at 35-48 DAI.

Infected IR8, IR20, and TN1 plants developed deformed leaves with chlorotic and serrated edges and twisted leaf tips at 8-12 DAI. These symptoms are similar to those observed in rice plants infected with ragged stunt virus (RSV). At 14-20 DAI, the tips of the second and third youngest leaves turned orange. Later, entire leaves became discolored and rolled inward; they eventually wilted. In TN1, about 90% of infected plants developed ragged leaves. Infected plants without ragged leaves died about 7 wk after inoculation

(WAI), but those with ragged leaves died about 10 WAI.

Plants of japonica varieties Reiho and Fukumasari showed stunting, yellow discoloration, rusty spots on leaves, and wider leaf angle at 15-24 DAI. The symptoms were similar to those caused by rice GSV. Plants died at 26-60 DAI.

IR20, IR50, and TN1 had higher infection rates than did IR8, IR36, and FK135 (Table 10). None of the plants that showed symptoms after inoculation reacted with antisera to rice RSV, GSV, RTBV, or RTSV in the latex test or ELISA.

Variation in symptoms and transmission of rice grassy stunt virus 2 (*Plant Pathology*). TN1 rice plants infected with GSV 2 show extreme variability in symptoms, ranging from very severe to very mild. Three symptom types designated as GSe (severe stunting and yellowing, reduced tillering, premature death), GMo (moderate stunting and yellowing, profuse tillering, spreading growth habit), and GMi (mild stunting and yellowing, slightly profuse tillering, erect growth habit) were selected on TN1 seedlings through cycles of transfers by brown planthopper *Nilaparvata lugens* (BPH). After about 15 cycles of continuous selection for each symptom type, their ability to serve as the virus source for transmission by BPH was compared.

Second-instar BPH nymphs that were given 4 d access to plants infected with each symptom type were used to inoculate TN1 seedlings either in test tubes or in mass inoculation. GMo gave the highest transmission rate, GSe gave very low transmission rates, and GMi was almost nontransmissible (Table 11). Plants inoculated with GSe and GMi showed the symptoms typical of GSe and GMi, respectively. However, plants inoculated with GMo always showed symptoms of the three types. Many BPH that had fed on GMo-infected plants contained the virus antigen, while none or a few BPH fed on GMi- or GSe-infected plants contained the virus antigen. These results indicate that most BPH failed to acquire GMi and GSe. GMo can be used for effective screening for GSV resistance.

Table 10. Reactions of 8 rice varieties to orange leaf. IRRI, 1988.

Variety	Plants inoculated (no.)	Plants infected (%)	Symptoms[a]
FK135	38	29	Od, Lr
IR36	38	26	Od, Lr, Wl
IR50	40	48	Od, Lr
IR8	39	26	Od, Lr, Rl
IR20	35	60	Od, Lr, Rl
TN1	40	55	Od, Lr, Rl
Reiho	37	38	Yd, Lr, Wl
Fukumasari	35	43	Yd, Lr, Wl

[a]Od = orange discoloration, Lr = leaf rolling, Wl = wrinkled leaves, Rl = ragged leaves, Yd = yellow discoloration.

VECTOR RELATIONS

Plant Pathology Department

Tungro and green leafhopper development in fields. We studied tungro (RTV) development and vector density fluctuation in one ricefield each in Santo Tomas and Tanauan, Batangas, and in Liliw and Mabitac, Laguna, all in the Philippines. In Santo Tomas and Tanauan, the ricefields are under upland rainfed conditions, with one rice crop during June-November. In Liliw and Mabitac, the fields are irrigated, and rice is planted almost continuously throughout the year. The planting pattern is generally uniform in Liliw and staggered in Mabitac.

For serological indexing for RTBV and RTSV, leaf samples were randomly collected at 2-wk intervals starting from 2 WT to the ratoon stage. The density of *Nephotettix virescens, N. nigropic-*

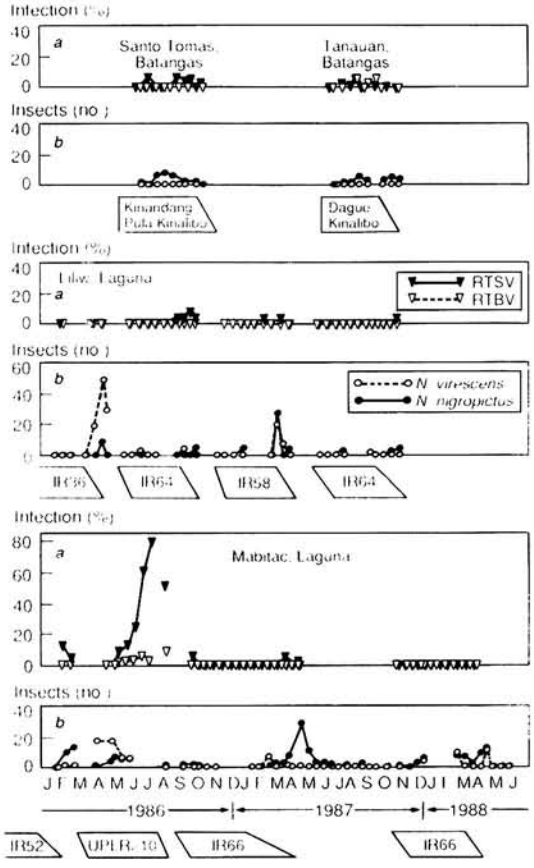
Table 11. Virus infectivity in rice and virus infection rates of brown planthopper (BPH) that had fed on plants infected with either of 3 symptomatic strains of grassy stunt virus. IRRI, 1988.

Symptom type	Infective BPH[a] (no.)	BPH (no.)		Seedlings (no.)	
		Tested[b]	Infected	Inoculated[c]	Infected
Severe	4	240	1	384	13
Moderate	63	180	45	300	234
Mild	0	240	0	414	4

[a]For each symptom type, 360 insects were tested. Six days after the acquisition access, each BPH was given daily serial inoculation access feeding for 12 d on a TN1 seedling in a test tube. [b]BPH was individually tested by ELISA for the presence of the virus. [c]BPH were confined with potted TN1 seedlings at a rate of 5-10/seedling in a cage.

tus, and *R. dorsalis* was assessed based on leafhopper number per 10 sweeps in seedbeds and main fields except during the reproductive phase.

In Batangas, virus incidence and vector density were low in 1986 and 1987 (Fig. 9). In 1986, RTBV incidence was 0.1% and RTSV was 2.2%. About 8% of the leafhopper catches were *N. virescens*, 63% *N. nigropictus*, and 29% *R. dorsalis*. In 1987, RTBV incidence was 1.6% and RTSV was 0.8%. About 88% of the leafhopper catches were *N. nigropictus* , and the rest were *R. dorsalis*.



9. Incidence of rice tungro bacilliform (RTBV) and spherical (RTSV) viruses (a) and vector leafhopper density (b) in Batangas and Laguna, Philippines, 1986-88.

In Liliw, RTSV incidence was very low and RTBV incidence was zero throughout the four crop seasons (Fig. 9). *N. virescens* density was high on ratoons in DS but generally low in WS. The density was especially high in 1986, when IR36 was planted. *N. nigropictus* density was generally low but higher on ratoons.

In Mabitac, most ricefields were fallow from April to October 1987 because of a shortage of irrigation water. In the 1986 first crop, UPLRi-10 was planted, and RTSV incidence was very high. In other seasons, leafhopper-resistant IR66 was planted, and virus incidence was very low. *N. virescens* density was high in the 1986 first crop but generally low in other seasons. *N. nigropictus* density was high on ratoons in the 1986 second crop.

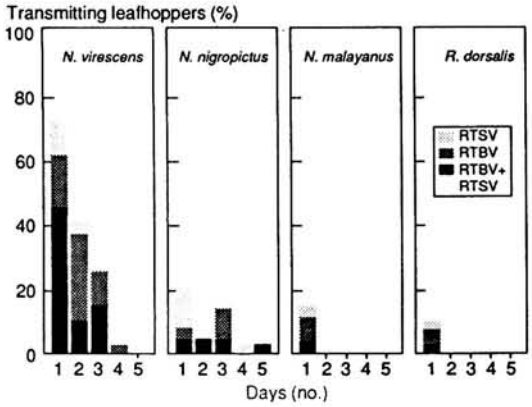
RTBV and RTSV occurred in upland fields, but there was no direct correlation between virus incidences and *N. virescens* density.

Rice tungro virus transmission by leafhoppers on rice and weeds. To study the role of leafhoppers other than green leafhopper (GLH) and of weeds on RTV epidemics, the transmission efficiency of four leafhoppers for RTBV and RTSV was examined. On rice, *N. virescens* was the most efficient vector of the viruses (Table 12) and retained them for 4 d. *N. nigropictus* was less efficient but retained them for 5 d. *N. malayanus* and *R. dorsalis* retained them for only 1 d (Fig. 10, 11).

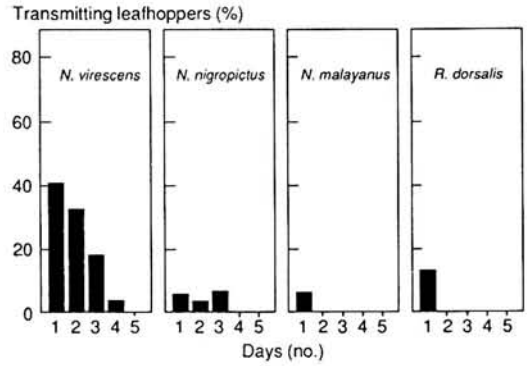
Table 12. Percentage of adult leafhoppers that transmitted RTBV and RTSV on TN1 seedlings in a 1-d inoculation access feeding after 1- or 2-d acquisition feeding on plants infected with RTBV+RTSV or RTSV alone. IRRI, 1988.

Leafhopper[a]	Leafhoppers (%) transmitting from RTBV+RTSV source			Leafhoppers (%) transmitting from RTSV source
	RTBV+RTSV	RTBV	RTSV	
Nephotettix virescens	45.8	18.1	9.7	63.6
N. nigropictus	4.2	4.2	12.5	6.2
N. malayanus	4.2	6.2	4.2	6.2
Recilia dorsalis	3.2	4.2	2.5	13.3

[a] For each species, 48 insects were tested.



10. Percent of adult leafhoppers that transmitted RTBV and RTSV in subsequent daily serial transfers for 5 d on TN1 seedlings after a 1-d acquisition access feeding on TN1 plants infected with RTBV+RTSV. IRRI, 1988.



11. Percent of adult leafhoppers that transmitted RTSV in subsequent daily serial transfers for 5 d after a 1-d acquisition feeding on RTSV-infected TN1 plants. IRRI,1988.

Young seedlings or rhizomes of *Eleusine indica, Echinochloa crus-galli, E. glabrescens, E. colona, Leptochloa chinensis, Leersia hexandra, P. repens,* and *C. rotundus* were infected with RTBV and/or RTSV when exposed to the four leafhoppers that had fed on RTBV + RTSV-infected plants (Table 13). These weeds were also infected with RTSV alone when exposed to the leafhoppers that had fed on RTSV-infected plants (Table 14). Only *N. nigropictus* was able to acquire the viruses on doubly infected plants of *E. crus-galli, P. repens,* and *C. rotundus* and transmitted them to rice seedlings (Table 15).

Table 13. Transmission of RTBV and RTSV on 8 weeds by 4 leafhoppers that fed on plants infected with RTBV and RTSV.[a] IRRI, 1988.

Weed and vector	Plants (no.) infected with[b]		
	RTBV+RTSV	RTBV	RTSV
Eleusine indica			
Nephotettix virescens	1	2	0
N. nigropictus	0	1	0
N. malayanus	0	2	0
Recilia dorsalis	0	0	0
Echinochloa crus-galli			
N. virescens	0	0	0
N. nigropictus	1	1	3
N. malayanus	0	0	0
R. dorsalis	0	0	0
E. glabrescens			
N. virescens	0	1	2
N. nigropictus	0	3	2
N. malayanus	7	0	3
R. dorsalis	0	1	0
E. colona			
N. virescens	0	0	0
N. nigropictus	1	3	1
N. malayanus	3	0	1
R. dorsalis	1	0	4
Leptochloa chinensis			
N. virescens	2	0	0
N. nigropictus	0	1	2
N. malayanus	1	0	1
R. dorsalis	0	1	0
Leersia hexandra			
N. virescens	1	0	0
N. nigropictus	0	0	0
N. malayanus	0	0	1
R. dorsalis	0	1	0
Panicum repens			
N. virescens	1	1	4
N. nigropictus	0	0	0
N. malayanus	4	0	4
R. dorsalis	0	0	0
Cyperus rotundus			
N. virescens	1	0	1
N. nigropictus	3	2	0
N. malayanus	0	0	0
R. dorsalis	0	0	0

[a] 12 plants were separately exposed to 10 leafhoppers in cages. [b] Plants were indexed by ELISA at 15, 30, and 45 DAI.

On rice, *N. virescens* fed mainly on the phloem and had high adult longevity, nymphal survival, and population growth (Fig. 12). On all weeds tested, *N. virescens* fed mainly on the xylem and had low adult longevity, nymphal survival, and population growth. This indicates a high level of biological affinity of *N. virescens* for rice. *N. nig-*

Table 14. Transmission of RTSV on 8 weeds by 4 leafhoppers that had fed on RTSV-infected plants.[a] IRRI, 1988.

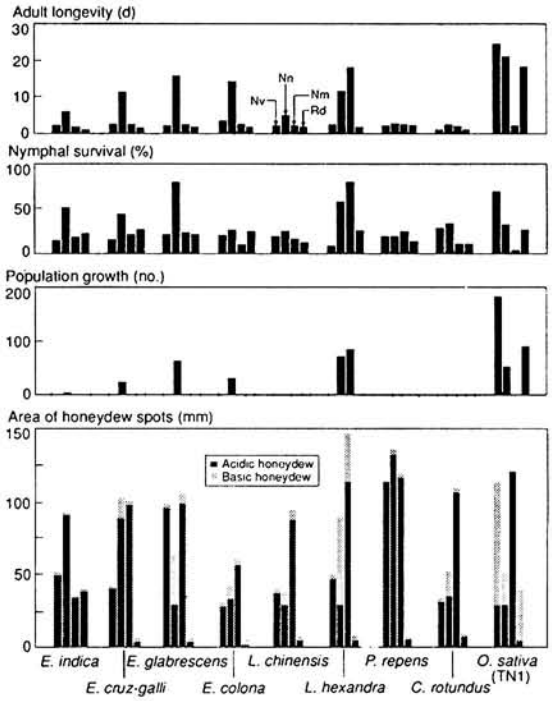
Weed species	Plants (no.) infected[a]	
	N. virescens	*N. nigropictus*
Eleusine indica	0	0
Echinochloa crus-galli	0	2
E. glabrescens	0	2
E. colona	0	2
Leptochloa chinensis	4	4
Leersia hexandra	0	0
Panicum repens	1	0
Cyperus rotundus	4	3

[a]12 plants were separately exposed to 10 leafhoppers in cages. [b]*N. malayanus* and *R. dorsalis* did not transmit RTSV.

Table 15. Tungro recovery on TN1 seedlings by *N. nigropictus* that had fed on 3 weed species infected with both viruses.[a] IRRI, 1988.

Weed species	Seedlings tested (no.)	Seedlings (no.) infected with[b]	
		RTBV+RTSV	RTSV
Cyperus rotundus	26	3	0
Echinochloa crus-galli	21	2	0
Panicum repens	16	1	3

[a]Each seedling was exposed to 5 leafhoppers that had fed on a source plant. [b]Seedlings were indexed by ELISA at 30 DAI. None showed RTBV symptoms.



12. Comparison of population characteristics of *N. virescens* (Nv), *N. nigropictus* (Nn), *N. malayanus* (Nm), and *R. dorsalis* (Rd) and their feeding on young seedlings or rhizomes of 8 weeds and 1 rice cultivar. IRRI, 1988.

ropictus had a high affinity for *E. crus-galli, E. glabrescens, E. colona, L. hexandra,* and *C. rotundus. N. malayanus* had a high affinity for *L. hexandra*, and *R. dorsalis* for rice. Among the leafhoppers, no correlation was observed between feeding site and transmission efficiency on any host. The low percentage of infection with RTBV and RTSV on weeds is probably due to their resistance to infection, not to their resistance to the leafhoppers.

Apparently, *N. nigropictus* can disperse RTBV and RTSV in weed hosts in fallow fields once the viruses are introduced from ricefields. Results of these experiments indicate that *N. virescens, N. nigropictus,* and *R. dorsalis* also have the potential to serve as carriers of RTBV and RTSV and disperse them from ricefields to fallow fields. Because the transmission efficiency of *N. nigropictus* for RTBV and RTSV is low, a large population is required to make their incidence high in weeds. Similarly, *N. malayanus* may be a potential vector to spread RTBV and RTSV in *L. hexandra*. The *N. nigropictus* population is generally high in fallow fields, and the *N. malayanus* population is high in *L. hexandra*-inhabited fields.

SEED PATHOLOGY

Plant Pathology Department

Effects of inoculation on sheath rot development in the field. The ShR pathogen *Sarocladium oryzae* is a common seedborne fungus. The importance of seedborne inoculum and seedling infection to ShR development in the field is not well understood. A field experiment during 1988 WS examined the effects of seedling inoculation on disease development.

Seed of IR29725-22-3-3-3 was treated with hot water to remove natural inoculum. After hot-water treatment, less than 1% infection was detected by the blotter test method. Pretransplanting and posttransplanting inoculation treatments and an uninoculated check were tested. In pretransplanting inoculations, seedlings were inoculated 10 DAS with rice grains colonized by *S. oryzae*. In posttransplanting inoculations, field plots were inoculated 4 times with 125 g of colonized grain/m^2, beginning at 25 DAS.

The presence of *S. oryzae* on leaf sheaths and culms was assayed from transplanting until harvest by examining incubated tissues for signs of the fungus. Seedlings inoculated at 10 DAS tended to show a higher incidence of *S. oryzae* infection compared with the other treatments. However, the differences were not statistically significant.

At harvest, disease incidence and severity, percentage of *S. oryzae* infection on flag leaf sheaths, and grain yield were recorded. Inoculated treatments showed significantly higher disease incidence and severity than the check treatment (Table 16). However, the ShR pathogen was commonly found in the uninoculated check plots, indicating that natural sources of inoculum were present.

Grain yield was not significantly affected, nor did the *S. oryzae* infection on flag leaf sheaths differ between treatments. There were also no significant differences in grain discoloration severity or in incidence of *S. oryzae* and fluorescent *Pseudomonas* infection on seed.

Results indicate that seedling infection may affect disease incidence at maturity.

Table 16. ShR incidence and severity at ripening of IR29725-22-3-3-3 inoculated during the vegetative phase.[a] IRRI, 1988 WS.

Treatment	Disease incidence (%)[b]	Disease severity index
Inoculated 10 DAS	72.8 a	16.7 a
Inoculated beginning 25 d after transplanting	69.5 a	14.9 a
Uninoculated	53.3 b	10.1 b

[a] In a column, means followed by a common letter are not significantly different at the 5% level by LSD test. [b] Incidence of symptoms on tillers from 20 hills/plot.

TECHNIQUES/METHODS

Plant Pathology Department

Improved method for rice tungro spherical virus purification. We describe the improved method of purifying RTSV without using organic solvent and driselase:

Infected TN1 plants at 45-60 d
  Harvest whole plants except roots
  Homogenize in 3 volumes of 0.01 M EDTA, pH 8.4
  Filter through cheesecloth
Filtrate
  Stir at room temperature for 2 h
  Incubate in water bath at 40 °C for 2 h
  15,000 g for 10 min
Supernatant
  Add PEG-8000 to 7%, NaCl to 0.2 M, and Triton X-100 to 1%
  Stir at room temperature for 1 h
  30,000 g for 30 min
Pellet
  Resuspend in 20 ml 0.01 M EDTA, pH 8.4
  11,000 g for 10 min
Supernatant
  100,000 g for 60 min
Pellet
  Resuspend in 2 ml 0.01 M phosphate buffer, pH 7.2
  11,000 g for 10 min
Supernatant
  Layer on 10-50% linear sucrose density gradient in phosphate buffer
  25,000 rpm for 2 h
  Collect a virus zone (about 3 cm below the meniscus)
  Dilute with 0.01 phosphate buffer
  130,000 g for 1 h
Pellet
  Resuspend in 2 ml 0.01 phosphate buffer
  11,000 g for 10 min
Supernatant (virus preparation)

The procedure takes 1.5 d. From 500 g infected plants without roots, current methods yielded 1 ml of purified preparation with absorbance at 260 nm ranging from 1.0 to 2.8. With 300 g materials, the modified method yielded 1 ml, with absorbance ranging from 13 to 20. The

ratio of absorbance at 260 nm and at 280 nm of the purified virus ranged from 1.70 to 1.75.

Purified preparations were injected into rabbits, and antiserum was obtained with a titer of 1/1280 in the ring interface precipitin test.

We also attempted to improve the purification method for RTBV. Without using driselase and organic solvent, the virus yield was not significantly improved. The rabbit antiserum to RTBV had a titer of 1/640. The antisera did not cross-react and did not react with healthy rice extracts in ELISA or the latex test.

Biotin-avidin ELISA for sensitive serological detection of rice tungro-associated viruses. Sensitive and reliable immunoassay for rice tungro-associated viruses is very important for routine screening for resistance and in epidemiological studies. Among the immunoassay techniques developed for rice, the double antibody sandwich ELISA (DAS-ELISA) is one of the most sensitive. However, the sensitivity of DAS-ELISA is limited by low titer of the antiserum or low virus concentration in the plant, as in the case of RTBV and RTSV. To overcome this limitation, the biotin-avidin ELISA (BA-ELISA) was applied and the sensitivity was compared with that of DAS-ELISA.

After several preliminary tests, a standard protocol for BA-ELISA was followed:

Biotin-avidin ELISA procedure for detection of RTBV and RTSV

- Coat wells (150 μl/well) with specific immunoglobulin (IgG) (1 μg/ml). Incubate at 37 °C for 3 h (or 4 °C overnight). Wash 3 times with phosphate-buffered saline with 0.1% Tween 20.
- Add plant sap (150 μl/well). Incubate at 37 °C for 3 h. Wash as above.
- Add biotin-labeled specific IgG (1 μl/ml; 150 μl/well). Incubate and wash as above.
- Add avidin-alkaline phosphatase-labeled (4000X dilution, 150 μl/ml). Incubate and wash as above.
- Add substrate (ρ-nitrophenyl phosphate, 1 mg/ml; 150 μl/well) in 10% diethanolamine (pH 9.8). Incubate for 30 min at room temperature. Read absorbance.

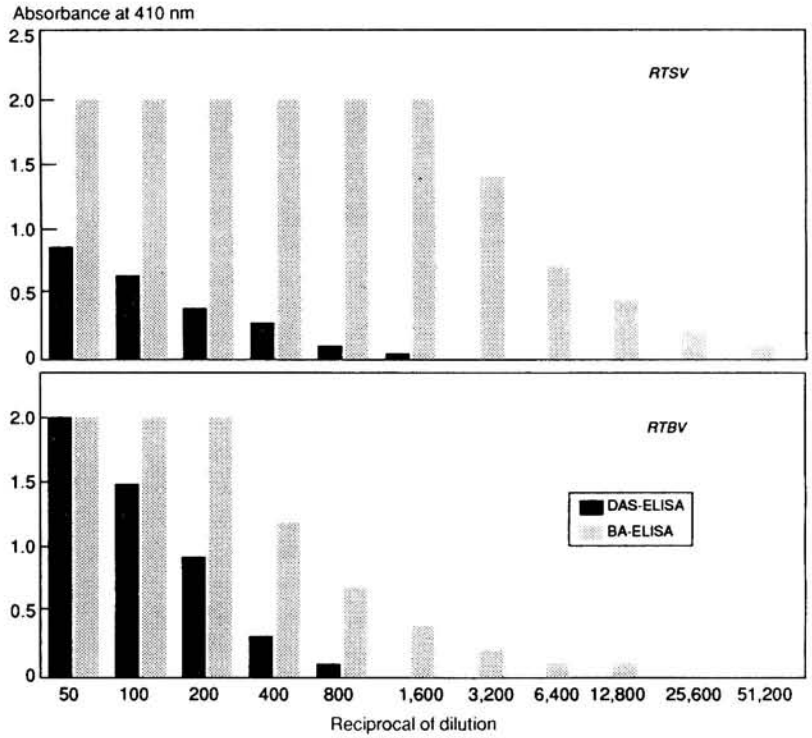
To test its sensitivity, sap of plants infected with RTBV and RTSV was diluted twofold from 50 up to 50,000 times. Each dilution was separately assayed in DAS-ELISA and BA-ELISA, using the same concentration of antiserum and other reagents for each step. The tests were repeated three times, with six replications per dilution. Compared with DAS-ELISA, BA-ELISA was 8 and 30 times more sensitive in detecting RTBV and RTSV, respectively (Fig. 13). DAS-ELISA detected RTBV and RTSV in sap diluted 800 times, while BA-ELISA detected both viruses in sap diluted 3,200 and 25,600 times, respectively. Leaves of about 150 TN1 plants infected with RTV were separately assayed in both DAS-ELISA and BA-ELISA. Results confirmed the high sensitivity of BA-ELISA. Absorbance readings (410 nm) were three to five times higher in BA-ELISA than in DAS-ELISA (Fig. 14).

BA-ELISA was evaluated for its practical application in disease surveillance (epidemiology). Its ability to detect very low concentrations of RTBV in the plant was confirmed when naturally infected plants were individually assayed. In 1 of the tests, 29 out of 172 plant samples showed negative reactions to RTBV in DAS-ELISA (av 410 nm = 0.02) but showed positive reactions in BA-ELISA (av 410 nm = 0.25). These plants were probably newly infected at the time of sampling and hence had low virus titers and negative reactions in DAS-ELISA. This assumption was confirmed when TN1 plants (1 mo old) inoculated in the greenhouse were assayed daily in DAS-ELISA and BA-ELISA for 5 d after infection. Results showed that even at 2 DAI, BA-ELISA detected RTBV and RTSV in about 40% of inoculated plants, while DAS-ELISA detected none (Table 17). These results showed the advantage of BA-ELISA over DAS-ELISA in detecting low concentrations of RTBV and RTSV in both naturally and artificially infected plants and its usefulness in routine screening for resistance and in RTV epidemiology.

BIOLOGICAL CONTROL

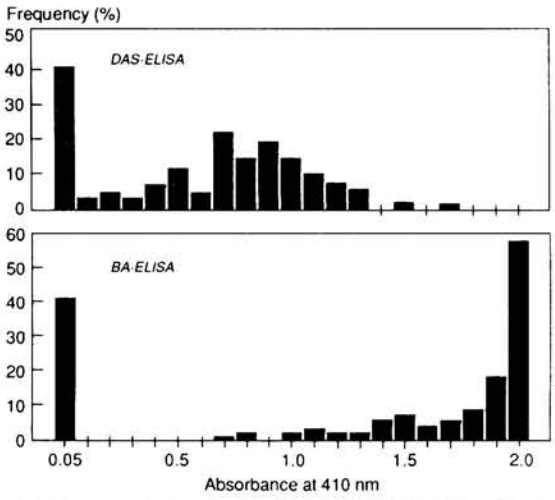
Plant Pathology Department and Rural Development Administration, Korea

Evaluation of bacterial strains against sheath blight and seedborne pathogens (*Plant Pathology*). We continued our efforts to screen bacteria



13. Comparison of double antibody sandwich-enzyme-linked immunosorbent assay (DAS-ELISA) and biotin-avidin-ELISA (BA-ELISA) in detecting RTSV and RTBV at different dilutions of infected sap. IRRI, 1988.

as biological control agents for rice diseases. In laboratory tests, 441 (24%) of the 1,856 strains screened inhibited the growth of *Rhizoctonia solani*, the ShB pathogen. Most strains were antagonistic to the three groups of fungal pathogens: seedborne, sclerotia-forming, and foliar fungi (Table 18). Some exhibited broad-spectrum antibiosis.



14. Histogram of absorbance at 410 nm in DAS-ELISA and BA-ELISA for RTBV of extracts of 150 artificially infected TN1 seedlings. IRRI, 1988.

One hundred of these bacteria were further evaluated for their efficacy in suppressing seedborne fungi in IR58 seeds. We followed the procedures of the International Seed Testing Association for blotter and growing-on tests, using a batch of 400 treated and nontreated seeds 5 d after bacterization. Twenty-six of them reduced the incidence of *Alternaria, Trichoconiella, Phoma, Sarocladium,* and *Fusarium* on rice seed. The treated seeds had infestation levels ranging from 5 to 25%, while the nontreated seeds had 60% fungal infestation. Some bacterial strains also promoted the growth of rice seedlings, perhaps because of their ability to suppress these seedborne fungal pathogens.

Field tests (*Plant Pathology*). Nineteen bacterial strains with broad-spectrum antibiosis toward *R. solani* (ShB), *Sclerotium oryzae* (stem rot, SR), and *Sarocladium oryzae* (sheath rot, ShR) were

Table 17. Comparison of double antibody sandwich enzyme-linked immunosorbent assay (DAS–ELISA) and biotin-avidin ELISA (BA-ELISA) in detecting RTBV and RTSV at various days after inoculation of 1-mo-old TN1 plants. IRRI, 1988.

Days after inoculation	Viruses detected (no. of plants)						
	DAS-ELISA[a]			BA-ELISA			
	RTBV+RTSV	RTBV	None	RTBV+RTSV	RTBV	RTSV	None
1	0	0	90	0	0	0	90
2	0	0	90	1	25	9	55
3	3	19	68	34	45	0	11
4	59	29	2	87	3	0	0
5[b]	82	7	1	86	3	0	0

[a]No RTSV was detected. [b]One plant died on the fifth day.

Table 18. Occurrence of bacterial strains inhibiting the mycelial growth of 3 groups of rice fungal pathogens. IRRI, 1988.

Pathogen	Total (no.)	With antagonistic activity	
		no.	%
Seedborne fungi			
Trichoconiella padwickii	441	106	24
Fusarium moniliforme	441	66	15
Sarocladium oryzae	441	72	16
Sclerotia-forming fungi			
Rhizoctonia oryzae	1856	441	24
Sclerotium oryzae	441	180	41
S. hydrophilum	441	133	30
Gaeumanomyces graminis	441	142	32
Foliar pathogens			
Helminthosporium oryzae	441	135	31
Pyricularia oryzae	441	176	40

chosen for a first field test at IRRI during the 1987 WS. Seedlings raised from bacteria-coated seeds and nontreated seeds of IR20 rice were transplanted in eight replicate field plots. The crops in 4 plots also received bacteria spray applications (10^7 colony-forming units [CFU]/ml) at 10, 25, 40, 55, and 70 d after planting (DAP). Both the treated and nontreated crops were inoculated with SR. All 19 strains significantly reduced SR in IR20 that received seed treatment, and 11 of the 19 strains reduced SR in the crop that also received spray applications. Significant yield increases occurred only in the crop that received spray applications.

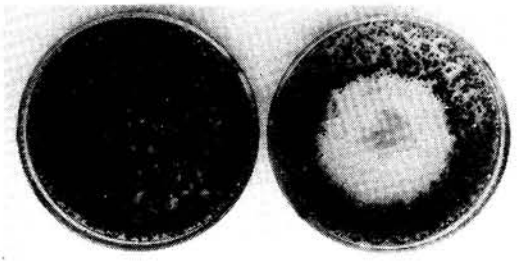
Further field tests were conducted during 1988 DS and WS with fewer promising strains of bacteria and with two fungicides, pentachloronitrobenzene and validamycin, as other treatments. During 1988 DS, bacteria were used only as seed treatments, and significant reductions in ShB, SR, and ShR occurred with some treatments (Table 19). Disease reductions were more pronounced in direct seeded IR58 and in transplanted IR62. In direct seeded IR58, all bacteria treatments were as effective as validamycin in suppressing ShB (Table 19). Also during 1988 WS, many of the bacteria used as seed treatments for IR58 were effective in causing significant ShB reductions. However, they did not suppress SR or ShR.

Blast control (*Plant Pathology*). As part of our effort to develop alternate strategies for rice disease management, bacteria strains isolated from IRRI ricefields were screened for their antagonism toward the Bl fungus *Pyricularia oryzae* (Fig. 15). From >100 bacterial strains used in the initial screening, 4 (2 fluorescent, 2 nonfluorescent) were chosen for a field test (RCBD with 4 replications) conducted at the IRRI upland rice research site in Cavinti, Laguna, Philippines. Seeds of UPLRi-5 rice were coated with bacteria (10^9 CFU/g seed) or with the fungicide fungarin and were then sown in field plots along with nontreated seeds. The crop also received 3 additional sprays of bacteria (10^7 CFU/ml) or fungarin when the plants were 20, 30, and 40 d old. Root and shoot samples collected at 10-d intervals to monitor bacterial populations suggested that the nonfluorescent strains had a higher population (10^5-10^6 CFU/g tissue) than the fluorescent strains until 110 DAP. Fungarin and all bacterial treatments caused significant reductions in leaf Bl

Table 19. Effect of seed bacterization of direct seeded (DSR) and transplanted (TPR) rice (IR58 and IR62) on incidence of sheath blight, stem rot, and sheath rot.[a] IRRI, 1988 DS and WS.

Treatment	1988 DS											
	Sheath blight severity				Stem rot disease index				Sheath rot (%)		Sheath blight severity in IR58 in 1988 WS	
	DSR		TPR		DSR		TPR		DSR	TPR	DSR	TPR
	IR58	IR62	IR58	IR62	IR58	IR62	IR58	IR62	IR58	IR62		
PCNB	1.62 a	0.98 a	1.93 b	1.03 a	2.24 a	2.22 ab	2.36 ab	2.27 ab	9.25 b	22.50 c	NT	NT
Validamycin	2.94 b	1.29 ab	1.93 b	0.79 a	2.33 a	2.61 b	2.41 ab	2.47 ab	5.75 b	5.75 a	4.99 ab	2.76 a
In-b-33	2.95 b	1.27 ab	2.62 bc	0.77 a	2.09 a	2.35 ab	2.46 b	2.44 ab	21.50 a	21.75 c	6.36 ab	9.27 bc
In-b-3	2.27 ab	1.90 ab	1.13 a	0.78 a	2.09 a	2.41 ab	2.52 b	2.42 ab	8.57 b	10.75 ab	NT	NT
In-b-784	1.72 a	1.59 ab	2.48 bc	0.86 a	2.25 a	2.31 ab	2.57 b	2.16 a	5.00 b	8.25 ab	5.09 ab	4.43 ab
In-b-655	2.06 ab	1.58 ab	3.08 c	0.67 a	2.35 a	1.99 a	1.97 a	2.52 ab	17.25 a	22.00 c	NT	NT
In-b-1-14-1	NT		NT		NT		NT		NT		0.19 a	5.99 ab
In-b-7-14	NT		NT		NT		NT		NT		2.11 a	5.02 ab
In-b-33+784	1.88 a	2.08 b	2.70 c	0.63 a	1.88 a	2.39 ab	2.28 ab	2.69 bc	6.75 b	22.50 c	NT	NT
Ib-b-33+1-14-1	NT		NT		NT		NT		NT		7.74 b	4.98 ab
Check	5.00 c	1.42 ab	2.62 bc	3.11 b	3.13 b	2.39 ab	2.12 ab	3.03 c	18.00 a	16.75 bc	13.39 c	12.83 c

[a]Av of 4 replications. NT = not tested.



15. Inhibition of *Pyricularia oryzae* (plate on the right) by fluorescent pseudomonad strain 7-14, IRRI, 1988. Plate on the left is control.

and marginal reductions in neck Bl severities (Table 20).

IRRI-Korea collaboration (*Plant Pathology and Rural Development Administration, Korea*). In previous tests (Annual reports for 1986, 1987), several Korean bacterial strains controlled rice Bl, ShB, and bakanae diseses in greenhouse tests. Three of these isolates—*Pseudomonas fluorescens* (P55), *P. putida* (P61), and *P. aureofaciens* (P62)—were evaluated further in the nursery and in the field. Rifampicin-resistant mutants of these strains, when used as seed treatments on five Korean rice cultivars in the greenhouse and subsequently monitored, colonized rice. Strain P62 (*P. aureofaciens*) had the highest population at 1 wk after seed treatment (Fig. 16).

The bacteria were as effective as validamycin in reducing ShB (Table 21) and seedling blight

Table 20. Effect of seed bacterization and sprays with antagonistic bacteria on rice blast in UPLRi-5. Cavinti, Laguna, Philippines, 1988 WS.

Treatment	Severity		Grain yield[c] (g)
	Leaf blast[a]	Neck blast[b]	
Bacterial strain			
4-03R	3.3	3.0	100.5
33R	3.5	3.7	95.5
4-15R	2.6	3.0	92.5
7-14RN	3.3	2.8	102.7
Fungarin	2.0	3.7	106.7
Check	6.3	3.8	96.3
LSD (0.05)	2.2	1.8	96.3

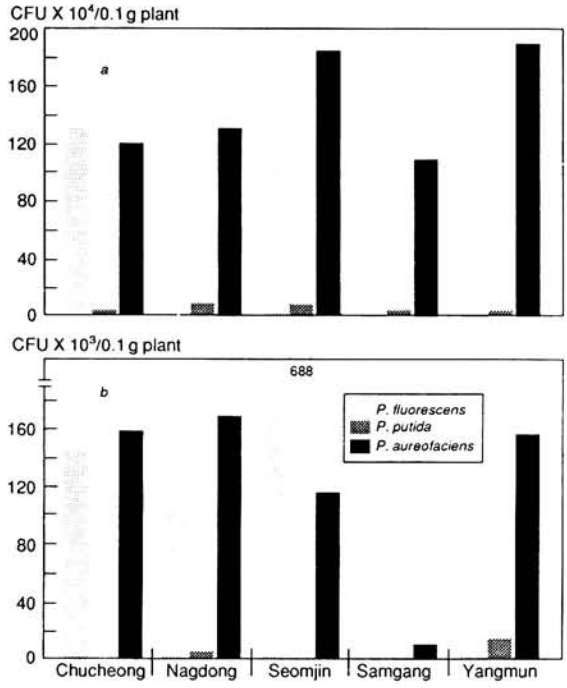
[a]Number of lesions/cm² leaf area.

[b]Severity index = $\frac{n(1) + n(2) + n(3) \ldots n(9)}{\text{total } n} \times 100$

where n (1), n (2), etc. are number of tillers with disease score 1, 2, etc. [c]From 100 panicles/plot.

Table 21. Effect of seed treatment on variety Cheo-cheong byeo and soil incorporation of antagonistic bacteria on sheath blight in the nursery. Korea, 1988.

Treatment	Relative lesion height (%) at given time after sowing		
	4 wk	5 wk	6 wk
Seed treatments			
Pseudomonas fluorescens (P55)	6.9	8.8	17.0
P. putida (P61)	11.6	12.2	19.4
P. aureofaciens (P62)	13.1	13.7	17.1
P. aureofaciens (P62) + *P. fluorescens* (P55)	5.2	9.9	18.1
Untreated	15.5	20.0	28.0
Soil incorporation			
P. fluorescens (P55)	9.8	9.7	16.5
P. putida (P61)	5.2	12.5	19.5
P. aureofaciens (P62)	8.4	13.4	17.7
Validamycin	12.6	13.4	19.8
Untreated	17.6	21.7	29.1



16. Colonization of 5 Korean rice cultivars by antagonistic bacteria 1 wk (a) and 1 mo (b) after seed treatment. Korea greenhouse, 1988.

(Table 22) in Cheo-cheong byeo when used as seed treatment, soil incorporation, or spray application. Seed treatments or spray applications of these strains increased grain yields, and *P. aureofaciens* (P62) was most effective in reducing ShB severity and enhancing grain yield.

Bacteriocin production in *Xanthomonas campestris* pv. *oryzae* (*Plant Pathology*). We studied bacteriocin production in *Xanthomonas campestris* pv. *oryzae* (Xco) to explore its use as a biocontrol agent. Bacteriocins are antibiotic-like compounds that act only against the same or closely related species. Our immediate goal is to gain a better understanding of the specificity of bacteriocin produced by Xco.

Table 22. Reduction of seedling blight incidence by seed treatment on Cheo-cheong byeo and soil incorporation of antagonistic bacteria.[a] Korea, 1988.

Treatment	Seedling blight (% incidence) with				
	Rhizoctonia oryzae	*R. solani*	*R. oryzae-sativae*	*Pythium* spp.	*Fusarium* spp.
Seed treatment					
P. putida	50 b	57 abc	47 bc	41 bc	60 abc
P. fluorescens	38 ab	55 ab	39 bc	45 abc	64 abc
P. aureofaciens	35 ab	39 a	46 bc	40 c	57 ab
Soil incorporation					
P. putida	27 ab	65 a-d	31 ab	32 ab	46 a
P. fluorescens	42 ab	58 abc	46 ab	22 a	55 ab
P. aureofaciens	18 a	44 ab	21 a	23 a	45 a
Spray application					
P. aureofaciens	82 c	75 bcd	68 cd	78 de	83 c
P. aureofaciens + *P. fluorescens*	80 c	86 d	79 d	74 d	83 bc
Control	85 c	83 cd	81 d	80 e	84 bc

[a] Av of 3 replications.

A total of 285 Xco isolates were tested for bacteriocin production on 30 randomly chosen indicator strains. Isolates were spotted on nutrient agar plus sucrose and incubated at 22 °C. After 2 d, colonies were chloroform-treated, and indicator strains were overlaid on the colonies. Plates were incubated at 30 °C for 2 d, and zones of growth inhibition (clearing) of indicator strains were measured around colonies of bacteriocin producers. The radii of zones ranged from 0.5 to 4 mm. Sixty-five percent of the strains tested for bacteriocin production inhibited one or more of the indicator strains. The number of bacteriocin producers from each race varied from 42.2 to 100% (Table 23). All 6 strains of race 4 were producers, whereas race 2 isolates affected the least number of indicator strains (4.8%). More indicator strains were sensitive to the bacteriocins from the six isolates of race 4, suggesting that the bacteriocins produced by race 4 isolates might have broader specificities. Concurrently, nonpathogenic mutants of bacteriocin producers were produced by nitrosoguanidine mutagenesis. These mutant strains could be used to evaluate the effect of bacteriocin on disease development in co-inoculation experiments.

CULTURAL CONTROL

Plant Pathology, Multiple Cropping, and Soils Departments; and Justus-Liebig University, Germany

Blast in upland rice (*Plant Pathology, Multiple Cropping, and Soils; and Justus-Liebig University, Germany*). Planting resistant varieties is probably the most effective means of Bl control, especially for resource-poor upland farmers. However, few durably Bl-resistant varieties have been developed. To supplement disease resistance, various cultural practices are possible; some are being tested for their ability to improve crop growth and suppress Bl. The work is an interdisciplinary effort in a special project with the Justus-Liebig University, Giessen, Federal Republic of Germany.

Effect of rice hull application on upland rice growth and blast disease on an acid upland soil (*Plant Pathology, Multiple Cropping, and Soils; and Justus-Liebig University, Germany*). Silica may play an important role in resistance to rice Bl, especially under rainfed conditions. Research has begun to elucidate the factors influencing silica uptake by the rice plant under different levels of fertilization.

Rice hulls are a source of silica that is potentially available to upland farmers. Substantial amounts also increase soil moisture, which seems to be a key factor for silica availability in upland soils.

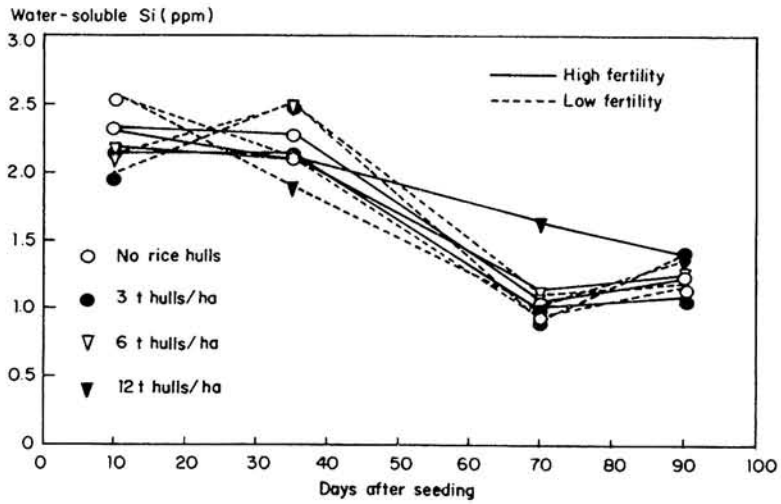
At the acid upland site in Cavinti, Laguna, the application of rice hulls was studied during 1987 WS for effects on crop growth and Bl. The rice hulls used contained 24% SiO_2. Using a factorial RCBD, increasing hull rates (0, 3, 6, and 12 t/ha) were tested at low (30-30-30 NPK) and high (90-45-30 NPK) fertilization. The aim was to increase the available silica in the soil and the silica content in the plant, and thereby enhance crop growth and Bl resistance.

Water-soluble Si in saturation extracts of soil

Table 23. Survey of bacteriocin production by *Xanthomonas campestris* pv. *oryzae* against indicator strains at 30 °C. IRRI, 1988.

Race	Isolates tested (no.)	Bacteriocin producers[a]		Producers (%) effective against indicator strains in six race groups[b]					
		no.	%	1	2	3	4	5	6
1	45	21	42.2	9.4	27.4	19.2	0.2	18.8	7.6
2	150	91	60.6	3.4	10.4	8.4	0.6	5.4	0.9
3	38	25	65.2	7.6	3.0	40.4	0.6	35.4	2.8
4	6	6	100	75.0	76.6	56.8	13.4	95.7	26.6
5	26	22	84.6	20.8	44.8	32.8	0	18.4	36.8
6	13	6	46.1	43.0	0	46.0	32.0	39.8	18.6
Unassigned	7	4	57.1	0	28.5	0.87	0	4.8	3.2
Total	285	185							

[a] A strain causing a radius of zone of clearing of at least 0.5 mm against any indicator strain was considered a bacteriocin producer. [b] Five randomly chosen strains from each race were used.



17. Kinetics of Si availability (ppm water-soluble Si) at 0-10 cm depth in an acid upland soil during the growth of variety UPLRi-5. Cavinti, Laguna, Philippines, 1987 WS.

samples was monitored during the growing season (Fig. 17). Silicon availability remained high until 35 DAS, followed by a sharp decrease. The treatments did not significantly affect the water-soluble Si concentrations, although soil moisture, known to increase Si availability, was slightly increased by hull application (Fig. 18).

The silica content in the plant remained near the critical level (5%) at both 35 and 90 DAS in all treatments. Silica was the only nutrient significantly correlated with leaf BI (Table 24).

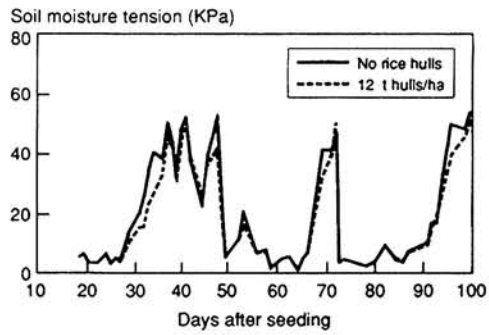
The relation between BI and plant silica content was strongly inverse with high fertilization (Fig. 19). With low fertilization, disease severity ranged from 20 to 40% DLA regardless of Si content (5.4-8%), and Si content tended to be higher compared with that at the high fertilization level (Fig. 19).

Table 24. Correlation of nutrient content in the plant at 35 DAS with leaf BI severity (% diseased leaf area) at 50 DAS. Cavinti, Laguna, Philippines, 1987 WS.

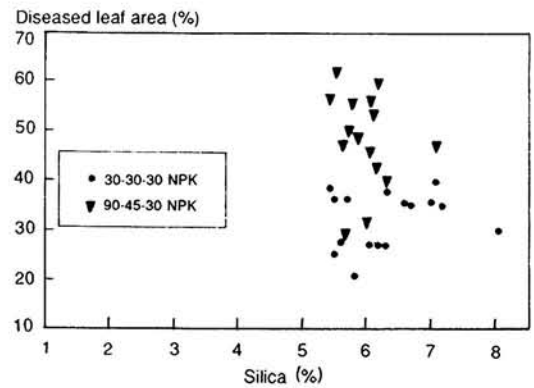
N	P	Si[a]	Mn	Ca	Fe	Al
−0.01	−0.01	−0.36*	−0.13	0.03	−0.14	−0.23

[a] * = significant at the 5% level by *f*-test.

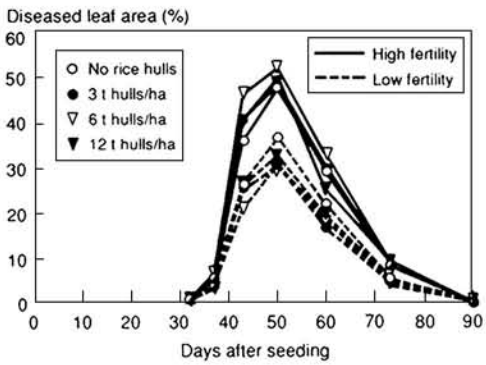
Leaf BI development was significantly higher at the high fertilization level (Fig. 20). Panicle BI



18. Effect of rice hull application on soil moisture tension at 15-cm depth in plots of UPLRi-5 in an acid upland soil. Cavinti, Laguna, Philippines, 1987 WS.



19. Relation of Si content in the plant at 35 DAS to leaf BI severity (% diseased leaf area) at 50 DAS. Cavinti, Laguna, Philippines, 1987 WS.



20. Development of leaf Bl severity (% diseased leaf area) on UPLRi-5 grown at an acid upland site. Cavinti, Laguna, Philippines, 1987 WS.

infection tended to decrease with increasing application rate, but the trend was not statistically significant.

Total dry matter, grain yield, and yield components were not significantly affected by any of the hull treatments and did not even respond to the high fertility level.

Effect of nitrogen timing on Bl disease and upland rice growth (*Plant Pathology and Multiple Cropping; and Justus-Liebig University, Germany*). The importance of N to the occurrence and severity of Bl epidemics is well known. We tested the possibility of using the time of N application as a means of suppressing Bl. Disease and crop development were assessed in a field experiment at the acid upland site in Cavinti, Laguna, during 1987 WS. The experiment was a split-plot design with inoculation/fungicide treatments as main plots and N treatments as subplots. A total of 90 kg N/ha was applied as urea in 2 early, 2 late, 3 equal, and 5 equal splits. Controls received no N. The moderately Bl-susceptible UPLRi-5 was seeded at 80 kg/ha at 25-cm spacing.

The time of N application had a significant effect on leaf Bl and on other fungal diseases (Table 25). Leaf Bl intensity was lowest with late split application at 30 and 60 DAS and was equal to the no-N control. Panicle Bl was affected by the treatments to a lesser extent, and differences were not significant. To better understand the effects of N application on disease development, analysis is under way to relate various crop and disease variables. For example, plant density (no. of tillers/m^2) and canopy cover (%) were positively correlated with leaf Bl at 44 DAS (Table 26).

The total dry matter, grain yield, and yield components were not significantly affected by N treatments. However, grain yield was reduced significantly in the diseased plots when compared with the fungicide-treated plots. Panicle Bl showed a significant negative correlation with the grain yield (r = -0.56**), while leaf Bl was not significantly correlated (r = -0.16ns).

CHEMICAL CONTROL

Plant Pathology Department

Timing of insecticide application for tungro control. Field experiments in 1986-88 at IRRI gave us a better understanding of the onset and development of RTV disease. Based on these findings, we treated TN1 and IR20 plants with cypermethrin at 40 liters ai/ha and buprofezin at 10 kg ai/ha with 1 application in the seedbed at 10

Table 25. Effect of N timing on severity of leaf diseases measured as percentage of diseased leaf area in plots of upland rice UPLRi-5. Cavinti, Laguna, Philippines, 1987 WS.[a]

Treatment[b] (kg N/ha)	Leaf blast (% DLA) at 44 DAS	Brown spot (% DLA) at 56 DAS	Leaf scald (% DLA) at 90 DAS
Control (0)	3.2 a	1.6 a	1.5 a
60-0-30-0-0	11.5 b	4.3 c	4.2 c
0-0-30-0-60	1.4 a	2.5 ab	2.0 ab
30-0-30-0-30	18.7 c	3.5 bc	3.2 bc
18-18-18-18-18	13.3 b	3.5 bc	2.4 ab

[a] Analysis based on arc sine transformed data. [b] N applied at 0, 15, 30, 45, and 60 DAS.

Table 26. Correlation of crop development variables with leaf Bl severity measured as percentage of diseased leaf area in UPLRi-5 at 44 DAS in an experiment on N timing. Cavinti, Laguna, Philippines, 1987 WS.

Parameter	Correlation[a]
Tillers (no./m^2) at 30 DAS	0.55**
Canopy height (cm) at 30 DAS	0.38 ns
Canopy cover (%) at 30 DAS	0.58**
Total dry matter at 45 DAS	0.38 ns

[a] ** = significant at the 1% level by f-test. ns = not significant.

DAS and at 3, 13, and 24 DT. Treated TN1 had very low infection by any of the RTVs at 61 DT compared with untreated TN1. Regardless of treatment, RTSV-resistant IR20 showed only RTBV infection at a very low level (Table 27).

A few adult GLH and no nymphs were collected by D-Vac suction machine at 13 DT in all treatments. But at 34 DT and after 3 field sprays, almost no GLH were collected in the treated plots, whereas nymphs and adults were obtained in the untreated plots of both varieties (Table 28). Infectivity tests of GLH collected in all plots showed RTSV infection at 13 DT except in treated IR20. Although RTBV- and RTSV-infective GLH were obtained at 34 DT, they were not enough to cause high infection levels.

Applying insecticides at early plant growth stages delayed disease development without causing high infection levels later, even in highly susceptible TN1. The use of insecticides combined with varieties resistant to RTSV gave the best results for RTV management.

INTEGRATED PEST MANAGEMENT

Plant Pathology, Entomology, and Agronomy Departments; and Maros Research Institute for Food Crops, Indonesia

Tungro management in South Sulawesi, Indonesia (*Plant Pathology and Maros Research Institute for Food Crops*). The IRRI-AARD (Agency for Agricultural Research and Development, Indo-

Table 27. Percentage infection[a] with RTBV and RTSV in insecticide-treated and untreated TN1 and IR20 plants at various days after transplanting (DT). IRRI, Oct-Dec 1988.

Variety and treatment	Infection (%)								
	11 DT			32 DT			61 DT		
	RTBV+RTSV	RTBV	RTSV	RTBV+RTSV	RTBV	RTSV	RTBV+RTSV	RTBV	RTSV
TN1									
Treated	0.2	0.3	1.4	0.6	0.7	4.7	0.6	1.0	2.9
Untreated	0.2	0.2	0.6	2.9	1.6	21.4	64.6	2.4	20.5
IR20									
Treated	0	0.5	0	0	1.3	0	0	1.4	0
Untreated	0	0.2	0	0	1.6	0	0.1	2.1	0

[a] A leaf from each hill of 25 that composed a sample unit was taken and indexed by ELISA. There were 53 sample units in quincuncial arrangement per 25- X 50-m plot.

Table 28. Number and infectivity of green leafhoppers (GLH) on insecticide-treated[a] and untreated TN1 and IR20 plants at 13 and 34 days after transplanting (DT). IRRI, Oct-Dec 1988.

Variety and treatment	GLH[b] (no.)			GLH infectivity[d]					
	13 DT[c]	34 DT		Insects tested (no.)	Infective[e] (%) with RTSV at 13 DT	Insects tested (no.)	Infective (%) at 34 DT with		
	Adults	Nymphs	Adults				RTBV+RTSV	RTBV	RTSV
TN1									
Treated	8	0	0	16	18	17	24	12	6
Untreated	9	38	36	17	25	21	48	10	19
IR20									
Treated	12	1	0	5	0	18	22	11	6
Untreated	11	28	63	26	8	25	28	8	8

[a] Sprayed at 10 DAS and 3, 13, and 24 DT. [b] Collected by D-Vac suction machine from 20 plants per treatment consisting of 25 hills each. [c] No nymphs were caught. [d] Collected by aspirator and individually tested on TN1 seedlings in test tubes for 24-h inoculation feeding. Seedlings indexed by ELISA 3-4 wk after inoculation. [e] No cases of RTBV+RTSV and RTBV infection.

nesia) Collaborative Research Project on RTV conducted in South Sulawesi from October 1987 to April 1988 aimed at understanding the epidemiological implications of the integrated RTV management scheme that has been widely adapted in South Sulawesi since 1983.

Since 1969, occasional RTV outbreaks had occurred in several Indonesian provinces including South Sulawesi. Resistant varieties were introduced and planted widely in RTV-affected areas. However, the resistant varieties suffered from RTV after a few years of intensive cultivation. Through epidemiological studies and greenhouse evaluation of varieties, using vector GLH populations selected on the resistant varieties, the Maros Research Institute for Food Crops (MORIF) found that the RTV resistance of the varieties was due to their resistance to the vector. The resistant varieties had high RTV infections when exposed to viruliferous GLH populations that had been reared on resistant cultivars. Based on these findings and results of RTV epidemiology in South Sulawesi, MORIF formulated an integrated RTV management scheme with four components: 1) appropriate planting time, 2) synchrony of planting, 3) rotation of varieties with different resistance to GLH, and 4) application of insecticide. Since the scheme was adapted in 1983, RTV incidence in South Sulawesi has been very low.

Tungro and green leafhopper situation before 1983. Data on GLH density and RTV incidence from MORIF and from the Extension and Crop Protection Office, Ministry of Agriculture, indicated a fairly uniform annual fluctuation of GLH density in South Sulawesi. The pattern generally had two peaks, one in WS and one in DS. Tungro incidence was generally high during the period when GLH density was higher. The peak period for GLH density and RTV incidence generally overlapped in each area. In Sidenreng Rappang (Sidrap), the major peak appeared at the end of the WS crop in August-September, with another peak at the end of the DS crop in February-March. GLH density declined during the fallow periods. The fluctuation was probably affected by the rice cropping intensity in the area. Generally, GLH density in ricefields declines as the rice approaches maturity, and it remains low during the fallow period.

Tungro management scheme. Based on the annual fluctuation patterns of GLH density and RTV incidence, the best planting time was formulated. The recommended planting time for the WS crop is at the peak of rainfall when GLH population is very low. The recommended planting time for the DS crop is about 6-7 mo after the planting time for the WS crop. According to the maturity of the varieties to be planted, planting date is also adjusted to coincide with the peak time of GLH density after the late tillering or flowering stage. The most critical period for RTV infection is the first 30-45 DT, after which plants are less susceptible and suffer less damage when infected.

Based on the varietal reaction to RTV infection when inoculated by selected GLH populations, MORIF grouped varieties into four (T0: IR5, Cisadane, Pelita, Cikapundung; T1: IR26, IR30, IR46; T2: IR36, IR42, IR48, Cimanuk, Semeru; T3: IR54, IR56, IR64, Bahbolon, Kelara). Varieties are strategically rotated from season to season to reduce GLH opportunities to gain higher virulence on resistant varieties. Varieties to be planted in each season at each location are selected following basically the rotation strategy. For the selection of varieties, days to maturity, eating quality, and levels of rat and bird infestation in the area are also considered. When late planting is unavoidable, varieties with resistance higher than that of the ones that were recommended are selected for planting.

Implementation of the scheme. Adoption of the RTV management scheme was surveyed in Sidrap. Sidrap is located in the border areas of two distinct climatic zones and was one of the RTV "hot spots." It has 68,000 ha of ricefields, of which 75% are irrigated and 25% are rainfed; 60% have 2 annual rice crops. The average yield is 5.5 t/ha in WS and 6.5 t/ha in DS.

After adoption of the RTV management scheme in 1983, areas planted early or late were reduced greatly in Sidrap. In 1985 and 1986, at least 90% of the ricefields were planted following the recommended schedule. Rice cultivation now has a high level of synchrony, with definite fallow periods of 1-2 mo between crops.

Areas planted to the recommended varieties averaged 80% in 1985 (ranging from 55 to 91%) and 85% in 1986 (73 to 96%). Varieties with

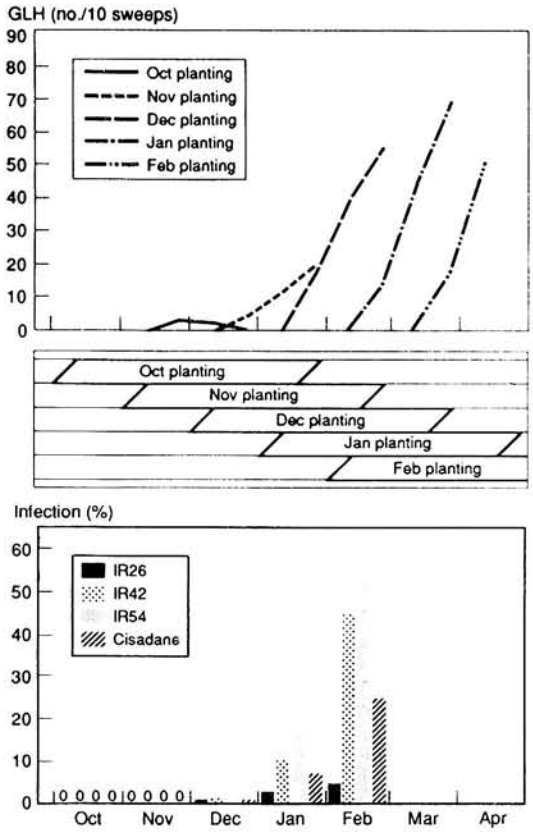
GLH resistance have been planted continuously, but following the rotation strategy. Susceptible varieties were not included in the rotation cycles. The reduction of RTV incidence in Sidrap after the adoption of the scheme could be due largely to synchrony in planting. After 1983, ricefields planted late often have severe RTV incidence.

Tungro and green leafhopper development under the scheme. We conducted field experiments in Sidrap during 1987 and 1988 DSs. Ricefields selected had more or less similar ecological conditions, and irrigation water was available during DS. IR26, IR42, IR54, and Cisadane were planted monthly from October to February. The October-February plantings were established in farmers' fields with approximately 200 m between them. In each field, 4 varieties were planted in 10- x 10-m plots with 4 replications.

In fields planted in October or November, GLH *N. virescens* and *N. nigropictus* density was low (Fig. 21). In the December planting, GLH density started to increase in mid-January and reached a high level in 1 mo. GLH developed similarly in fields planted in January and February. Average GLH number/10 sweeps caught in the area was high in February-March (Fig. 21). Tungro incidence at 56 DT was high in the February planting, less in the January planting, and negligible or zero in the October, November, and December plantings (Fig. 21). Tungro incidence was high on IR42, IR54, and Cisadane, but low on IR26. In the surrounding fields, mainly IR42 was planted in November; it had no RTV incidence.

In fields planted in December, GLH developed as in fields planted in January or February. Tungro incidence was negligible in the December planting, but was very high in later plantings. The incidence was higher in fields established after rice in the surrounding fields reached maturity. Apparently, the RTV source was present in the uniformly planted fields, though no RTV was observed. Tungro infection might occur at the late growth stage in the fields. High RTV incidence in IR42 and IR54, which have resistance to GLH, might result from the continuous planting of the two and other related varieties in the area.

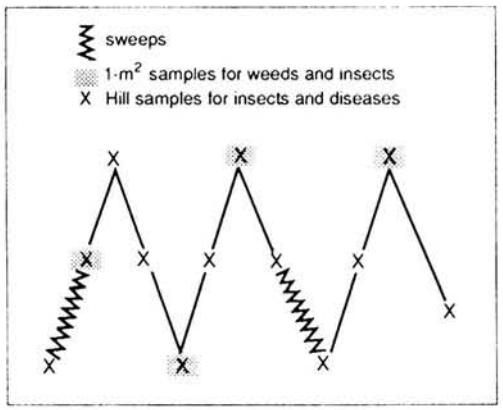
Integrated pest survey *(Plant Pathology, Entomology, and Agronomy)* A survey, which started



21. Green leafhopper population (average) monitored every 2 wk (a) and RTV incidence at 56 DT (b) in selected varieties planted monthly from October 1987 to February 1988 in Sidrap, South Sulawesi, Indonesia.

in crop year 1987-88, aimed to determine the distribution and severity of pests in Bulacan, Pampanga, and Nueva Ecija Provinces of Central Luzon; to relate the distribution and severity of pests to crop management practices, water status, soil conditions, and other factors; and to establish "pest zones." Pest zones are areas in a region that favor certain pests arising from the combination of certain environmental factors and crop management practices.

Ninety fields were selected from each town on the basis of variety planted, method of planting, and planting date. The zigzag sampling pattern was used to assess the pests (Fig. 22). Transplanted fields were visited and sampled at the seedling stage (about 21 d in seedbed), at about 30 DT for the first field observation, at 60 DT for the second field observation, and at harvest for



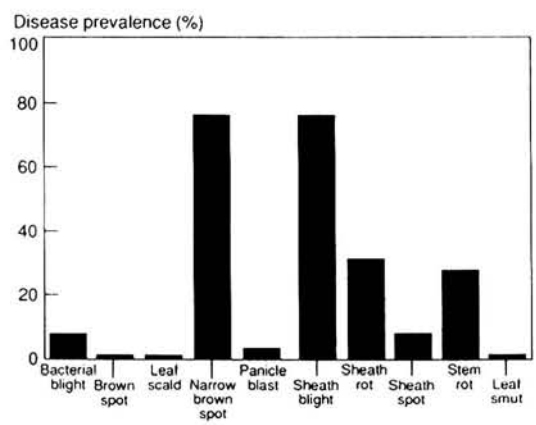
22. Zigzag pattern of sampling used in the IRRI integrated pest survey, 1987-88.

the third observation. Direct seeded fields were sampled at about 21 DAS, at 51 DAS for the first field observation, at 81 DAS for the second, and at harvest for the third. Results for the first crop 1987-88 are presented.

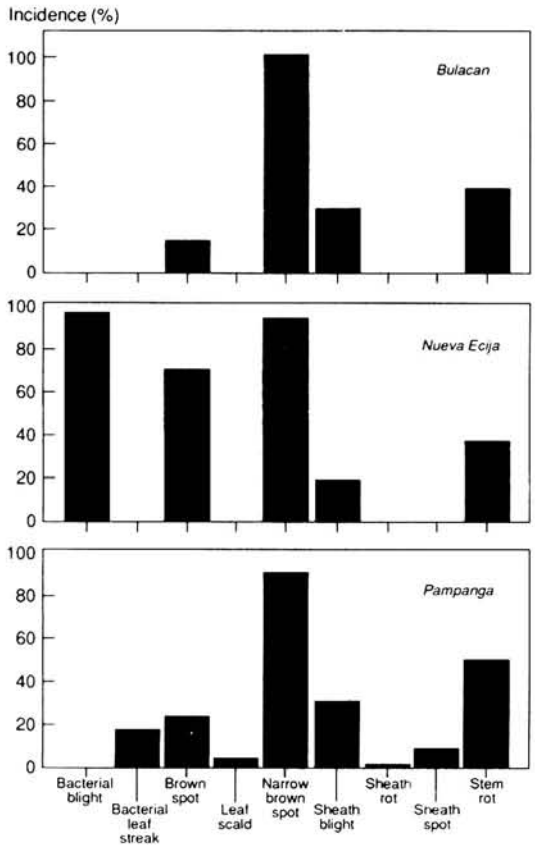
Bakanae. Five of 27 seedbeds in Bulacan had bakanae disease, with 11.2% average incidence. In the field, the incidence based on the number of infected hills was 3.7% and 1.8% for the first and second observations, respectively.

Leaf, stem, and panicle diseases. In the first field observation, diseases were observed in 13 fields. Bacterial leaf streak (BLS) occurred in 10 of the 13 fields. Of the BLS-infected fields, 90% were in Nueva Ecija. The disease prevailed in IR64, in transplanted rice, in irrigated rice, and in fields with soft soil with standing water. In the second observation, the number of infected fields increased from 13 to 45. ShB was most common, occurring in 32 of 45 fields in all 3 provinces and at all levels of field water status. Because of differences in maturity period of the varieties, the crop stage during the second observation ranged from stem elongation or panicle initiation (PI) to ripening. ShB prevailed at most growth stages. At the milk stage and at the dough to ripening stage, most fields were infected with stem rot (SR) and narrow brown spot (NBS), respectively. ShB, followed by SR, also prevailed in both transplanted and irrigated fields. More IR64 fields were infected with ShB, followed by IR42 fields. More diseases were recorded in the third observation than in the first or second. NBS and ShB, observed in 75.8% of diseased fields, were most prevalent, followed by ShR and SR, which occurred in 32.3% and 29.0% of the fields, respectively (Fig. 23). Brown spot, leaf scald (LS), and leaf smut were recorded in only 1.6% of the fields. NBS and ShB occurred in all three provinces, in IR64, in transplanted rice, and in irrigated fields. More IR42 fields were also infected, not only with NBS and ShB but also with ShR. Plants were at the dough to the fully mature stage during the third observation, and ShB was prevalent only at ripening to the fully mature stage. ShB occurred more in fields without standing water, regardless of soil conditions, while NBS occurred in fields with soft soil regardless of water conditions.

During the first field observation, BLS had the highest mean incidence of 69.6%. More than 90% was observed in Nueva Ecija fields in Barangay Sta. Cruz, Zaragoza; Rajal Norte, Sta. Rosa; and Malimba, in Gapan. The incidence was highest in variety R10, in wet seeded fields, in irrigated fields, and in fields with soft soil and standing water. During the second observation, the average incidence of NBS was highest at 92.9%. NBS incidence was high in all three provinces (Fig. 24); at almost all growth stages; in IR42, IR60, IR64, and IR66; in both rice culture types; and in both planting methods. BB was also high in Nueva Ecija in one field that was transplanted to IR64, was irrigated, and had soft soil with standing water.



23. Prevalence of diseases in third observation of the first crop, 1987-88, in 3 Philippine provinces.



24. Incidence of diseases in 3 Philippine provinces in the second observation of the first crop, 1987-88.

In the third observation, the mean incidence of NBS declined to 82.4%, but it was still the highest. High incidence was observed in all three provinces, in both planting methods, and in both rice culture types. NBS was followed by leaf smut and BB in Nueva Ecija. One hundred percent incidence was recorded in varieties Cadeo, IR60, and IR68, followed by 91.4% in IR64. High incidence occurred at the dough, ripening, and fully mature stages. Considering the water status of the field, a higher incidence of NBS, ShB, sheath spot (ShS), and SR was observed in fields with hard soil without water.

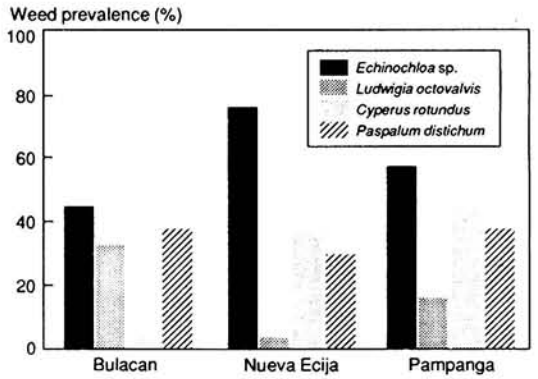
Diseases were light only in the first field observation. In the second observation, the highest severity was 24.5% BB in a Nueva Ecija field of irrigated, transplanted IR64 at the milk stage, with soft soil and standing water. In the third observation, no disease could yet be considered serious except perhaps BB, which reached 33.5% severity in a field in San Agustin, Santo Domingo, Nueva Ecija, at the fully mature stage. BB severity was highest in IR64 at 20.9%; in a field with soft soil without standing water at 18.5%; and in transplanted and irrigated rice, both at 14.3%.

Planting date had no effect on disease prevalence, incidence, or severity in all observations except the third, where ShR and SR were recorded only in fields with mid-late and late planting dates. Results were similar to those for date of visit, where ShR and SR were observed only in fields visited at later dates in the third observation.

Tungro. Tungro was minimal, with only 2, 6, and 18 fields showing RTBV, RTSV+RTBV, and RTSV, respectively. The virus particles were detected mostly in IR42, at the reproductive phase of the crop, and in only 1 of the 12 samples/field.

Nematodes. Hirschmanniella sp. was observed in root samples in 70.3 and 55.2% of the fields in the first and second observations, respectively. Nematode prevalence in soil samples was less. Highest average counts of 153/3 g roots and 81/200 ml soil were obtained in Frances, Calumpit, Bulacan, in the first observation. The soil samples also yielded *Tylenchorynchus* sp. in 29.9% of the fields, with a highest mean count of 53/200 ml soil in the first observation.

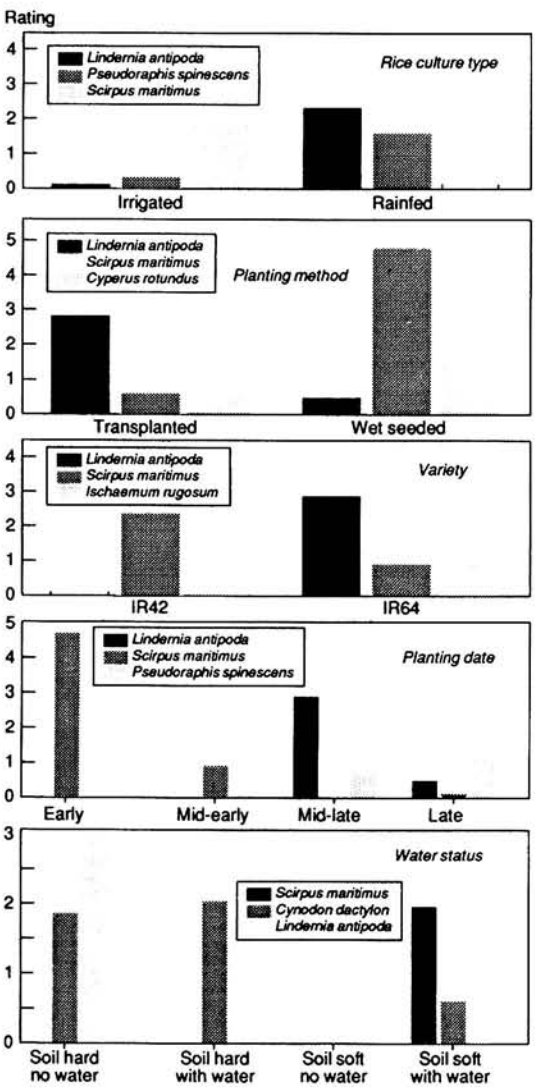
Weeds above canopy. In observation of seedlings, *Echinochloa* spp. seen in most seedbeds in the three provinces were the most prevalent or predominant, followed by *Paspalum distichum* and *Ludwigia octovalvis* in Bulacan, and by *Cyperus rotundus* and *P. distichum* in both Nueva Ecija and Pampanga (Fig. 25). *Scirpus maritimus* and *Ischaemum rugosum* obtained the highest ratings of 3.0 and 3.3 in Bulacan and Nueva Ecija, respectively. In Pampanga, the highest rating was 4.0 in both *I. rugosum* and *Sphenoclea zeylanica.* The three wet seeded ricefields in Bulacan were free from weeds above the canopy at the seedling stage. Very few weeds were recorded in Pampanga and Nueva Ecija except for *S. zeylanica*, which was rated 4.0 in one field in Pampanga. In both first and second field observations, *E. glabrescens* predominated, regardless of province, rice culture type, planting date, planting method, variety (only IR42 and IR64 were considered),



25. Prevalent weeds in seedbeds in 3 Philippine provinces observed in the first crop, 1987-88.

or water status. The most serious weed in the first observation was *Scirpus maritimus*, with a rating of 8.0 in a wet seeded field in Pampanga planted to IR42, irrigated, planted early, and having soft soil with standing water. Other weed ratings ranged from only 0.5 to 2.0. There were more weeds in the second observation.

Weeds below canopy. Monochoria vaginalis prevailed in the three provinces regardless of time of observation. It was followed by *Cynodon dactylon* and *S. supinus* in the first observation and by *P. distichum* and *Fimbristylis miliacea* in the second observation in Bulacan; by *E. glabrescens, Cyperus difformis, P. distichum*, and *S. supinus* in both observations in Nueva Ecija; and by *Sphenoclea zeylanica, Scirpus supinus, E. glabrescens,* and *C. difformis* in the first observation in Pampanga. *P. distichum* was as predominant as *M. vaginalis* in Pampanga in the second observation. As in weeds above the canopy, *S. maritimus* also obtained the highest rating of 4.7, also in observation 1. In the first observation, *M. vaginalis* was predominant regardless of planting method, variety, or planting date. Considering rice culture type and water status features, *M. vaginalis* predominated only in irrigated fields and in fields with soft soil regardless of water conditions, respectively. *E. glabrescens, C. difformis*, and *S. supinus* were next common in irrigated rice culture, in transplanted rice, in IR64, in mid-early planting date, and in fields with soft soil with standing water. *Lindernia antipoda* had the highest ratings in rainfed, transplanted, mid-late planted rice, in IR64, and in hard soil without water, while *S. maritimus* was highest in irrigated, wet seeded, early planted rice, in IR42, and in fields with soft soil with standing water (Fig. 26). *Cynodon dactylon* was dense in hard soil regardless of water condition. In the second observation, *M. vaginalis* was still predominant, since it occurred in the most fields regardless of rice culture, type, planting method, or variety. *M. vaginalis* predominated in mid-early, mid-late, and late plantings, while *P. distichum* prevailed in early plantings. *M. vaginalis* was common in



26. Weeds below the rice canopy with high rating, by field feature, in the first observation of the first crop, 1987-88, in 3 Philippine provinces.

fields without water regardless of soil conditions, and in fields with soft soil with standing water while, *F. miliacea* predominated in hard soil with standing water. *E. glabrescens, P. distichum*, and *S. supinus* were next to *M. vaginalis* in predominance in irrigated, mid-early, transplanted rice, and in fields with soft soil with standing water. *C. dactylon* obtained the highest rating in rainfed and wet seeded ricefields, while *Azolla* sp. predominated in mid-late planting and in IR42.

Date of visit showed no difference in weed occurrence or density.

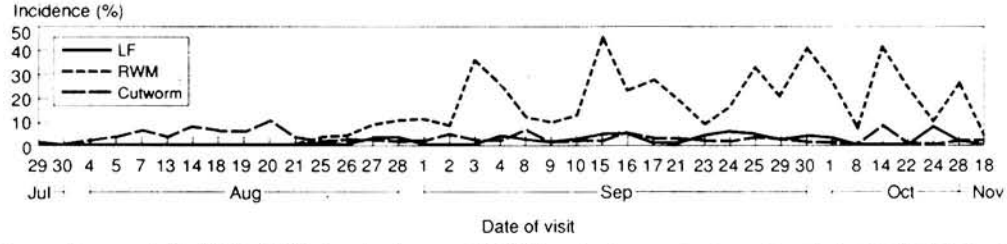
Herbicide use pattern. The density of weeds either above or below the crop canopy was not associated with herbicide use patterns in either observation.

Observation of insects in hill sample. In observation 1, cutworm damage was most prevalent, occurring in all fields sampled. It was followed by rice whorl maggot (RWM) damage, leaffolder (LF) damage, and deadheart (DH) at 80.7, 67.0, and 38.6%, respectively. The infestations were most prevalent in Nueva Ecija, in fields with soft soil with standing water, in transplanted rice, in irrigated rice, in IR64, and in fields at tillering. The number of infested fields was not associated with date of visit except for LF and RWM, which were generally observed only starting on the 11th day of the visit. In observation 2, fewer fields were infested. Cutworm and LF were most prevalent, followed by RWM and DH. There were more infested fields in Bulacan, in fields with soft soil with standing water, in transplanted rice, in irrigated rice, in IR42, and in fields at booting. The number of infested fields was not associated with the date of visit.

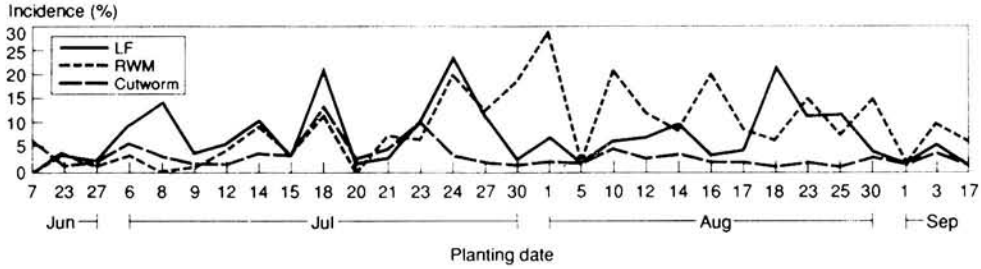
RWM had the highest mean incidence of 14.3% during the first field observation. Highest incidence was 24.7% in IR42. Incidence was also high in Pampanga, in fields with soft soil with standing water, in transplanted rice, in rainfed fields, and in fields at tillering. RWM was observed starting late August and became generally high in September to October. In contrast, cutworm remained low throughout the observation period (Fig. 27). It generally became high at later plantings, while RWM was low at all planting dates. In the second observation, RWM was also the highest, although it declined to an overall average of only 7.6%; 11.7% was recorded in IR66. RWM was high in Nueva Ecija and Bulacan, and LF in Bulacan alone. More RWM and LF damage was observed in fields with hard soil without water, in transplanted rice, in irrigated rice, and in fields at PI and booting. Incidence was not affected by date of visit. RWM was generally higher in later plantings, while cutworm remained low at all planting dates except 18 Jul and 23 Jul; LF was inconsistent (Fig. 28).

Observation of insects in 1-m²-area sample. Results during the first observation were similar to those from hill samples. In the second observation, cutworm and LF were the most prevalent, as in the hill samples, followed by RWM and whitehead (WH). All observed insects were most prevalent in Nueva Ecija, in fields with soft soil with standing water, in transplanted rice, in irrigated rice, and in fields at booting. Cutworm, LF, and WH were high in IR64, and RWM in IR42. In observation 3, the most prevalent insect was LF at 96.4%. Cutworm and WH followed, at 83.9 and 82.1%, respectively. LF and cutworm prevailed in Bulacan. More fields with soft soil without water, transplanted fields, irrigated fields, fields planted to IR42, and those with rice at the ripening to fully mature stage were infested with LF, cutworm, and WH.

The highest damage was caused by RWM at



27. Incidence of damage by leaffolder (LF), rice whorl maggot (RWM) and cutworm at various dates during the first observation of hill samples from the first crop, 1987-88, in 3 Philippine provinces.



28. Incidence of damage by LF, RWM, and cutworm by planting date during the second observation of hill samples from the first crop, 1987-88, in 3 Philippine provinces.

7.6% incidence in the first observation. RWM was highest regardless of province, water status, planting method, rice culture type, or variety. For growth stage, incidence was highest only at tillering and stem elongation. IR42 had the highest incidence at 13.4%. RWM incidence became high at mid-late and late planting dates. The overall highest average incidence in observation 2 was only 2.6%, recorded in LF; 7.4% was obtained in variety Super 42. Incidence in other field features could have been too low to detect. In observation 3, WH had the highest general mean incidence of 2.2%, although 13.5% LF was observed in fields with hard soil with standing water.

In 1-m^2 samples in all observations, the prevalence and incidence of insect damage were not associated with date of visit.

The prevalent insects occurred at almost all planting dates, but the common field count was only one on each date in all observations and in both hill and 1-m^2 samples.

Insect counts from sweeping and from water pan sampling are still being summarized.

Insecticide use pattern. Generally, the incidence of damage by insects was not associated with insecticide application in any observations from either hill or 1-m^2 samples.

Grain yield. Grain yield was not associated with insecticide use pattern. Considering weed control practices, fields with preemergence herbicide, regardless of postemergence herbicide treatment and spot weeding by hand, had slightly higher yields than those with postemergence herbicide alone or hand weeding alone or a combination. Fields with preemergence and postemergence herbicide + hand weeding yielded the best; those with neither herbicide application nor hand weeding yielded the lowest, as expected. Although the yield was higher in fertilized fields, it was not associated with frequency or time of fertilizer application. Likewise, rat and snail damage, lodging, and Zn deficiency did not affect yield. Comparing the harvest from a crop cut of 3 × 10 m^2/field with the harvest reported by farmers indicated that farmers tended to overestimate their yields, statistically.

Management of rice pests

Insects

Entomology, Plant Pathology, and Agricultural Economics Departments

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ECOLOGY AND BIOLOGY

Entomology Department

Food web of *Chilo* stem borers. Arthropod food webs show the diversity of natural enemies affecting insect pests of rice. Natural enemies in turn are preyed upon by secondary predators and parasitized by hyperparasites. In the Philippines, there are two stem borers (SB) within the genus *Chilo*: *suppressalis* (Walker) and *auricilius* Dudgeon. A third species, the darkheaded SB *Chilo polychrysus*, occurs in other Asian countries. As far as is known, all three *Chilo* SBs share the same complex of natural enemies.

The food web of the two *Chilo* SBs in the Philippines comprises 111 species: 57 predators, 33 parasitoids, 18 hyperparasitoids, and 28 secondary predators (25 spiders double as predators and secondary predators) (Fig. 1). The dominant predators are spiders (25), odonatans (9), beetles (7), and orthopterans (6). Ants prey on all stages except the adult, and earwigs feed on the larvae and pupae. The predominant egg parasitoids are the trichogrammatids. Most braconids and ichneumonids are larval parasitoids, although some ichneumonids are larval-pupal parasitoids. The eulophid *Tetrastichus ayyari* is a pupal parasitoid. The 46 species of secondary natural enemies are primarily hymenopterans, attacking spiders, the meadow grasshopper, and coccinellids.

Biology of the short-horned grasshopper. The short-horned grasshopper *Oxya hyla intricata* (Stal) is one of two subspecies of *O. hyla*. It was reported that among the 17 species of genus *Oxya*, only 2 are found in the Philippines. These are *O. hyla intricata* and *O. japonica japonica*. They are known to be pests of rice, sugarcane, and other crops. They damage crops to a lesser degree than *Locusta migratoria manilensis*.

O. hyla intricata may be cultured in the insectary in wooden cages with top and sides covered with fiberglass screen (50 × 50 × 70 cm) (Fig. 2).

Eggs are deposited in clusters on the leaf blades. They hatch in 26-34 d. The nymphs undergo 7 instars of from 5 to 19 d each (Table 1). Some, however, become adults after the 5th or 6th instar. The life cycle is shown in Figure 3.

Adult longevity is 19-138 d for males and 21-146 d for females. The female lays eggs in pods of 2-24 at intervals of 1-11 d.

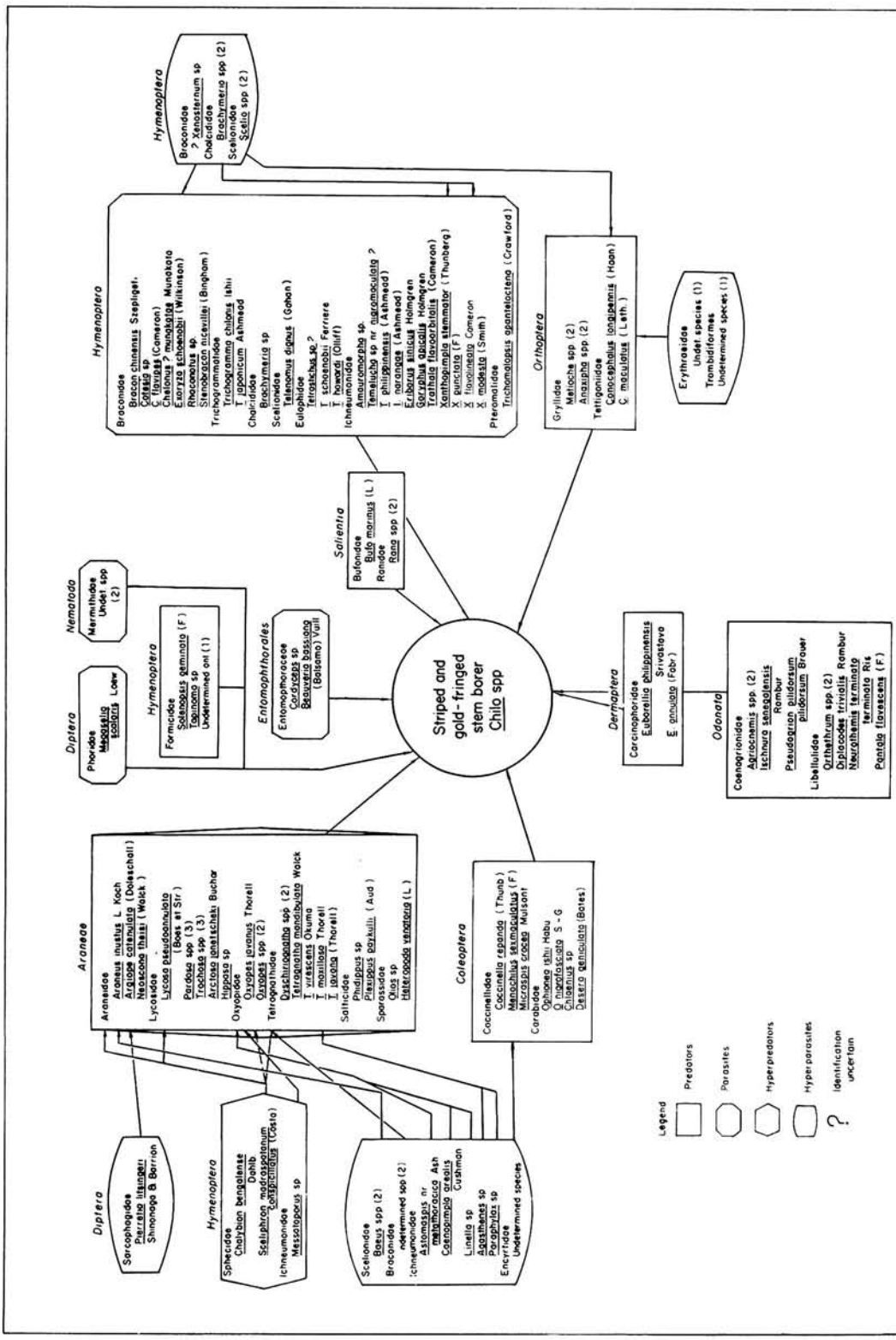
Six parasitoids were recorded attacking the eggs of *O. hyla intricata*: *Pediobius* sp. (Eulophidae), *Platyscelio abnormis* (Scelionidae), *Gonatocerus* sp. (Mymaridae), *Aphelinus* sp. (Aphelinidae), *Anastatus* sp. (Eupelmidae), and *Eurytoma* sp. (Eurytomidae). Egg parasitization rates at various localities are shown in Table 2.

Life history and host range of *Sogatodes pusanus*. *Sogatodes pusanus* (Dist.) is often confused with the more common *Sogatella furcifera* (Horvath) in ricefields. We studied the development of these 2 species on 15 common ricefield plants from 3 families: Poaceae (9), Cyperaceae (5), and Sphenocleaceae (1). Individual host plants were caged in mylar cages with side and top vents. Survivorship, growth index, fecundity, and life cycle duration of five pairs of newly emerged adults were determined.

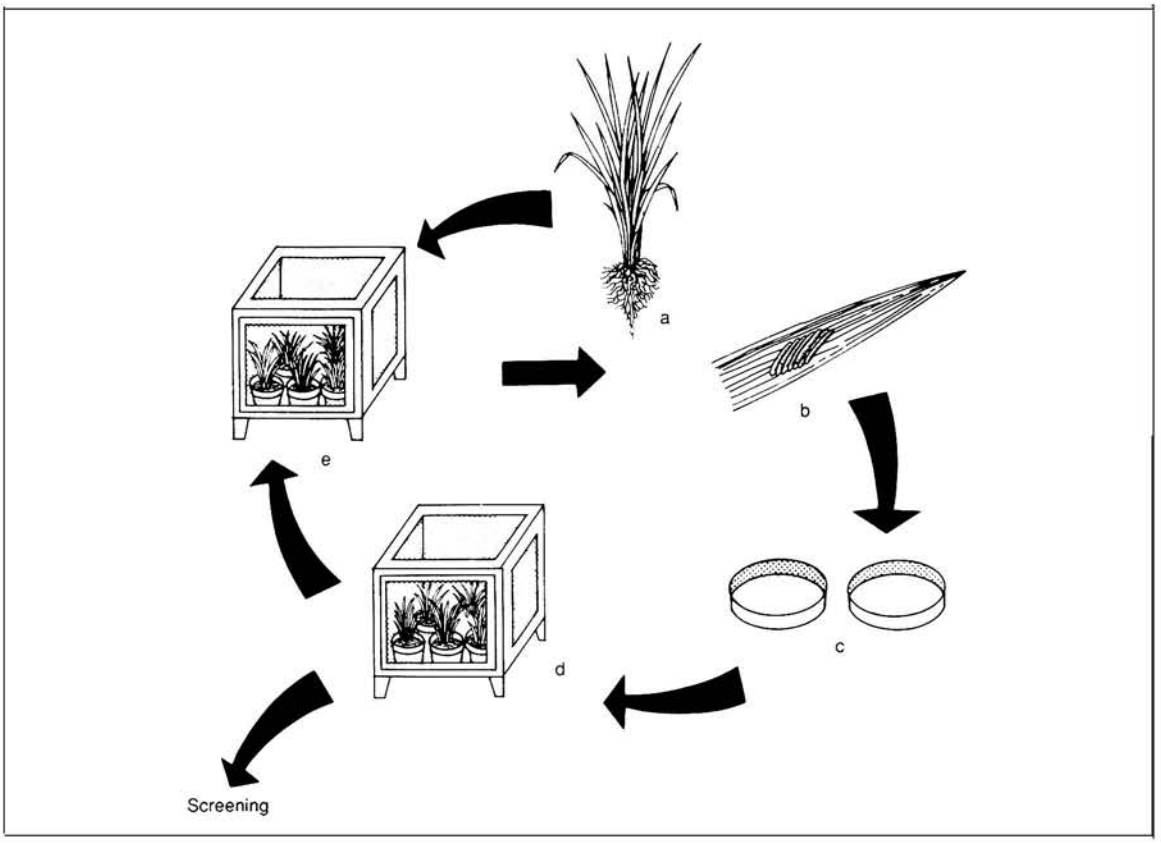
Sogatodes pusanus completed its life cycle only on *Echinochloa* spp. (Table 3). On *Echinochloa colona*, development from egg to adult took 19.7 ± 0.6 d with an incubation period of 7.5 ± 0.5 d; stadium I, 3.0 ± 0.7 d; stadium II, 3.3 ± 0.4 d; stadium III, 2.6 ± 0.8 d; and stadium IV, 3.3 ± 0.5 d. Survival was 88 ± 5%. On *E. crus-galli* ssp. *hispidula*, development took 20.1 ± 1.6 d with a similar incubation period and 4 stadia: stadium I, 3.3 ± 0.6 d; stadium II, 3.3 ± 0.5 d; stadium III, 2.6 ± 0.4 d; and stadium IV, 3.3 ± 0.5 d. Survival was 84 ± 4%. Longevity of adults in both host plants was 5.6 ± 1.6 d. All the host plants tested including rice (TN1) served as ovipositional hosts.

Sogatodes pusanus feeds on *Echinochloa* but not on rice. A colony of 100 adults can cause hopperburn in a plant with 10 tillers in 5-7 d.

Black bug biology and alternate hosts. Two hundred black bug adults collected from farmers' fields were caged overnight for egg laying on potted TN1 plants in a greenhouse at the Palawan National Agricultural College. The incubation period of eggs kept in petri dishes lined with moist filter paper was recorded. The number and duration of instars were recorded by caging 136 newly emerged nymphs individually on 15-d-old potted TN1 plants. Preoviposition period, fecundity, and longevity were determined from 49 individual pairs of males and females caged on 20-d-old TN1 plants. In a separate test, newly emerged 1st instars were caged on selected plants as possible alternate hosts.



1. Food web of striped stem borer *Chilo suppressalis* (Walker) and gold-fringed borer *Chilo auricilius* Dudgeon in the Philippines. IRRI, 1988.



2. A simple rearing technique for *Oxya* sp. a) Field-collected grasshopper, b) leaf blade contains egg pod, c) petri dishes for egg stage, d) rearing cage (50 x 50 x 70 cm), and e) oviposition cage (50 x 50 x 70 cm). IRRI, 1988.

Average incubation, nymphal development, and preoviposition periods were 5, 47, and 21 d, respectively (Table 4). A female adult laid 265 eggs with 97% hatchability. Both males and females could live for about 110 d. Black bug nymphs completed their life cycle on plants of *Colocasia* sp., *Zea mays, Alocasia mycorhiza, Leersia hexandra*, and *E. crus-galli*.

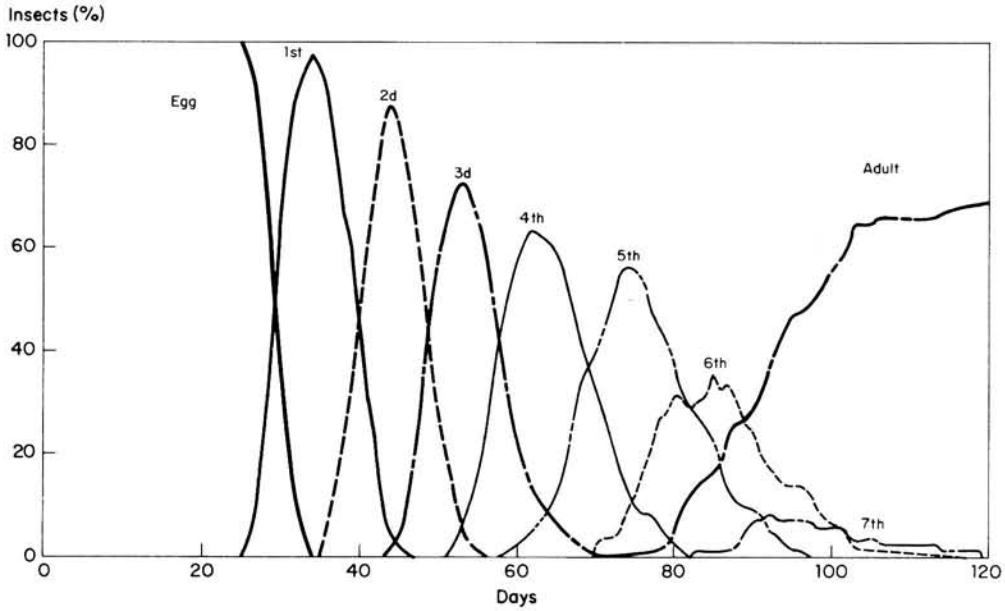
Table 1. Developmental stages of *Oxya hyla intricata*. IRRI, 1988.

Stage		Range (d)	Mean (d)	Standard deviation
Egg[a]		26-34	29.84	1.95
Nymphs:	1st instar	7-15	10.60	1.87
	2d instar	6-17	8.92	1.98
	3d instar	5-17	9.34	2.35
	4th instar	5-18	11.16	2.39
	5th instar	6-18	12.23	2.59
	6th instar	9-19	13.61	2.37
	7th instar	10-15	12.56	1.67
Adult[b]:	Male	19-138	58.28	32.33
	Female	21-146	74.48	35.76
Preoviposition period[c]		10-15	12.35	1.35

[a] n = 87. [b] n = 25. [c] n = 20.

Table 2. *Oxya hyla intricata* egg parasitization. IRRI, 1988.

Location	Egg pods exposed (no.)	Egg pods parasitized (no.)	Parasitization (%)
IRRI	205	189	92
Lumban, Laguna	5	5	100
Bay, Laguna	10	1	10
Pagsanjan, Laguna	2	2	100
Masapang, Victoria, Laguna	12	8	67
Guimba, Nueva Ecija	19	5	26
Zaragoza, Nueva Ecija	26	9	35



3. Life cycle of *Oxya hyla intricata*. IRRI, 1988.

Table 3. Host range of *Sogatodes pusanus*. IRRI greenhouse, February 1988.

Plant species	Eggs laid (no./5 females)	Egg viability[a] (%)	Survival from nymph to adult[b] (%)	Growth index[c]
Poaceae				
Echinochloa colona (L.) Link	245.7 ± 86.6 a	80.1 ± 9.9 a	87.5 ± 4.9 a	5.7 ± 0.8 a
E. crus-galli (L.) Beauv. ssp. *hispidula* (Retz.) Honda	138.2 ± 61.9 b	76.2 ± 9.1 b	83.7 ± 3.6 a	5.1 ± 0.6 a
Paspalum conjugatum Berg.	44.7 ± 36.4 c	0	0	0
Leptochloa chinensis (L.) Nees	26.2 ± 17.7 d	0	0	0
Oryza sativa L.	25.5 ± 23.3 d	0	0	0
Panicum repens L.	23.5 ± 9.7 d	0	0	0
Chloris barbata Sw.	23.0 ± 2.1 d	0	0	0
Brachiaria mutica (Forsk.) Stapf.	11.7 ± 7.9 d	0	0	0
Eleusine indica (L.) Gaertn.	11.2 ± 9.2 d	0	0	0
Cyperaceae				
Cyperus brevifolius (Rottb.) Hassk.	9.0 ± 3.6 d	0	0	0
Fimbristylis miliacea (L.) Vahl	7.4 ± 3.0 d	0	0	0
C. iria L.	4.0 ± 1.6 d	0	0	0
C. kyllingia Endl.	3.2 ± 2.7 d	0	0	0
C. rotundus L.	2.8 ± 1.5 d	0	0	0
Sphenocleaceae				
Sphenoclea zeylanica Gaertn.	16.3 ± 13.6 d	0	0	0

[a] $\text{Egg viability (\%)} = \frac{\text{eggs hatched (no.)}}{\text{eggs laid (no.)}} \times 100$

[b] $\text{Survival (\%)} = \frac{\text{nymphs (no.) becoming adults}}{\text{eggs hatched (no.)}} \times 100$

[c] $\text{Growth index} = \frac{\text{survival (\%)}}{\text{mean developmental period (d)}}$

Table 4. Duration of developmental stages, longevity, and fecundity of black bug *Scotinophara coarctata* on TN1 rice plants.[a] IRRI, Palawan, 1988.

Character	Av ± standard error	Range
Developmental period (d)		
Incubation period	5.3 ± 0.4	4-8
1st instar	4.2 ± 0.6	3-5
2d instar	9.8 ± 1.3	8-11
3d instar	8.7 ± 2.2	6-11
4th instar	11.3 ± 2.7	8-14
5th instar	13.0 ± 3.0	10-16
Nymph to adult	47.0 ± 3.3	43-50
Preoviposition period (d)	20.7 ± 7.8	13-29
Male longevity (d)	110.9 ± 23.2	87-134
Female longevity (d)	109.4 ± 24.2	85-133
Fecundity (eggs [no.]/♀)	265.8 ± 109.7	156-376
Egg masses (no.)/♀	6.7 ± 2.5	4-9
Hatchability (%)	88.7 ± 8.8	79-98

[a] n = 136.

Host range of the armyworm. We evaluated the development of *Spodoptera mauritia acronyctoides* Guenée on 33 common plant species from families Poaceae (22), Cyperaceae (8), Commelinaceae (1), Onagraceae (1), and Pontederiaceae (1). Individual host plants were kept in mylar cages with side and top vents. Ten neonate larvae were released per cage, and host suitability was determined based on three biological parameters: survival, growth index, and duration of life cycle (Table 5).

In a separate setup, a pair of 3- to 5-d-old pupae was placed inside a mylar cage containing an individual host plant. Honey solution (10%) was provided as food for the moths. Ovipositional preference and fecundity were determined.

The adult chose 11 species (33%) for oviposition. The order of preference was rice >*E. glabrescens* > *E. indica* > *Paspalum conjugatum* > *P. paspalodes*. The larvae had a wider host range and completed development on 24 (73%) plant species. Rice was the best host, with the highest insect survival percentage (50%) and growth index (1.7). It supported a life cycle of 33 d, followed by *Digitaria* > *Eleusine* = *Cynodon* = maize.

Thirteen host plants where moths failed to oviposit supported complete development of *S. mauritia acronyctoides* larvae. Larval development, however, was longest (31-46 d) under these hosts except in *C. dactylon* (29 d).

Nine species—three each of Poaceae and Cyperaceae and one each of Commelinaceae, Onagraceae, and Pontederiaceae—were not acceptable hosts.

Color polymorphism in the armyworm. Identification of field-collected larvae of the armyworm *S. mauritia acronyctoides* is often difficult because of color polymorphism. We reared newly hatched larvae individually on TN1 rice up to the last instar and monitored daily color changes based on seven abdominal areas: three dorsal (median, subdorsal, and dorsolateral) and four lateral (laterodorsal, midlateral, laterobasal, and basal).

The first and second larval instars have green bodies. However, the second instar is reddish-violet posteriorly.

The third-instar larvae exhibited four color morphs. The first was yellow-green with brownish violet laterodorsal (L2) and pinkish laterobasal areas. The rest of the color morphs were a combination of green, dull brown, brownish violet, and brownish green. The laterodorsal (L2) and laterobasal (L3) color bands were the most stable in the four color morphs observed (Table 6). Traces of subdorsal black lunar spots were already discernible on color morphs II and III.

Five color morphs ranging from brown to green to pink-violet were exhibited by the fourth and fifth larval instars (Table 7). The black sublunar spots were prominent subdorsally on the first three color morphs but were replaced by a thin black line on the fourth color morph. Lunar spots broadened on the 5th color morph. In the fourth and fifth instars, the laterodorsal black band was consistent in all five color morphs.

Rearing method for the armyworm on graminaceous plants. To track the development of individuals, workers often rear armyworms in petri dishes with moistened paper towels and cut rice leaves. This method can be unsatisfactory and unreliable, because it entails daily changing of plants and removal of feces. Larval survival is often unsatisfactory. We designed a setup (Fig. 4) to culture this insect in the laboratory.

A host plant was uprooted and tillers separated and wrapped with moistened cotton. Each tiller was placed in a 10.5 × 2.5 cm test tube with a cardboard plug to prevent the larvae from drowning. Each plant was enclosed in a small cylindrical

Table 5. Host range of *Spodoptera mauritia acronyctoides*.[a] IRRI greenhouse, Jul-Nov 1988.

Plant species	Survival[b] (%)	Growth index[c]	Duration of life cycle[d] (d)	Eggs laid (no./female)
Poaceae				
Oryza sativa L.	50.0 a	1.7 j	33.0	144.3 e
Digitaria ciliaris (Retz.) Koel.	34.0 f	1.2 i	30.4	0 a
Eleusine indica (L.) Gaertn.	30.0 ef	1.1 hi	30.6	54.6 c
Cynodon dactylon (L.) Pers.	28.0 ef	1.1 hi	29.0	0 a
Zea mays L.	27.0 ef	0.9 ghi	32.0	4.8 a
Paspalum conjugatum Berg.	26.0 def	0.9 ghi	36.3	49.4 c
Leptochloa chinensis (L.) Nees	24.0 def	0.8 fgh	34.0	0 a
P. paspalodes (=*P. distichum* L.)	15.0 bcd	0.4 b-e	38.3	31.8 bc
Triticum aestivum L.	15.0 bcd	0.5 c-f	30.6	0 a
Paspalidium flavidum (Retz.) A. Cameron	11.0 abc	0.3 a-d	35.0	0 a
Echinochloa colona (L.) Link	7.0 ab	0.1 ab	38.2	24.3 ab
Brachiaria distachya (L.) Stapf.	6.0 ab	0.1 ab	43.0	7.5 a
E. crus-galli (L.) Beauv. ssp. *hispidula* (Retz.) Honda	4.0 ab	0.1 ab	33.0	3.0 a
E. glabrescens Munro ex Hook f.	4.0 ab	0.1 ab	39.2	81.5 d
Eriochloa procera (Retz.) C. E. Hubb.	4.0 ab	0.1 ab	40.0	1.0 a
Paspalum scrobiculatum L.	3.0 a	0.1 ab	42.0	0 a
Rottboellia cochinchinensis (Lour.) Clayton	3.0 a	0.1 ab	45.6	0 a
Chloris barbata Sw.	2.0 a	0.1 ab	45.0	0 a
Dactyloctenium aegyptium (L.) Beauv.	1.0 a	0.1 ab	40.0	0 a
Bambusa sp.	0 a	0 a	0	0 a
Imperata cylindrica (L.) Beauv.	0 a	0 a	0	0 a
Unidentified Poaceae	0 a	0 a	0	0 a
Cyperaceae				
Cyperus kyllingia Endl.	23.0 def	0.7 efg	38.3	0 a
Cyperus sp. 1	20.0 cde	0.6 d-g	38.0	0 a
C. brevifolius (Rottb.) Hassk.	7.0 ab	0.2 abc	33.0	0 a
Fimbristylis miliacea (L.)	4.0 ab	0.1 ab	38.0	0 a
C.	2.0 a	0.1 ab	40.0	2.5 a
C. difformis L.	0 a	0 a	0	0 a
C. rotundus L.	0 a	0 a	0	0 a
Cyperus sp. 2	0 a	0 a	0	0 a
Commelinaceae				
Commelina benghalensis L.	0 a	0 a	0	0 a
Onagraceae				
Ludwigia octovalvis (Jacq.) Raven	0 a	0 a	0	0 a
Pontedereaceae				
Monochoria vaginalis (Burm. f.) Presl.	0 a	0 a	0	0 a

[a] Av of 10 replications. Means followed by a common letter are not significantly different at the 5% level by DMRT.

[b] $\text{Survival} = \frac{\text{Larvae (no.) becoming pupae}}{\text{Total no. of larvae infested}} \times 100$

[c] $\text{Growth index} = \frac{\text{No. of larvae becoming pupae}}{\text{Mean developmental period (d)}}$

[d] $n = 10$.

mylar cage with nylon mesh vents on the side and top. Nylon mesh was attached to the base of the mylar cylinder to trap feces. We used a camel's hair brush to place a first-instar larva on each plant. The caged plants were held upright in a compartmentalized 47 × 85 cm² seedbox accommodating 60 setups.

With this procedure, plants were replaced every 3 d. The average pupation percentage of *S. mauritia acronyctoides* larvae was 3.3 times higher

Table 6. Color polymorphism in the 3d larval instar of *S. mauritia acronyctoides*. IRRI greenhouse, Jun-Jul 1988.

Abdominal area	Color morph			
	I	II	III	IV
Dorsal				
D1 (median)	Yellow-green	Green	Dull brown	Brown
D2 (subdorsal)	Yellow-green	Dark green with traces of black spots	Brown with traces of black spots	Green
D3 (dorsolateral)	Yellow-green	Green	Dull brown	Dull green
Lateral				
L1 (midlateral)	Yellow-green	Green	Dull brown	Dull green
L2 (laterodorsal)	Brownish violet	Brownish violet	Brownish violet	Brownish violet
L3 (laterobasal)	Pinkish	Pinkish	Pinkish	Pinkish
L4 (basal)	Yellow-green	Green	Brown	Green

Table 7. Color polymorphism in the 4th and 5th larval instars of *S. mauritia acronyctoides*. IRRI greenhouse, Jun-Jul 1988.

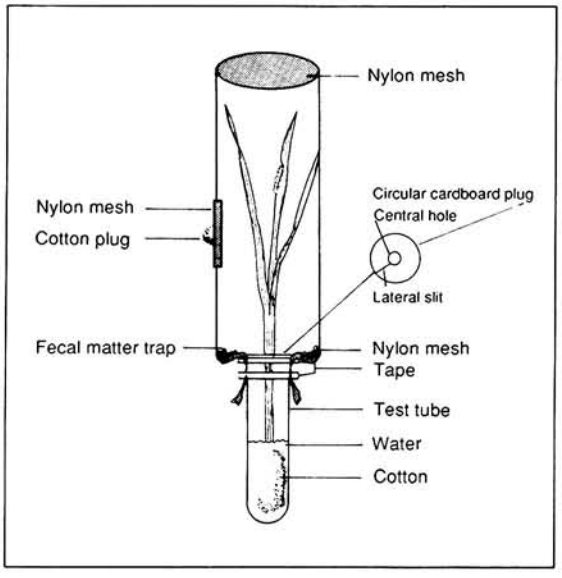
Abdominal area	Color morph				
	I	II	III	IV	V
Dorsal					
D1 (median)	Greyish brown	Dull brown	Dull brown	Tinged with pink and violet	Tinged with pink and violet
D2 (subdorsal)	Very black sublunar	Dirty brown with black lunar spots	Dirty brown with black lunar spots	Greenish with thin black line beneath lunar spots	Dark green with 4 black spots on 1/3 of body anteriorly
D3 (dorsolateral)	Light grey	Dull green	Dull brown	Dull green	Dull green
Lateral					
L1 (midlateral)	Dark greyish brown beneath is light greyish brown	Dark green and beneath is a dull green line	Tinged with green and brown	Greenish	Dark green and dull green beneath
L2 (laterodorsal)	Black	Black	Black	Black	Black
L3 (laterobasal)	Greyish brown	Dull brown	Dull brown	Dark pinkish violet	Dark pinkish violet
L4 (basal)	Dark greenish	Dull greenish	Brownish green but more of green	Greenish	Dark green

(86%) in the new method than in the petri dish technique (26%) (Table 8).

Ecology of arthropod communities. Studies were begun on arthropod communities in the lowland rice environment. The arthropod population of an IRRI field plot planted to IR66 was sampled periodically with an arthropod cone sampler during two crops, the first planted during February and the second in July. At each sampling, 20 random samples consisting of 2 hills each were taken.

The composition of the arthropods in both crops was similar. Class Insecta was represented by eight orders. Order Hemiptera constituted more than 80% of the total arthropods found. Class Arachnida constituted about 10%. In the order Hemiptera, pest species were more dominant (about 60%) than predator species (Fig. 5).

Arthropod colonization and establishment were similar in both cropping periods. Although colonization was earlier in the first crop by a few days, species diversity by the Shannon-Weiner Index—$H(s)$—in both cropping periods was similar (Fig. 6). A lower $H(s)$ implies lower species diversity. The index seemed to converge on a value of around 2 at 3 wk after transplanting (WT).



4. Rearing method for armyworm. IRRI, 1988.

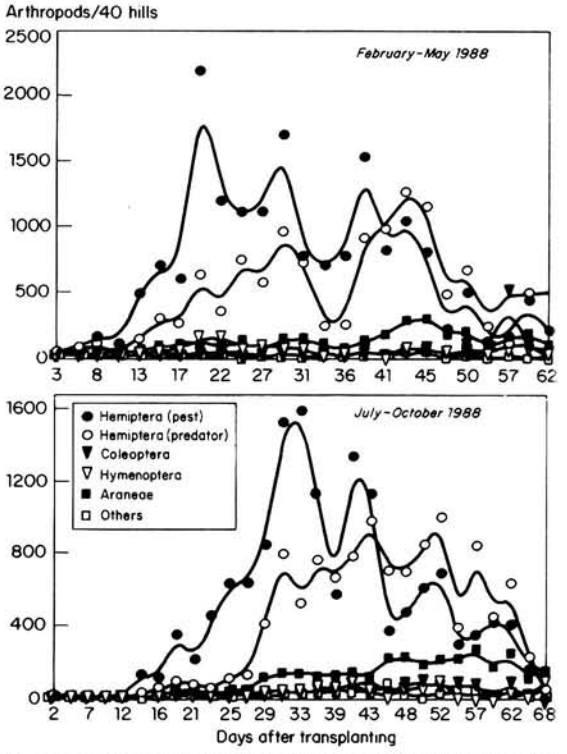
Table 8. Pupation percentage of *S. mauritia acronyctoides* reared on graminaceous host plants.[a] IRRI laboratory and greenhouse, Jun-Jul 1988.

Plant	Pupation (%)	
	Petri dish method	Whole plant method
Oryza sativa L.	0	100
Echinochloa glabrescens Munro ex Hook f.	20	100
E. colona (L.) Link	40	100
Brachiaria distachya (L.) Stapf.	20	80
E. crus-galli (L.) Beauv. ssp. *hispidula* (Retz.) Honda	40	80
Paspalum conjugatum Berg.	40	80
Leptochloa chinensis (L.) Nees	20	60
Mean	26	86

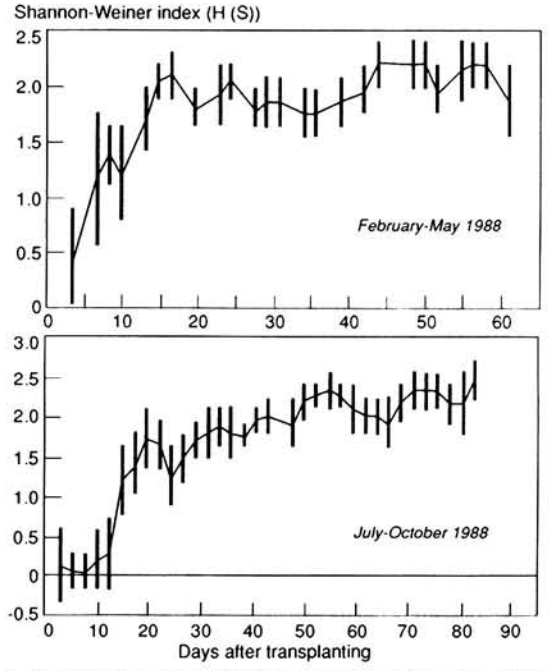
[a] Av of 5 replications.

Similar samples taken from various locations in Luzon also showed differences in *H(s)* at different crop stages (Table 9).

Arthropod populations in weeded and unweeded fields. In weeded and unweeded fields of IR66, green leafhopper (GLH) populations were higher than those of brown planthopper (BPH). Peaks were observed at 3 and 6 WT in weeded fields; only one peak was seen in unweeded fields (Fig. 7).



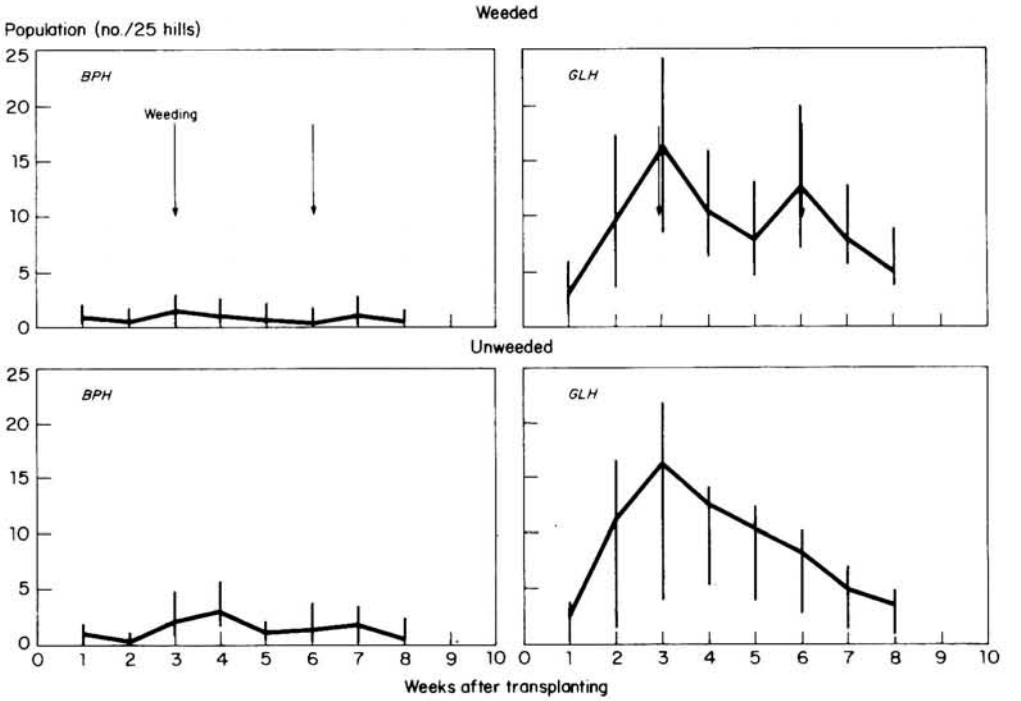
5. Arthropod density patterns in 2 crops of IR66 grown under submerged conditions. IRRI, 1988.



6. Species diversity on IR66 in a flooded environment. IRRI, 1988. Bars indicate standard deviation.

Table 9. Index of species diversity [H(s)] at different locations on Luzon, Philippines, Mar-May 1988.

Location and elevation (m above sea level)	Species diversity [H(s)] at given crop growth stage		
	Vegetative	Flowering	Heading
IRRI, Laguna (21)	1.65 ± 0.27	2.02 ± 0.19	2.41 ± 0.21
Bayombong, Nueva Vizcaya (305)	1.17 ± 0.42	1.97 ± 0.21	1.52 ± 0.30
Ambahag, Lagawe, Ifugao (732)	0.68 ± 0.48	1.47 ± 0.36	1.99 ± 0.49
Nagakadan, Lagawe, Ifugao (1067)	0.99 ± 0.53	1.61 ± 0.48	2.36 ± 0.22
Banawe, Ifugao (1372)	0.85 ± 0.50	1.13 ± 0.30	1.21 ± 0.57



7. Brown planthopper (BPH) and green leafhopper (GLH) populations in weeded and unweeded ricefields. IRRI, 1988.

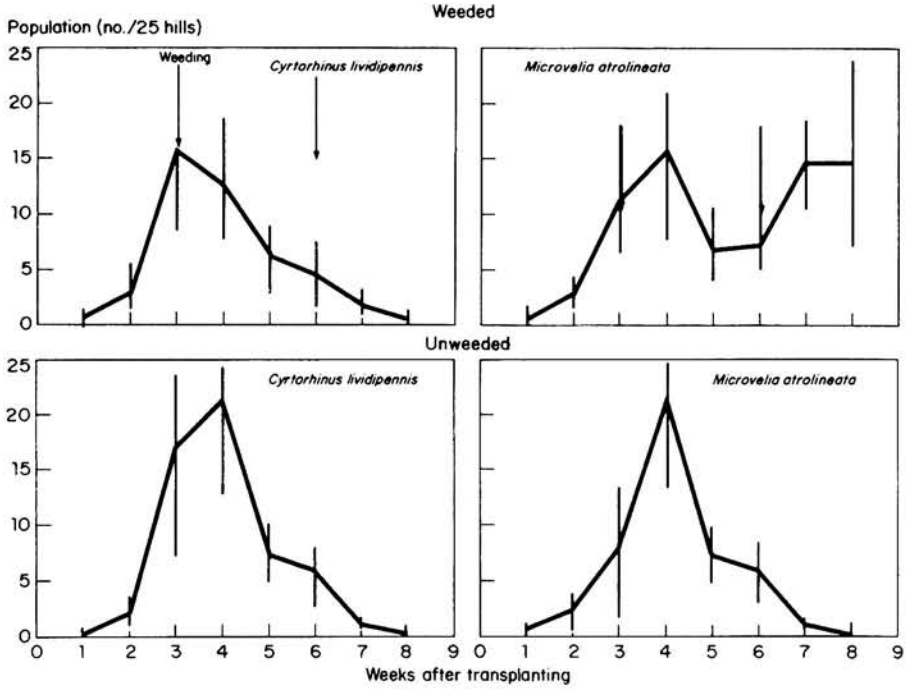
However, no significant difference in GLH density was recorded. *Cyrtorhinus* sp. and *Microvelia* populations are shown in Figure 8.

Yellow stem borer moth sampling and distribution. We compared numbers of yellow stem borer moths that were captured in ricefields with 10 sweeps of a sweep net (28 cm diameter) with those flushed from 10 m^2 by brushing the tops of plants with an elbowed stick (1 m long). An equal amount of time was required for each method, and there was no significant difference in number of moths detected by flushing (120) or sweeping (103) in 12 samples for each method in a heavily infested field.

We sampled 15 fields at periodic intervals during the day to determine the optimum sampling time. Significantly more moths were detected at sunset than at any other time. Also, more moths (60%) were captured in field borders that were open than in those that were shaded by trees.

Moths collected within fields and from weedy borders (within 1 m of field edge) were dissected to determine their reproductive status. More moths with mature ovaries were found near the borders, while more with depleted ovaries were found within the fields.

Sampling of arthropods in flooded rice. Systematic (SS), simple random (RS), and stratified



8. *Cyrtorhinus* and *Microvelia* populations in weeded and unweeded ricefields. IRRI, 1988.

random (SRS) sampling procedures were compared for estimation of population densities in rice of BPH *Nilaparvata lugens*; whitebacked planthopper (WBPH) *Sogatella furcifera*; GLH *Nephotettix virescens, N. nigropictus*, and *N. malayanus*; the mirid *Cyrtorhinus lividipennis*; and spiders *Lycosa pseudoannulata, Tetragnatha* spp., *Oxyopes* spp., and *Callitrichia* spp. The experiments were conducted in the 1988 dry season (DS) in Victoria, Laguna (at 27, 35, 64, and 80 d after transplanting [DT]); Guimba, Nueva Ecija (at 17, 25, 40, and 58 DT); and Zaragoza, Nueva Ecija (at 11, 24, 45, and 62 DT). Thirty samples per plot were collected using the FARMCOP sampler during the active tillering, maximum tillering, grain filling, and milk stages.

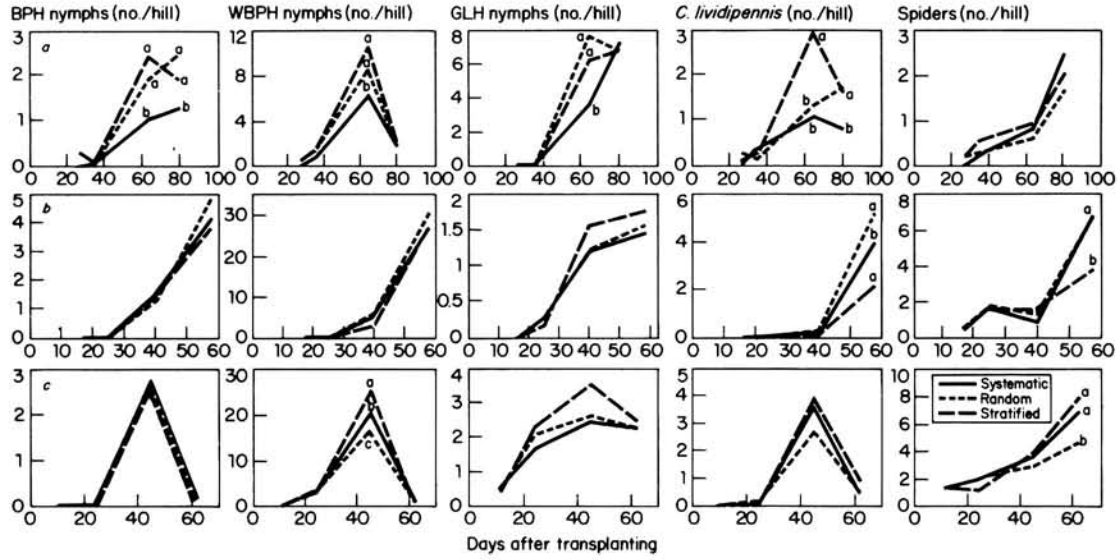
Population densities of the hoppers and predators at all sampling sites were generally low. In samples with higher densities, most species distributions approximated the negative binomial.

There were generally no significant differences in estimates of all arthropods, regardless of the sampling procedure followed, with some exceptions. In Victoria, BPH, WBPH, and GLH estimates from SS were significantly lower than those from RS and SRS at grain filling (Fig. 9). The same was true for BPH and *C. lividipennis* estimates from SS at the milk stage (Fig. 9). Estimates from SRS were significantly higher at grain filling. On the other hand, estimates of spiders from SRS were lower at the milk stage (Fig. 9). The growth stage at which samples are taken appears to have no effect on the efficiency of the sampling procedures.

PHYSIOLOGY AND BEHAVIOR

Entomology Department

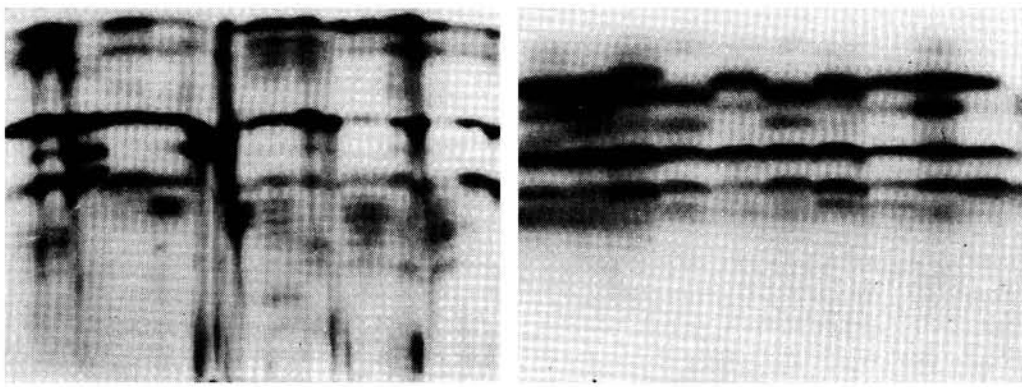
Isozyme differentiation of two rice leaffolders. Two rice leaffolders (LF), *Cnaphalocrocis medinalis* and *Marasmia patnalis*, are usually found in association on rice plants. Studies on the comparative biology and population dynamics of these species when they are sympatric require precise identification of their larvae and pupae, which are similar in morphology and are difficult to differentiate. The spinning and feeding behaviors of the two species on rice plants are also very similar.



9. Comparison of 3 sampling procedures for estimating mean numbers of BPH, WBPH, GLH, *C. lividipennis*, and spiders in flooded rice. Victoria (a), Guimba (b), Zaragoza (c), Philippines, 1988. Lines having the same letter are not significantly different at the 5% level by DMRT.

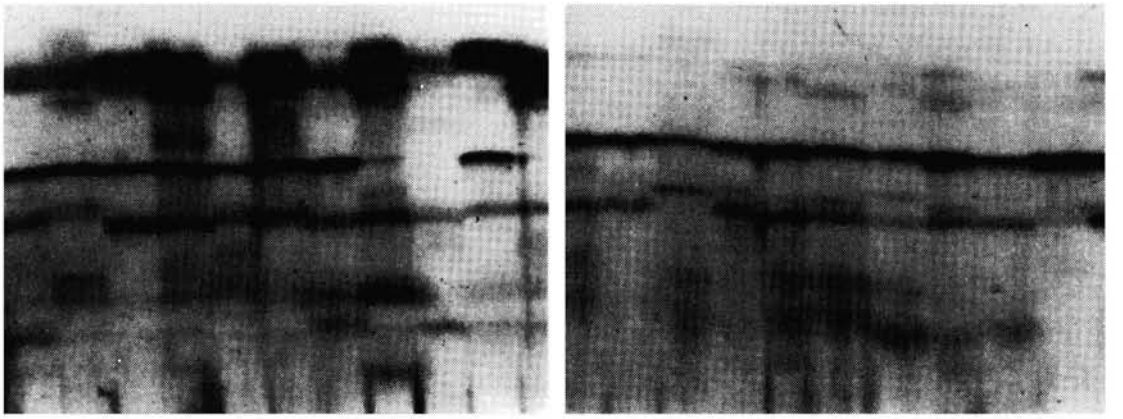
We used horizontal starch gel electrophoresis of soluble isozymes as a rapid method to distinguish the larvae and pupae of the two LFs. In a survey of 10 enzyme systems, consistent electrophoretic differences were found in 2: isocitric dehydrogenase (IDH) and esterase (EST) (Fig. 10, 11). Second- to fifth-instar larvae and pupae of the two species were accurately identified with IDH and EST. The use of electrophoresis proved to be a valuable technique for the precise identification of *C. medinalis* and *M. patnalis* larvae and pupae collected from ricefields.

Attraction of lepidopterous larvae to colored surfaces. The responses of first-instar larvae of rice LFs *C. medinalis* (Guenée) and *M. patnalis* Bradley, and of rice SBs *Scirpophaga incertulas* (Walker) and *Chilo suppressalis* (Walker) were tested on several colored surfaces with known reflectance spectra (Fig. 12). Results for 11 colors tested against a blank and a leaf cut of a preferred



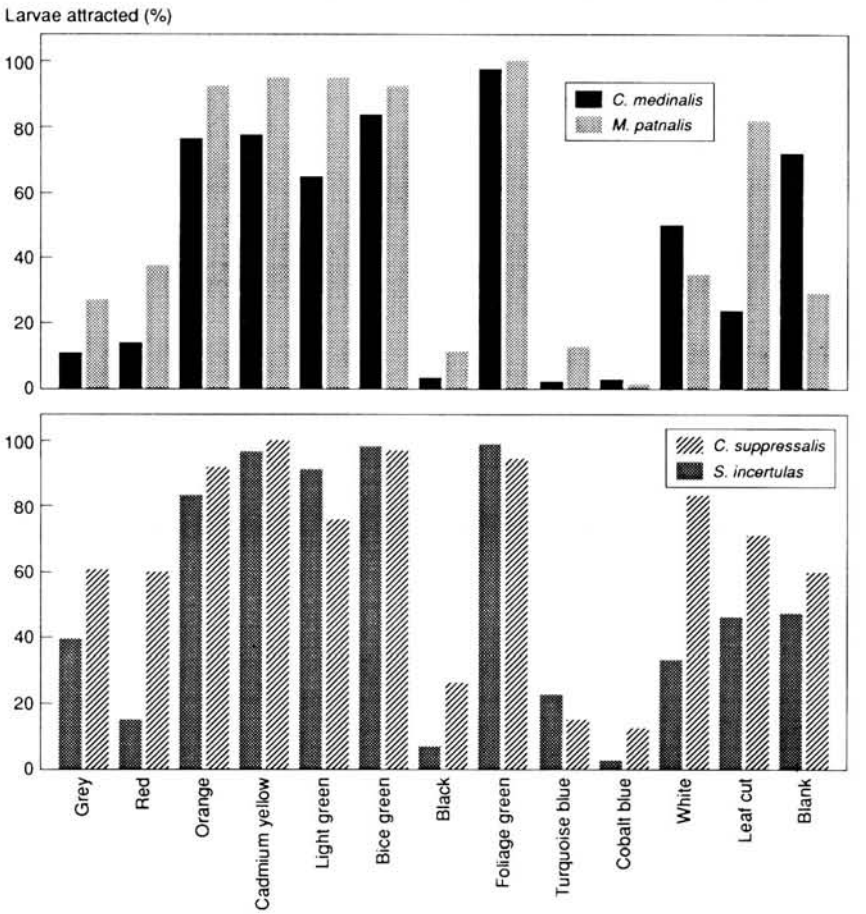
C. medinalis *M. patnalis*

10. Esterases of the fifth-instar larvae of *C. medinalis* and *M. patnalis*. IRRI, 1988.



C. medinalis *M. patnalis*

11. Esterases of the pupa of *C. medinalis* and *M. patnalis*. IRRI, 1988.



12. Percentage of first-instar larvae of leaffolders (LF) *C. medinalis* and *M. patnalis* and stem borers *C. suppressalis* and *S. incertulas* attracted by 11 colors of known reflectance spectra tested against an IR36 leaf cut and a blank control. IRRI, 1988.

rice variety revealed that foliage green, bice green, and cadmium yellow were the most attractive to *C. medinalis*. All these colors were significantly more attractive than the blank or the leaf cut. Light green and white were also attractive, but less so than the leaf cut. Red, grey, black, cobalt blue, and turquoise blue were least attractive, even less so than the blank. For similarly tested *M. patnalis*, foliage green has 100% larval attraction. Cadmium yellow, light green, bice green, and orange were also significantly more attractive than the blank or the leaf cut, while grey, turquoise blue, black, and cobalt blue attracted even fewer larvae than the blank.

Cadmium yellow proved to be more attractive to *Chilo suppressalis*, attracting 100% of the larvae, than to *S. incertulas*. Bice green, foliage green, orange, white, light green, and grey also attracted more larvae than the leaf cut or the blank, on the average. Red attracted almost the same number of larvae as the blank. Black, turquoise blue, and cobalt blue were least attractive, drawing even fewer larvae than the blank. For *S. incertulas*, bice green and foliage green were the most attractive, attracting 99% of the larvae on the average. Cadmium yellow and orange attracted more larvae than either the leaf cut or the blank. For this species of SB, the blank and the leaf cut attracted almost the same number of larvae. Grey, white, turquoise blue, red, black, and cobalt blue were least attractive, drawing fewer larvae than either the leaf cut or the blank.

The results of this study will be useful in determining which colors are suitable for trapping first-instar larvae from infested rice plants.

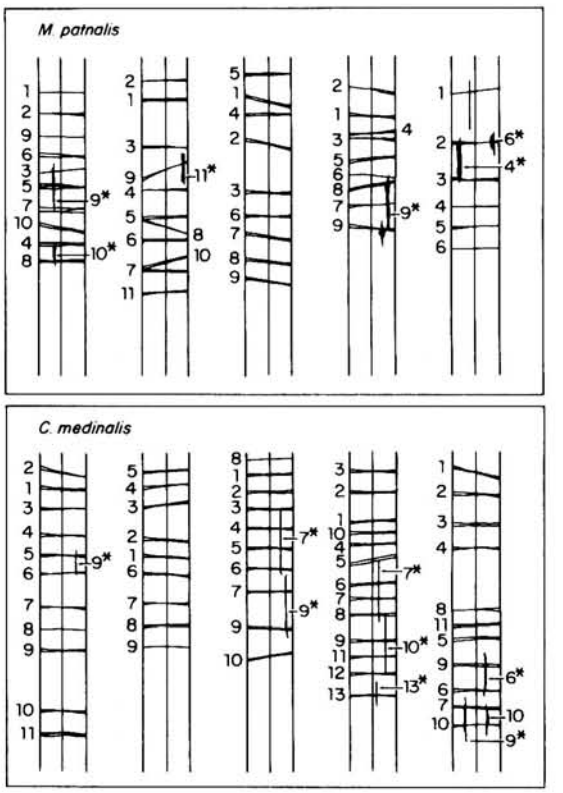
Spinning behavior of two rice leaffolders. We compared the spinning behavior of the rice LFs *C. medinalis* (Guenée) and *M. patnalis* Bradley. *C. medinalis* larvae made 5-11 stitch sets in 0.3 to 8.1 min, while *M. patnalis* larvae made 5-14 sets in 0.5 to 11.0 min along the leaf cut. Analysis of variance of the average time taken to finish each stitch set showed a significant difference between the species.

Feeding behavior in relation to spinning was also observed. Feeding could occur before the start of spinning, between two stitch sets, after spinning, not at all, or in any combination of these. However, chi-square testing of the data showed no significant differences between the two species.

We observed that the stitch sets could be spun one after another and always outside the sets previously spun. This pattern was designated as orderly. On the other hand, stitch sets could be spun randomly, such as on top of old sets and between two previously spun sets (Fig. 13).

The chi-square test of independence of the spinning order showed that the two species differed in the proportion of larvae spinning orderly as opposed to randomly. Further testing of the fixed ratio hypothesis showed that almost equal numbers of *C. medinalis* larvae spun orderly and randomly, while more *M. patnalis* larvae in a given population spun randomly than orderly.

Mating behavior of rice leaffolder. The mating behavior of *M. patnalis* was observed in the labo-



13. Schematic diagram of spinning behavior of 2 rice LF species, IRRI, 1988. Numbers indicate chronological spinning order by 5 larvae of each species. An asterisk denotes feeding, which occurred after finishing the stitch set indicated by the number.

Table 10. Insect pests of rice and their natural enemies attracted to different colors of light in a ricefield.

Insect	Insects (no.) attracted/20 d							
	Ultraviolet	White	Red	Orange	Yellow	Green	Violet	Blue
Pests								
Nilaparvata lugens	481	2461	267	1081	793	1277	422	534
Sogatella furcifera	48	188	68	15	53	77	18	27
Nephotettix virescens	124	3843	228	330	427	415	99	172
Cnaphalocrocis medinalis	3	4	5	–	11	1	15	2
Marasmia patnalis	2	–	1	–	1	1	–	1
Chilo suppressalis	148	284	221	286	310	160	153	108
Scirpophaga incertulas	61	42	33	9	51	18	37	–
Predators								
Microvelia sp.	100	334	46	73	187	81	24	90
Cyrtorhinus sp.	18	240	–	24	52	44	26	19
Formicidae	173	532	118	101	378	379	163	279
Opius sp.	92	358	32	29	78	58	36	88

ratory under a 12-h light, 12-h dark (12L:12D) cycle. Ten out of 36 (28%) same-age pairs, 2 out of 10 pairs (20%) with opposite sexes having a 1-d age gap, and 1 out of 5 pairs (20%) with a 2-d age gap were observed to mate. Mating usually occurred 2-3 d after emergence and 6 h into scotophase. Mating activity commenced with the calling behavior of the female, followed by the male approaching the female from the rear, curving its abdomen, and turning 180° for copulation, which lasted from 30 min to about 2 h. Preliminary field trials showed that, on the average, traps baited with one female moth attract two male moths, while those baited with two and four female moths attract four and five male moths, respectively.

Attraction of pests and natural enemies to colored lights. In a field experiment, leafhoppers and planthoppers, and their natural enemies such as *Microvelia* sp., *Cyrtorhinus* sp., *Opius* sp., and members of family Formicidae were most attracted to white light (Table 10). Of the two SBs, *Chilo suppressalis* (Walker) was most attracted to yellow light, while *S. incertulas* (Walker) was attracted to ultraviolet light. The LFs did not prefer any of the eight light colors tested.

BIOLOGICAL CONTROL

Entomology Department

The sword-tailed cricket, a predator of lepidopterous pests. We studied the feeding of *Anaxipha longipennis* (Serville) on various densities of leaffolder *Cnaphalocrocis medinalis*, green hairy caterpillar *Rivula atimeta* (Swinhoe), and green horned caterpillar *Melanitis leda ismene* Cramer under laboratory conditions. Adult insects were collected from the field, caged with 35-d-old TN1 rice plants, and permitted to oviposit for 24 h. Eggs on leaves were removed to obtain 10, 20, or 40 eggs/plant. A single *A. longipennis* that had been starved for 24 h was placed in each cage. There were 5 replications. The number of eggs consumed was recorded daily for 3 d.

A. longipennis consumed more eggs of *C. medinalis* and *R. atimeta* than of *M. leda ismene* (Table 11). The crickets consumed almost all the eggs of

Table 11. Cumulative number of eggs of *Cnaphalocrocis medinalis*, *Rivula atimeta*, and *Melanitis leda ismene* consumed by the cricket *Anaxipha longipennis*.[a] IRRI insectary, 1988.

Insect	Egg density (no./cage)	Eggs consumed (no.) at given time		
		24 h	48 h	72 h
C. medinalis	10	8.2	10.0	10.0
	20	15.0	18.0	18.8
	40	34.2	39.6	39.6
R. atimeta	10	10.0	10.0	10.0
	20	16.2	19.0	19.2
	40	33.7	39.0	40.0
M. leda ismene	10	2.0	2.0	3.6
	20	4.0	4.6	4.8
	40	5.6	9.6	11.2

[a] Av of 5 replications.

C. medinalis and *R. atimeta* by the second day, but only about a quarter of *M. leda ismene* eggs by the third day. In general, egg predation on *C. medinalis* and *R. atimeta* was about three times higher than predation on *M. leda ismene*. The eggs of *M. leda ismene* are larger, which may explain the difference. Most eggs were located and consumed within 24 h. The results showed that *A. longipennis* has the potential to suppress populations of *C. medinalis* and *R. atimeta* by feeding on their eggs.

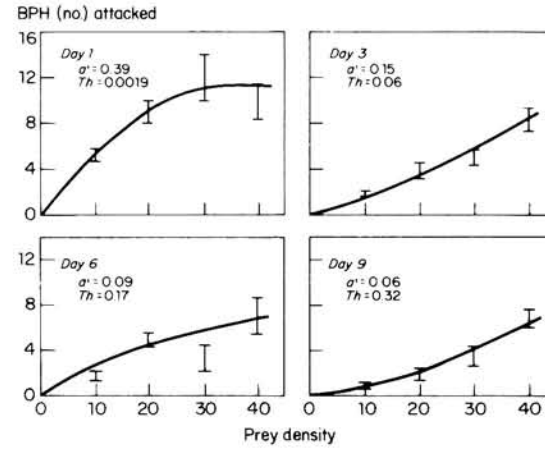
Predation efficiency of *Lycosa pseudoannulata*. Searching efficiencies of *L. pseudoannulata* for GLH and BPH adults were evaluated in the insectary. Adult female spiders collected in the field were reared in the insectary. The spiders were starved for 3 d before being exposed to various densities of 1-d-old GLH and BPH adults. The number of prey killed was recorded after 24 h. Prey was replaced and the number killed recorded after another 24 h. This was repeated for 9 consecutive days.

As the prey densities increased, the number of prey killed declined until a plateau was reached for both GLH and BPH. Searching efficiency, a' and handling time T_h, were estimated, using the Random Predator Equation (Fig. 14, 15). *Lycosa* had better searching efficiency for BPH. Searching efficiencies for both GLH and BPH declined with time after caging.

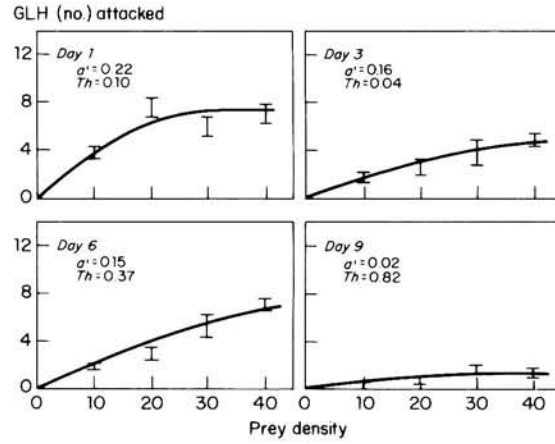
Compared with that of the adult *Lycosa*, the searching efficiency of the second-instar spiderlings was lower by more than 10 times.

Searching preference of *Lycosa pseudoannulata*. *L. pseudoannulata* is a polyphagous predator that will attack several species. When BPH and GLH adults were presented to *Lycosa* by themselves in the functional response experiments, the predator displayed better searching ability for BPH. In preference experiments, where GLH and BPH adults in varying ratios were presented, *Lycosa* showed a marked preference for BPH in experiments using whole plants. In experiments using cut tillers 10 cm high, *Lycosa* did not display preference for either prey. This implies that preference for BPH is due to where *Lycosa* was foraging.

From field observations, *Lycosa* spiders are found mainly in the first 10 cm above the water



14. Searching efficiency of *Lycosa pseudoannulata* for BPH adults. IRRI insectary, 1988.

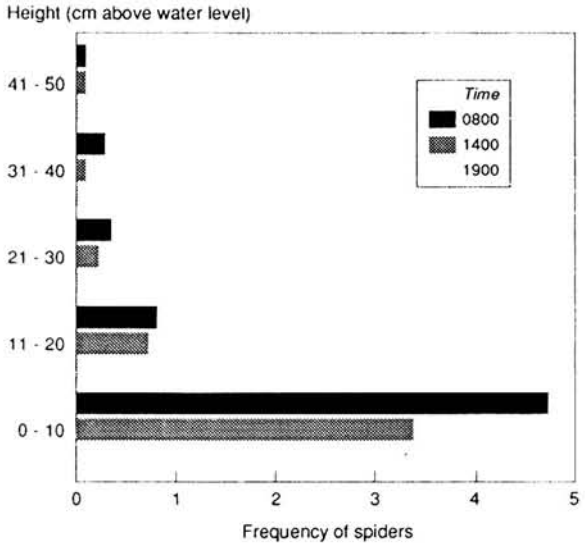


15. Searching efficiency of *Lycosa pseudoannulata* for GLH adults. IRRI insectary, 1988.

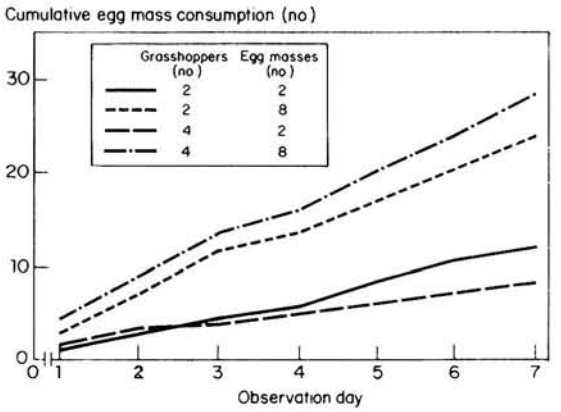
(Fig. 16), supporting its preference for BPH, which are found mainly at the base of plants.

Effect of flooding on black bug. Black bug egg masses were submerged for 0, 6, 12, 18, 24, and 36 h. Bug survival decreased from 96% (not flooded) to 3% after 18 h of flooding. No bugs emerged from eggs flooded longer than 18 h; however, parasites emerged from eggs that were flooded for 36 h.

Flooding for 2, 4, 6, and 8 h forced female bugs to leave egg masses. After 2 and 4 h of flooding, 50% of the females returned to the egg masses,



16. Vertical distribution of *L. pseudoannulata* in the rice ecosystem. IRRI, 1988.



17. Consumption of yellow stem borer egg masses by various densities of meadow grasshopper *Conocephalus longipennis* de Haan. IRRI, 1988.

while less than 20% returned after 16 or 24 h of flooding.

Cricket feeding on black bug eggs. Two crickets, *Metioche vittaticollis* and *Anaxipha longipennis*, are common in ricefields. In laboratory trials, they were offered bug eggs for 10 d, and then egg consumption was determined. Average consumption was about 15 eggs/d for *M. vittaticollis* and 10 eggs/d for *A. longipennis*.

Predation by the meadow grasshopper. Studies have shown that the meadow grasshopper *Conocephalus longipennis* de Haan feeds on rice foliage and panicles and on yellow stem borer egg masses. This experiment was conducted to determine if grasshoppers continue to feed on foliage and panicles when adequate egg masses are available.

Grasshoppers at densities of 2 or 4 were caged on plants (1 m^2) in the field with 0, 2, or 8 egg masses, in 6 replications. We recorded egg mass consumption daily for 7 d, and consumed egg masses were replaced daily. Plant damage was estimated by recording numbers of damaged leaves and missing panicles.

Grasshoppers consumed 2-4 egg masses/d (Fig. 17). When no eggs were present, 2 grasshoppers damaged an average of 19.7 leaves/m^2. When egg masses were available, averages of damaged leaves dropped to 13.5 and 14.3 at 2 and 8 egg masses, respectively.

CHEMICAL CONTROL

Entomology Department

Effect of flooding on insecticide efficacy for black bug control. Malayan black bug females are commonly found with their egg masses near the base of plants. If the water level is raised, the egg masses are flooded, and the bugs move higher into the plants. Here, they are more likely to be exposed to insecticide treatments.

A field was flooded to force bugs into the upper portions of plants. Monocrotophos 30 EC at 0.125 kg active ingredient (ai)/ha was applied. Bug populations were counted 2 d after treatment. Numbers of bugs were significantly reduced by the treatment.

Reducing the amount of insecticide would result in savings to the grower and in reduced effects on nontarget organisms.

Insecticide efficacy on rice whorl maggot. Losses due to the rice whorl maggot can be reduced by applying an ovicide, azinphos-ethyl, at 0.6 kg ai/ha. This trial was conducted to determine if lower rates are effective.

A twin-nozzle knapsack sprayer was used to apply 300 liters/ha. Treatments were made at 5-d

intervals starting 5 d after the egg density reached an average of 0.5/hill. Plant damage was assessed 4 d after treatment. There were 4 replications.

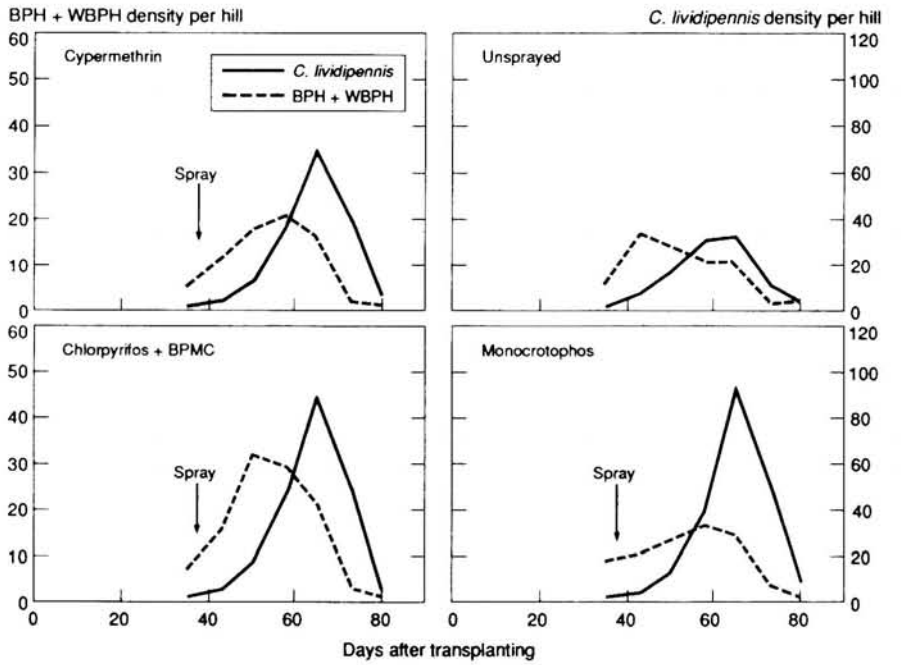
Significant damage reduction occurred in all cases when dosages totaled 300 g ai/ha or higher (Table 12). Effects were marginal at concentrations of 50 g ai/ha. There was no increase in efficacy when rates were split from two applications to three applications.

Susceptibility of predators to insecticides. Field populations of *M. vittaticollis*, coccinellids, and *Tetragnatha* sp. did not reach their peaks when sprayed at 35 d after transplanting (DT), while field populations of *Cyrtorhinus lividipennis* increased after spraying (Fig. 18). The peaks of *M. vittaticollis* and coccinellid abundance were at the grain filling stage, and the peaks of *Tetragnatha* sp. and *C. lividipennis* abundance were at flower-

Table 12. Dosage and frequency of ovicide insecticide spray for rice whorl maggot control.[a] Koronadal, South Cotabato, Philippines, Aug-Sep 1988.

Dosages/application[b] (g ai/ha)	Damaged leaves (%) at indicated time[c]			
	14 DT	18 DT	22 DT	26 DT
200 + 200	19 ab	13 a	12 ab	13 a
200 + 100 + 100	16 a	12 a	9 a	11 a
100 + 100 + 100 + 100	18 ab	15 ab	13 b	12 a
150 + 150	16 a	15 ab	11 ab	13 a
100 + 100 + 100	20 ab	15 ab	13 b	11 a
100 + 100 + 50 + 50	19 ab	16 ab	13 b	12 a
100 + 100	20 ab	17 ab	14 b	15 ab
100 + 50 + 50	21 abc	19 bc	14 b	13 a
50 + 50 + 50 + 50	23 bc	20 bc	14 b	17 b
Untreated	26 c	23 c	21 c	22 c
CV (%)	17	20	15	18

[a] Av of 4 fields. [b] A 2-nozzle knapsack sprayer was used to spray the different dosages of azinphos-ethyl emulsified in spray volume of 300 liters/ha applied at 5-d intervals when egg count reached threshold of 0.5 egg/hill. [c] Damage assessment was done 4 d after insecticide application. DT = days after transplanting.



18. Field populations of planthoppers and *C. lividipennis* when sprayed with different insecticides. IRRI, 1988.

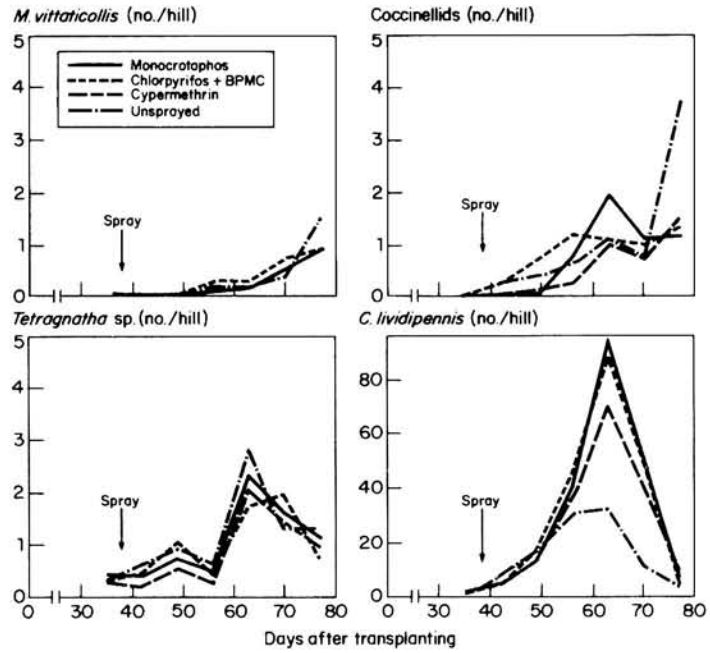
ing. Cypermethrin decreased predator population more than monocrotophos and chlorpyrifos + BPMC. The increase in *C. lividipennis* population may be a response to an increase in planthopper population after spraying (Fig. 19).

BOTANICAL PEST CONTROL

Entomology Department

Effect of neem oil on brown planthopper courtship signals. Newly emerged BPH females were topically treated with neem oil at 1, 2.5, or 5 μg/female or caged on plants sprayed with 3, 6, or 9% neem oil. Three days later, the females were kept individually on a 40-d-old potted TN1 plant. A cassette player was used for playing back prerecorded male signals to stimulate female calls. The substrate-transmitted courtship signals produced by the female were recorded with a crystal cartridge and a preamplifier connected to a recorder. Normal courtship signal production and mating behavior were disrupted with neem oil treatments (Table 13).

Effect of neem derivatives on green leafhopper and its predators. Potted TN1 rice plants sprayed with neem oil or neem seed bitters (NSB) were in-



19. Field populations of predators when sprayed with different insecticides. IRRI, 1988.

Table 13. Effect of neem oil on courtship signals and mating behavior of *Nilaparvata lugens* females. IRRI, 1988.

Treatment	PRF[a] of signal (Hz)	Duration[b] of female call (s)	Premating[c] period (s)	Duration[d] of mating (s)
Topical (μg/female)				
1.0	21.5 b	75.9 a	113.5 a	66.5 a
2.5	21.9 b	38.7 b	230.0 ab	72.8 a
5.0	20.3 ab	14.8 c	314.6 b	65.0 a
0 (control)	18.7 a	84.2 a	89.8 a	76.9 a
Foliar (%)				
3	20.8 b	52.1 b	91.2 a	64.2 a
6	20.8 b	27.0 bc	268.0 b	66.7 a
9	21.2 b	20.2 c	219.5 ab	55.5 a
0 (control)	19.1 a	82.8 a	94.8 a	65.5 a

[a-d] Av of 8, 36, 12, and 10 replications, respectively. PRF = pulse repetition frequency.

fested with 30 3d-instar GLH nymphs. Control plants were sprayed with 1.6% Teepol and water. For each treatment, one set of infested plants was provided with the mirid *C. lividipennis* or the spider *L. pseudoannulata*, while the other set was kept without predators. GLH mortality in pots with spiders and mirids was recorded daily for 5 and 10 d, respectively. If needed, nymphs were added to maintain the number at 30.

GLH mortality was higher with neem oil (Table 14). Mortality increased with *Lycosa* on treated plants. Predation by the mirid on plants sprayed with 9% neem oil also increased GLH mortality. NSB treatment did not affect predation efficiency of *Lycosa* or of the mirid (Table 15).

Seedling root dips with neem seed kernel extract and neem seed bitters against green leafhopper. We determined GLH egg laying and hatchability on TN1 seedlings whose roots were dipped for 12 or 24 h in an aqueous neem seed kernel extract (NSKE) or NSB solution. Oviposition and hatchability were significantly reduced on IR42 seedlings dipped in 5% NSKE solution for 24 h; NSB treatment was ineffective (Table 16).

Effects of neem seed and leaf bitters on green leafhopper and brown planthopper. Neem leaves can also be a possible source of bitters. We compared the efficacy of neem leaf bitters (NLB) and NSB on GLH and BPH oviposition and development. TN1 rice plants sprayed with an aqueous solution of NSB or NLB (from fresh or dried leaves) were infested with five pairs of newly emerged GLH or BPH males and females. Five days later, the insects were removed and the plants were kept for nymphal emergence and count of unhatched eggs. In another test, roots of 7-d-old TN1 seedlings were dipped for 12 h in a solution of NLB or NSB and infested singly with 1st-instar nymphs. The percentage of nymphs becoming adults and their development periods were recorded. Neem treatments significantly reduced egg laying, nymphal emergence, and development (Table 17).

Neem treatments for green leafhopper and tungro control. Combined treatments with NSKE at the seed (presowing treatment with 10% NSKE solution for 24 h), seedling (root immersion in 5% NSKE for 12 h), and vegetative (foliar spray

Table 14. Mortality of *Nephotettix virescens* nymphs on TN1 rice plants sprayed with neem oil, and with or without *Lycosa* or mirid.[a] IRRI, 1988.

Concentration (%) of neem oil	Mortality (%)					
	With *Lycosa*	Without *Lycosa*	Difference[b]	With mirid	Without mirid	Difference[c]
3	15.8 c	0.8 b	15.0**	40.1 c	42.2 c	−2.1 ns
6	21.9 b	2.3 ab	19.6**	66.6 b	76.8 ab	−10.2 ns
9	–	–	–	87.6 a	66.4 b	21.2 **
12	26.9 a	6.1 a	20.8**	84.2 ab	85.4 a	−1.2 ns
0	16.4 c	0.3 b	16.1**	5.3 d	5.3 d	0.0 ns

[a] Av of 5 replications. [b] Av of 5 daily mortality readings. [c] Mortality at 10 d after treatment.

Table 15. Mortality of *N. virescens* nymphs on TN1 rice plants sprayed with neem seed bitters, and with or without *Lycosa* or mirid.[a] IRRI, 1988.

Concentration (ppm) of neem seed bitters	Mortality (%)					
	With *Lycosa*	Without *Lycosa*	Difference[b]	With mirid	Without mirid	Difference[c]
100	15.0 a	1.7 a	13.3*	10.0 cd	4.0 c	6.0*
500	12.2 a	2.0 a	10.2*	14.7 abc	5.3 c	9.3*
2,500	14.1 a	1.5 a	12.6*	13.3 bcd	13.3 ab	0.0 ns
5,000	13.3 a	2.6 a	10.7*	22.0 ab	22.0 a	0.0 ns
10,000	13.4 a	4.7 a	8.7*	24.0 a	19.3 ab	4.7 ns
0 (control)	11.5 a	5.1 a	6.4*	5.3 d	3.3 c	2.0 ns

[a] Av of 5 replications. [b] Av of 5 daily mortality readings. [c] Mortality at 10 d after treatment.

Table 16. Oviposition, nymph emergence, and hatchability of *N. virescens* eggs on TN1 seedlings with roots immersed in an aqueous solution of neem seed bitters (NSB) or neem seed kernel extract (NSKE) for 12 or 24 h.[a] IRRI, 1988.

Treatment	Eggs laid (no.)	Nymphs that emerged (no.)	Hatchability (%)
	12 h		
NSB			
2500 ppm	42.8 b	39.8 cd	75 bc
5000 ppm	26.6 b	19.4 bcd	71 bc
NSKE			
2.5%	20.7 b	20.4 bcd	89 bc
5.0%	20.7 b	16.5 bcd	76 bc
	24 h		
NSB			
2500 ppm	15.3 ab	11.0 abc	55 abc
5000 ppm	18.8 ab	11.7 bc	67 bc
NSKE			
2.5%	14.5 ab	7.2 ab	36 ab
5.0%	7.6 a	5.0 a	28 a
0 (control)	50.0 b	50.0 d	100 c

[a] Av of 10 replications.

applications with 4% NSKE solution at 10-d intervals) stages of varieties IR42 and IR36 were field evaluated for GLH and tungro (RTV) control in 1988 DS and wet season (WS). Controls comprised no treatment and foliar spray applications of monocrotophos at 10-d intervals commencing at 5 DT.

In 1988 DS, the GLH population was generally lower and RTV incidence significantly less at 25 and 45 DT in neem-treated plots than in the untreated controls (Table 18). Monocrotophos reduced GLH population and RTV incidence, but also decreased mirids and spiders.

In 1988 WS, RTV incidence was also significantly less at 45 and 65 DT in neem-treated and insecticide-treated plots (Table 19). The neem package and insecticide treatments were alike in controlling LFs. Yields were significantly higher in treated than in untreated control plots. The net gain was higher with neem treatments because of the low cost involved than when monocrotophos was used.

Table 17. Ovipositional response of *N. virescens* and *Nilaparvata lugens* and hatchability of eggs on TN1 plants sprayed with 3 concentrations of neem bitters from dried leaves (DNLB), fresh leaves (FNLB), and seed kernel (NSB).[a] IRRI, 1988.

Treatment	Eggs laid[b] (no.)			Nymphs that emerged[b] (no.)			Nymphs becoming adults[c] (%)		
	500 ppm	2500 ppm	5000 ppm	500 ppm	2500 ppm	5000 ppm	100 ppm	500 ppm	2500 ppm
				N. virescens					
DNLB	448 aA	398 aA	456 bA	444 aA	392 aA	447 bA	50 bA	0 aB	0 aB
FNLB	374 aA	411 aA	393 bA	371 aA	411 aA	386 bA	35 aA	16 bB	0 aC
NSB	341 aB	334 aB	170 aA	337 aB	314 aB	149 aA	25 aB	0 aA	0 aA
				N. lugens					
DNLB	1750 aA	1497 aA	1684 bA	1750 aA	1481 aA	1521 bA	66 bA	61 bA	20 bB
FNLB	1688 aA	1691 aA	1452 bA	1683 aA	1672 aA	1446 bA	80 bA	82 bA	39 bB
NSB	1613 aB	1358 aB	802 aA	1612 aB	1356 aB	791 aA	39 aB	10 bAB	0 aA

[a] In a column within a parameter, means followed by the same lowercase letter are not significantly different at the 5% level by LSD; in a row, significance is designated by capital letters. [b] Av of 5 replications. [c] Av of 10 replications, 10 1st instars per replication.

Table 18. Effect of sequential neem treatments or an insecticide on *N. virescens* population, RTV incidence, and density of predators in plots planted to IR42.[a] IRRI, 1988 DS.

Treatment	GLH (no./20 hills) at		RTV incidence (%) at		Predators (no./20 hills) at	
	18 DT	28 DT	25 DT	45 DT	18 DT	48 DT
Neem package[b]	3.7 b	17.3 b	0.7 a	8.6 b	5.9 ab	38.6 a
Monocrotophos	2.3 a	7.6 a	0.8 ab	4.5 a	3.9 b	20.3 b
Control[c]	4.4 b	27.9 c	1.5 b	16.1 c	7.7 a	31.6 a

[a] Av of 7 replications. DT = days after transplanting. [b] Includes seed treatment, seedling root dip, and foliar sprays. [c] Unsprayed.

Table 19. Effects of sequential neem treatments or an insecticide on RTV incidence, yield of IR36, and cost effectiveness.[a] IRRI, 1988 WS.

Treatment	RTV incidence (no. of infected hills/plot) at		Yield (t/ha)	Yield value ($)	Treatment cost ($)	Net gain ($)
	45 DT	65 DT				
Neem package[b]	83 b	153 a	3.1 a	517	6	511
Monocrotophos[c]	44 a	106 a	3.5 a	583	177	406
Control[d]	138 c	307 b	2.5 b	417	–	–

[a]Av of 7 replications. DT = days after transplanting. [b]Includes seed treatment, seedling root dip, and foliar sprays at 10-d intervals. [c]Foliar sprays at 10-d intervals from 5 DT. [d]Unsprayed.

Field evaluation of neem-mixed carbofuran for tungro control. In a field trial at IRRI and in Imbunia, Nueva Ecija, we tested whether neem seed cake powder mixed with carbofuran at 1 kg ai/ha was as effective as carbofuran at 2 kg ai/ha against RTV. Carbofuran at 1 or 2 kg ai/ha, carbofuran at 1 kg ai/ha mixed with neem cake at 75 kg/ha, and neem cake at 75 kg/ha were applied first basally prior to planting and then at 30 DT. Untreated plots served as controls. At IRRI, RTV incidence was significantly lower in plots treated with carbofuran alone or in combination with neem cake, while yield and net gain were highest in plots treated with neem-mixed carbofuran (Table 20). In Imbunia, RTV incidence was low and all carbofuran treatments were equally effective. Yield in plots treated with neem-mixed carbofuran at 1 kg ai/ha was on par with carbofuran at 2 kg ai/ha and significantly higher than in control plots. The net gains were also higher in these two treatments.

Effects of neem seed bitters on leaffolder feeding. Thirty-day-old TN1 plants were treated by dipping foliage in water (control) or aqueous NSB solutions and allowing it to dry for 30 min. A 4th-instar prestarved LF larva tethered with an 18-μm-diameter gold wire was placed on the plant, and waveform patterns of the insect feeding for 60 min were recorded with an electronic device. In another test, 20 4th-instar larvae were allowed to feed for 24 h on 20 treated or control leaf cuts in a petri dish. Feeding was determined by measuring the leaf area scraped by the larvae.

Spinning and head or body movements of larvae were not affected by NSB treatments. However, the feeding duration decreased on treated plants, while nonfeeding or rest periods increased significantly compared with the control (Table 21). The leaf area scraped by larvae was also less on treated than on control leaf cuts.

Effects of neem seed derivatives on leaffolder and parasitoids. The feeding activity of individual 4th-instar LF *Marasmia patnalis* larvae, freshly parasitized by *Goniozus triangulifer* (4-5 eggs/larva), was monitored for 24 h on rice leaf cuts dipped for 5 s in NSB solution or water (control) and com-

Table 20. Field efficacy of neem-mixed carbofuran on RTV incidence, yield of IR36, and cost effectiveness.[a] IRRI, 1988 WS.

Treatment (at 0 & 30 DT)	Infected hills (no.)/plot at 65 DT	Yield[b] (t/ha)	Yield value ($)	Treatment cost ($)	Net gain ($)
Carbofuran 2 kg ai/ha	117 a	4.0 ab	667	100	567
Carbofuran 1 kg ai/ha	131 a	3.9 ab	650	50	600
Carbofuran 1 kg ai/ha + neem cake 75 kg/ha	134 a	4.4 a	733	64	669
Neem cake 75 kg/ha	228 b	4.1 ab	683	14	669
Untreated	249 b	3.6 b	600	–	–

[a]DT = days after transplanting. [b]Av of 5 replications.

Table 21. Means of electronically recorded events during a 1-h feeding period by 4th-instar *Cnaphalocrocis medinalis* larvae on plants sprayed with neem seed bitters (NSB). IRRI, 1989.

NSB (ppm)	Feeding[a] (min)	Rest[a] (min)	Leaf cut damage[b] (cm^2)
500	–[c]	–[c]	1.12 ab
2,500	7.1 a	10.8 ab	1.42 ab
5,000	8.8 a	13.9 ab	0.96 a
10,000	8.4 a	17.8 a	–[c]
0 (control)	17.9 b	6.4 b	3.14 b

[a]Av of 9 replications, 1 fresh larva and 1 fresh plant per replication. [b]Av of 3 replications, 20 larvae and 20 leaf cuts per replication. [c]Not tested.

pared with that of unparasitized larvae. NSB did not affect feeding, but parasitized larvae fed less than unparasitized larvae.

Contact effect of neem seed bitters on leaffolder larvae. Fourth-instar larvae were dipped individually for 5 s in NSB solution containing 250 ppm of Citowett; control larvae were dipped in water or water containing Citowett. In another test, larvae were dipped in NSB solution without Citowett, which had some deleterious effects on larval development.

Pupation decreased when larvae were dipped in >5,000 ppm NSB solution (Table 22). Fewer moths emerged at 5,000 ppm NSB, and only 3% at 10,000 ppm. Longevity and fecundity of females decreased significantly at ≥5,000 ppm NSB, and hatchability was reduced even at 2,000 ppm NSB.

Reduction in leaffolder damage on neem seed bitters-treated plants. Fifty-day-old, potted IR70 plants (4 plants/pot) were infested with 2d-instar larvae at 5 larvae/pot and placed in a greenhouse for 9 d. When the larvae reached the 4th-instar stage, the infested plants were sprayed with 2,500, 5,000, or 10,000 ppm NSB solution (at 12.5 ml/4 pots or 400 liters/ha). Control plants were sprayed with water or water containing Citowett. After 2 wk, pupae were counted and removed from plants. Lengths of folded leaves were measured, and damage was rated on a 0-3 scale using the *Standard evaluation system* (0 = no leaf area scraped, 1 ≤ 1/3, 2 = 1/3-1/2, 3 ≥ 1/2 leaf area scraped). Using the number of leaves with each damage grade, the damage rating was computed.

Plants were damaged less and fewer larvae pupated on treated than on control plants (Table 23). Also, fewer leaves were folded on treated plants.

Effects of neem seed bitters on parasitoids. Neem seed bitters were evaluated against juvenile and adult stages of LF larval (*G. triangulifer*) and pupal (*Tetrastichus ayyari*) parasites.

Table 23. Reduction in feeding activity and development of *Marasmia patnalis* larvae on potted rice plants sprayed with a solution of NSB.[a] IRRI, 1988.

NSB (ppm)	Leaf length, folded (cm)/ 4 plants	Damage rating	Pupae (no.)/4 plants
2,500	537 b	8.6	3.2 b
5,000	425 ab	7.2	0.6 a
10,000	306 a	6.2	0.0 a
0 (control)[b]	841 c	16.1	7.0 c

[a]Av of 5 replications, 20 larvae per replication. [b]250 ppm Citowett in water.

Table 22. Effect on pupation, longevity, and fecundity when 4th-instar *M. patnalis* larvae were dipped in a solution of neem seed bitters (NSB).[a] IRRI, 1988.

NSB (ppm)	Pupation (%)	Moths that emerged (%)	Longevity (d)	Fecundity (no. of eggs/ female)	Hatchability (%)
1,000	72 bc	63 d	9.2 bc	114 bc	48 a
2,000	60 b	45 bc	5.8 ab	59 ab	18 a
5,000	65 b	35 b	3.8 a	14 a	19 a
10,000	12 a	3 a	–[c]	–[c]	–[c]
0 (control)[b]	60 b	53 cd	13.3 cd	237 c	65 b
Water (control)	87 c	83 e	9.2 bc	157 bc	57 b

[a]Av of 4 replications, 10 4th-instar larvae per replication. [b]250 ppm Citowett in water. [c]Not tested because of insufficient females.

Effect on larval parasites. Newly emerged, mated *G. triangulifer* females were treated topically with 0.1 μl of acetone-water (1:1 vol/vol) solution of NSB at a dose of 5, 10, 20, or 50 μg/female. Control females were treated with solvents only. The females were kept singly in test tubes plugged with honey-soaked cotton. The next day, 50% of the females were provided singly with individual host larvae for recording eggs laid daily, while the remaining females were kept without the host to determine the longevity of nonovipositing females.

Neem treatment did not affect the longevity of *G. triangulifer* females, but fecundity decreased at 50 μg/female.

In another test, control or treated plants were infested with fourth-instar LF larvae, each carrying four to five parasite eggs. After 10 d, developing parasites with the host were transferred to test tubes. Pairs of newly emerged males and females of the parasite were confined to test tubes with a fresh host larva, and the eggs laid were counted daily for 5 d.

Neem treatment did not affect *G. triangulifer* development except at 1,000 ppm of NSB. Parasite fecundity decreased slightly when they emerged on hosts that had fed on neem-treated plants.

Effect on pupal parasites. The toxicity of NSB to 1-d-old *T. ayyari* females was compared with that of monocrotophos using a spray tower. Insect mortality was registered at 1, 4, and 12 d after treatment. Even after 12 d, survival of neem-treated females was as high as that in controls, but females in the insecticide treatment died within 4 h.

Effects of neem seed bitters on predation. We evaluated NSB effects on LF egg predation by the cricket *Metioche vittaticollis*. Rice plants with LF eggs (50 eggs/plant) were sprayed with 10,000 ppm NSB solution, 12% neem oil, monocrotophos at 0.44 kg ai/ha, or water containing Citowett. After 3 h, 2-d-starved, field-collected *M. vittaticollis* females were caged individually for 5 d on plants with LF eggs. Egg predation was recorded daily. Surviving predators were transferred to a diet of mashed potato, and their survival was monitored for another 4 d.

NSB treatment did not affect predation. Neem oil decreased cumulative egg predation. On monocrotophos-treated plants, predation was negligible because of early mortality of the predator; moreover, emerging LF larvae died from contact toxicity.

In the field, populations of predators *M. vittaticollis, Ophionea nigrofasciata,* and *Micraspis* were not affected by neem oil, but fewer *Anaxipha longipennis* adults were harbored in treated plots.

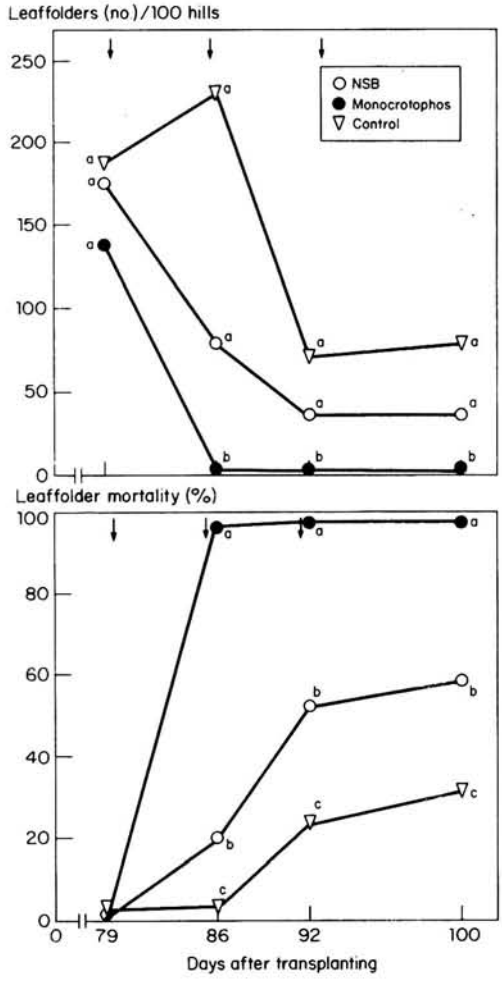
To determine neem oil's effect on predation, 10 potted rice plants carrying LF eggs on marked leaves were placed randomly among rice hills in unsprayed plots and in plots sprayed with an electrodyn formulation of neem oil at 1.75 liters/ha. Egg predation in treated plots, recorded 3 d later, was as high as in untreated plots, while hatchability of LF eggs decreased with neem treatment.

Effects of neem seed bitters on field populations of natural enemies. We compared the effects of NSB and an insecticide on populations of natural enemies using natural and controlled LF infestations.

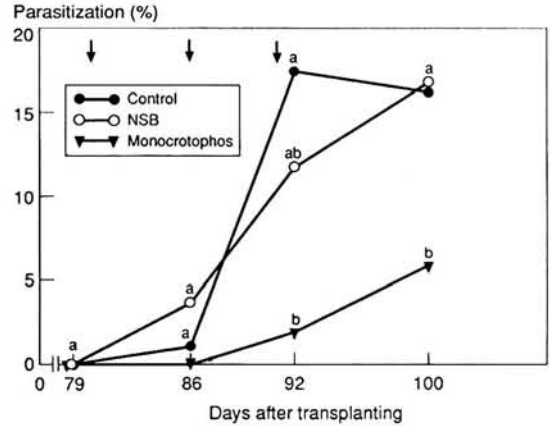
Natural infestation. Field plots planted to IR70 were sprayed at 80, 85, or 90 DT with 10,000 ppm of NSB at 8 liters/ha or monocrotophos at 0.44 kg ai/ha; controls were sprayed with a 250-ppm Citowett solution. LF larvae and pupae were collected before spray applications and reared until moths or parasites emerged. Mobile predators were sampled with a sweep net.

Larval population was negligible with monocrotophos; it declined in neem-treated plots, but increased in control plots (Fig. 20). Parasitization of larvae was significantly higher in neem-treated plots than in insecticide-treated plots (Fig. 21). Predator population in insecticide-treated plots continued to decline, but that with neem treatment remained high (Fig. 22). Compared with the control, LF damage was one-tenth with insecticide, and one-half with neem treatment. At the observed pest density, however, yields in treated and control plots were similar.

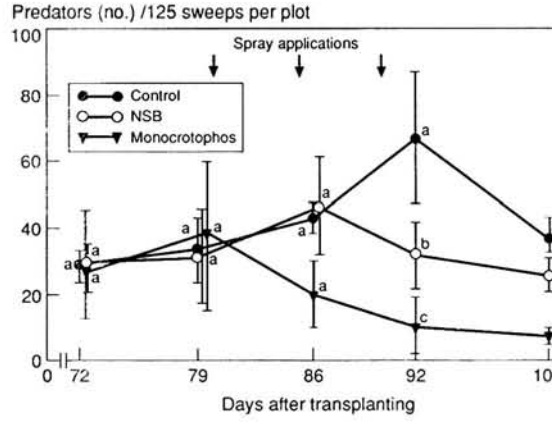
Controlled infestation. In another test, plots scheduled for the above treatments were sprayed with cypermethrin at 62 DT to kill natural enemies and then enclosed with 1.5 m^2 nylon mesh cages. One week later, the caged plants were infested with 600 LF eggs at the blackhead stage; 2 wk later, LF establishment was recorded on 10 randomly selected hills. Another set of cages was



20. Population of *M. patnalis* larvae and pupae in ricefield plots sprayed with a solution of neem seed bitters (NSB) or monocrotophos (0.44 kg ai/ha) using an ULV-spray applicator. IRRI, 1988. Values on the same day followed by a common letter are not significantly different at the 5% level by DMRT.



21. Parasitization of *M. patnalis* larvae by *G. triangulifer* in a 1-ha ricefield sprayed with a 10,000 ppm solution of NSB or monocrotophos (0.44 kg ai/ha) using an ULV applicator, IRRI, 1988. Control plots were sprayed with a 250-ppm Citowett solution. Values on the same day followed by a common letter are not significantly different at the 5% level by DMRT.



22. Cumulative counts of 5 species of predators of *M. patnalis* recorded in a 1-ha ricefield sprayed with a 10,000 ppm solution of NSB or monocrotophos (0.44 kg ai/ha) using an ULV applicator, IRRI, 1988. Values transformed by square root (x + 0.5). Control plots were sprayed with water or a 250-ppm Citowett solution. Values on the same day followed by a common letter are not significantly different at the 5% level by DMRT. Bars represent standard deviations.

left undisturbed. Six cages in each plot were removed, starting with the first application, while others were opened for treatment only and then closed immediately. Surviving LF larvae and pupae and enclosed puparia in caged and exposed plots were recorded.

LF population in control plots decreased significantly when exposed to predation (Table 24). Yield in control plots was not affected by the presence of predators. With insecticide, LF population decreased significantly with or without the predator. NSB decreased LF population even when predators were excluded, but yield was at par with control.

Field evaluation of neem seed bitters and neem seed kernel extract on mungbean pests. We compared the efficacy of neem derivatives and an

Table 24. Population of *M. patnalis* larvae and pupae in plots sprayed with an insecticide or NSB when exposed to predation (P) or when predators were excluded (PE).[a] IRRI, 1988.

Treatment[b]	Leaffolder larvae or pupae (no./10 hills) at											
	79 DT (1 d before 1st spray)			86 DT			100 DT			108 DT		
	P	PE	Difference	P	PE	Difference	P	PE	Difference	P	PE	Difference
NSB (10,000 ppm)	10 b	9 a	ns	5 b	5 a	ns	3	6 b	ns	1 a	2 a	ns
Monocrotophos (0.44 kg ai/ha)	6 a	7 a	ns	0.7 a	4 a	ns	0	1 a	ns	0 a	1 a	ns
0 (control)[c]	10 b	9 a	ns	5 b	12 b	*	2	10 c	*	1 a	7 b	*

[a]Av of 3 replications; each replication comprised 3 spots with 49 rice hills covered with cages (i.e., predators excluded), and 3 spots with 49 rice hills without the cages (i.e., with predators). [b]Solution of neem bitters or insecticide was applied at 88, 101, and 108 d after transplanting (DT). [c]250 ppm Citowett in water.

insecticide for controlling mungbean pests in a rice-based cropping system in Nueva Ecija. NSB at 5,000 ppm, NSKE at 3%, or monocrotophos at 0.3 kg ai/ha was applied at 20, 35, and 50 d after seeding (DAS). Control plots were sprayed with water. Observations were made prior to first spraying and 15 d after each subsequent spray. Damage to leaflets, plants, or pods by larvae of LF or cutworms, and aphids were assessed randomly in 1-m^2 areas. Harvest was done in 10-m^2 areas, and pod borer incidence was registered as percentage of infested pods.

Leaflet damage was significantly reduced and yield was higher in insecticide- or neem-treated plots than in control plots. Although net gain was higher with insecticide, the benefit-cost ratio was double in the case of NSB.

INTEGRATED PEST MANAGEMENT

Entomology, Plant Pathology, and Agricultural Economics Departments

Effect of roguing on tungro. In RTV control, early insecticidal spraying and frequent roguing of diseased rice plants are recommended. We transplanted 21-d-old seedlings of IR42 in a 1/8-ha field at IRRI in 1988 WS. The area was divided into 12 plots, with 6 randomized plots each serving as replications of rogue and nonrogue treatments.

Starting at 14 DT and at weekly intervals up to 60 DT, RTV-infected hills were rogued, and plants that were removed were replaced with healthy plants taken from the adjacent hills. Assessment of RTV incidence was done by absolute counting at 30, 45, and 60 DT. RTV percentage was taken using this formula:

$$\text{RTV (\%)} = \frac{\text{no. of RTV diseased hills}}{\text{total no. of hilis (diseased + healthy hills)}} \times 100$$

Grain yield was also taken by absolute sampling of each replication excluding the two border rows.

RTV percentage on three sampling occasions was found to be consistently lower in the rogued than in the nonrogued treatment. Despite significant differences in RTV infection of the 2 treatments at 45 and 60 DT, crop yields were not significantly different. The yield from both treatments was notably low, indicating that the variety used suffered from RTV disease pressure whether or not roguing was done.

Effect of rice whorl maggot damage on yield of a modern cultivar. There are conflicting reports as to whether or not damage by the rice whorl maggot (RWM) *Hydrellia philippina* Ferino causes significant yield loss. The controversy on its pest status is due mainly to the high incidence of damage from it during the seedling stage and to the disappearance of damage symptoms at later crop growth stages. Some have reported that, being hydrophilic, RWM could be managed simply by maintaining the water at a saturated level during the seedling stage.

We planted a 1/8-ha field at IRRI with the modern but RWM-susceptible variety IR72 and divided it into two equal plots. In 1 plot, 3-5 cm water depth was maintained, while in the other the soil was kept saturated from transplanting until maximum tillering.

In both plots, rice hills were scored for percentage of RWM damage and then labeled based on the following scale: I = control, II = 1-10%, III = 11-20%, IV = 21-30%, V = 31-40%, VI = 41-50%, VII = 51-60%, VIII = 61-70%, IX = 71-80%, X = 81-90%, and XI = 91-100%. Percentage of RWM damage was calculated as follows:

$$\text{RWM damage (\%)} = \frac{\text{damaged leaves (no.)}}{\text{damaged leaves (no.)} + \text{undamaged leaves (no.)}} \times 100$$

In each plot, a maximum of 40 randomly selected hills was tagged and scored for RWM damage at 21 DT. Tagged hills were then assessed at 29, 36, and 43 DT to determine further damage by or disappearance of symptoms from RWM attacks.

The control plants (score I) were protected from RWM by covering them with nylon mesh on the seedbed and in the field up to 43 DT.

Incidences on tagged hills of other pests that may cause yield loss were recorded.

Yield and its components—panicle number per unit area, number of spikelets per panicle, percentage of ripened grain, and weight of ripened grain—were recorded.

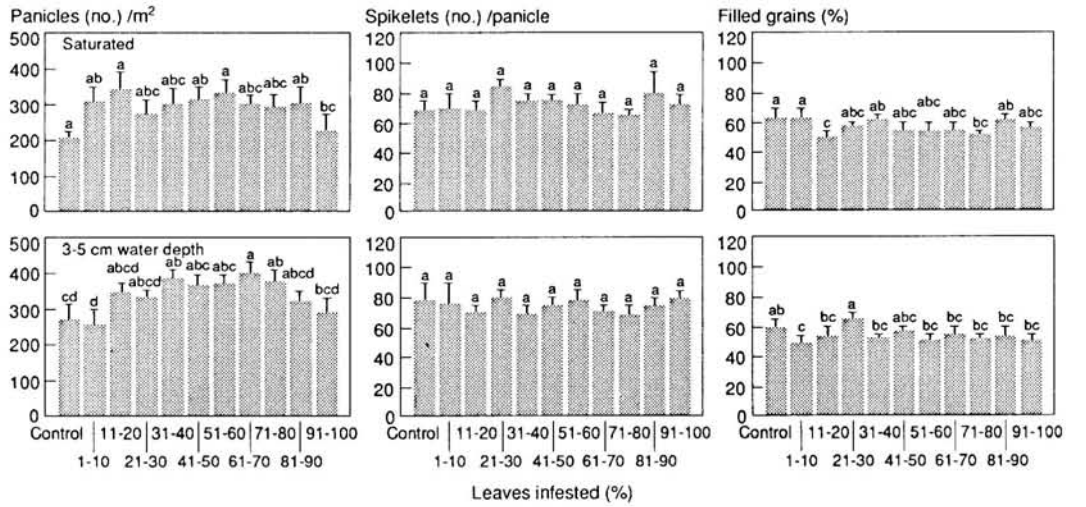
In general, rice hills in both plots showed varying degrees of damage by RWM, irrespective of water regime. In both plots, symptoms of RWM damage on rice hills with high initial damage score (>50%) gradually disappeared; rice hills with low initial damage score showed severe damage during the first assessment at 29 DT but that gradually disappeared in subsequent assessment periods.

Analyses of yield components showed no significant differences in the number of spikelets per panicle. However, variations in the number of panicles per square meter and percentage of filled grains can hardly be attributed to RWM damage (Fig. 23). Yield was correlated with severity of RWM damage.

Stem borer damage (whiteheads [WH]) was recorded on tagged hills, but the incidence was negligible. No other major pest that may cause yield loss was recorded.

Effect of black bug infestations on yield. Malayan black bugs are a serious pest of rice in Palawan. We determined the effect of infestations that occur during the seedling and reproductive stages.

Black bugs were caged on 35-d-old direct seeded "229" rice at 0, 1, 2, 4, or 6 bugs/plant. They were allowed to feed for 1, 2, 4, or 6 d. Feeding damage included rolling of the tallest leaf (after 1 d),



23. Yield components of rice plants with leaves infested with rice whorl maggot under water-saturated conditions and with 3-5 cm water depth. IRRI, 1988.

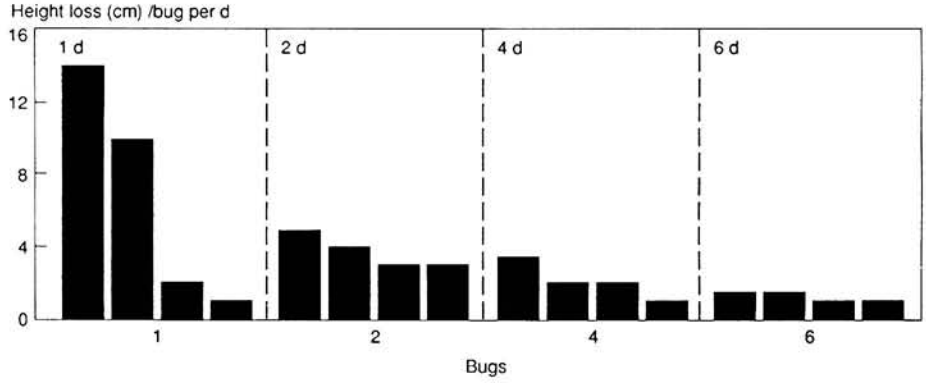
deadheart (DH) or dry leaves (4 d), and dried tip of new leaves (7 d). These symptoms are commonly called "bugburn." Plant height, determined after 10 d, was significantly reduced by both increased number of bugs and longer feeding duration (Fig. 24).

When panicles emerged, individual panicles were caged, and 0, 1, 2, 4, or 6 bugs were placed in each cage and permitted to feed for 1, 2, 4, or 6 d. After the panicles matured, the grain was dried and weighed. Yield was significantly reduced as number of bugs and duration of feeding increased (Fig. 25).

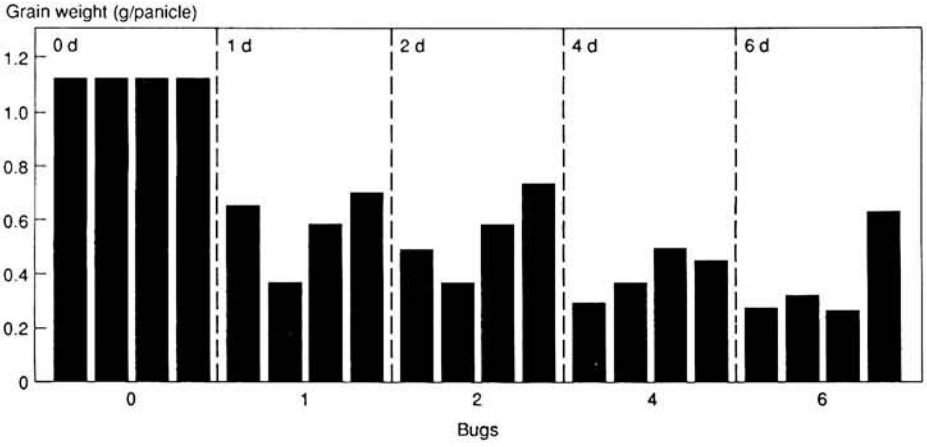
These data indicate that black bug infestations are important whether they occur early or late in the development of the rice crop.

A feeding model of the rice leaffolder. The larvae of the rice LF *Cnaphalocrocis medinalis* attack the vegetative and reproductive phases of the rice crop. They fold and/or scrape the leaf tissues. Experiments were carried out to study the amount of leaf area consumed by each larval instar at different crop stages.

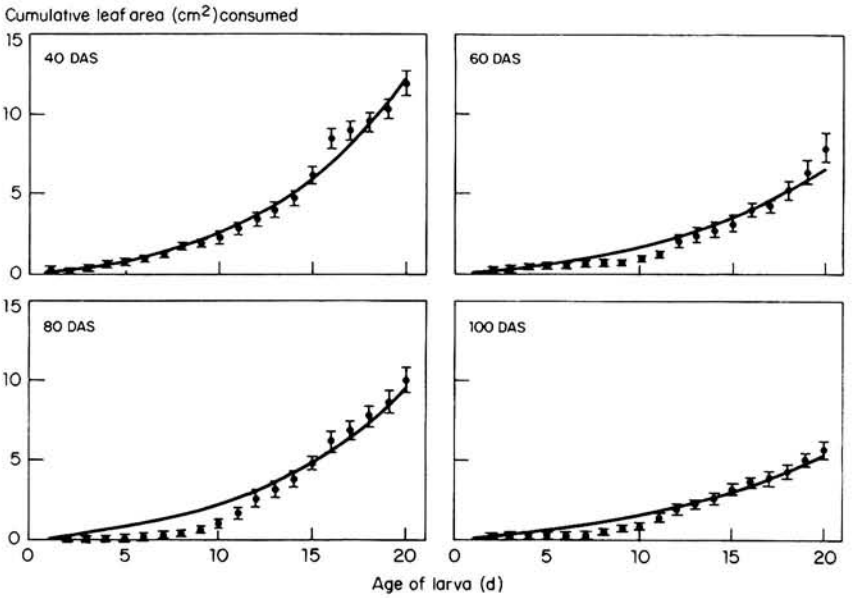
Newly emerged larvae of the different instars were introduced onto each plant (IR36) of known age and covered with a mylar cage. Ten larvae were used in each experiment. The infested plants were kept in a controlled room having a temperature of 27 $\pm$ 3 °C and 12 h light. The leaf area damage was traced onto a plastic film using a fine black marking pen. Area measurements were done using the LI-3000 leaf area meter.



24. Plant height reduction caused by black bug feeding. IRRI, 1988.



25. Yield reduction caused by black bug feeding. IRRI, 1988.



26. Leaf area consumed by rice LF *C. medinalis* larvae on IR36. IRRI insectary, 1988.

The leaf area consumed differed substantially at different crop ages (Fig. 26). The highest leaf consumption was 12.0 cm^2 on plants at 40 DAS and the lowest was 6.0 cm^2 at 100 DAS.

In all cases, the data fitted the exponential model:

$$C_t = e^{\beta t} - 1.0$$

where C_t = age-specific cumulative amount of leaf area consumed in cm^2 from age 0 to age t,
β = the feeding rate at day t.

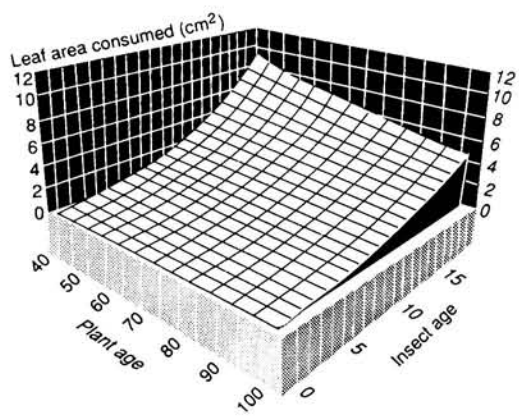
The feeding rates, β, differed significantly for plants of different ages (Table 25). The data likewise fitted a linear model, $\beta = 0.1434 - 0.0005 \times$ DAS ($R^2 = 0.53$), wherein the plant stages were expressed in DAS. These two models quantify the relationship between the leaf area consumed by different larval instars feeding on plants at different growth stages (Fig. 27). Both models could now be validated on other varieties.

Designing multipest economic thresholds. Single- and multiple-pest thresholds were estimated from experimental data collected by the Entomology Department in Zaragoza, Nueva Ecija, in 1988 WS. The single-pest thresholds for SB in the vegetative (35 DT) and reproductive (56 DT)

Table 25. Feeding rate coefficient at different plant ages. IRRI insectary, 1988.

Plant age (d after sowing)	β^a	VR^b
40	0.1296 ± 0.0007	1195 **
60	0.1009 ± 0.0013	958 **
80	0.1179 ± 0.0010	3414 **
100	0.0923 ± 0.0011	1500 **

[a] β = feeding rate coefficient and standard error at 95% confidence. [b] VR = variance ratio from regression analysis of linearized data; ** = significance at P = 0.001.



27. Feeding model of rice LF on IR36. IRRI, 1988.

phases were both 8%, but only 7% in the ripening phase (70 DT). For caseworm (CW) and LF, the thresholds in the vegetative and ripening phases were both 9%. Thus, pest control in the vegetative phase is warranted when SB damage reaches 8% or CW damage reaches 9%. Similarly, spraying is necessary in the reproductive phase when SB damage reaches 8% and in the ripening phase when SB damage reaches 7% or LF damage reaches 9%.

To account for the simultaneous occurrence of several insect pest species, multipest economic threshold levels (ETLs) were estimated (Table 26, 27). Combinations of CW and SB damage in the vegetative phase, or LF and SB in the ripening phase where the benefit of pest control is equal to the cost of pest control, are expressed in terms of the following estimated iso-loss equations:

$$\%\,DH = 7.83 - 0.89\,CW \quad (1)$$
$$\%\,CW = 8.81 - 1.12\,DH \quad (2)$$
$$\%\,WH = 6.7 - 0.71\,LF \quad (3)$$
$$\%\,LF = 9.4 - 1.40\,WH \quad (4)$$

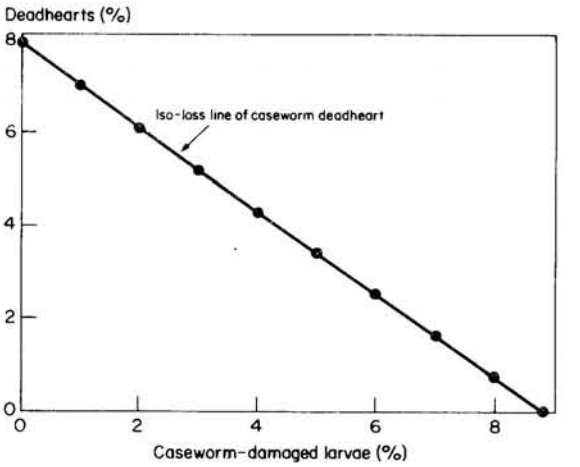
Plotting those equations forms the iso-loss lines (Fig. 28, 29). Any combination of % DH and % CW or % WH and % LF falling on or above the line means that spraying is warranted. Thus, at 5% DH, spraying is needed when damage due to CW reaches 3.2%. Also, at 5% WH, spraying is warranted when damage due to LF reaches 2.4%. Note that the individual levels of damage were below the single-pest thresholds: 5% DH < 8% DH, 3.2% CW < 9% CW, 5% WH < 7% WH, and 2.4% LF < 9% LF. The intercepts of the multipest equations are the single-pest thresholds. If

Table 26. Iso-loss points of vegetative phase deadheart and caseworm-damaged leaves. IRRI, 1988.

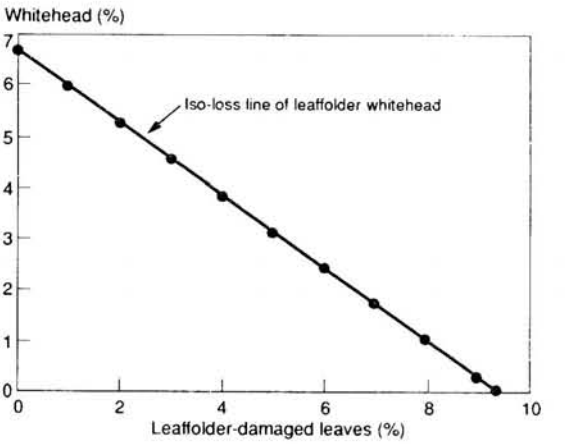
Caseworm-damaged leaves (%)	Deadhearts (%)	Deadhearts (%)	Caseworm-damaged leaves (%)
0	7.8	0	8.8
1	6.9	1	7.7
2	6.1	2	6.6
3	5.2	3	5.5
4	4.3	4	4.3
5	3.4	5	3.2
6	2.5	6	2.1
7	1.6	7	1.0
8	0.7		
8.8	0.0	7.8	0.0

Table 27. Iso-loss points of ripening phase whitehead and leaffolder-damaged leaves. IRRI, 1988.

Leaffolder-damaged leaves (%)	Whiteheads (%)	Whiteheads (%)	Leaffolder-damaged leaves (%)
0	6.7	0	9.4
1	6.0	1	8.0
2	5.3	2	6.6
3	4.6	3	5.2
4	3.9	4	3.8
5	3.2	5	2.4
6	2.4	6	1.0
7	1.7	6.7	0.0
8	1.0		
9	0.3		
9.4	0.0		



28. Multipest threshold of deadheart and caseworm in the vegetative phase. IRRI, 1988.



29. Multipest threshold of leaffolder and whitehead in the ripening phase. IRRI, 1988.

CW damage percentage is zero, the threshold level of DH is 7.8%. As CW damage increases, the multipest ETL of DH declines as per equation 1. No multipest ETL in the reproductive phase was estimated because, except for SB, no other pest significantly affected rice yield.

The probability of reaching the vegetative multipest ETL was 0.51; this is higher than the single-pest ETL for SB (0.28) and CW (0.25). Similarly, the probability of reaching the ripening multipest threshold was 0.75. Again, this is larger than the probability of reaching the single-pest ETL for WH (0.30) and LF-damaged leaves (0.61). Thus, the decision to spray is more likely with the multipest ETL than with the single-pest ETL. Since farmers usually apply insecticides even before reaching the single threshold, the multipest ETL may provide a better guide to control decision-making because it incorporates the right time of spraying where pest damage combinations are below the single-pest ETL.

All thresholds are location-specific because

- the value of ETL depends upon the value of the damage or loss coefficient; the damage coefficient is a function of the severity of pest damage and of yield, whereas pest damage is a function of biotic and abiotic factors; and
- thresholds are directly related to chemical costs and inversely related to the price of rice; if the price of chemical decreases, the ETL value decreases; likewise, if the price of rice increases, the ETL value decreases.

Since the damage coefficient and input and output prices vary across locations, thresholds are location-specific.

The use of predators as a biocontrol is an ideal substitute for chemical control. Predators do not leave chemical residues on food and cause no

Table 28. Yield and error (risk) response to pest management variables and N. Guimba, Zaragoza, and Koronadal, Philippines, 1982-88.[a]

Variable	Guimba		Zaragoza (DS)	Koronadal (WS)
	Wet season	Dry season		
Dependent variable: Ln yield				
Intercept	-0.807***	-0.731***	0.700***	0.919***
	(0.205)	(0.309)	(0.234)	(0.152)
Ln insecticide	0.036***	0.023***	0.015***	0.008**
	(0.011)	(0.010)	(0.004)	(0.004)
Ln nitrogen	0.108**	0.244***	0.138***	0.166***
	(0.047)	(0.076)	(0.053)	(0.037)
Dv	1.774***	0.973***	0.360***	
	(0.062)	(0.097)	(0.062)	
Ds				0.119***
				(0.023)
r^2	0.87	0.63	0.25	0.15
F computed	275.47***	89.56***	21.66***	13.65***
Observations (no.)	127	158	183	213
Dependent variable: Ln error				
Intercept	-1.138**	-3.919***		
	(0.578)	(1.075)		
Ln insecticide	-0.065*	-0.010 ns		
	(0.035)	(0.034)		
Ln nitrogen	0.040 ns	0.832***		
	(0.127)	(0.261)		
Dv	0.306 ns	-0.622**		
	(0.230)	(0.346)		
r^2	0.10	0.10		
F computed	2.30*	3.43**		
Observations (no.)	127	158	183	213

[a] Figures in parentheses are standard errors. Dv = variety dummy for Guimba and Zaragoza, Ds = synchronous dummy for Koronadal. Error = absolute difference between observed and predicted yields. ***, **, * = significant at the 1%, 5%, and 10% levels, respectively, by *t*-test. ns = not significant.

pollution. Thus, the incorporation of predators in future ETL calculations can be most promising.

Production risk, pest control, and productivity of pesticides. Utilizing panel data collected by the Entomology Department from on-farm integrated pest management (IPM) trials in Guimba, Zaragoza (Nueva Ecija), and Koronadal (South Cotabato), this study analyzed the effects of pest management variables (insecticides, resistant variety, and synchronous planting) and N on mean yield and production risks. The Heteroscedastic Error Model formulated by Just and Pope and the Preserved Output Model constructed specifically for the given experimental data were used. Implications of the results for research and pest management policies were also examined.

Production function analysis showed that the relative contribution of insecticides to mean yield was substantially lower than the contribution of resistant variety, synchronous planting, or N. Output elasticity estimates in Table 28 show that the contribution of insecticides to rice output ranged from 0.8 to 3.6% for all sites and both seasons, while that of N ranged from 10.8 to 24.4%. Intercept dummy coefficients ranged from 0.36 to 1.774 for resistant variety; for synchronous planting the value was 0.119. However, the contribution of insecticide to reducing the variance (or production risks) was significant only in WS. In DS, use of resistant variety substantially reduced risk, while N increased risk. Apparently, resistant variety is a better risk-reducing input than insecticides.

Insecticides exhibited diminishing marginal product; results were consistent for all sites and in both seasons (Table 29). However, insecticide use proved more beneficial in areas or seasons of high yield potential, that is, in Koronadal and Zaragoza and in DS. The efficiency of insecticides in pest control was generally lower in WS because of the frequent and heavy rains that washed out the chemicals. Pest control during the flowering stage was most beneficial, but yield losses were evident at all stages.

Table 29. Productivity of insecticides using the Preserved Output Model for DS and WS, Guimba, Zaragoza, and Koronadal, Philippines, 1982-88.[a]

Variable	Guimba	Zaragoza	Koronadal
Dependent variable: preserved output			
	Wet season		
Insecticide	0.098***	0.080***	0.404***
	(0.093)	(0.017)	(0.063)
Insecticide^2	−0.003 ns	−0.001*	−0.021***
	(0.002)	(<0.001)	(0.004)
r^2	0.60	0.60	0.45
F computed	39.14***	52.86***	38.02***
Av product (kg/ha)	95	79	383
Observations (no.)	55	73	95
	Dry season		
Insecticide	0.183***	0.539***	0.290***
	(0.047)	(0.163)	(0.051)
Insecticide^2	−0.007***	−0.133*	−0.014***
	(0.003)	(0.073)	(0.003)
r^2	0.57	0.60	0.51
F computed	39.16***	52.86***	59.30***
Av product (kg/ha)	176	406	276
Observations (no.)	62	37	115

[a] Figures in parentheses are standard errors. Preserved output = yield of protected plot minus yield of unprotected plot. ***, **, * = significant at the 1%, 5%, and 10% levels, respectively. ns = not significant.

Management of rice pests

Weeds

Agronomy Department

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HERBICIDE SCREENING

Research to identify herbicides for weed control in rice continued at IRRI; at the Maligaya, Bicol, and Visayas research stations of the Philippine Bureau of Plant Industry; and in farmers' fields in Nueva Ecija.

Echinochloa crus-galli ssp. *hispidula*, *E. glabrescens*, *Monochoria vaginalis*, and *Cyperus difformis* were common at most transplanted and broadcast seeded lowland sites. *E. colona*, *Eleusine indica*, *C. rotundus*, *Rottboellia cochinchinensis*, *Commelina benghalensis*, and *Amaranthus spinosus* were dominant in the upland fields.

Preliminary screening. *Irrigated transplanted rice.* The dominant weeds of transplanted IR66 were *Echinochloa glabrescens*, *E. crus-galli* ssp. *hispidula*, *M. vaginalis*, *Cyperus difformis*, and *Scirpus maritimus*. Highest grain yield was obtained from plots hand-weeded at 15 and 30 d after transplanting (DT). Sindax, a new herbicide, when applied alone (0.01 kg ai/ha) at 4 DT or in combination with thiobencarb (1.0 kg ai/ha) or butachlor (0.3 kg ai/ha) at 4 or 10 DT, and the butachlor check (1.0 kg ai/ha at 4 DT) substantially reduced weed population. These treatments gave higher grain yields than the untreated check. Sindax applied at 10 DT did not control the grasses, whereas Mon 7200 (0.1 kg ai/ha) applied at 4 DT did not control the sedges. Consequently, both treatments gave very low yields. None of the herbicides were toxic to rice.

Irrigated wet seeded rice. Sindax (0.1 kg ai/ha) in combination with either thiobencarb or butachlor (1.0 kg ai/ha), single application of thiobencarb, Mon 7200 applied at 5 d after seeding (DAS), and Sindax applied at 8 DAS adequately reduced the weed populations and gave higher yields than did the untreated check (Table 1). The butachlor check at 1.0 kg ai/ha applied at 5 DAS reduced the weeds but was toxic to wet seeded rice (WSR); hence, yields were low.

Rainfed transplanted rice. The dominant weeds were *M. vaginalis*, *C. difformis*, and *S. maritimus*. All herbicide treatments—thiobencarb or butachlor (1.0 kg ai/ha) at 4 DT, Mon 7200 (0.1 kg ai/ha) at 4 DT or 10 DT, Sindax (0.01 kg ai/ha) at 4 or 10 DT, and Sindax + thiobencarb or butachlor at 4 or 10 DT—adequately reduced the broadleaf weed population but only moderately reduced the sedge population. Yields did not differ significantly from those of the untreated check, possibly because of low grassy weed pressure. Nevertheless, yield increases due to herbicide treatments ranged from 0.4 to 1.9 t/ha. All herbicides were safe for transplanted rice (TPR).

Rainfed wet seeded rice. The herbicide treatments—thiobencarb or butachlor (1.0 kg ai/ha) at 5 DAS, Mon 7200 (0.1 kg ai/ha) at 5 or 8 DAS, Sindax (0.01 kg ai/ha) at 5 or 8 DAS, and Sindax + butachlor or thiobencarb—gave 30-94% control of the grasses and sedges. Though yields were generally low because of a typhoon 2 wk

Table 1. Effect of weed control treatments on weed control, crop tolerance, and yield of irrigated wet seeded IR66.[a] IRRI, 1988 WS.

Treatment[b]	Application		Weed weight (g/m²)			Visual toxicity rating[d]	Grain yield (t/ha)
	Rate (kg ai/ha)	Time (DAS)[c]	Broadleaf weeds	Grasses	Sedges		
Sindax + thiobencarb	0.01 + 1.0	8	0 a	4 a	9 a	4	3.6 a
Hand-weeded check	Twice	15 + 30	1 a	8 a	15 a	0	3.4 a
Sindax + thiobencarb	0.01 + 1.0	5	0 a	5 a	18 a	3	3.3 a
Sindax + butachlor	0.01 + 0.3	5	0 a	17 ab	24 a	5	3.2 a
Thiobencarb	1.0	5	2 a	31 ab	40 abc	3	3.1 a
Mon 7200	0.1	5	3 a	5 a	30 ab	6	3.0 a
Sindax	0.01	8	0 a	19 ab	25 ab	3	2.6 ab
Butachlor	1.0	5	0 a	3 a	36 ab	8	1.6 bc
Untreated check	–	–	23 b	51 ab	107 bcd	0	1.5 bc
Mon 7200	0.1	8	4 a	78 b	144 d	3	1.4 bc
Sindax	0.01	5	0 a	70 ab	127 cd	2	1.3 c

[a] Av of 3 replications. [b] A plus (+) sign means the herbicides were tank-mixed. [c] DAS = days after seeding. [d] Rated 2 wk after herbicide application on a scale of 0-10: 0 = no toxicity, 10 = complete kill.

before harvest, most treatments gave higher yields than did the untreated check. The herbicides were slightly toxic to WSR.

Dry seeded rice. Two herbicide trials were conducted in Guimba, Nueva Ecija, from July to November 1988. The dominant weed species in the first experiment were *E. colona, C. rotundus*, and *Cynodon dactylon*. In the second experiment, the dominant species up to 60 d after emergence (DE) were *E. colona, Fimbristylis miliacea*, and *Scirpus supinus*, while *Ischaemum rugosum* dominated from 60 DE until harvest.

In the first experiment, all the treatments except pyrazosulfuron + propanil, pyrazosulfuron + fenoxaprop-ethyl, and fenoxaprop-ethyl applied at 0.045 kg ai/ha reduced weed growth. These treatments also failed to increase the yield significantly compared with the untreated check. The yields of the other treatments—pyrazosulfuron; pyrazosulfuron + oxadiazon, butachlor, or thiobencarb; fenoxaprop-ethyl alone or followed by 2,4-D; butachlor followed by hand weeding; and pendimethalin followed by propanil—were comparable to that of the hand-weeded check.

In the second experiment, the highest yield of 2.4 t/ha was obtained from the plot that was hand weeded three times at 12, 20, and 35 DE. The highest yield (2.0 t/ha) of a herbicide treatment was obtained with a tank mixture of propanil + thiobencarb applied at 3.0 + 1.0 kg ai/ha at 11 DE. Fenoxaprop-ethyl at 0.45 kg ai/ha applied at 11 DE gave excellent control of the grasses but failed to control the sedges and the broadleaf weeds. As a result, no yield was obtained with that treatment.

Upland rice. Low rates of nonselective herbicides were compared with selective postemergence herbicides and a standard preemergence check, pendimethalin.

The dominant weeds were the grasses *R. cochinchinensis, Eleusine indica, Echinochloa colona*; the sedge *Cyperus rotundus*; and two broadleaf weeds *Commelina benghalensis* and *A. spinosus*. On the basis of weed weight, grasses composed 64%, broadleaf weeds 28%, and sedges 8% of the weeds in the unweeded plots at 42 DE.

Plots that were weeded twice had the lowest weed weights at 42 DE. Glyphosate-isopropylamine did not control the weeds regardless of the rate and time of application because of the low rates used (Table 2). Glyphosate at 0.36 and 0.72 kg ai/ha applied at 14 and 28 DE gave weed control comparable to that of the hand-weeded plot. Fenoxaprop-ethyl, propanil, pendimethalin, and fluazifop-butyl significantly reduced the weed weight compared with no weeding.

Fenoxaprop-ethyl gave excellent control of the grasses but had no effect on the broadleaf species

Table 2. Weed weight and grain yield of UPLRi-5 rice as affected by weed control treatment. IRRI, 1988 WS.

Treatment[a]	Rate (kg ai/ha)	Time of application	Weed weight at 42 DE (g/m^2)	Yield (t/ha)
Propanil	3.0	10 DE	59 a-d	2.3 a
Hoe + hand weeding	–	14, 28 DE	96 b-f	2.2 a
Glyphosate	0.72	14 DE	34 ab	1.9 ab
	0.36	14 DE	80 a-d	1.4 a-d
	0.18	14 DE	179 c-i	0.7 def
	0.09	14 DE	230 f-k	0.2 f
Propanil + monocrotophos	3.0 + 0.5	10 DE	64 a-d	1.7 abc
Hand weeding, 3 times	–	14, 28, 56 DE	8 a	1.6 abc
Pendimethalin	1.5	PE[b]	89 a-e	1.5 a-d
Fluazifop-butyl	0.08	8 DE	115 b-f	0.9 c-f
Fenoxaprop-ethyl	0.112	18 DE	113 a-f	1.2 b-e
Glyphosate	0.72	28 DE	48 abc	0.3 ef
	0.36	28 DE	69 a-d	1.4 a-d
	0.18	28 DE	142 a-g	1.2 b-e
	0.09	28 DE	150 b-h	0.6 ef
Unweeded	–	–	218 e-k	0.2 f

[a] All plots were weeded from 56 to 60 d after emergence (DE). [b] Preemergence.

or on *Cyperus rotundus*. Propanil alone and in combination with monocrotophos gave excellent control of *R. cochinchinensis* and *E. colona* but had no effect on *C. rotundus* and *Commelina benghalensis*. Fluazifop-butyl controlled the grasses but had no effect on the broadleaf weeds and the sedges. Pendimethalin did not control *Cyperus rotundus* or *Commelina benghalensis*..

None of the herbicide treatments gave complete or sustained weed control. Because of this, all plots were hand weeded from 56 to 60 DE.

Glyphosate caused yellowing and burning of the rice leaves and stunting of the rice plants even at the lowest application rate. Stunting was still evident at harvest at the highest rates and with later application. Maturity was delayed by 3-4 wk in all glyphosate-treated plots.

Despite the additional hand weeding, yields were low in the unweeded and glyphosate-isopropylamine plots because of the intense weed growth before the weeding was done (Table 2). The weeding was too late to enable the crop to recover from the early competition. Hoe + hand weeding (HW) and propanil alone gave the highest grain yields. Pendimethalin and propanil + monocrotophos also gave yields comparable to that of the hand-weeded plots.

Rice plants treated with glyphosate at 0.36-0.72 kg ai/ha at 14 DE and 0.18-0.36 kg ai/ha at 28 DE were able to recover from the initial damage due to the herbicide, and with the additional HW at 60 DE gave a yield similar to that of the plots hand weeded 3 times.

Combinations of the treatments that performed well in this trial need to be tested with other weed-reducing management practices to come up with a suitable weed control technology for upland rice.

Advanced screening. *Transplanted rice*. In the dry season (DS), all treatments—bensulfuron, butachlor, 2,4-D, quinclorac, pendimethalin, pretilachlor + fenclorim, naproanilide - thiobencarb, and piperophos - 2,4-D—across sites gave similar grain yields.

In the wet season (WS), all treatments gave similar yields at IRRI and the Maligaya and Visayas sites. At the Bicol site, all herbicides gave yields significantly higher than that of the untreated check and, except for pendimethalin, gave yields similar to that of the hand-weeded check.

Wet seeded flooded rice. All treatments at the Maligaya and Visayas stations gave similar yields in DS. All herbicides, except for pretilachlor + fenclorim at Bicol and three herbicides at IRRI, gave significantly higher yields than did the untreated checks (Table 3).

In WS, most of the herbicide treatments at IRRI and the Visayas site and all at the Maligaya site gave grain yields similar to those of the untreated checks (Table 3). At the Bicol site, all treatments except pendimethalin gave significantly higher yields than the untreated check.

Upland rice. Grasses *E. colona, Eleusine indica, R. cochinchinensis*, and broadleaf weeds *A. spinosus* and *Trianthema portulacastrum* were dominant. All treatments—pendimethalin, propanil,

Table 3. Effect of early postemergence (6-8 DAS) application of granular herbicides on yield of broadcast seeded flooded IR64 at 3 sites in the Philippines. 1988 DS and WS.

Treatment[a]	Rate (kg ai/ha)	Dry season yield[b] (t/ha)		Wet season yield[b] (t/ha)		
		IRRI	Bicol	IRRI	Bicol	Visayas
Bensulfuron[c]	0.04	5.8 a	3.1 bc	2.8 b	3.5 b	2.5 abc
Naproanilide – thiobencarb	1.0 - 0.7	3.8 bcd	3.7 a	1.1 cd	3.5 b	1.0 d
Butachlor fb hand weeding[d]	0.5	5.1 ab	3.3 abc	3.7 a	4.7 a	2.9 a
Thiobencarb – 2,4-D	1.0 - 0.5	5.0 abc	3.6 ab	1.2 cd	3.4 b	2.6 ab
Quinclorac[c]	0.2	3.7 bcd	3.2 abc	1.4 c	3.3 bc	2.3 a-d
Piperophos – 2,4-D	0.3 - 0.2	3.0 de	3.2 abc	1.0 cd	3.5 b	2.2 a-d
Pretilachlor + fenclorim[e]	0.45	3.4 cd	2.3 d	1.0 cd	2.9 cd	1.9 a-d
Butachlor	1.0	2.2 de	2.8 c	0.7 cd	2.7 d	1.3 bcd
Pendimethalin	0.75	1.5 e	2.9 c	0.5 d	2.2 e	1.4 bcd
Untreated check	–	2.2 de	2.1 d	0.9 cd	2.1 e	1.2 cd
CV (%)		29	11	36	9	42

[a] A spaced dash (–) means the herbicides were applied as a proprietary mixture. [b] Av of 4 replications/site. [c] Wettable powder. [d] At 35 DAS. fb = followed by. [e] Emulsifiable concentrate.

butralin, and butachlor (2.0 kg ai/ha); oxadiazon (1.0 kg ai/ha); dinitramine (1.5 kg ai/ha); thiobencarb (3.0 kg ai/ha); and oxyfluorfen (0.36 kg ai/ha); all at 3 DAS—reduced the grassy weed population, whereas only butachlor and thiobencarb did not control the broadleaf weeds. In general, yields were low because of typhoons at rice maturity. However, most treatments produced higher yields than did the untreated check. Only oxadiazon and oxyfluorfen were slightly toxic to rice.

APPLICATION TECHNIQUES

Wet seeded rice. Undiluted bensulfuron, when applied to pregerminated IR66 seed before planting, did not affect crop stand, but pretilachlor + fenclorim did (Table 4). No stand reductions were observed when either herbicide was applied directly into standing water in the field. Pretilachlor + fenclorim reduced plant height irrespective of application method. Plant height was not affected by the bensulfuron treatment.

The major weeds were *Echinochloa glabrescens, M. vaginalis, Paspalum distichum*, and *Leptochloa chinensis*. Weed weights were not significantly different among the plots treated with herbicides, but were significantly lower in the herbicide-treated plots than in the untreated plots except when pretilachlor + fenclorim was applied as a seed treatment. Yields were higher in the plots treated with herbicides than in the untreated plots regardless of herbicide or application method.

Postemergence chemical weed control using controlled droplet applicators in wet seeded rice. The efficacy of four postemergence herbicides (2,4-D, bensulfuron, propanil, and fluazifop-butyl) applied using three types of sprayer (Micronherbi and Birky controlled droplet applicators, and the conventional hydraulic knapsack sprayer) was evaluated in irrigated IR64 during DS and in rainfed IR66 during WS at different experimental sites.

In DS, sprayer type did not affect total weed weight or grain yield, but the kind of herbicide did (Table 5). Bensulfuron gave the lowest total weed weight and the highest grain yield, whereas fluazifop-butyl gave the highest weed weight and the lowest grain yield. This could be attributed to the weed composition of the experimental area, which was

Table 4. Stand count, plant height, weed weight, and yield of IR66 as affected by herbicide and application method. IRRI, 1988 DS.

Treatment	Stand count (no./m²) at 14 DAS	Plant height (cm) at 14 DAS	Weed weight (g/m²) at 45 DAS	Yield (t/ha)
Pretilachlor + fenclorim (0.45 kg ai/ha)				
Seed treatment	213 b	17 c	19 ab	5.3 a
Poured at 3 DAS	385 a	19 b	9 a	5.0 a
Bensulfuron (0.04 kg ai/ha)				
Seed treatment	425 a	20 ab	13 a	5.1 a
Poured at 6 DAS	366 a	20 ab	7 a	5.3 a
Untreated	425 a	21 a	74 b	4.3 b

Table 5. Effect of sprayer type and herbicide on total weed weight at 52 d after seeding and on grain yield of irrigated broadcast seeded IR64.[a] IRRI, 1988 DS.

Herbicide/sprayer	Total weed weight (g/m²)				Rice grain yield (t/ha)			
	Micronherbi	Birky	Conventional	Mean	Micronherbi	Birky	Conventional	Mean
2,4-D (1.0 kg ai/ha)	89	43	112	81 bc	1.3	1.3	0.8	1.1 b
Bensulfuron (0.05 kg ai/ha)	58	47	47	51 c	1.7	1.9	1.8	1.8 a
Propanil (2.0 kg ai/ha)	98	145	124	122 b	0.8	1.2	1.4	1.1 b
Fluazifop-butyl (0.05 kg ai/ha)	168	288	234	230 a	0.5	0.5	0.0	0.3 c
Mean	103 A	129 A	129 A		1.1 A	1.2 A	1.0 A	

[a] Av of 3 replications. Means followed by a common lowercase letter (in a column) or by a common uppercase letter (in a row within a measured parameter) are not significantly different at the 5% level by DMRT.

dominated by the sedge *S. maritimus*. Low yields may have been due to tungro infestation.

In WS, sprayer type had a similar effect on total weed weight as in DS. 2,4-D, bensulfuron, and propanil gave similar total weed weights, which were lower than that with fluazifop-butyl. The experimental area was also dominated by *S. maritimus*. Grain yield data are not included because of rat damage.

Spray volume and application timing in upland rice. The efficacy of four postemergence herbicides (2,4-D, bentazon, fluazifop-butyl, and propanil) was tested in upland rice UPLRi-5. The herbicides were applied in a single dose at recommended rates or in 2 splits at half the recommended rate using 3 spray volumes: low (120 liters/ha), medium (200 liters/ha), and high (350 liters/ha). Spray volume was varied by fitting nozzles of different sizes into the hydraulic knapsack boom sprayer.

Spray volume did not affect the control of broadleaf weeds, grasses, or the sedge *Cyperus rotundus*, but the kind of herbicide did (Table 6). A single application of propanil best controlled the broadleaf weeds, as did a single or split application of 2,4-D and a split application of propanil. Single or split application of fluazifop-butyl gave excellent control of grasses. *C. rotundus* was most effectively controlled by split application of 2,4-D or bentazon.

Propanil and fluazifop-butyl in split application gave the lowest total weed weight, which was similar to treatments with single applications of the same herbicides. Regardless of spray volume, fluazifop-butyl controlled broadleaf weeds and bentazon controlled *C. rotundus* more effectively when either was applied in two splits than in a single dose. All other herbicides were the same in controlling weeds when applied in a single dose or in two splits.

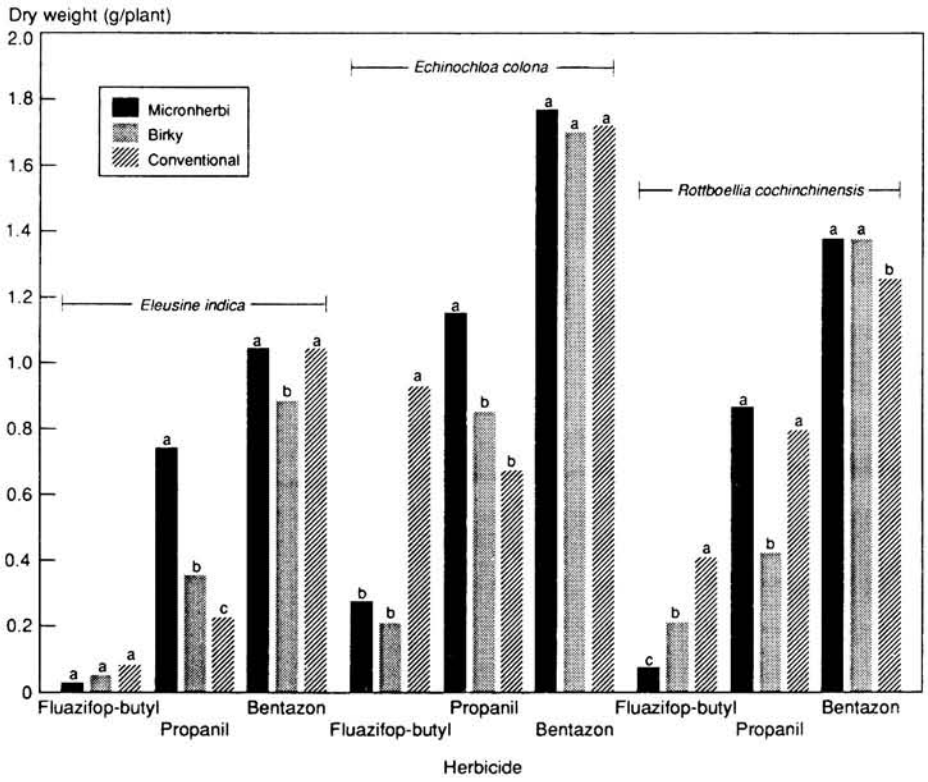
Effect of sprayer type on the biological efficacy of herbicides. Three upland grass weeds (*Eleusine indica, Echinochloa colona*, and *R. cochinchinensis*) were grown separately in the greenhouse at 1 seedling/9-cm pot. At 12-18 DE, 3 postemergence herbicides at 1/4 and 1/2 of the recommended rate and at actual recommended rates were sprayed on the weed seedlings using 3 sprayer types – Micronherbi, Birky, and the conventional hydraulic knapsack sprayer – at approximate spray volumes of 20, 55, and 300 liters/ha, respectively.

Sprayer type and herbicide significantly affected weed dry weight at 41 DE (Fig. 1). With fluazifop-butyl herbicide, *Eleusine indica* dry weight was similar across all sprayer types, whereas *Echinochloa colona* and *R. cochinchinensis* dry weights were lower with Micronherbi and Birky than with the conventional sprayer. With propanil, *Eleusine indica* and *Echinochloa colona* dry weights were lower with Birky and the conventional sprayer than with Micronherbi, whereas *R. cochinchinensis* dry weight was lower with Birky than with Micronherbi and the conventional sprayer. When bentazon was used, *Eleusine indica* dry weight was lower with Birky than with the two other sprayers, whereas *R. cochinchinensis* dry weight was lower

Table 6. Effect of herbicide application rate and timing on weed control in upland rice UPLRi-5.[a] IRRI, 1988 WS.

Treatment	Application		Dry weight[b] (g/m²)			
	Rate (kg/ha)	Time (DE)	Broadleaf weeds	Grasses	Sedges	Total
2,4-D	1.0	20	42 de	273 ab	41 cd	356 abc
2,4-D fb 2,4-D	0.5 fb 0.5	14 fb 21	29 de	304 a	15 d	349 abc
Bentazon	1.0	20	86 c	264 ab	71 abc	443 a
Bentazon fb bentazon	0.5 fb 0.5	14 fb 21	71 cd	293 a	24 d	388 a
Fluazifop-butyl	0.05	14	184 a	18 d	88 ab	290 bc
Fluazifop-butyl fb fluazifop-butyl	0.025 fb 0.025	10 fb 20	130 b	46 d	105 a	281 c
Propanil	3.0	10	10 e	204 bc	83 abc	296 bc
Propanil fb propanil	1.5 fb 1.5	7 fb 15	33 de	177 c	47 bcd	257 c
LSD (0.05)			41	78	42	89

[a] Av of 3 replications and 3 spray volumes. fb = followed by. [b] Weeds were sampled at 41 DE.



1. Effect of sprayer type and herbicide on dry weight of 3 upland grass weeds at 41 d after emergence (DE), IRRI greenhouse, 1988 WS. Comparison of sprayer types for each herbicide and weed species is at the 5% level by DMRT.

with the conventional than with the other sprayers. *Echinochloa colona* dry weight was similar for all sprayer types.

Among the herbicides, fluazifop-butyl gave the best control of the three weeds; bentazon gave the least, regardless of sprayer type. Propanil performed better than did bentazon but was inferior to fluazifop-butyl, except when the conventional sprayer was used on *E. colona*, where propanil and fluazifop-butyl gave similar *E. colona* dry weights.

Eleusine indica thus appeared to be the most susceptible to the herbicides used, and *Echinochloa colona* the least. *R. cochinchinensis* had intermediate susceptibility.

Effect of sethoxydim on upland rice and weeds. The efficacy of sethoxydim was evaluated in the greenhouse during WS. Sethoxydim at 0, 0.025, 0.05, 0.10, and 0.20 kg/ha was sprayed on individual seedlings of *E. colona, Eleusine indica, R. cochinchinensis,* and UPLRi-5 rice at 7, 14, 21, and 28 DE. All plant species were grown in 9-cm plastic pots under upland conditions.

Sethoxydim at all application rates reduced the shoot dry weight of *Echinochloa colona* and *R. cochinchinensis* and, at 0.05 kg/ha, that of *Eleusine indica* and rice (Table 7). Thus, *E. indica* was more tolerant of sethoxydim at 0.025 kg/ha than were the other weeds. Sethoxydim was selective for rice only at 0.025 kg/ha.

Application time of sethoxydim did not affect shoot dry weight of rice (Fig. 2). Shoot dry weight of each weed species was lowest when sethoxydim was applied at 7 DE. Spraying sethoxydim at 21 DE gave highest shoot dry weight for *Echinochloa colona* and *Eleusine indica.* Results suggest that *Echinochloa colona* and *Eleusine indica* are least susceptible to sethoxydim at 21 DE, and *R. cochinchinensis* at 14 DE.

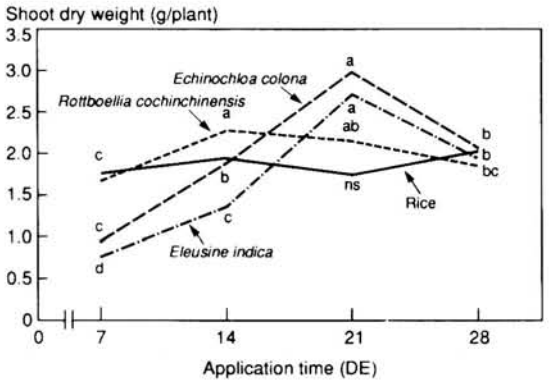
Table 7. Effect of sethoxydim application rate on the shoot dry weight at 46 DE of UPLRi-5 and 3 grass weeds grown under upland conditions.[a] IRRI greenhouse, 1988 WS.

Application rate (kg/ha)	Shoot dry weight (g/plant)			
	UPLRi-5	*E. colona*	*R. cochinchinensis*	*E. indica*
0	2.9 a	3.5 a	4.2 a	2.9 a
0.025	2.4 a	2.3 b	2.6 b	2.4 a
0.05	1.4 c	1.9 b	2.0 c	1.2 b
0.10	1.9 b	1.3 c	0.8 d	1.0 b
0.20	0.8 d	1.0 c	0.6 d	1.1 b

[a] Av of 3 replications and 4 application times.

NITROGEN FERTILIZER MANAGEMENT AND WEED CONTROL PRACTICES

Timing of nitrogen and weed control applications. A field trial in 1988 DS and WS evaluated the effect of applying basal N before and after weed control on N uptake and grain yield of wet seeded flooded rice. Each of the three N application treatments was split into four weed control timings. IR64 was planted in DS and IR72 in WS. *S. maritimus* was the dominant weed.



2. Effect of application time of sethoxydim on shoot dry weight at 46 DE of UPLRi-5 and 3 grass weeds grown under upland conditions, IRRI greenhouse, 1988 WS. Av of 3 replications and 5 application rates. Within a species, means accompanied by the same letter are not significantly different at the 5% level by DMRT.

In DS, broadcasting and incorporating N significantly increased N uptake by rice, and N applied at 15 DAS increased grain yield (Table 8). In WS, N application did not affect N uptake; but it increased grain yield when N was broadcast and incorporated. Neither N uptake nor grain yield, however, was affected by N application timing.

In neither season was N uptake affected by weeding or weeding time. All treated plots except those weeded at preemergence in DS gave significantly higher yields than did the unweeded check (Table 9). Yields from plots weeded at postemergence were generally higher than from those weeded at preemergence because of lower *S. maritimus* regrowth in the former.

Nitrogen management and weed control. The efficiency of N fertilizer management practices was evaluated in three weeding regimes in rainfed transplanted IR64. The amount and time of N

Table 8. Nitrogen uptake and grain yield of broadcast seeded flooded rice as affected by timing of N application.[a] IRRI, 1988.

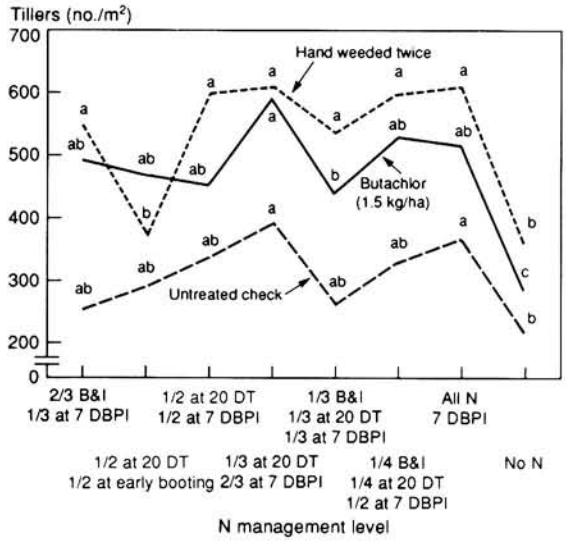
Treatment[b]	Dry season[c]		Wet season[d]	
	N uptake (%)	Grain yield (t/ha)	N uptake (%)	Grain yield (t/ha)
No N check	1.8 b	3.8 b	1.6 a	2.8 b
2/3 B&I + 1/3 7 DBPI	2.2 a	4.4 ab	1.6 a	3.7 a
2/3 15 DAS + 1/3 7 DBPI	2.0 ab	4.6 a	1.6 a	3.4 ab

[a] Av of 4 replications and 4 weed control treatments/season. [b] B&I = broadcast and incorporated. DBPI = days before panicle initiation, DAS = days after seeding. [c] IR64. [d] IR72.

Table 9. Grain yield as affected by timing of weed control.[a] IRRI, 1988.

Time of weeding	Grain yield (t/ha)	
	Dry season	Wet season
No weeding	3.6 c	1.2 c
Preemergence (3 DAS)	4.1 bc	3.8 b
Early postemergence (10 DAS)	4.6 ab	4.3 a
Late postemergence (20 DAS)	4.7 a	4.0 ab

[a] Av of 4 replications and 3 N treatments/season.



3. Effect of N fertilizer management and weed control on tiller number of rainfed transplanted IR64, IRRI, 1988 WS. Mean comparison at each weeding regime is at the 5% level by DMRT. B&I = broadcast and incorporated, DBPI = days before panicle initiation, DT = days after transplanting.

fertilizer application were varied while maintaining a total application rate of 80 kg N/ha as urea.

At 49 DT, weed control treatments decreased total weed weight, with weed weight lower in hand-weeded than in butachlor-treated plots (Table 10). Although tiller count at 47 DT was higher in hand-weeded than in butachlor-treated plots, leaf area index and grain yield were similar.

Rice plants fertilized with N were taller than those that received no N. Among the N treatments, 3 equal splits of N applied basally, at 20 DT, and at 7 d before panicle initiation (DBPI) produced the tallest plants, but they were similar to those fertilized with 1/3 N at 20 DT and 2/3 N at 7 DBPI.

With good weed control, single-dose or split applications of N before booting improved rice tillering (Fig. 3). When weeds were not controlled, split N application, where 1/3 N was applied at 20 DT and 2/3 N at 7 DBPI, and all N applied at 7 DBPI performed better.

Without weed control, grain yields were similar regardless of N management level (Fig. 4). When weeds were controlled, plots with 3 split N applications consistently produced higher yields than did the nonfertilized plots, which gave yields similar to those with single-dose or 2 split N applications.

CONTROL OF PROBLEM WEEDS

Scirpus maritimus. In DS, grain yield of rotary-weeded plots in a continuous TPR pattern was higher than that of bentazon-treated plots (Table 11). The untreated check had no yield because the *S. maritimus* population was intense.

In continuous TPR in WS, rotary-weeded plots gave higher yields than did bentazon-treated plots. Both treatments, however, gave higher yields than did the untreated check (Table 12).

Table 10. Effect of weeding regime on total weed weight at 49 DT and on growth and grain yield of rainfed transplanted IR64.[a] IRRI, 1988 WS.

Weeding regime	Total weed weight (g/m^2)	Tillers ($no./m^2$) at 47 DT	Leaf area index at 47 DT	Grain yield (t/ha)
Butachlor (1.5 kg ai/ha)	96 b	480 b	2.1 a	1.6 a
Hand weeded twice[b]	26 c	533 a	2.2 a	1.8 a
No weeding (check)	230 a	309 c	1.3 b	0.5 b

[a] Av of 3 replications and 8 N fertilizer management levels. [b] At 15 and 30 d after transplanting (DT).

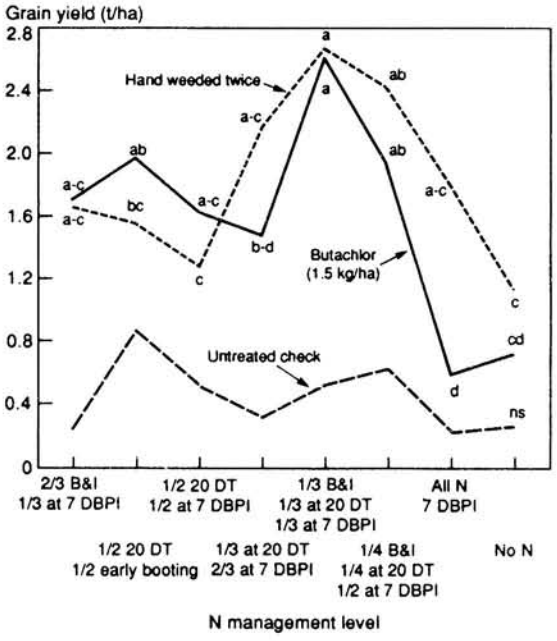
In upland crop - TPR, yields were similar in rotary-weeded and bentazon-treated plots. Yields of untreated plots were low because of infestation with annual sedge *F. miliacea*, which seemed to replace *S. maritimus*.

In dry seeded, rainfed, bunded rice following maize, yields were higher with hand weeding. Butachlor-treated plots gave low yields because of *Macroptilium lathyroides* and *Ipomoea triloba*.

Untreated plots gave zero yield because of mixed populations of broadleaf weeds and other annual sedges. *C. rotundus* was not observed in any of the plots.

Salvinia molesta. Herbicide application. Preplanting applications of glyphosate at 1.5 kg/ha and glyphosate + ammonium sulfate at 0.3 kg/ha provided excellent control of *S. molesta*, which causes problems with crop establishment in irrigated rice areas in Central Visayas, Philippines. Follow-up postplanting herbicide treatments did not cause a further decrease in *S. molesta* dry weight. In the absence of a preplant herbicide application, however, butachlor, bensulfuron, metsulfuron-methyl, and piperophos - 2,4-D when applied postplanting reduced *S. molesta* dry weight significantly. These treatments were not as effective as the preplanting treatments, reducing *S. molesta* only 49% compared with the 96% reduction with glyphosate.

Postplanting herbicide treatments that gave excellent control of the other weed species in the



4. Effect of N fertilizer management and weed control on grain yield of rainfed lowland IR64, IRRI, 1988. Mean comparison at each weeding regime is at the 5% level by DMRT.

Table 11. Effect of weeding method and cropping pattern on crop yield and population density of weeds.[a] IRRI, 1988 DS.

Cropping pattern and weeding treatment[b]	Yield[c]	Weeds (no./m²)				
		Broadleaf weeds	Grasses	Sedges	*Scirpus maritimus*	*Cyperus rotundus*
Continuous TPR						
	Rice (t)					
Rotary weeding	4.2 a	3	2	17	110	0
Bentazon (1.5 kg ai/ha)	3.1 b	0	13	0	156	0
No weeding	0 c	0	0	24	1200	0
Upland crops - TPR						
	Maize (ears) + soybean (kg)					
Hand weeding	32,750 a + 459 a	68	12	25	0	0
Butachlor (1.5 kg ai/ha)	11,750 b + 482 a	188	19	0	0	0
No weeding	8,000 c + 280 a	301	6	3	0	0
Maize - rainfed bunded DSR						
	Maize (ears)					
Hand weeding	28,250 a	28	10	9	0	0
Butachlor	18,750 b	198	40	6	5	0
No weeding	15,750 b	104	58	22	0	0

[a]Av of 2 replications. [b]TPR = transplanted rice, DSR = dry seeded rice. [c]Within a crop, values followed by a common letter are not significantly different at the 5% level by DMRT.

Table 12. Effect of weeding method and cropping pattern on rice yield and population density of weeds.[a] IRRI, 1988 WS.

Cropping pattern and weeding treatment	Rice yield (t/ha)	Weeds[b] (no./m²)			
		Broadleaf weeds	Grasses	Sedges	*Scirpus maritimus*
Continuous TPR					
Rotary weeding	4.9 a	40	34	396	42
Bentazon	3.9 b	50	54	116	98
No weeding	0.1 c	17	14	148	928
Upland crop - TPR					
Rotary weeding	4.4 a	30	60	460	10
Bentazon	3.9 a	50	10	365	7
No weeding	1.2 b	13	7	640	110
Upland crop - rainfed bunded DSR					
Hand weeding	1.2 a	66	12	11	0
Butachlor	0.7 b	84	13	28	0
No weeding	0.0 c	92	8	301	3

[a] Av of 2 replications. [b] There was no *Cyperus rotundus*.

experimental plots were quinclorac, bensulfuron, piperophos - 2,4-D, and bensulfuron + metsulfuron-methyl + quinclorac. Stand reductions were caused by butachlor, pretilachlor + fenclorim, and piperophos - 2,4-D.

Tillage. A ricefield heavily infested with *S. molesta* was used for two studies on the effects of degree of tillage and weed control treatments on weed control and crop yield. In both trials, the tillage levels were a) low (1 plowing + 1 rototilling 1 wk later), b) medium (1 plowing + 2 rototillings at weekly intervals), and c) high (1 plowing + 3 rototillings at weekly intervals). A water buffalo was used for the plowing operations and a hydrotiller for the rototillings. The crop was planted on the same day in each tillage treatment.

In both TPR and WSR, *S. molesta* was effectively controlled by the tillage operations—the hydrotiller effectively buried the weed in the mud—and the tillage levels did not significantly differ in weed control.

In both experiments, grain yield was not affected by tillage level; the average yield for TPR was 4.9 t/ha, that for WSR 4.0 t/ha. In TPR, grain yield in the plots infested with *S. molesta* was similar to that in the hand-weeded or butachlor-treated plots (4.9 t/ha vs an average of 5.1 t/ha). Yields were significantly lower (4.6 t/ha) when other weeds in addition to *S. molesta* competed with rice. The average weed weight of the other weeds was low (33.1 g/m²) because of the continuous flooding and the suppressive ability of *S. molesta*.

In the WSR trial, weed weights were reduced by increasing seeding rate and herbicide application. Yields were increased by herbicide application but decreased because of increased seeding rate due to intraspecific competition.

RICE-WEED COMPETITION

Transplanted rice. *Naturally occurring weed flora.* Two experiments were conducted to determine the effect of different percentages of the naturally occurring weed flora, based on area, on TPR yield. In the first experiment, conducted during DS, the percentage weed cover ranged from 1 to 50%. Weed-free (0%) and weedy (100%) plots were included as checks. The dominant weeds, in decreasing order, were *Echinochloa* spp., *C. difformis*, and *Monochoria vaginalis*. The number of rice tillers and the grain yield were reduced at all levels of weed infestation (Table 13).

In the second experiment, conducted during the rainy season, the percentage weed cover ranged from 0.16 to 6.25%. Weed-free and weedy checks were also included. The dominant weed species was *C. difformis*. The number of tillers was reduced when the percentage of weed cover reached 0.32%, but yield was not significantly reduced until there was 1% weed cover (Table 14). There was a linear relationship between yield and weed weight at 5 ($Y = 4.459 - 0.034X$, $r = -0.99^{**}$) and

Table 13. Effects of varying degrees of weed infestation on weed weight, number of rice tillers, and yield of transplanted IR66.[a] IRRI, 1988 DS.

Treatment (% infestation)	Weed weight (g/m²)				Tillers (no./m²) at 8 WT	Yield (t/ha)
	5 WT		8 WT			
	g/m²	%	g/m²	%		
0	7 a	2.8	42 a	7.7	342 a	2.6 a
1	37 ab	15.6	223 ab	40.8	246 b	0.8 b
6	76 abc	31.8	196 ab	35.8	250 b	1.0 b
12	105 bc	44.0	317 bc	57.9	195 bc	0.6 b
25	90 bc	37.7	331 bc	60.4	234 b	0.6 bc
50	128 c	53.8	333 bc	60.8	207 bc	0.6 bc
100	238 d	100.0	458 c	100.0	157 c	0.1 c

[a]WT = weeks after transplanting.

Table 14. Effects of varying degrees of weed infestation on weed weight, number of rice tillers, and yield of transplanted IR66. IRRI, 1988 WS.

Treatment (% infestation)	Weed weight (g/m²)				Tillers (no./m²) at 8 WT	Yield (t/ha)
	5 WT		8 WT			
	g/m²	%	g/m²	%		
0	2 a	1.4	4 a	1.2	394 a	4.4 a
0.16	5 a	4.0	24 a	6.7	352 ab	4.4 a
0.32	7 a	5.9	32 a	9.3	311 b	4.4 a
0.48	9 a	7.7	46 ab	13.3	333 b	4.1 ab
0.68	19 a	16.1	50 ab	14.3	330 b	3.8 abc
1.00	25 ab	22.1	112 bc	32.0	340 b	3.4 bc
6.25	43 b	37.0	170 c	48.5	307 b	3.0 c
100	115 c	100	351 d	100	215 c	0.6 d

8 ($Y = 4.593 - 0.011X$, $r = -0.99^{**}$) wk after transplanting (WT).

In both experiments, the percentage of weed infestation based on area was always lower than the infestation percentage based on weed weight (Table 13, 14). There was less competition at the lower levels of weed infestation; as a result, more growth occurred.

Lowland weed species. A trial in 1987 WS determined the effect of the density of different weed species on TPR. Yield losses ranged from 0-22% when there was competition from 5 weeds/m² to 34-100% when 80 weeds/m² competed. The weed density required to reduce grain yield significantly ranged from 5 for *E. colona* to 40 for *M. vaginalis* (Table 15). For all species, there was a sigmoidal relationship between weed density and crop yield.

Salvinia molesta. An experiment on the effect of different levels of N fertilizer on the competitive effect of *S. molesta* confirmed previous findings that even though *S. molesta* reduced the stand of WSR, yield was not affected. *S. molesta* reduced tiller number by as much as 18%, but the rice crop compensated by producing longer panicles and more grains per panicle.

Nitrogen application significantly reduced the dry weight of *S. molesta* at crop harvest, indicating that the crop was more competitive against the weed when N was applied. *S. molesta* had a suppressive effect on the other weed species in the experimental plots.

Pistia stratiotes. Different levels (0-100% cover) of *P. stratiotes* at the 5- to 7-leaf stage that were inoculated into WSR at 3 DAS had no adverse effect on crop stand and grain yield. In fact, yields

Table 15. Effect of weed density on yield loss in transplanted rice. IRRI, 1987 WS.

Species	Density[a] (no./m²)	Regression equation	r^2
Echinochloa colona	5	$Y = 0.29 + 2.00e^{-x^2}$	0.789**
Cyperus iria	10	$Y = 0.0746 + 1.451e^{-x^2}$	0.846**
Sphenoclea zeylanica	20	$Y = 1.422 + 0.9767e^{-x^2}$	0.804**
Monochoria vaginalis	40	$Y = 0.245 + 1.416e^{-x^2}$	0.889**

[a] Needed to reduce yield significantly.

from the plots infested with 80-100% weed cover were significantly higher (av 2.9 t/ha) than those from plots with lower levels of infestation and the plot without *P. stratiotes* (av 2.2 t/ha). The high *P. stratiotes* cover in these plots might have increased N uptake efficiency by the crop by reducing NH_3 volatilization, which is a major means of N loss in flooded soil.

Upland rice. Trials were conducted to determine the grain yield reduction in 3 upland rice cultivars by densities of 0-32 plants/m² of different weed species.

Commelina benghalensis. Yields of Dinorado and UPLRi-5 were significantly reduced by 32 plants of *C. benghalensis*/m², while that of IR29429-B-3-B-1-4 was significantly reduced by 16 and 32/m². Dinorado had significantly lower grain yield than the other cultivars. There was a significant negative correlation between grain yield and weed density for all cultivars:

UPLRi-5 $Y = 4.103 - 0.06479X$, $r^2 = 0.939***$

IR29429-B-3-B-1-4 $Y = 3.897 - 0.05617X$, $r^2 = 0.843***$

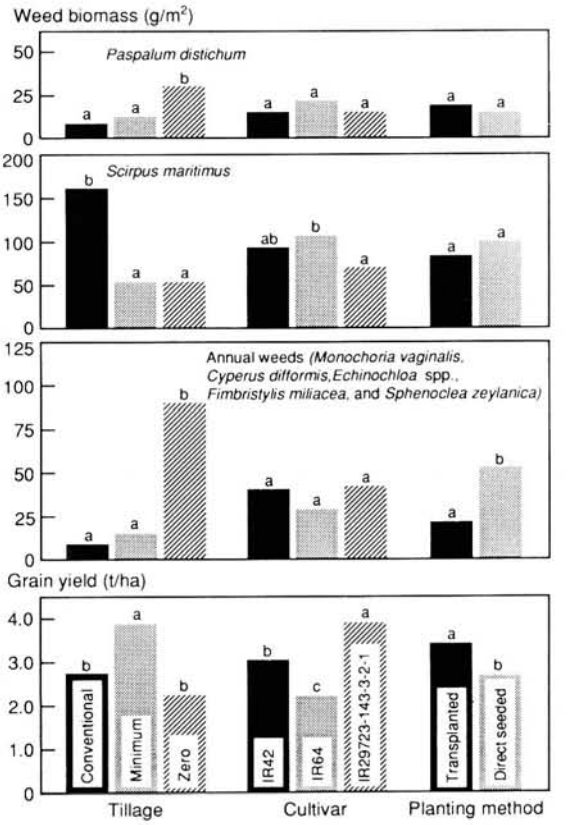
Dinorado $Y = 2.1857 - 0.04055X$, $r^2 = 0.854**$

Cyperus rotundus. *C. rotundus* had no effect on grain yield of the same upland rice cultivars. Because *C. rotundus* is shade-sensitive, it could not grow well to compete against cultivars that, at maturity, were 102-142 cm high.

INTEGRATED WEED MANAGEMENT

Effect of tillage, cultivar, and planting method. Research continued on the long-term effects of tillage level (conventional, minimum, and zero), cultivar (IR42, IR64, and IR29723-143-3-2-1), and planting method (transplanted and direct seeded). Conventional tillage comprised 1 plowing and 2 harrowings, minimum tillage was 1 plowing and 1 harrowing, and zero tillage was cutting and removing rice and weed debris in DS (29th crop) and applying glyphosate at 1.0 kg ai/ha in WS (30th crop).

In the 29th crop, conventional tillage gave significantly lower *Paspalum distichum* and annual weed growth but higher *Scirpus maritimus* growth than did zero tillage (Fig. 5). Minimum tillage,

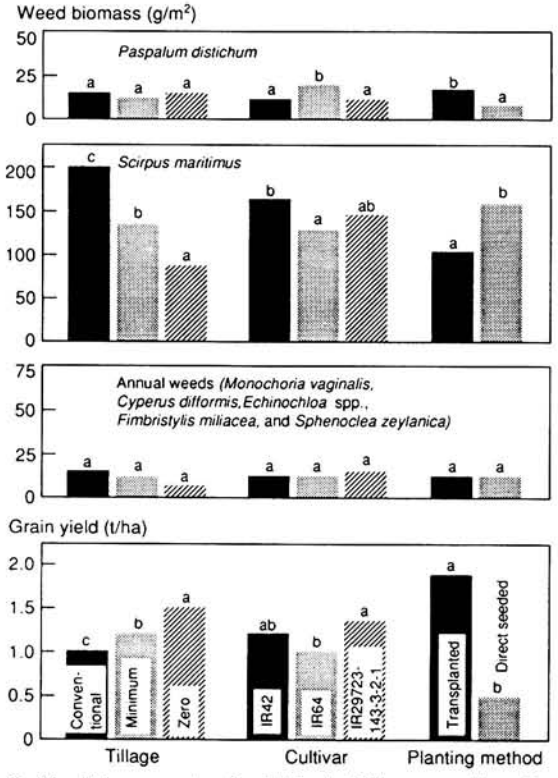


5. Weed biomass and grain yield in the 29th crop as affected by tillage, cultivar, and planting method, IRRI, 1988 DS. Within a parameter, e.g., tillage, bars with a common letter are not significantly different at the 5% level by DMRT.

which gave consistently lower biomass of all weed types than did either of the other tillage treatments, gave significantly higher yields. Yield was more a function of inherent cultivar yielding capacity than of weed infestation. IR29723-143-3-2-1 yielded significantly higher than IR42, which yielded higher than IR64. Biomass of annual weeds was substantially lower and grain yield higher with transplanting.

In the 30th crop, *S. maritimus* stand markedly declined and grain yield steadily increased with each decrease in tillage intensity (Fig. 6). IR29723-143-3-2-1, which provided adequate control of *P. distichum* and *S. maritimus*, gave the highest yield. Poor stand establishment of direct seeded rice led to heavier *S. maritimus* growth and lower yield than that of TPR.

Weed-insect-irrigation interactions. An experiment was conducted to determine the effect of irrigation, weed control, and insecticide application on weed growth, insect pest control, and yield of TPR. Because insect damage did not reach the economic threshold level, the values for the no insect control treatment and the economic threshold level were averaged.



6. Weed biomass and grain yield in the 30th crop as affected by tillage, cultivar, and planting method. IRRI, 1988 WS. Within a parameter, e.g., tillage, bars with a common letter are not significantly different at the 5% level by DMRT.

The dry weights of grasses and sedges at 45 DT were significantly reduced by irrigation immediately after transplanting compared with those plots that received irrigation at 30 DT. The reverse was true for broadleaf weeds.

At 60 DT, weed weights in the plots irrigated immediately after transplanting were significantly lower than those in the plots irrigated at 30 DT. Weed weights were reduced by HW at 14 DT but were not affected by insecticide application.

Whorl maggot *Hydrellia philippina* damage at 21 DT was significantly lower in the plot that had not been flooded (9.2%) than in the plots that were irrigated immediately after transplanting (av 14.6%). Whorl maggot damage was reduced significantly from 14.1 to 10.4% by application of monocrotophos and chlorpyrifos + BPMC at weekly intervals.

Damage of *E. glabrescens* by stem borer *Acigona steniella* was reduced significantly in all irrigation regimes by insecticide application. Less damage was observed in the plot that was irrigated until 30 DT than in the other plots. This insect does not attack rice.

Average grain yields were significantly higher when the plots were irrigated from transplanting to harvest and from transplanting to 30 DT than when the plots were irrigated from 5 or 30 DT (Table 16). Plots irrigated at 5 DT yielded significantly higher than those irrigated from 30 DT. Yields were also increased by prophylactic insect protection, despite the low insect incidence, and weed control.

Solar radiation. A trial was conducted to determine the effect of reduced solar radiation on weed competition in TPR. At 45 DT, the height of IR66 increased as a result of a 52% reduction in solar radiation; that of *E. glabrescens* was not affected (Table 17). Tiller number of IR66 was reduced when it was grown alone or in combination with *E. glabrescens*; that of *E. glabrescens* was reduced only when it was grown alone.

Plant height of both species was unaffected by competition. Tiller number of rice was reduced

Table 16. Effects of time of irrigation, insect control, and weeding on yield of transplanted IR66 rice.[a] IRRI, 1988 WS.

Weed control treatment	Yield (t/ha)		
	Complete insect control	No control	Mean
	Irrigation from transplanting until 30 DT		
HW, 14 DT	4.9 a	4.1 a	
No weeding	3.8 b	3.4 b	
Mean	4.3	3.8	4.0 a
	Irrigation from transplanting until harvest		
HW, 14 DT	4.5 a	4.0 a	
No weeding	3.7 b	3.2 b	
Mean	4.1	3.6	3.8 a
	Irrigation from 5 DT until harvest		
HW, 14 DT	3.5 a	4.7 a	
No weeding	2.7 a	2.2 b	
Mean	3.1	3.4	3.3 b
	Irrigation from 30 DT until harvest		
HW, 14 DT	4.1 a	2.9 a	
No weeding	1.4 b	1.4 b	
Mean	2.7	2.2	2.4 c
Mean	3.6 A	3.2 B	

[a]In a column within each irrigation regime, means followed by a common lowercase letter are not significantly different at the 5% level by DMRT. In the last row, means followed by a common uppercase letter are not significantly different at the 5% level by DMRT.

Table 17. Effects of solar radiation on plant height and tiller number at 45 DT, and weed weight and grain yield at harvest of transplanted IR66 rice.[a] IRRI, 1988 DS.

Radiation	IR66	*Echinochloa colona*	Mixture	
			IR66	*Echinochloa glabrescens*
	Plant height (cm)			
Not shaded	63 b	91 a	60 b	81 a
Shaded	70 a	90 a	71 a	88 a
	Tillers (no./hill)			
Not shaded	22 a	21 a	17 a	9 a
Shaded	18 b	15 b	14 b	7 a
	Weed dry weight (g/m²)			
Not shaded	–	509 a	–	196 a
Shaded	–	298 b	–	125 a
	Grain yield (t/ha)			
Not shaded	2.6 a	–	0.8 a	–
Shaded	1.0 b	–	0.6 a	–

[a]Within a parameter, means in a column followed by a common letter are not significantly different at the 5% level by DMRT.

about 25%, while that of *E. glabrescens* was reduced about 55% irrespective of light intensity.

When the species were grown alone, the yield of rice and the dry matter production of *E. glabrescens* were reduced significantly by shading, but when the two were grown together, shading had no effect on those parameters.

Yield reduction due to weeds was 70% when they were not shaded, but only 38% when shaded (Table 17). This implies that yield losses due to weed competition would be lower in WS, when light intensities are lower than in DS.

Dry seeded rice. The dominant weed species in the experimental area was *E. colona*, comprising more than 95% of the total weed weight. Weed growth in this experiment was very intense, and *E. colona* emerged earlier than rice. At 10 DT, it was difficult to distinguish rice from *E. colona* seedlings.

Butachlor at 2.0 kg ai/ha applied after germinating rain followed by HW, hoe weeding, or interrow cultivation (IRC) at 28 DE, hoe weeding + HW at 14 and 35 DE, and IRC + HW at 14 and 35 DE gave weed control comparable to that obtained with two HW (Table 18). Hoe weeding or IRC alone did not provide adequate weed control.

Grain yield was highest in the plot that was treated with butachlor + HW at 28 DE (Table 18). The lower yield obtained from the plot that was hand weeded twice could have been due to the stand reduction that occurred during HW.

Although there were no weeds between the rows, weed growth within rice rows was profuse with hoe weeding or IRC. This resulted in complete yield loss.

ECOPHYSIOLOGY OF RICE WEEDS

In a continuing effort to understand the response of weeds to the environment, the responses of upland weeds *Amaranthus spinosus, C. rotundus, E. colona, Eleusine indica*, and *R. cochinchinensis*, as well as those of UPLRi-7, Kinandang Patong, and IR43, to environmental resources, N fertilizers, moisture, and light were studied using ecophysiological techniques.

Nitrogen response. Nitrogen fertilizer as urea was added at 0, 25, 50, 75, 100, and 150 kg/ha to plants grown in the IRRI greenhouse. As N in-

Table 18. Effects of weed control combinations on weed growth and yield of dry seeded IR66 rice. Guimba, Nueva Ecija, Philippines, 1988 WS.

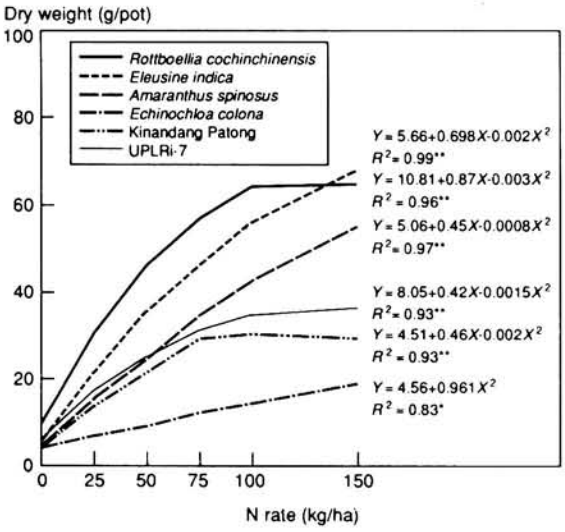
Weed control method[a]	Rate (kg ai/ha)	Time of application	Weed weight (g/m^2)	Grain yield (t/ha)
Butachlor + hand weeding	2.0	PE + 28 DE	56 ab	3.8 a
Hand weeding	–	14 & 35 DE	41 ab	2.6 b
Butachlor + hoe weeding	2.0	PE + 28 DE	121 abc	2.4 c
Butachlor + IRC	2.0	28 DE	272 bcd	1.9 c
Hoe weeding + hand weeding	–	14 & 35 DE	35 ab	1.2 d
IRC + hand weeding	–	14 & 35 DE	21 a	1.4 d
IRC + hand weeding	–	14 DE	446 de	0 e
Hoe weeding	–	14 DE	315 cd	0 e
IRC	–	14 & 35 DE	401 de	0 e
IRC	–	14 DE	482 de	0 e
Hoe weeding	–	14 & 35 DE	568 e	0 e
Hoe weeding + hand weeding	–	14 DE	586 e	0 e

[a] IRC = interrow cultivation. Butachlor at 2.0 kg ai/ha was applied immediately after the germinating rain.

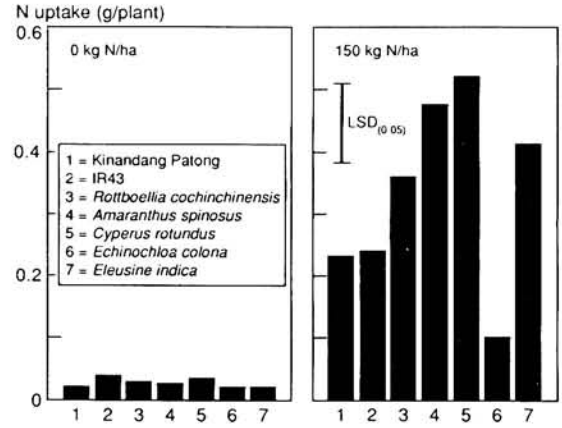
creased, biomass yield of all plant species rapidly increased, then gradually rose to a maximum (Fig. 7). Rice yield was optimum with 75 kg N/ha application, whereas that of weeds was up to 150 kg N/ha. Weeds were generally more sensitive to low soil N than rice (Fig. 7). Yield sensitivity to low soil N was estimated from the N level at which the yield was 50% of the observed maximum. The N uptake of rice and weeds was similar at 0 kg N/ha but was greater in weeds than in rice at 150 kg N/ha application (Fig. 8).

N fertilizer application markedly increased leaf area duration in weeds but not in rice (Fig. 9). Results suggest that under field conditions, competition for N is widespread when optimum N rates for rice are applied and weeds are not controlled. N application increases the likelihood of the other environmental factors to become limiting.

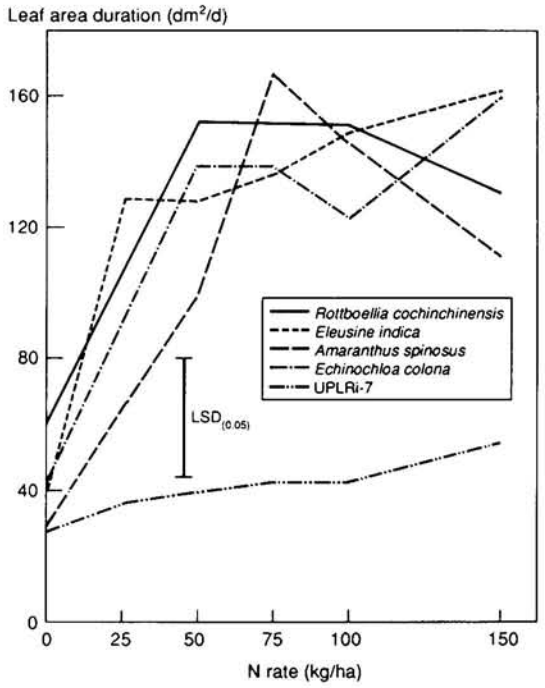
Response to light. Rice and weeds that were grown in the greenhouse were transferred to growth cabinets in the phytotron at 1, 3, 5, 7, and 9 wk after planting and maintained under photosynthetically active irradiance (PAR) of 150, 250, and 400 $\mu E/m^2$ per s for 2 wk. The growth cabinets were maintained at 34/33 °C day/night temperature, 70% relative humidity, and 12-h daylength.



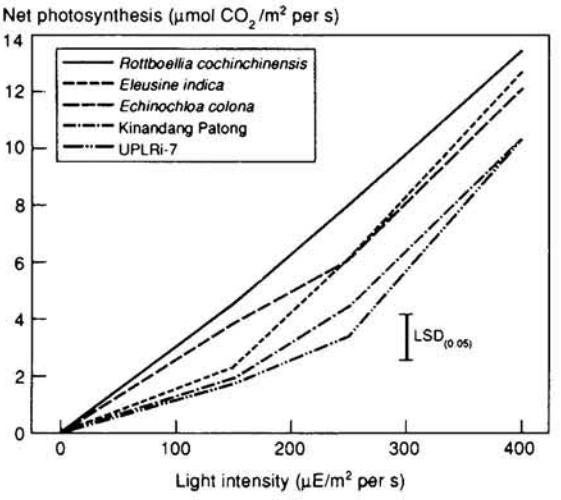
7. Dry weight of 4 weed species and 2 rice cultivars as affected by N rate. IRRI, 1988.



8. N uptake by 5 weed species and 2 rice cultivars in soil receiving 0 and 150 kg N/ha at 63 d after planting. IRRI, 1988.



9. Effect of N on leaf area duration of 4 weed species and UPLRi-7 at 28 d after planting. IRRI, 1988.



10. Light response curves of photosynthesis rate in 3 weed species and 2 rice cultivars at 21 d after planting after 2-wk exposure to light intensity. IRRI, 1988.

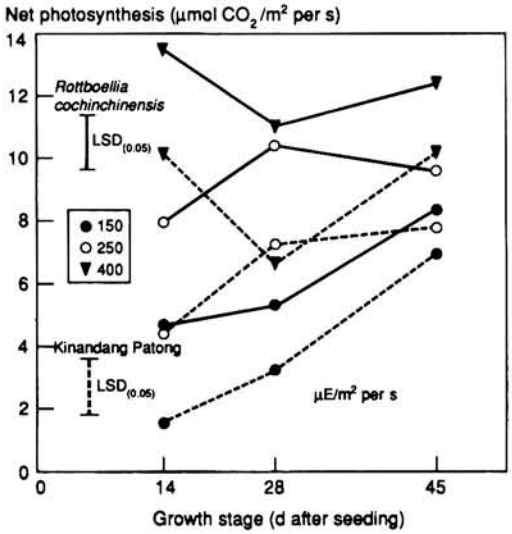
Weeds had higher net photosynthetic rates than rice at all light intensities (Fig. 10). All species showed compensatory response to reduced irradiance by their increased photosynthetic rate (Table 19). The longer the exposure to low irradiance, the higher was the photosynthetic acclimation. Photosynthetic rates of older plants were least affected by low irradiance (Fig. 11). Plants recovered from early season reduction in biomass due to low irradiance. Results suggest that the C_4 weeds have a competitive advantage over rice under all light environments. Rice has the ability to tolerate shading up to a weed density threshold.

Response to moisture. In the IRRI greenhouse and phytotron, biomass yield was higher in C_4 weeds at all moisture levels (Fig. 12). Weeds had lower leaf conductance than rice (Table 20) and hence transpired much less water than did rice (Fig. 13). Also, weeds had higher water use efficiency, which is associated with their high photosynthetic rates and relatively low transpiration rates. This enables the C_4 weeds to tolerate moisture stress better than does rice, and to remain aggressive when moisture is in short supply.

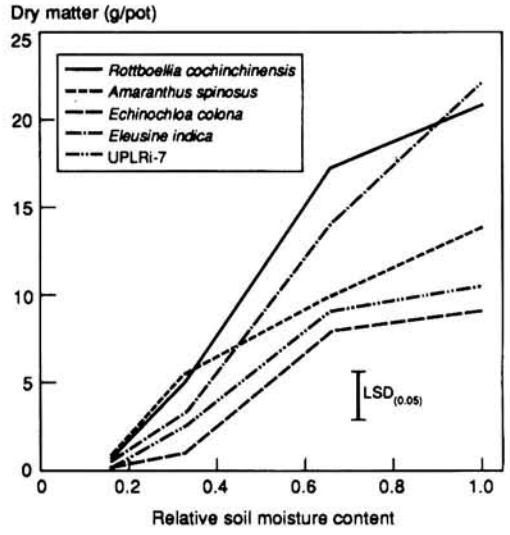
Table 19. Photosynthetic rate of 2 rice cultivars and 3 weed species as affected by 3 growth periods and 3 light levels (PAR of 150, 250, 400 μE/m² per s).[a] IRRI, 1988.

	Photosynthetic rate (μmol CO_2 /m² per s)									
	7-12 DAS			22-35 DAS			36-49 DAS			LSD
Species	150	250	400	150	250	400	150	250	400	(0.05)
UPLRi-7	1.7	3.4	10.3	3.5	5.9	7.3	4.7	6.5	6.8	1.8
Kinandang Patong	1.9	4.5	10.3	5.4	6.5	8.2	5.2	6.2	8.8	1.5
R. cochinchinensis	4.5	7.9	13.5	4.7	8.0	9.4	6.1	7.4	9.3	0.9
E. indica	2.2	6.0	12.7	5.5	9.2	9.7	8.8	9.8	15.1	2.6
E. colona	3.9	6.1	12.2	6.3	9.8	12.3	7.4	9.7	11.3	2.5

[a] PAR = photosynthetically active irradiance.



11. Light response curves of net photosynthesis rate in *Rottboellia cochinchinensis* and Kinandang Patong at different growth stages. IRRI, 1988.

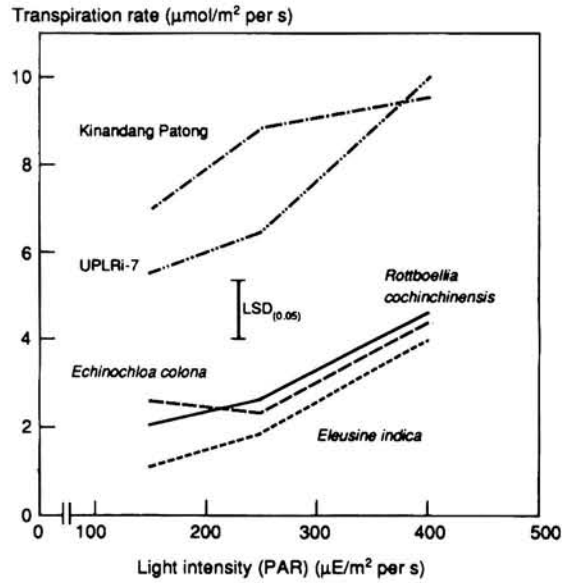


12. Dry matter weight of 4 weeds species and rice as affected by moisture at 48 d after planting, IRRI, 1988. Relative moisture content of 1.0 = 4320 ml of water/pot per wk.

Interaction between light and nitrogen. Field and growth chamber experiments in 1988 WS evaluated the effect of the interaction between light and N on rice growth. In the field, *R. cochinchinensis* and *Echinochloa colona* were planted

Table 20. Leaf stomatal conductance and water use efficiency at 21 d after seeding of rice and weed species grown at PAR of 400 μE/m^2 per s. IRRI, 1988.

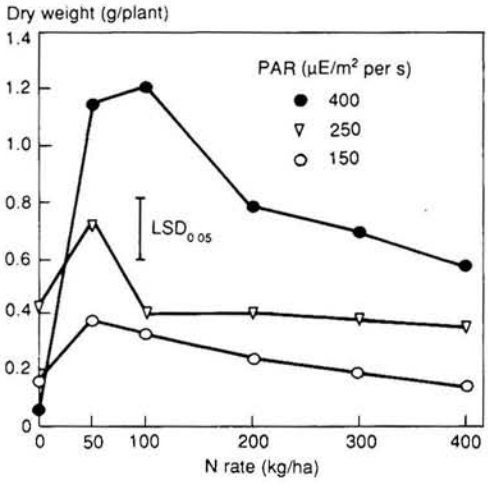
Species	Conductance (cm/s)	Water use efficiency (μmol CO_2/μmol H_2O)
UPLRi-7	0.66	1.05
Kinandang Patong	0.92	1.08
R. cochinchinensis	0.19	2.91
E. indica	0.10	3.18
E. colona	0.22	2.76
LSD (0.05)	0.15	0.51



13. Transpiration rate of 3 weed species and 2 rice cultivars at 21 d after planting. IRRI, 1988.

Table 21. Effect of rice sunlit leaf area index (LAI) and N on the growth of *R. cochinchinensis* and *E. colona*. IRRI, 1988.

Plant	N (kg/ha)	*R. cochinchinensis*		*E. colona*	
		Sunlit LAI	Total LAI	Sunlit LAI	Total LAI
UPLRi-7, weed-free	0	0.7	1.2	1.0	1.5
UPLRi-7, weed-free	100	2.1	2.3	2.3	2.8
UPLRi-7 + weeds	0	0.3	0.3	0.9	1.0
UPLRi-7 + weeds	100	0.3	0.5	1.7	2.1
LSD (0.05)		0.6		2.1	



14. Effect of N and light interaction on dry matter production of rice at 42 d after planting. IRRI, 1988.

at different times to provide different levels of shading. The highest canopy light extinction coefficients were obtained from *R. cochinchinensis* under high soil N (Table 21). A strong interaction between N and light intensity was observed. At low soil N, low light stimulated shoot dry matter yield of rice and increased the shoot N concentration (Fig. 14). Under optimum soil N, however, rice response was highest under high light intensity. N fertilizer is therefore beneficial under high light intensity when weeds are controlled.

Water management

Water Management, Plant Physiology, and Agricultural Economics Departments

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HYDROLOGICAL ANALYSIS OF FARM RESERVOIRS IN A RAINFED ENVIRONMENT

Water Management Department

A study was conducted during 1987-88 to develop a better understanding of the hydrological characteristics of farm reservoirs, which is necessary for assessing their potential viability in other areas, and to develop a methodology for such characterization. A layout of each of four selected reservoir sites in Tarlac Province, Philippines, where many farmers use this technology, is shown in Figure 1. Two reservoirs (no. 1 and 2) were chosen to compare runoff from catchments with similar slopes (2-8%) and soil types, but with different land use. One of them had its catchment under terraced ricefields, the other had a grassed catchment.

Water flow analysis. A water balance analysis was done on each reservoir to estimate reservoir inflows for direct rainfall and through runoff, and losses through overflow, seepage, and percolation. The analysis estimated runoff volume that contributed to reservoir storage, but flows that were diverted past the reservoir, i.e., runoff that was not allowed to enter the reservoir, were not measured.

In the catchment area of reservoir 1, planted to rice, the depths of water stored in the soil layer at which percolation starts and runoff occurs were calculated from average water content and matric suction data for puddled sandy loam soils in Tarlac Province. Water storage was considered in three layers: 1) surface storage, 2) puddled layer, and 3) free-draining layer below the puddled layer.

The seepage and percolation (S&P) losses obtained from the water balance analysis were averaged over 10-d intervals, and a regression analysis was done to relate them to reservoir water depth.

To investigate the saturated zones in the embankment, five perforated polyvinyl chloride tubes were installed in the embankment of each reservoir. The tubes were buried to a depth of about 3 m from the surface of the embankment, and spaced about 1-2 m apart (Fig. 2). The positions of the free water surface lines were measured once every 2 wk using a dipstick. Flownet diagrams were constructed for each site, assuming that the geometry of the flow lines was similar to that of the free surface lines in the embankment. The flownet analysis was used to determine the hydraulic gradient through the reservoir embankment of each site, from which the hydraulic conductivity for each embankment was calculated.

Reservoir inflows. The total inflow of a reservoir was between two and three times the reservoir storage capacity. This reflects the continuous process of water collection, use, and loss during the year.

Runoff contribution to water inflow was lower for reservoirs 3 and 4 (56 and 35%, respectively) than for reservoirs 1 and 2 (65 and 70%, respectively). The lower values were due to the inadequate capacity of the water inlets, which caused a large fraction of the runoff to be diverted past reservoirs 3 and 4.

Seasonal runoff coefficients are given in Table 1. For reservoir 1, the runoff coefficients for individual rainfall events varied between 0 and 0.78; the maximum value was obtained from a rainfall depth of 150 mm. In reservoir 2, the runoff coefficients for individual rainfall events varied from 0 to 0.27, with the highest value occurring for a rainfall event >50 mm that occurred the day after a previous rainfall event that also caused runoff.

Even with high surface storage in ricefields, the runoff yield from the rice catchment was nearly four times higher than that from the grassed catchment. This difference is explained primarily by the relatively impermeable hard pan that is developed in ricefields because of plowing and puddling operations.

Maximum runoff coefficients for single rainfall events are useful in designing water diversion and spillway channels, and seasonal runoff coefficient values are needed to determine the minimum catchment area that is needed to support a reservoir of a given water storage capacity.

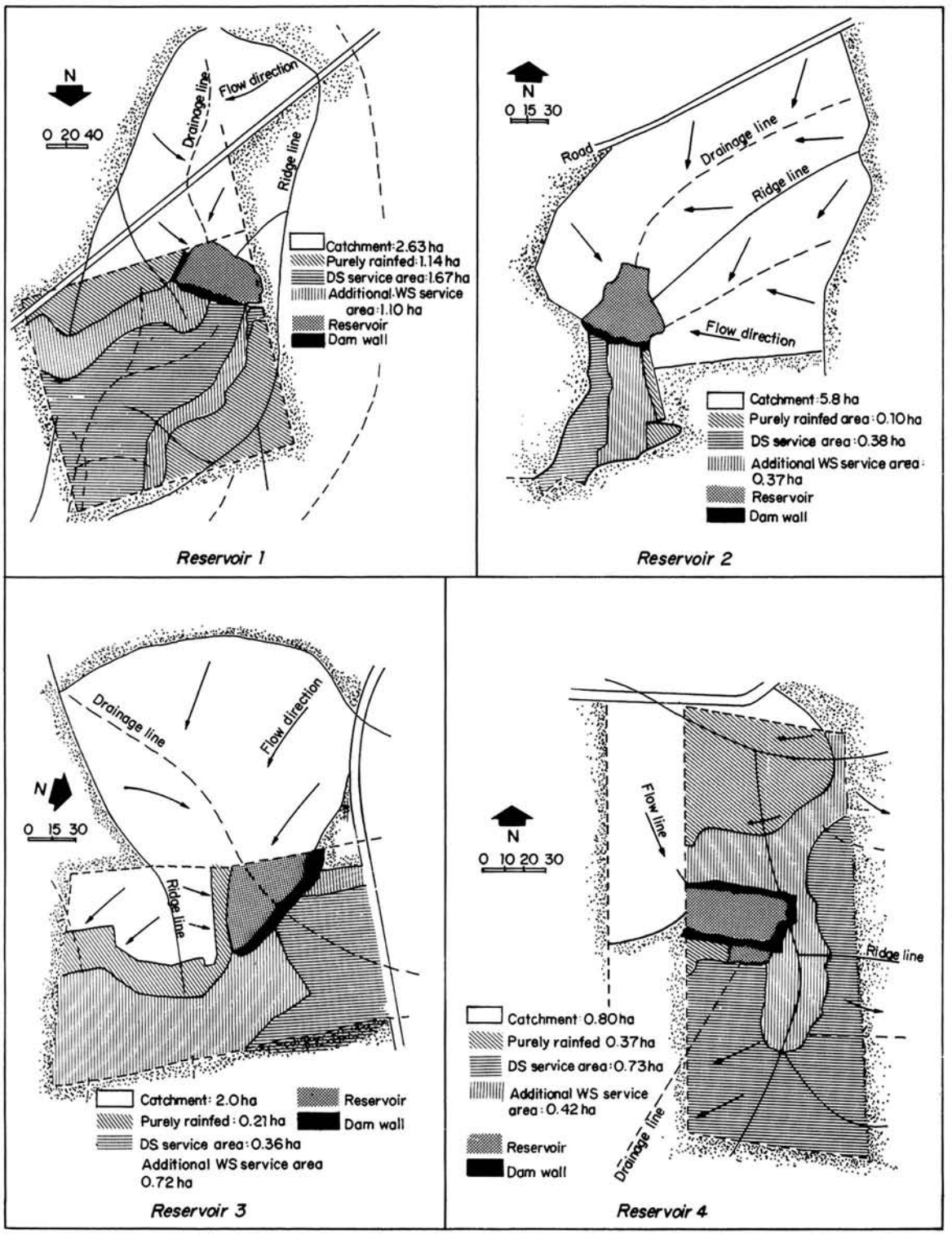
The minimum catchment area for a reservoir of known storage capacity may be calculated using the equation:

$$A = (p \times V)/(10{,}000 \times c \times f \times R)$$

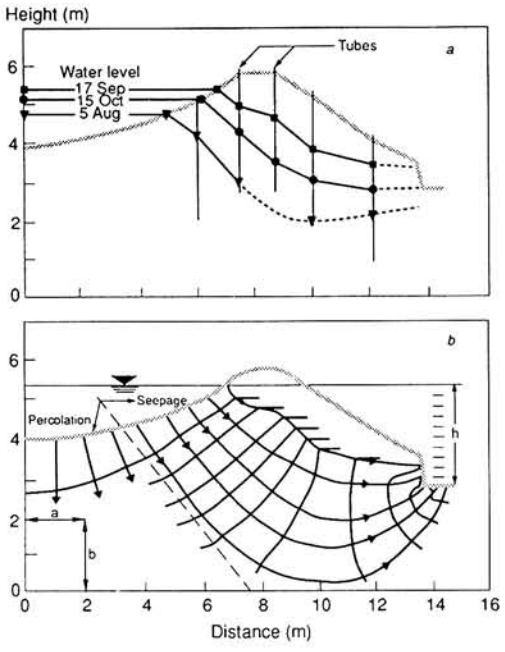
where

A = minimum catchment area in ha,

p = proportion of total inflow contributed by runoff,



1. Catchment and service areas in relation to farm reservoirs, Tarlac Province, Philippines, 1987. DS = dry season, WS = wet season.



2. Water levels in reservoir and observation wells (a) and constructed flownet (b) in reservoir 3, Tarlac Province, Philippines, 1987.

V = reservoir storage capacity in m^3,
f = capacity-inflow ratio,
c = estimated seasonal runoff coefficient, and
R = average annual rainfall in m.

The capacity-inflow ratio is defined as the reservoir storage capacity divided by the total annual inflow. Values of capacity-inflow ratio for the study sites were between 0.35 and 0.48 (av, 0.42).

From the equation, the required minimum catchment area is 0.94 ha for reservoir 1 (V = 3,997 m^3) and 3.24 ha for reservoir 2 (V = 2,872 m^3). The actual catchment areas of reservoirs 1 and 2 were 2.6 and 5.8 ha, respectively—about 2-3 times larger than the minimum catchment area calculated from the equation. In an average year, therefore, these reservoirs are expected to be filled during the monsoon.

Allowing generalizations, calculations using the equation show that the minimum size of a catchment area for a reservoir of given storage capacity is nearly five times higher for a grassed catchment than for a catchment planted to rice. Seasonal runoff coefficients, which are used to determine the minimum catchment area for a given reservoir storage capacity, are approximately half the value of the maximum runoff coefficients from single rain events.

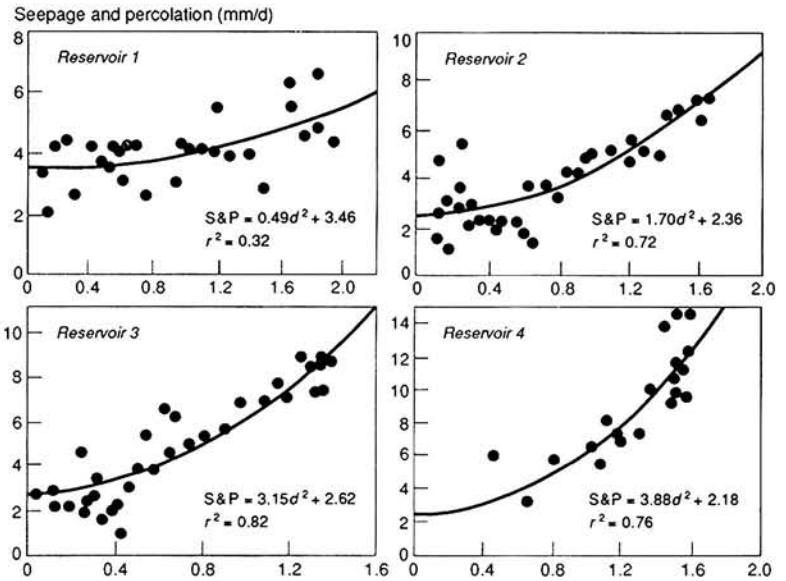
Reservoir outflows. The relationship between S&P losses and reservoir water depth is shown in Figure 3 for the four sites. S&P losses were found by regression analysis to vary with the square of the water depth. The minimum loss rates were similar for all sites: 2-4 mm/d. Maximum rates occurred at maximum water depths, with values between 6.0 and 15.0 mm/d.

From the flownet analysis, the average hydraulic gradient was found to be 0.317 m/m of embankment width (Table 2). The hydraulic conductivity

Table 1. Collected and diverted runoff based on actual rainfall events at 4 study sites. Tarlac, Philippines, 1987-88.

Parameter	Farm reservoir and catchment cover			
	1 Rice	2 Grass	3 Rice	4 Rice
Maximum runoff coefficient from single storm	0.78	0.27[a]	0.27[b]	0.75
Total rainfall (mm)	1619	1349	1456	1394
Total collected runoff (mm)	250	111	71	196
Rainfall collection coefficient	0.15	0.08	0.05	0.14
Total estimated runoff (mm)	633	141	–[d]	–
Estimated seasonal runoff coefficient[c]	0.39	0.10	–	–
Runoff collected fraction	0.40	0.79	–	–
Runoff diverted fraction	0.60	0.21	–	–

[a]Reservoir 2 had no diversion facilities; low yield was due to the catchment being grassed and having sandy loam topsoil. [b]The inlet capacity of reservoir 3 was too small, and a large fraction of the available runoff was diverted even when the reservoir was empty. [c]Calculated from total runoff divided by total rainfall during the season. [d](–) = not measured.



3. Seepage and percolation (S&P) losses through reservoir embankments versus water depth (d) at 4 sites in Tarlac Province, Philippines, 1987.

(K) was then calculated for each of the reservoir embankments, assuming a constant hydraulic gradient.

Soil texture was determined at each site for a depth of 0-60 cm. Soil textures varied from sandy loam to sandy clay loam, with a clay content of 22-34%. With the exception of reservoir 1, the clay content did not explain the variation in K. A better explanation for the variation was found when K was plotted against reservoir age as shown in Figure 4. The linear graph shows that K drops by an average of 0.089 m/d each year after reservoir construction. The actual variation in K is better explained by the curved graph, which shows a more rapid decrease in K due to continued settlement of the embankment for the first 5 yr after construction.

Table 2. Hydraulic conductivity K of reservoir embankments. Tarlac, Philippines, 1987-88.

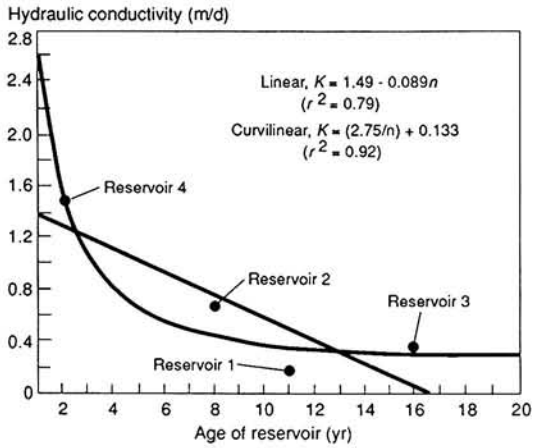
Parameter	Unit	Farm reservoir			
		1	2	3	4
Seepage loss rate per unit length, Q^a	m^3/m per d	0.077	0.276	0.134	0.132
Maximum head, h^b	m	2.10	2.80	2.60	0.74
Hydraulic gradient^c	m/m	0.412	0.291	0.323	0.240
Average flux^d	m^2/m	0.433	0.407	0.420	0.089
Hydraulic conductivity, K^e	m/d	0.178	0.678	0.319	1.483

[a] Calculated using maximum depth, open water area, dam length, and the coefficient of the squared term from seepage and percolation equations in Figure 3. [b] Head measured from water level at capacity to lowest point of downstream embankment. [c] Determined from flow net analysis. [d] Product of hydraulic gradient and half of maximum head. [e] Loss rate per unit length divided by average flux.

The decrease in K with age implies that embankment materials placed by bulldozer are poorly compacted. Compaction of the embankment during construction would reduce seepage losses from new reservoirs.

Water used for land preparation and irrigation accounted for about 30% of the total outflow volume. There is a clear need to determine means by which this use could be increased to achieve greater benefits from the water in storage. Wet season (WS) land preparation (plowing and puddling) occurred after cumulative rainfall had reached a depth of 320-430 mm, indicating scope for earlier land preparation using reservoir water.

Estimation of dry season service area. Useful fractions of reservoir capacity, i.e., the fraction



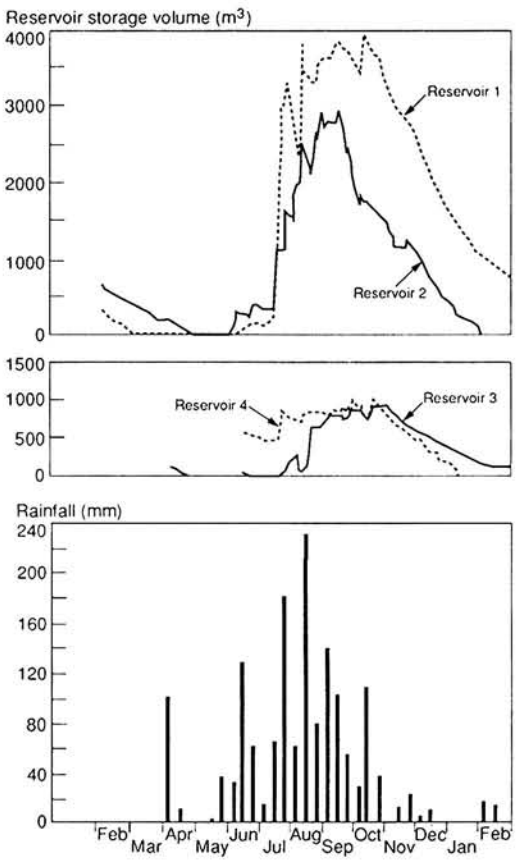
4. Hydraulic conductivity K of reservoir embankment with age n. Four sites in Tarlac, Philippines, 1987.

available for dry season (DS) irrigation, were calculated for three of the study sites. Reservoirs 1 and 4 had similar useful fractions of 0.69 and 0.62, respectively. In reservoir 2, the useful fraction was only 0.3, which can be explained by the dynamics of storage volumes in Figure 5, which shows that the reservoir was half empty at the end of October when the others were still at or near full capacity. During September and October, reservoir 2 site received less rainfall than did the other sites.

At each site, the reservoir storage volume decreased with time after early November, when water loss rates exceeded inflow rates because of a very low rainfall (Fig. 5). This indicates the benefits that can be obtained by establishing the DS crop as early as possible.

The irrigation requirement of a 108-d rice variety in DS was estimated to be 300 mm if the crop is started in mid-October, when most farmers start their DS rice in the seedbed. The actual depth of irrigation water applied by the farmers in the study sites was between 50 and 90% of the estimated requirement, with corresponding yields of between 1.6 and 3.0 t/ha.

Farmers have great difficulty in determining how much of their farm should be grown to DS rice, which can be adequately supported by the reservoir's useful fraction. The area can be determined by estimating values of reservoir capacity, useful fraction, and required irrigation depth. If the DS rice is transplanted before the end of



5. Dynamics of reservoir storage and 10-d total rainfall. Four sites in Tarlac, Philippines, 1987-88.

October, an estimate of the irrigation volume available from the reservoir may be obtained by multiplying the volume of water present in the reservoir at transplanting by a useful fraction of 0.65, which is the average value of the fraction for 2 sites (reservoirs 1 and 4). For example, with an available volume of 1,300 m^3 (65% of reservoir capacity of 2,000 m^3) and a crop water requirement assumed at 300 mm, a typical farm reservoir can adequately support a DS rice area of 0.4 ha.

RICE SUSCEPTIBILITY TO EXCESS WATER

Water Management and Plant Physiology Departments

Rice yields are adversely affected by excess water, the damage depending on the cultivar, the stage of plant growth at the time of the event, depth and turbidity of the water, and duration of the excess

water stress. There is very limited information on the quantitative relationship linking excess water (i.e., flooding, inundation, and waterlogging) and rice yield.

A mechanistic model of rice yield response to excess water is currently being developed for better water management and determination of parameters and criteria for effective rice drainage, and as a predictive tool for improved assessment of yield reduction. The underlying concept of the model is the decomposition and synthesis of both the flood or excess water event and the corresponding plant response. A continuous flood event with a varying water depth is decomposed into a sequence of discrete events of shorter duration over which the water depth may be considered stable. If there are established quantitative relationships of the detrimental effects of excess water at each one of these shorter events and for the given stage of plant growth, and if their interrelationships are known, then the cumulative rice yield response can be determined from the synthesis of the individual effects.

The theoretical basis of the model is the relation of rice yield to the concept of the stress day index (SDI). SDI can be determined from a relationship of the type

$$SDI = \sum_{i=1}^{N} \left[\sum_{j=1}^{m_i} [({}_hSD_j)_i \cdot ({}_hCS_j)_i] \right] \quad (1)$$

where N = the number of growth stages, $({}_hSD_j)_i$ = a stress day factor at the j-th period of the i-th growth stage at a water depth h, and $({}_hCS_j)_i$ = a crop susceptibility factor during the same period and for the same water depth. The yield response is determined from the relationship

$$Y_R = 1 - f(SDI) \quad (2)$$

where Y_R is the relative yield and $f(SDI)$ is a function of SDI, to be determined. The stress day factor is a measure of the degree and duration of the excess water stress.

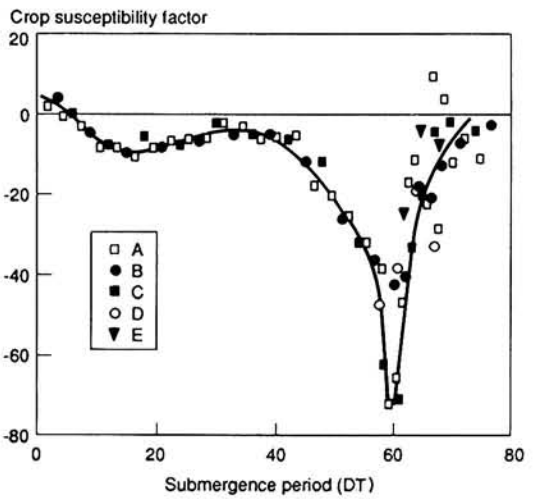
The crop susceptibility factor depends on the rice cultivar and its physiological growth stage and indicates the susceptibility of the plant to a certain stress. It is defined by the relationship

$$({}_hCS_j)_i = \frac{({}_hY_j)_i}{Y_0} - 1 \quad (3)$$

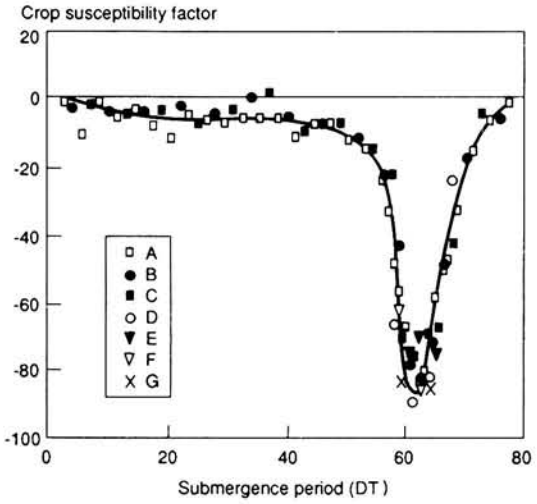
where Y_0 is the rice crop yield corresponding to no excess water stress during the growing season (reference yield), and $({}_hY_j)_i$ is the yield corresponding to inundation to a depth h at the j-th period of the i-th growth stage and no stress during the rest of the season. By decreasing the duration period we can obtain a crop susceptibility function covering the whole life span of rice. Determination of the crop susceptibility function for a wide range of submergence levels is a necessary step in the development of the model.

The crop susceptibility functions for submergence levels to 100 and 125% of plant height for IR66 are presented in Figures 6 and 7. They were obtained from greenhouse experiments with 74 and 77 treatments of varying stress periods (1-6 d). They were adjusted to reflect susceptibilities to single-day stresses, thus making possible the derivation of the crop susceptibility functions.

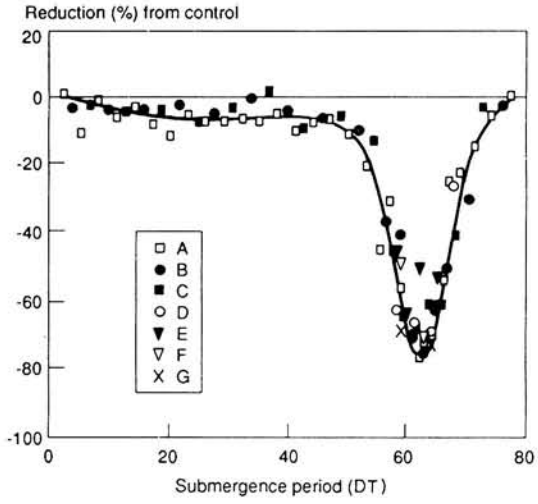
The two curves exhibit similar patterns. Increased susceptibility between transplanting and maximum tillering corresponds to a reduction in



6. Crop susceptibility factors for 100% submergence at various times, IRRI, 1988 DS. A = 3 d submergence between 1 d after transplanting (DT) and 56 DT, 2 d submergence at 57-58 DT, 1 d submergence between 59 and 68 DT, 2 d submergence between 69 and 73 DT, 3 d submergence at 76 DT. B = 5 d submergence between 1 and 58 DT, 2 d submergence between 59 and 68 DT, 4 d submergence between 69 and 72 DT, 6 d submergence at 73-78 DT. C = 5 d submergence between 3 and 56 DT, 2 d submergence between 57 and 67 DT, 3 d submergence at 68-70 DT, 5 d submergence at 71-75 DT. D = 3 d submergence between 56 and 68 DT. E = 3 d submergence between 61 and 68 DT.



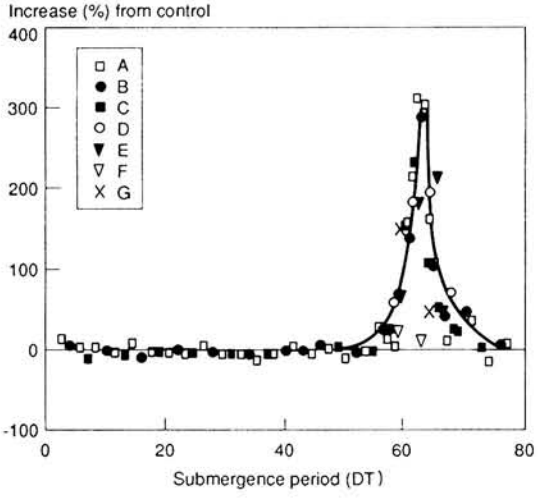
7. Crop susceptibility factors for 125% submergence at various times, IRRI, 1988 WS. A, B, and C as in Figure 6. E = 3 d submergence between 61 and 65 DT. F = 4 d submergence between 57 and 63 DT. G = 5 d submergence between 57 and 65 DT.



8. Reduction in number of total filled grains for 125% submergence at various times as percentage of control, IRRI, 1988 WS. A-G as in Figure 7.

the number of tillers. The values of $({}_hCS_j)_i$ decrease very rapidly in the period between booting and flowering. The highest susceptibilities, denoted by the lowest $({}_hCS_j)_i$ values, occur during the first 2 d of flowering, when yield reductions of 76 and 83% (significantly different at the 5% level) are observed after a single day of 100 and 125% submergence, respectively. Sequential stresses were shown to be additive until booting, resulting in yield reductions equal to the sum of the daily crop susceptibility factors. However, after flowering this does not hold true, in which case the bulk of the yield reduction occurs within the first day of inundation. Longer submergence results in minimal incremental daily yield decreases of 2-6%.

The changes in the numbers of filled and unfilled grains, expressed as percentages of the numbers in the control treatments, are shown in Figures 8 and 9 for the 125% treatments.The curve in Figure 8 follows almost identically the crop susceptibility function in Figure 7. The curve in Figure 9 has a mirror image relationship to Figures 7 and 8, its maximum coinciding with their minimum. The curves for the 100% treatment exhibit similar behavior. Yield reduction is thus due entirely to a decrease in the number of grains,



9. Increase in number of total unfilled grains for 125% submergence at various times as percentage of control, IRRI, 1988 WS. A-G as in Figure 7.

since the 1,000-grain weight of the treatments did not differ appreciably from the control.

Important differences exist between the two curves: 100% submergence of newly transplanted rice seedlings shows consistently beneficial effects on yield, which may be attributed to the observed increased number of tillers. The same curve exhibits a double trough pattern, with increased susceptibility at the time of active tillering

(shallow first trough) and a narrow and steep second trough at the beginning of flowering. These are probably due to the fact that in DS—when the 100% submergence experiment was conducted—a larger number of tillers and flowers appear in a shorter interval, and the damage may be more pronounced. The deep trough of the 125% submergence curve is markedly wider, reflecting the longer flowering period in the wet season (WS).

MINIMIZING RICE FARMING RISKS IN FLOOD-PRONE ENVIRONMENTS

Water Management Department

About 6,000 ha of the Rinconada sub-basin in the Bicol River Basin, Camarines Sur Province, Philippines, are grown to rice during WS, despite the annual risk of flooding. Flooding is caused by heavy rainfall induced by tropical weather disturbances during WS, especially in July, September, November, and December. Severe floods, in which water surface elevation in the field exceeds 8.0 m above mean sea level (1-3 m depth of water in the field), have an annual probability of 47% and are expected in September and later in the season. Experiments in 1987 in farmers' fields as well as in controlled tanks showed that rice plants suffer complete destruction when fully submerged for 6 d or longer, and are partially (but significantly) damaged with 4-5 d of full submergence (Annual report for 1987). Most farmers rely for their livelihood on one rice crop per year in WS.

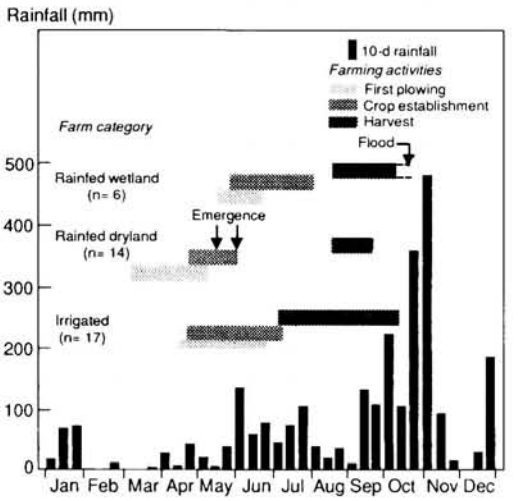
Farm-level strategies that can reduce the risk of flooding are 1) early establishment of WS rice, and 2) use of early-maturing varieties. Together, these strategies allow harvest of WS rice by early September, after which time the probability of severe floods is relatively high. Successful early crop establishment depends on access to irrigation water for early land preparation, or use of dryland preparation and dry seeding, which allow seedling emergence with early (premonsoon) rains. Most rainfed farmers wait until monsoon rains have set in before starting wetland preparation, which pushes the crop to higher-risk time periods. For example, the probability of crop damage by a severe flood is about 50% higher if harvest is delayed from September to October.

In 1988, farming practices and associated risks were evaluated in the Rinconada sub-basin area for 37 farms divided into 3 categories: 1) 14 rainfed farms that used dryland preparation and dry seeding, 2) 6 rainfed farms that used wetland preparation and transplanting or wet seeding, and 3) 17 irrigated farms (using shallow groundwater by pumping) that used wetland preparation and transplanting or wet seeding. Farmers with pumps for land preparation started plowing in mid-April through June, and harvested in mid-August through mid-October; seven of these farms at lower elevations were all harvested in August.

A severe typhoon occurred on 24 October, submerging about 10,130 ha of riceland in the Rinconada sub-basin.

Dry plowing at the rainfed sites (rainfed-dryland) was done in March and April and up to the first week of May; rice was dry seeded in May. A 25-mm rainfall in the last week of May and sustained rainfall in early June caused seed germination. These sites completed harvesting in the last week of August through the third week of September, ahead of the other farm categories (Fig. 10).

The rainfed wetland farmers completed land preparation between the last week of May and 3 August, using sustained monsoon rains. This group was the last to complete the job. Two of these farms were transplanted, and the rest used wet seeding. These sites were harvested in the last



10. Land preparation and crop establishment in relation to rainfall use. Bicol River Basin, Camarines Sur, Philippines, 1988.

week of August through October because of the delay in starting wetland preparation. The crop on one farm was completely destroyed because of the prolonged submergence due to the 24 October typhoon.

Irrigated farms with pumps were significantly larger than rainfed farms. Table 3 shows that chemical inputs and total cash costs invested per hectare were higher on the irrigated farms, indicating the tendency to invest more when water supply is assured. Among rainfed farms, family members contributed about 60% of total labor for farming activities—from land preparation to harvesting and hauling of rice—as compared with only 21% for irrigated farms.

Irrigated farms achieve a 1.8-t/ha higher average yield and significantly higher returns to cash costs than the rainfed farms. Yields were low on rainfed dryland farms because of the problems of seed germination, weed competition, and lack of water in August and early September (Fig. 10). Consequently, the gross return from the sale of rice was highest on irrigated farms, followed by that on rainfed wetland farms. Between the rainfed categories, the higher return to cash costs on wetland farms was due mostly to the higher yields than on the dryland farms.

Farmers in the flood-prone areas of Camarines Sur Province should keep August or early September as the target for harvest. Land preparation can be started in early May, and crop establishment by transplanting or broadcasting of pregerminated seeds can be done about mid-May. Early-maturing and submergence-tolerant varieties are ideally combined with early crop establishment to reduce the risk of crop exposure to flood.

When the monsoon rains come in early June, wetland preparation in rainfed areas can be a more profitable alternative. However, the high variability of rainfall at the onset of WS does not guarantee adequate rainfall during early June every year, and therefore dryland preparation and dry seeding are an attractive alternative to the conventional wetland system.

Table 3. Characteristics and means of costs and returns on irrigated and rainfed farms in low-lying areas of Bula, Camarines Sur, Philippines, 1988 wet season.

Parameter	Irrigated by pumps	Rainfed dryland	Rainfed wetland
Farms (no.)	17	14	6
Mean farm size (ha)	1.0	0.4	0.2
Mean yield (t/ha)	3.9	1.9	2.6[a]
Costs and returns ($/ha)[b]			
Material inputs[c]	64	26	37
Labor and power[d]	142	198	150
Imputed (%) for family	21	62	59
Fuel for pumping	32	0	0
% of total cash cost	14	0	0
Total production cost	438	282	260
Imputed (%)	48	57	46
Total cash cost	226	132	149
Gross return from rough rice	547	233	366
Net return	109	–49	106
Return to cash cost	321	101	217

[a]One farm was completely damaged by flood. [b]Conversion rate: $1 = 21 pesos. [c]Including chemicals, seed, and fuel for hand tractor and thresher. [d]From land preparation to harvesting and hauling of rice.

PET: AN EXPERT SYSTEM FOR POTENTIAL EVAPOTRANSPIRATION DETERMINATION

Water Management Department

Knowledge of potential evapotranspiration E_{tp} is essential in all facets of water management and water resource development, and is necessary for the design, planning, and operation of irrigation systems. A large number of methods for E_{tp} estimation, all empirical to various extents, are commonly used and present the user with a bewildering choice. Because of the empiricism of the available methods, unfamiliarity with the particular assumptions and conditions of their development may lead to either 1) selection of methods inappropriate for the available data, desired accuracy, and local climatic regime; 2) collection of inappropriate or insufficient data over the wrong period for a given selected method; or 3) inability to provide an estimate of E_{tp} from limited data sets.

PET is a microcomputer expert system designed for simple, easy, and rapid selection of the appropriate E_{tp} equation from a number of suitable methods, as well as for execution of the corresponding calculations. It is intended for the water management specialist, the irrigation design engineer, the irrigation system operator, the hydrologist, and the researcher and requires minimal familiarity with microcomputers. It was developed for the Apple Macintosh™, was writ-

ten in BASIC, and requires 500K bytes of computer memory.

For maximum flexibility and ease of operation, the expert system was developed in modular form. The general flow chart of PET (Fig. 11) consists of four separate but related sequential modules: 1) the selection module, 2) the data entry module, 3) the calculation module, and 4) the data display, printing, and storage module. PET allows the use of any of the lower modules if the ones above it have been completed even once.

Selection module. There are 13 E_{tp} estimation methods available in PET, covering all the general categories of E_{tp} determination, i.e., combination theory, humidity, temperature, evaporation, radiation, and others.

The selection of the appropriate method is a two-step process based on two criteria: the minimum period of meteorological measurements and the type of meteorological data available. PET allows choice from among 5 periods of data measurement—hourly, daily, 5-d periods, 7- to 10-d periods, and 30 d periods or longer—and makes the first selection by matching the period of available data measurements with the minimum periods over which the various E_{tp} estima tion methods are applicable.

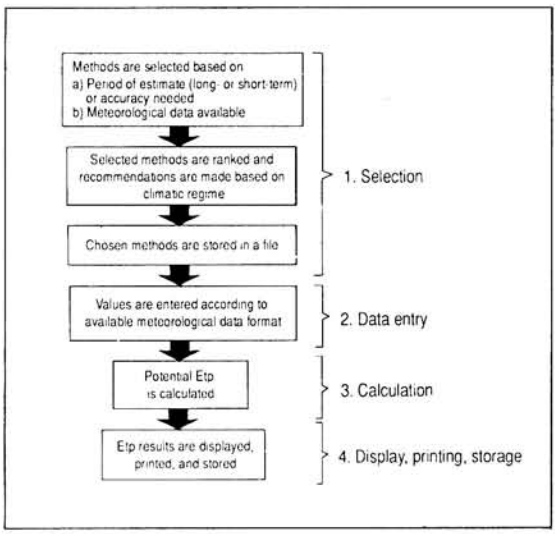
At the next step the meteorological data requirements of the selected methods are compared with the available data. PET accepts any combination of the following kinds of data:

- Location and date data—latitude, hemisphere, elevation, month and year; they are not necessary but may be needed if other data are insufficient.
- Temperature data—maximum and minimum, mean
- Radiation data—solar radiation, net radiation, actual sunshine hours, and cloud cover
- Humidity data—wet bulb temperature, dry bulb temperature, dew point, maximum and minimum relative humidity, mean relative humidity
- Wind data—hourly run, daily run, height of measurement
- Pan evaporation data—evaporation, type of pan, type of ground cover in adjacent areas, general climatic regime

If direct measurements are not available but location information is furnished, PET can evaluate solar radiation from prestored global data and can even accept qualitative estimates for mean temperature, sunshine ratio, mean relative humidity, and windspeed. The second stage of selection is completed with the elimination of methods that are inapplicable for the available data set.

At the next stage the selected methods are evaluated and ranked, and recommendations are made based on the general climatic regime of the location and the climatic criteria proposed by the American Society of Civil Engineers. The user has the option of retrieving specific information on each method, its data requirements, the conditions under which it was developed, and the locations at which it has been tested. However, the recommendations are nonbinding, and the user has the option of selecting for final use any combination of methods selected after the second step. The selection list determines the format of the subsequent data entry and may be stored for future use or reference.

Data entry module. Data are entered according to a format set in the previous module. PET offers three options for data entry: 1) directly from the keyboard using the PET database system, 2) reading from a disk using the PET database system, and 3) reading from a disk using the Microsoft EXCEL™ database. The data sets can be of any size.



11. General conceptual flow chart of the expert system PET. IRRI, 1988.

The first and second options were designed for familiarization and training on PET. The user has the option of requesting clarification and explanation of each meteorological variable. This makes the process of data entry slow and cumbersome. For someone who has mastered the essentials of PET, interface with the EXCEL™ database offers easy and rapid data manipulation and entry.

Calculation module and display, printing, and storage module. The calculations for E_{tp} estimation are carried out here using the corresponding equations. For optimum efficiency the calculations are "global" rather than "local," allowing several methods to use the same relevant data if more than one evaluation method is desired.

The calculated E_{tp} estimates are stored in the computer memory, and the following choices are offered: permanent storage on a floppy or a hard disk, display on the terminal, and printing. The format of the printout allows easy comparison of the differences in E_{tp} estimates among the various methods chosen.

BASIN IRRIGATION DESIGN FOR UPLAND CROPS ON RICELAND

Water Management Department

The potential of irrigated upland (nonrice) crops in crop diversification schemes is seldom realized, particularly because of inappropriate water management. Inadequate or excessive water applications, stemming from lack of experience with nonrice crops, result in low application efficiencies and uniformities. Thus, yields are adversely affected, and limited water, energy, and financial resources are wasted.

These problems are compounded by the physical constraints that rice soils place on upland crops. Soil puddling destroys the soil structure of rice soils and results in high resistance to root penetration, low porosities and permeabilities, and the formation of a shallow traffic pan, which further inhibits vertical water movement, thus reducing the rates of infiltration and percolation. The heavier soil textures usually associated with rice soils magnify these problems by restricting drainage and promoting waterlogging. Moreover, such soils tend to crust when irrigated. These conditions reduce root aeration, impede root development of upland crops, and adversely affect crop growth and yields. While supplying needed water, irrigation of upland crops tends to accentuate these problems by reducing air-filled porosity and promoting waterlogging. A much higher level of management is necessary to overcome these deficiencies.

Development of the method. The development of our method consisted of three steps: selection of the appropriate surface irrigation technique, determination of the constraints and principles associated with the particularities of the rice soils, and design of an irrigation system incorporating the information and parameters obtained from the first two steps.

Basin irrigation was selected as the most appropriate technique because of the following reasons: 1) the flat topography of irrigated ricefields (ideally suited for basin irrigation), 2) minimum disturbance of ricefield geometry, 3) simplicity and low construction costs, 4) minimal maintenance requirements, and 5) ease of operation.

Considerations and constraints. The design of an efficient basin irrigation system for upland crops on riceland is expected to meet the following requirements:

1. minimal deep percolation for water and energy conservation
2. alleviation of waterlogging, which is a very serious constraint to upland production. A major cause of waterlogging is the existence of a shallow traffic pan characterized by extremely low hydraulic conductivity at a depth of 15-20 cm. The problem is addressed by ensuring that infiltrated water does not reach the traffic pan. The maximum permissible water application depth d_{max} for waterlogging alleviation was determined to be 5 cm. Water applications of less than 3 cm were operationally inefficient. Application depths have to be between these two extremes, i.e.,

$$d_{min} \leq d_{da} \leq d_{max} \Rightarrow 0.03 \text{ m} \leq d_{da} \leq 0.05 \text{ m} \quad (1)$$

   The conditions in equation 1 dictate a high number of low-volume irrigations to supply the same quantity of water covering the crop requirements, thus defining a high frequency basin irrigation method.
3. high application efficiency E_a

4. high uniformity to minimize water and energy losses and to maximize crop yields. Design for items 3 and 4 has to account for spatial and temporal variabilities in the infiltration characteristics and the hydraulic characteristics of the soil surface, as well as variability of the flow rate of the water supply.

The irrigation system had to be capable of accommodating considerable changes in the values of any combination of the uncertainties described above without a significant decrease in application efficiency.

Mathematical model. Our irrigation system design is based on solutions of the surface irrigation volume balance equation obtained from the mathematical modeling of the rate of advance of the advancing water front in a basin. The governing equation is

$$Q_u \cdot t_l = C_s \cdot l + \int_0^l fz\,(t_{op})dx \qquad (2)$$

where

$$Q_u = \frac{Q}{W} \qquad (3)$$

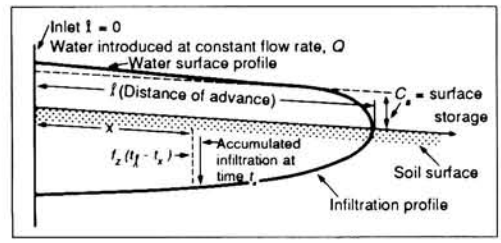
Q = the inflow rate (m^3/s),
Q_u = the stream size (m^2/s),
t_l = the stream advance time to reach a distance l from the inlet (s),
W = the basin width (m),
C_s = the surface storage (m),
$fz(t)$ = cumulative infiltration function (m),
t_{op} = the infiltration opportunity time (s), and

$$t_{op} = t_l - t_x \qquad (4)$$

where t_x is the advance time to distance x from the inlet. The quantities involved are depicted in Figure 12. C_s represents the average depth of water at the soil surface and is computed as

$$C_s = 0.9 \cdot n^{3/8} Q_u^{9/16} [(t_{m,l})_k^{3/16} + (t_{m,l})_{k-1}^{3/16}] \qquad (5)$$

where
n = the Manning roughness coefficient;
$(t_{m,l})_k$ = the time of current calculation at the time point k (min);
$(t_{m,l})_{k-1}$ = the time of last calculation (min).
For $k = 1$, $k - 1 = 0$, $(t_{m,l})_0 = (t_{m,l})_1$



12. Water profiles during the advance phase of basin irrigation. IRRI, 1988.

From a large number of double ring infiltrometer field tests, the cumulative infiltration of rice soils was determined to be of the form

$$fz = a\ t_m^b + c = a\left(\frac{t}{60}\right)^b + c;\ 0 \le b \le 1;\ t > 0 \qquad (6)$$

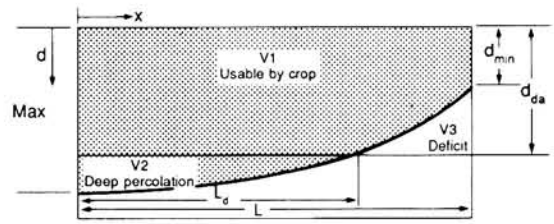
where
a, b, c = constants, and
t_m = elapsed time (min).

Once the advancing water front reaches L, equation 2 is no longer valid, and the infiltration volume is given by the equation

$$I = \int_0^t fz\,(t - t_l)\,dl, \qquad t \ge t_L \qquad (7)$$

which defines the infiltration profile shown in Figure 13. No analytical expression is available for $t_l = t_l(l)$. Therefore, I has to be evaluated numerically using the data points $(t_l,l)_1,(t_l,l)_2,\ldots,(t_l,l)_{nL}$, where n_L is the data point number corresponding to the end of the field.

Determinations of the "cut-off time" t_{co} (sometimes called the "application time"), the "basin-wide opportunity time" t_{opb} (defined as the time



13. Infiltrated depth profile, IRRI, 1988. L is a measure of distance from water delivery point.

required for water to infiltrate in the basin), and the application efficiency E_a (defined as the fraction of the water applied to a field which remains within a management defined soil zone) were of critical importance.

A computer program was written in FORTRAN 77 to carry out the necessary complicated calculations. For maximum accuracy, double precision variables were used.

Design procedure. The design procedure is based on a "worst case" scenario and involves the following steps:

- Parameters a, b, and c of the infiltration equation and their range of values are determined experimentally. Of the three parameters, c has the most pronounced effect on E_a because of its magnitude and variability. The value of c was found to range between 0.002 and 0.023 m, depending on soil texture, moisture content, land preparation practices, and time lapse since land preparation. The largest value of c corresponds to the lowest E_a and is used for the design. The value of c is usually at its highest immediately after the end of land preparation, i.e., at the first irrigation. If no information is available, a design c value of 0.015-0.017 m is adequate for the conditions of most ricefields.
- The Manning roughness coefficient n is determined from Table 4.
- The minimum available well flow rate is determined and used as the design flow rate.
- The minimum permissible application depth d_{min} is taken as the design application depth, i.e., $d_{dsn} = d_{min} = 0.03$ m.
- The design application efficiency, $(E_a)_{dsn}$, is set at 90%. When ample water supplies are available and the soil is a silty clay loam or lighter, $(E_a)_{dsn}$ may be taken as low as 80%.

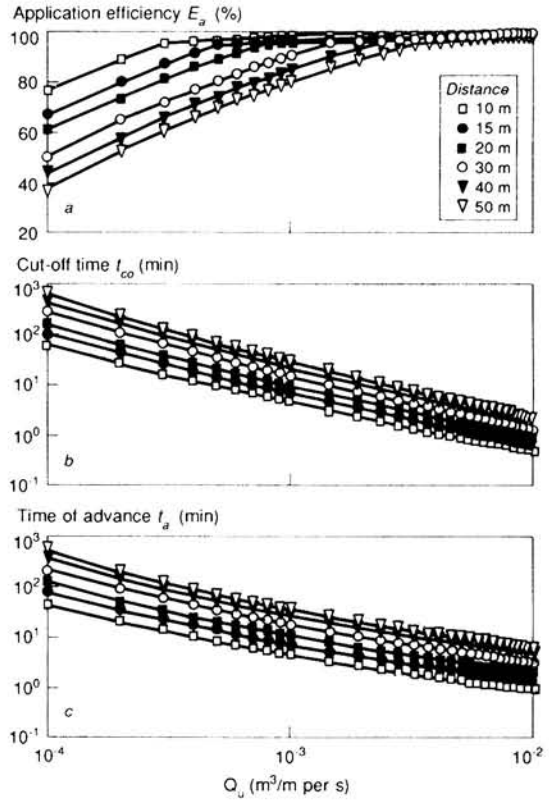
The values of these design parameters correspond to the "worst case." Any change in their number represents an improvement and results in higher E_a. While this is an admittedly conservative approach, it was deemed necessary to overcome the extreme sensitivity of rice soils to waterlogging.

Using the aforementioned parameters and the computer solution of the advance equation, the values of t_{co}, t_a, and E_a are determined for a wide combination of basin dimensions W and L. The resulting families of curves are plotted as shown in Figure 14 (with $Q_u = Q/W$ as the independent variable).

Using these curves, the basin dimensions for a desired d_{dsn} can be determined. For practical rea-

Table 4. Common Manning roughness coefficients (n) used in basin irrigation design. IRRI, 1988.

Surface characteristics	n
Smooth, bare soil surfaces, noncultivated	0.04
Small grain, drill rows parallel to direction of water flow	0.10
Broadcast small grains	0.15
Dense sod crops, small grains with drill rows across the water flow direction	0.25



14. Application efficiency E_a (a), cut-off time t_{co} (b), and time of advance t_a (c) curves for a desired application $d_{dsn} = 0.003$ m when the infiltration equation is $fz = 0.003 \cdot t_{in}^{0.5} + 0.006$ (m). IRRI, 1988. Distance is from water delivery point.

sons, the basin width $W \geq 4$ m. The process can be repeated for a number of desired application depths d_{dsr} and a set of graphs similar to the ones in Figure 14. If the infiltration equation does not change significantly with time, these graphs can be used to determine the t_{co} and t_a for subsequent irrigations and to evaluate the performance of the irrigation system. If the infiltration equation changes significantly with time, then the computer program has to be used to perform these tasks.

The use of the graphs in Figure 14 in the design procedure is demonstrated in the following examples:

Example 1: Basin design. The infiltration equation for a ricefield is $fz = 0.003 \cdot t_m^{0.5} + 0.006$ (t_m in min, fz in m), and the available water flow rate is $Q = 5.0 \times 10^{-3}$ m³/s. Determine the sub-basin length L if the desired $W = 10$ m.

Using the computer solution of the advance equation and the procedure already described, we obtain the graphs in Figure 14.

For $L = 20$ m, $(E_a)_{dsn} = 90\%$, and from Figure 14a, we have

$$Q_u = 5.7 \times 10^{-4} \text{ m}^2/\text{s} = Q/W \quad \Rightarrow \quad W = 8.77 \text{ m}$$

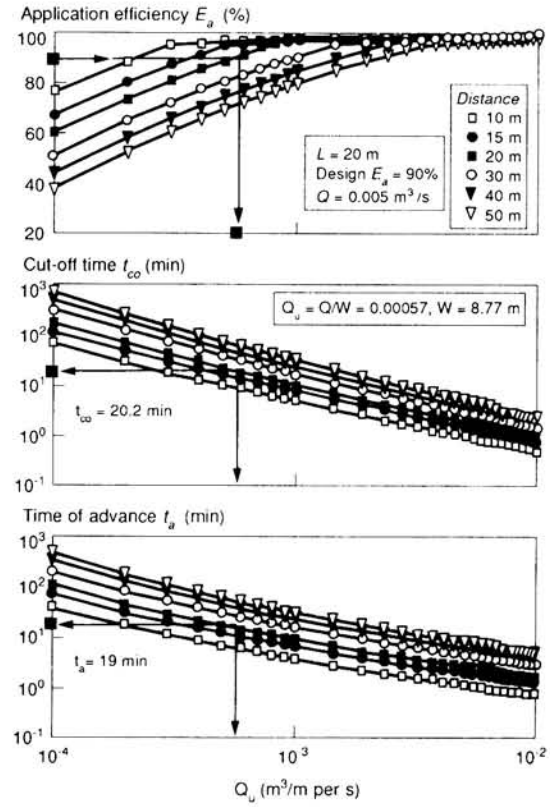
The process is illustrated in Figure 15.

Example 2: Basin irrigation operation. The sub-basin dimensions of a field are $L = 20$ m and $W = 10$ m. The rest of the parameters remain as in Example 1. If the desired application depth $d_{da} = 30$ mm, determine E_a, t_{co}, and t_a.

The stream size $Q_u = Q/W = 5 \times 10^{-3}/10 = 5 \times 10^{-4}$ m²/s. For $L = 20$ m, we obtain from Figure 14a, $E_a = 88\%$, from Figure 14b, $t_{co} = 23$ min, and from Figure 14c, $t_a = 20$ min.

Example 3: Evaluation of basin irrigation efficiency. For the sub-basin of Example 2, the observed advanced time $(t_a)_{obs}$ is 14 min instead of the estimated $t_a = 20$ min. Determine the application efficiency of the system.

From Figure 14c and for $(t_a)_{obs} = 14$ min, $Q_u = 5 \times 10^{-4}$ m²/s, we obtain an "apparent basin length" $L_a = 15$ m, which is the length of a basin with the same Q_u and advance time $t_a = (t_a)_{obs}$ as the basin in question. For the same Q_u and $L = L_a = 15$ m, Figure 14a yields $E_a = 94\%$, which is the actual application efficiency of the system.



15. Determination of the design sub-basin width W, example 1. IRRI, 1988.

Field testing of the method. The method was tested for maize irrigation in three ricefields in Guimba, Nueva Ecija, from November 1987 to March 1988 (DS). The first (F1) and second (F2) fields had been planted to maize in the past and had a sandy clay loam and a clay texture, respectively. The third (F3) field had a clay loam texture and had been planted exclusively to rice.

Land preparation consisted of one plowing and two harrowings. Infiltration measurements were taken after land preparation, and the infiltration parameter values were used in the design. Hybrid maize (Pioneer 3274) was planted in rows spaced 80 cm apart, with a plant spacing of 20 cm. Fertilizer NPK was applied at 110-60-40 kg/ha.

Water was supplied from shallow (approximately 10 m deep) wells in all 3 fields. A number of infiltration measurements were taken in the fields prior to irrigation and the measured para-

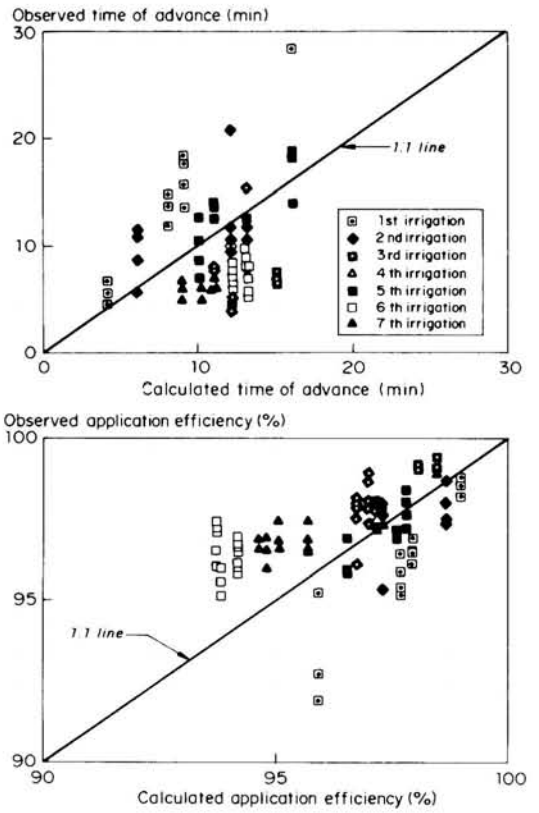
meters were used in the design. These parameters showed the largest changes in the first month after land preparation. Thereafter, changes in the individual parameters were moderate, and the cumulative infiltration volume vs time relationship did not change significantly over time.

The principle of our high frequency basin irrigation method was based on the replacement of the moisture depleted from the top 15-20 cm of the soil. Irrigation scheduling was based on evapotranspiration water losses. The FAO version of the Class A Evaporation Pan method was used to determine soil moisture losses. Irrigation water was applied when the actual cumulative evapotranspiration since the previous irrigation had reached 30 to 50 mm. The computer program was used to determine the theoretical values of t_{co}, t_a, and E_a for all irrigations.

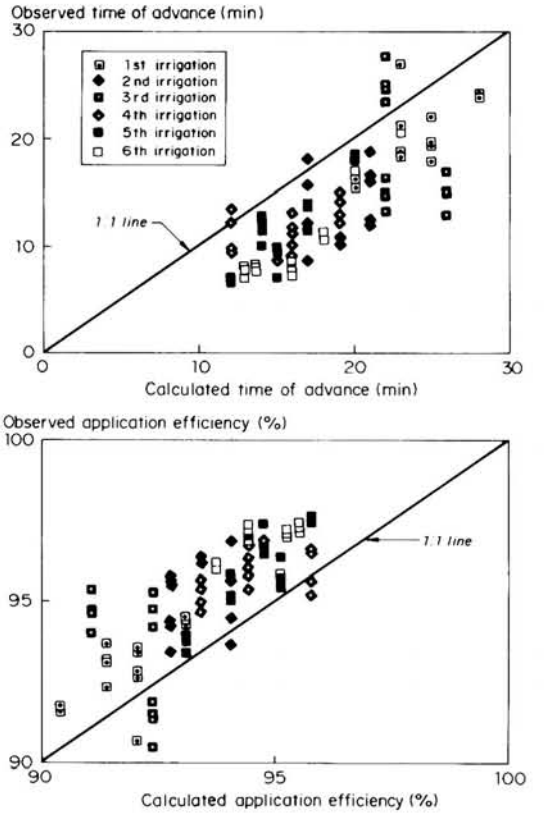
Results and conclusions. The observed advance time $(t_a)_{obs}$, as opposed to the theoretically calculated t_a, is a simple and accurate measure of the efficiency of the design of the basin irrigation system. The larger their difference, the less time it takes for water to reach the end of the field (thus allowing more time for more uniform infiltration) and the higher the application efficiency.

Observed vs calculated advance times, and the corresponding application efficiencies, for subbasins of the three fields are presented in Figures 16-18. Values of $(t_a)_{obs}$ smaller than their calculated t_a's (and indicating a system performance higher than expected) appear as data points below the 1:1 line. Observed application efficiency values $(E_a)_{obs}$ higher than the calculated ones appear as data points above the 1:1 line.

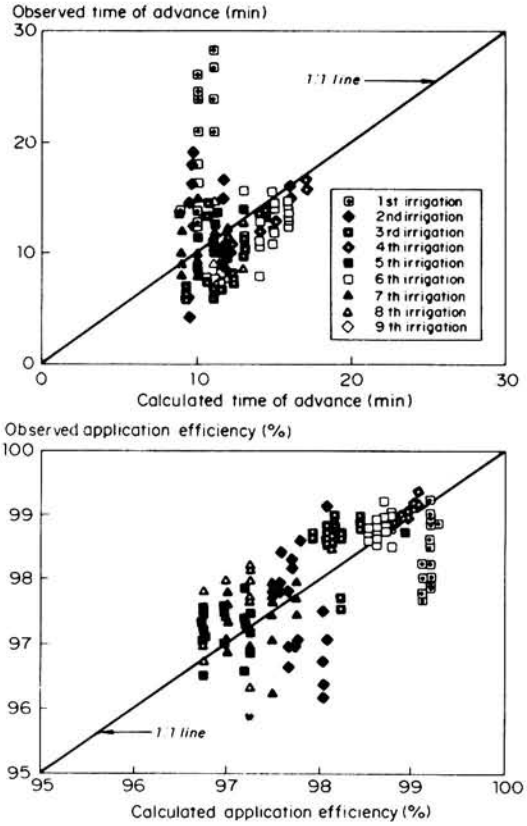
Observed times of advance $(t_a)_{obs}$ lower than the calculated t_a's—corresponding to observed application efficiencies $(E_a)_{obs}$ higher than the calculated E_a's—were measured on a very large number of occasions. This indicated an irrigation



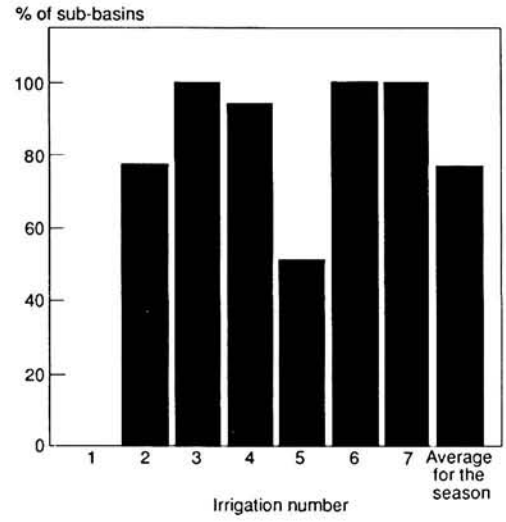
16. Observed vs calculated times of advance t_a and application efficiencies E_a for field 1. IRRI, 1988.



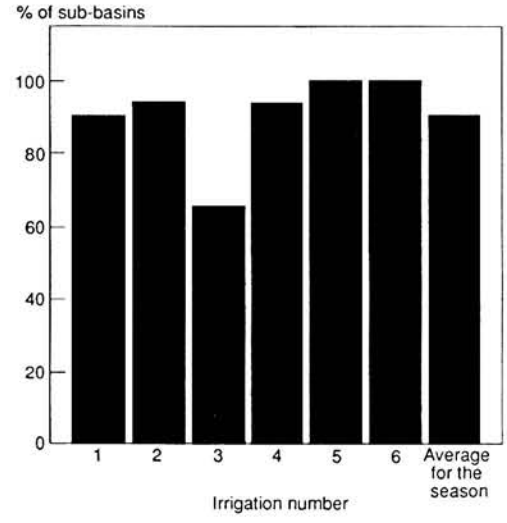
17. Observed vs calculated times of advance t_a and application efficiencies E_a for field 2. IRRI, 1988.



18. Observed vs calculated time of advance t_a and application efficiencies E_a for field 3. IRRI, 1988.



19. Percentage of sub-basins with $(E_a)_{obs}$ > calculated E_a for field 1. IRRI, 1988.

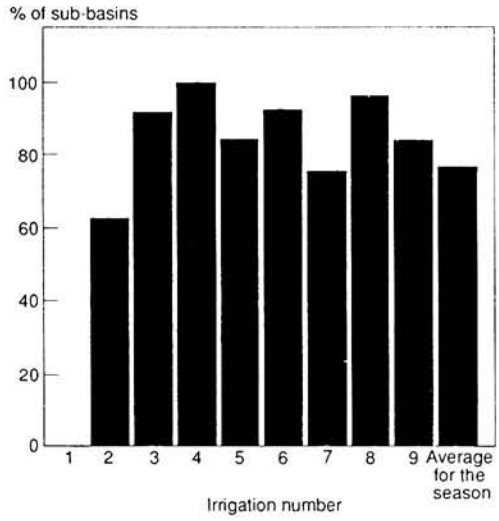


20. Percentage of sub-basins with $(E_a)_{obs}$ > calculated E_a for field 2. IRRI, 1988.

system that performed more efficiently than expected. The percentage of sub-basins where this occurred at each irrigation is shown in Figures 19-21 for fields F1, F2, and F3, respectively.

The percentage of sub-basins where observed application efficiencies $(E_a)_{obs}$ were higher than the calculated E_a's increased with the number of irrigations (Figs. 19-21). The largest increases occurred after the first irrigations and can be attributed to the reduction of the value of the c parameter in the infiltration equation because of the water-induced smoothing of the soil surface. Reductions in the percentage of sub-basins after the first irrigations were observed as a result of crust-breaking, which reintroduced increased soil hydraulic roughness. These reductions were always followed by gradual increases. Although the high percentages in Figures 19-21 indicate a system hydraulically more efficient and uniform than expected, this may not always be desirable. Persistently very high or rapidly increasing percentages may also be a sign of a soil's tendency to crust.

Although $(t_a)_{obs}$ values were sometimes significantly larger than the calculated t_a's (up to 280%), the corresponding reduction in the observed application efficiency $(E_a)_{obs}$ was never larger than 6%. Moreover, all the recorded application efficiencies exceeded the design efficiency of $(E_a)_{dsn}$ = 90%. This indicated an irrigation system design



21. Percentage of sub-basins with $(E_a)_{obs}$ > calculated E_a for field 3. IRRI, 1988.

with the ability to accommodate substantial changes in the operation parameters without significant adverse effects on performance.

The "worst case" scenario on which the design had been based performed better than expected and was probably quite conservative, but it was felt to be necessary. The total water applications and the corresponding yields, as well as other pertinent information appear in Table 5. Overall water application efficiencies for the whole season were very high for all three fields and resulted in high application uniformities. For 0.33, 0.34, and 0.37 m of irrigation water, yields of 8.08, 6.14, and 9.17 t/ha were obtained. The quantity of applied water was very close to the actual plant evapotranspiration water requirements for the growing period and significantly lower than the 60-80 cm of water usually needed for maize production. By our method, water was applied frequently in small quantities, replenishing an amount of depleted soil moisture roughly equal to the plant evapotranspiration and never stressing the plants. The farm irrigation system design made possible high yields for small quantities of water while conserving water and energy and limiting the associated costs. The lower yield in F2 can be attributed to the heavy texture of the soil (56% clay) and the fact that rice was concurrently grown in adjacent fields. These factors resulted in waterlogging, a very high water table (20-30 cm from the surface), and a shallow root system.

This study is based on the assumption of complete water control, which is the case with shallow, privately owned wells. This may not be the case for larger communal or regional irrigation systems. Although the same principles of hydraulics apply, the lack of control of water delivery may cause serious irrigation scheduling and operation problems. For successful application of the method, development of entirely new large irrigation system management practices interfacing with farm-level techniques may be required.

MICROECONOMICS OF CROP DIVERSIFICATION IN A DIVERSION IRRIGATION SYSTEM

Agricultural Economics Department

This study, part of the IRRI-International Irrigation Management Institute collaboration on diversified irrigated cropping systems, is based on the hypothesis that even if irrigation infrastructure is geared exclusively toward rice production, the farmer has several options to grow nonrice crops during DS. The objectives are 1) to understand the irrigation-related constraints to DS crop choice at the farm level and examine how farmers respond to these constraints, 2) to identify changes

Table 5. Evapotranspiration (ETP), number of irrigations, desired and gross applications, overall efficiency, and yields for fields F1, F2, and F3. IRRI, 1988.

Field	Total actual ETP (m)	Irrigations (no.)	Desired total application (m)	Gross total application (m)	Overall application efficiency (%)	Maize yield (t/ha)
F1	0.284	8	0.30	0.33	91.1	8.08
F2	0.323	7	0.31	0.34	92.4	6.14
F3	0.327	10	0.35	0.37	93.7	9.17

in the allocation and distribution of water at the system level in response to changing DS crop mix, 3) to explore means of increasing water use efficiency at the farm level without physical rehabilitation, and 4) to document the relative profitability of the existing dominant cropping patterns. Thirty farmers from the Upper Talavera River Irrigation System (UTRIS), Nueva Ecija, Philippines, service area are being intensively monitored to collect data not only on input-output of the farm but also on various current and historical issues related to crop diversification. This was complemented by open-ended interviews of system personnel and officers of the farmers irrigation association. The background of sample farmers is given in Table 6.

In the UTRIS system the main alternative to DS rice is onion, which requires higher levels of capital and labor and thus entails higher risk. However, the returns to a rice - onion cropping pattern are almost twice the returns to rice - rice. To alleviate constraints, farmers have made arrangements with onion traders who give credit in exchange for the exclusive right to purchase all the output at the market price at harvest. The traders benefit from the substantial price increase between the harvest and postharvest months.

Table 6. Characteristics of the sample. Upper Talavera River Irrigation System (UTRIS), Nueva Ecija, Philippines, 1988.

Parameter	Farmers or farms (no.) in		
	Lateral A	Lateral B	Main canal
Farmers	7	11	12
Parcels	8	15	22
Distance from irrigation canal			
Near	4	6	8
Far	3	5	4
Cropping pattern			
Rice - rice	6	–	2
Rice - onion	1	8	5
Rice - onion/vegetable	–	3	2
Rice - rice/onion	–	–	3
Soil type			
Galas (sandy loam)	–	11	6
Lagkit (clay)	6	–	4
Mestizo lagkit (clay loam)	1	–	2
DS water stress			
Yes	7	10	8
No	–	1	4

To diffuse price risks and reduce the problem of higher labor demand, farmers resort to seasonal tenancy arrangements. Farmers tend to divide their land into two, cultivating one part and giving the other part to seasonal tenants, who pay a fixed rent of $138/ha plus water charges or who have a 50-50 share arrangement.

There has been a dramatic change in the land preference of farmers in the area, as well as changes in land values. In DS, when returns to nonrice crops dominated returns to rice, the demand for and the price of land with the least constraints to diversification out of rice became the highest.

Water allocation and distribution rules give priority to upstream areas to minimize conveyance losses and to maximize output. The irrigation fee is 125 kg rough rice/ha for WS and 175 kg rough rice/ha for DS. For nonrice crops, the fee is 60% of the fee charged for rice. Table 7 shows the frequency of irrigation and the distance from irrigation canals. In general, farmers in the main canal area use more irrigation water than farmers in the laterals. In fact, farmers in the laterals use pumps to supplement their irrigation water requirement. More than half of the sample farmers in the system had not paid their irrigation fees; those farmers near the canal and in the upper sections were the ones most delinquent. The reason is that they can get water easily, even stealing if necessary.

The efficiency of irrigation water use at the farm level could be increased by 1) adjustment in water scheduling and distribution to reflect the evolution from rice monocropping to diversified agriculture; 2) adjustment in irrigation fees—rather than a flat fee—to reflect, however partially, difference in water use; and 3) adoption of tech-

Table 7. Plots (no.) of dry season onion receiving 1 to 12 irrigations by distance from irrigation canal. UTRIS, Nueva Ecija, Philippines, 1988. N = 21.

Distance from irrigation canal	Irrigations (no.)											
	1	2	3	4	5	6	7	8	9	10	11	12
Near lateral B	1	1	1	2	1							
Far from lateral B	3			1	1							
Near main canal				1	1			1	1		1	1
Far from main canal		1		2			1					

niques that conserve water and require less frequent irrigation.

IMPACT OF IMPROVED WATER MANAGEMENT ON INCOME DISTRIBUTION

Water Management and Agricultural Economics Departments and National Irrigation Administration, Philippines

An improved method of control and distribution of canal irrigation water was implemented in 1987 in the service area of the Inarihan River Irrigation System, Camarines Sur, Philippines, in collaboration with the Philippine National Irrigation Administration. Previous analyses had shown that, in spite of the severe drought in 1987, productivity and income were higher for farms with the improved water management than for those without (Annual report for 1987).

To evaluate the impact of the improved water management measures on income distribution, three approaches were used: 1) functional income distribution or factor share, 2) personal income distribution or earner share, and 3) the Gini coefficient. Functional income distribution involves the allocation of income among production factors and determination of the ratios of costs of factor inputs used in the production process to the total value of output. Personal income distribution refers to the distribution of income among resource owners. The Gini coefficient is an indicator of income inequality that ranges between 0 and 1: the lower the value of the coefficient, the more equal the income distribution.

The improved control and distribution of canal water favored all production factors. All factor payments (for capital, current inputs, labor, land, and management) were significantly higher in the "with" than in the "without" situation (Table 8). The increase in factor payments ranged from 89 kg/ha (for capital) to 304 kg/ha (for management).

On the other hand, the factor shares for labor and current inputs were slightly lower by 2 and 7%, respectively, in the "with" situation. This was, however, offset by the higher factor share (9%) for management or operator's surplus, which implies that the farmer-operator in the "with" situation received a market wage (or a share) for

Table 8. Comparative factor payments and factor shares in rice production, with and without improved control and distribution of canal water. 116 sample farms, Camarines Sur, Philippines, 1987 DS.

Item	With improvement	Without improvement	Difference[a]
Rice output (kg/ha)	3100	2100	1000***
Factor payments (kg/ha)			
Current inputs	809	700	109***
Capital	299	210	89*
Labor	956	703	253***
Land	768	523	245***
Operator's surplus (management)	268	(36)	304*
Rice output (%)	100	100	0
Factor shares (%)			
Current inputs	26	33	(7)
Capital	10	10	0
Labor	31	33	(2)
Land	25	25	0
Operator's surplus	8	(1)	9

[a] Significant at 1% (***) and 10% (*) levels by *t*-test.

Table 9. Allocation of total rice output (rice equivalent per hectare) to earners in the rice production system, with and without improved control and distribution of canal water. 116 sample farms, Camarines Sur, Philippines, 1987 DS.[a]

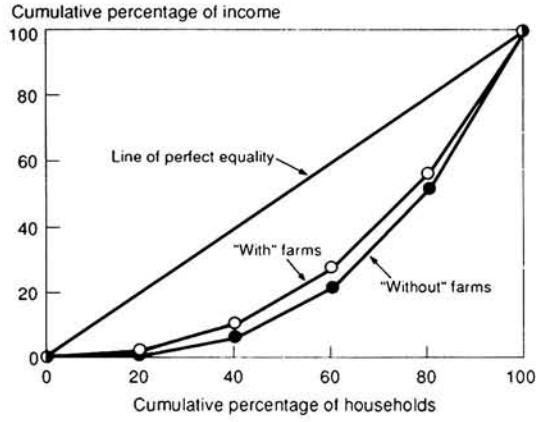
Earners	With improvement		Without improvement		Difference
	Allocation (rice equivalent/ha)	%	Allocation (rice equivalent/ha)	%	
Hired laborers	747	24	548	26	199[ns]
Current input earners	809	26	700	33	109***
Landlord	768	25	523	25	245***
Other earners[b]	188	6	122	6	66*
Operator's surplus	588	19	207	10	381**
Total	3100	100	2100	100	1000***

[a] Figures in parentheses are percentage of output allocated to earners in the rice production system. Significant at the 1% (***), 5% (**), and 10%(*) levels by *t*-test. [b] Recipient of rentals on tractors, threshers, and animal power.

his efforts in managing the farm, unlike those in the "without" situation, who had none.

The highest personal income or earner share went to current input earners (Table 9). All earner groups in the "with" project situation, except the hired laborers, had significantly higher real income (rice equivalent per hectare) than those in the "without" project farms. Moreover, a much higher percentage share of income was obtained by the farmer-operators in the "with" situation, suggesting that they were greatly benefited, as intended, by the improved control and distribution of canal water.

The farms with improved water management had a lower Gini coefficient, 0.42, than the "without" situation, 0.49. This was best depicted by the Lorenz curves for the two situations (Fig. 22). The lower Gini coefficient for the "with" situation indicates an improved equality in income distribution. Thus, the findings in this study could support programs for improving the efficiency of existing irrigation systems, not only from technical water efficiency considerations but also for better income distribution objectives.



22. Lorenz curves for all sample farms with and without improved control and distribution of canal water. Camarines Sur, Philippines, 1987 DS.

Soil and crop management

Soil characterization

Soils Department and University of Oxford, United Kingdom

DYNAMICS OF SOIL PHOSPHORUS UNDER AEROBIC AND REDUCED CONDITIONS **320**
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DYNAMICS OF SOIL PHOSPHORUS UNDER AEROBIC AND REDUCED CONDITIONS

Soils Department

Phosphorus deficiency in rice is highly influenced by the physical and chemical properties of the soil, forms and amounts of native P, organic matter content, and water regime. We studied the effects of water regime and straw amendment on P dynamics in different soils and their impact on rice growth.

Three soils varying widely in physical and chemical properties (Table 1) and forms and amounts of native P (Table 2) were planted to IR64 with and without 50 mg P/kg and 0.15% rice straw. The soils were in pots kept at field capacity (aerobic) and under flooded (reduced) conditions.

Although the total P contents of the soils were within normal range (402-590 mg/kg), available P (Olsen) was nil in the strongly acid Luisiana soil, optimum (9 mg/kg) in slightly acid Maahas soil, and high (33 mg/kg) in calcareous Pila soil (Table 2). Water-soluble P in the soil solution was <0.2 mg/liter in the strongly and slightly acid soils during the entire period of rice growth, but increased to almost 3 mg/liter in the calcareous soil after 9 wk. The inorganic P fractions of the dried soils were dominantly bound as Fe/Al-P in the strongly acid soil, as Ca-bound P in the calcareous soil, and at a 1:1 ratio of both forms in the slightly acid soil. Carbonate occluded-P was present in small amounts in all three soils, while there was no reductant soluble-P. Figures 1 and 2 show the distribution of the inorganic P fractions with regard to water regimes and straw and P treatments. Generally, the Fe/Al-P increased while carbonate occluded-P decreased. The Ca-P fraction differed with soil and treatment.

The Fe/Al-P fraction increased over time in all soils, though the pattern differed. The highest increment occurred in the reduced strongly acid soil. Differences between aerobic and reduced conditions in the slightly acid and calcareous soils were small. Phosphorus application increased the Fe/Al-P fraction, while straw amendment did not.

The carbonate occluded-P fraction decreased with time in all treatments. Initially it was highest in the calcareous soil, ranging from 40 to 100 mg/kg), and lowest in the slightly acid soil (<10 mg/kg). Phosphorus and straw treatments barely affected the pattern of the carbonate occluded-P fraction.

The Ca-P fraction was very high (>300 mg/kg) in the calcareous soil and lowest (<25 mg/kg) in the strongly acid soil. Under reduced conditions, P or straw application increased the initial concentration of Ca-P in the calcareous soil only, but caused higher concentration at 12 wk in all soils.

Table 1. Soil chemical properties (air-dried basis) of 3 Philippine soils, 1988.

Soil property	Luisiana	Maahas	Pila
pH	4.6	6.6	7.9
Organic C (%)	2.15	1.43	1.31
Total N (%)	0.236	0.148	0.166
Exchangeable Ca (meq/100 g)	9.75	21.6	36.7
CEC (meq/100 g)	37.6	24.6	39.9
Available Zn (mg/kg)	8.0	1.4	0
Active Fe (%)	5.77	1.19	0.586
Soil texture	Clay	Clay	Clay loam

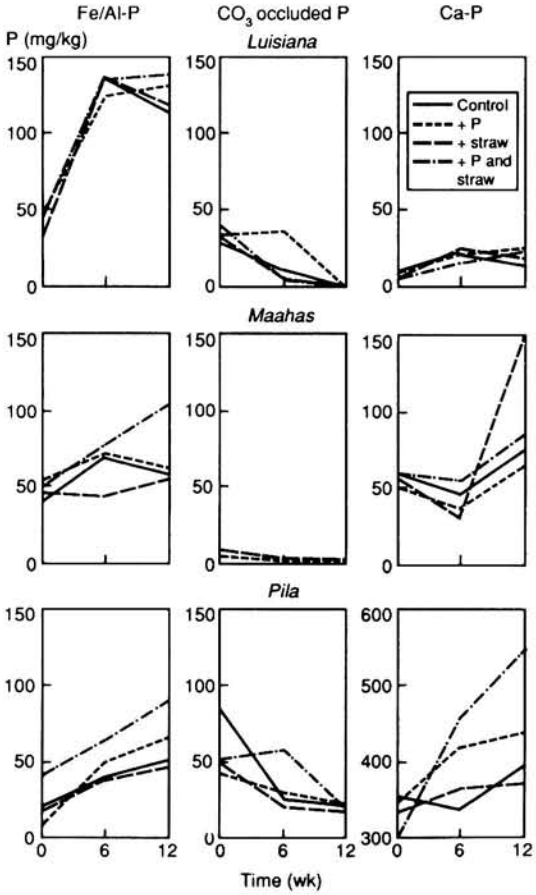
TISSUE ANALYSIS BY FOUR METHODS

Soils Department

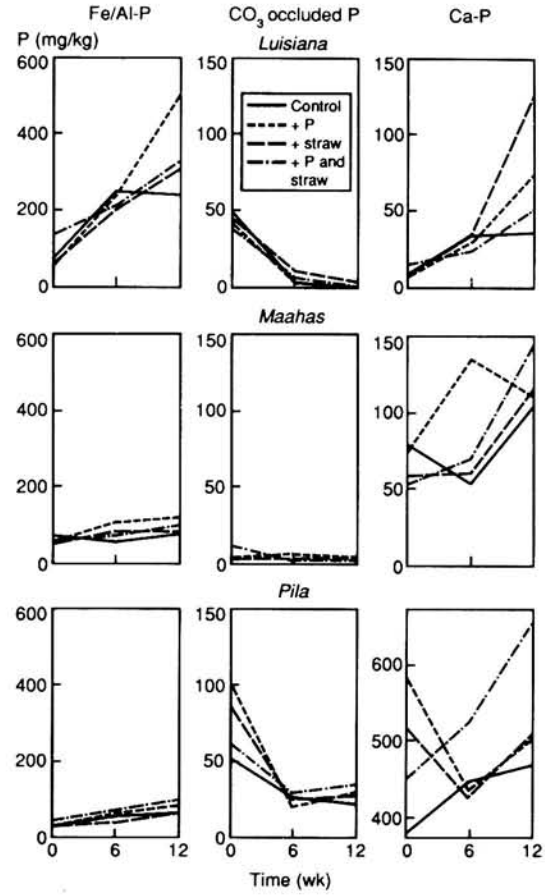
In looking for alternative methods of plant nutrient analysis that are quick, reliable, and safe, the 0.1 N HCl and the 0.1 N HAc methods of the University of Sussex Plant Physiology group, and the NH_4OAc/HOAc method were compared with

Table 2. Forms and amounts (mg/kg) of P in 3 Philippine soils, 1988.

Soil	Total P	Olsen P	Organic P	Inorganic P fractions			
				Fe/Al-P	CO_3 sorbed P	Reductant-soluble P	Ca-P
Luisiana clay	578	0	319	55	43	0	19
Maahas clay	402	9.2	175	34	2	0	42
Pila clay loam	590	33	235	21	17	2	172



1. Pattern of inorganic P fractions under aerobic conditions in 3 Philippine soils, 1988.



2. Pattern of inorganic P fractions under reduced conditions in 3 Philippine soils, 1988.

the standard tri-acid digestion method employed at IRRI.

Fifteen plant samples were dried, cut, and ground, using a Tecator cyclotec mill and following standard Soils Department procedures. The samples were then extracted with 0.1 N HCl, 0.1 N HAc, NH_4OAc/HOAc solution, and concentrated HNO_3/$HClO_4$/H_2SO_4 acid mixture.

Table 3 shows the correlations between analytical values obtained by the three alternated methods and the values from the standard tri-acid method. Iron and Ca in the plants cannot be determined successfully by the simpler methods. For the other elements, 0.1 N HCl and the NH_4OAc/HOAc solution were as suitable as the standard method. Although the values obtained for some elements correlated with the standard values, different critical limits must be set because analytical values

Table 3. Plant nutrient contents extracted by 3 methods compared with contents extracted by the standard tri-acid method. IRRI, 1988.

Element	Correlation coefficient (r)[a]		
	0.1 N HCl	NH_4OAc/HAc	0.1 N HAc
Cu	0.63 *	0.81 ** C	0.71 **
Zn	0.94 ** C	0.90 ** C	0.95 **
Fe	0.0 ns	0.0 ns	0.51 ns
Mn	0.99 **	0.99 **	0.99 **
Na	0.86 **	0.88 **	0.0 ns C
K	0.91 **	0.92 **	0.70 ** C
Ca	0.69 **	0.10 ns	Readings too low
Mg	0.71 **	0.89 **	0.70 **
P	0.95 ** C	0.92 ** C	0.88 **

[a] * = significantly correlated with the standard tri-acid method at the 5% level. ** = significantly correlated with the standard tri-acid method at the 1% level. ns = not significant. C = critical limits must be reestablished for this nutrient.

obtained were either lower or higher than the tri-acid values.

SOIL MAPS OF IRRI LOWLAND FARM

Soils Department

Maps of the soil properties of the IRRI farm were prepared to provide an inventory of soil characteristics that will help to distinguish and arrange areas, and to determine the factors associated with their characters. Maps of soil pH, organic C, total N, available P, exchangeable K, available Zn, available B, depth of plow layer, and soil textural class were completed in 1988. Maps were based on analyses of 4 soil samples per 0.25 ha. Areas with similar properties were derived by computerized generation of isolines (SAS programs: G3 Grid and G Contour).

Four major distinctions of soil characteristics were identified in the lowland areas:

- The most fertile soils are found in blocks B, C, R, and S, with total N >0.2% and organic C >2.0%. Although somewhat low in available Zn, these soils have no B toxicity. Less fertile areas are blocks 300, 800, and 1000.
- Variability in soil properties is low in blocks A to E, moderate in blocks 100 to 2000, and high in blocks F to T.
- Zinc-deficient areas are blocks 200, 500, 600, 1000, and 2000. Areas with B toxicity are blocks 400, 500, 600, and 700.
- Four soil textural classes were distinguished: clay, silty clay, clay loam, and silty clay loam. Blocks A to E and F to T have clay soils; blocks 100 to 2000 have silty clay to silty clay loam.

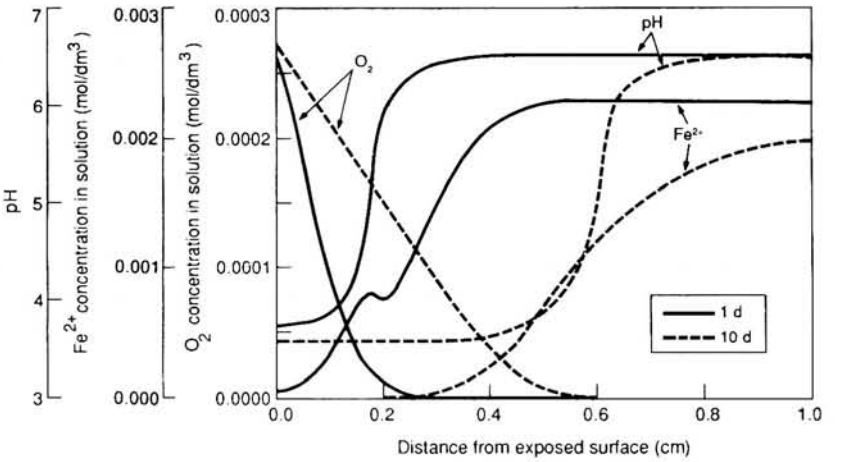
A MODEL OF THE COUPLED DIFFUSION AND OXIDATION OF FERROUS IRON IN FLOODED SOILS

Soils Department and University of Oxford, United Kingdom

To better understand chemical conditions in the rice rhizosphere, we are investigating the factors influencing simultaneous oxidation-reduction and diffusion processes involving Fe in flooded soils. Our aim is to develop a simulation model of chemical conditions in the rice rhizosphere. Since the rice rhizosphere is highly inaccessible for experiments, simulation models validated on simpler experimental systems may prove invaluable in investigating its processes.

In 1988, we considered what happens in a block of saturated anaerobic soil when it is exposed to air at one end, and we developed a mathematical model with which to predict the profiles of O_2, pH, and reduced and oxidized Fe that developed in the soil. As ferrous Fe is oxidized, acidity is generated according to the reaction

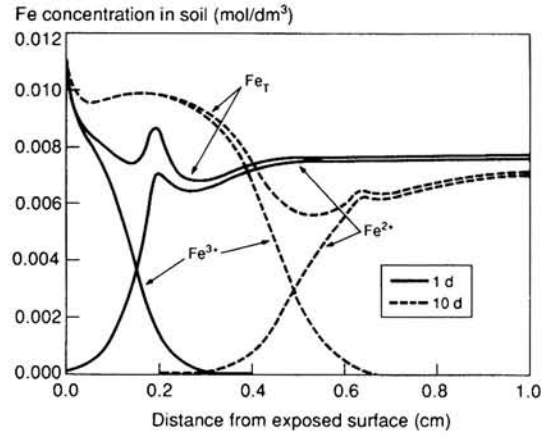
$$4Fe^{2+} + O_2 + 10H_2O = 4Fe(OH)_3 + 8H^+$$



3. Concentration of Fe^{2+} and O_2 in solution and pH vs distance from exposed surface.

The model solves mathematical equations for the diffusion of Fe and O_2 and for soil acids and bases that move in response to the decrease in pH caused by acidity. Information on the kinetics of the Fe oxidation reaction was taken from experiments with soil suspensions.

Figures 3 and 4 give the model's predictions for 1 and 10 d of reaction under ordinary flooded soil conditions; we are currently doing laboratory experiments to validate these predictions. The peaks in the Fe profiles are a result of a complex interaction between the Fe, O_2, and soil acids and bases; these species all have very different mobilities. Such peaks are consistent with experimentally observed distributions of Fe near oxidizing rice roots. Acidification by rice roots has also been observed qualitatively. The acidification caused by Fe oxidation is likely to be compounded by acid release from roots to balance the excess uptake of cations over anions, N being supplied in reduced soils chiefly as NH_4^+. A large decrease in pH near roots would have major implications for other soil processes: for example, nitrification in an acid but oxidized rhizosphere would be very slow, and the P sorption capacity of freshly precipitated Fe oxides at low pH would be very high.



4. Concentration of Fe^{2+}, Fe^{3+}, and total Fe (Fe_T) in soil vs distance from exposed surface.

Soil and crop management

Management of soil and fertilizer nitrogen

Agronomy, Agricultural Engineering, and Plant Physiology Departments; International Fertilizer Development Center; Department of Agriculture, Thailand; and University of California at Davis

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DIRECT MEASUREMENT OF AMMONIA VOLATILIZATION AND DENITRIFICATION LOSSES IN TRANSPLANTED RICE

Agronomy Department and International Fertilizer Development Center

Ammonia volatilization and denitrification were directly measured in transplanted IR66 after urea application into the floodwater at 11 d after transplanting (DT) in Calauan, Laguna, Philippines, during the 1988 dry season (DS). Ammonia volatilization loss was measured using the mass balance micrometeorological technique; denitrification was measured in cooperation with the International Fertilizer Development Center (IFDC) using a floating chamber for collection of evolved $(N_2 + N_2O)$- ^{15}N and the electric arc technique for ^{15}N analysis.

High NH_3 fluxes measured for 10 d following urea application resulted in a cumulative loss of 49% of the applied urea. The cumulative recovery of the evolved $(N_2 + N_2O)$-^{15}N for the 20 d following urea application, however, was only about 0.1% of the applied urea.

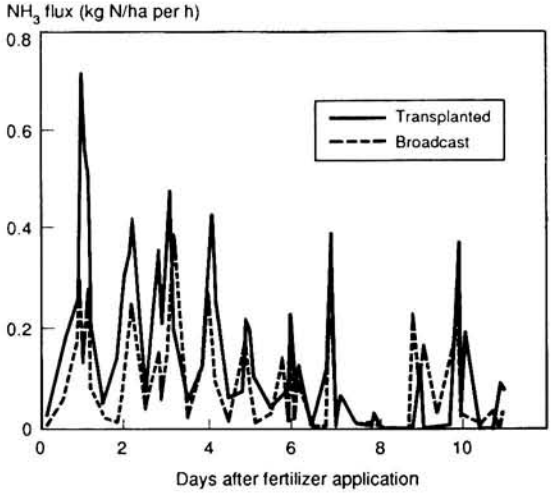
The measured high NH_3 fluxes indicate that NH_3 volatilization was the dominant loss process taking place, whereas the low denitrification loss obtained from directly measuring evolved $(N_2 + N_2O)$-^{15}N suggests that denitrification was not a major loss mechanism from urea applied into the floodwater at 11 DT at this site. Urea is rapidly hydrolyzed to ammoniacal N (NH_4^+ and NH_3) and thus would be susceptible to NH_3 loss. With denitrification, however, ammoniacal N must first be converted to NO_3^-, which then moves to the reduced zone and is thereafter reduced to N_2 and N_2O.

In spite of the high NH_3 volatilization loss, the measured $(N_2 + N_2O)$-^{15}N failed to match the difference between the total N loss (52%) from the ^{15}N balance and the directly measured NH_3 loss. This suggests that some of the N gases (3%) may have been trapped in the soil and had not yet escaped to the atmosphere.

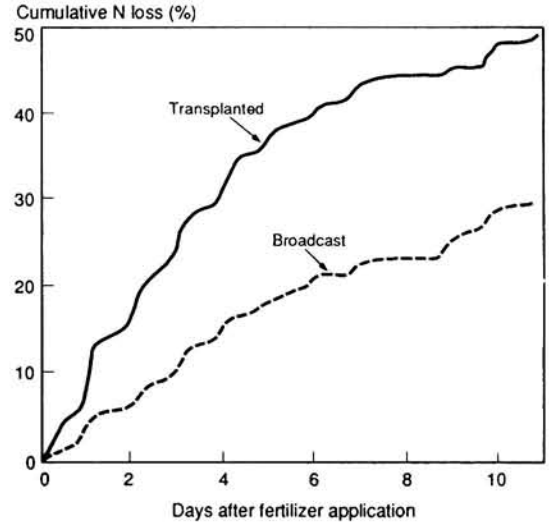
COMPARISON OF TOTAL NITROGEN LOSS AND NH_3 VOLATILIZATION LOSS IN BROADCAST SEEDED AND TRANSPLANTED RICE

Agronomy Department

NH_3 volatilization loss, estimated by the micrometeorological technique, and ^{15}N balance were measured in broadcast seeded flooded rice (BSFR) and transplanted rice (TPR) in Calauan, Laguna, Philippines, in 1988 DS. The difference between total N loss and NH_3 loss was estimated as nitrification-denitrification loss.

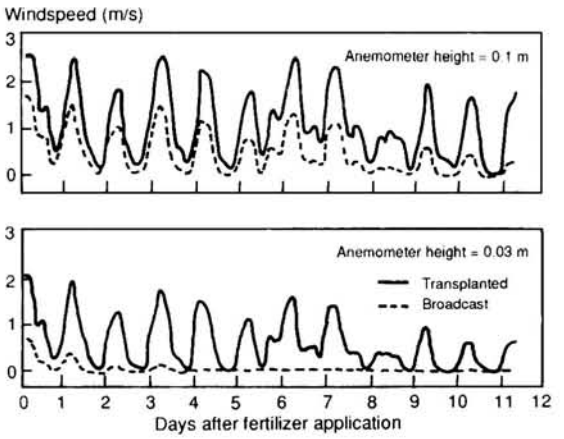


1. Ammonia fluxes from urea applied to broadcast seeded and transplanted IR66 in circular plots as measured by micrometeorological technique. Calauan, Laguna, Philippines, 1988 DS.



2. Cumulative NH_3 loss from urea applied to broadcast seeded and transplanted IR66 in circular plots. Calauan, Laguna, Philippines, 1988 DS.

An NH_3 flux of 0.7 kg N/ha per h was measured on the first day after urea application in a circular plot of TPR rice by using windspeed and excess NH_3 concentrations over the background NH_3 at various heights in the profile (Fig. 1). On the second day, the NH_3 flux decreased to 0.4-0.5 kg N/ha per h. It continued decreasing until day 6 but increased again on days 7 and 10. In a circular plot of BSFR, the NH_3 flux was 0.3 kg N/ha per h on the first day and remained low after day 6. It was equal to the NH_3 flux in TPR on days 9 and 10.



3. Windspeed pattern in transplanted and broadcast seeded rice during the measurement of ammonia fluxes. Calauan, Laguna, Philippines, 1988 DS.

The cumulative NH_3 loss was 49% in TPR and 30% in BSFR (Fig. 2). The diurnal floodwater temperature and pH trends were similar for both planting methods.

Windspeed patterns at heights of 0.8-3.0 m above the floodwater were similar for both planting methods. However, at heights of as low as 0.03-0.1 m above the floodwater, windspeed was higher for TPR than for BSFR (Fig. 3), and may explain the higher cumulative NH_3 loss in TPR.

The measured NH_3 flux density was correlated with the product of windspeed (u) and the equilibrium NH_3 concentration minus the background NH_3 concentration for TPR and for BSFR (Fig. 4). The resultant equation for NH_3 flux (F) in kg N/ha per h is

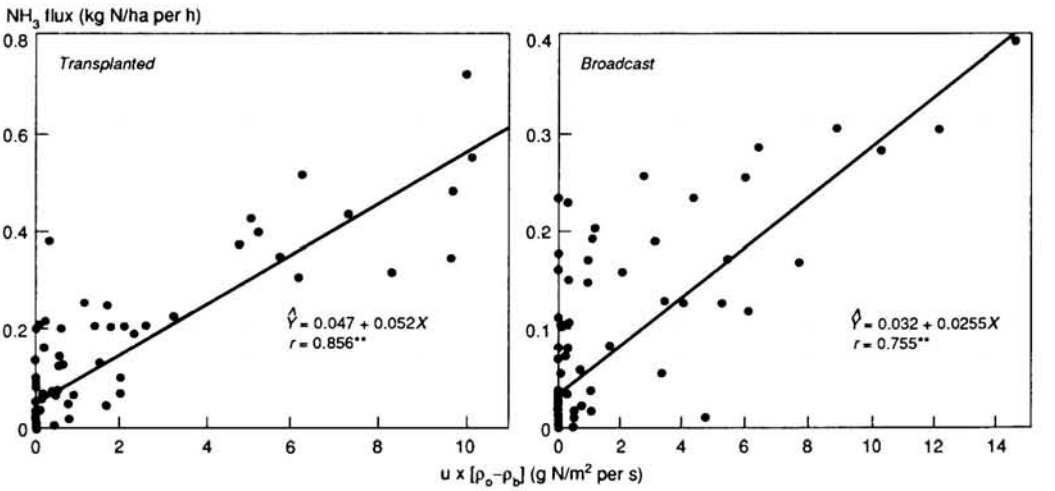
$$F = K\,\bar{u}_{0.8}\,(\bar{c}_{H_2O} - \bar{c}_B)\,10^{-3}$$

where c_{H_2O} is the equilibrium NH_3 concentration (in g N/m^3) in the floodwater in the miniplot and c_B is the mean background NH_3 concentration (in g N/m^3) in the atmosphere at 0.8 m. This equation is used to predict NH_3 loss under different management treatments.

For TPR $F = 0.047 + 0.052 \times r = 0.856^{**}$
For BSFR $F = 0.032 + 0.0255 \times r = 0.755^{**}$

where

$$x = \bar{u}_{0.8}\,(\bar{c}_{H_2O} - \bar{c})10^{-3}$$



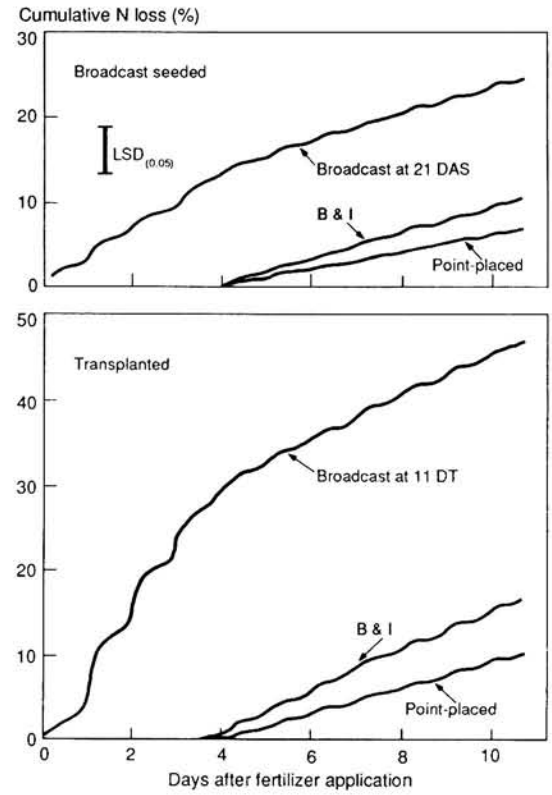
4. Relationship between NH_3 emission rate in transplanted and broadcast seeded rice and the product of windspeed and the difference between the NH_3 gas concentration in floodwater and that in the background. Calauan, Laguna, Philippines, 1988 DS.

Although the highest recorded product of windspeed and NH_3 concentration was greater in BSFR than in TPR (Fig. 4), NH_3 flux was less in BSFR than in TPR. Ammonia flux was shown to be a result of a very strong interaction between windspeed and NH_3 concentration in the floodwater. Wind is needed to blow the NH_3 vapors above the floodwater to effect the loss.

With both planting methods, NH_3 concentration loss was maximum when urea was topdressed at 11 DT (Fig. 5). Fertilizer incorporation into mud effectively reduced NH_3 loss. Deep placement of urea supergranules (USG) gave the least NH_3 loss. However, TPR gave a consistently higher NH_3 loss than did BSFR regardless of fertilizer management practice. Broadcast application at 11 DT gave 47% NH_3 loss with TPR compared with only 25% NH_3 loss with BSFR.

With BSFR, urea application at 21 d after seeding (DAS) gave the highest plant recovery of 27% (Table 1). Plant recovery was lowest in TPR with point placement of USG. Uptake of ^{15}N was higher with BSFR than TPR, perhaps because of BSFR's earlier establishment and tillering compared with TPR, which has "transplanting shock."

Total ^{15}N recovery was highest with USG point placement, whether in TPR or BSFR. In TPR, basal incorporation into mud gave a higher total



5. Cumulative NH_3 loss from urea applied to broadcast seeded and transplanted rice as affected by 3 N management practices, Calauan, Laguna, Philippines, 1988 DS. B&I = basal and incorporated, DAS = days after seeding.

Table 1. Recovery of ^{15}N-labeled urea in soil and plant, and total N loss at 20 d after fertilizer application as affected by N application method and water depth. Calauan, Laguna, Philippines, 1988 DS.

Water depth (cm)	N (kg/ha) timing		^{15}N recovery (%)			Total N loss (kg/ha)
	Basal	11 DT or 21 DAS[a]	Plant N + roots	Total soil	Unaccounted for	
			Transplanted			
0	53	–	6	44	50	27
5	–	53	6	32	62	33
0	80[b]	–	2	91	7	6
	LSD (0.05)		10	12	11	7
5	–	53[c]	11	37	52	28
			Broadcast seeded			
0	53	–	15	29	56	30
5	–	53	27	29	44	23
0	80[b]	–	9	79	12	10
	LSD (0.05)		10	12	11	7
5	–	53[c]	27	30	43	23

[a]DT = days after transplanting, DAS = days after seeding. [b]Urea supergranules (USG) placed at 10-cm soil depth at 1 DT or at 1 d before seeding. [c]In a circular plot.

recovery (50%) than did broadcast application at 11 DT (38%). In BSFR, however, broadcast application at 21 DAS led to greater recovery (56%) than did fertilizer incorporation before seeding (44%).

At crop maturity, highest recovery was again obtained with point placement (81% for TPR, 85% for BSFR) (Table 2). BSFR gave lower plant recovery with deep placement than did TPR, because of lodging. Broadcast application at 21 DAS gave high plant ^{15}N recovery in BSFR.

The unaccounted for ^{15}N with USG point placement increased from the first early sampling to maturity (Table 1, 2). Additional N loss could also have occurred from the second dose of urea applied at 5-7 d before panicle initiation (DBPI) or 10 d after panicle initiation. Estimated NH_3 loss by the bulk aerodynamic method was approximately 10% for BSFR and 17% for TPR when urea was incorporated without standing water (Table 3). Denitrification loss as calculated by the difference between the estimated NH_3 loss and total ^{15}N loss ranged from 33 to 46%. Total N loss with deep placement of N fertilizer was lowest, indicating its superiority over other application methods in minimizing N losses.

Table 3. Relationship between total N loss and NH_3 volatilization. Calauan, Laguna, Philippines, 1988 DS.

Water depth (cm)	N (kg/ha) timing		Total N loss (%)	NH_3 loss (%)	Estimated nitrification-denitrification loss[a] (%)
	Basal	11 DT			
		Transplanted			
0	53	–	50	17	33
5	–	53	62	47	15
0	80[b]	–	7	10	0
–	LSD (0.05)		11	5	–
5	–	53[c]	52	49	3
		Broadcast seeded			
0	53	–	56	10	46
5	–	53	44	25	19
0	80[b]	–	8	7	1
–	LSD (0.05)		11	5	–
5	–	53[c]	43	30	13

[a] By difference. [b] USG placed at 10-cm soil depth at 1 d after transplanting or 1 d before seeding. [c] In a circular plot.

EVOLUTION OF DINITROGEN AND NITROUS OXIDE FROM FERTILIZER APPLIED TO FLOODED RICE SOIL

Agronomy Department and International Fertilizer Development Center

Despite the difficulties of directly measuring denitrification in flooded rice, efforts have been

Table 2. Recovery of ^{15}N-labeled urea (80 kg N/ha) and total N loss in soil and plant at harvest as affected by N application method and water depth.[a] Calauan, Laguna, Philippines, 1988 DS.

Water[b] depth (cm)	N (kg/ha) timing				^{15}N recovery (%)				Total N loss (kg/ha)
	Basal	11 DT or 21 DAS	5-7 DBPI	10 DAPI	Straw	Grain	Soil + root	Unaccounted for	
				Transplanted					
0	53	–	27	–	9	21	34	36	28
5	–	53	–	27	10	21	33	36	29
0	80[c]	–	–	–	31	34	16	19	15
–	LSD (0.05)				5	10	6	14	11
5	–	53[d]	–	27	10	18	24	48	38
				Broadcast seeded					
0	53	–	27	–	11	24	32	33	26
5	–	53	–	27	11	31	24	33	27
0	80[c]	–	–	–	36	22	27	15	12
–	LSD (0.05)				5	10	6	14	11
5	–	53[d]	–	27	9	29	26	36	29

[a] DT = days after transplanting, DAS = days after seeding, DBPI = days before panicle initiation, DAPI = days after panicle initiation. [b] Water depth only at basal application; fertilizer topdressed at 5-7 DBPI and 10 DAPI with 5-cm water. [c] USG placed at 10-cm soil depth at 1 DT or 1 d before seeding. [d] In a circular plot.

continued to devise methods of directly measuring this gaseous N loss mechanism. A field experiment under flooded conditions measured the $(N_2 + N_2O)$-^{15}N flux and the ^{15}N enrichment of the N gases in the floodwater and soil after application of ^{15}N-labeled KNO_3, which was used as the standard for methodology development. Floodwater NO_3^--N was also measured to relate it to the evolved $(N_2 + N_2O)$-^{15}N.

The concentration of NO_3^--N in floodwater rapidly decreased following application (Fig. 6). Correspondingly, the flux of $(N_2 + N_2O)$-^{15}N increased for 2 d after NO_3^- addition. As the concentration of floodwater NO_3^--N decreased, $(N_2 + N_2O)$-^{15}N continued to evolve; it then became negligible after complete disappearance of NO_3^--N (Fig. 6).

A highly positive correlation was found between $(N_2 + N_2O)$-^{15}N flux and floodwater NO_3^--N measured 48 h earlier:

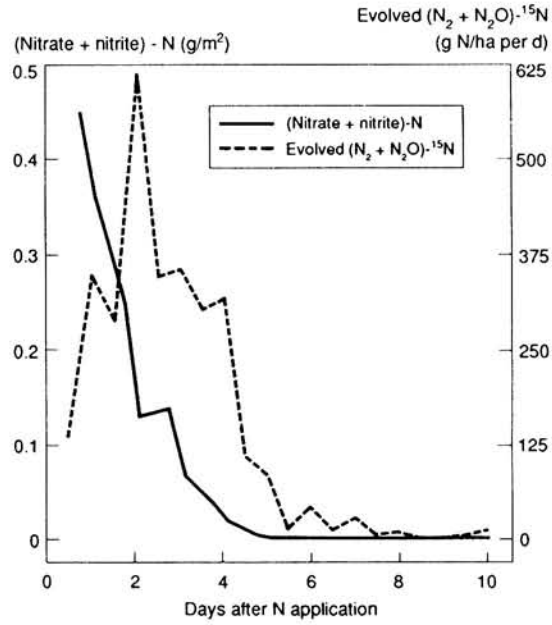
$$\text{Daytime } (N_2 + N_2O)\text{-}^{15}N \text{ flux} = 19.4 + 62.3\ NO_3^-\text{-N}, \quad r = 0.91^{**}$$

$$\text{Nighttime } (N_2 + N_2O)\text{-}^{15}N \text{ flux} = 12.6 + 32.0\ NO_3^-\text{-N}, \quad r = 0.96^{**}$$

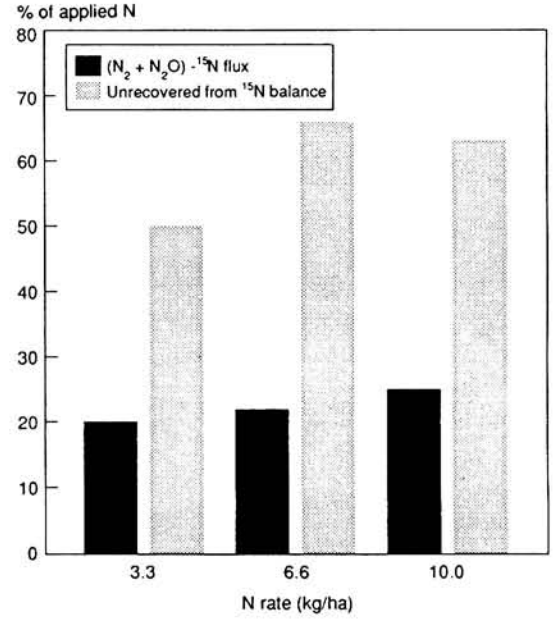
This suggests a time lag when floodwater NO_3^--N was reduced to $(N_2 + N_2O)$-^{15}N before escaping into the atmosphere.

Unrecovered ^{15}N from the ^{15}N balance at the end of the 10-d gas sampling period ranged from 48 to 64% of the applied NO_3^- (Fig. 7). Since runoff and leaching losses were prevented, the unrecovered ^{15}N was assumed to equal denitrification loss. However, the cumulative recovery of the $(N_2 + N_2O)$-^{15}N flux ranged from 20 to 25% of the applied NO_3^-, or only about 40% of the total denitrification loss. These results suggest that not all of the $(N_2 + N_2O)$-^{15}N gases formed by denitrification escaped to the atmosphere.

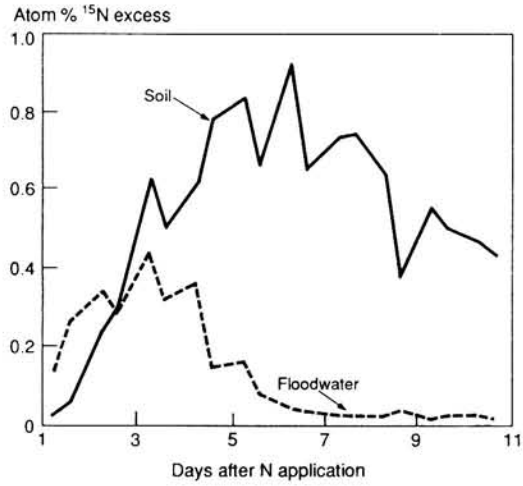
Because of the discrepancy between the unrecovered ^{15}N from the ^{15}N balance and the $(N_2 + N_2O)$-^{15}N flux, gases in the floodwater and soil were collected and analyzed for ^{15}N to verify the entrapment of $(N_2 + N_2O)$-^{15}N in the floodwater and soil. Results confirm the ^{15}N enrichment of the N_2 and the N_2O gases in the floodwater and soil (Fig. 8). The atom % ^{15}N excess of the N gases in the floodwater increased for the first 4 d after NO_3^- addition and then diminished on succeeding days. On the other hand, the atom % ^{15}N excess of the soil N gases continued to increase.



6. Floodwater NO_3^--N and evolved $(N_2 + N_2O)$-^{15}N after application of nitrate. IRRI, 1988.



7. Cumulative recovery of $(N_2 + N_2O)$-^{15}N in relation to the unrecovered ^{15}N from applied KNO_3. IRRI, 1988.



8. ^{15}N enrichment of the floodwater and soil N gases. IRRI, 1988.

Even on the 10th day after NO_3 addition, a substantial amount of the ^{15}N excess in the soil N gases was still measured, while $(N_2 + N_2O)$-^{15}N flux was already negligible (Fig. 8). Thus, some of the N_2 and N_2O gases formed by denitrification may have remained entrapped in the soil.

A highly positive correlation existed between the $(N_2 + N_2O)$-^{15}N flux and the atom % ^{15}N excess of the $(N_2 + N_2O)$-^{15}N in the floodwater (r = 0.86). This suggests that the $(N_2 + N_2O)$-^{15}N in the floodwater escapes into the atmosphere. No correlation (r = -0.34) was found, however, between the $(N_2 + N_2O)$-^{15}N flux and the atom % ^{15}N excess of the N gases in the soil.

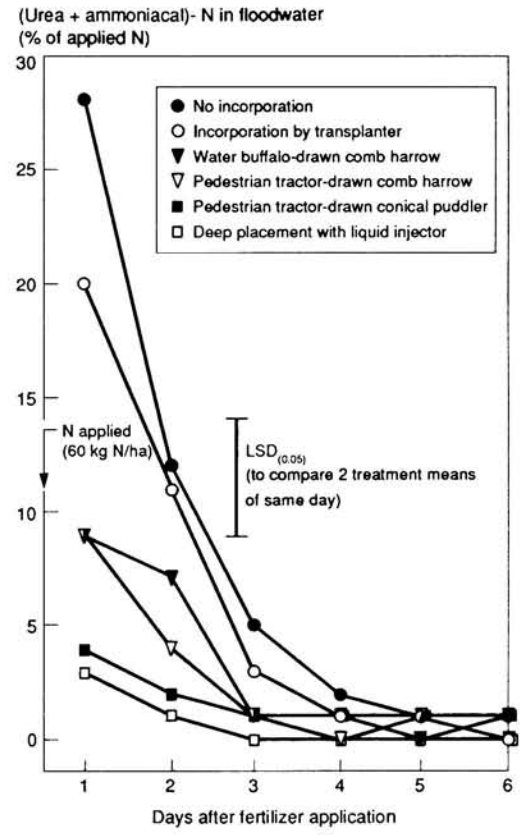
EFFECTIVE INCORPORATION OF UREA FERTILIZER

Agronomy and Agricultural Engineering Departments and International Fertilizer Development Center

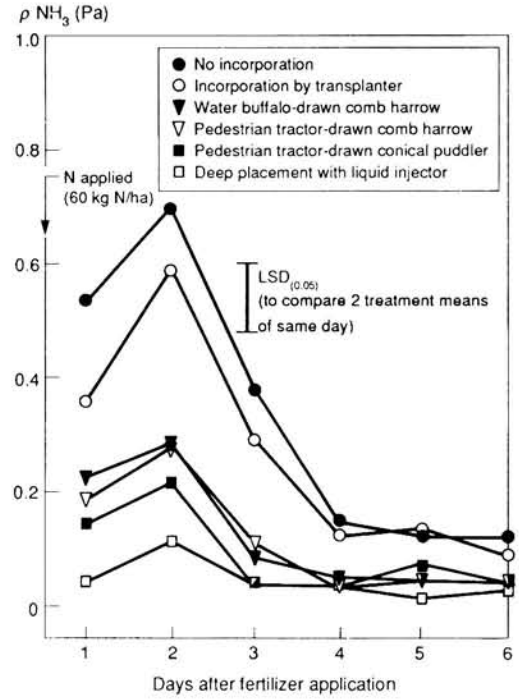
Nitrogen losses from prilled urea (PU) can be reduced, but not eliminated, by thorough incorporation of the urea without standing water prior to transplanting. Research was conducted in 1988 DS in Pila, Laguna, Philippines, to compare the effectiveness of several implements in incorporating PU.

Urea was broadcast at 60 kg N/ha into puddled soil with 0.5 cm standing floodwater. The urea was then incorporated with two passes of either pedestrian tractor- or water buffalo-drawn implements. Irrigation was added immediately after incorporation to bring the depth of standing water to 3 cm. The effectiveness of urea incorporation was assessed from the relative differences in floodwater (urea + ammoniacal)-N and partial pressure of ammonia, ρNH_3.

Without any incorporation, 28% of the applied PU was present as (urea + ammoniacal)-N at 1 d after N application (Fig. 9). Incorporation of PU with either a pedestrian tractor- or water buffalo-drawn comb harrow was equally effective in significantly reducing the fraction of N remaining in the floodwater and ρNH_3 (Fig. 9, 10). A pedestrian tractor without a harrow was as effective as the tractor with a comb harrow in incorporating urea. However, use of a pedestrian tractor with a conical puddler was significantly



9. Effect of method of incorporating urea on (urea + ammoniacal)-N in floodwater. Pila, Laguna, Philippines, 1988 DS.



10. Effect of method of incorporating urea on partial pressure of ammonia, Pila, Laguna, Philippines, 1988 DS.

more effective than the tractor with a comb harrow in reducing floodwater N after 1 d. A power weeder was comparable in effectiveness to a water buffalo-drawn comb harrow.

The passage of transplanters through the field slightly incorporated urea but not as effectively as any of the implements (Fig. 9, 10). The ρNH_3 measurements suggest that none of the tested implements would be completely effective in preventing NH_3 volatilization loss. Deep placement of urea with a liquid injector in the absence of standing water was more effective than any implement in reducing ρNH_3.

STRATEGIES TO INCREASE NITROGEN USE EFFICIENCY

Agronomy Department and International Fertilizer Development Center

Strategies for reducing the high gaseous losses of N from urea applied to lowland rice by Asian farmers include 1) amendment of urea with a urease inhibitor, 2) improved timing and incorporation of urea, 3) basal application of coated (slow-release) urea, and 4) deep placement of urea. In 1988 DS, field experiments were conducted in two provinces in the Philippines to compare these strategies with a conventional delayed split application of urea (2/3 broadcast into 5 cm floodwater at 11 DT and 1/3 broadcast at 5-7 DBPI). The urease inhibitor was N-(n-butyl) thiophosphoric triamide (NBPT), which in earlier research effectively suppressed the accumulation of ammoniacal N in floodwater following urea application. The coated urea was sulfur-coated urea (SCU) in granules approximately 2 mm in diameter with a 21% 7-d release rate in water. Deep placement of urea was with hand point-placed USG.

Amendment of urea with NBPT significantly increased plant N at maturity in Muñoz (Table 4) but not in Pila (Table 5). Nonetheless, grain yield was not significantly greater with NBPT at either site (Table 4, 5).

Basal incorporation of the initial urea application, as recommended to farmers, rather than delaying the first application of urea until 11 DT, significantly increased plant N and grain yield at both sites (Table 4,5). The basal application of urea presumably reduced gaseous N losses and promoted early seedling vigor and tillering. Amendment of urea, applied by the less effective delayed split with NBPT, was clearly inferior to basal incorporation of unamended urea.

Table 4. Effect of N fertilizer treatment on IR66 grain yield and total plant N at maturity. Muñoz, Nueva Ecija, Philippines, 1988 DS.

Treatment	Plant N[a] (kg/ha)	Grain yield[a] (t/ha)
Urea, delayed split[b]	84 c	6.3 b
Urea + NBPT[c]	91 b	6.5 b
Urea, recommended split[d]	97 a	7.1 a
Sulfur-coated urea (SCU)[e]	100 a	7.1 a
Urea supergranules (USG)[f]	102 a	7.1 a

[a]Each value is the mean of 4 nonzero N rates. Values followed by a common letter are not significantly different by LSD (0.05). [b]2/3 N at 11 d after transplanting (DT) and 1/3 N at 5-7 d before panicle initiation (DBPI). [c]2/3 N at 11 DT with 0.33 kg NBPT/ha and 1/3 N without NBPT at 5-7 DBPI. [d]2/3 N basal incorporated without standing water and 1/3 N at 5-7 DBPI. [e]All N as basal incorporated. [f]Deep-placed at 10-cm depth in the middle of 4 hills at 3 DT.

Table 5. Effect of N fertilizer treatment on IR66 grain yield. Pila, Laguna, Philippines, 1988 DS.

Treatment	Grain yield[a] (t/ha)			
	35 kg N/ha	70 kg N/ha	105 kg N/ha	140 kg N/ha
Urea, delayed split[b]	4.7 c	5.9 bc	6.5 c	7.4 ab
Urea + NBPT[c]	4.9 bc	5.6 c	7.0 bc	7.6 ab
Urea, recommended split[d]	5.3 ab	6.3 ab	7.4 ab	7.5 ab
SCU[e]	5.6 a	6.6 a	7.9 a	7.2 b
USG[f]	5.5 a	6.6 a	7.5 a	7.9 a

[a] In a column, values followed by a common letter are not significantly different by LSD (0.05). Grain yield for the no-N control was 3.9 t/ha. [b] 2/3 N at 11 d after transplanting (DT) and 1/3 N at 5-7 DBPI. [c] 2/3 N at 11 DT with 0.33 kg NBPT/ha and 1/3 N without NBPT at 5-7 DBPI. [d] 2/3 N as basal incorporated without standing water and 1/3 N at 5-7 DBPI. [e] All N as basal incorporated. [f] Deep-placed at 10-cm depth in the middle of 4 hills at 3 DT.

The slightly higher plant N and grain yields with SCU and USG than with the recommended split of urea were not statistically significant. The results illustrate the substantial increase in urea N use efficiency (kg grain/kg N applied) possible with a basal application that is thoroughly incorporated into the soil.

COATED UREA FERTILIZERS FOR LOWLAND RICE

Agronomy Department and International Fertilizer Development Center

SCU has long been recognized as an effective N fertilizer for rice. However, it is expensive, containing approximately 20% coating by weight. SCU has traditionally been evaluated only as an all basal application of solely coated fertilizer. Two strategies for reducing the cost of coated urea fertilizer are 1) use of alternative lighter weight coatings, and 2) combined use of coated urea with conventional PU.

One alternative lightweight coated urea product is reactive layer coated urea (RLCU) prepared by IFDC, with 3% polymer coating by weight of fertilizer. RLCU, either as an all basal application or combined with conventional PU, was compared with the widely evaluated SCU and recommended split for PU in a 1988 DS experiment at two sites.

RLCU in combination with PU appeared to be effective for reducing the quantity of N applied as the relatively more expensive coated urea. Basal application of two-thirds of the N as RLCU combined with one-third of the N as PU topdressed at 5-7 DBPI was as effective as an all-basal application of SCU and superior to the recommended split for urea at IRRI. The use of RLCU could be further reduced to only two-thirds of the basal N with no significant reduction in rice yield.

ALTERNATIVE TECHNOLOGY FOR INCREASING NITROGEN EFFICIENCY IN LOWLAND RICE

Agronomy Department

In evaluating alternative technology for increasing N use efficiency in lowland rice, the traditional variety Binato did not respond to added N. Without N, the modern variety IR29723-143-3-2-1 yielded higher than Binato by 0.2 t/ha in DS, and by 0.5 t/ha in wet season (WS).

In DS, N application increased IR29723-143-3-2-1 yield by at least 1.6 t/ha. At 58 kg N/ha, most improved methods and timing of N application produced yields similar to those with farmers' practice. Point placement of USG by press wedge gave yield inferior to that of other methods. At 87 kg N/ha, basal broadcast and incorporated SCU and researchers' split of PU gave significantly higher yield than did farmers' split.

In WS, hand point placement of USG at 29 kg N/ha in IR29723-143-3-2-1 gave a significantly higher yield than did farmers' split. Improved methods and timing of N application and farmers' split gave comparable grain yields. The yield with USG point placement by press wedge was inferior to that with hand point placement. At 58 kg N/ha, hand point placement of USG, point placement by press wedge, and band placement of PU by plunger/auger gave significantly higher yields than did farmers' split.

INTEGRATED NITROGEN MANAGEMENT IN LOWLAND RICE

Agronomy Department

We continued to evaluate supplementary N fertilizer sources in the 12th (DS) and 13th (WS) consecutive crops at IRRI and in a farmer's field in Victoria, Laguna (Table 6).

Table 6. Effect of supplementary N fertilizer source on IR66 grain yield at IRRI (field G-11) and in a farmer's field in Victoria, Laguna, Philippines, 1988 DS (12th crop) and WS (13th crop).

N source[a]	Grain yield (t/ha)		
	IRRI DS	Victoria DS	Victoria WS
No fertilizer N (control)	4.0 d	4.2 d	2.8 c
Single sources			
PU, best split	5.5 b	6.3 ab	3.4 b
USG	6.2 a	6.8 a	3.5 ab
Fresh azolla, soil incorporated	4.9 c	5.4 bc	3.6 ab
Fresh rice straw, soil incorporated	5.6 b	4.8 cd	3.5 ab
Rice straw compost, soil incorporated	4.6 c	4.4 d	3.4 b
Fresh sesbania, soil incorporated	5.6 b	–[c]	–[c]
Combined sources[b]			
Fresh azolla + PU, best split	5.8 ab	5.5 bc	3.5 ab
Fresh rice straw + PU, best split	5.6 b	6.1 ab	3.5 ab
Rice straw compost + PU, best split	5.5 b	5.8 b	3.6 ab
Fresh azolla + USG	5.6 b	6.7 a	3.4 b
Fresh rice straw + USG	6.0 ab	6.1 ab	3.6 ab
Rice straw compost + USG	5.6 b	6.2 ab	3.8 a
CV (%)	6.0	11.2	7.4

[a] All treatments were applied at equal N rates. For best split application, 2/3 urea was broadcast and incorporated (B&I) at planting + 1/3 topdressed at 5-7 DBPI. N was applied at 116 kg N/ha in DS and at 58 kg N/ha in WS. [b] For combined applications, 58 kg N/ha from each of organic and inorganic sources in DS and 29 kg N/ha from each of the sources in WS. [c] Not tested.

Grain yield. At both sites in DS, highest yields were obtained with USG. However, organic N sources applied alone also gave significantly higher yields than did the control. Fresh rice straw and sesbania at IRRI, and azolla in the farmer's field gave grain yields similar to that of PU alone.

Organic sources combined with PU or USG consistently produced better yields than did the control. Likewise, yields from combined applications were comparable to that with PU alone and, often, to that with USG.

In WS, crops at both sites were damaged by a typhoon. At IRRI, there were no significant yield differences among the treatments because of severe crop lodging that occurred at least 2 wk before harvest. In the farmer's field, however, treated plots gave comparable yields that were significantly higher than that of the control.

Soil analysis. Table 7 shows the soil chemical properties of the experimental sites after 10 consecutive croppings. In both soils, continuous application of fresh rice straw markedly increased exchangeable K. Likewise, continuously applying organic sources alone increased the percentages of organic C and of total N in most cases.

LIQUID CHEMICAL INJECTOR

Agricultural Engineering and Agronomy Departments

The improved liquid injector (Annual report for 1987) continued to show consistent results in 1988 tests (Table 8). Injection of the water-dissolved N gave higher N use efficiency by TPR than the researcher's split of 2/3-1/3 broadcast. Row seeding with N injection similarly gave higher agronomic efficiency than broadcast seeding and researcher's split.

NITROGEN UPTAKE PATTERN IN RICE

Agronomy Department and University of California at Davis

A study was initiated to explain 1) variations in N uptake pattern of rices with different maturities, 2) the relationship between N utilization and fertilizer N application, and 3) the distribution of soil N and fertilizer N during growth succession. During 1988, work concentrated on ^{15}N analysis.

Total, soil, and plant fertilizer nitrogen uptake pattern. The total N uptake of early- (100-109 d), medium- (110-119 d), and late- (≥ 120 d) maturing rices increased gradually from 30 to 40 DT, then accelerated rapidly until 70 DT. Thereafter, N uptake by early- and medium-maturing rices slowed down before it peaked until maturity. For late-maturing rices, N uptake gradually increased until maturity. The total and soil N uptake patterns were the same for both seasons, whereas N absorption from fertilizer by rice plants was generally low (Fig. 11). Fertilizer N absorption in DS was maximum at 60 DT. In WS, fertil-

Table 7. Soil analyses after the 10th cropping in the trial on supplementary N fertilizer source for rice. IRRI, and Victoria, Laguna, Philippines, 1987 WS.

N source[a]	IRRI						Victoria[b]					
	pH (1:1)	Organic C (%)	Total N (%)	Available P (Olsen, ppm)	Exchangeable K (meq/ 100 g)	Available Zn (ppm)	pH (1:1)	Organic C (%)	Total N (%)	Available P (Olsen, ppm)	Exchangeable K (meq/ 100 g)	Available Zn (ppm)
No fertilizer N (control)	6.6	1.94	0.184	40	1.26	1.3	6.6	2.77	0.267	11	0.409	1.9
Single sources												
PU, best split	6.7	1.85	0.176	34	1.07	1.5	6.7	2.77	0.262	7.3	0.381	1.6
USG	6.9	1.77	0.173	36	1.05	0.90	6.5	2.88	0.287	8.3	0.318	1.4
Fresh azolla, soil incorporated	6.7	2.07	0.186	41	1.36	1.1	6.5	2.86	0.273	11	0.568	1.5
Fresh rice straw, soil incorporated	6.3	2.52	0.229	46	2.06	2.0	6.5	3.52	0.318	46	1.37	2.0
Rice straw compost, soil incorporated	6.2	2.41	0.215	44	1.30	2.5	6.5	2.93	0.290	14	0.571	1.4
Fresh sesbania, soil incorporated[c]	6.5	2.12	0.199	40	1.37	1.7	–	–	–	–	–	–
Combined sources[d]												
Fresh azolla + PU, best split	6.9	1.84	0.173	36	1.18	0.88	6.6	2.90	0.281	10	0.433	1.7
Fresh rice straw + PU, best split	6.7	2.11	0.190	39	1.50	1.3	6.5	2.83	0.278	8.8	0.602	1.7
Rice straw compost + PU, best split	6.6	2.18	0.202	37	1.22	1.6	6.6	2.96	0.282	10	0.581	1.7
Fresh azolla + USG	6.9	2.01	0.196	35	1.16	0.88	6.5	2.80	0.256	7.8	0.382	1.9
Fresh rice straw + USG	6.5	2.50	0.213	38	1.57	1.6	6.5	2.94	0.282	14	0.991	2.5
Rice straw compost + USG	6.7	2.25	0.207	39	1.18	1.3	6.6	2.79	0.272	7.8	0.367	1.3

[a] All treatments were applied at equal N rates. For best split application, 2/3 urea was B&I at planting + 1/3 topdressed at 5-7 DBPI. N was applied at 116 kg N/ha in DS and 58 kg N/ha in WS. [b] Sesbania not used. [c] After 5 consecutive croppings (sesbania incorporation started in 1985 WS). [d] For combined applications, 58 kg N/ha in DS and 29 kg N/ha in WS from each of the organic and inorganic sources.

Table 8. Effect of seeding or planting method and method of fertilizer N application on IR64 grain yield and agronomic efficiency.[a] Muñoz, Nueva Ecija, Philippines, 1988 DS.

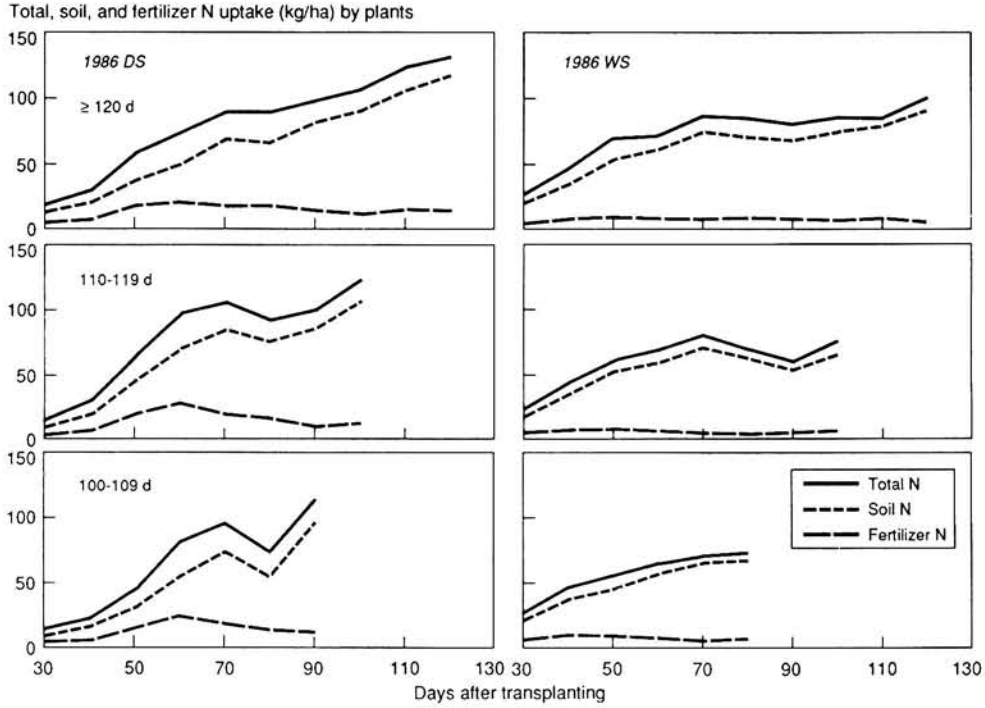
Treatment[b]	Grain yield (t/ha)	Agronomic efficiency (kg additional grain/ kg N applied)
Transplanted		
No fertilizer N	5.5	–
2/3 B&I + 1/3 broadcast at 5-7 DBPI (researcher's split)	8.8	38
1/3 injected at 14 DT + 2/3 injected at 5-7 DBPI	9.2	43
Broadcast seeded		
No fertilizer N	4.3	–
2/3 B&I at seeding + 1/3 broadcast at 5-7 DBPI (researcher's split)	8.0	43
Row seeded		
No fertilizer N	4.2	–
1/3 injected at 20 DAS + 2/3 injected at 5-7 DBPI	9.1	56
LSD (0.05)	0.4	

[a] Av of 4 replications. Total fertilizer rate was 120 kg N/ha. [b] B&I = basal, broadcast, and incorporated, DBPI = days before panicle initiation, DT = days after transplanting, DAS = days after seeding. "injected" = aqueous NH_3 applied with the liquid chemical injector.

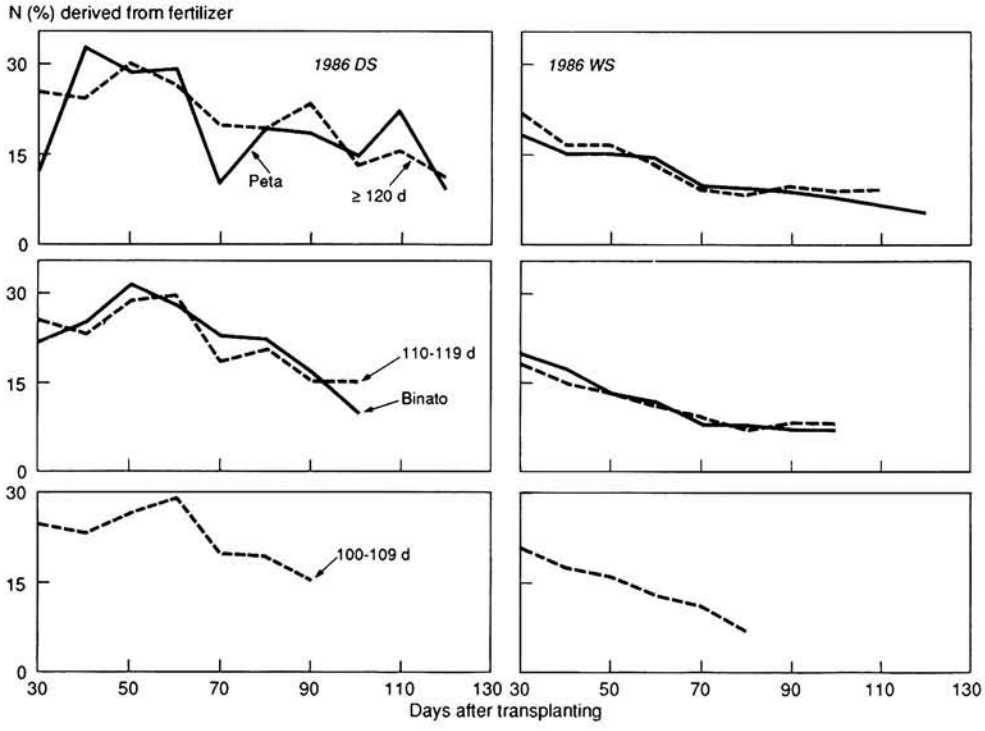
izer N absorption peaked at 50 DT for all growth durations.

Percent of nitrogen derived from fertilizer. The amount of N obtained by rice plants from applied fertilizer was high during the early rice growth stages and decreased with time as the plants reached maturity (Fig. 12). With 60 kg N/ha application in DS, the maximum percentage of N absorbed by rice from fertilizer was about 29% for rices of all growth durations. In WS with 30 kg N/ha applied, the percentage of N absorbed by rice plants was 20, 18, and 21 for early-, medium-, and late-maturing rices, respectively, at 30 DT.

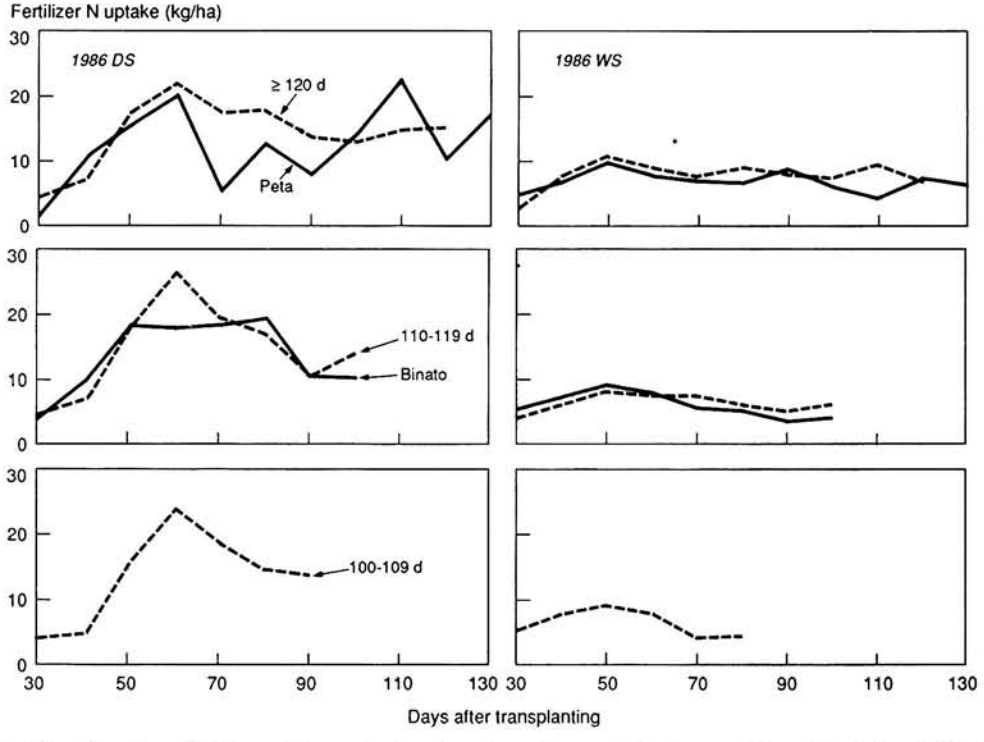
Fertilizer nitrogen use of traditional and modern rices. Peta (130 d) and Binato, both traditional varieties, were among the 33 varieties tested for their fertilizer N use. Peta had 2 accelerated periods of fertilizer N use: from 30 to 60 DT, and from 90 to 110 DT (Fig. 13). Fertilizer N use of Binato increased gradually from 30 to 50 DT, with a lag period from 50 to 80 DT. After 80 DT, it decreased until maturity. For modern rices grouped in 100-109, 110-119, and ≥120-d durations, the average fertilizer N use increased



11. Total, soil, and fertilizer N uptake by plants of rices of 3 growth durations (100-109, 110-119, and ≥120 d) at 10-d growth intervals. IRRI, 1986.



12. Overall percentage of N derived from fertilizer in modern rices of 3 growth durations, and in 2 traditional varieties. IRRI, 1986.



13. Fertilizer N uptake at 10-d growth intervals of modern rices of 3 growth durations, and 2 traditional rices. IRRI, 1986.

from 30 DT, then accelerated at a higher rate to peak at 60 DT in DS and at 50 DT in WS before decreasing. Generally, low fertilizer N use was observed in WS.

NITROGEN ABSORPTION PATTERN OF RICE PLANTS GROWN UNDER DIFFERENT CULTURAL CONDITIONS

Plant Physiology Department

The amount of N absorbed by rice plants in the tropics is a function of the number of days after transplanting. An exponential equation ($y = ab^x$) was observed in early growth stages (up to the maximum tiller number stage) and a linear one in the middle and late growth stages. The duration of the exponential phase was affected by cultural practices, temperature at tillering, and kind of fertilizer. Narrow spacing and high temperature shortened the exponential phase. Narrow spacing, high temperature, high mineralization rate of soil organic N, and high rate of basal N accelerated N absorption during the exponential phase. On the other hand, N absorption rate during the linear phase was not affected by basal N rate and spacing.

During the exponential phase, plants absorbed mainly basal N and rapidly decomposable soil organic N compounds. During the linear phase, plants absorbed slowly decomposable soil organic N compounds, particularly in nontopdressed plots (Table 9). This was due to the presence of NH_4-N (derived from basal N and rapidly decomposable N compounds) in the plow layer during the exponential phase. A varietal difference in N absorption was noted during this phase. During this period, narrow spacing and basal N increased absorption of soil N (mainly derived from rapidly decomposable soil organic N compounds).

The amount of soil N absorbed by plants was affected by the mineralization rate of soil organic N, which in turn was affected by the chemical characteristics of the soil and the soil conditions of the ricefield before planting. The mineralization rate of soil organic N was higher in dried than in wet soil and varied with the duration of the drying period (Table 10; Fig. 14, 15). The longer the drying period, the higher was the mineralization rate of soil organic N and the more N was absorbed by the plant. Drying effects were very apparent during the exponential phase and some portion of the linear phase.

Nitrogen absorption pattern as a function of cultural practices affected the yield-determining process. The potential sink was correlated with the amount of N in the plant at late spikelet initiation. However, the contribution of N in the plant at flowering to the potential sink varied

Table 9. Amount of N in plants from different origins. 1988.

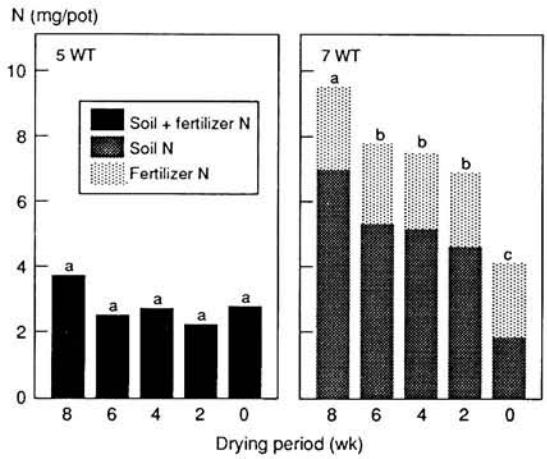
Field	Spacing (cm)	Amount (g/m²) of N in plants					
		5 wk after transplanting			Flowering		
		Basal N[a]	Soil N[b]		Basal N[a]	Soil N[b]	
			R	S		R	S
		1986 WS					
Block E	20 × 10	1.9	4.4	0.5	1.9	4.4	3.2
	20 × 20	1.7	3.8	0.4	1.8	3.8	3.1
	20 × 20[c]	–	3.2	0.3	–	3.2	3.1
Block M	20 × 10	1.8	3.9	0.4	1.8	3.9	2.5
	20 × 20	1.7	3.0	0.3	1.8	3.0	2.5
	20 × 20[c]	–	2.2	0.2	–	2.2	2.2
		1987 DS					
Block E	20 × 10	1.7	4.0	0.4	1.7	4.0	3.0
	20 × 20	1.5	2.5	0.3	1.7	2.5	3.2
	20 × 20[c]	–	2.0	0.2	–	2.0	3.1

[a]Determined by isotopic method. Amount of basal N = 6 g/m², no topdressing. [b]R = rapidly mineralizable soil N, S = slowly mineralizable soil N. [c]No nitrogen.

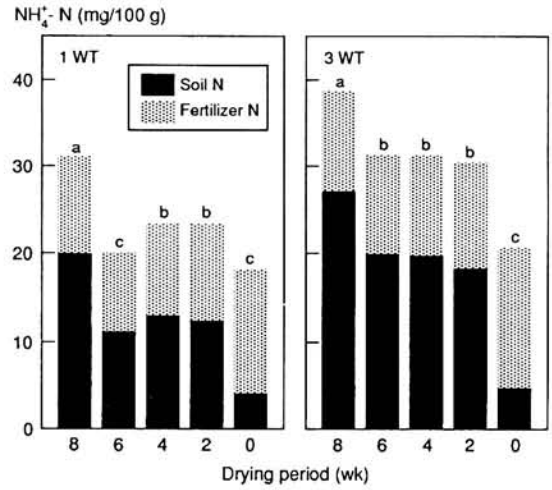
Table 10. Amount of mineralized N in soil in 2 plots, IRRI, 1988.[a]

Drying period (wk)	Mineralized N (mg/100 g)			
	1 WAI	2 WAI	4 WAI	8 WAI
	Block M			
8	7.68 b	11.72 b	10.56 bc	16.29
6	10.04 a	11.87 b	11.16 ab	17.84
4	10.88 a	14.64 a	13.77 a	18.62
2	4.55 c	7.19 c	8.44 c	14.96
0	3.73 c	1.79 d	3.93 c	5.47
	Block E			
8	24.32 a	25.87 a	23.66 a	26.90 a
6	15.01 b	15.67 b	21.82 a	25.12 a
4	13.84 b	16.05 b	18.62 a	20.44 a
2	13.99 b	15.84 b	16.68 a	22.74 a
0	4.65 c	3.00 c	4.00 b	6.39 b

[a]WAI = weeks after incubation.



14. Effect of drying period on N absorption. Block E, IRRI, 1988. Bars with the same letter are not significantly different at the 5% level by DMRT.



15. Effect of drying period on NH_4^+-N in soil. Block E, IRRI, 1988. Bars with the same letter are not significantly different at the 5% level by DMRT.

with spacing, as was observed only in the short-duration variety (Table 11). Narrow spacing increased the contribution of N to potential sink in the short-duration variety by increasing the duration of the vegetative lag phase, but not in the medium-long duration line in spite of an increase in the vegetative lag phase. In the short-duration variety, the panicle primordia initiation stage nearly coincided with the maximum tiller number stage; the panicle primordia initiation stage sometimes occurred before the maximum tiller number stage. Hence, a short-duration variety has a chance to increase N uptake from the panicle primordia initiation to the late spikelet initiation stage because of the duration of the vegetative lag phase. The contribution of N absorbed from panicle primordia initiation to late spikelet initiation was low compared with the N absorbed before the panicle primordia initiation stage. In the medium-long duration line, the panicle primordia initiation stage occurred much later than the maximum tiller number stage. Therefore, the amount of N uptake during the period from panicle primordia initiation to late spikelet initiation was not affected by the duration of the vegetative lag phase.

EFFECT OF SLOW-RELEASE FERTILIZER ON NITROGEN UPTAKE AND YIELD

Plant Physiology Department

Cultural practices have a limited capability to increase N absorption after the maximum tiller

Table 11. Effect of spacing and N level on the contribution to sink. IRRI, 1986 WS.

Variety	N level (g/m^2)	Spacing (cm)	Vegetative lag phase (d)	Contribution[a]	
				PS/N	S/N
IR64	6	20 X 10	10	100	76
		20 X 20	5	97	73
		20 X 30	−2	90	70
IR36892-163-1-2-2-1	6	20 X 10	31	117	76
		20 X 20	26	115	75
		20 X 30	20	115	78

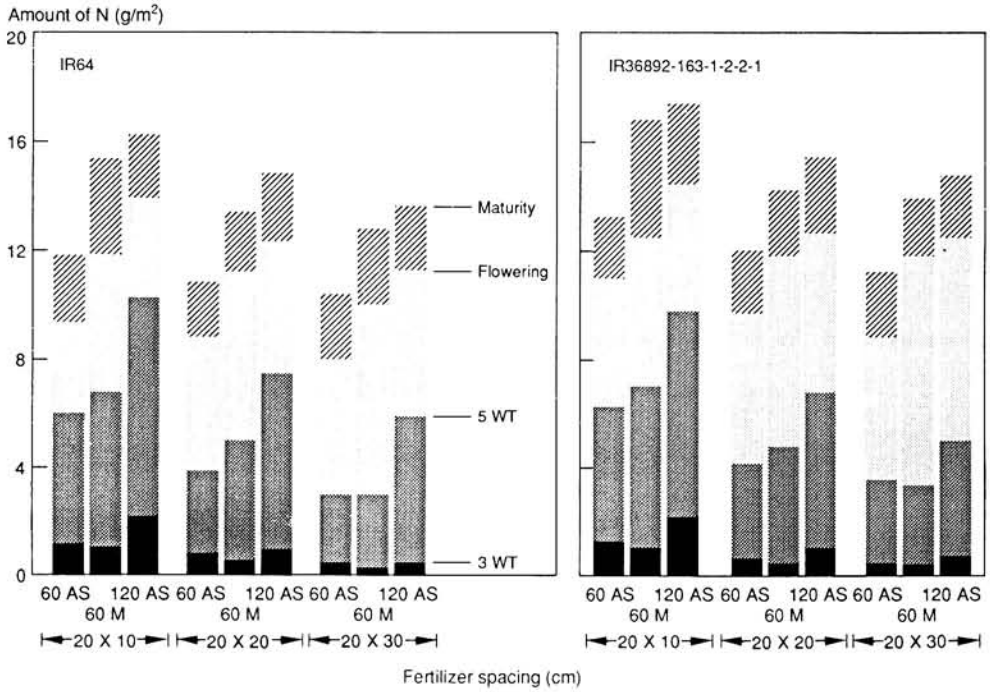
[a]PS = potential sink size, S = sink size, N = amount of N in plant at flowering.

number stage. During this period, deep placement of modified urea materials such as urea briquettes and USG increases fertilizer N efficiency in lowland rice. However, deep placement of fertilizer requires much labor. To save labor costs, a synthetic slow-release urea fertilizer (Meister) was developed. This fertilizer is coated with synthetic thermoplastic resins and surfactants that allow diffusion at a desired N release rate.

Field experiments were carried out from 1986 WS to 1988 DS at IRRI to study the effect of slow-release fertilizers on the N absorption pattern and yield of rice plants. Slow-release fertilizers varying in rate of N release (Meister 7, Meister 10, Meister 15, and Meister 20) were used, with ammonium sulfate (AS) as the control. Short- and medium-duration varieties were planted at three spacings and three N levels.

In all experimental plots, the amount of N in the plant increased exponentially ($y = ab^x$) up to the maximum tiller number stage and linearly ($y = a+bx$) thereafter. However, the amount of N in the plant at the start of the exponential phase was higher in AS plots than in Meister plots, particularly at wide spacing (Fig. 16). Likewise, recovery of basal N by plants at 5 wk after transplanting (WT) was higher in AS plots (Table 12). Absorption of basal N by plants was almost finished at 5 WT in AS plots. Plants grown in Meister plots, however, could absorb basal N during the linear phase; hence, the total percentage recovery of basal N was higher in Meister plots. Because the rate of N absorption was higher in Meister plots than in AS plots during the linear phase, total N in the plant was higher in Meister plots at flowering and maturity. At flowering and maturity, the amount of N in the plant grown in Meister plots was almost equivalent to a double dose of basal AS plots (Fig. 16).

The N absorption pattern of plants grown in Meister plots was also affected by plant density. Narrow spacing increased N absorption at early growth stages, and the effect of spacing on N absorption was much higher in Meister plots than in AS plots (Fig. 16). Generally, yield and sink size were higher in Meister plots than in AS plots, reflecting the amount of N in plants at



16. Amount of N in plants at different growth stages. IRRI, 1986 WS. AS = ammonium sulfate, M = Meister, WT = weeks after transplanting.

Table 12. Amount of plant N at different growth stages.[a] IRRI, 1987 WS.

Spacing (cm)	Fertilizer	Plant N (g/m²) at 5 WT			Recovery (%)	Plant N (g/m²) at flowering			Recovery (%)
		Total	Soil	Fertilizer		Total	Soil	Fertilizer	
20 × 10	$(NH_4)_2SO_4$	4.43	2.79	1.64	27.3	7.60	6.01	1.59	26.5
	Meister 15	4.51	2.99	1.52	25.3	8.91	6.35	2.56	42.7
20 × 20	$(NH_4)_2SO_4$	2.82	1.55	1.27	21.2	7.01	5.52	1.49	24.8
	Meister 15	2.34	1.25	1.09	18.2	8.04	5.78	2.26	37.7

[a]WT = weeks after transplanting.

flowering and maturity (Table 13). No difference in yield among Meister plots was observed, since the rate of N release was different. However, when the combination of a very short-duration variety and extremely slow-release fertilizer was used, the yield of Meister plots was almost equivalent to that of AS plots.

SOIL AND WATER AS SOURCES OF NITROGEN FOR DEEPWATER RICE

Agronomy Department and Department of Agriculture, Thailand

Differences in the N uptake of deepwater rice in field experiments at the Huntra Experiment Station and Prachinburi Rice Research Center, Thailand, were related to differences in soil acidity and fertility (on incubation, the Huntra soil released 4 times the N of Prachinburi soil), but there are also unknown contributions of floodwater N, derived from dissolved nutrients and algal N_2 fixation.

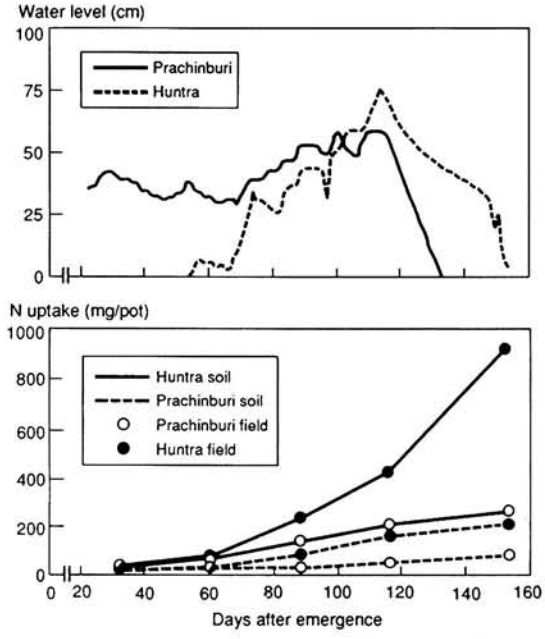
Pots containing 10 kg of soil from Prachinburi (acid sulfate, pH 4.0) and Huntra (pH 5.5) were sown with either RD19 or SPR'76 Com 3-5-2, with 6 plants/pot and 4 replications. One set was kept in a greenhouse and watered with tapwater (negligible N) throughout. A second set was transferred into a flooded field at Prachinburi when the floodwater was rising, and a third into a flooded field at Huntra. Plants were sampled for dry weight and N content at the beginning of flooding and at 4, 8, and 12 wk later. The last sample was taken as the water level started to recede.

Both varieties had almost identical dry weights, and N uptake was closely correlated with dry weight (r^2 >0.9). Uptake of N (Fig. 17) and dry weight production by plants in pots with soil from Huntra were much greater than those of plants grown in soil from Prachinburi. The N uptake of plants placed in the flooded field at Prachinburi was similar to that of plants in pots in the greenhouse, indicating no additional N

Table 13. Yield of plants grown under different fertilizers, 1988 DS.

Spacing (cm)	Fertilizer[a]	Sink (g/m²)	Yield (g/m²)
	IR58		
20 × 10	AS	688	641 def
	M7	835	772 a-d
	M10	804	736 a-e
	M20	685	639 def
20 × 20	AS	677	631 def
	M7	767	705 b-f
	M10	737	671 b-f
	M20	623	569 f
	IR66		
20 × 10	AS	742	695 b-f
	M7	872	817 ab
	M10	870	780 a-d
	M20	954	859 a
20 × 20	AS	710	659 c-f
	M7	744	688 b-f
	M10	809	735 a-e
	M20	870	805 ab
	IR36892-163-1-2-2-1		
20 × 10	AS	873	693 b-f
	M7	1073	797 a-c
	M10	1063	798 a-c
	M20	1121	781 a-d
20 × 20	AS	796	645 def
	M7	997	794 ac
	M10	972	763 a-d
	M20	1074	816 ab

[a]M = Meister. Each type is defined by the number of days required for releasing 80% of the N under field conditions at 20 °C. M7 = 70-d duration, M10 = 100-d duration, M15 = 150-d duration, M20 = 200-d duration.



17. Nitrogen uptake by deepwater rice plants grown in pots placed in flooded fields at Prachinburi and Huntra, Thailand, 1988 WS.

source in the floodwater at Prachinburi. However, dry weight and N uptake increased rapidly after plants were placed in the flooded field at Huntra, with final N uptake being 2.6 times (Prachinburi soil) to 3 times (Huntra soil) that of equivalent plants in the flooded field at Prachinburi. Plants in Prachinburi soil did not respond as much to the floodwater at Huntra as did the plants in pots with Huntra soil. The latter had more stems per pot at the start of flooding.

Preliminary measurements did not show differences in N content of the floodwater between sites, but at Huntra the soil may be releasing more N into the water, and algal populations are known to be higher. At Prachinburi, added N is necessary for good yields, but at Huntra yields are sustainable without N fertilizer.

Soil and crop management

Nitrogen fixation and azolla management

Soil Microbiology Department; National Agricultural Research Center, Japan; Office de la Recherche Scientifique et Technique Outre-Mer, France; Université Catholique de Louvain, Belgium; Washington State University, USA; and International Atomic Energy Agency

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BIOLOGICAL NITROGEN FIXATION

Soil Microbiology Department and National Agricultural Research Center, Japan

Evaluation of rice cultivar differences associated with nitrogen fixation, uptake, and utilization efficiency (*Soil Microbiology*). In 1987 dry season (DS), we measured the N_2 fixation (measured by acetylene-reducing activity [ARA] per plant) associated with the rice plant, the N uptake, and the N utilization efficiency (NUE = grain yield/N uptake) of 37 rice cultivars in a wetland field at IRRI without N fertilizer. There were significant ($p < 0.05$) cultivar differences in plant ARA, N uptake, and NUE, even among cultivars with similar growth durations (Table 1). Generally, cultivars having high ARA matured late and produced high biomass and N uptake, as shown by the significant ($p < 0.05$) positive correlations between ARA and number of days to heading, root dry weight and shoot dry weight at heading, total plant dry weight at maturity, and total N at maturity (Table 2). However, significant differences in ARA were found even among some cultivars with similar growth duration, biomass at heading, and N uptake, e.g., IR62 vs C662083; IR46R vs BR51-46-1-C1, suggesting the possibility of breeding rice for high N_2-fixing ability.

Table 1. Acetylene-reducing activity (ARA), N uptake, and N utilization efficiency of rice cultivars. IRRI, 1987 DS.

Variety or line	Days to heading	ARA (μmol/ 6 h per plant)	N uptake (mg/plant)	Grain yield/N uptake (g/g)
Pelita I-1	107	5.51 a	305 d-i	52.6 b-d
IR19672-140-2-3-2-2	87	4.97 ab	388 a-e	37.1 h-n
IR42	96	4.89 ab	311 d-i	29.3 n
IR46R	73	4.78 a-c	354 a-g	43.4 c-k
IR15323-78-1-3-1	103	4.77 a-c	369 a-f	29.3 n
IR29723-88-2-3-3	91	4.65 a-c	400 a-d	40.5 e-m
IR26	86	4.13 b-d	308 d-i	42.1 c-k
IR24638-238-3-2-1	87	4.10 b-d	356 a-g	50.9 b-e
IR13240-82-2-3-2-3-1	72	4.07 b-d	342 a-g	50.6 b-f
IR54752B	90	3.71 c-e	417 a-c	47.8 b-h
IR62	67	3.70 c-e	351 a-g	48.8 b-f
IR54752A-IR46R	73	3.66 c-f	423 ab	52.1 b-d
IR54	73	3.41 d-g	343 a-g	48.4 b-g
IR8192-200-3-3-1-1	72	3.40 d-g	331 b-h	50.2 b-f
IR18349-135-2-3-2-1	86	3.40 d-g	291 e-i	40.6 e-l
Suweon 290	80	3.22 d-h	357 a-g	46.3 b-i
IR13540-56-3-2-1	70	3.11 d-h	283 e-i	47.5 b-i
IR13429-150-3-2-1-2	67	3.10 d-h	341 a-g	65.2 a
IR18349-22-1-2-1-1	78	3.05 d-h	317 c-h	34.3 k-n
PR106	82	3.00 d-i	329 b-h	29.9 l-n
BR51-46-1-CI	74	2.96 d-i	356 a-g	45.8 b-j
C5444	65	2.95 d-i	211 i	16.7 o
IR54752A/IR54	73	2.90 d-i	322 b-h	55.3 bc
IR50	58	2.80 e-i	253 g-i	48.4 b-g
IR9729-67-3	58	2.78 e-i	300 d-i	48.3 b-g
IR18348-36-3-3	66	2.75 e-i	296 d-i	48.1 b-h
Pinulot 330	83	2.71 e-i	268 f-i	36.4 j-n
BG367-4	65	2.66 e-i	330 b-h	56.9 ab
CICA8	80	2.44 f-i	305 d-i	29.8 l-n
C5053	86	2.35 g-i	282 f-i	18.7 o
KN1B361-1-8-6-10	66	2.23 g-i	228 hi	33.0 k-n
Kulu	72	2.21 g-i	441 a	35.0 j-n
IR19735-2-3-2-1	60	2.19 g-i	279 f-i	41.3 e-l
IR9752-1-2-1	67	2.04 hi	290 e-i	39.5 f-n
IR8866-30-3-1-4-2	60	2.04 hi	263 f-i	37.6 g-n
IR8608-167-1-2	60	2.02 hi	309 d-i	41.5 d-k
C662083	69	1.78 i	294 d-i	43.7 c-k

Table 2. Correlations between ARA and plant characters (n = 37). IRRI, 1987 DS.

ARA vs	r
Days to heading	0.692**
Root dry weight at heading	0.843**
Shoot dry weight at heading	0.735**
Total plant dry weight at heading	0.809**
Total plant dry weight at maturity	0.617**
Total plant N at maturity	0.425**
Grain yield	0.266 ns
Grain yield/N at maturity	0.124 ns

Pelita I-1, IR19672-140-2-3-2-2, and IR42, which had consistently exhibited high ARA in previous trials, ranked high in ARA. But of these three, only IR19672-140-2-3-2-2 ranked high in N uptake. Among the short-duration cultivars (those that reached heading within 72 d after transplanting [DT]), IR62 and IR13429-150-3-2-1-2 ranked high on the basis of ARA, N uptake, and NUE. The high NUE of IR13429-150-3-2-1-2 has also been reported by the Agronomy Department. BG367-4 ranked high in both N uptake and NUE, but only medium in ARA. In contrast, C5444, which ranked lowest in N uptake and NUE, ranked high in ARA among the short-duration cultivars. The same result was observed in 1986 DS. C662083, which ranked lowest in ARA, ranked medium in N uptake and NUE.

Contribution of biologically fixed nitrogen to rice nitrogen nutrition (*Soil Microbiology and National Agricultural Research Center, Japan*). The N in a plant that originates from biologically fixed N has a lower ^{15}N content than that from soil. Soil was labeled with ^{15}N (substrate labeling); control soil was not labeled. In the latter case, a slight difference in ^{15}N in natural abundance between soil N and biologically fixed N was determined. IRRI soil was put in concrete pots 30 cm deep and in 10-liter Wagner pots. In concrete pots, ^{15}N-labeled $(NH_4)_2SO_4$ (20 atom % excess ^{15}N, 60 kg N/ha) was added. In Wagner pots, unlabeled N compound was added. After growing one rice crop under continuously flooded conditions, seven rice cultivars were grown. One rice crop was grown to stabilize ^{15}N labeling in the available soil N pool. The ^{15}N content (natural abundance) in the grain without labeled N was analyzed by the National Agricultural Research Center, Japan. Table 3 shows the differences in ^{15}N contents determined by both methods. The ranking correlation coefficient was 0.85, indicating good parallelism. IR42 was found to be lower in ^{15}N than the other cultivars, indicating a higher fraction of biologically fixed N. In ^{15}N-labeled pots, the second leaf sheaths were taken at 42 DT, heading, and harvest. The ^{15}N content of IR42 was always lower than that of IR50, showing that the ^{15}N labeling technique can be used to determine the contribution of biologically fixed N in rice N nutrition.

Table 3. ^{15}N abundance in rice grains by substrate labeling and natural abundance. IRRI, 1987 DS.

Variety or line	Growth duration (d)	^{15}N atom % excess	$\Delta\ ^{15}N$ value[a]
IR50	97	0.446 bc	9.9 c
IR9729-67-3	97	0.434 bc	9.1 b
IR19735-2-3-2-1	97	0.470 c	9.7 bc
IR13429-150-3-2-1-2	112	0.430 bc	9.1 b
IR18349-135-2-3-2-1	112	0.399 ab	9.0 ab
C662083	112	0.415 ab	9.5 bc
IR42	125	0.380 a	8.2 a
Standard error		0.017	0.3

[a] $\Delta^{15}N$ = [(^{15}N atom % of sample − ^{15}N atom % of standard)/^{15}N atom % of sample] × 1000.

Fixation by coculture of cellulolytic and diazotrophic microorganisms on rice straw (*Soil Microbiology*). Small-scale laboratory experiments with sterile straw were conducted to determine its potential as a C source for biological N_2 fixation (BNF) and to identify the efficient combination of cellulolytic and N_2-fixing microorganisms. Chopped or powdered straw (2.0 g) with N-free medium (enough to remain flooded) was sterilized in an erlenmeyer flask with cotton plug.

Strains of aerobic, cellulolytic fungus (*Trichoderma* obtained from the National Institutes of Biotechnology and Microbiology, University of the Philippines at Los Baños, and IRRI's Plant Pathology Department) and a microaerobic, cellulolytic bacterium (*Cellulomonas* sp. strain CS1-17, a mutant with enhanced cellulase production and ability to accumulate simple sugars in the medium, obtained from the University of New South Wales, Australia) were used for inoculation, either singly or together with the microaerobic, N_2-fixing *Azospirillum brasilense* Sp7 (ATCC 29145). Incubations were made in static conditions at 32 °C for 45 d. Initial and final dry weight and N content of the straw were determined.

Trichoderma *experiment.* The loss in straw weight and increase in N content differed significantly among nine species or strains of *Trichoderma* with *A. brasilense* and of *A. brasilense* alone (Table 4). *Trichoderma* strains *T. harzianum* and *T. viride* Pers Ex Fr., showing the highest N content (1.35 and 1.29%, respectively), also had high straw consumption (~25%). However, the efficiency of N gain (mg N/g straw lost) in these treatments was similar to that of *A. brasilense* alone, which had significantly lower N content.

Cellulomonas *experiment.* The percentage of N increased significantly in the CS1-17, Sp7, and CS1-17 + Sp7 treatments compared with the noninoculated treatments but was not different among the three inoculated treatments. The straw loss ranged from 17 to 21%. The highest N gain (mg/g straw lost) was obtained by the coculture (Table 5). *Cellulomonas* mutant CS1-17 alone had a positive N gain, but it did not show any nitrogenase activity (ARA). This strain may be an efficient scavenger of traces of NH_3 from the air.

Effect of surface-applied straw on microbiological aspects of a wetland rice soil (*Soil Microbiology*). The effects of straw application to the soil-floodwater surface before and after transplanting on the population of diverse bacteria (including phototrophic bacteria), microbial biomass, and N_2 fixation (ARA) were evaluated in a field experiment in 1986 DS at IRRI. Treatments were 1) control: no straw; 2) treatment 1: chopped (10-15 cm) rice straw (5 t/ha) surface applied in 3-5 cm floodwater 21 d before transplanting (DBT) and incorporated at 2 DBT; and 3) treatment 2: whole-length rice straw (5 t/ha) applied at 21 DT in parallel rows between rice hills with a water level of 3-5 cm. All treatments also received broadcast superphosphate at 6.6 kg P/ha before transplanting, 4.4 kg P/ha at 21 DT, and 30 kg N/ha as urea before transplanting. Two-week-old seedlings of IR29723-88-2-3-3 were transplanted after dipping in 2% ZnO suspension.

Table 4. N gain by coculture of *Trichoderma* strains and *Azospirillum brasilense* with straw incubated under aerobic conditions. IRRI, 1987 DS.

Treatment	Weight loss (%)	N (%)	N gain (mg/g straw lost)
Noninoculated	0.00	0.592	
Azospirillum brasilense Sp7	8.82	0.874	19.4
Trichoderma aureoviride-1 + Sp7	13.73	0.883	9.78
T. aureoviride-2 + Sp7	12.2	0.800	11.07
T. aureoviride-3 + Sp7	10.79	0.828	14.29
T. aureoviride-116 + Sp7	25.72	1.003	5.80
T. viride Pers Ex Fr. + Sp7	23.96	1.290	16.61
T. viride JF4 + Sp7	26.37	1.100	8.87
T. pseudokoningii + Sp7	15.07	0.789	7.89
T. harzianum + Sp7	25.37	1.354	18.18
T. harzianum-1 + Sp7	14.37	0.805	7.59
LSD (P = 0.05)	7.65	0.222	

Table 5. N gain by monoculture and coculture of *Cellulomonas* and *A. brasilense* with straw incubated under aerobic conditions. IRRI, 1987 DS.

Treatment	Weight loss (%)	N (%)	N gain (mg/g straw lost)
Noninoculated	0.0	0.60	
Cellulomonas (mutant CS1-17)	17.4	0.86	6.3
A. brasilense Sp7	20.6	0.97	8.5
CS1-17 + Sp7	21.1	1.03	10.1
LSD (P = 0.05)	3.7	0.11	6.6

Bacterial population and biomass in soil. Soil samples were collected at 0-2 and 2-10 cm depths using a core sampler. Bacterial groups were counted by the following methods: total aerobic heterotrophs by the spread plate technique with 0.1% tryptic soy agar, cellulolytic bacteria by the pour plate technique with 0.5% cellulose agar, spore-forming anaerobes by the roll tube technique with glucose anaerobic agar, N_2-fixing heterotrophs by the most probable number method with glucose, nitrifiers by the microplate technique, and phototrophic bacteria by the roll tube technique. The measurement of total bacterial biomass was made from soil smear slides by counting bacteria and determining their biovolume.

The average populations of heterotrophic, cellulolytic, anaerobic, and nitrifying bacteria were not significantly different among treatments with and without straw. However, the populations of N_2-fixing and phototrophic bacteria were significantly higher in soil under both straw treatments than in the control (Table 6). In general, the bacterial populations were not different between surface and subsurface soils. The total bacterial

Table 6. Viable counts of various physiological groups of bacteria in soil as affected by surface application of straw. IRRI, 1986 DS.

Treatment	Viable bacteria count (log_{10} CFU/g soil)[a]	
	N_2-fixing	Phototrophic
Surface soil (0-2 cm)		
Control	4.58	2.99
Straw treatment 1	5.15**	3.39**
Straw treatment 2	5.09**	3.37**
Subsurface soil (2-10 cm)		
Control	4.86	
Straw treatment 1	5.29**	
Straw treatment 2	5.04**	

[a] Av of 14 weekly measurements throughout the experiment. CFU = colony-forming units. ** = significantly different from control at the 1% level by the *t*-test.

Table 7. Bacterial biomass in wetland rice soil as affected by surface application of straw. IRRI, 1986 DS.

Treatment	Bacterial biomass (mg/100 g soil)[a]			
	Total	C	N	P
Surface soil (0-2 cm)				
Control	307	154	46	9.8
Straw treatment 1	423*	212	63	13.5
Straw treatment 2	315	158	47	10.1
Subsurface soil (2-10 cm)				
Control	214	107	32	6.8
Straw treatment 1	230	115	34	7.4
Straw treatment 2	145	73	22	4.6

[a] Av of 14 weekly measurements throughout the experiment. * = significantly higher than the control at the 5% level of significance by the *t*-test.

biomass and bacterial biomass C, N, and P were generally higher in surface soil than in subsurface soil. The effects of straw amendments were not marked, except that the bacterial biomasses in the surface soil were higher in treatment 1 than those in the control and treatment 2 (Table 7).

Association of phototrophic bacteria with rice rhizosphere and root. The rice rhizosphere harbored an appreciable number of phototrophic bacteria. The average populations of 10 measurements throughout the crop duration in 3 treatments ranged from 7×10^4 to 6×10^5 colony-forming units (CFU)/g dry weight in rhizosphere soil and 1×10^6 to 5×10^6 CFU/g dry weight in roots. Straw application increased the population significantly only in the rhizospheric soil of treatment 1 over the control. The explanation for the high population of phototrophic bacteria in association with rice roots where light is limiting, and the role(s) they play need further investigation.

Acetylene-reducing activity and population of heterotrophic and phototrophic bacteria associated with degrading straw. Enumerations of heterotrophic and phototrophic bacteria in association with degrading straw were made as described earlier. Incubations for ARA measurements were made in a growth cabinet with temperature of 30 °C, relative humidity 70%, and light (fluorescent and tungsten) irradiation of 20 klux. For heterotrophic ARA, flasks with straw were covered with black cloth.

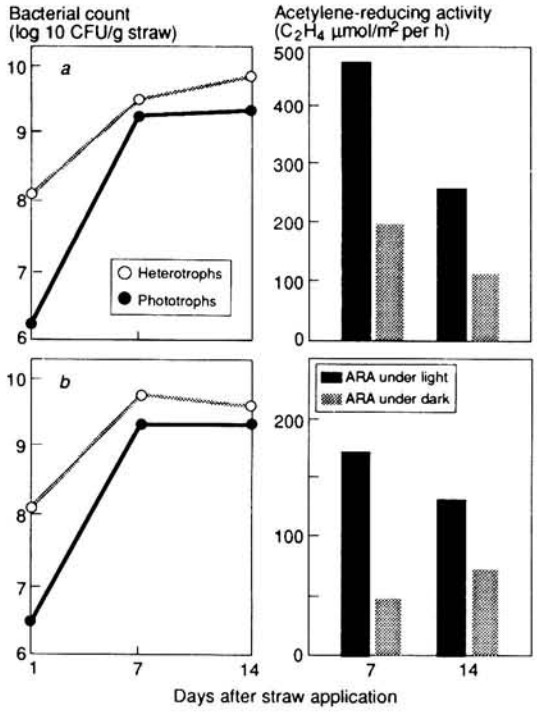
The heterotrophic bacterial count on sun-dried straw prior to application was 1.5×10^3 CFU/g and increased about sixfold at 1 d after straw application (DASA). Phototrophic bacteria were not found in dried straw at up to 10^{-2} dilution, but a very high population (1.2×10^6 CFU/g) was counted at 1 DASA. The populations of both groups of bacteria further increased several hundredfold at 7 DASA and remained at a high level at 14 DASA (Fig. 1). ARA associated with decomposing straw was higher under light than under dark conditions. It was also higher at 7 DASA than at 14 DASA. Treatment 1 exhibited higher ARA than did treatment 2 (Fig. 1). Whether such a high phototrophic ARA in association with the surface application of straw is due primarily to phototrophic bacteria or to blue-green algae (BGA) is not known. However, no visual BGA growth during the assay period was observed, which was also supported by the occurrence of significantly lower dissolved O_2 content of floodwater in plots with straw than in the control.

PHOTODEPENDENT BIOLOGICAL NITROGEN FIXATION AND PHOTOSYNTHETIC AQUATIC BIOMASS

Soil Microbiology Department and Office de la Recherche Scientifique et Technique Outre-Mer, France

Accuracy of field measurements on blue-green algae and photodependent biological nitrogen

fixation. The distribution pattern of organisms and their activities in the aquatic or terrestrial environment can be characterized by studying the correlation between means and variances of groups of replicated measurements. Distributions can be considered log-normal when the slope of the regression curve between mean and variance is close to the theoretical value of 2 (1.7-2.4).



1. Population of heterotrophic and phototrophic bacteria and acetylene-reducing activity (ARA) under light and dark conditions, associated with surface-applied straw treatment 1 (a) and treatment 2 (b). IRRI, 1986 DS.

Our studies of the correlation between means and variances of replicated field measurements of BGA populations (enumerations or biomass estimates) and photodependent ARA show that, in most cases, such variables approximate a log-normal pattern (Table 8). This distribution was observed for both 1) single-locus samples collected in the same plot, and 2) single-locus and composite samples collected in replicated plots. As an example, Figure 2 shows the correlation between means and variances of 442 replicated photodependent ARA measurements in 5 plots. The slope of the linear regression, close to 2, indicates a log-normal distribution.

In a log-normal distribution, the accuracy P of the mean of n measurements, defined as half of the confidence interval expressed as a fraction of the mean, is calculated as

$$P_e = \frac{1}{2}\left(10^{\frac{ts_y}{\sqrt{n}}} - 10^{-\frac{ts_y}{\sqrt{n}}}\right)$$

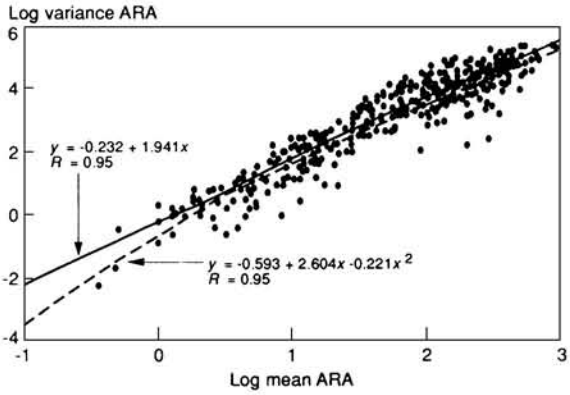
where t is the Student-Fischer statistic, n is the number of replications, and s_y is the standard deviation of the logarithms of the data.

Figure 3 is a graphic representation of this function for values of s_y ranging from 0.05 to 1.0. This graph can be used to forecast the accuracy of

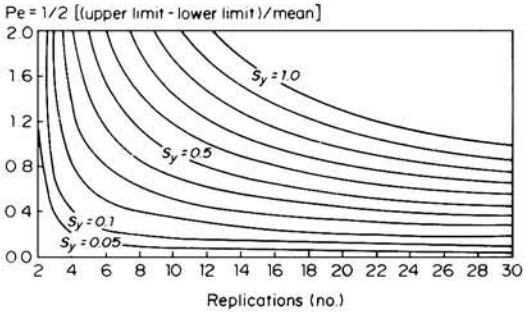
Table 8. Estimates of s_y values under various experimental conditions.

Variable	Groups of data (no.)	Replications (no.)	Subsamples[a] (no.)	Slope of the m/s² regression	s_y values			
					Min	Max	Median	SD
BGA number in 16-m² plots	36	4	10	1.9	0.04	0.90	**0.16**	0.22
BGA number in 16-m² plots	32	4	10	1.9	0.04	0.56	**0.12**	0.11
Algae number at 40 spots in a 0.25-ha ricefield	22	40	1	1.9	0.21	0.98	**0.46**	0.19
BGA biomass in 16-m² plots	67	4-5	16	1.5	0.06	0.89	**0.26**	0.17
ARA in 16-m² plots	28	10	5	2.0	0.19	1.08	**0.42**	0.26
ARA in 1-m² microplots	80	5	8	1.9	0.05	1.10	**0.25**	0.20
ARA in 16-m² plots	196	5	8	1.9	0.03	0.99	**0.29**	0.19
ARA in 16-m² plots	48	5	8	1.7	0.02	0.98	**0.38**	0.24
ARA in 16-m² plots	120	5	8	1.8	0.05	1.00	**0.44**	0.23
ARA in 16-m² plots	24	4	16	1.9	0.09	1.33	**0.43**	0.26
ARA at 35 spots in a 16-m² plot	2	35	1	–	0.47	0.63	**0.55**	–
Total	653				0.02	1.33	**0.32**	–

[a] Number of single-location samples combined in a composite sample.



2. Correlation between mean and variances of 442 groups of ARA measurements in 5 replicated 4- x 4-m plots. IRRI, 1988.



3. Accuracy of a mean of log-normally distributed data as a function of the number of replications (n) and the standard error of the logarithms of the data (s_y).

replicated measurements when n is known and s_y was estimated from previous measurements. It can also be used to determine the number of replications needed for a given accuracy or the number of subsamples needed for a given representativeness of a composite sample.

The large number of replicated field measurements on BGA populations and photodependent ARA that we performed during the last 4 yr allowed us to calculate a number of s_y values sufficient to draw general conclusions regarding the accuracy of such measurements and the limitations related to number of replications and subsamples.

The value of s_y varies with the variables measured, the methods of measurement, and the density of BGA populations. Table 8 summarizes 653 s_y values obtained under a wide range of conditions.

Number of replicated plots. When considering Figure 3 and s_y values from Table 8, one should not expect a high accuracy of averages of measurements on BGA in replicated plots. The median of 653 estimates of *Sy* is 0.317. The curve for $s_y = 0.3$ in Figure 3 indicates that, on the average, measurements in 10 replicated plots provide an accuracy of 0.5 (the confidence interval is equal to the mean).

However, rather than the accuracy of a mean, the major concern in field experiments is the number of replications needed to establish a significant difference between two means X_a and X_b. Assuming that $n_a = n_b$ and $s_{ya} = s_{yb}$, the ratio X_a/X_b required to establish a significant difference between X_a and X_b (P = 0.05) is given by

$$\frac{\overline{X}_a}{\overline{X}_b} = 10^{\sqrt{\frac{2s_y^2}{n}} \cdot t_{(2n-2)}}$$

where n is the number of replications, s_y^2 is the variance of transformed data, and $t_{(2n-2)}$ is the t value of the Student-Fischer statistic at (2n-2) degrees of freedom. Table 9 presents the calculation of X_a/X_b for $2 < n < 20$ and $0 < s_y^2 < 1$.

The values of X_a/X_b corresponding to the median value of s_y (0.3) (Table 9) show that, on the average, five replicated plots will permit us to find significant differences only between values whose ratio is about three. Ten replications would permit us to separate values whose ratio is two.

Field experiments on BGA usually have three or four replications, which is adequate for normally distributed data such as rice yield, but which might often be too low for studies of BGA biomass, photodependent ARA, or many other measurements of microbiological populations and activities.

Number of subsamples for a composite sample. The utilization of composite samples allows a marked decrease in the variability of the measurements within a plot. However, on the average (for $s_y = 0.3$), 10 core subsamples are needed for a representativeness of 0.5. A representativeness of 0.3 requires 26 cores, and a representativeness of 0.2 requires 55 (Fig. 3). These data show that, in most cases, the number of subsamples to be collected from a plot is determined by methodological limitations rather than a chosen accuracy.

Table 9. Values of the ratio of 2 means of n replicated measurements (X_a/X_b) that ensure that X_a is different from X_b at p = 0.05 for $2 < n < 20$ and $0 < s_y^2 < 1$.

Replicated measurements (no.)	Values of ratio at given s_y										
	0.22	0.32	0.45	0.55	0.63	0.71	0.77	0.84	0.89	0.95	1.00
2	9	23	84	227	527	----------> 1000----------					
3	3.2	5.2	10	17	27	40	57	79	106	141	185
4	2.4	3.5	5.9	8.9	12	17	22	28	35	44	54
5	2.1	2.9	4.5	6.3	8.4	11	13	17	20	24	29
6	1.94	2.6	3.8	5.1	6.5	8.1	10	12	14	17	19
7	1.82	2.3	3.3	4.3	5.5	6.7	8.0	9.4	11	13	15
8	1.74	2.2	3.0	3.9	4.8	5.7	6.8	7.9	9.1	10	12
9	1.67	2.1	2.8	3.5	4.3	5.1	5.9	6.9	7.8	8.9	10
10	1.62	1.98	2.6	3.3	3.9	4.6	5.3	6.1	6.9	7.8	8.7
11	1.58	1.91	2.5	3.1	3.7	4.3	4.9	5.5	6.2	7.0	7.8
12	1.55	1.85	2.4	2.9	3.4	4.0	4.5	5.1	5.7	6.4	7.0
13	1.52	1.80	2.3	2.8	3.3	3.7	4.2	4.8	5.3	5.9	6.5
14	1.49	1.76	2.2	2.7	3.1	3.5	4.0	4.5	5.0	5.5	6.0
15	1.47	1.72	2.2	2.6	3.0	3.4	3.8	4.2	4.7	5.1	5.6
16	1.45	1.69	2.1	2.5	2.9	3.2	3.6	4.0	4.4	4.8	5.3
17	1.43	1.66	2.1	2.4	2.8	3.1	3.5	3.8	4.2	4.6	5.0
18	1.42	1.64	2.0	2.3	2.7	3.0	3.3	3.7	4.0	4.4	4.7
19	1.40	1.61	1.97	2.3	2.6	2.9	3.2	3.5	3.9	4.2	4.5

As the coefficient of variation of 100% observed with the log-normal distribution of single-locus measurements rapidly decreases in composite sampling when the number of subsamples increases, the accuracy of the mean of measurements in replicated plots depends mainly on the number of plots. It does not improve much when the value of the accuracy of the measurements in each plot decreases beyond the value of the accuracy that can be expected from the number of replicated plots. Therefore, the determination of the optimal number of subsamples to be collected in a plot should take into account the accuracy or representativeness for the lower limit and the number of replicated plots for the upper limit.

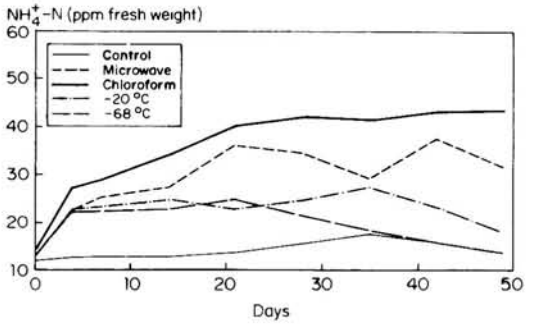
Contribution of the photosynthetic aquatic biomass to the microbial biomass in flooded soils. With regard to the recognition of the soil microbial biomass as the major source of nutrients for plants, especially available N, we initiated a study of the direct and indirect contribution of the photosynthetic aquatic biomass (PAB = algae and aquatic macrophytes) to soil microbial biomass.

Determination of microbial biomass in flooded soils. Methodological studies were conducted on the estimation of the soil microbial biomass by indirect methods that measure mineralization of N from microbial populations killed by physical or chemical treatments. The stable difference in mineralized N observed between an untreated control and a treated sample after a certain number of days is taken as an index of soil microbial biomass and is referred to as flush-N.

The comparison of 1) chloroform treatment for 20 h, 2) heating in a microwave oven at 2450 MHz at less than 80 °C for 4 periods of 1 min each, 3) freezing at -20 °C for 20 h, and 4) deep-freezing at -68 °C for 20 h—all followed by incubation under microaerobic conditions—showed that the highest and most regular release of mineralized N from the microbial biomass was obtained with chloroform treatment (Fig. 4). Long-term incubation of chloroform-treated soil showed that, whereas an incubation of 3 wk is usually considered sufficient to estimate flush-N in upland soils, an incubation of 4-5 wk might be necessary with wetland soils.

The study of the intraplot variability of flush-N within a 16-m^2 plot using 25 single-locus estimates showed a coefficient of variation of 18% in the 0-2 cm soil layer and 13% in the 2-7 cm soil layer. The higher variability in the upper soil layer was obviously due to the heterogeneous distribution of algae there.

Standardization trials with a bacterium (*Pseudo-*



4. Estimation of Maahas soil microbial biomass by different pretreatments and incubation under microaerophilic conditions. IRRI. 1988.

monas sp.) and three algae (*Aphanothece* sp., *Nostoc* sp., and *Mougeotia* sp.) showed recoveries of added N ranging from 40 to 80% in chloroform-treated soils (Table 10). In the case of the bacterium, which could survive after being incorporated into the soil, N recovery was doubled by chloroform treatment as compared with a non-treated control. With two of the algae, N recovery was better in nonfumigated soil. Photosynthetic organisms incorporated into the soil die, and their mineralization might be better in a nonfumigated soil than in a fumigated one because of the more numerous microflora in the former. The relatively low N recovery from *Nostoc* sp. was probably due to the ability of the strain to form a large number of spores resistant to mineralization.

Contribution of the photosynthetic aquatic biomass to soil microbial biomass. The contribution of PAB to soil microbial biomass was studied by comparing dark controls with various treatments exposed to light.

A greenhouse experiment was conducted in 0.25-m^2 microplots filled with about 4 cm unplanted Maahas soil (7.5 kg dry weight [dw]). A dark control was compared with plots exposed to light in which weeds and algae were reincorporated into the soil at 2- to 3-wk intervals. Each treatment had 10 replications.

After 1 yr, total N content in the soil exposed to light had increased by 47% in the first centimeter but had remained constant in the lower layer (Table 11). The increase was due to BNF. In the soil kept in the dark, N content decreased by about 11% in the first centimeter and 15% in the lower layer.

Mineralization of the microbial biomass after chloroform fumigation followed by 4 wk incubation caused release of 33 ppm NH_4^+-N on a fresh weight (fw) of soil basis (98 ppm on dw basis) in the first centimeter of soil, and 24 ppm NH_4^+-N on a fw basis (51 ppm NH_4^+-N on dw basis) in the lower layer of the soil exposed to light. About 13 ppm NH_4^+-N fw basis (30 ppm dw) was released in both layers of the soil kept in darkness. Nitrogen released by mineralization of the microbial biomass corresponded to 3-4% of the total N of soil exposed to light and about 2% of the total N of soil in darkness, showing that PAB was directly (by itself) and indirectly (through its nutrient inputs) accountable for about 40% of the soil microbial biomass in the 4-cm soil layer.

A field experiment during 1988 DS and WS studied the effect of weed incorporation, weed removal, and suppression of photosynthetic ac-

Table 10. Mineralized N from soil, and algae and bacteria added to the soil after 4 wk of incubation, with and without chloroform pretreatment.[a]

Treatment	Added N (ppm)	Nonfumigated		Fumigated	
		Total N mineralized (ppm)	% of added N mineralized	Total N mineralized (ppm)	% of added N mineralized
Soil 1	0	30	–	137	–
With *Aphanothece* sp.	250	279	99	332	78
With *Mougeotia* sp.	932	673	69	616	51
Soil 2	0	25	–	103	–
With *Pseudomonas* sp.	260	104	31	260	60
With *Nostoc* sp.	226	118	41	199	42

[a] Each value is the average of 2 replicated measurements. Average difference between replicated measurements is 8%.

tivity in the floodwater on soil microbial biomass estimated in ppm NH_4^+-N of fresh soil (flush-N) by the chloroform treatment method.

Table 11. Comparison of total N content and microbial biomass estimated by chloroform treatment and 4 wk of incubation in unplanted, continuously flooded, Maahas soil either exposed to light or kept in darkness for 1 yr. IRRI, 1988.

Parameter	Total N (% of soil dry weight)	Microbial biomass	
		ppm of soil dry weight	% of total soil N
Soil exposed to light			
Initial total N content	0.168 c		
1st cm	0.249 a	97.6 a	3.9 a
Deeper soil	0.168 c	51.3 b	3.0 b
Soil kept in darkness			
Initial total N content	0.180 b		
1st cm	0.161 c	30.4 c	1.9 c
Deeper soil	0.151 c	27.7 c	1.8 c

The study was conducted in 65 plots 4 x 4 m in size (10 replications) receiving combinations of 2 treatments: urea (none, 55 kg N/ha split broadcast, 55 kg N/ha deep-placed), and weed management (weeds removed, or incorporated at 31 and 52 DT). In each of the plots, a metallic frame 1 x 1 m in size was inserted and covered with a layer of black cloth inserted between two pieces of polystyrene foam. The cover had holes to allow rice plant growth.

A higher flush-N generally appeared in the upper soil layer. After a peak at the beginning of the crop, flush-N in the upper soil layer remained more or less constant; in the lower layer, it continuously decreased during crop growth (Table 12).

Nitrogen fertilizer had little effect on flush-N except at the beginning of the crop (27 DT, 1988 DS), when urea broadcasting (N_s) and high light availability allowed the blooming of unicellular green algae and increased flush-N by about 15%

Table 12. Effect of management of the photosynthetic aquatic biomass and N fertilizer on soil microbial biomass in the first 7 cm of soil, estimated by chloroform treatment.[a] 1988 DS and WS.

Time[b] (DT)	Soil depth	Photosynthetic biomass management				N fertilizer management[c]			
		Weeds incorporated	Weeds removed	Dark	Analysis of variance	N_0	N_s	N_d	Analysis of variance
				1988 dry season					
27	0-2 cm (ppm)	47.7	47.7	37.5	**	43.0	48.7	41.2	ns
(before weeding)	2-7 cm (ppm)	41.8	41.8	28.1	**	35.7	41.1	35.0	ns
	0-7 cm (kg/ha)	44.2	44.2	30.3	**	38.1	43.6	37.0	ns
48	0-2 cm (ppm)	34.3	34.9	28.6	ns	30.3	34.6	33.0	ns
	2-7 cm (ppm)	31.3	28.9	29.6	ns	29.9	31.5	28.4	ns
	0-7 cm (kg/ha)	32.7	31.1	29.0	ns	30.3	32.7	29.9	ns
76	0-2 cm (ppm)	36.2	34.5	23.6	*	32.3	34.5	27.4	ns
	2-7 cm (ppm)	28.2	27.8	26.9	ns	29.5	28.6	24.7	ns
	0-7 cm (kg/ha)	30.9	30.1	25.8	*	30.6	30.5	25.7	**
91	0-2 cm (ppm)	36.4	39.9	25.3	**	34.3	32.5	34.8	ns
	2-7 cm (ppm)	26.5	26.2	25.9	ns	27.2	26.9	24.6	ns
	0-7 cm (kg/ha)	29.7	30.4	25.5	**	29.4	28.6	27.6	ns
				1988 wet season					
2[d]	0-7 cm (ppm)	37.9	37.1	32.9	**	34.4	35.6	37.9	ns
	0-7 cm (kg/ha)	38.7	37.8	33.6	**	35.1	36.3	38.7	ns
92	0-2 cm (ppm)	40.4	33.9	25.4	**	32.9	33.6	33.3	ns
	2-7 cm (ppm)	32.7	29.7	28.1	*	31.2	29.9	29.4	ns
	0-7 cm (kg/ha)	32.8	29.8	27.1	*	30.7	30.1	29.0	ns
Av	0-7 cm (ppm)	35.2	34.2	28.2	**	32.5	33.9	31.2	**

[a] Data are expressed in ppm NH_4^+-N of fresh soil and extrapolated in kg N/ha. Each value is the average of 2 measurements on a composite sample of 20 cores collected in 10 replicated plots. [b] DT = days after transplanting. [c] N_0 = control without N, N_s = 55 kg N/ha broadcast split, N_d = 55 kg N deep-placed. [d] 2 d before transplanting.

over the control and the treatment where urea was deep-placed. During the first crop and at the end of the second crop, flush-N was lowest for deep placement, corresponding to highest yield and highest N removal from the soil, but the difference was generally not statistically significant.

During the first crop (1988 DS), flush-N values in the upper soil layer of the dark control were consistently significantly lower than in the soils exposed to light. Values were consistently lower in plots where weeds were removed than in plots where they were incorporated, but the difference was not statistically significant.

At the end of the second crop a significant effect of weed removal and elimination of light was observed. Flush-N was about 22% lower in the dark control than in the treatment where weeds were incorporated.

These results need to be confirmed on a longer term basis but already show that PAB constitutes a major component and source of nutrients for the microbial biomass in the upper soil layer and a significant source of nutrients for the microbial biomass in deeper soil.

AZOLLA

Soil Microbiology Department; Université Catholique de Louvain, Belgium; Washington State University, USA; and International Atomic Energy Agency

Azolla collection and distribution (*Soil Microbiology and Université Catholique de Louvain, Belgium*). The number of azolla accessions at IRRI increased to 410 (Table 13). New accessions (38) were added from Paraguay and the University of the Philippines. Morphological, biochemical, and physiological tests revealed misclassification of some accessions, and their accession numbers were changed.

In response to requests, 465 accessions were sent to 39 people from 7 countries. *A. microphylla* and *A. pinnata* var. *pinnata* were most requested.

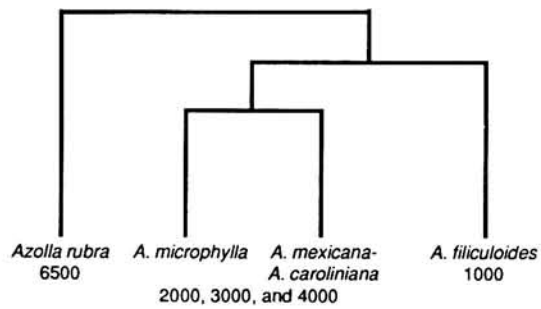
Azolla in Paraguay (*Soil Microbiology and Washington State University, USA*). Because the promising strain 4018 came from Paraguay, a trip to Paraguay was made to collect field populations. A total of 14 accessions were gathered. All of them were kept at Washington State University,

Table 13. Azolla collection at IRRI at the end of 1988.

Species	Accessions (no.)			
	Total	Anabaena-free	Hybrids	
			Sexual	Algal
A. pinnata var. *imbricata*	125	1	0	0
A. filiculoides	70	7	0	4
A. mexicana	25	0	2	0
A. caroliniana	58	1	0	0
A. microphylla	80	4	9	19
A. nilotica	2	0	0	0
A. rubra	7	0	0	0
A. pinnata var. *pinnata*	42	1	0	0
Unclassified	1	0	0	0
Total	410	13	11	23

then transferred to IRRI. There are at least two kinds of azolla in Paraguay: green and red. The green azolla was found 390 km north of Asuncion along the Trans Chaco Route (#4066-4072) and was morphologically similar to #4018. Soils in this area are solonets (annual rainfall 400-600 mm). Red azolla was distributed up to 250 km north from Asuncion along the Trans Chaco Route, and east and southeast of Asuncion (#4062-4065, 4073-4075). Examination of fertile plants (#4067 and 4075) showed that both belonged to *A. microphylla*.

Biochemical classification (*Soil Microbiology and Washington State University, USA*). *Azolla* section strains were classified by the standardized method of polyacrylamide gel electrophoresis for isoenzymes. Thirteen enzymes were used, three of which appeared to be monomorphic. Cluster analysis revealed the phenogram shown in Figure 5. *A. filiculoides* and *A. rubra* were clearly sepa-



5. Dendrograms of azolla species by electrophoresis pattern of enzymes, IRRI, 1988. The numbers are accession numbers.

rated, but "*A. japonica*" was not discernible from the European *A. filiculoides* in zymogram pattern and in the distinctly protuberant single-cell leaf trichome. *A. filiculoides* was separated from three other species—*A. caroliniana*, *A. mexicana*, and *A. microphylla*—which were phenotypically similar. Some azolla accessions from Colombia, misplaced in the 1000 series, were distinct from *A. filiculoides*.

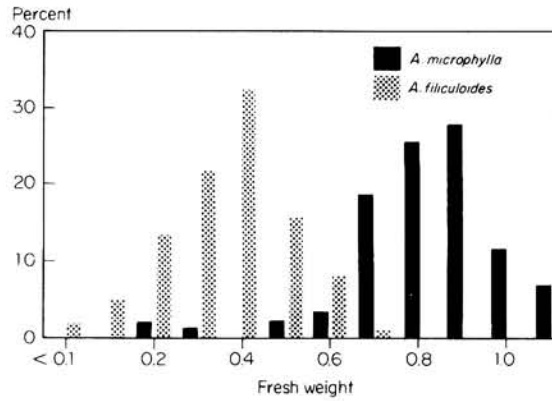
Isozyme patterns of shikimate dehydrogenase were examined for *A. microphylla* accessions. There are eight kinds of bands in zymograms. Some accessions (#4060, 4061, 4081, and 4510—ADEC pattern) taken from field populations at IRRI and in Koronadal, South Cotabato, Philippines, are supposed to be distributed from IRRI as #4018. But their isozyme pattern is different from that of the #4018 kept in the phytotron and from those originating from the Fujian Academy of Agricultural Science (ABC pattern). It appears that mislabeling occurred during maintenance or distribution. Azolla accessions from the Galapagos Islands (BF bands) are discernible from those from Paraguay. Zymograms of two kinds of azolla from Paraguay—red and green—are not distinctly different. Zymograms of F_1 populations are different from those of parents, suggesting that vegetatively growing populations are heterozygous or from a genetically heterogeneous population. It was found, therefore, that zymogram patterns are useful for identifying accessions.

Response to temperature (*Soil Microbiology*). A rapid screening method was developed to find the tolerance of azolla for high temperatures. Azolla grown in water culture was exposed to gradually increasing temperatures in a growth cabinet: 1 d at 28 °C (32/24 °C day/night); 2 d each at 30, 32, 34, and 36 °C; and 5 d at 38 °C before final harvest. Fresh weight of the final harvest was measured. Surface coverage, necrosis, color, and fragmentation were measured by semiquantitative rating at the end of exposure at each temperature level. Ten sets of experiments employed 384 accessions.

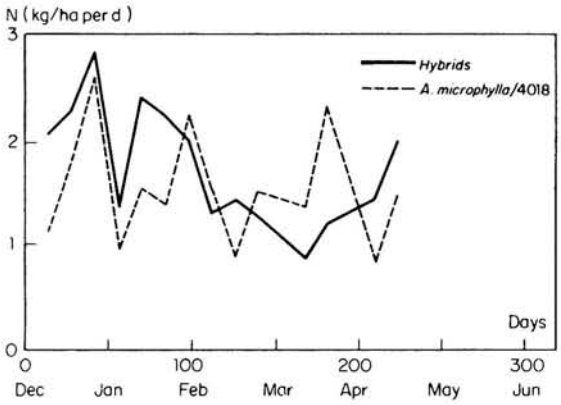
The Colombia azolla accessions that were misclassified as *A. filiculoides* had tolerance similar to that of the *A. microphylla* group. No distinction was possible among *A. microphylla*, *A. mexicana*, and *A. caroliniana*. Tolerance for high temperature coincided with morphological and biochemical classification. Tolerant species are *A. microphylla*, *A. mexicana* and *A. caroliniana*; intermediate ones are *A. pinnata* var. *imbricata* and *A. pinnata* var. *pinnata*; and sensitive ones are *A. filiculoides*, *A. rubra*, and *A. nilotica* (Fig. 6). There were differences within a species. Hybrid azolla strains (#4028 and 4030) were more tolerant than parent azolla. Brazilian *A. filiculoides* strains were more tolerant than European ones.

Growth of hybrids in the field (*Soil Microbiology*). Hybrid azolla (#4028 and 4030) were grown in a field at IRRI. The growth and N_2 fixation of hybrids between *A. filiculoides* and *A. microphylla* in IRRI fields were better in the cooler season (December-March) than that of parent *A. microphylla*, but the opposite was true in the hotter season (April-May) (Fig. 7). Concentration of N was always higher in hybrids (average 3.8%) than in *A. microphylla* 4018 (average 2.9%).

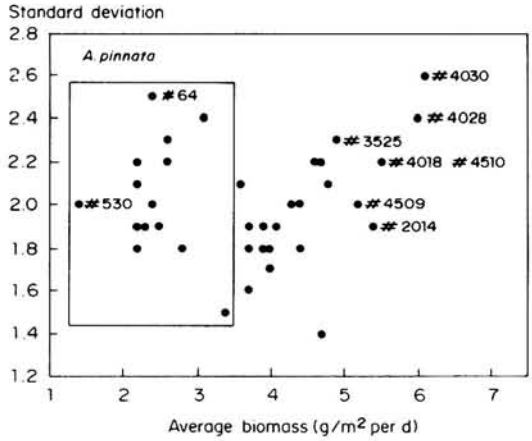
Growth of various strains in the field (*Soil Microbiology and Université Catholique de Louvain, Belgium*). After preliminary screening in the greenhouse, 39 azolla strains were grown in an IRRI field from 4 Jul 1987 to 24 Jul 1988. They were inoculated every week at 1 kg/m² in a 0.5-m² floating basket. After draining the basket, its weight was measured to estimate the fresh weight of azolla with little disturbance. From samples, dry weight and N concentrations were determined. The average daily dry biomass production and its standard deviation among different harvests were plotted (Fig. 8). *A. microphylla* hybrids produced the high-



6. Distribution of fresh weight in *A. microphylla* and *A. filiculoides* at the end of exposure at 38 °C. IRRI, 1988.



7. Nitrogen production of azolla hybrids (av of #4028 and 4030) and *A. microphylla* (av of 2 strains of 4018) in an IRRI field, 1988.



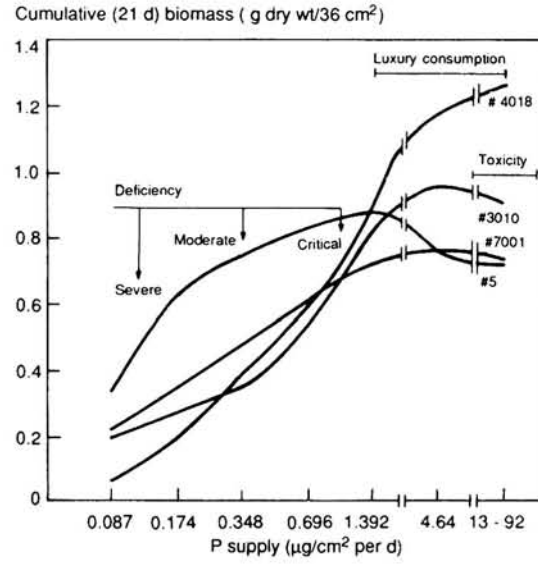
8. Average biomass production (g dry weight/m² per d) vs standard deviation among weekly harvests throughout the year. IRRI, 1988. Figures are accession numbers. Points in box are from *A. pinnata*.

est biomass, followed by *A. microphylla* #4018 and #4510. *A. pinnata* produced less biomass than *A. microphylla*. Similar experiments in Richard Toll, Senegal, on the other hand, showed better growth of *A. pinnata* than of *A. microphylla*. Correlation analysis of biomass production with some climatic parameters revealed positive correlation with the difference in day and night temperature and a negative correlation with evapotranspiration.

Ability to grow in phosphorus-deficient conditions (*Soil Microbiology*). *Phosphorus deficiency symptoms*. Useful characteristics for identifying azolla accessions in P-deficient water culture are the reddening of the periphery of the plant (new fronds), entire parts of plant fronds, and the periphery of the ventral lobes; browning or dark browning of the fronds at the basal portion; and curling or elongation of roots. These characteristics were found in plants grown in both the greenhouse and the phytotron. Among green *A. microphylla*, there are two distinct groups. One group has spreading dark browning of fronds at the base of the rhizome, represented by #4510 (SKDH zymogram ADEC type). Another group has light brown color only at the base, represented by #4018 (SKDH zymogram ABC type). Because *A. microphylla* accessions represented by #4510 were often misnamed as #4018, the symptoms of P deficiency can be used to identify these two groups.

Symptoms of P deficiency in water culture are useful for identifying accessions, but not species.

Growth in water culture. To find the differences in ability to grow and fix N in P-deficient conditions, azolla strains were grown in water culture with varying P supply rates in the greenhouse. The biomass production until 21 d is shown in Figure 9. The P concentration after 21 d of growth decreased as the P supply decreased, but N concentration decreased only at a P supply lower than



9. Growth pattern of 4 azolla species due to increasing P supply. IRRI, 1988.

13.9 mg P/m² per d, indicating that a P supply higher than this was used for luxury consumption. In P-deficient conditions, *A. pinnata* #5 and #7001 grew more than *A. microphylla* #4018 and *A. mexicana* #3010. At sufficient P level, the opposite was the case. Despite the higher production of *A. pinnata* in P-deficient conditions, their P concentrations (0.062% at 1.74 mg P/m² per d) were higher than those of #4018 and #3010 (0.082-0.095). Although the N concentrations of *A. pinnata* were lower than those of the 2 others, the amount of N fixed by *A. pinnata* strains during 19-21 d was higher because of higher biomass production. This finding clearly shows that *A. pinnata* strains are more tolerant of P deficiency than Euazolla strains.

Inoculation of P-enriched azolla and P-starved azolla into P-limited water culture gave the identical ranking in growth. Because P-starved azolla was often fragile, the inoculation of P-enriched azolla was suitable for screening azolla tolerant of P deficiency. Among *A. microphylla* strains tested, none produced more biomass than *A. pinnata* strains (#5 and #7001). With continuous supply of P to keep approximately 0.02-0.06 ppm P in 60 liters water culture (concentration limited condition), *A. pinnata* #5 and #7001 gave higher biomass production in steady state condition (P uptake and growth were in equilibrium) than #4018 and #3010.

The screening method for the ability to grow in P-deficient conditions was standardized. Azolla grown in P-containing medium is inoculated into a low-P medium, renewed every 3 d. The P concentration is adjusted to give 1.74 mg P/m² (area of azolla growth) per d. Every week, half of the biomass is harvested. The plant is grown for 21 d. If P deficiency symptoms do not appear within this period, the growth period is extended. Preliminary study showed that hybrid azolla grew better in P-deficient conditions than did parent azolla.

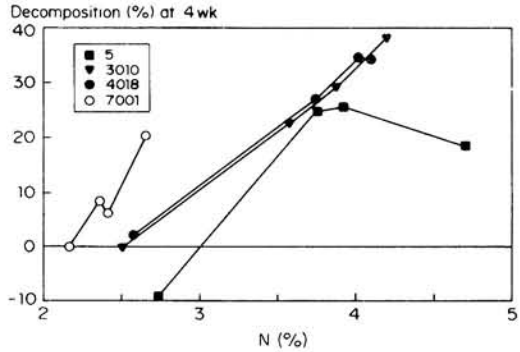
Growth in the field. Phosphorus-enriched azolla was grown in an IRRI field without P application. Every week, the biomass and its N and P concentrations were determined until 28 d after inoculation (Table 14). When P concentrations were high, *A. microphylla* #4018 accumulated more N than the others. When the plant became P deficient (P concentration < 0.2%), *A. pinnata* #7001 accumulated more N than the others. *A. pinnata* var. *imbricata* did not show better growth in P-deficient conditions than in P-enriched conditions.

Table 14. Daily N accumulation of azolla as affected by P concentration, IRRI field, Jan-Feb 1988.

Day	Species and accession no.	N accumulation (kg N/ha per d)	Average P (%)[a]
7	*A. pinnata* #5	0.91	0.425
7	*A. pinnata* #7001	0.76	0.224
7	*A. mexicana* #3010	0.82	0.420
7	*A. microphylla* #4018	1.94	0.445
9	*A. pinnata* #5	1.42	0.211
9	*A. pinnata* #7001	0.70	0.159
9	*A. mexicana* #3010	1.36	0.205
9	*A. microphylla* #4018	2.28	0.194
12	*A. pinnata* #5	2.00	0.177
12	*A. pinnata* #7001	1.03	0.127
12	*A. mexicana* #3010	1.31	0.188
12	*A. microphylla* #4018	1.88	0.173
24	*A. pinnata* #5	0.35	0.130
24	*A. pinnata* #7001	1.22	0.099
24	*A. mexicana* #3010	0.65	0.153
24	*A. microphylla* #4018	0.95	0.147

[a] Av of current and previous samplings.

Decomposition of azolla and availability of nitrogen to rice (*Soil Microbiology and International Atomic Energy Agency*). *Decomposability of azolla as affected by nitrogen concentration (Soil Microbiology).* Samples of four azolla strains as shown in Figure 10 taken at different days during growth in the field were incubated in the labora-



10. Mineralization of azolla under flooded conditions, by N content, IRRI, 1988. 5 = *A. pinnata* var. *imbricata*, 7001 = *A. pinnata* var. *pinnata*, 3010 = *A. mexicana*, 4018 = *A. microphylla*.

Table 15. Yields and fertilizer N recoveries from urea and azolla N in isotope plots. IRRI, 1987.

	N source	N level (% N)	Yield (t/ha)		N (kg/ha)		N recovery (%)	
			Grain	Straw	Absorbed	Applied	Difference	Isotope
1	0 N		4.1	3.0	75.4	0	–	–
2	Urea		6.0	5.0	111	51.5	69	35
3	*A. microphylla* 418	High (3.55)	5.2	4.3	101	46.9	55	23
4	*A. microphylla* 418	Low (2.42)	4.8	3.7	89.3	48.0	29	15
5	*A. pinnata* 5	High (3.15)	5.0	3.4	90.6	46.5	33	24
6	*A. pinnata* 5	Low (2.43)	5.4	4.4	108.3	53.1	59	25
7	*A. pinnata* var. *pinnata*	High (2.15)	4.9	3.5	88.8	46.2	29	19
8	*A. pinnata* var. *pinnata*	Low (1.82)	5.3	4.0	97.7	49.4	45	13
9	*A. caroliniana* 301	High (3.25)	4.8	3.9	91.4	48.3	33	23
10	*A. caroliniana* 301	Low (2.03)	4.7	3.7	87.1	53.2	22	18
	SE		0.2	0.3	7.2		16	2

tory for measuring N mineralization. Mineralization rates (mineralized N/total N in azolla) at 4 wk incubation were plotted against N concentration of azolla (Fig. 10). Decomposability decreased as N concentration decreased. The correlation coefficient of mineralization rate with N concentration was 0.86, that with acid detergent fiber concentration, -0.64, and that with acid insoluble lignin concentration, -0.43.

Utilization of azolla nitrogen by rice (Soil Microbiology and International Atomic Energy Agency). Four azolla species were grown with ^{15}N-labeled $(NH_4)_2SO_4$ in P-rich and -deficient conditions to make ^{15}N-labeled azolla high and low in N content, because azolla higher in P has higher N content. Azolla materials were incorporated before transplanting rice in 1-m^2 microplots. The ^{15}N contents of azolla and of rice at rice harvest are shown in Table 15. Despite a wide variation in N content ranging from 1.8 to 3.6%, azolla N was effectively used by rice. The correlation coefficient of N% with ^{15}N recovery by rice plants was significant ($r = 0.73$, $p > 0.04$). But azolla species with similar N contents showed different N recoveries. In each azolla strain except for *A. pinnata* var. *imbricata,* that with the higher N content had the higher ^{15}N recovery by rice.

After the first crop, a second rice crop was grown. Recovery of ^{15}N in the rice plants was about 4%, with no difference among treatments, indicating that the residual effect of azolla N is similar to that of urea.

Soil and crop management

Management of organic manures

Soils, Agronomy, and Soil Microbiology Departments; University of Hamburg, Justus Liebig University, and University of Giessen, Germany

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NUTRIENT LOSSES FROM BURNING RICE STRAW

Soils Department

Burning, a major method of rice straw disposal in the Philippines, destroys pests and saves labor and energy for field preparation. However, it pollutes the atmosphere and leads to nutrient losses.

Straw is piled in the field before burning. The temperature of burning straw in contact with the atmosphere is about 700 °C, resulting in losses of all C and N, 25% of P, and 20% of K. But inside the pile the straw burns slowly at about 500 °C, which greatly reduces nutrient losses. In field burning, losses were about 70% for N, 5% for P, 20% for K, 20% for Mg, 40% for Mn, and 50% for Zn. No loss was detected for Ca, Fe, or Si.

DYNAMICS OF ORGANIC MATTER IN PHILIPPINE RICE SOILS

Soils Department and University of Hamburg, Germany

The steady state phase of organic matter decomposition in rice soils was described by the natural distribution of C isotopes in the profiles.

Eight Philippine rice soils (Entisols, Inceptisols, Ultisols) were analyzed. Soil samples were taken from an area of 0.5-1 m^2 at 2-cm increments down to a depth of about 80 cm.

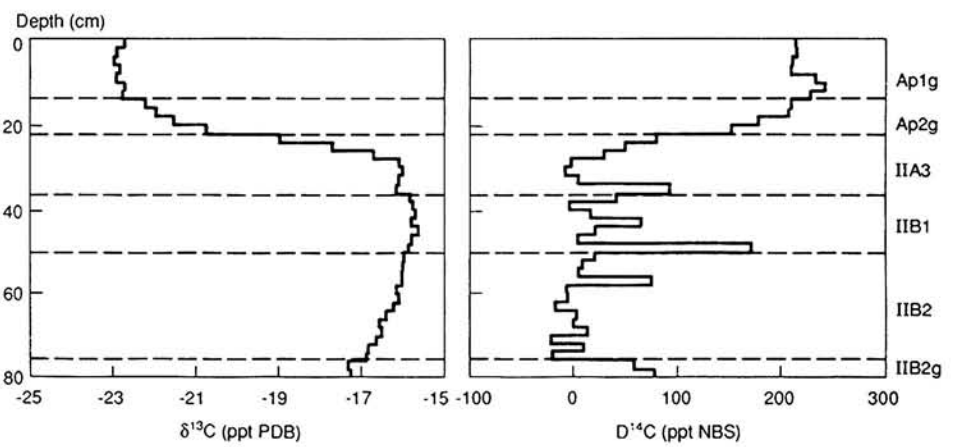
Analyses of the natural ^{14}C and ^{13}C concentrations are given in parts per thousand (ppt) as relative deviations of the isotope ratios from those of the related international reference standards: U.S. National Bureau of Standards oxalic acid for ^{14}C and Peedee Belemnite carbonate reference standard for ^{13}C. The reference value for ^{14}C is the atmospheric ^{14}C concentration of 1950. Due to atomic bomb tests, the atmospheric value at sampling time was about 200 ppt.

Discrimination of the heavier ^{13}C isotope against ^{12}C during photosynthesis leads to mean ^{13}C values of plant material of about -25 ppt in C3- and about -14 ppt in C4-type plants. Decomposition results in enrichment of ^{13}C in the residues and depletion of ^{13}C in released gases.

The natural distribution of C isotopes in an Aeric Tropaquept in Los Baños, Philippines, is shown in Figure 1.

The high D ^{14}C values in the topsoil reveal recent organic substrates of C3-type rice plants with enriched fresh C (roots) at 8-12 cm depth. The uniform values of δ ^{13}C in the entire Ap_{1g} horizon indicate homogeneous mixing and decomposition conditions. The δ ^{13}C value below the puddled layer increases by about 4 ppt, which is very high compared with that of terrestrial soils. This may be caused by high CH_4 production under anaerobic conditions; CH_4 is known to gain the least ^{13}C values of about -60 ppt, which in turn is accompanied by a correspondingly higher ^{13}C of the residues.

The steep slope of the D ^{14}C and δ ^{13}C curve below the puddled layer indicates strong adsorp-



1. Distribution of C isotopes in an Aeric Tropaquept, Los Baños, Philippines, 1988.

tion of highly δ ^{13}C-enriched metabolized ($\delta^{13}C$-enriched) and aged ($D^{14}C$-depleted) humic substances with clay. Younger material percolates through the traffic pan. This can be concluded from both the inflection of δ ^{13}C and the high $D^{14}C$ values in the deeper soil layers.

High $D^{14}C$ values in deeper layers of the soil reveal temporal accumulation of fresh C because of impeded percolation through textural changes or fluctuating groundwater levels.

The distribution of natural C isotopes indicates a fast turnover of organic matter in this Tropaquept, which is in accordance with former decomposition studies of ^{14}C-labeled rice straw.

The distribution of C isotopes in an Fe-toxic rice soil (Typic Paleudult) in San Dionisio, Philippines, is shown in Figure 2. The soil lay idle for 3 yr. The enrichment of ^{13}C in the topsoil is likely to have been caused by the accumulation of C from C4-type plants, probably weeds. The constant δ ^{13}C values below a depth of 30 cm reveal very low C dynamics, which is in accordance with the gradual increase in age of C with depth (decreasing ^{14}C values). The pattern of C isotopes in this Paleudult indicates a low turnover of organic matter. The pattern of δ ^{13}C does not indicate CH_4 formation in this soil.

The distribution of the natural C isotopes (steady state phase) will be combined with the results of decomposition studies with ^{14}C-labeled substrates (short-term phase) to model the decomposition and accumulation pattern in rice soils.

GREEN MANURE FOR ADVERSE SOILS AMENDMENT

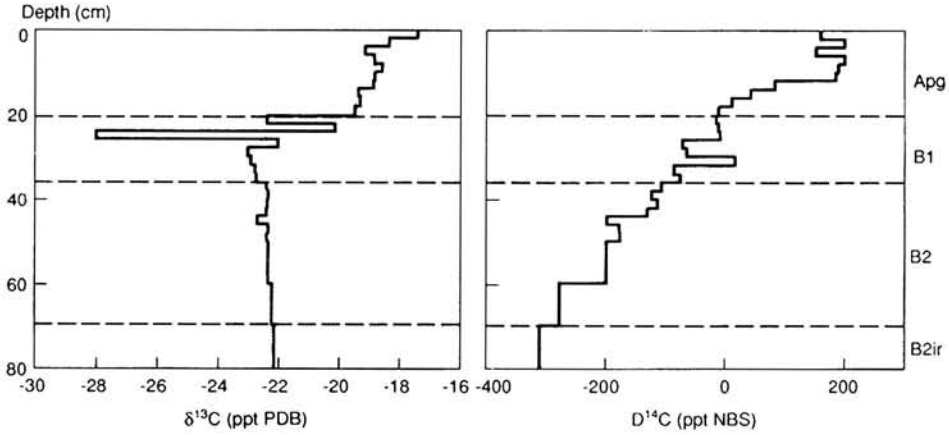
Soils Department

A greenhouse experiment to assess the effect of green manure (GM) on adverse soils was started by growing *Sesbania rostrata,* a stem nodulating tropical legume, on 9 Philippine soils representing a wide range of soil fertility (pH 3.7-7.5, 0.8-6.9% organic C, 0.08-0.46% total N, 0.03-12 mg available Zn/kg, 1.2-18.5 mg available P/kg) and adverse soil conditions (salinity, acidity, and Zn deficiency) under flooded and upland conditions. The results reveal that available P and exchangeable K are major growth-limiting factors under both water regimes (Fig. 3); *Sesbania rostrata* can grow under a salinity level of 10 dS/m; acidity affects the root system, thus retarding growth and development; available Zn does not affect *Sesbania rostrata*. Since sesbania is more tolerant of salinity than rice, it may also be a suitable green manure crop on saline soils when water is available but salt levels are too high for rice.

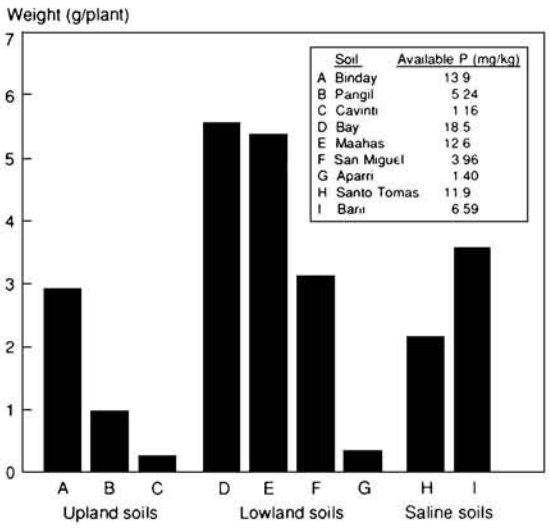
LOWLAND RICE RESPONSE TO GREEN MANURE AND FERTILIZER NITROGEN APPLICATION

Agronomy Department

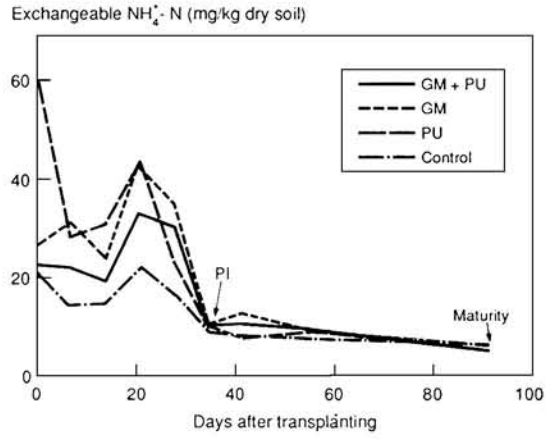
In 1988 dry season (DS), a field experiment was conducted on a silty clay soil (pH 5.8, 1% organic C, 0.10% total N, CEC 30 meq/100 g, 0.45 ppm available Zn) at the Central Luzon State Univer-



2. Distribution of C isotopes in a Typic Paleudult, San Dionisio, Philippines, 1988.



3. Dry matter weight of *Sesbania rostrata* at 45 d after sowing as affected by soils of varying P content. IRRI, 1988.



4. Kinetics of exchangeable NH_4^+-N in soil as affected by green manure (GM) and fertilizer N management in transplanted flooded rice. Central Luzon State University (CLSU), Nueva Ecija, Philippines, 1988 DS. PU = prilled urea, PI = panicle initiation.

sity, Muñoz, Nueva Ecija, Philippines. Research objectives were 1) to compare the yield response of IR66 to basal incorporation of ^{15}N-labeled and nonlabeled *Sesbania rostrata* GM with that of ^{15}N-labeled and nonlabeled prilled urea (PU), and combined application of sesbania and PU; and 2) to measure the magnitude of N loss through NH_3 volatilization.

The ^{15}N-labeled sesbania was cultured in the greenhouse, while the nonlabeled sesbania was grown outside the experimental area. Sesbania crops were cut at 46 d after emergence, chopped, and incorporated into puddled plots at 1 d before transplanting rice.

Kinetics of exchangeable NH_4^+-N in soil. *S. rostrata* decomposed immediately after soil incorporation, as evidenced by the foul odor that emanated from the sesbania-treated plots. The kinetics of exchangeable soil NH_4^+-N was monitored weekly during crop vegetative growth. Exchangeable NH_4^+-N values from basally incorporated sesbania (alone) peaked at 21 d after transplanting (DT), then gradually decreased to a very low level 14 d later (Fig. 4). Sesbania combined with fertilizer N gave a similar trend, but NH_4^+-N levels were considerably lower because of lower sesbania biomass and N applied up to that sampling period. Basal incorporation of 87 kg N/ha as PU gave the highest NH_4^+-N value at day 0, but the value dropped sharply 1 wk later, then rapidly increased again up to 21 DT. The NH_4^+-N level at 28 DT, before the remaining 29 kg N/ha was topdressed, was much lower than those of the 2 GM treatments. All treatments followed the release pattern of the native soil NH_4^+-N at 8 wk after transplanting (WT) until maturity.

Uptake and apparent recovery of applied nitrogen. Nitrogen uptake from sesbania, PU, and sesbania + PU treatments was not affected by sampling time (Table 1). Plant N accumulations with split-applied PU at 5-7 d before panicle initiation (DBPI) and at flowering were significantly higher than those with sesbania alone. At maturity, however, total N uptake of both treatments were comparable. Plant N of sesbania + PU treatment at all sampling times was similar to that observed with sesbania, or PU applied alone except at 5-7 DBPI. Total uptake of native soil N averaged 69 kg/ha (Table 1). Apparent recovery of applied N by rice was highest (57%) with split-applied PU. Sesbania and sesbania + PU treatments apparently recovered 53 and 46% of the applied N, respectively.

Grain yield and agronomic efficiency. Grain yield of IR66 responded significantly to basal incorporation of *S. rostrata* applied alone or combined with PU (Table 1). The high yield (4.6

Table 1. N uptake of transplanted IR66 during vegetative and reproductive growth stages and at maturity, grain yield, and agronomic efficiency as affected by *Sesbania rostrata* green manure and fertilizer N management in lowland soil. Central Luzon State University, Nueva Ecija, Philippines, 1988 DS.

N source	N uptake (kg/ha)					Apparent N recovery (%)	Grain yield (t/ha)	Agronomic efficiency (kg rough rice/ kg applied N)
	5-7 DBPI	Flowering	Grain	Straw	Total			
No fertilizer N	26 c	60 c	47 b	22 c	69 b	–	4.6 c	–
At 116 kg N/ha								
Sesbania[a]	40 b	114 b	85 a	45 a	130 a	53	6.7 b	18
Prilled urea (PU)[b]	65 a	157 a	94 a	41 ab	135 a	57	7.8 a	28
Sesbania + PU[c]	35 b	132 ab	86 a	36 b	122 a	46	6.6 b	18

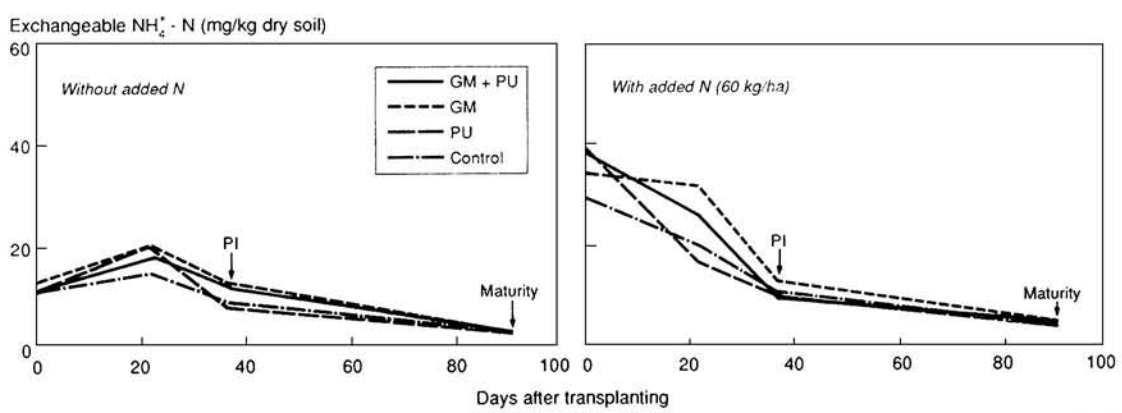
[a] *Sesbania rostrata* basal incorporation without standing water. [b] 87 kg N/ha as PU basal broadcast and incorporated onto mud + 29 kg N/ha topdressed at 5-7 d before panicle initiation (DBPI). [c] 87 kg N/ha as sesbania basally incorporated without standing water + 29 kg N/ha as PU topdressed at 5-7 DBPI.

t/ha) of the nonfertilized control was further increased by the GM treatments. At 116 kg N/ha, however, these treatments failed to match the grain yield of 7.8 t/ha with split-applied PU. Agronomic efficiency (kilogram rough rice per kilogram applied N) was highest (28) with split-applied PU. Both sesbania and sesbania + PU treatments produced 18 kg rough rice/kg of N applied.

Residual effects of green manure and urea on second rice crop. A wet season (WS) experiment evaluated the lowland rice response to residual effects of applied sesbania and urea. All plots were divided equally into 2, using thick galvanized iron sheets pushed 20 cm deep into the soil with 10 cm of the sheets remaining above the surface. Only one-half of the divided plots received 60 kg N/ha as PU.

Kinetics of exchangeable NH_4^+-N in soil. All treatments, with or without added N, followed similar N release patterns from transplanting to maturity (Fig. 5). Exchangeable NH_4^+-N values peaked at 20 DT, with the exception of peak values at day 0 for treatments with added N. Without added N, exchangeable NH_4^+-N levels at 20 DT were similar for sesbania, sesbania + PU, or PU. But with added N, both sesbania-treated plots provided higher NH_4^+-N levels than did PU-treated plots, suggesting that NH_4^+-N released from the residual GM was influenced by the applied mineral N.

Total nitrogen uptake and grain yield. With or without added N, residual effects of sesbania, PU, and their combination on total N uptake by the second rice crop were not significant. Also, no



5. Kinetics of exchangeable NH_4^+-N in soil as affected by residual green manure and fertilizer N in transplanted flooded rice. CLSU, Nueva Ecija, Philippines, 1988 WS.

residual effect on grain yield was observed, even with added N. Without added N, however, only sesbania applied alone gave a significant yield increase over the nonfertilized control. Grain yields with PU and sesbania + PU were comparable, but PU gave significantly lower yield than did sesbania applied alone. Yield differences among treatments also may have been reduced by the strong typhoon that hit the site 10 d before crop harvest.

COMPARISON OF DIRECT SEEDED AND TRANSPLANTED IR64 WITH *SESBANIA ROSTRATA* AND *AESCHYNOMENE AFRASPERA* GREEN MANURE AS NITROGEN SOURCES

Agronomy Department and Justus Liebig University, Germany

A field experiment at the Maligaya Rice Research and Training Center (MRRTC), Muñoz, Nueva Ecija, during the 1988 DS and WS studied the grain yield response of direct seeded (DSR) and transplanted (TPR) IR64 to *S. rostrata* and *A. afraspera* GM crops. Nitrogen fertilizer as urea and no N fertilizer were the control treatments.

In DSR, incorporation of GM into the soil increased rice vegetative growth and straw production (Table 2). Thus lodging was a serious problem during ripening. In WS, grain yields decreased significantly in DSR compared with TPR. Harvest indices were lower in DSR. *S. rostrata* as the N source generally gave higher grain yields than did *A. afraspera*. Nevertheless, both GM crops met the N requirements of the rice crop.

Despite the lodging problems, *S. rostrata* and *A. afraspera* are suitable N sources for DSR and TPR and can compete with mineral N fertilizers.

RESIDUAL EFFECT OF *SESBANIA ROSTRATA* ON THE SECOND SUBSEQUENT RICE CROP

Agronomy Department and Justus Liebig University, Germany

A field experiment conducted at MRRTC, Muñoz, Nueva Ecija, in 1988 studied the residual effect of *S. rostrata* GM on the yield of the second subsequent rice crop. In DS, *S. rostrata* GM at 90 kg N/ha was used as the N source for IR64. During WS, rice was transplanted in the same experimental area, but different N inputs were used (Table 3). N input as GM in DS was equivalent to 60 kg N/ha.

Yield data clearly show that N input as GM in DS and no N input in WS caused a significantly

Table 2. Grain and straw yield and harvest index of direct seeded and transplanted rice as affected by N management. Maligaya Rice Research and Training Center (MRRTC), Muñoz, Philippines, 1988.

Treatment[a]	Dry season			Wet season		
	Grain (t/ha)	Straw (t/ha)	Harvest index	Grain (t/ha)	Straw (t/ha)	Harvest index
			Direct seeded			
N input as *S. rostrata*	7.7	8.0	0.49	4.5	7.4	0.38
N input as *A. afraspera*	7.2	7.8	0.48	4.4	7.1	0.42
N input as urea	8.1	7.5	0.52	4.1	5.0	0.45
No N input	4.3	4.4	0.51	2.8	3.3	0.46
			Transplanted			
N input as *S. rostrata*	8.2	8.1	0.50	5.4	5.8	0.48
N input as *A. afraspera*	7.5	7.2	0.51	5.4	6.7	0.44
N input as urea	8.6	7.2	0.54	5.1	5.2	0.50
No N input	5.5	4.6	0.54	3.5	3.2	0.52
LSD (0.05)	0.3	0.4	0.02	0.4	0.4	0.03

[a] N inputs were 90 kg N/ha for DS and 60 kg N/ha for WS as urea or green manure crops.

Table 3. Residual effect of *S. rostrata* applied in DS on the second subsequent rice crop grown in WS as affected by N management practice. MRRTC, Muñoz, Nueva Ecija, Philippines, 1988.

DS treatment	WS treatment	Yield (t/ha)		Harvest index
		Grain	Straw	
N input as green manure	No N input	4.7	4.0	0.54
N input as green manure	N input as green manure	6.1	5.2	0.54
N input as green manure	60 kg N/ha as urea	6.1	5.5	0.53
90 kg N/ha as urea	60 kg N/ha as urea	6.1	5.4	0.53
90 kg N/ha as urea	No N input	3.2	2.7	0.54
No N input	No N input	3.1	3.3	0.48
LSD (0.05)		0.4	0.5	0.02

higher grain yield than did N input as urea in DS and no N input in WS. Thus, higher soil fertility can be sustained by using GM for several seasons than when mineral N as urea is applied.

EPIPHYTIC GROWTH OF STEM NODULE BACTERIA

Soil Microbiology Department

The populations of stem nodulating rhizobia on the leaves and flowers of *S. rostrata* (host) and *S. aculeata* (nonhost) plants grown in the field were studied to find if these rhizobia are epiphytic (on the surface of plant) on the host and nonhost plants. *S. rostrata* rhizobia *(Azorhizobium caulinodans)* was present up to 5×10^5/cm^2 of the leaf of the host throughout plant growth, and, to a lesser extent, on its flower. *A. caulinodans* was also present on the leaf of *S. aculeata*, although the population was much smaller (<100/cm^2 leaf).

The surveys of stem nodulating and non-nodulating species of *Aeschynomene* showed the presence of rhizobia of stem nodulating *A. afraspera* and *A. aspera* on the leaves of host and nonhost plants and the flowers of hosts. The rhizobia of nonstem nodulating *Aeschynomene* was not epiphytically present.

These findings suggest a causal relationship between stem nodulation and epiphytic growth of rhizobia. The epiphytic growth of rhizobia is probably required for the initiation of stem nodulation.

PLANTING METHOD AND OPTIMUM SEEDING RATE FOR HIGHER BIOMASS PRODUCTION AND NITROGEN FIXATION IN *SESBANIA ROSTRATA*

Soil Microbiology Department

An experiment with *S. rostrata* at IRRI from November 1987 to January 1988 determined the 1) optimum sampling size for measuring plant density, biomass, and acetylene-reducing activity (ARA), and 2) optimum seeding rate and planting method for obtaining higher biomass and N_2 fixation. A split-plot design was used, with seeding rate (20, 40, and 60 kg/ha) as the main plots and planting method (broadcast, row seeding at 15 cm between rows, and row seeding at 30 cm between rows) as the subplots. Each treatment had 3 replications (blocks) and each plot was 2 x 6 m. Biomass and ARA were measured at 41 d after seeding (DAS).

Optimum sampling size. For estimating plant density, the 30 x 30 cm sampling unit gave better precision than the 30 x 60 cm or the 60 x 60 cm sampling unit in all treatments. Therefore, better efficiency is achieved by taking small sampling units many times rather than bigger sampling units a few times. This is especially recommended for plants with uneven distribution. But, it increases the labor input. With the 30 x 30 cm sampling unit, the coefficients of variation of the mean CV ($\bar{x}$) for sample sizes of 4, 8, and 12/block were 12.4, 8.8, and 7.2%, respectively.

In determining plant biomass, the two-plant sampling unit generally gave better precision than the four-plant unit when seed was broadcast or planted in rows. Using the 2-plant sampling unit, CV ($\bar{x}$) for sample sizes of 2, 4, and 6/block were 14.6, 10.3, and 8.4%, respectively.

For ARA measurements, the 4-plant sampling unit generally gave better efficiency than the 2-plant unit when seed was planted in rows (15-30 cm apart) and plant samples were taken from adjacent rows. With the 4-plant sampling unit, CV ($\bar{x}$) for sample sizes of 2, 4, and 6/block were 13.6, 9.6, and 7.9%, respectively. When plants were sampled from the same row or when seeds were broadcast, however, the two-plant sampling

unit gave better precision than the four-plant sampling unit.

Optimum seeding rate and planting method. When seed was broadcast or sown in rows with 15 cm between them, increasing the seeding rate from 20 to 60 kg/ha increased the number of plants and plant biomass per m^2. But when the distance between rows was 30 cm, the increased seeding rate increased these 2 parameters only up to 40 kg/ha (Fig. 6)—the overcrowding of seeds within rows resulted in lower germination. By increasing the number of rows (i.e., decreasing the distance between rows to 15 cm), crowding of seeds within rows was minimized. This explains why, at the same seeding rate of 60 kg/ha, plant density and biomass per m^2 were higher with a distance of 15 cm than with 30 cm between rows. Therefore, planting in 15-cm rows is recommended, especially at higher seeding rates.

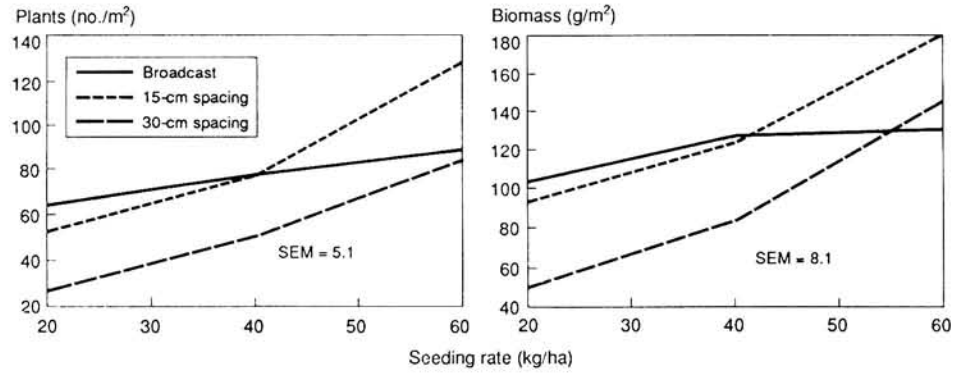
Planting method significantly affected ARA/plant, but seeding rate had no effect. Averages of ARA at 3 seeding rates were 12.1, 10.3, and 9.7 μmol C_2H_4/plant per h, with a standard error of the mean of 0.6 for broadcast, 15-cm row seeding, and 30-cm row seeding, respectively. This seems to be related to plant density, which was lower when seed was broadcast. On the other hand, both planting method and seeding rate had significant effects on ARA per unit area. Planting method and seeding rate produced similar effects on ARA per unit area as on estimated biomass per unit area. ARA estimated per m^2 was 597, 823, and 746 μmol C_2H_4/plant per h with a standard error of 50, at broadcasting, 15-cm seeding, and 30-cm seeding treatments, respectively. Planting in 15-cm rows would be suitable for high N_2 fixation.

STANDARDIZATION OF ACETYLENE REDUCTION ASSAY WITH FIELD-GROWN AQUATIC LEGUMES

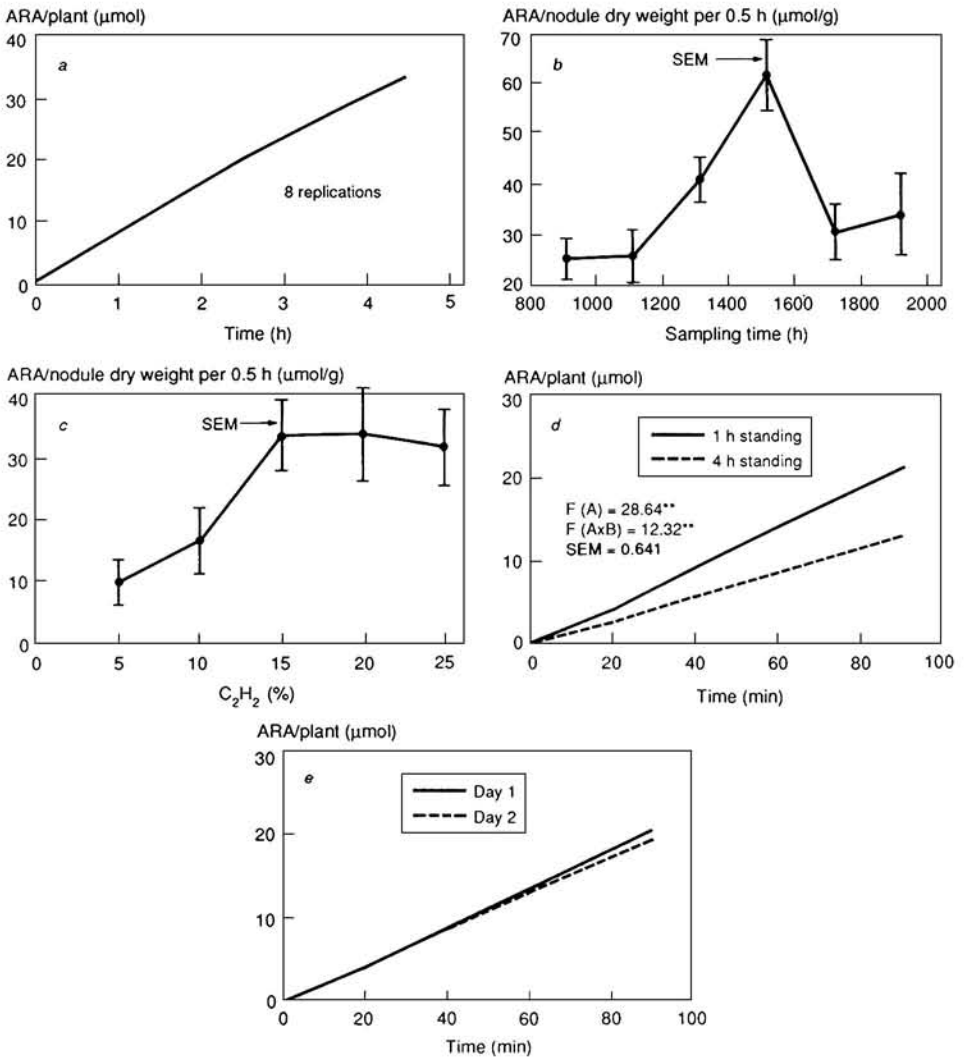
Soil Microbiology Department

To standardize a simple and efficient acetylene reduction assay for routine measurements of N_2 fixation by root- and stem-nodulating GM leguminous plants, the optimum time of plant sampling, duration, and conditions for acetylene reduction assays were determined. Stem and root nodule ARA of *S. rostrata* increased linearly from 0 to 2.5 h of incubation, after which a slight reduction was observed (Fig. 7a). A short incubation period of 1 h can therefore be recommended. ARA of whole and cut plants incubated in the dark was not significantly different. However, ARA of whole plants incubated in the dark was significantly lower (about 40%) than that of whole plants incubated in light. It is more convenient to measure ARA using cut plants because they require smaller plastic bags (or incubation vessels) and less acetylene-air mixture than whole plants. Furthermore, dark incubation eliminates the need for extra light facilities.

The time of plant sampling and acetylene concentration affected ARA. ARA was highest between 1300 and 1600 h (Fig. 7b), and the optimum acetylene concentration was 10-15% (Fig. 7c). The effect on ARA of a prolonged time interval between field sampling and the acetylene reducing assay was also determined. A 4-h inter-



6. Effect of seeding rate and planting method on a) plant density of *S. rostrata*, b) biomass per unit area of *S. rostrata*. IRRI, 1988.



7. ARA of cut *S. rostrata* incubated in darkness as affected by a) incubation time, b) sampling time, c) acetylene concentration, d) time interval between field sampling and AR assay, and e) 2 consecutive days of measurements. IRRI, 1988.

val between the sampling and assay significantly reduced the ARA as compared with a 1-h interval (Fig. 7d). It is therefore important to process (sampling from field, washing, cutting, and sealing the plants with plastic bag, etc.) the plants as quickly as possible. About 40 plants/h can be sampled and assayed by 4 persons. If an experiment involves doing ARA measurements for a large number of plants, it may be advisable to assay only half of the desired number of replications on one day and the second half the following day, as no significant difference in ARA was obtained from two consecutive days of sampling (Fig. 7e).

SEASONAL CHANGES IN PERFORMANCE OF *SESBANIA ROSTRATA* AND *AESCHYNOMENE AFRASPERA*

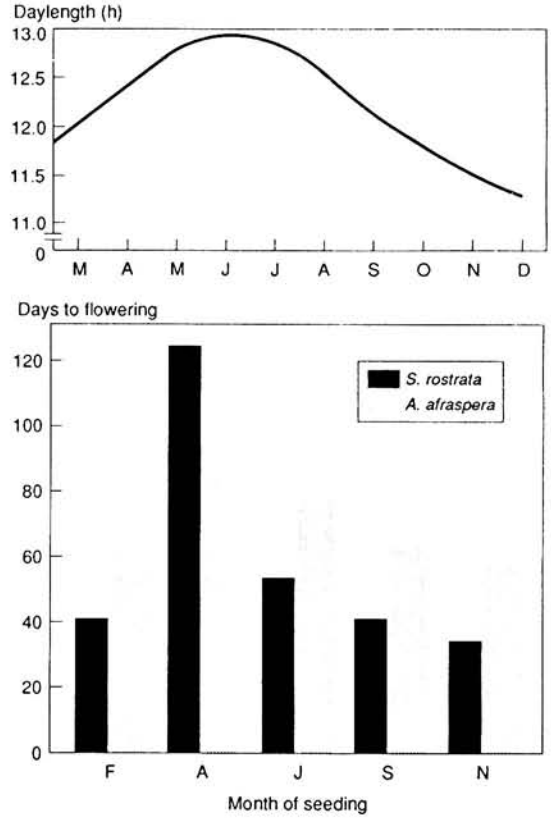
Soil Microbiology Department and University of Giessen, Germany

A field experiment with *S. rostrata* and *A. afraspera* was conducted in randomized complete block design (RCBD) with four replications at IRRI.

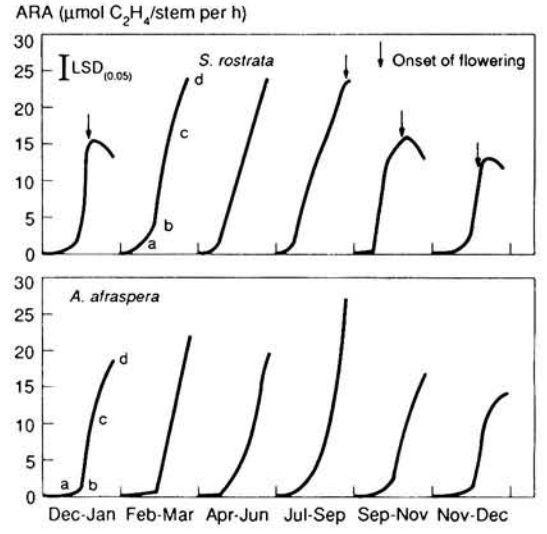
Four-day-old seedlings of both species were planted 6 times throughout the year (from July 1987 to June 1988), and their respective rhizobia (*Rhizobium* sp. ORS 322 for *A. afraspera* and *Azorhizobium caulinodans* ORS 571 for *S. rostrata*) were inoculated by spraying on the soil surface at 25 liters/ha. Rhizobia were grown in yeast-lactate broth with continuous shaking at 28 °C for 3 d to obtain a suspension of about 10^8 cells/ml. The broth was diluted 10 times with water and used for inoculation.

Flowering behavior, plant height, and dry matter production. The study of growth parameters throughout the year revealed different patterns for *S. rostrata* and *A. afraspera*. Seasonal variation of most growth parameters was less pronounced in *A. afraspera* than in *S. rostrata*. The flowering behavior in response to daylength revealed higher photosensitivity of *S. rostrata* than of *A. afraspera*. Depending on the month of planting, *S. rostrata* flowered between 37 and 125 DAS as compared with 54 and 83 DAS in the case of *A. afraspera* (Fig. 8). The pattern of plant height and dry matter production showed a large variation among different plantings and species. Generally, *S. rostrata* grew taller and produced higher biomass than *A. afraspera*. *S. rostrata* grew taller in the long-day period (April to September) than in the short-day period (November to February). However, *A. afraspera* exhibited the opposite trend: plants were taller in December than in June. The minimum dry matter production by *S. rostrata* was 3 t/ha in 8-wk-old plants grown in November-December; the maximum value was 15 t/ha in plants grown in July-August. *A. afraspera* exhibited a more or less constant dry matter production pattern of about 6 t/ha in 8 wk throughout the year.

Nodulation, nitrogen fixation, and nitrogen accumulation. The stem nodule number—generally higher in *A. afraspera* than in *S. rostrata*—correlated with the amount of rainfall. In 8-wk-old *S. rostrata*, a decrease in stem nodule number compared with 6-wk-old plants was observed, probably due to senescence and abortion of nodules in the submerged portion of the stems. Generally, the number of root nodules was, in both species, lower than the number of stem nodules. Maximal root nodule number was observed in 4-

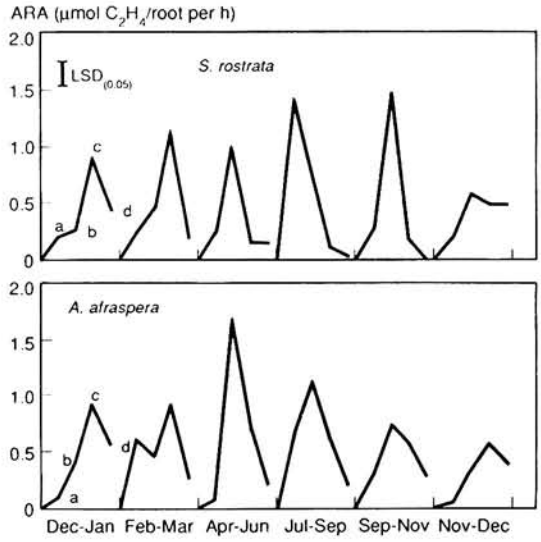


8. Photoperiod behavior of *S. rostrata* and *A. afraspera*. IRRI, 1988.



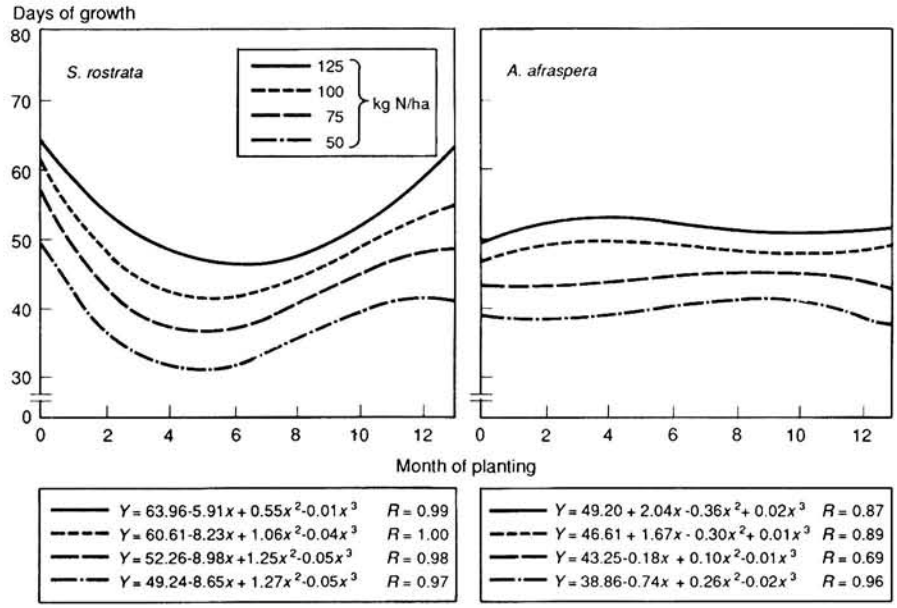
9. Pattern of ARA of stem nodules at 2 (a), 4 (b), 6 (c), and 8 (d) wk growth of *S. rostrata* and *A. afraspera* planted throughout the year. IRRI, 1988.

to 6-wk-old plants and then declined rapidly. The pattern of ARA of stem and root nodules is shown in Figures 9 and 10, respectively. Daylength affected ARA, which declined in *S. rostrata* with the onset of flowering. A lower variation in ARA throughout the year was observed in *A. afraspera* as no flowering occurred within the 8-wk growth period. Root ARA was maximum at a plant age of about 4 wk and then declined; on the other hand, stem ARA continued to increase up to 8 wk (Fig. 9). N_2 fixation is mostly by root nodules at early stages of plant growth, and mostly by stem nodules at later growth stages. However, the contribution of root nodules to total N_2 fixation seems to be much less than that of stem nodules.



10. Pattern of ARA of root nodules at 2 (a), 4 (b), 6 (c), and 8 (d) wk growth of *S. rostrata* and *A. afraspera* planted throughout the year. IRRI, 1988.

Nitrogen accumulation in *S. rostrata* followed the pattern of dry matter production and ARA, with highest values in July and lowest in December. In *A. afraspera*, it was more or less constant throughout the year. Depending on the season, N accumulation in 6-wk-old plants varied between 54 and 115 kg N/ha for *S. rostrata* and between 56 and 73 kg N/ha for *A. afraspera*. It is of practical interest to know for how many days a green manure must be grown to accumulate a desired amount of N. Based on regression equation analysis of the N accumulation graphs, iso-N accumulation graphs were calculated (Fig. 11). They represent the growth duration requirements of *S. rostrata* and *A. afraspera* throughout the year to accumulate 50, 75, 100, and 125 kg N/ha. A large seasonal variation in



11. Iso-N accumulation graphs of *S. rostrata* and *A. afraspera* for 50, 75, 100, and 125 kg N/ha. IRRI, 1988.

number of days of growth to accumulate a given amount of N was observed in *S. rostrata*. Nearly no variation was observed in *A. afraspera*.

EFFECT OF MINERAL N, P, AND K FERTILIZATION ON GROWTH AND NITROGEN FIXATION OF *S. ROSTRATA* AND *A. AFRASPERA* AND THEIR EFFECT AS GREEN MANURE ON LOWLAND RICE

Soil Microbiology Department and University of Giessen, Germany

Experiments were conducted in the glasshouse and in the field. The glasshouse experiment was conducted in Wagner pots (3.5 kg homogenized, air-dried Tarlac Tropofluvent, 0.07% N, 3.1 ppm Olsen P, CEC 7.7 meq/100 g, pH 6.4) with *S. rostrata* and *A. afraspera* during March-April 1987, in the phytotron with natural light and controlled day/night temperature (29/24 °C) and relative humidity (80%). Five replications were used, with 2 plants/pot. The plants were harvested at 6 WT. In the N experiment, soil was fertilized with P (50 mg/kg soil) and K (100 mg/kg soil), and increasing amounts of urea were added to obtain N concentrations of 0, 10, 20, 30, and 40 mg/kg soil on a dry basis. In the PK experiments, $Ca(H_2PO_4)_2$ and KCl were applied to give P concentrations of 0, 50, and 100 mg/kg soil and K concentrations of 0, 100, 200, and 300 mg/kg soil. Fertilizers were applied as 0.1 M nutrient solution and homogeneously mixed into the soil before transplanting. The field experiments were conducted in Floridablanca (N experiment: Tropofluvent, 0.06% N, 7.3 ppm Olsen P, CEC 6.1 meq/100 g, pH 5.3) and San Manuel, Tarlac (PK experiment). Both experiments were laid out as RCBD with 4 replications and a plot size of 20 m^2. Treatments are shown in Table 4.

Table 4. Treatments involved in N and PK experiments. IRRI and Tarlac, Philippines, 1987.

N experiment		
Treatment	*S. rostrata* N (kg/ha)	Rice N (kg/ha)
1	0	0
2	30	0
3	No green manure	60
4	No green manure	0

PK experiment						
Treatment	Nutrients (kg/ha) in *S. rostrata*			Nutrients (kg/ha) in rice		
	N	P	K	N	P	K
1	0	0	0	0	40	40
2	0	40	0	0	0	40
3	0	0	40	0	40	0
4	0	40	40	0	0	0
5	No green manure			60	40	40
6	No green manure			0	40	40

Influence of mineral nitrogen. In the glasshouse experiment, plant height and dry matter were not affected by small amounts of mineral N (up to 20 ppm) but decreased at higher N concentrations. Increasing amounts of mineral N resulted in a gradual decrease in nodule number and ARA of the roots (Table 5). A different pattern was exhibited by the stem nodules. A low concentration of N (10 ppm) increased ARA significantly, but at higher N concentrations, nodule number and ARA declined, showing a significant reduction at only 40 ppm N.

Adding 10 ppm N resulted in an additional N accumulation in the plant dry matter of about 60 mg N. In the field, the addition of 30 kg mineral N/ha stimulated growth, nodulation, and N_2 fixation in *S. rostrata*, as in the greenhouse experiment. The N accumulation of plants grown with mineral N reached 252 kg N/ha as compared with 195 kg N/ha accumulated by control plants. With the addition of 30 kg mineral N/ha, an additional N gain of about 60 kg/ha was reached, probably through increased biological nitrogen fixation. However, rice grain yield after incorporation of N-fertilized *S. rostrata* was not significantly higher than that with unfertilized GM. The exact reason for this is not known.

Effect of phosphorus and potassium. In the glasshouse, plant dry weight, ARA, and N accumulation responded strongly to both P and K. A combination of P and K increased the N_2 fixation of *S. rostrata* and *A. afraspera* about fourfold and the plant-N accumulation about twofold (Table 6). In the field, plant dry weight, nodule number, ARA, and total N accumulation of *S. rostrata* were also increased by applying P and K. A combination of P and K gave the highest biofertilizer production. Unfertilized *S. rostrata* accumulated

Table 5. Influence of increasing amounts of mineral N on growth, nodulation, and acetylene-reducing activity (ARA) of 6-wk-old *Sesbania rostrata*. IRRI pot experiment, 1987 WS.

Parameter	N (ppm)					
	0	10	20	30	40	LSD (0.05)
Plant height (cm)	146.4	153	149.4	141	114.8	12
Total dry weight (g)	9.1	10.3	10.6	8.0	5.6	1.9
Stem nodules (no.)	182.2	201.4	177	129.7	108.6	29.4
Root nodules (no.)	49.8	49.2	34.8	20.6	11.0	15.7
ARA in stem (μmol C_2H_4/plant per h)	32.9	43.5	32.1	29.2	12.2	8.2
ARA in root (μmol C_2H_4/plant per h)	2.74	2.06	1.68	1.54	0.76	0.56
N (mg/plant)	249.2	308.2	307.4	244.8	209.0	51.8

Table 6. Effect of increasing amounts of P and K on growth, nodulation, and N fixation of *S. rostrata*. IRRI pot experiment in the greenhouse, 1987 WS.

Parameter	Fertilizer (ppm)								
	0 P 0 K	0 P 100 K	0 P 200 K	0 P 300 K	100 P 0 K	100 P 100 K	100 P 200 K	100 P 300 K	LSD (0.05)
Plant height (cm)	96	114	109	121.2	107.2	133.6	138	145.4	11
Dry weight/plant (g)	11.3	1.7	12.2	13.4	12	21.4	24.7	23.7	3.8
Stem nodules (no.)	173.3	199	206	217.3	210.8	355.9	384.5	403	49.9
Root nodules (no.)	60	135.5	113.5	158	69.8	136	122.8	134.5	42.4
ARA in stem (μmol C_2H_4/plant per h)	10.9	18.7	19.5	24.9	17.1	32.4	41.2	43.7	7.1
ARA in shoot (μmol C_2H_4/plant per h)	0.85	2.75	2.48	2.73	2.65	3.5	2.83	3.48	1.2
N (mg/plant)	389	361	346	381	404	687	755	771	121

Table 7. Effect of P and K fertilization on biofertilizer production by *S. rostrata*, and rice grain yield. Field experiment in Tarlac, Philippines, 1987 WS.

Parameter	No PK	K	P	PK	LSD 0.05
Plant height (cm)	175.5	181.3	189.1	192.8	9.9
Dry weight/plant (g)	6.2	7.7	10.6	10.7	2.4
Stem nodules (no.)	37	49	80	72	21
ARA (μmol C_2H_4/plant per h)	8.7	10.6	17.3	16.7	4.9
Dry weight (t/ha)	5.0	6.0	6.3	6.4	0.3
N (%)	2.07	2.08	2.26	2.24	0.19
N (kg/ha)	103.5	124.8	142.4	143.5	16.4
Yield increase (%)	36	42	37	39	12

about 100 kg N/ha, while the PK-fertilized *S. rostrata* accumulated 140 kg N/ha. No significant differences in rice grain yield were observed between the GM treatments with and without fertilizer application (Table 7). This is because a considerable amount of N released from the incorporated *S. rostrata* went into straw production.

EFFECT OF AZOLLA AND AQUATIC GREEN MANURE ON WETLAND RICE

Soil Microbiology Department

In 1985, a long-term experiment was begun to compare the effects on rice of two GM crops that can grow under flooded conditions: *Azolla microphylla* #4018 and *S. rostrata*.

Table 8. Effect of azolla and sesbania green manure on wetland rice yield. IRRI, 1988 DS and WS.

Crop	Dates	Variety	N input (kg N/ha)			Rice grain yield (t/ha)			
			Urea	Azolla	Sesbania	Control	Urea	Azolla	Sesbania
6th	Jan-Apr 1988	IR66	60	85	65	5.2	7.7	8.5	7.4
7th	Jul-Oct 1988	IR68	60	97	82	4.8	6.1	6.5	5.9

In the 6th trial, sesbania was grown for 57 d until incorporation. Its N content was 1.81% and its dry matter was 3.5 t/ha. In the 7th trial, sesbania was grown for 48 DAS until incorporation; its N content was 1.36% and dry matter, 6.0 t/ha. Azolla was incorporated three times before and once after transplanting. Its N content was 2.8-3.6% in the 6th trial and 3.5-4.4% in the 7th trial. The effect of GM on rice yield was comparable to that of urea in both trials (Table 8).

One month after the harvest of the 7th trial, soil was taken from the 0-20 and 20-60 cm layers. Although the N content per soil dry weight was clearly higher in GM-treated plots, there was no difference in total N per unit area because of the lower bulk density of GM-treated plots.

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LONG-TERM FERTILITY TRIALS

Long-term fertility trials continued at IRRI, at three Philippine Bureau of Plant Industry (BPI) stations, and in farmers' fields.

IRRI. The 48th (dry season [DS]) and 49th (wet season [WS]) consecutive crops were grown in irrigated plots using IR8, IR64, and IR29723-143-3-2-1 as test cultivars (Table 1). In DS, IR8 and IR64 were infected with viral diseases and hence gave lower yields than did the late-maturing IR29723-143-3-2-1. All test rices gave significant yield response to 140 kg N/ha, with IR29723-143-3-2-1 exhibiting the highest yield increase and IR8 the least. Applying N and K did not increase yields significantly over those with N alone. Averaged over all cultivars, yields were significantly lower with N and K application than those with N and P. Application of complete NPK fertilizers, either purely inorganic or a combination of organic (rice straw compost) and inorganic sources, gave the highest yields. P and K fertilizers each applied alone did not increase yield significantly.

Yield trends were the same during WS. With less disease infection, IR8 and IR64 yielded as well as did IR29723-143-3-2-1.

BPI stations. At Maligaya, the highest yield was obtained with complete NPK fertilizer application, where K was applied full dose as basal at 50 kg/ha or in split dose of 50 kg/ha basal + 25 kg/ha at about panicle initiation (PI) (Table 2). However, applying N and P produced similar yields, indicating that P was a critical nutrient for obtaining reasonable yields at this site. Only IR64 gave a significant yield response to N alone. There may have been a nutrient imbalance when IR64 and IR29723-143-3-2-1 with N and K application yielded lower than without fertilizer application.

Typhoons damaged the WS crop; hence yields were low. The yield response trend, however, was similar to that in DS.

At the Bicol site in DS, IR64 and IR29723-143-3-2-1 yields from NP-treated plots were not different from those in plots with complete NPK (Table 3). With IR8, NP application gave yields similar to those with application of N alone and of NPK with K applied at 50 kg/ha. Across all cultivars, N application alone did not significantly increase yields from those without fertilizer application. NK application did not increase yields in IR8 and IR64 but caused IR29723-143-3-2-1 to yield significantly higher.

Table 1. Effect of NPK fertilizers on yield of test rices in the long-term fertility trial. IRRI, 1988.

Fertilizer (kg/ha)			Yield[b] (t/ha)			
N[a]	P	K	IR8	IR64	IR29723-143-3-2-1	Mean
			Dry season			
0	0	0	1.7 c	1.5 c	2.4 b	1.9 d
140	0	0	3.3 b	4.1 ab	6.0 a	4.5 bc
0	13	0	2.1 c	1.9 c	2.7 b	2.2 d
0	0	25	2.0 c	1.7 c	2.6 b	2.1 d
140	13	0	3.6 ab	4.4 a	6.5 a	4.8 ab
140	0	25	3.2 b	3.6 b	6.0 a	4.2 c
140	13	25	3.5 ab	4.7 a	6.5 a	4.9 ab
140[c]	13	25	4.2 a	4.6 a	6.5 a	5.1 a
			Wet season			
0	0	0	3.4 d	3.0 d	3.5 b	3.3 e
60	0	0	4.3 bc	5.1 a	4.2 b	4.5 c
0	13	0	4.0 cd	3.2 d	4.1 b	3.8 d
0	0	25	3.6 cd	3.2 d	3.8 b	3.5 de
60	13	0	5.4 a	4.9 ab	5.6 a	5.3 a
60	0	25	5.0 ab	4.2 bc	5.0 a	4.7 bc
60	13	25	5.1 a	5.1 a	5.6 a	5.3 a
60[c]	13	25	5.6 a	4.1 c	5.3 a	5.0 ab

[a] Includes topdressing of 40 kg N/ha in DS and 20 kg N/ha in WS at 5-7 d before panicle initiation (DBPI). [b] Within a season, yields in a column followed by a common letter are not significantly different at the 5% level by DMRT. CV = 14% for DS and 11% for WS. [c] 24 kg N/ha from rice straw compost.

Table 2. Effect of NPK fertilizers on yield of test rices in the long-term fertility trial. MRRTC, Muñoz, Nueva Ecija, 1988.

Fertilizer (kg/ha)			Yield[b] (t/ha)			
N[a]	P	K	IR8	IR64	IR29723-143-3-2-1	Mean
			Dry season			
0	0	0	2.3 b	2.2 c	2.1 bc	2.2
140	0	0	2.6 b	3.3 b	2.7 b	2.8
140	26	0	5.6 a	6.4 a	6.5 a	6.2
140	0	50	2.6 b	1.8 c	1.7 c	2.0
140	26	50	6.2 a	6.0 a	6.7 a	6.3
140	26	50+25	5.3 a	6.6 a	7.2 a	6.4
			Wet season			
0	0	0	0.8 b	0.8 b	0.9 b	0.9
70	0	0	0.8 b	0.8 b	1.3 ab	1.0
70	26	0	1.7 a	2.0 a	1.5 a	1.7
70	0	50	1.0 b	0.9 b	1.3 ab	1.1
70	26	50	1.9 a	2.3 a	1.4 a	1.9
70	26	50+25	1.5 a	2.3 a	1.4 a	1.9

[a] Includes topdressing of 40 kg N/ha in DS and 30 kg N/ha in WS at 5-7 DBPI. [b] Within a season, numbers in a column followed by a common letter are not significantly different at the 5% level by DMRT. CV = 13% for DS and 20% for WS.

Table 3. Effect of NPK fertilizers on yield of test rices in the long-term fertility trial. Bicol Experiment Station, Pili, Camarines Sur, Philippines, 1988.

Fertilizer (kg/ha)			Yield[b] (t/ha)			
N[a]	P	K	IR8	IR64	IR29723-143-3-2-1	Mean
			Dry season			
0	0	0	4.0 c	4.1 b	4.3 c	4.1
140	0	0	5.0 bc	5.5 b	5.3 bc	5.3
140	26	0	5.9 b	7.7 a	8.0 a	7.2
140	0	50	3.9 c	5.4 b	6.2 b	5.2
140	26	50	6.5 b	7.9 a	8.2 a	7.6
140	26	50	8.1 a	7.8 a	8.6 a	8.1
			Wet season			
0	0	0	4.9 b	3.9 c	3.9 b	4.2
70	0	0	4.8 b	4.1 c	4.2 b	4.4
70	26	0	6.1 a	5.1 b	5.4 a	5.5
70	0	50	5.1 b	4.1 c	4.3 b	4.5
70	26	50	6.0 a	5.9 a	5.6 a	5.9
70	26	50	6.1 a	5.6 a	5.6 a	5.8

[a] Includes topdressing of 40 kg N/ha in DS and 30 kg N/ha in WS at 5-7 DBPI. [b] Within a season, numbers in a column followed by a common letter are not significantly different at the 5% level by DMRT. CV = 14% for DS and 5% for WS.

In WS, IR8 and IR29723-143-3-2-1 showed similar grain yield response to various fertilizer treatments. N alone and NK gave yields similar to that of the control, while NP produced yields similar to those with NPK. For IR64, NP application gave significantly lower yields than did NPK application but was also significantly higher than those for N, NK, and no-fertilizer plots.

At the Visayas site, irrespective of cultivar, N application significantly increased grain yield in DS (Table 4). Applying NP further increased yield significantly. While IR64 yields with NK application were significantly better than with N alone, N application alone gave similar yields in IR8 and IR29723-143-3-2-1.

In WS, IR64 was harvested before the typhoons occurred, while IR8 and IR29723-143-3-2-1 were damaged, hence the high CV. As in DS, a signifi-

Table 4. Effect of NPK fertilizers on yield of test rices in the long-term fertility trial. Visayas Experiment Station, Hamungaya, Iloilo City, Philippines, 1988.

Fertilizer (kg/ha)			Yield[b] (t/ha)			
N[a]	P	K	IR8	IR64	IR29723-143-3-2-1	Mean
			Dry season			
0	0	0	1.8 c	1.9 d	2.2 c	2.0
140	0	0	3.1 b	2.7 c	2.9 b	2.9
140	26	0	4.5 a	4.9 a	4.5 a	4.6
140	0	50	3.3 b	3.4 b	3.5 b	3.4
140	26	50	4.4 a	4.8 a	4.7 a	4.6
140	26	50+25	4.7 a	5.0 a	4.7 a	4.8
			Wet season			
0	0	0	2.1 b	2.7 d	1.1 c	2.0
70	0	0	3.2 a	3.9 bc	2.2 ab	3.1
70	26	0	3.7 a	5.0 a	2.9 a	3.9
70	0	50	3.1 a	3.4 cd	1.7 bc	2.7
70	26	50	3.4 a	4.5 ab	3.0 a	3.6
70	26	50+25	3.1 a	4.5 ab	3.0 a	3.5

[a]Includes topdressing of 40 kg N/ha in DS and 30 kg N/ha in WS at 5-7 DBPI. [b]Within a season, numbers in a column followed by a common letter are not significantly different at the 5% level by DMRT. CV = 14% for DS and 5% for WS.

cant response to N application was observed. In IR64, NP application caused yields to be similar to those with NPK.

Farmers' fields. The 22d (DS) and 23d (WS) crops in Tanay, Rizal (Vertic Tropaquept), and the 24th (DS) and 25th (WS) crops in Luisiana, Laguna (Aquic Troporthent), were grown in farmers' fields (Table 5, 6). IR66 and IR29723-143-3-2-1 were the test rices.

Grain yield. NPK-treated plots gave the highest grain yields for both varieties. The no-fertilizer treatment (control) gave grain yields mostly lower than those for P or K alone. Applying N alone significantly increased grain yield; N combined with either P or K increased yield further. A typhoon hit Luisiana in WS and caused very low yields of IR29723-143-3-2-1.

Yield response to N, either alone or in combination (NPK vs PK), was noted on both soils. On the other hand, P response (N vs NP, NPK vs NK) of both varieties, although also observed on calcareous Tanay soil, was consistent on acidic Luisiana soil in both seasons. The highest P response (1.7 t/ha) was in Tanay with IR29723-143-3-2-1,

Table 5. Effect of NPK on yield of IR66 and IR29723-143-3-2-1 in the 22d (DS) and 23d (WS) consecutive crops in the long-term fertility trial. Tanay, Rizal, Philippines, 1988.

Fertilizer treatment[a]	Yield[b] (t/ha)			
	Dry season		Wet season	
	IR66	IR29723-143-3-2-1	IR66	IR29723-143-3-2-1
Control	3.2 d	3.2 d	3.4 c	3.4 b
N	3.9 cd	4.1 bc	4.3 b	3.2 b
P	3.4 d	3.5 cd	3.6 c	3.5 b
K	3.4 d	3.2 d	3.7 c	3.1 b
NP	4.2 bc	4.8 ab	4.5 ab	4.3 a
PK	3.6 cd	3.6 cd	3.6 c	3.4 b
NK	4.8 ab	4.1 bc	4.4 b	3.0 b
NPK	5.0 a	5.2 a	5.0 a	4.7 a

[a]120 kg N/ha for DS and 60 kg N/ha for WS; 17.5 kg P/ha and 33 kg K/ha in both seasons. [b]CV = 12% for DS and 10% for WS.

Table 6. Effect of NPK on yield of IR66 and IR29723-143-3-2-1 in the 24th (DS) and 25th (WS) consecutive crops in the long-term fertility trial. Luisiana, Laguna, Philippines, 1988.

Fertilizer treatment[a]	Yield[b] (t/ha)			
	Dry season		Wet season	
	IR66	IR29723-143-3-2-1	IR66	IR29723-143-3-2-1
Control	3.0 d	3.0 d	2.6 d	1.4 d
N	4.6 b	4.1 bc	3.3 b	2.3 b
P	2.8 d	3.3 d	2.8 cd	1.9 c
K	3.2 d	2.7 d	3.1 bc	1.8 c
NP	4.9 ab	4.9 a	3.7 a	3.1 a
PK	2.7 d	3.6 c	3.0 bc	1.8 c
NK	4.0 c	4.0 bc	3.2 b	2.1 bc
NPK	5.3 a	5.1 a	3.9 a	3.1 a

[a] 120 kg N/ha for DS and 60 kg N/ha for WS; 17.5 kg P/ha and 33 kg K/ha in both seasons. [b] CV = 10% for DS and 8% for WS.

while the highest N response (2.6 t/ha) was in Luisiana with IR66. IR66 yields responded to K application (NPK vs NP) on Tanay soil in DS.

Soil analyses. After 21 consecutive croppings on Tanay soil, and 23 consecutive croppings on Luisiana soil, NPK fertilizer application did not considerably affect the pH, total N, exchangeable Ca, or available Zn of both soils.

P was the most critical fertilizer requirement in both soils. On high-pH Tanay soil, plots that did not receive P for 21 croppings were highly P-deficient (<10 ppm, critical limit for Olsen P analysis). Similarly, on Luisiana soil, plots that continuously received P alone or in combination with other nutrients had P contents higher by 2-4 ppm than the control. Available P on the soil of control plots was below the critical level (<20 ppm, critical limit for Bray 2 P analyses). N content may have been critical on Luisiana soil, whereas below-critical K values of 0.10 meq/100 g have been recorded on the high-pH Tanay soil.

Table 7. Properties of soil used in P source trials. Bugallon, Pangasinan, Philippines, 1988.

Soil property	Dry season	Wet season
pH (1:1)	5.2	5.8
Organic matter (%)	3.9	3.0
Total N	0.190	0.165
Exchangeable bases (meq/100 g)		
Na	0.237	0.269
K	0.024	0.049
Ca	12.1	13.0
Mg	11.1	12.0
CEC (meq/100 g)	27	28
Total P (ppm)	113	136
Available P (ppm)		
Bray 2	15	12
Olsen	1.6	Nil
Available Zn (ppm)	0.46	0.05
Particle size (%)		
Sand	29	25
Silt	56	60
Clay	15	15
Texture	Silty loam	Silty loam

PHOSPHORUS SOURCES FOR RICE ON ACID SOILS

P deficiency is an important nutritional problem of rice on acid soils. Aside from their low available P content, acid soils fix P fertilizer in highly insoluble forms. Trials were initiated in 1988 in farmers' fields to determine the short- and long-term effects of various P sources and application rates on rice grain yield. Table 7 shows the soil properties of farmers' fields in Bugallon, Pangasinan.

Grain yield response to P application was noted in both seasons (Table 8). Highest yield response to P (1.4 t/ha) was obtained in DS with triple superphosphate (TSP) or less reactive phosphate (LRP). Except with North Carolina phosphate rock and partially acidulated phosphate rock (15% acidulation), grain yields increased when P fertilizer was applied in DS. But within a P source, yields did not significantly differ with application rate.

Table 8. Grain yield of IR66 as affected by P source and application rate. Bugallon, Pangasinan, Philippines, 1988.

Treatment[a] (kg P/ha)		Grain yield (t/ha) Late DS	WS
No fertilizer (control)		1.7 h	1.4 f
No P fertilizer		2.8 fg	1.7 e
TSP	10	4.2 a	1.8 e
	20	4.0 a	2.0 b-e
	30	4.1 a	2.2 a-d
	40	–	2.4 a
NCPR[b]	10	3.1 efg	1.9 cde
	20	3.2 defg	1.8 e
	30	3.3 b-f	1.8 e
	40	–	1.9 cde
PAPR (15%)	10	2.6 g	2.0 b-e
	20	3.3 b-f	1.9 cde
	30	3.2 defg	1.9 cde
	40	–	2.0 b-e
PAPR (30%)	10	3.2 defg	1.9 cde
	20	3.5 a-e	2.3 ab
	30	3.5 a-e	1.9 cde
	40	–	1.9 cde
LRP (guano)	20	3.8 a-d	1.9 cde
	30	4.2 a	2.0 b-e
	40	3.9 abc	2.2 a-d
	60	–	2.2 a-d
CV (%)		10	11

[a]TSP = triple superphosphate, NCPR = North Carolina phosphate rock, PAPR = partially acidulated phosphate rock, LRP = less reactive phosphate. [b]Morocco phosphate rock was used in WS.

Yields were poor in WS because a typhoon caused the crop to lodge 1 wk before harvest. Also, strong winds at flowering caused high sterility percentage in the crop. However, a significant P response of 0.7 t/ha was recorded with TSP at 40 kg/ha.

In both seasons, TSP and LRP were equally effective and produced comparatively higher yields than did the other sources. Therefore, LRP can be used at lower cost than TSP in some soils.

BALANCED NUTRITION IN LOWLAND NUTRIENT-DEFICIENT SOIL

Urea, TSP, and KCl are effective high-grade fertilizers that are cheap sources of N, P, and K, respectively. However, their continuous use contributes to S deficiency. Thus, an experiment in Bugallon, Pangasinan, during the 1988 cropping seasons studied the effectiveness of S-containing complete fertilizers in increasing the grain yield of lowland rice. Table 9 shows the characteristics of the top 20-cm soil layer at the site. The soil used was N-, P-, and K-deficient but S-sufficient.

Table 9. Properties of the upper 0- to 20-cm depth of a nutrient-deficient silty loam soil. Bugallon, Pangasinan, Philippines, 1988.

Soil property	Value
pH (1:1, soil:water)	5.2
Organic C (%)	1.8
Total N (%)	0.15
CEC (meq/100 g soil)	26
Available P (ppm)	
Bray 2	15
Olsen	0.98
Exchangeable K (meq/100 g soil)	0.007
Available Zn (K&P, ppm)	1.18
Sulfate S (ppm)	21

In DS, 120 kg N/ha was applied as 2/3 broadcast and incorporated into mud at 1 d before transplanting + 1/3 topdressed at 5-7 d before PI. P, K, and S fertilizers were applied during DS and WS (Table 10) with the first N application. In WS, a total of 60 kg N/ha was applied.

Yields were highest in both seasons with either NPKS or NPK (Table 10). Yield responses to P (NPKS vs NKS) and K (NPKS vs NPS) applications were significant. N application (NPKS vs PKS) did not significantly increase grain yields because of high initial N fertility (total N 0.15%). Yields were low because of late planting.

Table 10. Grain yield response of IR66 to N, P, K, and S application to a nutrient-deficient soil. Bugallon, Pangasinan, Philippines, 1988 late DS and late WS.

Source	Elements supplied[a]	Grain yield[b] (t/ha) DS	WS
9-20-20 + 7.5% S	NPKS	4.3 a	2.8 a
TSP + KCl + gypsum	PKS	3.6 ab	2.7 ab
Urea + KCl + gypsum	NKS	3.3 b	2.2 c
38-5-0 + 4% S	NPS	3.3 b	2.1 c
Urea + TSP + KCl	NPK	4.0 ab	3.1 a
Urea + TSP	NP	3.3 b	2.3 bc
Urea + KCl	NK	3.6 ab	2.3 bc
Control	None	2.4 c	1.1 d

[a]Urea, TSP, KCl, and gypsum were added to a total of 120-26-50-25 kg NPKS/ha, respectively, in DS; and to a total of 60-13-25-25 NPKS/ha, respectively, in WS. [b]CV = 14% in DS and 12% in WS.

LONG-TERM SULFUR FERTILITY TRIAL

The experiment on the effects of continuous application of high-analysis fertilizers (urea, TSP, and KCl) on rice grown in a clay soil was continued at IRRI during 1988 DS and WS (12th and 13th crops).

In DS, application of N fertilizer in combination with other nutrients produced higher number of tillers and grain yield increases over the control (Table 11). The same trends had been observed in previous years, indicating that N remains limiting. Zn fertilizer applied alone or with P, K, or both gave no response. The yield from NK + Zn was higher than from NP + Zn, suggesting that N and K were more limiting than NP. Despite the use of high-analysis fertilizers containing almost no S, S deficiency is not yet apparent.

There was no response in all the treatments during WS because of heavy rains at the crop reproductive phase.

Table 11. Yield of 15 treatments in the long-term S fertility trial with irrigated IR66 rice. IRRI, 1988 DS.

Treatment[a]	Tillers (no./m²)	Grain yield (t/ha)
Control	268 b	2.9 c
Zn alone	260 b	2.9 c
N + Zn	393 a	4.5 ab
P + Zn	285 b	3.0 c
K + Zn	246 b	2.8 c
NP + Zn	421 a	4.0 b
NK + Zn	369 a	4.7 a
PK + Zn	274 b	3.0 c
NPK + Zn	415 a	4.6 ab
NPK only	379 a	4.4 ab
NPK + S	418 a	4.3 ab
NPK + Zn + S	427 a	4.2 ab
NPK + azolla + S	418 a	4.3 ab
NPK + straw + S	364 a	4.2 ab
NPK only	403 a	4.4 ab

[a] Zn as root dip in 4% ZnO solution, S as urea-S at 40 kg S/ha.

Soil and crop management

Rice crop cultural practices

Agronomy, Entomology, Plant Physiology, Soils, and Statistics Departments; Universities of Hamburg and Giessen, Germany; Dairy Training and Research Institute, University of the Philippines at Los Baños; and Thailand Department of Agriculture

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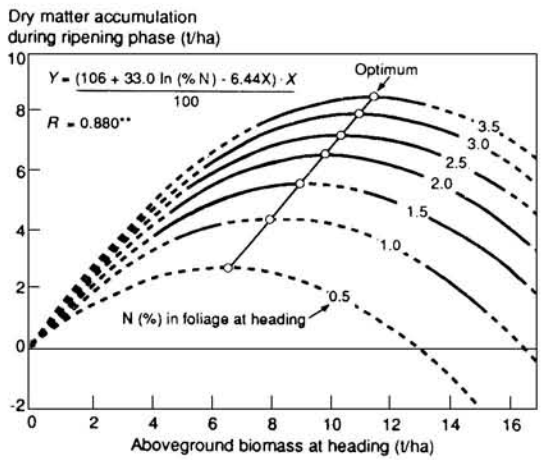
FACTORS LIMITING GROWTH OF DIRECT SEEDED FLOODED AND TRANSPLANTED RICE DURING THE REPRODUCTIVE PHASE

Agronomy Department and Universities of Hamburg and Giessen, Germany

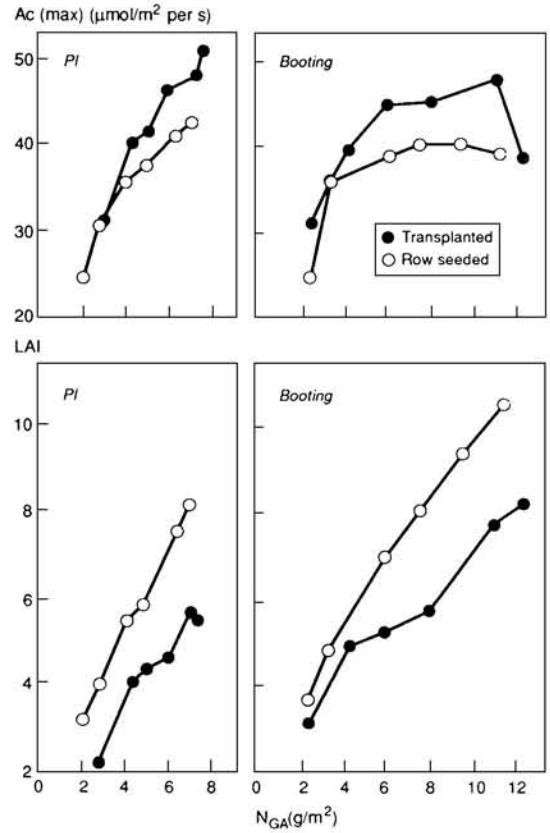
Cooperative research between IRRI and the Universities of Hamburg and Giessen, Germany, indicated that the vegetative growth and yield potential of direct seeded flooded rice are superior to those of transplanted rice (TPR). But since crop growth rate during ripening is low in direct seeded planted rice, potential grain production has not been achieved. Analyses of canopy CO_2 assimilation, growth kinetics, and tissue N concentration now provide a better understanding of this phenomenon.

Total rice dry matter (DM) produced during ripening was a function of aboveground biomass and foliage N concentration at heading, irrespective of planting technique (transplanted or direct seeded into puddled soil) or genotype (IR64, IR58, and IR29723-113-3-2-1) (Fig. 1). When plant biomass exceeded the optimum, further DM accumulation during ripening was impeded by high maintenance respiration and, hence, reduced growth efficiency. Increased foliage N concentration at heading, however, promoted growth during ripening even when DM at heading was high.

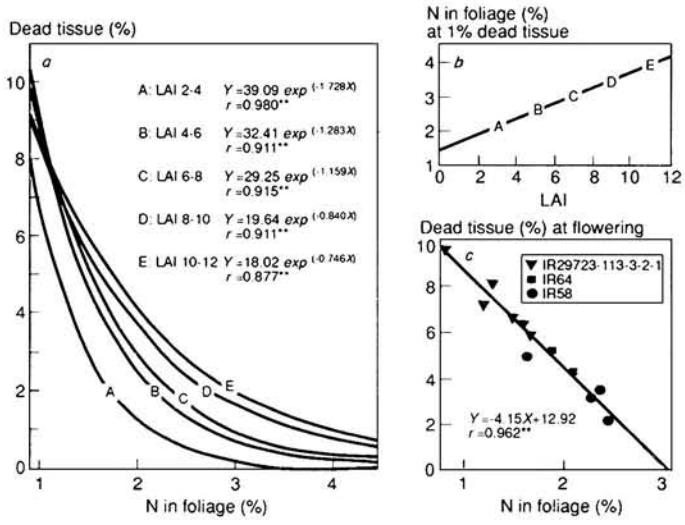


1. Relationship among biomass growth during ripening, foliage N concentration, and aboveground biomass at heading of direct seeded flooded and transplanted IR58, IR64, and IR29723-113-3-2-1. Muñoz, Nueva Ecija, Philippines, 1988 dry season (DS).

Earlier studies showed that direct seeded flooded rice has lower foliage N concentration but higher plant biomass than TPR during most growth stages. These observations can now be understood using the relationship shown in Figure 1. High vegetative growth in direct seeded (row seeded) flooded rice caused N dilution in the plant's tissues, including the foliage (Fig. 2). At a given amount of N present in the foliage (N_{GA}), direct seeded flooded rice produced a significantly higher leaf area index (LAI). This, in turn, led to a reduction of net CO_2 assimilation rates of the canopy, particularly during the reproductive phase. Low foliage N concentration in combination with high LAI promoted tissue death, hastening senescence (Fig. 3). At flowering, the proportion of dead tissue in the shoot varied between 2 and 10%, depending linearly on foliage N concentration.



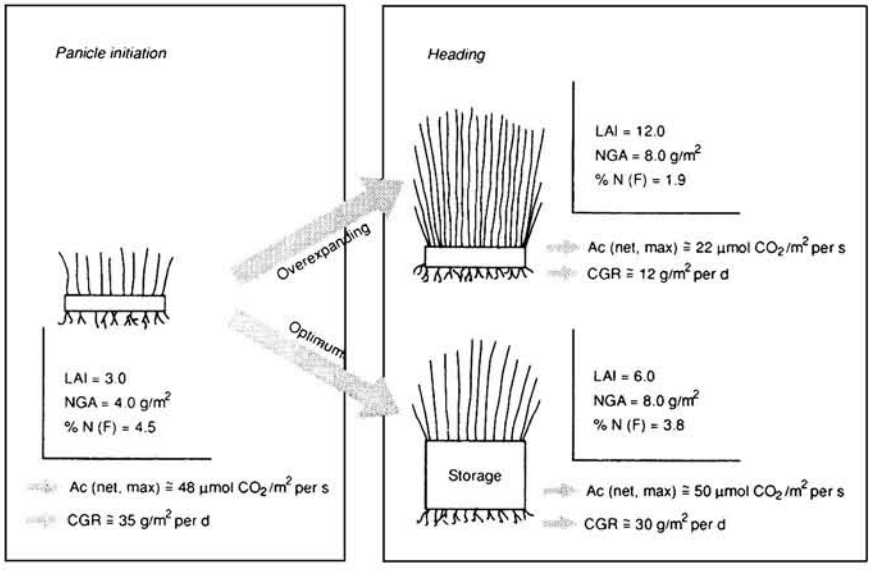
2. Maximum canopy photosynthesis (Ac) and leaf area index (LAI) as affected by foliage N content per ground area (N_{GA}) in transplanted and row-seeded IR64 at panicle initiation (PI) and booting. Muñoz, Nueva Ecija, Philippines, 1988 DS.



3. a) Relationship between dead shoot tissue (gravimetric) and foliage N concentration at various LAIs across 3 genotypes and various cultural practices. b) Tissue death threshold as affected by LAI. c) Relationship at flowering. Muñoz, Nueva Ecija, Philippines, 1988 DS.

With increased LAI, higher foliage N concentration was needed to prevent tissue senescence.

We conclude that DM accumulation during ripening and, thus, grain yield of direct seeded flooded rice can be improved if leaf area is limited during reproductive growth and is accompanied by an increase in foliage N concentration (Fig. 4). Vegetative biomass production during this growth period should not be channeled into further expansion of the foliage but instead should be allocated to remobilizable vegetative storage tissues in the stems and leaf sheaths. This concept of assimilate and N partitioning in the rice plant may increase gross photosynthesis and growth effi-



4. Diagram of the effect of foliage overexpansion on crop growth rate (CGR) in rice. IRRI, 1988.

ciency, delay senescence, and, thus, enable higher harvest index and grain yield in direct seeded flooded rice.

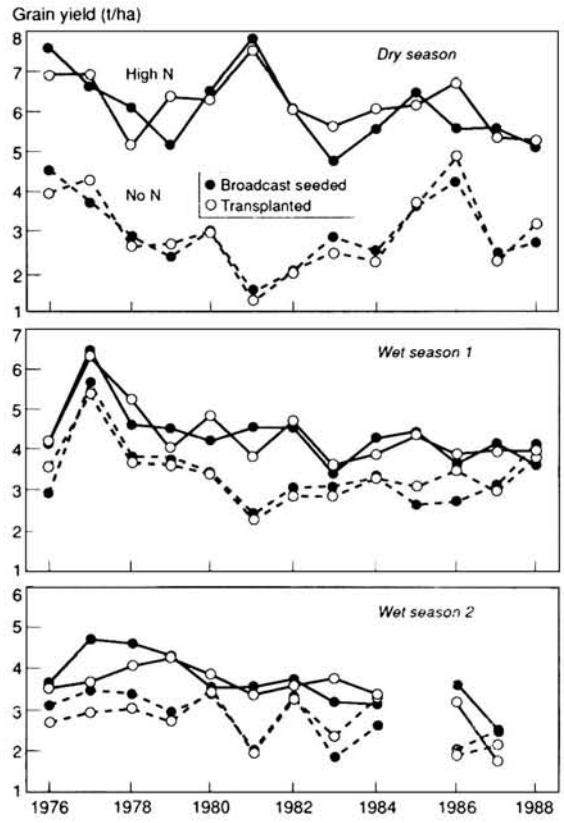
CONTINUOUS CROPPING

Agronomy Department

The continuous cropping experiment compared TPR and broadcast seeded crop establishment methods using seven rices at four N rates. Three crops were grown each year.

The 74th crop (2d wet season [WS]) was harvested from December 1987 to January 1988, the 75th crop (dry season [DS]) in May 1988, and the 76th crop (1st WS) in September 1988. Yields in DS were higher than those in WS (Table 1). The first WS crop produced higher yields than did the second WS crop.

Among the rice entries, IR8 and IR36 were extensively tested. IR8, however, was often infected with tungro (RTV). Figure 5 shows that with or without fertilizer application, the two crop establishment methods gave similar IR36 grain yields. Yield gain due to fertilizer N application was apparent only in DS (Fig. 6). The low yields during the 74th crop were probably due to a typhoon, bird damage, and RTV.



5. Yields of transplanted and broadcast seeded IR36 with or without N application. IRRI, 1976-88.

EFFECTS OF PLANT GROWTH REGULATORS

Agronomy Department

Research on the effects of synthetic plant growth regulators (PGR)—CGR-811 3% and 5% G, PP-333 25% EC, CCC 40% EC, and HOE-785-03PO3 3% EC—on lodging of short-statured and moderately lodging-resistant IR66 and of tall and moderately lodging-susceptible IR70 continued in 1988.

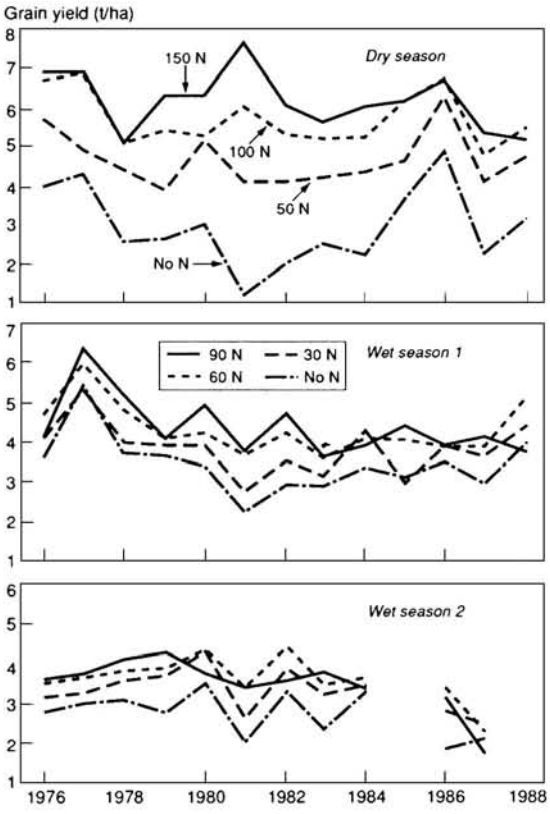
Table 1. Average yields of 7 rices at 4 N rates. Continuous cropping experiment, IRRI, 1987-88.

Variety or line	Yield[a] (t/ha)					
	74th crop (2d WS)		75th crop (DS)		76th crop (1st WS)	
	TPR	BSR	TPR	BSR	TPR	BSR
IR8	2.1	1.9	3.2	2.8	3.6	3.9
IR36	2.2	2.6	4.6	4.1	4.3	4.1
IR58	1.9	2.3	4.2	4.1	3.0	2.8
IR64	2.0	2.3	–	–	–	–
IR25587-133-3-2-2-2	2.6	2.3	4.8	4.3	4.0	3.2
IR32429-47-3-2-2	2.3	2.6	4.3	3.9	4.0	3.2
IR35366-90-3-2-1-2 (IR72)	–	–	5.2	4.8	4.8	4.6

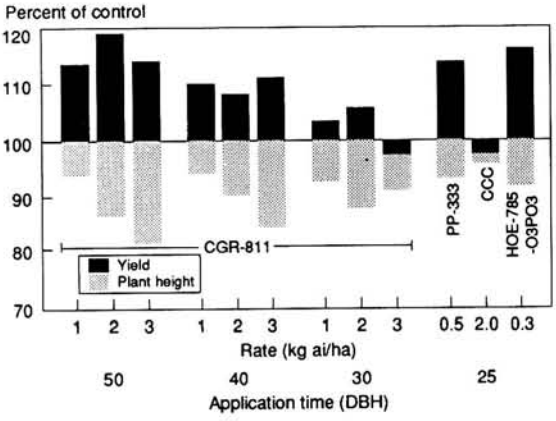
[a] Av of 4 replications. TPR = transplanted rice, BSR = broadcast seeded rice.

Effect on plant height and grain yield. In DS, N fertilizer was applied at 150 kg/ha to induce lodging. CGR-811 at 1, 2, and 3 kg ai/ha was broadcast at 30, 40, and 50 d before heading (DBH). PP-333, CCC, and HOE-785-03PO3 were applied as foliar spray at 0.5, 2, and 0.3 kg ai/ha, respectively, at booting (25 DBH).

Application of PGR reduced IR66 plant height by 4-18% and increased grain yield by 3-14% (Fig. 7). Except for CGR-811 applied at 1 kg ai/ha at 50 DBH, all PGR treatments reduced IR70 plant height and grain yield; plant height decreased with increase in CGR-811 rate, irrespective of application time, followed by a considerable yield decrease.



6. Yields of transplanted IR36 at 4 N rates. IRRI, 1976-88.



7. Effect of plant growth regulators on plant height and grain yield of IR66, IRRI, 1988 DS. DBH = days before heading.

During WS, 3% and 5% granule formulations of CGR-811, and PP-333, CCC, and HOE-785-03PO3 were tested. CGR-811 was applied at 2 kg ai/ha at 40 and 50 DBH. PP-333, CCC, and HOE-785-03PO3 were applied as foliar sprays at 0.5, 2, and 0.3 kg ai/ha, respectively, at booting.

In IR66, all PGRs, except CCC reduced plant height significantly. No PGR significantly affected grain yield, except HOE-785-03PO3, which reduced yield by 0.4 t/ha.

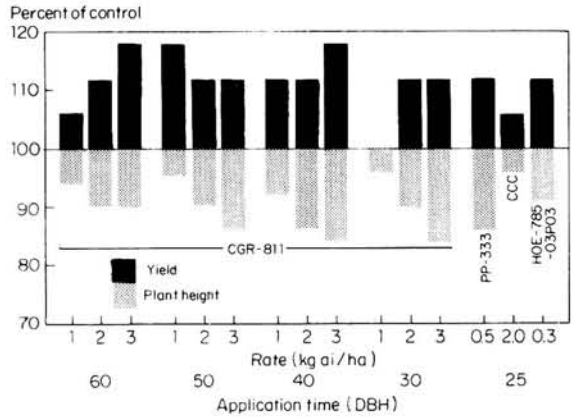
Plant height reduction was more pronounced in IR70. Most PGR treatments significantly reduced plant height by 19%, except CCC (4.4%). Most PGR treatments did not significantly affect grain yield. PP-333 increased yield by 0.3 t/ha.

Effect on lodging. IR66 did not lodge significantly. In IR70, control plants and those treated with CCC lodged significantly. Low yields obtained with both varieties were due to stem rot and a typhoon.

In another experiment, CGR-811 5% G was further evaluated by an additional treatment at 60 DBH. Treatments with PP-333, CCC, and HOE-785-03PO3 remained the same.

CGR-811 at 2 and 3 kg ai/ha effectively reduced IR66 plant height irrespective of application time (Fig. 8). CCC was the least effective liquid PGR in suppressing plant growth.

CGR-811 at 2 and 3 kg ai/ha applied at 30, 40, and 50 DBH suppressed IR70 plant height by 13-17%. Among the liquid PGRs, PP-333 and HOE-785-03PO3 suppressed plant height significantly. Grain yield decreased by 5-19% with CGR-811, the greatest yield reduction (19%) coming from application of 2 kg ai/ha at 40% DBH, 1 kg ai/ha at 30 DBH, and HOE-785-03PO3 applied at booting. PP-333 increased yield by 10%. The yield



8. Effect of plant growth regulators on plant height and grain yield of IR66. IRRI, 1988 WS.

decrease may be attributed to the severe stem rot infection and the effect of a typhoon that occurred during the flowering and dough stages.

EFFECT OF CYTOZYME ON IRRIGATED RICE YIELD

Agronomy Department

Cytozyme is a plant promoter derived from a series of fermentation processes developed and improved by the Cytozyme Laboratories Inc., Salt Lake City, Utah, USA. It contains biologically activated microelements, enzymes, hydrolyzed protein complexes, and microbial metabolites that contribute to the improvement of grain yield.

An experiment was conducted to verify the remarkable results obtained from trials done earlier by the Department of Agriculture and Bureau of Soils.

Three cytozyme plant products—Seed Plus, Soil Plus, and Crop Plus—which are complementary liquid fertilizers, were tested at IRRI and at the Bicol Experiment Station in 1988. Cytozyme treatments were superimposed at 4 N levels: 0, 80, 120, and 160 kg/ha in DS; and 0, 40, 80, and 120 kg/ha in WS. Seed Plus treatment involved soaking seeds in a solution of 1 ml Seed Plus/liter of water per kilogram seeds. Soil Plus was sprayed at the rate of 1.0 liter/ha at 4 d after transplanting (DT) in DS and at 20 DT in WS. Crop Plus was applied as foliar spray at 0.5 liter/ha at 5-7 d before panicle initiation (DBPI) during DS. The application rate in WS was 0.3 liter/ha each at 15 DT and at 5-7 DBPI.

At IRRI, grain yield increased with increasing N application rate. Cytozyme treatments did not significantly affect grain yields, except that with Crop Plus at 80 kg N/ha, the yield obtained was 0.7 t/ha lower than that of the control.

At the Bicol site, yields were higher (5.3-5.9 t/ha) than at IRRI irrespective of N rate. Cytozyme treatments increased yields, though non-significantly, only up to 80 kg N/ha application.

EFFECT OF WATER DEFICIT AND WEED DENSITY ON IR36 AND *ECHINOCHLOA GLABRESCENS*

Agronomy Department

Weeds compete with rice for water, nutrients, sunlight, and other growth factors. We hypothesized that under limited water availability, competition by weeds can magnify the yield reduction effects of water deficit and that weed control can reduce the water deficit effects on rice yields. A field experiment during 1988 DS studied the water relations of rice and weeds under well-watered and water-deficit lowland conditions.

The experiment used a split-plot design with 3 water regimes as main plot treatments: 1) continuously flooded, 2) water withheld from 20 to 45 DT, 3) and water withheld from 50 to 75 DT. Subplot treatments were 3 densities of *Echinochloa glabrescens,* 0, 10, and 20 weeds/m^2: imposed by transplanting 10-d-old weed seedlings at 3 DT. *E. glabrescens* had apparent advantages over rice. Weeds were taller, produced more tillers, and maintained higher leaf water potential (LWP) throughout the growing period.

Total dry weight of both IR36 and *E. glabrescens* was reduced by water deficit at 20-45 DT (Fig. 9). Competition exerted by *E. glabrescens* reduced the dry weight of IR36 even under continuously flooded conditions. *E. glabrescens* was less affected than was rice by water deficit treatments.

Continuous flooding gave the highest grain yield, and water deficit at 20-45 DT the lowest (Fig. 10). Compared with yields of continuously flooded plants, grain yields of plants stressed at 20-45 DT were 70, 38, and 41% at 0, 10, and 20 weeds/m^2, respectively.

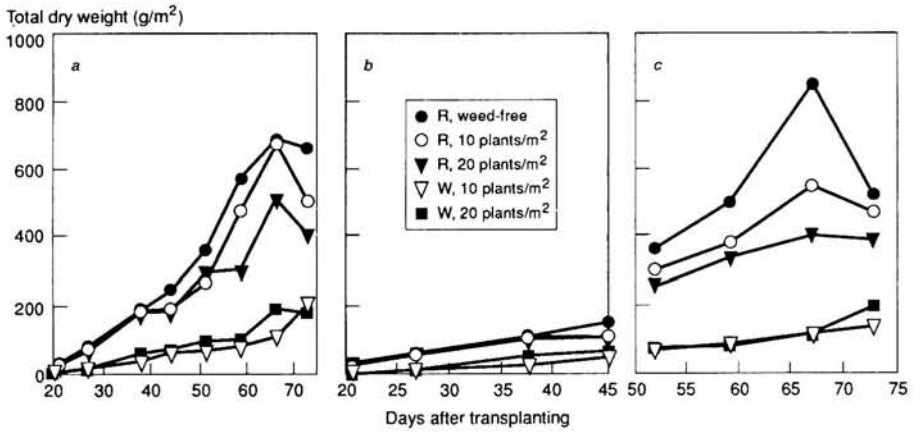
Plants stressed at 50-75 DT yielded 83, 72, and 63% of the control, respectively.

Despite water deficit conditions at 20-45 DT or 50-75 DT, total DM of *E. glabrescens* at harvest was 80-83% at 10 plants/m^2 and 71-92% at 20 plants/m^2 compared with continuously flooded conditions (Fig. 11). This capacity to accumulate DM even under drought stress shows *E. glabrescens*'s ability to compete for resources that could otherwise have been used by rice.

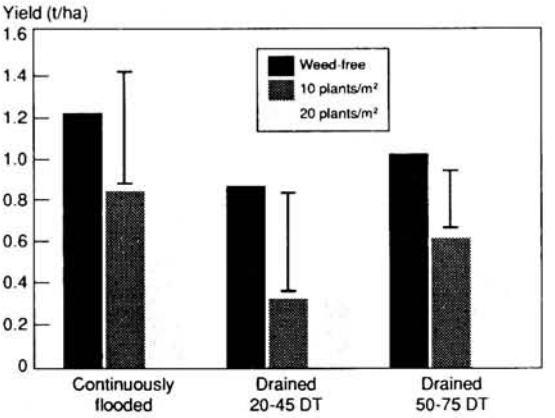
CONSERVATION OF RICE FORAGE AS SILAGE

Plant Physiology Department; and Dairy Training and Research Institute, University of the Philippines at Los Baños

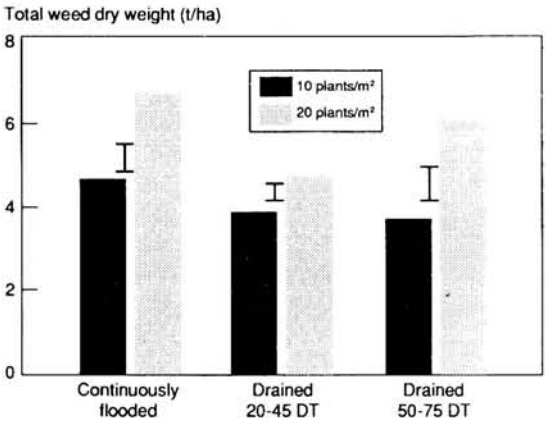
Rice forage from B4259, a long-duration variety, pruned at 30, 40, 50, 60, 70, and 80 DT, was



9. Effect of water regime and weed population on total dry weight of IR36 and *E. glabrescens* when a) continuously flooded, b) drained from 20 to 45 DT, or c) drained from 50 to 75 DT. IRRI, 1988. R = rice at 20 x 20 cm, W = weeds.



10. Effect of water regime and weed population on grain yield of IR36. IRRI, 1988 DS.



11. Effect of water regime and weed population on total dry weight of *E. glabrescens* at harvest. IRRI, 1988 DS.

conserved as silage using 5 treatments in 1-liter bottles: control (no additive), 5% molasses, 10% molasses, 10% maize, and 20% maize. The crude protein content of rice forage cut 15 cm above the ground decreased from 25.2% at 30 DT to 7.7% at 80 DT, but the crude fiber and N-free extract increased as the plant matured (Table 2).

Conservation of rice forage as silage showed that rice forage cut at 50-80 DT can be ensiled successfully without pretreatment with molasses (5 or 10%) or maize (10 or 20%). Ensiling at the earlier stage of 40 DT is acceptable with addition of either 5-10% molasses or 10-20% maize, as reflected by low pH and good levels of crude protein (Table 3). The spoilage percentage in terms of dry weight of rice forage ensiled for 1 mo was not significantly different among treatments cut at 30, 40, 60, and 70 DT. A higher spoilage percentage was found in rice forage cut at 50 DT treated with 10% molasses and at 80 DT treated with 5% molasses.

INTERACTIONS OF PHYSICAL, NUTRITIONAL, AND BIOLOGICAL STRESSES IN IRRIGATED TRANSPLANTED RICE

Agronomy, Entomology, Plant Pathology, Soils, and Statistics Departments

When rice suffers more than one growth-limiting stress simultaneously, the stresses may interact. The rice then experiences a decrease in growth and yield that is proportionately larger than the

product of the decreases caused by the individual stresses acting alone. Management that alleviates one particular stress might therefore have increased benefit by also lessening the decrease in growth caused by the associated interactions. To test this hypothesis for transplanted IR62 rice under realistic field conditions, a multidisciplinary team of agronomists, entomologists, plant

Table 2. Proximate composition of rice forage cut at different days after transplanting (DT) (dry matter basis).[a] IRRI, 1988.

Item	Percent at given cutting time (DT)					
	30	40	50	60	70	80
Crude protein	25.2 a	20.8 b	10.1 c	10.1 c	10.1 c	7.7 d
Ether extract	2.0 a	2.4 a	1.8 a	1.7 a	1.8 a	1.5 a
Crude fiber	22.7 d	25.0 c	33.0 a	33.6 a	31.7 b	33.2 a
Ash	17.5 b	18.5 a	16.1 c	17.1 b	16.1 c	16.1 c
N-free extract	32.5 c	33.1 c	38.0 b	37.4 b	40.4 a	41.4 a

[a] In a row, means followed by the same letter are not significantly different at the 5% level by DMRT.

Table 3. Proximate composition of rice silage as affected by cutting age and ensiling treatment (after 1 mo ensiling). IRRI, 1988.

Cutting age (DT)	Treatment (additive)	Percent[a]				
		CP	CF	EE	Ash	NFE
30	Control	22.3 b	22.3 a	5.9 a	20.7 a	28.8 a
	5% molasses	23.7 a	20.3 b	5.3 ab	18.1 b	32.6 b
	10% molasses	22.1 b	19.2 c	5.7 a	17.6 c	35.5 c
	10% maize	19.3 c	16.4 d	5.6 a	14.9 d	43.8 d
	20% maize	17.1 d	13.2 e	4.8 b	10.4 e	54.5 e
40	Control	16.9 a	25.6 a	4.5 ab	21.9 a	31.0 a
	5% molasses	16.4 a	21.8 b	4.9 a	20.6 b	36.2 b
	10% molasses	16.6 a	22.1 b	4.9 a	19.8 c	36.5 b
	10% maize	17.1 a	16.6 c	5.1 a	15.7 d	45.5 c
	20% maize	14.4 b	12.7 d	4.1 b	10.5 e	58.3 d
50	Control	10.9 ab	32.5 a	4.2 ab	20.7 a	31.7 a
	5% molasses	11.2 ab	30.6 b	4.8 a	17.7 b	35.8 b
	10% molasses	11.6 a	27.6 c	4.6 a	17.7 c	39.5 c
	10% maize	10.4 b	19.5 d	3.8 bc	14.6 d	51.8 d
	20% maize	10.5 ab	18.6 e	3.2 a	11.2 e	56.5 e
60	Control	9.1 c	33.1 a	2.4 b	18.3 a	36.9 a
	5% molasses	7.8 d	29.3 b	3.6 a	17.2 b	42.1 b
	10% molasses	11.4 a	26.1 c	3.5 a	16.4 c	42.6 b
	10% maize	9.9 b	25.4 c	3.0 ab	15.1 d	46.7 c
	20% maize	8.1 d	16.8 d	2.5 b	9.3 e	63.3 d
70	Control	10.3 a	34.5 a	3.3 ab	19.3 a	33.0 a
	5% molasses	10.3 a	30.4 b	3.8 a	17.7 b	37.8 b
	10% molasses	10.8 a	27.8 c	3.1 b	17.7 b	40.6 c
	10% maize	10.4 a	24.7 d	3.0 b	14.0 c	47.9 d
	20% maize	10.4 a	32.6 e	2.9 b	12.4 d	50.7 e
80	Control	7.3 b	34.1 a	1.9 b	18.7 a	38.0 a
	5% molasses	7.4 b	30.0 b	2.8 a	16.4 b	42.9 b
	10% molasses	7.2 b	26.3 c	1.9 b	16.5 b	48.0 c
	10% maize	7.6 ab	24.4 d	1.9 b	14.5 c	51.6 d
	20% maize	8.3 a	16.6 e	1.7 b	8.7 d	66.7 e

[a] CP = crude protein, CF = crude fiber, EE = ether extract, NFE = N-free extract. In a column within a cutting age, means followed by the same letter are not significantly different at the 5% level by DMRT.

pathologists, statisticians, soil chemists, and soil physicists conducted during 1987-88 three multifactor interaction experiments to determine the magnitude of such interactions and also to make supporting measurements to understand their mechanisms.

In each experiment, five stresses were imposed --water, nutritional (Zn), insect (stem borer), pathogen, and weed stresses -- each at two levels: no stress as far as practicable and a realistic field stress. All 32 combinations of stresses were tested, each with 5 replications. Water stress was imposed through a scheduled withholding of irrigation; nonstressed plots were fully irrigated. Stem borer damage was simulated by artificial defoliation of a chosen proportion of tillers. Zn stress occurs naturally at the test site and was relieved for nonstressed plants by dipping seedlings in ZnO. Pathogen stresses were generated by natural infections; nonstressed plants were treated with fungicides. In the first and second experiments, weed stress was generated through natural infestations, but in the third experiment weeds were deliberately transplanted among the rice plants to increase weed stress, while nonstressed plants were hand-weeded.

In the 3 experiments, nonstressed plants yielded 5.9, 5.7, and 5.5 t/ha each ±0.2 t/ha. Water stress was maximal at panicle initiation (PI) in the first experiment, at PI and at flowering in the second experiment, and at mid-ripening in the third experiment; the percentages of yield losses caused by water stress were respectively 55±1, 49±1, and 34±2%. Losses caused by simulated stem borers were 51, 9, and 13% (each ±2%); by weeds: 6, 3, and 34% (±1%); by pathogens: 13, 4, and 4% (±2%); and by Zn deficiency: 2, 0, and 1% (±2%). The combination of all stresses decreased yields by 84±12, 57±4, and 67±4%. In experiments where 2 or more factors each separately decreased yield by 9% or more, the experimental precision was sufficient to allow the detection of interactions of stresses.

In the first experiment, pathogens decreased the yield of fully irrigated plants by 9±3%; but when plants were water stressed, pathogens caused a yield loss (separate from the 55% caused by water stress) of 17±4%. For a farmer, the practical interpretation of this result is that, for the particular levels of water and pathogen stresses that occurred in this experiment, irrigation management to prevent the water stress would give pathogen-free plants a yield of 2.12±0.08 times that of water-stressed plants; correspondingly, effective control of pathogens would raise the yield of fully watered plants to 1.09±0.03 times that of pathogen-affected plants; the product of these two factors (2.12 × 1.09) would imply that the yield of fully irrigated pathogen-controlled plants should be 2.32±0.10 times that of plants suffering both water stress and pathogen stress. In fact, the ratio of yields was 2.43±0.08. This increase, by 0.11±0.13, indicates a "bonus" from the integration of effective irrigation and pathogen control equal to 5±6% (or 0.12±0.14 t/ha) more production. Furthermore, though the absolute yield response to pathogen control was equal, at 0.44±0.13 t/ha, for both irrigated and water-stressed plants, the higher proportional increase for water-stressed (17%) than for irrigated plants (9%) indicates that for farms with less reliable irrigation, or for rainfed lowland farms, the yield response to pathogen control is proportionately more rewarding than for fully irrigated farms.

In the second experiment, detillering decreased the yield of fully irrigated plants by 7±2% and of water stressed plants by 11±1%. Correspondingly, our simulated control of stem borers (no detillering) gave for fully irrigated plants a yield 1.08±0.02 times that of detillered plants; and for stem borer-free plants, irrigation to prevent the water stress raised yield to 1.91±0.03 times that of water-stressed plants. The product of these two factors is 2.06±0.05; but the yield of irrigated, non-detillered (stem borer-free) plants was 2.13±0.03 times that of water-stressed, detillered plants. The 0.07±0.06 increase indicates an interaction bonus of 3±3% (or 0.08±0.08 t/ha) extra production.

In the third experiment, water and weed stresses and simulated stem borers each gave effects large enough to reveal interactions. The effect of weeds (with high population achieved by weed transplants) was to decrease yields of non-detillered plants by 34±4%. Correspondingly, for non-detillered plants, yield on plots without weeds was 1.52±0.09 times that on weed-transplanted plots. Similarly, for weed-free plots, the yield of non-detillered plants was 1.08±0.01 times that of detillered plants. The product of these factors is

1.63±0.10. But the yield on weed-free, non-detillered plots was 1.79±0.12 times that on weed-infested, detillered plots. The increase of 0.16±0.16 represents an interaction effect of 10±10% (or 0.4±0.4 t/ha) additional yield.

Through differential reaction with water stress, those same transplanted weeds caused a yield decrease of 30±1% for irrigated plants and of 38±3% for water-stressed plants. Conversely, water stress decreased yield on weed-free plots by 28±1%, and on weed-transplanted plots by 39±2%. Thus, for weed-free plots, irrigation that prevented the water stress gave a yield 1.42±0.02 times that of water-stressed plants. And with irrigation, yield on plots without weeds was 1.43±0.02 times that on weed-transplanted plots. The product of the factors is 2.02±0.05. The irrigated, weed-free plots had a yield 2.27±0.11 times that of water- and weed-stressed plants. The difference of 0.25±0.12 represents a yield benefit of 12±6% or 0.4±0.2 t/ha from the interaction between weed and water management.

The three experiments thus detected four positive interactions among physical and biological stresses that individually decreased the non-stressed yield by at least 9%. Moreover, in 18 instances during the experiments, a stress that caused less than 9% yield loss was imposed in combination with a stress causing a larger loss. Though the interactions generated by these latter combinations were not individually statistically significant, 12 of the interactions were positive and only 6 negative, and their overall average interactive effect was to decrease production by about 25% of the average of the yield decreases caused by the weaker stresses acting separately. It must, however, be reported that one major interaction—between irrigation and detillering in the first experiment—was significantly negative in that detillered plants yielded less when irrigated than when water-stressed. This effect was possibly a spurious consequence of the method of detillering, which comprised injection of herbicide into the chosen tillers. The translocation of the herbicide, and its effectiveness in killing tillers and lessening growth and yield may have been enhanced by the stronger transpirational water stream within irrigated than within water-stressed plants. (In the second and third experiments, detillering was mechanical, not chemical.) But of the many positive interactions, those between weed and pathogen stresses, and between weeds and detillering were each positive in all three experiments. It may be that the pathogens and detillerings each lessened rice leaf area, thereby permitted more solar irradiance, and thus increased competitiveness to the weeds.

For rice farmers, especially rainfed lowland farmers, the findings of these experiments imply that they should not only manage their rice to prevent or avoid physical and biological stresses, but should also seek to ensure through integrated management that such stresses do not occur simultaneously. Our series of experiments showed that careful designs and high precision are needed to determine the magnitudes of interactions. Future research programs need to examine more intensely the major interactions of pairs or triplets of stresses, and to examine them at a greater number of stress levels than has so far been possible.

DROUGHT RESISTANCE IN UPLAND RICE AS AFFECTED BY PHOSPHORUS PLACEMENT

Agronomy Department

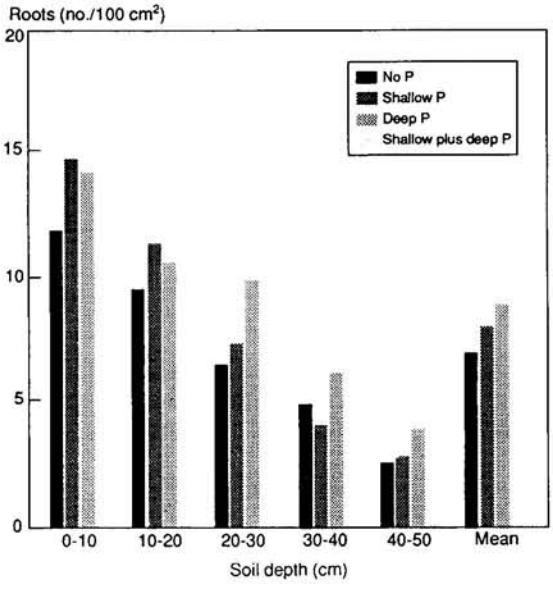
Acid soils generally have higher P-fixing capacity than other soils. In acid soils, added P fertilizers show little movement to lower soil depths. P availability decreases as soil moisture decreases, so P fertilizers in dry soil layers near the soil surface are mostly unavailable to the plant. Therefore, deep placement of P fertilizers may allow P uptake even if the surface soil layers are dry. Deep P placement may also stimulate deeper root growth and, therefore, better drought resistance.

To evaluate the effects of P placement on root growth and drought resistance, an experiment was conducted in Cavinti, Laguna, Philippines, during 1988 WS. The soil was an Orthoxic Palehumult with pH of 4.6 and 10 ppm available P.

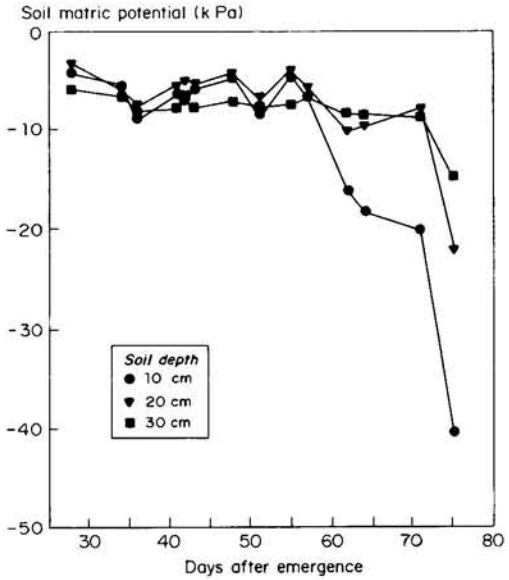
Four P fertilizer treatments were imposed: 1) no P applied (P0), 2) shallow P (PS) at 50 kg P/ha (triple superphosphate) banded beneath the rice rows in the top 5 cm of the soil, 3) deep P (PD) at 50 kg P/ha applied in bands 40 cm apart between pairs of rice rows, and 4) shallow plus deep P (PSD) at 25 kg P/ha placed at 25 cm soil depth plus 25 kg P/ha banded in the top 5 cm of the soil.

Root distribution was determined from soil profiles using a 10- × 10-cm grid. The mean number of roots across all depths was lowest for P0 (Fig. 12). From 20 to 50 cm soil depth, PD had the most roots. Thus, deep P placement enhanced root growth in deeper soil layers.

Based on the soil matric potential (Fig. 13), water deficit occurred from 60 to 80 d after emergence (DE) and was most severe in the upper soil layers. Because plants in treatments with deep-placed P had more roots in the deeper, wetter soil layers, they should have been better able to withstand water deficit than plants in the P0 and PS treatments.



12. Effect of P placement on root number of IR64. Cavinti, Laguna, Philippines, 1988 WS.



13. Soil matric potential at 3 depths. Cavinti, Laguna, Philippines, 1988 WS.

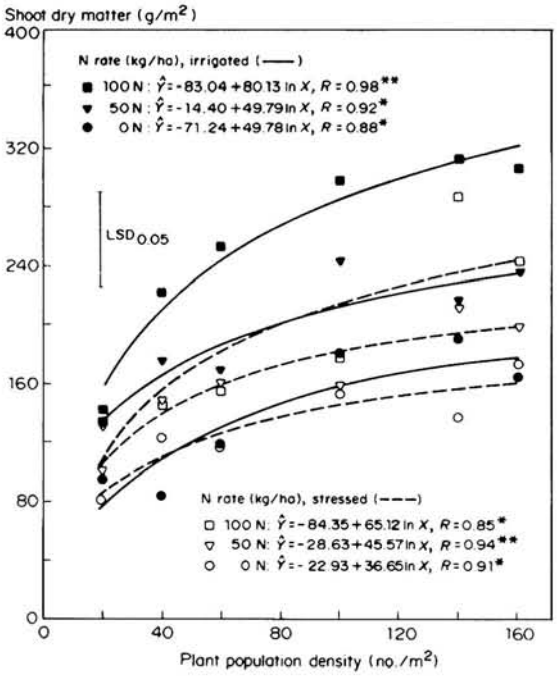
IRRIGATION AND NITROGEN FERTILIZATION EFFECTS ON UPLAND RICE YIELD ACROSS A PLANTING DENSITY GRADIENT

Agronomy Department

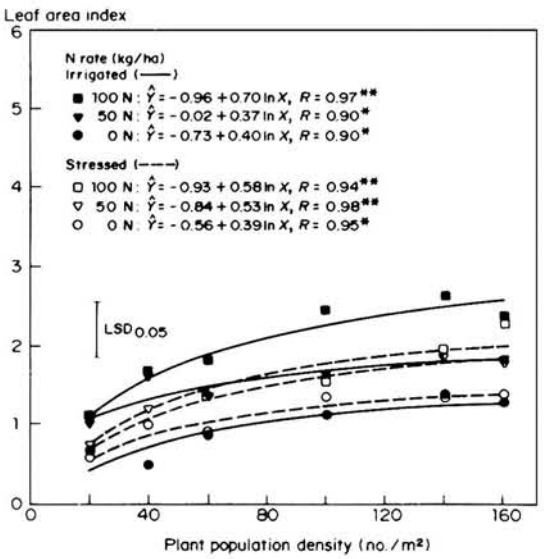
A follow-up study to that described in the Annual report for 1987 was conducted in 1988 DS. Unlike in the previous year, OS4, a deep-rooted, moderately drought-tolerant cultivar from Africa, was used. The previous experiment was arranged in a fan design, but this trial used rectangular plots (2 × 5 m) in a split-plot design. Main plot treatments were two irrigation levels (drought-stressed and well-watered). Subplot treatments were factorial combinations of 3 N levels (0, 50, and 100 kg/ha, one-half applied at seeding and one-half at maximum tillering) and 6 plant population densities ([PPD] 20, 40, 60, 100, 140, and 160 plants/m^2). The entire field was watered with overhead sprinklers. For the drought stress treatment, irrigation was stopped from 18 March to 7 April. Drainage canals were dug around well-watered plots to prevent seepage and runoff from well-watered to stressed plots.

Midday LWP was about 0.5 MPa higher in well-watered than in drought-stressed treatments, but LWP was not significantly influenced by PPD or N fertilization.

Post-stress shoot dry matter (SDM) for well-watered and drought-stressed treatments had similar responses to PPD. Under drought, however, the increase of SDM in response to N fertilization was minimal, even with 100 kg N/ha (Fig. 14). As PPD increased, SDM production leveled off above 100 plants/m^2 for well-watered plants and above 60 plants/m^2 for drought-stressed plants. Treatment effects on LAI were similar to those on SDM (Fig. 15). Although SDM responded to both PPD and N application, these responses



14. Shoot dry matter production in response to irrigation and N fertilization across a planting density gradient, IRRI, 1988. LSD 0.05 = for any combination of irrigation and N under same PPD. Significant at the 1% (**) or 5% (*) level.



15. LAI in response to irrigation and N fertilization across a planting density gradient, IRRI, 1988. LSD 0.05 = for any combination of irrigation and N under same PPD. Significant at the 1% (**) or 5% (*) level.

were not translated into yields. Overall, yields were very low, partly because of pest and disease incidence, and partly because OS4 seems to have a very low yield potential.

Observations confirm results of the previous study. Under both drought and well-watered conditions, farmers should try to maintain PPD of at least 100 plants/m². Below that, weed pressure is very strong, and there seems to be no increase in water available per plant. Under well-watered conditions, farmers should apply N only at high PPD; under drought conditions there is little advantage to N application.

PRODUCTION OF UPLAND CROP + DEEPWATER RICE INTERCROPS WITH CONCURRENT OR DELAYED SOWING OF DEEPWATER RICE

Agronomy Department; and Department of Agriculture, Thailand

Deepwater rice (DWR) variety HTA60 was sown at the same time or broadcast at 75 DE of 3 upland crops using the intercrop combinations and checks shown in Table 4. Mungbean (variety Uthong 1) was grown with DWR as a broadcast mixture, as pairs of rows at 1-m centers in broadcast DWR, or as 2 rows alternating with 2 rows of DWR. Rows were 25 cm apart. Double rows of red sesame or single rows of sunflower (Hysun 33) were also alternated with double rows of DWR (1 m between centers). Where DWR was broadcast at 75 DE, there was 75 cm between single rows of sunflower or between centers of pairs of sesame and mungbean. Broadcast DWR covered whole plots. Upland crops and the first sowing of DWR emerged about 7 May. Fertilizer was applied to the upland crops at recommended rates, and weeds were removed by hand.

Yields are given in Table 4 both in absolute amounts and as relative yield (percent of the monoculture of the same crop). For row-sown intercrop treatments, for which only half the area was sown to DWR, DWR had less than 10% decrease with mungbean and sunflower, and 18% reduction with sesame. Broadcast DWR in the intercrops gave higher yields than did DWR sown in rows.

The upland crop yields were similar for both row-sown and broadcast DWR, indicating that when DWR plants were growing within the rows

Table 4. Yields of deepwater rice (DWR) and upland crops when grown as intercrops and mixtures, or when DWR was sown 75 d after emergence (DE) of the upland crop. Huntra Experiment Station, Thailand 1988 WS.

Treatment		Upland crop yield		DWR yield	
Upland crop	DWR	kg/ha	Relative	t/ha	Relative
None	Broadcast	–	–	3.2 ab	100
None	Broadcast at 75 DE	–	–	2.8 bc	90
Mungbean, broadcast	Broadcast	173 b	32	3.4 a	109
Mungbean, rows	Rows	288 b	53	2.9 bc	91
Mungbean, rows	Broadcast	299 b	55	2.9 bc	91
Mungbean, rows	Broadcast at 75 DE	543 a	100	3.2 ab	102
Sunflower, rows	Rows	846 a	69	2.9 bc	93
Sunflower, rows	Broadcast	729 a	60	3.2 ab	104
Sunflower, rows	Broadcast at 75 DE	1221 a	100	2.7 c	87
Sesame, rows	Rows	383 b	59	2.6 c	82
Sesame, rows	Broadcast	365 b	57	2.9 bc	94
Sesame, rows	Broadcast at 75 DE	644 a	100	3.0 a-c	96

of the upland crops the effect of competition from DWR was not greater than when the two species were in separate rows. Yields of the upland crops when DWR was sown at the same time were considerably less than when DWR was broadcast at 75 DE, but wider row spacing was used for upland crops when DWR was sown at the same time, giving 80% of the upland plant population to each unit area.

Returns for gross incomes based on prices at harvest time were highest for upland crops followed by DWR sown at 75 DE, with the highest gross income being obtained with sesame + DWR (67% higher than DWR alone). Because upland yields were no better with row-sown than with broadcast DWR, there appears to be no incentive to go to the extra expense of row sowing DWR. However, while delayed sowing of DWR gave the highest returns in these experiments, it is more risky, and sowing both crops together may be best for areas where floods come early. With intercrops, sowing of the upland crop in rows is better for fertilizer application, pest control, weeding, and harvesting.

Soil and crop management

Tillage and management of soil physical conditions

Soils, Agricultural Engineering, and Agronomy Departments; Istituto per la Chimica del Terreno, Pisa, and Centro Studio Colloidi Suolo, Florence, Italy; University of Minnesota; International Irrigation Management Institute; Philippine Rice Research Institute; Philippine Bureau of Soils; Central Luzon State University, Philippines; and Agency for Agricultural Research and Development, Indonesia

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MANAGEMENT OF WETLAND SOILS FOR RICE

Soils and Agricultural Engineering Departments; Istituto per la Chimica del Terreno, Pisa; Centro Studio Colloidi Suolo, Florence; and Agency for Agricultural Research and Development, Indonesia

Wetland soil manipulation, water percolation, and rice yield (*Soils and Agricultural Engineering, Istituto per la Chimica del Terreno, Centro Studio Colloidi Suolo, Agency for Agricultural Research and Development*). One purpose of the physical manipulation of saturated or submerged riceland soil is to decrease the soil's porosity and hydraulic conductivity and hence lessen the amount of percolation water (rainfall or irrigation) needed to keep the soil continuously saturated through the rice season. Soil manipulation also helps control weeds and lessens soil strength so that rice roots may more easily proliferate. The manipulations and changes of porosity are usually accomplished using plows, harrows, or rotary implements. Additionally, in swelling soils the pretillage submergence of rice soils can cause porosity changes that depend on the soil's clay mineralogy and on the concentration and types of cations in the soil water. As suggested in the Annual report for 1987, animal-powered operations can cause significant porosity changes due to hoof pressure.

Research in 1988 sought to determine the effects on water percolation and infiltration, on soil strength, and on weed and rice production of engine-powered rototilling and of animal-powered plowing and harrowing, and to measure the effects on porosity and water infiltration of pretillage submergence and of soil compression by animal hooves. It sought also to extend and refine our 1987 procedures through which we attempted to predict water infiltration rate (and the effects thereon of soil manipulations) from micromorphometric measurements of widths, lengths, and shapes of soil pores.

Puddling, soil-physical effects, and rice production (*Soils and Agricultural Engineering, Istituto per la Chimica del Terreno, Centro Studio Colloidi Suolo, Agency for Agricultural Research and Development*). Our studies were made on IRRI fields F10 and 218, each with soils of 43% clay. F10 had 22 meq Ca^{++} and 13 meq Mg^{++}/100 g in 0-20 cm depth; and 218 had 18 meq Ca^{++} and 9 meq Mg^{++}. We compared the effects on physical properties and on rice production of conventional puddling by animal-drawn plow and harrow (P+H) and of engine-powered puddling using a 6-kW floating rototiller (FRT). Comparisons were made against nontilled (NT) control treatments, using 4 replications of 4.5- × 5.5-m plots in F10 and 5 replications of 4.0- × 4.5-m in 218—each in randomized complete block design (RCBD). We estimated that the energy imparted per unit ground area by each puddling (with allowance for trampling by the water buffalo hooves) was about 6 kJ/m^2. In each experiment, 20-d-old seedlings of IR58 in F10 and IR36 in 218 were transplanted at 20- × 20-cm spacing. The transplantings and subsequent soil and crop managements and measurements were made from wooden boards raised above the soil surface so that there was no additional energy input or soil disturbance. In F10, rice was transplanted on only one-half of each plot, and water infiltration rates on cropped and noncropped areas were compared. Also on this field, we collected—for porosity and micromorphometric analyses—soil samples at 5-cm increments through 0-25 cm depth immediately before a prepuddling 3-d submergence that followed a 7-d draining that simulated the interlude between successive rice crops; we also collected samples before and after puddling, and at rice harvest. After harvest, the tillage treatments were reimposed using the same RCBD and plot allocations, and the infiltration observations were repeated, but with no sampling for porosity or micromorphometry. In both fields, measurements were made (in 218 in cooperation with an Indonesian colleague) of the proportion of fine particles (silt plus clay) that were made dispersible by the puddling operations, of soil strength by cone penetrometer, and of saturated hydraulic conductivity—using undisturbed soil samples of 7 cm diameter × 7 cm high (5 replications/treatment) taken in increments through 0-40 cm depth and also (in 218 only) using 20-cm-diameter × 20-cm-high samples (3 replications) taken from 0-20 cm.

Values for dispersible silt plus clay (an indicator of the effectiveness of puddling) for both F10 and 218 were about 20% after 1 puddling, and about 40% after a second puddling (F10) (Table 1). Results from F10 for 1985 and 1986 are also

Table 1. Effect of puddling implement on amount of silt-plus-clay dispersed (as fraction by mass of total soil) in 0-10 cm in 2 Vertic Tropaquept silty clays overlying clay loam. IRRI fields F10 and 218, 1985, 1986, and 1988.

Field	Year	Dispersible silt-plus-clay (%) with[a]			
		No tillage	Floating rototiller	Plow and harrow	Standard error (%)
218	1988	15	24	20	3
F10	1988[b]	18	17	19	3
	1988[c]	48	38	41	5
F10	1986[b]	6	19	nm	3
	1986[c]	nm	31	nm	3
F10	1985	13	34	37	3

[a] nm = not measured. [b] After 1 puddling. [c] After 2 puddlings.

consistent with higher dispersion following a second than a first puddling. The reason may be that the submergence maintained between the puddlings caused changes in the dispersiveness of this soil, which is moderately dispersive (Class 3) by Emerson's classification. The hypothesis that the preceding submergence was a cause of high dispersiveness is supported by data presented in the Annual report for 1985, which indicate that, irrespective of puddling energy, F10 plots wetted by prolonged upwelling of groundwater gave higher proportions of dispersed material after rototilling than did plots without upwelling that were wetted only by surface inundation. The farmer practice of prolonged prepuddling submergence, which serves in part to lessen the soil's mechanical strength and consequently the draft force required for tillage operation, may also serve to increase the soil's dispersiveness.

The 3-d submergence (F10) that followed the 7-d draining ahead of the first puddling affected soil porosity. Total porosity ϵ_T (from bulk-density measurements) *decreased* in the 0-5 cm depth by 0.029 ± 0.022 from its presubmergence value of 0.654 ± 0.021; if this change was real, it could indicate a decrease of ϵ_T caused by a movement of dispersed finer particles into some water-transmitting pores of this surface layer. In the 5-20 cm layer, a 0.022 ± 0.010 *increase* in ϵ_T (from 0.596 ± 0.003) represented the increase in void space that occurs during normal swelling.

The effect on porosity of the growing rice crop (and its attendant submergence) was determined by comparing ϵ_T measured at various depths immediately after the first and second puddlings. For nonpuddled plots, ϵ_T in the 10-20 cm depth increased negligibly, but in 0-10 cm it increased by 0.034 ± 0.018, perhaps in response to surface cracking on these plots, which could not be maintained continuously submerged because of rapid water infiltration. For both P+H and FRT, ϵ_T in 5-20 cm decreased between puddlings by 0.023 ± 0.008, perhaps indicating that some pores became partially filled by migrating clay particles or biological residues, and others became smaller because gravitational force caused the soil matrix to settle to a less open structure. But in 0-5 cm, ϵ_T decreased only 0.003 ± 0.011—much less than in the deeper layers, perhaps because of the surface cracking, which, however, penetrated only about 5 cm in the puddled plots as compared with 10 cm in the nonpuddled plots.

Apart from the effects of submergence, the effects on porosity of P+H and FRT in the first puddling were to increase ϵ_T in 0-5 cm by 0.030 ± 0.018 and 0.056 ± 0.015, respectively; in 5-15 cm, P+H and FRT each increased ϵ_T by 0.025 ± 0.007, and in 15-20 cm there was essentially no change in ϵ_T. In the second puddling, P+H and FRT caused lesser increases in ϵ_T than in the first: 0.014 ± 0.018 for P+H and 0.033 ± 0.021 for FRT in 0-5 cm, a possible (compactive) decrease of 0.026 ± 0.010 for both P+H and FRT in 5-15 cm, and a nonsignificant decrease of 0.010 ± 0.032 in 15-20 cm.

However, though many of these changes in total porosity in the 0-15 cm depth were statistically significant (for effects both of submergence and puddling), they had little practical significance. Moreover, from a corresponding experiment in F10 in 1986, recently completed and time-consuming measurements of porosity (using critical-point drying and kerosene-replacement techniques in Florence) showed that in 0-5 cm the combined effect of submergence and either type of puddling was a nonsignificant decrease of total porosity; in 1988, the corresponding effect on ϵ_T (as derived from bulk density) was a nonsignificant increase. Both results would be consistent with a zero change in ϵ_T.

Changes in the *distribution* of porosity among various sizes of pores did have both statistical and

practical significance. Measurements by Hg intrusion (in Florence) showed that in 0-5 cm the porosity contributed by pores of 20-200 μm equivalent diameter (the water-transmitting pores) was 0.070 cm^3/g before tillage and was reduced to 0.030 cm^3/g by P+H (and also by a skid-supported rototiller that was tested in 1986 but not in 1988), and to 0.015 cm^3/g by FRT. Puddling also decreased the porosity from pores of 2-20 μm, and there were consequent increases in porosity from pores smaller than 2 μm.

The changes in distribution of porosity had significant and practical effects on water infiltration rate (I, measured by double-ring infiltrometer and standardized for conditions of water table close to the ground surface). In F10 in 1988, during both the first and second rice crops, I was 180 $\pm$ 10 mm/d for NT, 50 $\pm$ 10 mm/d for FRT, and 20 $\pm$ 5 mm/d for P+H. Corresponding values for 1986 were 14, 14, and 8 mm/d. In 218, rates were respectively 50, 17, and 21 mm/d (all $\pm$ 5 mm/d). The much higher rates in F10 in 1988 probably resulted from a preceding long period of nonsubmergence of the soil, during which fissuring and aggregation of soil may have occurred. In 1988, saturated hydraulic conductivity in F10 in 0-5 cm at 20 d after puddling was of the order of 1,000 mm/d for both FRT and NT plots (though measured only for 1 replication each, which by chance were replications having relatively high infiltration rates); these values are comparable to those for 0-40 cm reported for NT in 1986 dry season (DS).

The effects on I of growing rice (and its associated microorganisms and roots) differed between puddled and nonpuddled soil. In puddled soil, I was essentially unaffected by growing rice; in nonpuddled soil, I was decreased by about 20% by growing rice, perhaps indicating that roots and microorganisms decreased the water-transmitting porosity.

The depths to which the various puddlings affect the soil saturated hydraulic conductivity, and the influence of sample size on measurements of those conductivities, are shown in Table 2. For nonpuddled and puddled soils, conductivity increased with depth through 0-40 cm. For nonpuddled soils, this variation probably represents a legacy of previous puddlings. The effect of puddling extended more deeply for P+H than for FRT, but FRT lessened conductivity in 0-20 cm more effectively than P+H.

Table 2. Effects of puddling implement on water infiltration rate and of implement and sample size on saturated hydraulic conductivity at various soil depths in a Vertic Tropaquept silty clay overlying clay loam. IRRI field 218, 1988.

Soil depth (cm)	Puddling implement and conductivity-sample diameter[a] (cm)					
	No tillage		Floating rototiller		Plow and harrow	
	7[b]	20[c]	7[b]	20[c]	7[b]	20[c]
	Conductivity[d] (mm/d)					
0-10	25	nm	1	nm	9	nm
10-20	27	nm	5	nm	10	nm
20-30	43	nm	12	nm	23	nm
30-40	245	nm	154	nm	62	nm
0-20	26[e]	143	2[e]	2	9[e]	7
20-40	73[f]	400	22[f]	110	34[f]	96
0-40[g]	38	210	4	4	14	13
	Infiltration[h] (mm/d)					
	50		17		21	

[a]nm = not measured. [b]Samples 7-cm diameter X 7-cm high, geometric mean of 5 replications. [c]Samples 20-cm diameter X 20-cm high, geometric means of 5 replications for 0-20 cm and 3 replications for 20-40 cm. [d]SE = ± 20% of listed values. [e]Calculated from conductivities shown for 0-10 and 10-20 cm. [f]Calculated from conductivities shown for 20-30 and 30-40 cm. [g]Calculated from measured or calculated values for 0-20 and 20-40 cm. [h]Infiltration into whole profile, geometric mean of 5 replications, using 20-cm-diameter for inner rings, SE = ± 5 mm/d.

The influence on conductivity of sample size was minimal where soil was thoroughly homogenized, i.e., for puddled soil in 0-20 cm. But for soil of more heterogeneous structure—for nonpuddled soil and in the deeper (20-40 cm) layer in puddled soil—conductivities were consistently larger when measured on larger samples. Nonetheless, measured I, which we may expect to match the conductivity of the 0-40 cm layer, was more closely predicted from 7-cm- than from the 20-cm-core measurements (Table 2).

The compactive effect of animal hooves may lessen infiltration to a comparable or greater extent than the implements during animal-powered plow and harrow puddling. This hypothesis was tested on a previously nonpuddled silty clay Typic Hapludoll, where on 4 replications each of 3.0- × 3.0-m plots (and following a preparatory submer-

gence and 1-d draining) comparisons were made of ϵ_T and I resulting from 1) NT, 2) from P+H that imparted to the soil 11 kJ energy/m^2 ground area through the implements and an additional 4 kJ/m^2 from compaction by hooves, and 3) from compaction (COM) by the same water buffalo, pulling no implements, for the same time used in P + H, and thereby imparting 8 kJ/m^2 energy (the compactive energy was higher than with P+H because the animal takes more steps per minute when not required to pull an implement).

Measurements of bulk density showed that the effect of animal hoof compaction (8 kJ/m^2) was to *decrease* ϵ_T in 20-30 cm and in 10-20 cm by 0.02 and 0.01, respectively and to *increase* ϵ_T in 0-10 cm by 0.02 (each $\pm$ 0.01); the increase in 0-10 cm may indicate a loosening effect when a hoof is withdrawn from the saturated soil.

Measured values of I supported the hypothesis that soil compaction by hooves is the dominant process in lessening infiltration: on NT plots, I (geometric mean of 4 replications) was 82 $\pm$ 20 mm/d, and (at 4 $\pm$ 2 mm/d) was less by a factor 1/(21 $\pm$ 12) with P+H, and (at 0.9 $\pm$ 0.2 mm/d) by a factor 1/(89 $\pm$ 30) after COM. If we assume that the 8 kJ/m^2 imparted by COM had an effect on I equivalent to the product of the effects of *two* successive compactions of 4 kJ/m^2, then the decrease caused by *one* 4 kJ/m^2 compaction would be $1/\sqrt{(89 \pm 30)} = 1/(9.5 \pm 1.7)$. Hence, the lessening ($\times$ 1/[21 $\pm$ 12]) of I by P+H could be considered to be compounded of a factor 1/(9.5 $\pm$ 1.7) due to 4 kJ/m^2 energy from compaction by hooves, and a factor 1/(2.2 $\pm$ 1.3)—derived as (21 $\pm$ 12) $\div$ (9.5 $\pm$ 1.7)—from the 11 kJ/m^2 imparted by the implements (the traditional plow and tooth-peg harrow). Thus, the effectiveness of the compaction is (4.2 $\pm$ 2.6) $\times$ (=[9.5 $\pm$ 1.7] $\div$ [2.2 $\pm$ 1.3]) greater than that of the implements. The implication for the farmer is that when his objective of wetland preparation is to lessen infiltration (as opposed to weed control or incorporation of residues), then a water buffalo walking through the ricefield but not pulling any implement can be more effective in lessening water loss—and is quicker and less stressful on the animal—than traditional P+H.

Infiltration is affected also by depth to water table (WTD), which is itself influenced by regional drainage and hydrology. The experiment that evaluated the effect on infiltration of compaction by animal hooves was also designed to allow manipulation of WTD by controlling the water level in surrounding ditches. (Results earlier presented for effects on I of P+H and COM were averaged over all WTD.) The influence of WTD was greatest for NT, where all four replications showed a positive increase of I as WTD increased. Similarly, for two replications of P+H with low I, and for all COM replications, I was much less affected by WTD. This suggests that where physical manipulation of the soil lessens I by severely decreasing transmission porosity, then recession of water table causes proportionately much smaller change in I, and free water should be retained longer on the soil surface—a feature of considerable benefit to the farmer.

The effects of wetland soil-physical management on soil strength and on rice and weed growth were studied in F10. The effects on soil strength (which markedly affects rice rooting) were evaluated (following the first puddling only) through measurements of soil resistance to cone penetrometer through 0- to 50-cm depth. The prepuddling submergence decreased soil strength by 0.5 MPa (from about 1.0 MPa) in 0-25 cm, and by about 0.8 MPa (from a range of 1.5-3.0 MPa) in 25-50 cm. Strength in 0-20 cm was further decreased by the puddlings: the depth of soil throughout which strength was less than 0.5 MPa (a strength at which rice root extension is much impeded) was 4 cm for NT and was increased by FRT to 8 cm, and by P+H to 12 cm (all $\pm$ 1 cm). Thus P+H may promote more effective root and shoot growth than FRT, and growth may be expected to be least for NT.

From the first puddling, rice grain yield and plant height (Table 3) were highest (though not significantly so) for P+H, and least for NT. But in the second experiment, in which soil strength was not measured, grain yield was the same for P+H and FRT. After each puddling, weed mass (determined at 22 d after transplanting [DT]) was about 0.5 t/ha for both P+H and FRT, compared with 1.0 t/ha for NT.

Predicting percolation from pore size (*Soils and Istituto per la Chimica del Terreno*). The experiments in F10 in 1985-86 included measurements (by colleagues at Pisa) of the porosity contributed in each 5-cm layer in 0-30 cm depth by pores of

Table 3. Effect of puddling implements on grain yield and plant height of IR58 and on weed mass. IRRI, 1987-88.

Puddling[a]	Puddling implement[b]			
	No tillage	Floating rototiller	Plow and harrow	Standard error of difference
	Rice grain yield[c] (t/ha)			
First	3.3	4.4	5.0	0.7
Second	2.4	3.5	3.3	0.3
	Plant height (cm) at 68 DT			
First	62	67	73	3
Second	nm	nm	nm	
	Weed mass (t/ha) at 22 DT			
First	1.0	0.5	0.5	0.3
Second	1.0	0.4	0.6	0.2

[a]Vertic Tropaquept silty clay overlying clay loam, field F10, IRRI. First puddling = 1987-88 DS, second puddling = 1988 WS). DT = days after transplanting. [b]nm = not measured. [c]Excluding replication 4, where yields were improbably low for all treatments.

Table 4. Predictions (using equations of Kozeny-Carman [K-C] and of Marshall[a] [M]) and measurements[b] for rate of water percolation through Vertic Tropaquept silty clay overlying clay loam as influenced by various wetland preparation methods. IRRI field F10, 1985-86.

Value by	Relative percolation[c] for land preparation by				
	No tillage	Skid-supported rototiller	Floating rototiller	Plow and harrow	Standard error of difference
Prediction K-C	1.9	1.5	4.7	1.0	0.3
Prediction M	nc	1.4	1.1	1.0	0.2
Measurement[b]	2.2	1.5	1.3	1.0	0.2

[a]Predictions were made using K-C and M equations from porosities measured by thin-section micromorphometry. [b]Measurements (geometric means of 2 replications and for daytime observations only) were made using double-ring infiltrometers and corrected to a standard water table depth of 30 cm. [c]Normalized in relation to values for plow and harrow. nc = not completed.

different widths and shapes, including elongated pores that facilitate water transmission; these measurements were made on thin sections of soil prepared from each 5-cm layer in plots on which had been imposed the various wetland preparations.

These porosity values may be used to predict values for the relative hydraulic conductivities of zones of similar soil subjected to the various structural manipulations. Predictions for the 6 successive depth layers in 0-30 cm may be combined through a simple electrical resistance analogue model to estimate relative rates of percolation through (and hence of infiltration into) the variously treated soil. Estimates using the Kozeny-Carman equation were presented in the Annual report for 1987 and showed encouraging agreement between predicted and measured infiltration except for an unrealistically high prediction for FRT. In 1988, the 1985-86 thin-section images were reanalyzed in Pisa to allow prediction of conductivity from porosity using the more rigorous model of Marshall. Relative values for percolation (infiltration) were normalized to an assumed value of 1.0 for P+H, and preliminary results (Table 4) show that predictions through the model of Marshall are closer to measured values than are the predictions through the Kozeny-Carman equation.

Through these studies of the effects of various wet-tillage implements and procedures on the pore shapes and sizes and resultant water transmission, we expect to gain insights that will help improve the design and execution of those implements and procedures.

TILLAGE AND SHALLOW GROUNDWATER FOR LEGUMES FOLLOWING IRRIGATED RICE IN PREVIOUSLY PUDDLED SOIL

Soils and Water Management Departments, International Irrigation Management Institute, Philippine Rice Research Institute, Philippine Bureau of Soils, and Central Luzon State University

Irrigation systems designed for wet season (WS) rice production often have some capacity for dry season (DS) irrigation of rice or nonrice crops. Additionally in such systems, after rice harvest, the preceding irrigation for rice may leave a residue of shallow groundwater that could be used by a succeeding nonrice crop—either by mechanical pumping of water, or by tillage and crop management that allow the crop roots direct access to the water. In a cooperative study at the Upper Talavera River Irrigation System (UTRIS) in Nueva Ecija, Philippines, we seek to determine the extent of such shallow groundwater reserves and to identify tillage technologies that allow postrice

legume crops to reach that water by their roots, and to determine the methods of tillage that promote highest production of legumes that are irrigated by pumping the water and distributing it along furrows to the crop rows.

Inventory of shallow groundwater at UTRIS. (*Soils and Central Luzon State University*). To assess the extent and usefulness of the DS groundwater resource, we seek to determine at what depth and for how long and for which regions within UTRIS resources of shallow groundwater persist (after cessation of irrigation) within depths accessible by roots of DS nonrice crops and thus are able to contribute to production of such crops.

We made a twice weekly sampling of fifty-two 2.5-m-deep perforated tubewells located throughout UTRIS on a rectangular grid of nonsubmerged fields.

Results for the survey of water table depths are presented in Table 5, in which sites have been categorized according to their depth of water table on 2 sampling occasions—mid-February (at the commencement of 7 d of sampling) and in late April (at the peak of DS). At each of these times, the sites were characterized according to their potential for aiding the production of DS nonrice crops; water table depths of 20-90 and 90-150 cm are considered to have high and slight potential, respectively, for DS cropping, and water tables below 150 cm to have no contribution to such cropping. Thus, in February, 30% of the sites had water tables between 20 and 90 cm, 8% between 90 and 150 cm, and 45% below 150 cm. The remaining 17% of the sites were on irrigated ricefields. By the end of April, no sites had water within 20-90 cm, 15% had potentially usable water tables between 90 and 150 cm, and 77% had water tables below 150 cm. Within the system, the shallow water table early in DS was predominantly near the main canal; at the peak of DS, it was near the deep pumped wells.

Table 5. Percentage of sample sites having water tables within specific depth ranges at early and late sampling dates.[a] Upper Talavera River Irrigation System, Nueva Ecija, Philippines, 1988 DS.

Depth range (cm)	Potential for aiding DS cropping	Percentage of sites	
		Mid-February	End April
20-90	High	30	0
90-150	Slight	8	15
>150	None	45	77
0-20	Irrigated riceland	17	8

[a] Location of shallowest water: February = near main canal, April = near deep-pumped wells.

For DS cropping, the *persistence* of a shallow water table is equally important as water table depth. Although 50% of sites had *no* water staying within the 10-100 cm depth range, 14% had potentially exploitable water that persisted for 20-77 d, and a further 22% had water for 1-20 d, which could possibly be managed for the benefit of nonrice DS crops.

Tillage and irrigation (*Soils and Water Management, Philippine Rice Research Institute, International Irrigation Management Institute, Bureau of Soils, Central Luzon State University*). Our studies on tillage and irrigation for legumes following irrigated lowland rice aim to measure and interpret the effects and interactions of tillage, irrigation, and other soil-physical management on the growth and yield of legumes following rice in previously puddled soil. These studies were pursued at UTRIS, and also at the Friar Lands River Irrigation System (RIS) and at the Santa Cruz RIS. At the Friar Lands RIS and at the Santa Cruz RIS, we collaborate with Philrice in seeking to determine and interpret the effects of irrigation, postrice residual soil moisture, tillage, and seeding method on the growth and yield of cowpea and mungbean in soils of high clay content. At the Friar Lands RIS, the soil is a Vertic Tropaquept with 55% clay; at the Santa Cruz RIS, the soil is a Lithic Mollic Tropaquept with 60% clay.

At the Friar Lands RIS, we measured the effect of irrigation on grain yield of mungbean and cowpea grown in 1988 DS after rice in previously puddled soil. In these trials, we used no postrice tillage and we seeded manually. We imposed 3 irrigation schedules: no irrigation, and waterings at -80 and -50 kPa soil water potentials (Table 6). The yields were low, but the percentage increase for irrigation at -50 kPa was 67% for cowpea and 33% for mungbean. The irrigation was supplemented by 12 mm at seeding and 20 mm rain when the crop was 48 d old. For the -50 kPa treatment, we had scheduled an additional final irrigation, but the crop was harvested before it was needed. The water table was consistently below 100 cm.

Table 6. Effect of irrigation on grain yield of CES-1d-21 mungbean and IT82D-889 cowpea grown after rice in previously puddled soil at Friar Lands RIS, in 1988 DS.

Irrigation schedule	Irrigation[a] total (mm)	Cowpea yield[b] (t/ha)	Mungbean yield[b] (t/ha)
None	0	0.15	0.30
At −80 kPa soil water potential	120	0.21	0.36
At −50 kPa soil water potential	90[c]	0.25	0.40
% increase for irrigation at −50 kPa		67	33

[a]Plus 12 mm at seeding, plus 20 mm rain at 48 d after sowing. Water table was consistently below 100 cm. [b]No postrice tillage; manual seeding. [c]Harvested before final scheduled irrigation.

Studies on the use of postrice residual soil moisture by DS mungbean were carried out at Friar Lands RIS and at Santa Cruz RIS. They measured the effects on grain yield of seeding delay, seeding method, and tillage. The three tillage methods were no tillage, conventional plowing and harrowing, and deep strip tillage to 35 cm depth along the seed rows to promote deep rooting and effective use of residual soil moisture. We compared manual seeding and seeding by an inverted-T seeder. Seedings were delayed at 12, 16, and 20 d after field draining. Table 7 shows that deep strip tillage combined with manual precision seeding gave high grain production of 1.9 t/ha with no irrigation, no fertilizer, and only 10 mm rainfall, and with the water table below 70 cm. This is a very effective use of postrice residual soil moisture.

From supporting studies with the Bureau of Soils into technology development and strategic research, findings were that seed line mulch was very beneficial for mungbean emergence and production; seed zone strength posed a greater constraint to emergence than seed zone dryness; a prototype relay seeder gave mixed results; and uniform irrigation was better achieved with furrows than with gutters or flushing, but was labor intensive.

Studies at UTRIS (with the Bureau of Soils) sought to determine the effects and interactions on DS mungbean of tillage, mulch, and irrigation. The tillage and seeding methods were tillage followed by row planting of mungbean; the farmer's method of plowing the field, then broadcasting the seeds, and then harrowing; conventional plowing and harrowing followed by row planting; and finally, deep strip tillage followed by conventional tillage, with row planting of mungbean. These were combined factorially with treatments without and with rice straw mulch at 1.6 t/ha. Additionally, these were factorially combined with and without irrigation of 80 mm at 38 d after sowing (DAS). The soil was fine, loamy, mixed Isohyperthermic Typic Tropaquept.

For tillage, with yields adjusted for equal plant population, the average response to deep or conventional tillage was an increase of 40% with an uncertainty of 20%; but for the nonmulched, deep-tilled treatments there was (because of the deep cracks) a yield decrease of 20% with an uncertainty of 20%. In response to mulch, emergence and plant height each increased 9% and yield by 26%. In response to irrigation, plant height increased by 20%, and yield by 21%. Mulching plus irrigation increased yield by 49%. The magnitudes of the various treatment yields were nontilled, nonmulched, nonirrigated $= 0.37 \pm 0.03$ t/ha; and for deep-tilled, mulched, irrigated $= 0.69 \pm 0.17$ t/ha, indicating a very worthwhile response to those treatments. For the plow, broadcast, harrow, mulching was more effective than irrigation. And plant heights were higher with mulch *if* plots were irrigated, and there was no change in plant height if plots were *not* irrigated.

Table 7. Use of postrice residual soil moisture by DS CES-1d-21 mungbean: effects on grain yield of seeding delay, seeding method, and tillage. Friar Lands RIS and Santa Cruz RIS, Philippines, 1988.

Tillage method	Seeding method	Grain yield[a] (t/ha) with seeding delay (d)			
		12[b]	16[b]	20[c]	20[d]
No tillage	Manual	1.5	1.0	1.6	1.6
Conventional	Manual	1.4	0.8	1.5	1.3
Deep strip[e]	Manual			1.6	1.9
No tillage	Inverted-T	1.1	1.1		
Conventional	Inverted-T	1.0	0.9		
Standard error of difference		0.1	0.2	0.1	0.1

[a]No irrigation, no fertilizer, 10 mm rainfall, water table below 70 cm. [b]FLRIS, 1988. [c]FLRIS, 1987. [d]SCRIS, 1987. [e]Tillage to 35-cm depth along seed lines to promote deep rooting and effective use of residual soil moisture.

The constraints that caused the low yields were low emergence because of high seed zone strength, low soil fertility, and heat stress in the hot Nueva Ecija environment.

CULTIVATION OF PUDDLED SOIL FOR DRY SEASON LEGUMES

Soils, Agricultural Engineering, and Agronomy Departments; and University of Minnesota

For DS mungbean grown on previously puddled soil and using soil water remaining after irrigated rice harvest, experiments in 1985, 1986, and 1987 identified a yield target of 2.6 t/ha for nonfertilized, nonirrigated 63-d mungbean cultivars in previously puddled soil. Toward this target, strip tillage to 0.35 m depth in 1986 achieved 2.2 t/ha. These experiments revealed also the adverse effect on mungbean yield of soil submergence during the preceding rice crop, and of the effect on mungbean emergence and production of delay (beyond 10 d after field draining) in mungbean seeding.

Research in 1988 measured mungbean growth and yield for seeding at various timings both before and after rice harvest, for zero, shallow, and deep tillage, using novel approaches of rice - legume sequence management that minimized the soil management problems that are created for mungbean by the roots and stubble remaining from preceding rice. Strategic research in 1988 measured the magnitude and time progression of soil strength close to emerging seeds both in the field and in complementary growth chamber studies, and made preliminary measurement of the effects of gypsum in lessening the strength of seed zone soil in the field.

Rice plant spacing, rice stubble management, and tillage for mungbean following irrigated rice (*Soils, Agricultural Engineering, and Agronomy*). To permit effective and convenient tillage for succeeding mungbean, irrigated rice was transplanted (on the Vertic Tropaquept soil used in the 1985-87 experiments) at 22-cm intervals along rows that were spaced alternately at 7- and 28-cm spacing, giving a plant population density equal to that of the usual 20- × 20-cm rice spacing. In 2 trials, yields were 3.29 $\pm$ 0.13 for the 7-cm system and 4.47 $\pm$ 0.08 t/ha for the 28-cm system—equal to the 3.22 $\pm$ 0.17 and 4.72 $\pm$ 0.07 t/ha achieved for 20- × 20-cm spacing. The 28-cm spacing between alternate rows allowed easy access of new prototype implements for interrow tillage (both shallow and deep), and the wider spacing of rice stubble meant that less energy was expended in tillage of stubble and roots. The succeeding mungbeans were planted in the tilled strips at 35-cm row spacing.

This method of between-the-stubble tillage and seeding was compared (in RCBD with 6 replications) against the farmer practice of relay-broadcast (RB) seeding at 4 d after field draining (DAD) and 6 d before rice harvest (DBH) with no tillage, and with manual seeding in rows before rice harvest at 5 and 8 DAD (RMP and RMD in Table 8), with zero tillage (T0) and manual row seeding after rice harvest (11 DAD, 1 d after harvest).

The between-stubble shallow tillage (T1) with manual row seeding was tested at 12 (prompt) and 19 (delayed) DAD (treatments T1MP and T1MD) and deep-plus-shallow between-stubble tillage (T6) was similarly tested for prompt (T6MP) and delayed (T6MD) operations. Because of heavy rains at 20 DAD, however, the T1MD and T6MD treatments had to be reimposed at 24 DAD.

The growth and yields for the various treatments are presented in Table 8. Production was highest with zero tillage and manual seeding (2.2 t/ha); however, the manual seeding was very labor-intensive, and this technology may be uneconomic for farmers. Moreover, the relay systems (RB, RMP, and RMD), though showing high production, had high pressures both from weeds and from ratoon rice, and controlling those problems would be costly; moreover, access to RB fields for soil, crop, and pest management was difficult compared with the row system treatments.

Deep tillage gave no benefit of production (either of yield or of yield per plant) in 1988. There was much higher than normal DS rain in 1988, and the mungbean had no need of the subsoil water that deep tillage would make available. The 1988 results (for the same reason of heavy rain) also indicated that deep strip tillage imposed on the same plots in 1987 gave no benefit to the 1988 crop.

Seed zone strength and mungbean emergence (*Soils and University of Minnesota*). When puddled

Table 8. Effect of seeding method, seeding delay after rice harvest, and tillage on growth and yield of CES-1d-21 rainfed mungbean.[a] IRRI, 1988 DS.

Treatment code	Seeding delay		Tillage	Season's rainfall (mm)	Seeding method	Plant height (cm) at 8 WAS[d]	Total dry matter at harvest (t/ha)	Grain yield (t/ha)	Grain yield (g/plant)	Weed mass (t/ha)
	DAD[b]	D B/A H[c]								
RB[e]	4	6 B	None	36	Broadcast	53	2.92	1.71	3.9	0.15
RMP[f]	5	5 B	None	36	Manual, rows	61	3.22	1.86	4.1	0.12
RMD[g]	8	2 B	None	36	Manual, rows	60	3.26	1.92	4.2	0.11
T0M[h]	11	1 A	None	36	Manual, rows	57	3.56	2.17	3.5	0.09
T1MP[i]	12	2 A	Shallow	56[j]	Manual, rows	62	3.53	2.08	3.5	0.04
T6MP[k]	12	2 A	Shallow	56[j]	Manual, rows	60	3.44	2.02	3.6	0.04
T1MD[l]	19[m]	9 A	Deep + shallow	117[n]	Manual, rows	51	2.70	1.68	3.2	0.04
T6MD[o]	19[m]	9 A	Deep + shallow	117[n]	Manual, rows	47	2.59	1.60	3.1	0.06
SED						1	0.20	0.10	0.2	0.03

[a]Soil was a Vertic Tropaquept silty clay loam overlying silty clay with no irrigation, no fertilizer. [b]Days after field draining. [c]Days before or after harvest. [d]Weeks after sowing. [e]Relay, broadcast. [f]Relay, manual, prompt. [g]Relay, manual, delayed. [h]Zero tilled, manual. [i]Shallow tillage, manual, prompt. [j]Late rain. [k]Deep and shallow tillage, manual, prompt. [l]Shallow tillage, manual, delayed. [m]Replanted at 24 DAD because of heavy rain. [n]Very late rain. [o]Deep and shallow tillage, manual, delayed.

soil dries after rice harvest in DS, increasing seed zone strength inhibits mungbean emergence. Measurements made using a new design of micropenetrometer developed in collaboration with the University of Minnesota showed that seed zone strength under field conditions increased from 0.1 MPa, soon after commencement of field draining, to 0.3 MPa after 14 d of draining. Correspondingly, rates of emergence declined from about 90% for seeding at 1 or 2 DAD (for both nontilled and tilled soil) to 30% for seeding into nontilled soil at 14 DAD, and to 5% for seeding at 14 DAD into tilled soil.

Complementary growth chamber studies at various temperatures and soil moistures, and using the new micropenetrometer showed that mungbean emergence is effectively 100% for soil strength (resistance to microcone penetrometer) below 0.17 MPa, and that at strength above 0.17 MPa emergence decreased with increasing strength according to the equation.

$$\text{Emergence (\%)} = 22 - \log_{10}(\text{Resistance/MPa}) \quad (r = -0.60^{***})$$

Preliminary tests of the application of gypsum into the ricefield standing water about 10 d before field draining showed a change in the friability and strength of the postharvest soil that promoted more effective emergence of mungbean. Further trials are proceeding, together with tests to determine whether the gypsum has adverse effects on the water infiltration rate during following wet season (WS) rice.

TILLAGE EFFECTS ON SOIL PHYSICAL PROPERTIES, WEED GROWTH, AND LOWLAND RICE YIELD

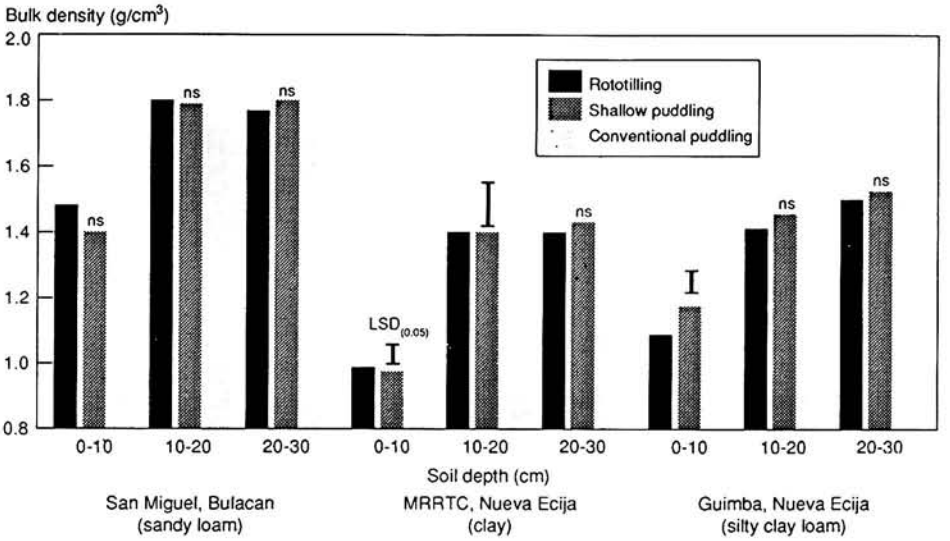
Agronomy Department

In 1988 WS, 3 tillage treatments were investigated: rototilling, shallow puddling (up to 5-cm soil depth), and conventional puddling (up to 15-cm soil depth). The sites were in San Miguel, Bulacan (sandy loam), at Maligaya Rice Research and Training Center, Nueva Ecija (clay), and Guimba, Nueva Ecija (silty clay loam).

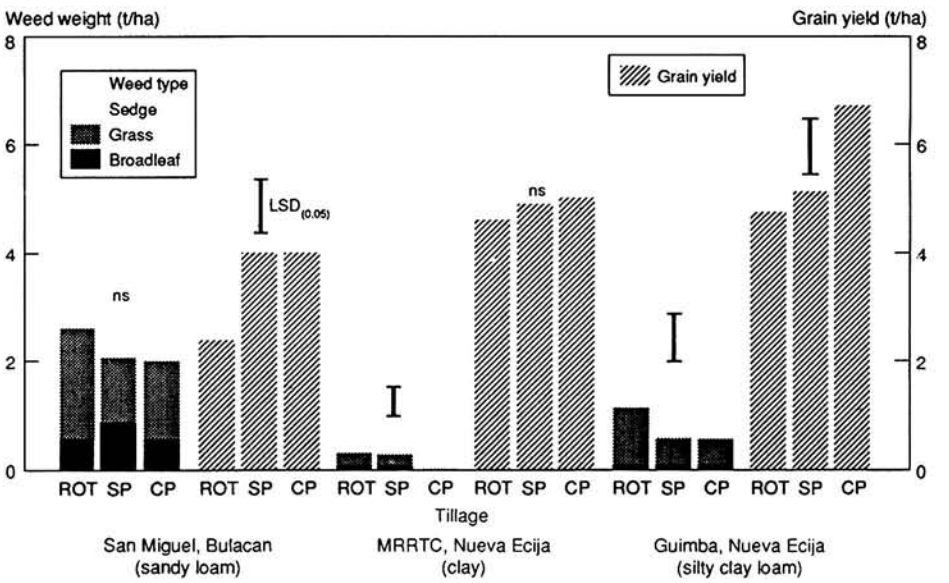
Bulk density was measured 1 wk after transplanting. In the 10-cm soil layer in sandy loam soil, there was no apparent change in bulk density (Fig. 1); in silty clay loam, puddling gave higher bulk density than did rototilling, while in clay soil, conventional puddling gave the lowest bulk density.

In the 10- to 20-cm soil layer, conventional puddling gave lower bulk density than did the other tillage methods only in clay soil. The deepest mud layer was in clay soil, extending down to 25 cm. Tillage did not affect the bulk density beyond the 20-cm soil depth.

At all sites, the rice crop did not suffer from moisture stress, for rainfall was abundant. The



1. Effect of 3 tillage treatments on soil bulk density in lowland rice soils at 3 Philippine sites, 1988 WS. MRRTC = Maligaya Rice Research and Training Center.



2. Effect of tillage on weed growth and grain yield in lowland rice soils at 3 Philippine sites, 1988 WS. ROT = rototilling, SP = shallow puddling, CP = conventional puddling.

clay soil was at saturation throughout the season, and water was not limiting for other soils. However, the matric potential for puddled plots was generally lower than that in rototilled plots.

Tillage did not affect grain yield in the clay soil (Fig. 2), and greater tillage intensity significantly reduced weed growth. In other soils, the occasional absence of standing water increased weed population in all treatments. This was more evident in sandy loam, where the dry weed biomass was greater than the grain yield in rototilled plots but not significantly different among tillage treatments. At the Nueva Ecija sites, increasing tillage intensity decreased weed growth.

Climatic environment and rice

International Rice Testing Program, and Multiple Cropping, Soils, and Entomology Departments

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VARIETAL RESPONSE TO CLIMATIC STRESSES IN IRTP TRIALS

International Rice Testing Program

The 1987-88 multilocation trials of the International Rice Testing Program (IRTP) identified several breeding lines and varieties tolerant of various climatic stresses. Complete results are published separately in the annual IRTP reports. Some of the entries that performed well across locations against various stresses are as follows:

- *Drought tolerance*
  From rainfed lowland:
  IR13240-39-3-3-3-P1,
  IR19274-26-2-3-1,
  IR21015-80-3-3-1-2,
  IR26933-16-2-3,
  IR31429-14-2-3,
  IR31429-20-2-3,
  IR4563-1-1-3-6-1E-P1,
  IR8073-65-6-1-1E-P2,
  KKN7205-35-1-SKN-1-1,
  Ratna, IR21188-87-3-3-2-2,
  MRC8009-3536, IR31432-2-3,
  RP1579-1863-73-32-53
  From upland nurseries:
  ADT31, CR222-MW10,
  CR289-1208, IR9729-67-3,
  B3016-TB-260-3-2-1-1-3,
  B3622E-TB-5-4-4,
  B3622F-TB-14-2, AUS257,
  AUS463, IAC118/81,
  IAC150/76, IAC233/79,
  IRAT112,
  B3906D-14-ST-16-48-3,
  CNA762069, GH319, IAC39/79
- *Submergence tolerance*
  FR13A, IR26933-16-2-3,
  IR31338-30-2-1, IR31429-14-2-3,
  IR31432-8-6,
  IR31432-9-3-2,
  IR31662-34-1-2,
  IR33238-25-2-3-2,
  IR39536-1-3-2-2,
  IR39536-1-3-4-1-2-3,
  IR4563-1-1-3-6-1E-P1,
  Janki, Leb Mue Nahng 111,
  NC505, OR142-99,
  SPT7106-2-3-3-1
- *Low temperature tolerance*
  JKAU9K0450-126-10,
  No. 11 (Takanenishiki)
  Suweon 303, Akiyudaka

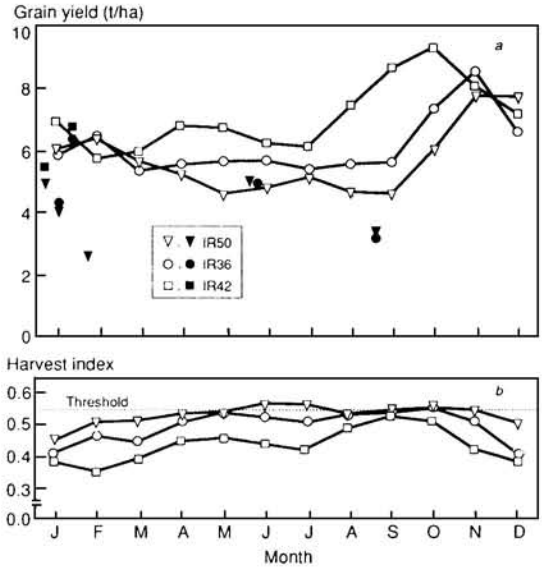
USING SIMULATION MODELING TO SUPPORT TESTING OF RICE VARIETIES IN INTERNATIONAL TRIALS

International Rice Testing Program and Multiple Cropping Department

IRTP and its collaborative rice breeders are searching for tools that permit more efficient screening and comparison of rice cultivars across locations and years. We investigated how simulation can support evaluation of rice crop performance in multilocation irrigated trials of IRTP. The potential productivity of three rice cultivars grown in five environments was studied. These environments were represented by one site each in five countries: Ahero (Kenya), Coimbatore (India), Joydebpur (Bangladesh), Los Baños (Philippines), and Sanpatong (Thailand). The cultivars represent three rice varietal maturity groups: very early (IR50), early (IR36), and medium (IR42).

The well-evaluated MACROS.CSM, a summary model based on physiological and physical processes, was used. The model generates crop productivity values as a function of actual solar radiation, and maximum and minimum temperature under optimal conditions of ample water and nutrients; and it assumes conditions of minimal stress. IRTP field observations on dates of seeding, transplanting, flowering, and maturity (harvest) at selected locations representing different latitudes were used to calibrate crop development in the model.

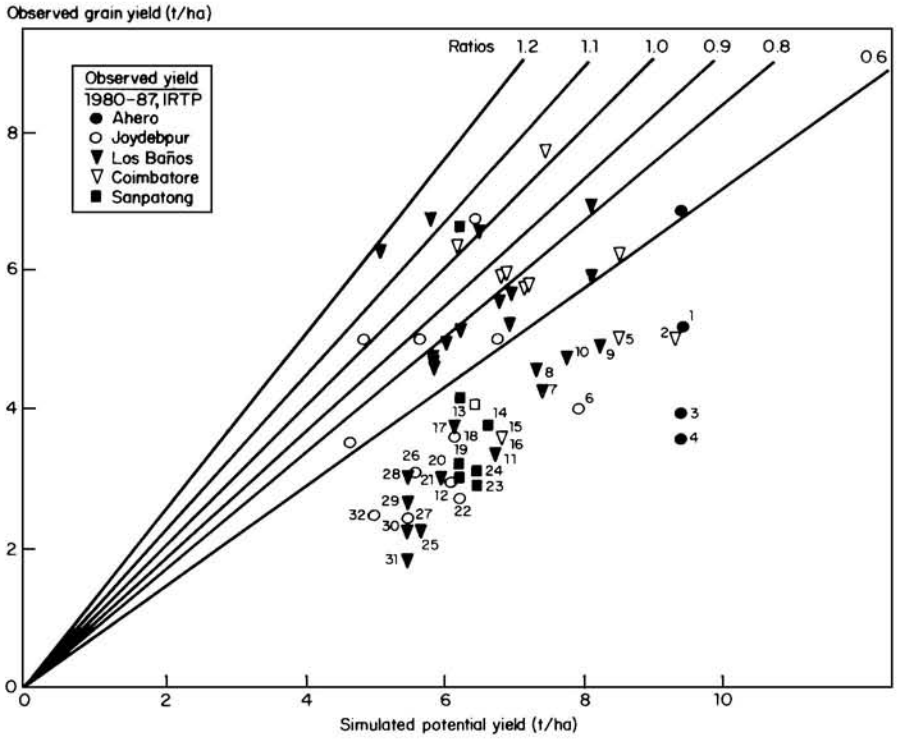
Grain yields simulated for irrigated transplanted rice throughout the year at monthly intervals show seasonality related to temperature and radiation variations. An example based on estimations for Joydebpur (Bangladesh) is shown in Figure 1. Comparing actual grain yields with potential yields in 65 trials showed that about half of the experimental yields were similar to simulated values; yields in the remaining cases were lowe; (Fig. 2). Reasons for this yield gap vary from year to year and site to site (e.g., pest and disease pressure, soil constraints, suboptimal fertilization), as indicated in IRTP reports.



1. *a.* Simulated potential yield and observed grain yields for IR50, IR36, and IR42 at Joydebpur. Open symbols represent simulated potential yields with 1984 weather data; closed symbols represent data from the International Rice Testing Program (IRTP) yield trial in 1984. *b.* Simulated harvest index.

Observed IRTP yields were put into long-term perspective by creating weather patterns with a weather generation program. A minimum of 2 complete years of weather data was used to create 20 weather patterns. Expected potential yields for 25, 50, and 75% probability levels were derived, and the magnitudes of the yield gap compared. The model performs adequately for different locations, and it quantifies crop response to weather factors (genotype × environment interaction)—the main objective of the study. Interaction effects of photoperiod sensitivity need to be considered in applying the model to cultivars sensitive to daylength.

The study suggests that 1) several production constraints apply to IRTP sites for which rough estimates of yield and cultivar response to environment are needed, 2) potential grain yields established through crop simulation can serve as reference for ongoing IRTP trials, and 3) crop simulation modeling can support IRTP decision-making on site and nursery selection.



2. Plots of observed versus simulated grain yield for 65 trials at 5 IRTP locations, 1980-87. Numbered trials represent those with actual yield less than 60% of potential yield.

CURRENT WEATHER AND RICE PRODUCTION

Multiple Cropping Department

Variability in weather affects the growth of rice and therefore its production. It is not easy, however, to evaluate the impact of a specific weather pattern. Weather variability provides "noise" that makes it more difficult to draw conclusions from yield differences in experiments. Crop simulation provides a way to quantify the impact of weather on the potential production of irrigated crops and also of rainfed crops. The values produced serve as a reference, since suboptimal fertilization and pests are excluded.

The MACROS.CSM model is based on physiological and physical processes such as photosynthesis, respiration, transpiration, and movement of water in the soil. Selecting appropriate submodels allows the model to run for different situations.

Four situations are selected: a short- and a medium-duration variety (IR36 and IR64) in fully irrigated conditions, IR64 transplanted on rainfed lowland, and Kinandang Pula dry seeded in rainfed upland. All situations exclude any shortage of nutrients or damage by pests and weeds.

Crop, soil, and weather parameters are required. The crop parameters for IR64 and IR36 are taken from experiments of the Plant Physiology Department in 1986. The crop parameters for Kinandang Pula are from 1986 experiments at the Institute of Environmental Science and Management, University of the Philippines at Los Baños. Soil data are taken from the 1984 (upland) and 1986-87 (lowland) experiments of the Multiple Cropping Department. Weather data are from the wetland station of the IRRI Climate Unit.

The simulation for potential production starts at a transplanting date that is 15 d after sowing. The initial dry weights are 6-8 kg/ha for the leaf and for the stem, and 11.3 kg/ha for the root. For the rainfed lowland case, simulation starts when the water content in the topmost layer of a clay loam soil exceeds 95% of saturation for 7 d within 3 wk. The water table depth on rainy days is 0.35 m in wet season (WS) and 1.10 m in dry season (DS). It recedes by 0.02 and 0.04 m for every rainless day during WS and DS, respectively, down to 1.2 m. For the rainfed upland simulation, emergence starts when more than 30 mm of precipitation is accumulated in 3 consecutive days in a clayey upland soil.

Potential grain yields of transplanted and dry seeded rice for irrigated and rainfed conditions are simulated using the weather conditions at IRRI for the previous 4 mo (Fig. 3). The median and quartile yield levels based on 24 yr of weather data (1960-86) are determined to put current values into perspective.

The results are distributed with the monthly summary of weather data. Such information can serve as a reference for ongoing field trials and can facilitate interpretation of year-to-year or season-to-season differences in growth and yield.

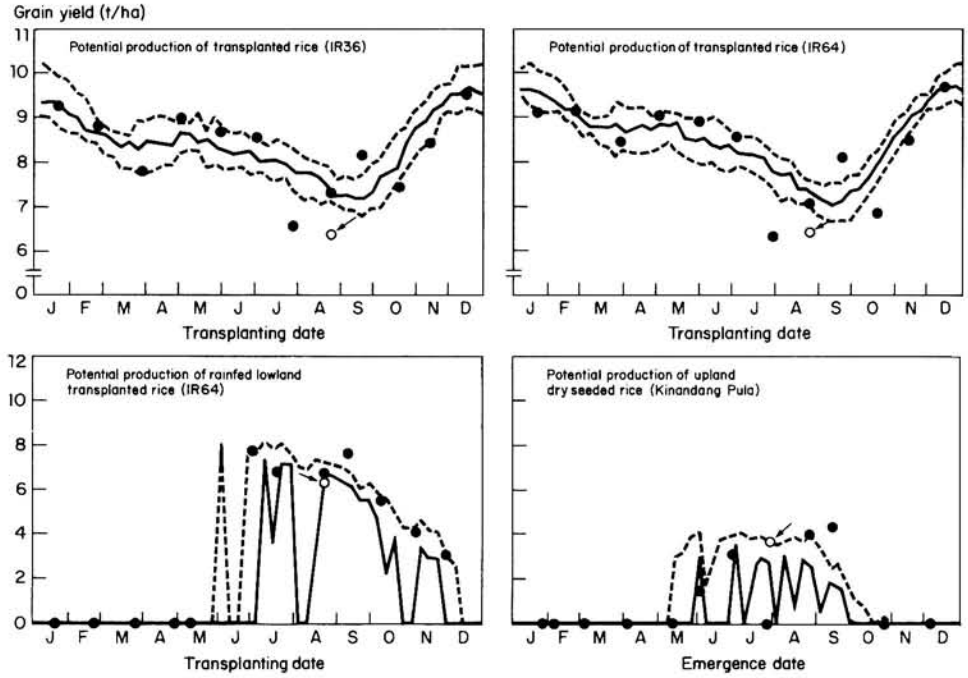
RELATIONSHIP BETWEEN PAN EVAPORATION AND ACTUAL EVAPORATION OF IR64 AT DIFFERENT GROWTH STAGES

Multiple Cropping Department

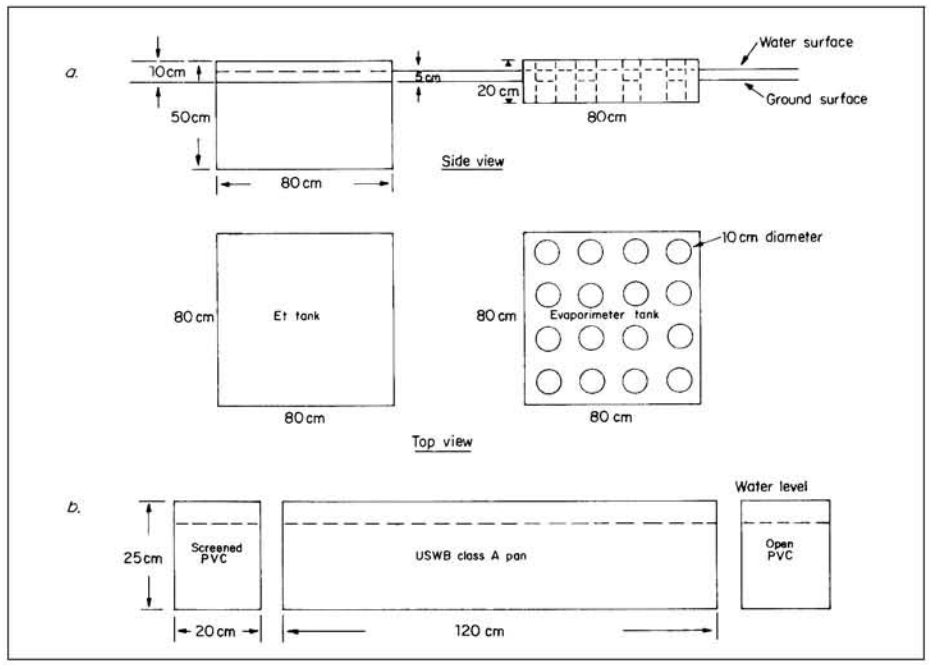
Estimates of evapotranspiration (Et) have an important role in rice crop modeling and water management. Evaporation pan data (U.S. Weather Bureau Class A pan) are routinely reported by agrometeorological stations and may be used to estimate Et. We determined the relationship between actual measured rice crop Et, pan evaporation (Epan), and potential Et (PEt) as estimated by the modified Penman method, and we examined how this relationship varied between WS and DS.

We constructed 3 Et tanks and 3 evaporimeter tanks (Fig. 4), using the method described by Sato for measuring each component of field evaporation. The Et tanks were used for direct determination of actual evaporation from IR64. The evaporimeter tanks were used to measure evaporation from the water surface. The difference between the two measurements was the estimated transpiration rate of the crop. The measurements were carried out through six plantings (three DS and three WS): 20 Feb 1986, 14 Jun 1986, 3 Nov 1986, 23 Feb 1987, 3 Jul 1987, and 12 Jan 1988 (Fig. 5). The work was done in a field adjacent to the IRRI wetland agrometeorological station.

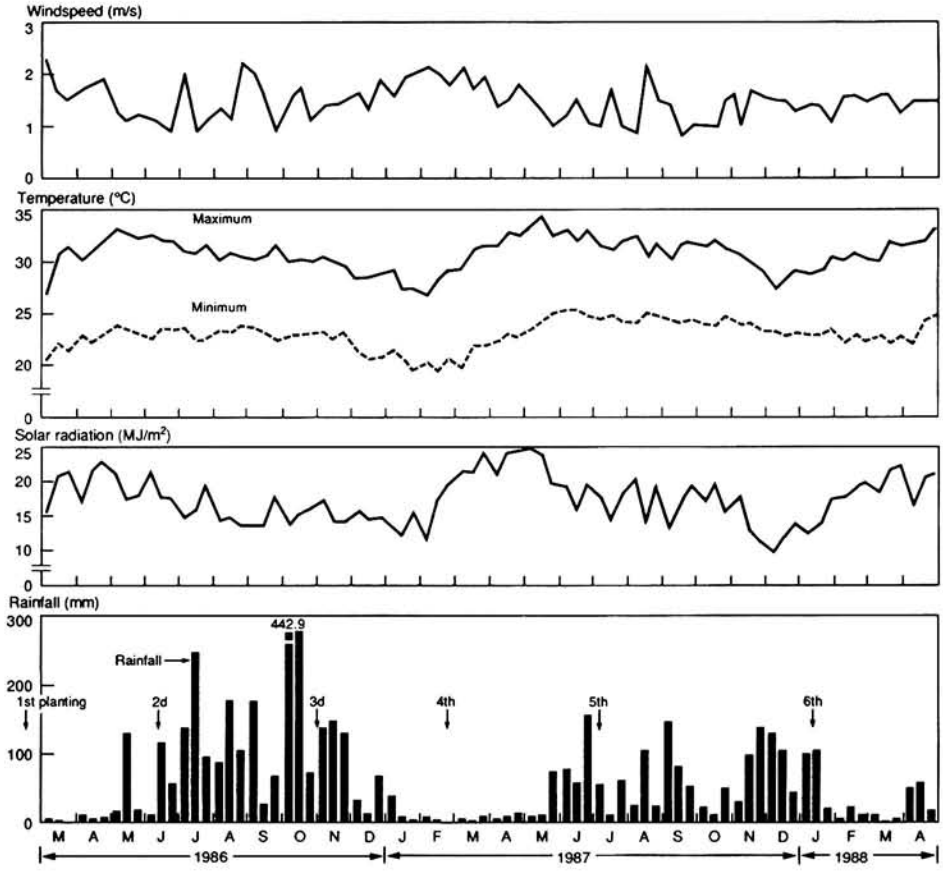
Because the dynamics of Et were distinctly different between WS and DS plantings, the data were averaged separately for the three DS plant-



3. Simulated potential grain yields (rough rice; 14% moisture content) for different situations in Los Baños, Philippines. The yield that would have been obtained for rice maturing within the last decade of November 1988 is shown (o); yields for 12 previous monthly plantings are also given (•). Lines represent the yield levels that have a 75%, 50%, and 25% probability of being exceeded, based on simulations with 24 yr of weather data.



4. Schematic diagram of evapotranspiration (Et) and evaporimeter tanks (a) and USWB class A pan and 20-cm-diameter PVC evaporimeters (b). IRRI, 1988.

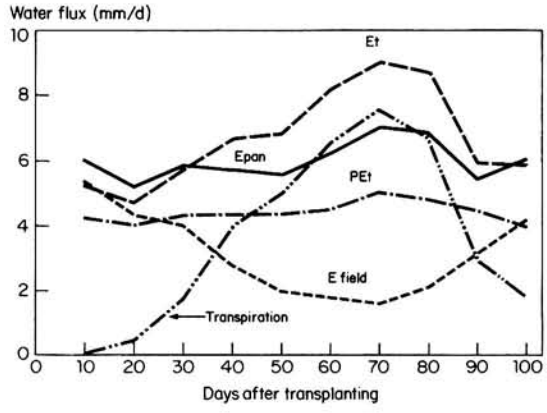


5. 10-d distribution of rainfall, solar radiation, wind velocity, and maximum and minimum temperatures at the IRRI wetland agrometeorological station and corresponding transplanting dates of IR64 in the lysimeter study. IRRI, 1986-88 DS and WS.

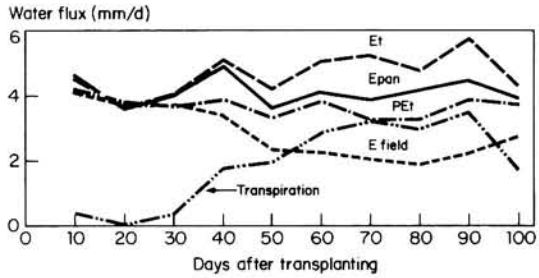
ings (20 Feb 1986, 23 Feb 1987, and 12 Jan 1988) and the three WS plantings (14 Jun 1986, 3 Nov 1986, and 3 Jul 1987). Transpiration increased gradually from 1 wk after transplanting (WT) to about 10 d before flowering and decreased thereafter up to harvest (Fig. 6, 7). The Et-to-Epan ratio (Fig. 8) increased gradually from 1 WT to a maximum that coincided with the highest transpiration and Epan rates (70 d after transplanting [DT]), and lowest field evaporation (Efield).

To establish the relationship between the actual Et of IR64 versus Epan or PEt, we pooled the daily values of these variables from 1 WT to harvest and regressed Et as a function of Epan or PEt. The resulting predictive equations were of the form

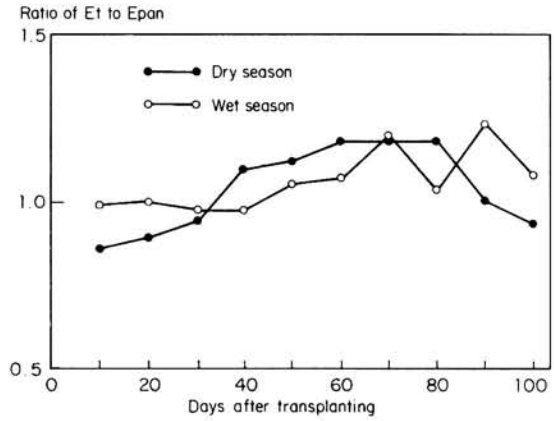
$$ET = a + b\,Epan$$



6. Average 10-d distribution of Et of IR64, evaporation from class A pan (Epan), potential evapotranspiration by Penman (PEt), and evaporation from the field (Efield), IRRI, 1988 DS. Av of 3 plantings, February 1986-April 1988.



7. Average 10-d distribution of Et for IR64, Epan, PEt, and Efield, IRRI, 1988 WS. Av of 3 plantings, February 1986-April 1988.



8. Ratio of Et of IR64 and Epan, 1986-88 DS and WS. IRRI, 1988.

The relationship was estimated independently for each major growth stage (Table 1,2). Four growth stages were recognized for the regression analysis: GS1 constituted the period from 6 DT to 30 DT, GS2 from 31 DT to panicle initiation (PI), GS3 from PI to flowering, and GS4 from flowering to harvest.

We determined whether the regressions differed from each other by the *t*-test. The slope coefficients for the equations covering the first two growth stages did not significantly differ from each other, nor did those for GS3 and GS4. Therefore, combined regressions were estimated for the entire period prior to PI (GS12) and post-PI (GS34) in Tables 1 and 2.

Table 1. Linear regression analysis to estimate actual evapotranspiration (Et) as a function of class A pan evaporation (Epan) using season pooled data for 3 DS trials. IRRI, 1986-88 DS.

Growth period[a]	Intercept a	Slope b	Standard error	R^2	Mean		Et/Epan ratio
					Et	Epan	
6 DT to harvest	1.0473	0.9475	1.077	0.64**	6.54	5.79	1.13
6 DT to 30 DT	-0.0706	0.9133	0.344	0.94**	4.99	5.54	0.90
31 DT to PI	1.8073	0.7931	0.701	0.74**	6.33	5.70	1.11
PI to flowering	2.1591	0.8881	1.013	0.72**	7.54	6.06	1.24
Flowering to harvest	0.6203	1.1043	1.065	0.60**	7.15	5.91	1.21
6 DT to PI	0.7534	0.8751	0.824	0.72**	5.67	5.62	1.01
PI to harvest	1.5548	0.9654	1.051	0.65**	7.33	5.98	1.23

[a] DT = days after transplanting, PI = panicle initiation.

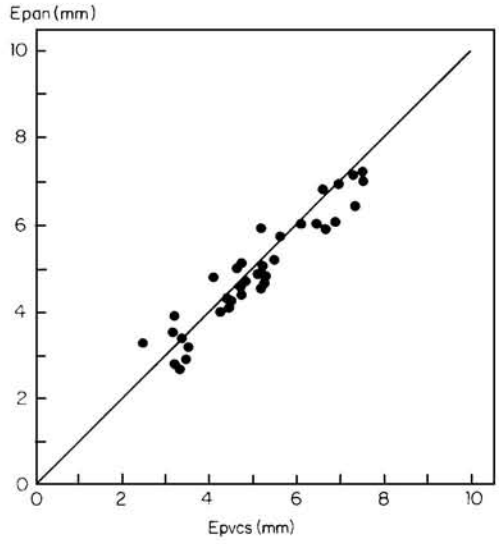
Table 2. Linear regression analysis to estimate Et as a function of Epan using pooled data for 3 WS trials. IRRI, 1986-88 WS.

Growth period[a]	Intercept a	Slope b	Standard error	R^2	Mean		Et/Epan ratio
					Et	Epan	
6 DT to harvest	0.8859	0.9155	0.865	0.68**	4.92	4.30	1.14
6 DT to 30 DT	0.7940	0.7919	0.569	0.78**	4.16	4.25	0.98
31 DT to PI	0.8708	0.8578	0.674	0.75**	4.80	4.58	1.05
PI to flowering	0.4348	1.0800	0.819	0.77**	4.94	4.18	1.18
Flowering to harvest	1.5037	0.8855	0.804	0.73**	5.28	4.26	1.24
6 DT to PI	0.7626	0.8462	0.650	0.75**	4.51	4.43	1.02
PI to harvest	0.9214	0.9898	0.827	0.75**	5.09	4.22	1.21

[a] DT = days after transplanting.

The overall Et-to-Epan ratio did not differ substantially between the pooled WS and DS data sets, particularly when calculated for the entire growing season (GS14) or for the GS12 or GS34 periods. The predictive estimation of Et using Epan data was much stronger than when PEt was used as the estimator (Table 3). Therefore, Epan is judged to be the more reliable estimator of the actual Et of a rice crop.

We also tested miniature evaporation pans made of polyvinyl chloride (PVC) with a volume of 8 liters, since smaller evaporation pans would be much more suitable in ricefield Et studies in locations remote from agrometeorological stations. The relationship between Epan and the miniature pans (either screened or unscreened) was quite strong (Fig. 9). A closer 1:1 correspondence was obtained with the PVC pan when a protective screen was placed over the top.



9. Comparison of pan evaporation from Epan and evaporation from screened PVC (Epvcs). IRRI, 1987-88 DS and WS.

AGROHYDROLOGY OF UPLAND RICE AND SIMULATIONS OF DEFOLIATING INSECTS

Soils and Entomology Departments

Toposequence water balance and yield of upland rice. For upland rice grown along a gently sloping hill toposequence, 1983-87 WS experiments determined the conditions under which uptake of shallow groundwater can increase growth and yield. The experiments of 1986 and 1987, with the 1988 experiment here reported, sought additionally to evaluate a numerical crop simulation SAWAH (Simulation Algorithm for Waterflow in Aqueous Habitats) and to develop a methodology for artificial detillering of upland rice plants to help develop a simulation, UPRIPE, for the effects of yellow stem borer (YSB). In a comparison of detillerings in 1987, herbicide injected into a specific proportion of tillers caused a greater

Table 3. Comparison of estimates of Et from either Epan or PEt. IRRI, 1986-88 dry and wet seasons.

Growth period	Days (no.)	Epan			PEt		
		Standard error	R^2	Et/Epan ratio	Standard error	R^2	Et/Epan ratio
			Dry season				
6 DT to harvest	90	1.077	0.64	1.13	1.132	0.60	1.51
6 DT to 30 DT	24	0.344	0.94	0.90	0.450	0.90	1.22
31 DT to PI	14	0.701	0.74	1.11	0.800	0.66	1.48
PI to flowering	25	1.013	0.72	1.24	1.017	0.71	1.71
Flowering to harvest	27	1.065	0.60	1.21	1.137	0.54	1.60
6 DT to PI	38	0.824	0.72	1.01	0.853	0.70	1.35
PI to harvest	52	1.051	0.65	1.22	1.106	0.61	1.65
			Wet season				
6 DT to harvest	90	0.865	0.68	1.14	1.234	0.36	1.30
6 DT to 30 DT	24	0.569	0.78	0.98	0.792	0.57	1.05
31 DT to PI	14	0.674	0.75	1.05	0.999	0.44	1.24
PI to flowering	25	0.819	0.78	1.18	1.170	0.54	1.38
Flowering to harvest	27	0.804	0.74	1.24	1.256	0.35	1.49
6 DT to PI	38	0.650	0.75	1.02	0.979	0.44	1.15
PI to harvest	52	0.827	0.75	1.21	1.242	0.43	1.43

Table 4. Relative elevation, and total dry matter and grain yields at harvest for upland IR36 and UPLRi-5, for 5 toposequence positions. IRRI field UQ2, 1988 WS.

Position/ elevation code	Elevation[a] (cm)	Total dry matter[b] (t/ha)		Grain yield[b] (t/ha)	
		IR36	UPLRi-5	IR36	UPLRi-5
1A	0	5.0	5.7	1.41	1.81
1B	14	4.0	5.8	1.40	1.41
2	54	–[c]	–[c]	–[c]	–[c]
3A	80	5.8	–[c]	1.64	–[c]
3B	97	5.4	–[c]	1.45	–[c]
SE	2	0.5	0.5	0.16	0.16

[a]Zero defined as mean elevation for position 1A. [b]Mean of 5 replicate plots at each elevation. [c]Not used in 1988.

grain yield loss than cutting and removing the same number of tillers—possibly because of translocation of herbicide to nontarget tillers. But cutting of tillers, whether at maximum tillering (MT), PI, or grain filling (GF) caused proportionately larger yield loss in the drier 1987 than in 1986; detillering possibly interacted with water stress.

Experiments in 1988 used the same field of Typic Hapludoll soil as in 1986 and 1987, but used both IR36 and UPLRi-5. For the agrohydrology studies, the 1988 experiment measured rice growth and yield at four toposequence elevations and hence at four water table regimes (compared with 5 in 1987 and 3 in 1986); however, the two lowest elevations differed by a few centimeters only, as did the two highest (Table 4). The detillering studies were confined to elevations 1A and 1B, so that effects would not be confounded by variations in depth to groundwater. Elevations 1A and 1B each had 10 plots: 5 of 5.4 × 11.0 m for detillering studies, and 5 of 9.0 × 11.0 m for agrohydrology studies. The 2 higher elevations each had 5 plots of 9.0 × 11.0 m. To lessen soil erosion, vertical wooden boards were placed between and upslope of all plots. The detillering experiments involved 3 detillering intensities (0, 15, and 30% of tillers cut by scissors and removed), 3 detillering timings (MT, PI, and GF), and 2 rice cultivars.

Land preparation comprised rototilling and harrowing, with basal fertilizer at 60-30-30 kg NPK/ha, plus additional urea topdressings (each 30 kg N/ha) at 22 and 47 d after seeding (DAS). IR36 and UPLRi-5 seed was sown by hand on 29 Jun 1988 into furrows opened by a lithao. Weeds were removed by hand at 22, 42, and 65 DAS; and insects and diseases were controlled by appropriate sprays. To regulate the water table regimes against the variations caused by rain and dry periods, canals along two sides of the field were kept filled with water. Soil and crop variables needed for the simulations were monitored at weekly or biweekly intervals.

Hydrologically, 1988 WS was very similar to 1985 WS, although the crop duration was slightly longer and the season's total of solar irradiance correspondingly higher (Table 5); rain of 5 mm or more fell on about one-third of the growing days—appreciably less than in 1986, but more than in 1987. The seasonal average depth to water table in 1988 was about 50 cm at elevations 1A and 1B, and 110 cm at elevations 3A and 3B; these depths (Table 6) were deeper than in 1986, but shallower than in the dry 1987 when (without water-filled surrounding canals) average depth to water table exceeded 80 cm at all elevations. Correspond-

Table 5. Hydrological features of 1985, 1986, 1987, and 1988 WS at IRRI.

Year and crop season	Crop duration (d)	Season's total rainfall (mm)	Season's days having rain >1 mm (%)	Season's days having rain >5 mm (%)	Season's total solar irradiance (MJ/m²)
1985					
20 Jun-20 Oct	122	1548	52	34	1897
1986					
18 Jul-3 Nov	108	1689	68	51	1641
1987					
17 Jul-4 Nov	110	659	47	27	1805
1988					
29 Jun-4 Nov	128	1556	58	35	1981

Table 6. Relative elevation, distance along slope, and depth to water table for 5 toposequence positions in IRRI field UQ2, 1985-88 WS.

Elevation code	Elevation[a] (cm)	Distance along slope[b] (m)	Depth to water table (cm)			
			1985	1986	1987	1988
1A	0	5.5	59	45	83	45
1B	14	16.5	47	47	92	52
2	54	44.5	79	58	106	–[c]
3A	80	63.0	97	–[c]	118	106
3B	97	74.0	102	75	122	118
SE	2	0.5	5	5	5	5

[a]Zero defined as mean elevation for position 1A. [b]Zero defined as lower boundary of position 1A. [c]Not used.

ingly, soil-water content in 0-60 cm (determined gravimetrically and averaged for 1985-88 WS) was higher by 0.02 ± 0.01 cm^3/cm^3 at elevations 1A and 1B than at 3A and 3B, implying a difference of plant-available water in 0-60 cm of 12 ± 6 mm; the water-filled canals surrounding the field in 1988 similarly caused a detectable increase in soil moisture.

Grain yields in 1988 (average for all elevations) were 1.5 ± 0.1 t/ha for both IR36 and UPLRi-5; these values are much less than those achieved under comparable hydrological conditions in 1985. The cause may be that the surrounding canals impeded drainage of field water after heavy rainfall. This is supported by the observation that total dry matter yield (TDMY) in 1988 was less at elevations 1A and 1B than at 3A and 3B and by the achievement of yields of 3.2 ± 0.1 t/ha in another upland rice experiment seeded on 17 Jun 1988 in a field 2 km away. TDMY reached 4.8 t/ha for IR36 and 5.9 t/ha for UPLRi-5. The low grain yields were thus associated with harvest indices of only 0.24-0.31 (± 0.03). TDMY scarcely differed among elevations; variations among years were much greater. Plant height at maturity for IR36 was lower (60 ± 3 cm) in 1988 than in other years (70 ± 5 cm), but maximum leaf area index (3.7 ± 0.3 for both IR36 and UPLRi-5) was relatively high.

These various soil and crop observations, with complementary data for weather variables and crop phenology, are now used to define parameters in the SAWAH simulation model.

Simulation of defoliation of upland rice. Synthesis of data for 1986-88 and for both IR36 and UPLRi-5 shows that for mechanical detillering at PI and GF (results combined), the proportional yield decreases for 15 and 30% detillerings were, respectively, 2.0 ± 0.1 and 1.5 ± 0.1 times the proportion of tillers removed. For detillering at MT, however, the proportional yield decrease (for 15 and 30% detillering intensities combined) was only 0.5 ± 0.1 times the detillering proportion. It is likely that at MT the rice can counteract detillering (and, by implication, YSB infestation) by compensatory growth of new tillers and translocation of existing carbohydrates to productive sites within the plant.

PRODUCTION BENEFITS FROM SOIL-EROSION CONTROL IN UPLAND AND RAINFED LOWLAND WET SEASON CROPPING

Soils Department

Soil erosion on sloping lands can be controlled by contour-planted bands of perennial grass such as *Panicum maximum*, and such control is needed for both upland rice and nonrice crops. Alternatively, but at higher initial cost, nonbunded sloping land in suitable rainfall regimes can be protected if it is terraced, bunded, and puddled to allow production of rainfed lowland rice. By lessening rainfall runoff as well as soil erosion, grass bands and terrace bunds may also conserve rainfall where it falls and thus increase the reserve of soil water available for crop production. Conversely, in WS with high rainfall, impounded water may injure or kill nonrice crops through submergence and waterlogging; and in dry years, rainfall total and distribution may be insufficient to allow puddling and transplanting, and production from rainfed lowland rice would be zero. The choice of crop and land management that will give the highest production in a particular year therefore depends on that year's WS rainfall pattern. A livelihood and soil-conserving strategy for the farmer may therefore be to have parallel along-slope strips of land allocated among upland (nonbunded) rice, rainfed lowland (bunded) rice, and (nonbunded) nonrice crops, but with the nonbunded land being protected by grass bands.

A medium-term experiment that commenced in 1987 on a 2% hillslope of previously nonpuddled

Table 7. Grain yield and grain value[a] from alternative upland crops and erosion-control managements. IRRI, 1987 and 1988 WS.

Crop	Erosion control	Yield (t/ha)		Estimated grain value ($/ha)	
		1987	1988	1987	1988
Lowland rice	Bunds	0	0	0	0
Upland rice	None	0.72 ± 0.06	3.18 ± 0.05	90	380
Upland rice	Grass bands	0.82 ± 0.06	3.23 ± 0.07	100	390
Mungbean	None	0.85 ± 0.03	1.18 ± 0.02	510	710
Mungbean	Grass bands	0.87 ± 0.03	1.23 ± 0.04	520	740

[a] Assuming $0.12/kg for rice and $0.60/kg for mungbean.

loam soil therefore seeks to determine, during a succession of IRRI WSs, the benefits of moisture conservation and crop production from the grass bands, and the relative productions of upland rice, rainfed lowland rice, and legumes. The five treatments are rainfed lowland rice, upland rice grown with and without grass bands, and mungbean with and without grass bands. Within each of 4 replicated along-slope blocks 66 m long, each treatment occupies a strip 3.6 m wide extending the whole block length, with each strip comprising six 11-m-long plots delimited at their sides by wooden boards and at their ends by wooden bunds, grass strips, or marker strings, depending on treatment. Within each plot, measurements are made of soil variables, including depth to water table, and of crop growth and yield.

In 1987 and 1988, the water table for all plots in this experiment was too deep to affect crop growth. But measurements of soil-matric water showed that, throughout the crop season, plots with grass bands had a moisture content consistently higher than that of plots without bands, to the extent that within the 0-40 cm layer there was in the grassed strips in 1988 an additional 20 ± 8 mm of plant-available water. In 1987 (a drier year), there had been 10 ± 4 mm additional water, and in 1985, in a preparatory study in a different field using wooden boards rather than grass-terrace bands to lessen erosion, there had been 12 ± 4 mm. These increases in stored water constitute a significant augmentation of the 0-40 cm layer's available water-holding capacity of about 60 mm, and of the root-zone water capacity of about 120 mm.

This additional water generated numerical but nonsignificant increases in production of both upland rice and mungbean in both 1988 and 1987 (Table 7); unfortunately, these slight increases would to some extent be offset by the roughly 20% decreases in rice and mungbean production caused by intercrop competition in the rows immediately next to the grass strips. Significantly, however, the value of mungbean production (about $700/ha in 1988) was almost twice that of upland rice, for which yield was 3.2 ± 0.1 t/ha; in the dry year of 1987, the value of mungbean production was 5 times greater than that of upland rice. For 1987 and 1988 combined, the value of mungbean production was about 2.5 times greater than that for upland rice. Moreover, the pattern of rainfall at IRRI in both 1987 and 1988 WS was unsuitable for puddling and transplanting in previously nonpuddled soil, so production from the bunded rainfed lowland strips was zero. But in much wetter years than 1987 and 1988, mungbean may have been destroyed, and best income achieved from rainfed lowland rice.

Consequences of new technology

Agricultural Economics Department and Ministry of Agriculture, Nepal

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DIFFERENTIAL ADOPTION OF MODERN VARIETIES AND LABOR MARKET ADJUSTMENT IN NEPAL

Agricultural Economics Department and Ministry of Agriculture, Nepal

The Agricultural Economics Department has been concerned with the analysis of the impact on income distribution of differential adoption of modern rice technology across production environments. This year we report the results of a collaborative research study on the experience of Nepal, where agriculture contributes nearly 60% of gross domestic product and employs more than 90% of the economically active population. Rice is by far the most important crop in Nepal, occupying about half of the total cultivated area located mostly in the two ecologically distinct regions of the country, i.e., the hills and the tarai or lowland areas.

Modern varieties (MVs) of rice were introduced to Nepal in the early 1960s, but their adoption was limited to only 36% of rice areas by the mid-1980s. The dominant "modern" variety in Nepal is Masuli, which was developed with the assistance of Japanese scientists in Malaysia in 1965, using Ponlai (or Taichung 65) and a local variety as parents. Compared with IR varieties or crosses between IR and local varieties, Masuli is generally less responsive to fertilizer application, and thus yield gain over local varieties is more modest than with IR varieties. This variety, however, is adaptable over wider areas, including the cold environment, which may explain its popularity in Nepal.

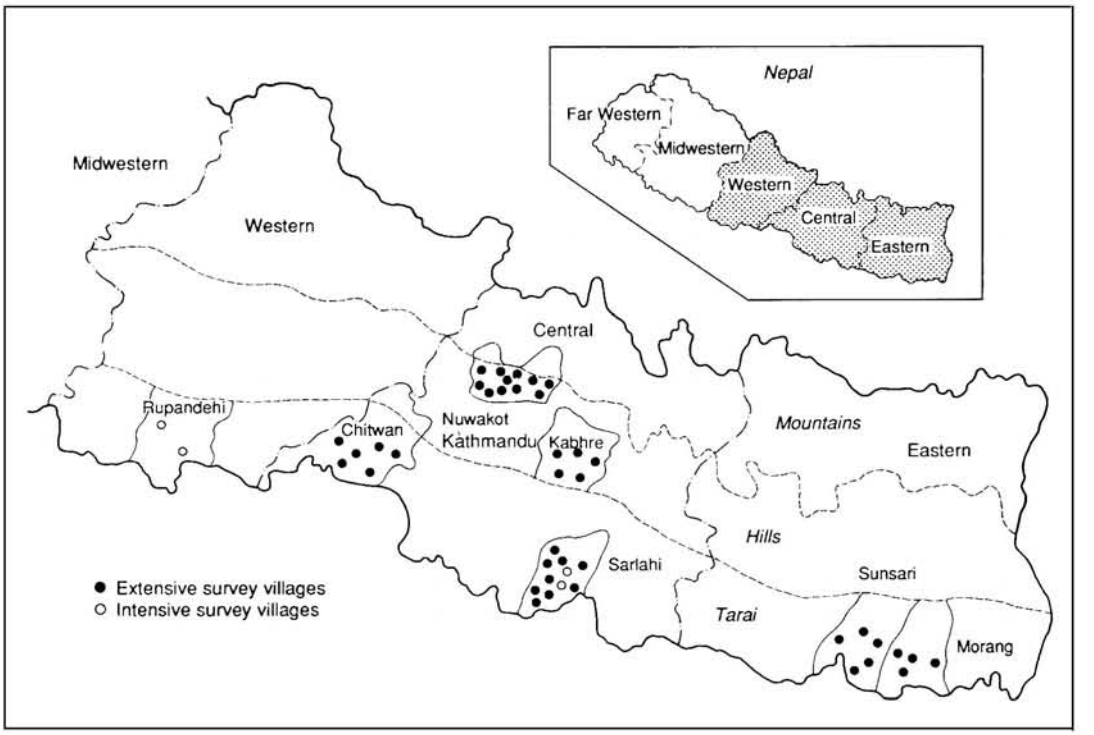
As in other developing countries in Asia, irrigation is a major factor constraining the adoption of MVs, since their productivity effect critically depends on the degree of water control. Rice MVs have been more widely adopted in the tarai, where most large-scale irrigation projects were constructed in the 1960s and 1970s. Even before the introduction of MVs, however, farm income in the tarai was generally higher than in the hills. There is concern, therefore, that the differential adoption of modern rice technology has accentuated the existing regional income disparity between the favorable and unfavorable areas. In the Nepalese context, this means not only the disparity between irrigated and nonirrigated areas, but also that between the tarai and the hill regions. We therefore first examine the impact of new technology on labor income, which governs the livelihood of the landless and small farmer households—the poorest segment of the rural society, who are critically dependent upon wage employment. Ultimately, however, we would like to explore how benefits are distributed among people or households. The second section deals with the impact of the production environment and associated technology on household income, including returns to land and nonfarm employment in both favorable and unfavorable production environments.

Two sets of data were collected for this purpose. The first is village-level data obtained through an extensive survey of 42 villages located in wide areas of the hills and the tarai. Data on yields, technology, labor market characteristics, seasonal migration, and history of permanent migration at the village level were collected by interviewing knowledgeable farmers. The villages were selected by a stratified random sampling procedure from six districts using environmental and technology information obtained from district agricultural officers. Two of the districts are the largest rice-growing areas in the tarai portion of the Eastern Region (Fig. 1). The four other districts (two in the hills and two in the tarai) are the leading rice-growing areas in the Central Region. Nearly two-thirds of the country's total rice area and production originate from these two regions.

The second set of data is an intensive household survey of four villages. Two villages, each representing the favorable and unfavorable production environments, were selected in Rupandehi District in the Western Region and Sarlahi District in the Central Region. Two adjacent villages in each district were deliberately chosen for ease of identifying the labor demand and income distributional effects of irrigation and modern rice technology, because factor and output prices and other characteristics of the production environment besides irrigation are highly similar.

Modern varieties and labor market adjustment. The impact of new rice technology on the welfare of landless households depends on the following:

- whether and to what extent adoption of modern rice technology raised demand for hired labor and, hence, wages;
- whether or not interregional migration, both



1. Location of study villages in extensive and intensive surveys in Nepal.

permanent and seasonal, from unfavorable to favorable areas significantly contributed to closing the interregional wage gap induced initially by differential technology adoption; and

- if adoption of labor displacing technology occurs in the favorable areas rather than interregional labor migration; if so, wages will be equalized but at a lower level.

Modern varieties and labor demand. Data from the intensive survey were used to analyze the labor demand effects of MVs. In the favorable villages, 90-100% of cultivated area is irrigated (Table 1). The lack of irrigation in the unfavor-

Table 1. Production environment, technology adoption, and labor use per hectare, Nepal intensive survey, 1987.

Item	Western Tarai		Central Tarai	
	Favorable	Unfavorable	Favorable	Unfavorable
Households (no.)	190	158	319	116
Area irrigated (%)	100	11	89	9
MV adoption (%)	97	80	70	5
Fertilizer application (kg NPK/ha)	43	14	15	8
Rice yield (t/ha)	2.8	2.2	2.4	1.9
Labor use (person days/ha)	128	114	159	149
(% hired)	(63)	(54)	(74)	(68)
Land preparation	21	31	38	33
(% tractor)	(69)	(13)	(0)	(0)
Transplanting	27	23	36	36
Crop care	33	22	44	39
Harvesting and threshing	47	38	41	41

able villages hindered the widespread adoption of MVs except by a few farmers who had tubewell irrigation.

Rice is produced once a year in almost all fields in the favorable villages, but only in a portion of the crop area in the unfavorable villages, reflecting the difference in the production environment for rice production. Fertilizer application per hectare and rice yield were significantly higher in the favorable villages, although these levels were lower than those observed in other Asian countries with similar population density.

Total labor input per hectare was higher in the favorable than in the unfavorable villages in both regions. Despite the higher mechanization level, this difference was relatively higher in the Western Tarai because of greater labor use in transplanting, crop care, harvesting, and threshing in the favorable villages. Labor input usually increases with the adoption of MVs, particularly in crop care activities, because of the larger application of fertilizer and the resulting need for weeding, and also in harvesting and threshing activities because of higher yield.

In the Central Tarai, the aggregate labor demand effect of the modern rice technology was less because in the villages under consideration, fertilizer application was low and the yield difference was relatively small. Nonetheless, the composition of the family and hired labor was remarkably different between production environments and regions. There was a tendency to use relatively more hired labor in more favorable environments, perhaps because of the sharper peak season labor demand in areas practicing double cropping, the income effect generated from higher income, and the specialization of family labor toward more skill-intensive tasks, leaving the more arduous tasks to hired labor.

Estimation of labor demand function. Labor demand functions per hectare were estimated separately for hired and family labor, based on the pooled farm household data and using the double log function specification. The wage rates and other factor prices are not included as independent variables, for there was no variation between the two villages, which are only a few kilometers apart. Table 2 presents the regression results of labor demand functions. Irrigation significantly increased demand for hired labor but not family labor in both regions. The coefficient of irrigation in the hired labor demand equation includes the effect of MVs. Adoption of MVs was not specified as a separate variable, because it is simultaneously chosen with labor demand by the farmer. As Table 1 demonstrated, irrigation is undoubtedly a highly

Table 2. Regression results of the demand function for hired and family labor per hectare in the Western and Central Tarai, Nepal intensive survey, 1987.

Item	Western Tarai[a]		Central Tarai[b]	
	Hired labor	Family labor	Hired labor	Family labor
Irrigation ratio[c]	17.55** (2.40)	3.60 (0.55)	0.38** (3.21)	−0.32 (−1.65)
Farm size	5.02*** (4.01)	−4.39*** (−3.92)	0.55** (6.57)	0.69** (−5.05)
Tenancy dummy[d]	16.27** (2.14)	−13.87** (−2.04)	0.10 (−0.80)	−0.10 (−0.46)
Mechanization dummy	5.82 (0.72)	−13.07* (−1.80)	—	—
No. of working members	−4.46*** (−2.67)	3.81*** (2.55)	−0.50** (−3.70)	0.70** (3.18)
Intercept	46.40	63.23	4.83	
R^2	0.28	0.27	0.40	0.31

[a]Regression based on linear specification. [b]Regression based on log-linear specification. [c]Irrigation dummy for Western Tarai. [d]Owner-operator dummy for Western Tarai.

significant factor contributing to the adoption of MVs. Hence, specifying irrigation alone in the regression would take into consideration the major impact of MVs, at the same time avoiding the simultaneity problem.

As expected, larger farm size was associated with higher employment of hired labor and lower employment of family labor, whereas the number of working family members had the opposite effect. Owner-operators have a significantly higher demand for hired labor and use significantly lower family labor. Tenure patterns do not seem to affect labor demand in the Central Tarai.

Modern varieties and labor supply adjustments. Since the MV technology uses hired labor intensively, wage rates of hired labor will increase, at least in the short run in the favorable areas adopting the new technology. This wage differential is expected to induce migration from unfavorable to favorable areas, equalizing wages in the long run. Permanent migration from the hills, the generally unfavorable rice areas, to the lowland tarai region is a well-known demographic phenomenon in Nepalese history. Availability of land and the adoption of modern rice technology were important pull factors in the hill-to-tarai migration. We explored the causes and the consequences of such demographic changes, with particular focus on the impact of modern rice technology and the regional wage differential using the extensive survey data.

Characteristics of sample villages. The 42 villages covered in the extensive survey were classified by region and production environment; villages in which more than 30% of the area was irrigated were considered favorable (Table 3). In general, the ratio of irrigated area was much higher in the tarai than in the hills. Differences in the availability of irrigation water accounted for the higher adoption rate of MVs in the favorable than in the unfavorable villages, since there was no difference in the ratio of MV adoption between the tarai and the hills. The difference in the average rice yield was closely related to the difference in the ratio of irrigated area, the highest being 3 t/ha in the favorable tarai villages and the lowest being 1.6 t/ha in the unfavorable hill villages.

Average farm and rice area per farm were found to be larger in the tarai. The higher ratios of landless households in the tarai may be the result of the migration of landless and near-landless people from the hills to the tarai. Consistent with our hypothesis that modern rice technology attracts the migration of landless households is the higher ratio of landless households in the favorable villages than in the unfavorable villages in both regions. The very low ratio of landless households in the hills, even in the favorable villages, may be explained by the greater availability of seasonal migrants during peak seasons such as transplanting and harvesting. Unlike in the tarai, where rice is a dominant crop, many different

Table 3. Socioeconomic characteristics of sample villages by region and by environment in the Nepal extensive survey, 1987 WS.

Item	Hills		Tarai	
	Favorable	Unfavorable	Favorable	Unfavorable
Villages (no.)	7	9	17	9
Irrigation ratio (%)	34	4	70	11
MV adoption (%)	73	13	69	16
Rice yield (t/ha)	2.7	1.6	3.0	2.2
Av farm size (ha)	1.1	1.0	1.9	1.8
Av rice area (ha)	0.6	0.4	1.5	1.3
Ratio of landless households[a] (%)	5	2	30	20
Ratio of owner-cultivators[b] (%)	89	91	49	70
Ratio of seasonal in-migrants[c] (%)	41	3	21	12
Distance from nearest commercial center (km)	3.7	5.0	3.4	2.5

[a]Ratio to the total number of households. [b]Ratio to the total number of farming households including landless households. [c]Ratio to the total hired labor during peak seasons of transplanting and harvesting.

crops with different peak seasons are grown in the hills. Seasonal migrants are readily available, even though the transportation network is poorly developed in this region. The availability of off-farm jobs may also be an important factor in rural labor markets, but there appears to be no difference in access to commercial centers across areas in terms of distance from the villages.

Modern varieties and migration. To test whether and to what extent higher demand for labor arising from MV adoption was followed by increased permanent and seasonal in-migration of landless people, the landless ratio function and seasonal in-migration function were estimated. Dependent variables were expressed as ratios, while the same set of independent variables was used in both regressions to represent technology, production environment, cost of migration, and characteristics of the land and the labor market. The ratio of landless households was used as a proxy variable for permanent in-migration because of difficulties in obtaining such data from the extensive survey. Results of the intensive survey indicate that the ratio of landless households is positively correlated with the adoption of modern rice technology.

The regression results based on the extensive survey (Table 4) show that irrigation positively affected the ratio of landless households, supporting our hypothesis that the adoption of modern rice technology as represented by irrigation plus MV adoption increases the labor supply by attracting the landless population from less favorable areas. The significant and positive coefficients for tarai and farm size suggest that the landless migrate to the tarai not only because of the larger demand for hired labor associated with the larger farm size in the tarai, but also because of other possible advantages, such as the lower man-land ratio and the larger opportunity to become tenants. The significant coefficient of distance variable likely captures certain advantageous effects of remote area on hired labor employment such as the larger skewness of farm size distribution, which would result in larger aggregate hired labor demand.

The seasonal in-migration function has low R^2, essentially because of the difficulty in obtaining accurate village-level information on the extent of seasonal in-migration during peak seasons. This was particularly so in the hills, where production environments are quite diverse even within one village. It is remarkable, however, to find the positive and significant effect of irrigation and the negative and significant effect of the tarai dummy on seasonal in-migration. The positive effect of irrigation clearly supports the hypothesis that modern rice technology increases seasonal in-migration by increasing hired labor demand. On the other hand, the negative locational effect of tarai is consistent with our earlier observation that seasonal migration is less common in the tarai because of the dominance of rice production. The coefficient of the contract dummy is positive and significant because everyone can participate in harvesting under the output sharing contract, unlike the case of a daily wage contract, which often requires certain qualifications.

The above results indicate that the differential adoption of modern rice technology and the differential endowment of land relative to labor induced permanent and seasonal migration. Particularly interesting is the finding that the supply

Table 4. Estimated results of MV adoption function, landless ratio function, and seasonal in-migration ratio function, based on the extensive survey in Nepal.[a]

Item	MV adoption	Landless ratio	Seasonal in-migration ratio
Intercept	−.15 (−.78)	−.12 (−1.00)	−.08 (−.26)
Irrigation ratio	.81** (5.77)	.19* (2.10)	.28* (2.02)
Tarai dummy	.08 (.93)	.17** (2.90)	−.20* (−1.82)
Distance	−.01 (−1.18)	.02* (2.39)	−.01 (−1.07)
Log farm size	−.01 (−.20)	.04* (2.20)	−.01 (−.10)
Ratio of owner-cultivator	.25* (1.73)	−.06 (−.68)	—
Contract dummy	—	—	.23* (2.39)
R^2	.57	.54	.24
F-value	9.68	8.47	1.80

[a] t-values are in parentheses. ** = significant at the 1% level, * = 5% level.

The above results indicate that the differential adoption of modern rice technology and the differential endowment of land relative to labor induced permanent and seasonal migration. Particularly interesting is the finding that the supply

of casual labor tends to be higher in the tarai because of the higher ratio of the landless, but lower because of the lower availability of seasonal in-migrants during peak seasons.

Regional wage differential. This section examines the impact of interregional labor market adjustments on regional wage patterns. The average wage rates of casual laborers in major activities across the hills and the tarai villages classified by production environment are shown in Table 5. Wages, including the imputed value of food provided by employers, are standardized to 8 h of work per day and expressed in real terms using rice price as a deflator. Female workers usually perform jobs that require relatively less physical strength such as transplanting, weeding, manuring, and harvesting, whereas male workers are engaged mostly in plowing and threshing, which require more physical effort. In certain villages in the tarai, output-sharing contracts were practiced in harvesting, and thus imputed labor earnings per day were estimated.

Except for land preparation, the difference in wage rate between the hills and the tarai was generally small. The wage rate was higher in the hills for land preparation, partly because of the greater physical efforts required to plow ricefields located in mountainous topography. The difference in wage rate between the favorable and unfavorable villages within the tarai was generally small. The higher wages in the favorable villages than in the unfavorable villages in the hills reflect the greater transaction and information cost of labor movement in the hilly regions.

The imputed wage rates under output-sharing contracts were much higher than the daily wage for harvesting. Daily wage workers tended to be less motivated to work, since their income was fixed regardless of their effort, while more able workers preferred the output-sharing contract to the daily wage contract for its higher remuneration at the higher level of work effort.

Regression results of wage rate functions for the various tasks are shown in Table 6. None of the estimated coefficient of irrigation ratios are significant, even though they are consistently positive. Given that irrigation was a major determinant of MV adoption and that adoption of MVs significantly raised the hired labor demand, the nonsignificant wage effect of irrigation can hardly be explained unless we take into account subsequent labor supply adjustments to the higher labor demand through changes in the landless population and seasonal in-migration.

Such interpretation is reinforced by the finding that the tarai dummy has significant and negative coefficients in nonpeak season activities of land preparation and threshing, but positive although not always significant coefficients in peak season activities of transplanting, weeding, manuring, and harvesting. The schedule of nonpeak activities can be staggered, whereas the peak season activities cannot be delayed without significant production loss. While the labor demand for nonpeak season activities is generally met by family labor and resident landless labor, seasonal migrants become important during peak seasons. As was shown in the previous section, the tarai is

Table 5. Daily wage rates of hired labor by activity and by environment in sample villages in the extensive survey in Nepal, 1987 WS.[a]

Activity	Daily wage (kg rice/d)			
	Hills		Tarai	
	Favorable	Unfavorable	Favorable	Unfavorable
Land preparation (male)	7.45	6.56	5.77	5.66
Transplanting (female)	4.69	4.14	4.74	5.19
Weeding and manuring (female)	4.45	3.94	4.48	4.76
Harvesting (female)	4.45	4.10	4.48 (10.88)[b]	4.76 (9.78)[b]
Threshing (male)	6.91	6.43	6.97	6.47

[a] Standardized wage rates for 8 h/d, expressed in real rice terms. [b] Imputed wage rates per day under output-sharing arrangements.

Table 6. Estimated results of log-wage rate functions based on the extensive survey in Nepal, 1987 WS.[a]

Item	Land preparation	Transplanting	Weeding and manuring	Harvesting	Threshing
Intercept	1.87	1.24	1.28	−1.42	1.88
	(8.42)	(5.42)	(5.79)	(6.95)	(7.34)
Irrigation	.14	.05	.07	.23	.21
	(.85)	(.27)	(.46)	(1.58)	(1.15)
Tarai dummy	−.22*	.20*	.12	.05	−.28*
	(−2.10)	(1.85)	(1.17)	(.46)	(−2.30)
Distance	−.03*	−.04**	−.03*	−.02*	−.04*
	(−1.92)	(−2.79)	(−2.20)	(−1.87)	(−2.27)
Log farm size	−.02	−.05	−.01	−.04	−.01
	(−.32)	(−.61)	(−.20)	(−.58)	(−.16)
Ratio of owner-cultivators	.10	.37*	.23	−.03	.04
	(−.32)	(2.18)	(1.37)	(−.17)	(.21)
Contract dummy	—	—	—	1.12**	—
				(11.17)	
R^2	.24	.33	.22	.88	.26
F-value	2.31	3.55	1.98	41.25	2.54

[a] t-values are in parentheses. ** = significant at the 1% level, * = 5% level.

characterized by a larger supply of resident landless and by lesser availability of seasonal in-migrants than the hills. The lower wage rates during nonpeak seasons and somewhat higher wage rates during peak seasons in the tarai are clearly consistent with such differences in labor market characteristics between the two regions. An important implication of this finding is that the "average" wage rates throughout the crop season would not differ substantially between the hills and tarai.

The estimated coefficients of distance from village to the nearest commercial center are consistently negative and significant, which would reflect the difficulty of conveying the labor market information and the large cost of traveling to distant areas. Farm size is found to have no effect on any wage rates, even though it is positively associated with hired labor demand. The ratio of owner-cultivators has a significant coefficient only in transplanting, whereas the contract dummy has a large and significantly positive coefficient in the harvesting wage regression.

The statistical evidence provided in this section, coupled with earlier findings on labor supply adjustments, strongly supports the hypothesis that interregional labor markets in Nepal are sufficiently integrated. Adjustment of supply and demand in local labor markets leaves no significant differences in the wage rates over wide rural areas through permanent and seasonal migration. This is remarkable in view of the facts that the favorable and unfavorable areas are, in a large measure, geographically separated and that transportation and communication facilities are underdeveloped in Nepal, so that migration costs appear to be far from negligible. Adoption of MV technology in a favorable area would not create a significant regional income differential within the poor segment of the rural population, whose livelihood depends on wage earnings, despite the fact that it created a regional productivity differential. Further research is being conducted to determine the interregional consequence on returns to land, an immobile factor, and on overall income distribution.

Determinants of household income. Returns to land are another major income source from rice farming, accounting for more than 40% of gross value added. Unlike labor, land is an immobile factor, and thus differential adoption of new technology between favorable and unfavorable production environments may widen interregional difference in land values.

At least two types of land market adjustments can mitigate such inequitable effects: changing farm size and changing farming systems. With

appropriate land market and tenancy transactions, labor migration may bring about an increase or decrease in farm size in unfavorable or favorable areas so as to equate total farm income across areas. Second, the lower profitability of rice farming in unfavorable areas may induce farmers to cultivate other crops and livestock or pursue nonfarm employment.

Household income by source. Table 7 presents average annual income by source in the favorable and unfavorable villages of the Western and Eastern Tarai. The average income levels for the favorable villages are similar except for a slightly higher income from nonagricultural sources in the Western Tarai. The major difference is in the much lower average income level in the unfavorable village in the Western Tarai compared with the Central Tarai. Indeed, while average income in the unfavorable village is significantly lower than in the favorable village in the Western Tarai, as may be expected, the opposite is the case in the two villages of the Central Tarai, where the average income of the unfavorable village exceeds that of the favorable village.

The markedly higher income from other crops and livestock in the unfavorable village of the Central Tarai more than compensated for the lower income from rice and nonagricultural sources. In the Western Tarai, income from all sources was lower in the unfavorable than in the favorable villages, where both farm size and cropping intensity were lower. In contrast, farm size in the unfavorable village of the Central Tarai was higher than in the favorable village, while cropping intensity was only slightly lower. The level of schooling, which increases farm productivity or nonfarm income, was also more widely different in the Western than in the Central Tarai.

Household income determination. Household income is composed of returns to assets, primarily land, and income from labor in farm or nonfarm work. Income from land will depend on farm size, quality of that land as indicated by irrigation, and the tenure status, which determines the proportion of land rental accruing to the farm household. Technology associated with irrigation such as MVs will affect land rental, but to avoid multicollinearity problems, only irrigation is specified in the equation. Income from labor will depend on the characteristics of the household worker, such as years of schooling.

The results of the regression analysis presented in Table 8 show generally good fit, with R^2 of about 0.8 for rice, nonrice, and total income equations. Farm size, irrigation with its associated technology, and other assets are generally the most important factors explaining household income levels. In the Western Tarai, irrigation raised not only returns to land per hectare for rice but also for nonrice farming by about 30-40%. In contrast, while coefficients of farm size and irrigation for rice income were similar for both Tarai regions, these were not the case for the nonrice and for the total income equation. Returns to land from nonrice income were much higher in the Central Tarai villages, and these were lower for irrigated than for rainfed areas. Consequently, irrigation did not significantly affect total income. The much higher coefficient of farm size in the total income equation of the Central Tarai implies a higher productivity of land in its rainfed village compared with that in the Western Tarai. Aside from variations

Table 7. Average income by source, cropping intensity, and farm size in representative favorable and unfavorable villages in Western and Central Tarai, Nepal, 1987 WS.

Item	Western Tarai		Central Tarai	
	Favorable	Unfavorable	Favorable	Unfavorable
Income (US$)				
Rice	464	370	457	275
Nonrice	423	132	397	803
Nonagricultural	249	149	75	46
Total	1136	651	929	1124
Cropping intensity (%)	209	157	210	200
Farm size (ha)	1.8	1.5	1.6	2.1
Schooling of household head (yr)	3.9	2.2	2.6	2.2

Table 8. Determinants of annual household incomes in 2 villages representing favorable and unfavorable villages each in Western and Central Tarai, Nepal, 1987 WS.[a]

Item	Western Tarai			Central Tarai		
	Rice	Nonrice	Total income	Rice	Nonrice	Total income
Farm size	2.88** (11.13)	1.99** (3.75)	2.96** (6.24)	2.922** (3.008)	9.773** (6.931)	9.674** (6.337)
Irrigation X farm size	3.80** (10.41)	2.80** (5.28)	7.10** (10.61)	4.143** (5.281)	−3.009** (−2.704)	0.973 (0.804)
Tenure X farm size	−1.19 (−1.59)	−1.95** (−2.95)	−1.27 (−0.93)	−2.184** (−5.281)	−4.647** (−2.233)	−5.933** (−2.637)
Schooling	0.67 (0.59)	−0.41 (−0.43)	5.28** (2.55)	−2.385** (−1.474)	−2.088 (−0.821)	−3.860 (−1.374)
Assets	0.005* (1.81)	0.02** (5.95)	0.06** (7.03)	0.015 (1.984)	0.005 (0.288)	0.039** (2.255)
Intercept	0.94	0.79	0.55	2.618	−2.709	1.707
R^2	0.89	0.88	0.89	0.768	0.733	0.827

[a] Numbers in parentheses are *t*-values. ** = significant at the 1% level, * = 5%.

in the quality of land, differences in human capital as measured by schooling seem to be a significant explanatory factor for the wide differences in income between favorable and unfavorable villages observed in the Western Tarai. The negative coefficient for tenure dummy is as expected.

Conclusions. Despite the fact that the adoption rates of modern rice technology were markedly different in the various regions of Nepal because of the diverse production environments, we found that the wage rates were largely equalized across regions by interregional migration, both permanent and seasonal, from unfavorable to favorable regions. Therefore, as far as the income of the landless and near-landless people, who belong to the poorest segment of the poor rural society, is concerned, there is little evidence to support the commonly held view that the location specificity of modern rice technology has created a significant regional differential. On the other hand, we also found that the presence of irrigation significantly affects household income through its effect on returns to land, thereby making the landowning class in favorable areas better off. The lower rice income in unfavorable areas, however, might be offset, at least partially, by the shift from rice to other crops, as our study in the Central Tarai villages indicates.

The emerging conclusion is that interregional labor market adjustments through migration, and product market adjustments through a shift in crops are important mechanisms by which income disparities, initially created by the differential adoption of modern rice technology, can be significantly reduced.

Cropping systems program

Analysis of the physical and biological environment

Multiple Cropping and Agricultural Economics Departments and Farming Systems Research Institute, Thailand

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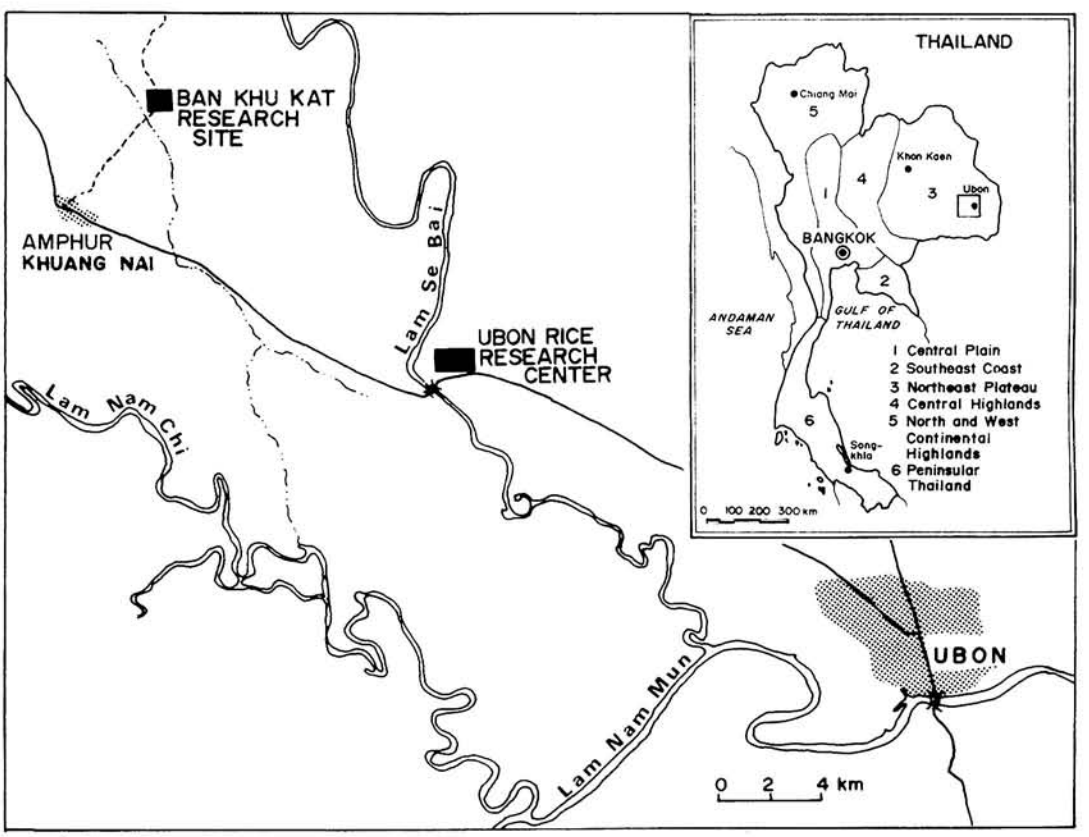
DROUGHT-PRONE RAINFED LOWLAND

Multiple Cropping and Agricultural Economics Departments and Farming Systems Research Institute, Thailand

Characterization of the Thai-IRRI rainfed lowland rice research site in Northeast Thailand (*Multiple Cropping and Agricultural Economics Departments and Farming Systems Research Institute, Thailand*). IRRI and the Thai Department of Agriculture initiated a joint research project in 1987 to address the constraints of the drought-prone and drought-and-submergence-prone rainfed lowland ricelands typical of Northeast Thailand, Laos, and Cambodia. The project is based at the Ubon Rice Research Center (URRC). The cooperating institutions include IRRI, the Farming Systems Research Institute, the Field Crops Institute, the Department of Land Development, and Khon Kaen University. On-station research is conducted at Ubon and at five other rice research stations in the northeast. On-farm research was initiated in Khu Khat village, located 23 km northwest of URRC (Fig. 1).

Rainfed lowland rice is the predominant culture type in the locality, with additional small areas of upland rice. Using both traditional and improved rice varieties, farmers grow a single crop per year (rice - fallow pattern). Drought and submergence are the two hydrological problems associated with rice production in the area; they depend on rainfall timing and distribution, and on the microtopographic position of the ricefield. The predominantly sandy soil is naturally drought-prone and has extremely low fertility.

The site lies within the Khorat Plateau, with elevation of 100-200 m above sea level. The generally flat to gently undulating plateau has slopes mostly less than 2%. The mean annual rainfall ranges from 1,250 to 1,875 mm. The



1. Thai-IRRI rainfed lowland rice project research sites, 1988.

moisture regime is dry for more than 6 mo (November-May) and moist to wet for 5 mo (June-October).

Accurate base materials were sought for detailed spatial analysis of Khu Khat and vicinity. Conventional black-and-white aerial photographs (scale 1:15,000, taken in October 1975) were systematically interpreted for landform and 1975 land-use analysis. The photographs also allowed estimation of three classes of tree density within the ricefields. Area measurements by planimetry were performed on maps produced from the aerial photographs, based on controlled area from a 1:50,000 topographical map.

For the landform and land-use analysis, a 3.8- x 4-km block covering all the experimental locations was used. This block of 1,500 ha represents the range of typical landforms and land uses in this environment.

Landform. Three main landscapes were identified over the research site. Nine detailed landform units resulted from the further subdivision of the main landforms, based on physiographic variations within the local toposequence (Fig. 2).

Area measurements by planimetry revealed that the gently undulating, less distinct knolls are the most extensive, representing 42% of the area. The gently sloping areas (map unit 2.1) found adjacent to most of the bottomlands, and the nearly level portions (map unit 2.3) of the intermediate landscapes (middle terraces) cover 15 and 18% of the area, respectively. Within the bottomlands, the low-lying floodplains and terraces along the creek cover 8%.

Bottomlands are generally more favorable for rice production than the slightly higher elevated middle terraces and knolls. However, the latter landscapes account for more than 80% of the land resources in Khu Khat.

Land use. Figure 3 shows the major land-use types during 1975, the time of the aerial photography: ricelands (map units 1, 2, and 3), forests (map units 4 and 5), residential areas (map unit 6), and lakes or ponds. Riceland covered 63% of the area, while forests occupied most of the nonrice portions (37%).

A large part of the riceland showed trees at three density levels:

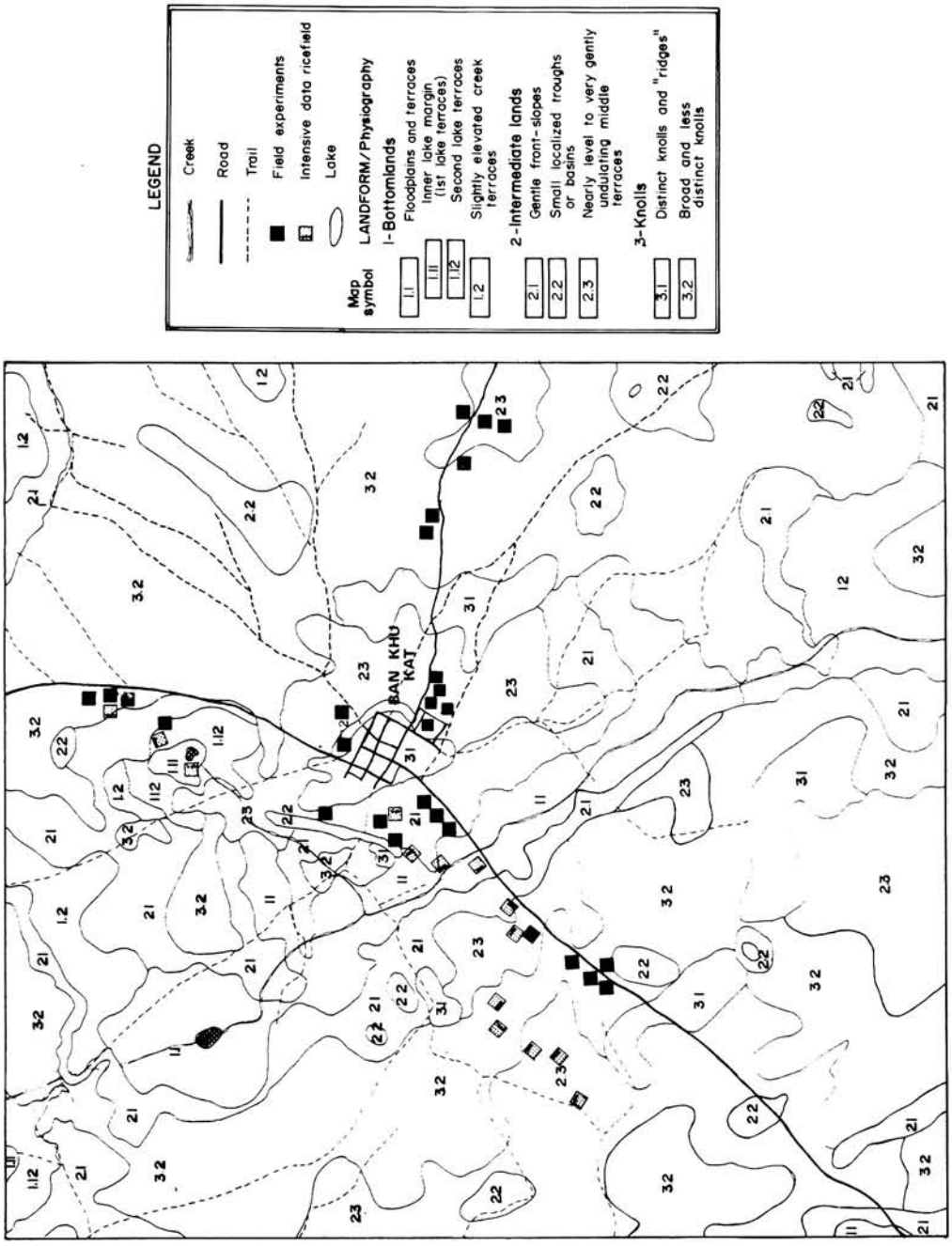
- Open ricefields with 12 or fewer trees/ha, equivalent to 1 tree/>800 m^2. The trees were growing mostly along the dikes or bunds. Open fields accounted for 31% of the rice area in 1975.
- Low tree-density ricefields with 13-24 trees/ha, or 1 tree/400-800 m^2. Trees were growing both on the bunds as well as inside the ricefields. Forty percent of the ricelands were mapped in this category.
- High tree-density ricefields with 25 or more trees in 1 ha, or 1 tree/<400 m^2. Trees were growing everywhere, suggesting that the riceland had been developed from forest. Tree density tended to be higher in ricefields that were close to forests. This class covered 29% of the rice-growing area.

Landform × land use. The extent of rice-growing areas over the major landform types was determined by the manual overlay technique. The bottomlands have been fully developed for rice production. More than 70% of the intermediate landscape and 40% of the uppermost landform (knolls) have also been utilized for rice.

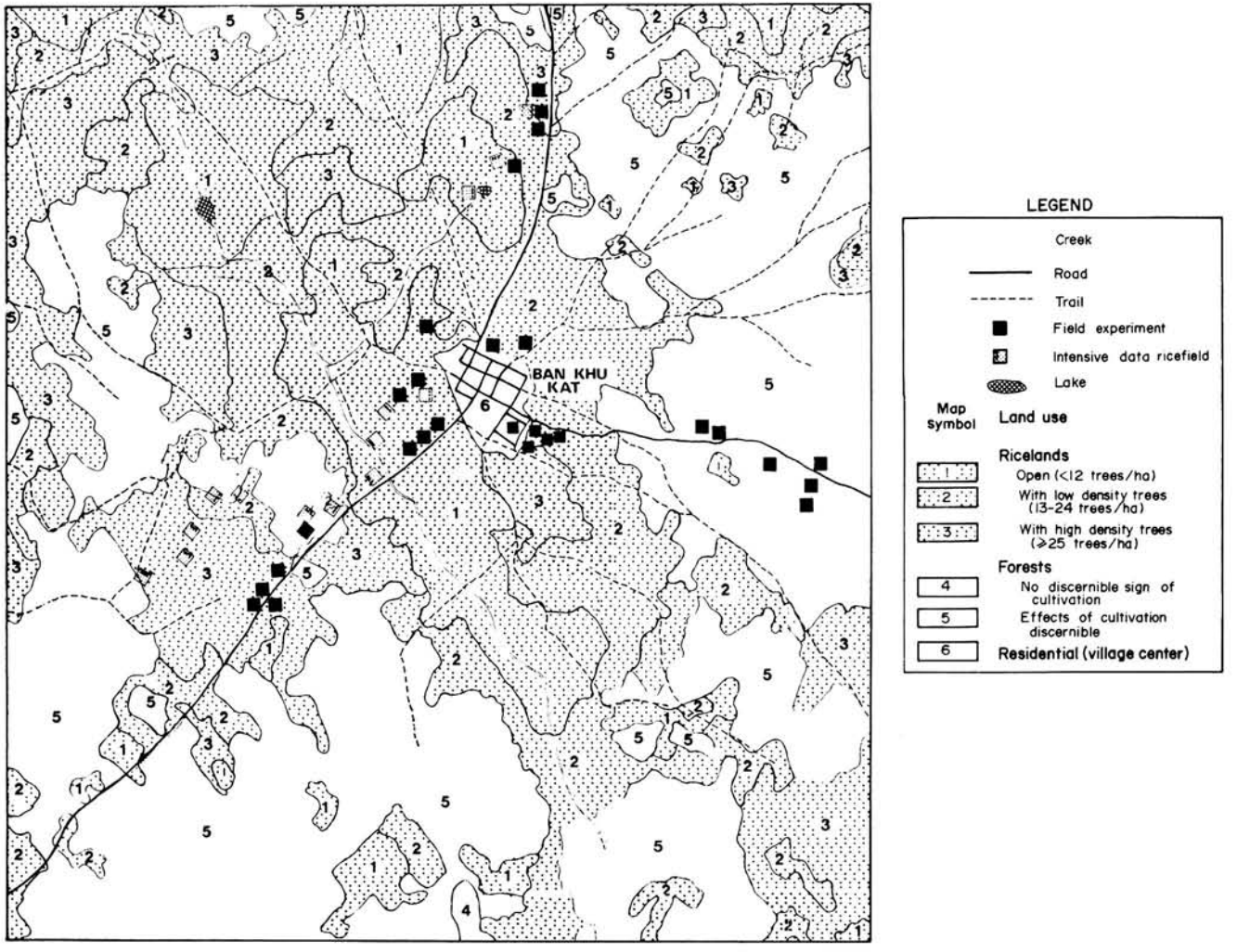
Laboratory analyses of soil profile samples collected from upper ricefields at three locations over the research area (within the Ubon soil series on the soil map) showed the characteristics given in Table 1.

Soil fertility in the experimental fields. Data from 54 soil samples collected from 18 experimental fields in 1987 present substantial evidence of the magnitude of problems related to soil fertility management (Table 2).

The majority of the samples fell into classes indicative of grave nutrient deficiency levels. Seventy percent showed pH 5.0 or lower (very strongly to extremely acid). Only three sites (Rod, Koon, and Soon) showed medium acid to near neutral soil (pH 5.6-6.6). Cation exchange capacity (CEC) was <3 meq/100 g (very low) in 96% of the samples. No sample had a CEC above 5.0. Ninety-six percent of the samples showed organic matter contents ≤1.0%, the majority of which had <0.5% (very low). Available P was also low to very low (<6 ppm Bray 2) in 74% of the samples. Very high available P contents (>45 ppm) were, however, noted in samples from 4 sites (Peng, 2 sites in Sompong, and Rod). K was very low (<30 ppm) in 76% of the samples.



2. Major landforms of Ban Khu Kat and vicinity, Amphur Khuang Nai, Ubon, Northeast Thailand.



3. Major land uses of Ban Khu Kat and vicinity, Amphur Khuang Nai, Ubon, Northeast Thailand.

Hydrology. Ricefield hydrology has been monitored since the start of the project in 1987. Fourteen intensive data ricefields (IDPs) along four transects located in the northern, middle, and southern parts of the village were selected. The IDPs represent three topographic levels along the toposequence, namely lower, middle, and upper ricefields.

Figure 4 presents the 1987 cropping season hydrographs that demonstrate the hydrological variations as affected by topographic position. In the lower ricefield, the water level remained mostly within 30-50 cm above the ground, then gradually receded at the end of the season. The hydrograph indicates a medium-deep water regime.

In the middle ricefield, the water level fluctuated between 5 and 20 cm above the soil surface

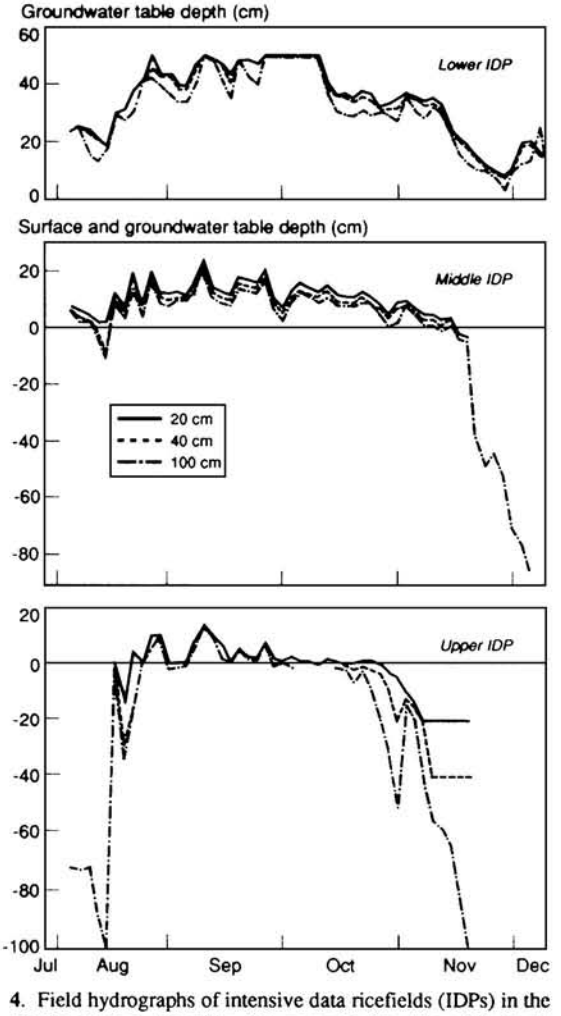
Table 1. Soil characteristics of upper ricefields in Khu Khat village, Ubon, Northeast Thailand.

Characteristic	Soil depth	
	0-12 cm	12-30 cm
Texture (%)		
Sand	70	66
Silt	27	29
Clay	3	5
pH (1:1 H_2O)	4.6	4.6
Cation exchange capacity, (meq/100 g soil)	0.8	0.8
Available Bray P (ppm)	1.0	0.8

Table 2. Noncumulative frequency distribution of soil samples analyzed for selected chemical properties from experimental sites in Khu Khat, Ubon, Northeast Thailand, 1987.[a]

Class (USDA)		Frequency distribution	Percentage
pH			
4.0 - 4.5	Extremely acid	12	22
4.6 - 5.0	Very strongly acid	26	48
5.1 - 5.5	Strongly acid	6	11
5.6 - 6.0	Medium acid	7	13
6.1 - 6.5	Slightly acid	2	4
6.6 - 7.0	Neutral	1	2
Cation exchange capacity (meq/100 g)			
0 - 3.0	Very low	52	96
3.1 - 5.0	Low	2	4
Organic matter content (%)			
< 0.5	Very low	36	67
0.6 - 1.0	Low	16	29
1.1 - 1.5	Moderately low	1	2
1.6 - 2.5	Medium	1	2
Available P (ppm, Bray 2)			
< 3.0	Very low	28	52
3.1 - 6.0	Low	12	22
6.1 - 10.0	Moderately low	2	4
10.1 - 15.0	Medium	0	0
15.1 - 25.0	Moderately high	1	2
25.1 - 45.0	High	1	2
> 45.0	Very high	10	18
K (ppm)			
< 30	Very low	41	76
31 - 60	Low	1	2
61 - 90	Medium	2	4
91 - 120	High	2	4
> 120	Very high	8	14

[a] No. of sites = 18; total samples = 54; depth of sampling = 0-15, 15-30, 30-60-cm.



4. Field hydrographs of intensive data ricefields (IDPs) in the middle transect, Ban Khu Kat research site, Ubon, Thailand, 1987.

Table 3. Respondents' classification of their ricelands and soils for each land-soil combination.[a] Ubon, Northeast Thailand, 1987 wet season.

Landscape position	Sandy		Sandy loam		Loamy		Saline		Forest		Total	
	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
Lower	17.9	18	21.4	22	10.6	11	11.8	12	0	0	61.8	63
Upper	23.4	24	5.6	6	1.9	2	0	0	4.3	4	35.2	36
Total	41.3	42	27.0	28	12.5	13	11.8	12	4.3	4	97.0	99

[a] Does not include respondents' garden or forest lands.

throughout the season, but dropped rapidly at the end of the rainy period—a typical shallow rainfed favorable water regime.

In the upper ricefield, surface water remained at <5 cm above the soil, except immediately following a heavy rainfall. Before the end of the rainy season, standing water had disappeared from the ricefield.

Research is in progress to correlate farmer land classification with the soil and hydrology classes derived from more formal classification.

Farmer land classification in relation to organic manure management in Northeast Thailand (*Agricultural Economics*). Farmyard manure (FYM) is an important rice crop nutrient resource of villages in Northeast Thailand that keep large animals. Use of green manure (GM) is another potential method to improve nutrient cycling and soil conditions. The possibility of linking GM experiments to farmers' soil nutrient management practices was explored. Farmers' classification of lands and soils, choice and management of crops and rice cultivars, and strategies to allocate limited quantities of FYM and inorganic fertilizer were examined before designing on-farm research on GM that would complement and take advantage of the farmers' use of FYM.

Twenty-six families (from about 200 villages) were randomly selected, and heads of households were interviewed in the 1987 wet season (WS). Farmers classified rainfed lowland ricefields as upper (*din don*, 37% of total area) or lower (*din lum*, 63%). Rice soils were classified as sandy (*din sai*, 42% of total bunded rice area), sandy loam (*ruan sai* or *din sai tom*, 28%), loamy (*din tom*, 13%), or saline (*din kem*, 12%). New ricefields with forest soils accounted for 4% of the area (Table 3).

Upper ricefields were drought-prone with mostly sandy soils. Flood-prone lower ricefields had more productive sandy loam in addition to sandy soils. The most productive lands were those with loamy soils, in the lower area, but not so low as to be flood-prone (*din tommada*, "normal" ricefield).

Farmers matched rice cultivars to soil and land combinations (Table 4). Farmers grew a nonglutinous upland/shallow rainfed selection, Khao Dok Mali (KDM), in upper ricefields. Reported yields averaged 1.3 t/ha. KDM was the most important source of villagers' cash income.

Sanpatong—a tall, medium-deepwater local glutinous cultivar—and improved glutinous RD6 were grown on lower, richer areas for consumption. Reported yields were 1.0-3.0 t/ha and averaged 1.7 t/ha. Considering farmer-described land-soil differences, respondents planted roughly equal

Table 4. Farmers' allocation of farmyard manure (FYM) over their land and soil categories for their 3 main cultivars.[a] Ubon, Northeast Thailand, 1987.

Land and soil	FYM (in % of rice area)			
	Sanpatong	RD6	Khao Dok Mali	Total
Lower				
Sandy	25	12	0	37
Sandy loam	7	13	3	23
Loamy	4	8	0	12
Subtotal	36	33	3	72
Upper				
Sandy	1	0	20	21
Sandy loam	0	0	5	5
Loam	0	0	2	2
Subtotal	1	0	27	28
Total	37	33	30	100

[a] Data for 23 respondents and their 100 ha of rainfed lowland ricefields.

areas of Sanpatong and RD6 on about 70% and KDM on about 30% of their ricelands.

Crop cuts (Table 5) confirmed farmer-reported yields. RD6 performed slightly better than Sanpatong in grain and total dry matter yields. Both outperformed the upper ricefield KDM. The higher straw yield of Sanpatong and RD6 is important, since straw is valued for animal fodder and conversion to FYM.

Khu Khat is a "cattle village"; almost all families have several cows and one or two water buffalo. Animals are penned at night. All rice straw is saved, and straw and cut weeds are used as fodder and bedding. FYM is hauled to the fields and dried before incorporation at first plowing. Farmers had an average of slightly more than 1 animal/ha of riceland.

FYM was applied either evenly over small fields or in larger fields on selected—often saline—areas or "spots" observed to be less productive. A few respondents rotated FYM annually to different portions of larger fields. FYM was applied to 60% of respondents' total riceland; 45% of the area was evenly manured and 15% was spot-manured. For the lower area, 47% was evenly manured and 19% was spot-manured; 38% of the upper area was evenly manured, and 5% was spot-manured.

Little FYM was applied to flood-prone low areas or drought-prone upper areas. Upper ricefields were usually not manured or fertilized because more weeds accumulated if the water level dropped. Farmers with loamy soils often applied FYM to other areas because of the greater inherent fertility of loam.

In areas treated with FYM, amounts averaged 801 kg/ha for Sanpatong, 636 kg/ha for RD6, and 531 kg/ha for KDM (Table 6). Rates for actually manured areas would be somewhat higher, since spot-manured fields were included.

Farmers applied small amounts of inorganic fertilizer (16-16-18 kg NPK/ha) evenly over fields. Only one respondent applied fertilizer to selected less productive spots.

Farmers placed rice cultivars, manure, and fertilizer according to their land-soil resources. FYM was applied first to lower (but not too low) fields and to the traditional Sanpatong. Lesser amounts were applied to RD6 and KDM. Inorganic fertilizer was applied in the greatest amounts to Sanpatong but was applied to greater proportions of the areas planted to RD6 and KDM. Farmers avoided placing such resources where they would be washed away by flooding or wasted because of drought. The strategy was clearly designed to provide first for rice subsistence needs via production of Sanpatong and RD6, and to then provide a cash income from the nonglutinous KDM planted on the riskier and less fertile upper ricefields.

Capture and culture riceland fisheries in Northeast Thailand (*Agricultural Economics*). Villagers of Khu Khat in Northeast Thailand have long harvested both rice and substantial quantities of natural fish from ricefields and waterways.

Table 5. Grain and total dry matter yields of farmers' 3 main rice cultivars; and farmers' yield estimates. Ubon, Northeast Thailand, 1987.

Parameter	Yields (t/ha)		
	Sanpatong	RD6	Khao Dok Mali[a]
Grain[b]	1.7	1.8	1.2
Farmers' estimate	1.7	1.7	1.3
Total dry matter[b]	4.2	5.1	2.5

[a]Transplanted KDM only. [b]Data collected by Multiple Cropping Department, 1987.

Table 6. Farmers' manure and fertilizer applications, by main cultivar.[a] Ubon, Northeast Thailand, 1987.

Parameter	Sanpatong	RD6	Khao Dok Mali
Manure			
Area (%) planted to each cultivar manured	83	54	40
Area (%) evenly manured	51	47	35
Area (%) spot manured	32	6	5
Manure (kg/ha)[b]	801	636	531
Fertilizer (16-16-18)			
Area (%) planted to each cultivar fertilized	59	97	80
N (kg/ha) on fertilized fields	12	8	8
Manure and fertilizer			
Area (%) planted to each cultivar receiving both manure and fertilizer[c]	44	32	5

[a]Data for 23 respondents and their 100 ha of rainfed lowland ricefields. [b]Based on farmer-reported applications of *rot* (cartloads equal to 750 kg) of FYM per *rai* (6.25 rai = 1 ha). [c]Even applications of manure and fertilizer only.

Rice - fish culture was introduced in the area, and the productivity of capture and culture riceland fisheries in the village was compared. The systems were about equally productive. The culture system was competitive with the capture system in requiring water control that inhibits seasonal expansion and contraction of the natural fish population.

Khu Khat farmers grew a single rainfed lowland rice crop per year, raised livestock, caught wild ricefield fish and frogs, and (many) worked in Bangkok in the dry season (DS). The decision to work in Bangkok or to catch fish after rice transplanting depended on the assessed potential of wild fish stocks. The village was also the site of a collaborative rice - fish project. Some farmers were stocking and harvesting cultured fish. This raises questions of comparative productivity and compatibility of the capture and culture systems.

Research to characterize the agroecosystem and interviews of a sample of 26 farm families (from a village total of about 200) were conducted in 1987 and 1988 WS. Gross returns from capture and cultured fisheries were obtained from a subsample of 13 families.

Ricefields in Northeast Thailand supply a range of foods consumed by humans and animals:

Ipomoea aquatica	Green vegetable
Pila pesmei	Large edible snail
P. polita	Large edible snail
Macrobrachium lanchesteri	Small prawn
Somanniathelphusa sinensis dugasti	Crab
Lethocerus indicus	Large edible water bug
Channa striata	Snakehead
Clarias batrachus	Walking catfish
Anabas testudineus	Climbing perch
Cyclocheilichthys apogon	Cyprinid
Puntius leiacanthus	Cyprinid
P. stigmatosomus	Cyprinid
Esomus metallicus	Cyprinid
Fluta alba	Swamp eel
Trichogaster pectoralis	Edible gouramy
Macrognathus aculeatus	Spiny eel
Rana limnocharis limnocharis	Frog
Nymphaea lotus	Water lily roots and stems
Tilapia sp.	Introduced fish
Pistia stratiotes	Pig feed
Hydrilla verticillata	Pig feed
Wild birds	
Field rats	

The system involves co-adaptation of many aquatic species. Productivity increases with the rains and peaks soon after fields are flooded and sediment is disturbed by plowing. Ample sunlight, high temperature, and species adaptation lead to rapid growth and reproduction. Productivity decreases as available nutrients are incorporated in the living biomass. Multiple species depend on adjacent permanent water bodies to maintain breeding stocks during DS.

Natural fish populations depend on an expanding and contracting (into small ponds) water system and on maintenance of food chains. With substantial harvests from the system, inorganic nutrient inputs are needed. These are supplied by FYM and some inorganic fertilizers in Khu Khat, where all respondents harvest natural fish and frogs.

Main capture species are walking catfish *Clarias batrachus* (locally *pla dook*) and snakehead *Channa striata* (syn. *Ophiocephalus striatus*; *pla chon*). Walking catfish are air-breathing insectivores. Snakeheads are air breathers that feed on smaller fish and frogs. Smaller fish include *pla moh* (*Anabas fostudineus*), *pla kradi* (*Trichogaster* spp., and *pla siu* (*Rasbora* spp.).

Fish, caught throughout WS, are harvested in quantity as waters recede in October or November. As fish populations and individuals grow in July-August, farmers set 30-100 short, thin bamboo stakes with attached hooks-and-line (*bed*) baited with earthworms (*sai duan*). Several long, helical, woven basket traps (*leeh*) are set at ricefield inlet and outlets; and bamboo sump traps can be dug. Thrownets (*sai*) and v-nets (*mong*) are placed across and along streams and canals. Farmers spear fish and frogs at night using locally made carbide lamps for illumination. As waters recede, farmers use scoop nets (*sa-wing*) and thrownets. Fish are caught as late as March or April in farm ponds, several of which have been dug—some by hired bulldozer—specifically to trap and maintain water and fish.

Fish are captured from lower ricefields, of which respondents each had an average of 2.15 ha. Catches of 36-294 kg averaged 134 kg/person. Individual catches were 25-125 kg/ha and averaged 62 kg/ha. Larger fish were eaten fresh; and families made an average of 120 kg of fermented fish (*pla rah*) with small fish. Half of the respondents made 3-10 kg of dried fish. Up to 10% of captured fish were sold (av earning of $18/respondent). Snakeheads and walking catfish sold for $1.20/kg; fermented fish for $0.40/kg.

Respondents caught an average of 10.5 kg frogs (*Rana limnocharis*) using 10-50 stakes and baited hooks-and-line and 10-20 small basket traps (*ngab*) set on land. Frogs were mostly eaten fresh, although some were sold ($1/kg), dried, or smoked. All respondents ate fish or frog at least once a day from July through December. Fermented fish lasted many families through the DS.

If sold at the farmgate price of $1.20/kg, the 134 kg of fish would have had a cash value of $161. The catch represented an average of 62 kg/ha for the mean 2.15 ha/respondent of lower ricelands and some $74/ha. Since the rice harvested from these fields was worth about $0.12/kg, the catch might be considered as equivalent to 620 kg rice/ha or to raising yields from 1.7 to 2.3 t/ha, a 36% increase (Table 7). The value of frogs would be additional.

Khu Khat farmers began raising cultured fish when government and nongovernmental organization programs provided technical assistance and fingerlings. Stocked species were common carp *Cyprinus carpio* (*pla nai*), tawes *Puntius gonionotus* (*pla tapian*), and some tilapia *Tilapia nilotica* (*pla nil*).

Of 26 respondents, 76% stocked an average of 1,400 fingerlings in 1986, and 60% stocked an average of 1,200 fingerlings in 1987. Those who quit in 1987 did so because insufficiently reinforced bunds led to flood losses. The decline in stocking rates was due to a decline in free fingerlings. The reported 1986 harvest averaged 75 kg/person stocking fish. Most fish were consumed.

Of 13 follow-up respondents, 60% stocked an average of 1,560 fingerlings/ha. Other than normal manure applications, no extra nutrients were supplied. Several informants reported substantially lowered fish yields because walking catfish and snakeheads entered the ricefields and ate the fingerlings. Harvest was 6-60 kg/respondent and averaged 40 kg/respondent, or an average of 70 kg/ha. Most fish were consumed.

Data comparing the small sample of rice - fish (cultured) adoptors and nonadoptors are only suggestive. Adoptors had more riceland (3 vs 4.5 ha), higher KDM yields (1.4 vs 1.0 t/ha), more animals (and manure), and larger capture fish yields (71 vs 43 kg/ha). Possibly a) more manure means more fish for adoptors, and b) nonadoptors did more off-farm work and less fishing than adoptors.

Local capture fisheries were relatively productive at about 62 kg/ha, and substantially higher than the average capture production estimated for Thailand of about 25 kg/ha. Sustainable production will require, among others, judicious insecticide use, maintenance of the diverse aquatic community, and maintenance of the pond-based expanding and receding water system.

Constraints to stocked fish raising at Khu Khat include inherently infertile soils and lack of added nutrient materials, flooding and bund breaching or labor needed for elevated construction, limited

Table 7. Rice - fish adoptors (9) and nonadoptors (4), Khu Khat, Ubon, Thailand, 1987.

Parameter	Adoptors	Non-adoptors	Mean (all)
Rice production			
Mean area of riceland (ha)	4.6	3.0	4.2
Mean area of Sanpatong or RD6 (ha)	2.9	1.8	2.6
Mean yield of Sanpatong or RD6 (t/ha)	1.7	1.7	1.7
Mean area of Khao Dok Mali (ha)	1.9	1.3	1.8
Mean yield of Khao Dok Mali (t/ha)	1.4	1.0	1.3
Fish production			
Mean lower, lum area (ha/respondent)	2.15	2.15	2.15
Total capture catch (kg)	1374	368	1742
Mean capture harvest (kg/ha per respondent)	153	92	92
kg/ha in lower lum area	71	43	62
Value in $/ha (at $1.20/kg)	2130	1290	1860
Equivalent kg rice per ha ($0.12/kg paddy)	710	430	620
Mean cultured harvest (kg/ha per respondent)	70	–	–

fingerling supply, predation by wild fish, and nonmarketability due to small size of individual fish (most reported 80-200 g, some up to 1 kg).

Under current circumstances, maintenance or enhancement of the productive capture system in Khu Khat may be the most appropriate strategy. Rice - fish programs need to seek innovations not competitive with existing capture systems. The water control required for culture systems may be detrimental to capture systems by blocking channels through ricefields or by blocking permanent aquatic refuges and areas with wet sediment for burrowing species (e.g., *Fluta alba*, *Clarias batrachus*).

Currently, farmers may be decreasing both stocking rates and area, partially because of fewer subsidized fingerlings but also as a response to the high productivity of the capture system. The Khu Khat villagers' continuation of the capture system and adoption of the culture system, and respective comparative productivities need to be monitored closely, especially as innovations change current circumstances.

FAVORABLE RAINFED LOWLAND

Multiple Cropping Department

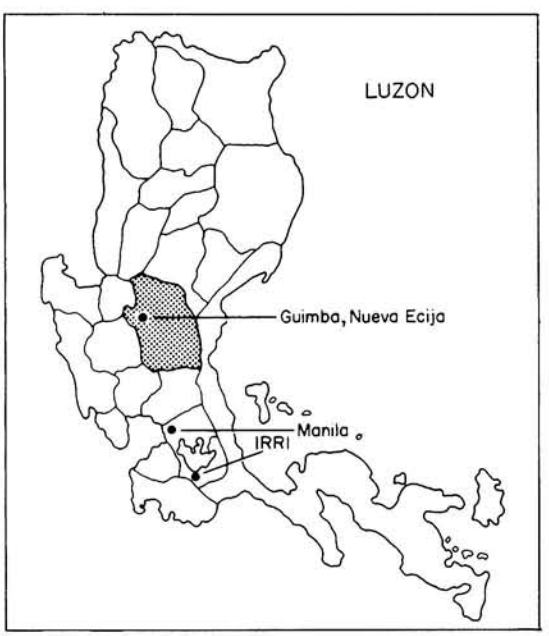
Landform-hydrology characterization of the rainfed lowland research site in Guimba, Nueva Ecija, Philippines. Cropping systems research in the rainfed lowland ecosystem has concentrated over the past several years on the crop intensification potential of more unfavorable rainfed environments, particularly drought-prone (Ubon, Northeast Thailand) and drought- and submergence-prone (Solana, Cagayan, Philippines) conditions. In 1987 the decision was made to initiate research at a favorable rainfed research site to determine the crop intensification potential in conditions where modern early-maturing rice varieties had been cultivated for more than a decade, but where only a single crop of transplanted rice was still cultivated.

The site selected was the village of Bacayao, located about 3 km from the partially irrigated key research site in the municipality of Guimba, Nueva Ecija, Central Luzon, Philippines.

The ricelands within a 10-km radius from the Guimba town center are either pump-irrigated or rainfed. Entirely rain-dependent areas are far more extensive than those having a relatively reliable water supply. The pump irrigation systems are operated mostly by individual farmers, although a few relatively larger systems function on a communal basis.

The area (Fig. 5) lies within a broad alluvial plain with an average elevation of 30 m above mean sea level. The topography is generally flat, but with distinct, small-scale variations across the site. These are probably imprints and relics of former stream levees, meander scars, and subsequent drainage lines that have undergone several cycles of degradational-aggradational processes. The construction of ricefield bunds has effectively arrested natural land-carving processes.

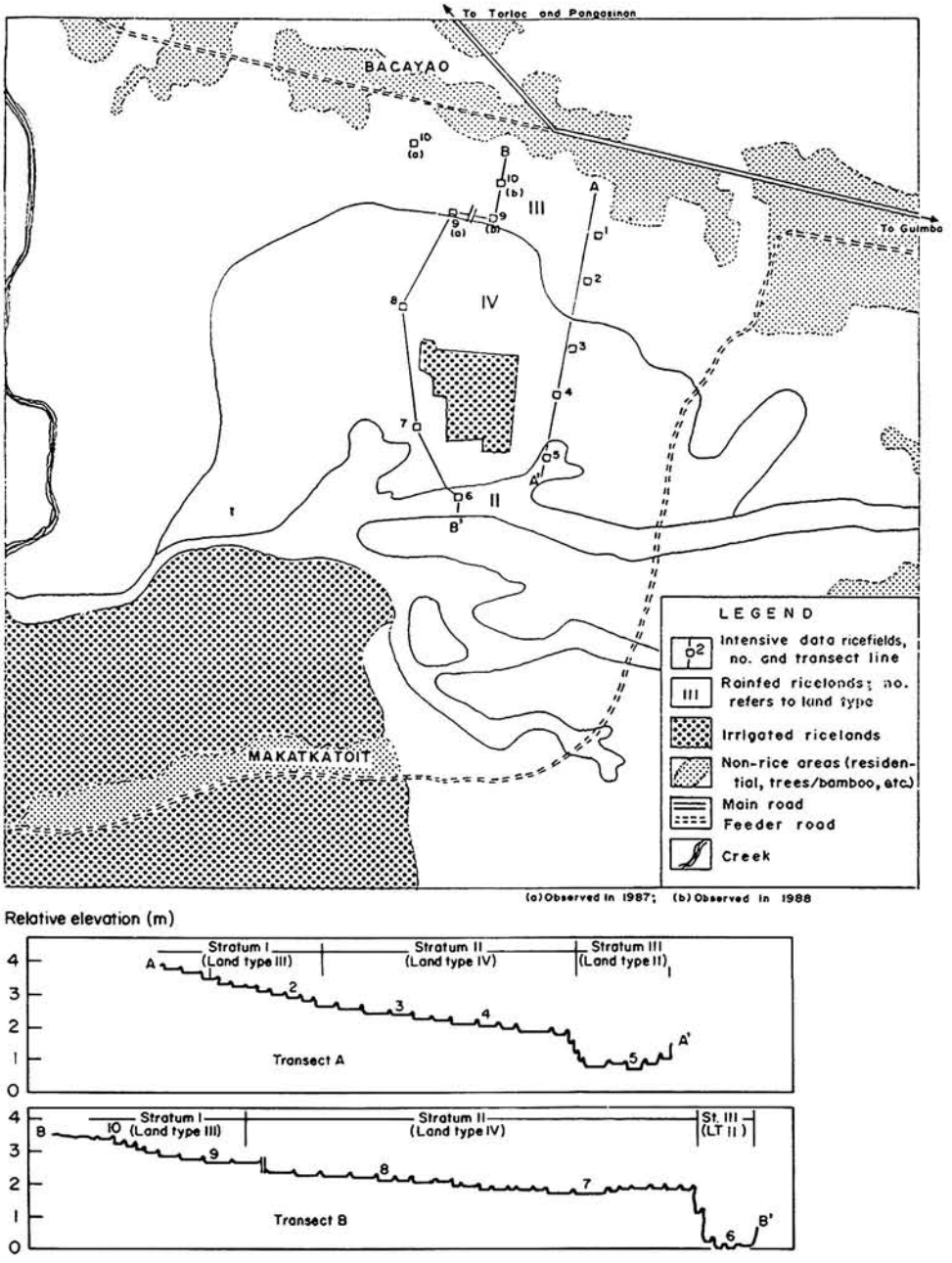
Based on the general landform observation, three land facets (detailed landform types) were distinguished. The cross-sectional profiles along two selected transects in Bacayao, subdivided into land facets (labeled stratum I, II, and III in order of decreasing elevation), are shown at the bottom of Figure 6. These profiles were drawn based on



5. The favorable rainfed key research site in Guimba, Nueva Ecija, Central Luzon, Philippines.

precise measurements of elevational differences along the transects using a Dumpy Level.

Stratum I includes mainly the broad convex levee. The average ricefield drop height ranges from 10 to 12 cm in both transects, an indication of good drainability, and speedier onset of drought. The theoretical gradient between the uppermost ricefield and the boundary of stratum II ranges from 0.55 to 0.58 cm/m. (The ricefields actually consist of a series of individually level land sur-



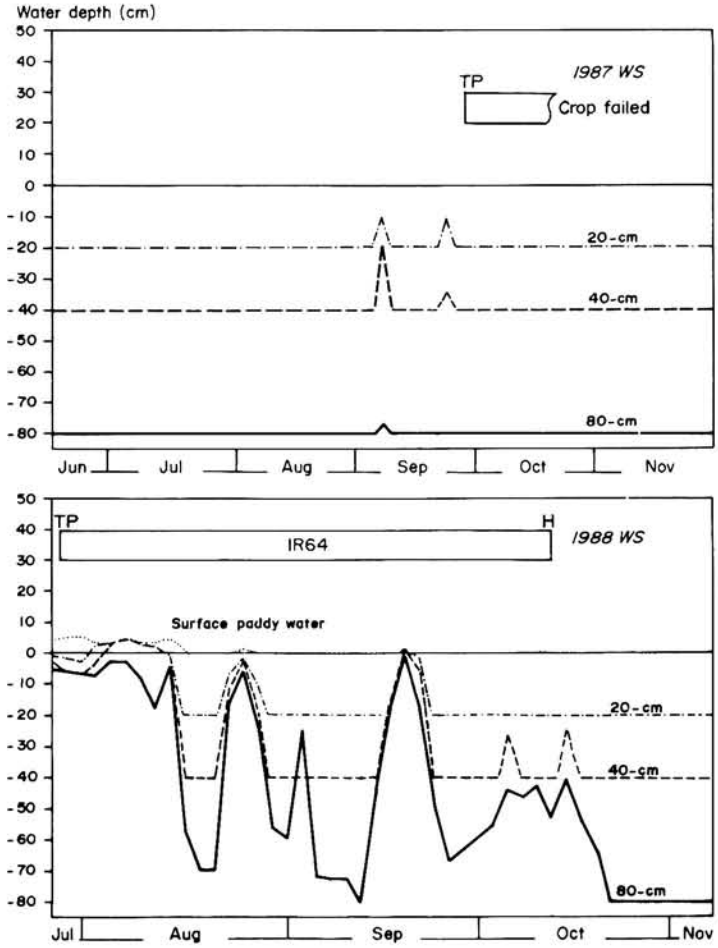
6. Rainfed land types, intensive data parcel locations, and cross-sectional site transects. Guimba rainfed research site, Nueva Ecija, Philippines, 1987-88.

faces, each having a negligible gradient.) The elevational variation between the upper and lower part of stratum I is 0.7-1.1 m on transects A and B, respectively.

Stratum II represents the nearly level to slightly concave areas below the levee (stratum I). Runoff from the upper lying facet generally tends to accumulate temporarily in this area. Direct rainfall and runoff create a better field hydrology for stratum II than for stratum I. Ricefield drop height is considerably less, ranging from 4.4 to 8.2 cm. The gradient ranges from 0.2 to 0.3 cm/m, indicating a nearly level topography.

Stratum III corresponds to the drainageway and its branches. The field hydrology is distinctly different from those of strata I and II because of the accumulation and conveyance of most of the runoff originating from the surrounding areas. There is an abrupt elevation drop of 1.1 to 1.8 m from the edge of stratum II down to stratum III.

Along transects A and B, 10 IDPs were identified, and hydrological monitoring instruments were set up in them. The instruments installed in each IDP consisted of 3-depth set of groundwater observation tubes (20, 40, and 80 cm) and depth gauges for measuring standing water. Representative hydrographs of selected IDPs from the highest and lowest of the three land facets are shown in Figures 7 and 8. Surface water accumulation was very limited in both the 1987 and 1988 growing seasons in IDP 1 in stratum I, but it was prolonged in IDP 6 in stratum III. The persistence of stand-

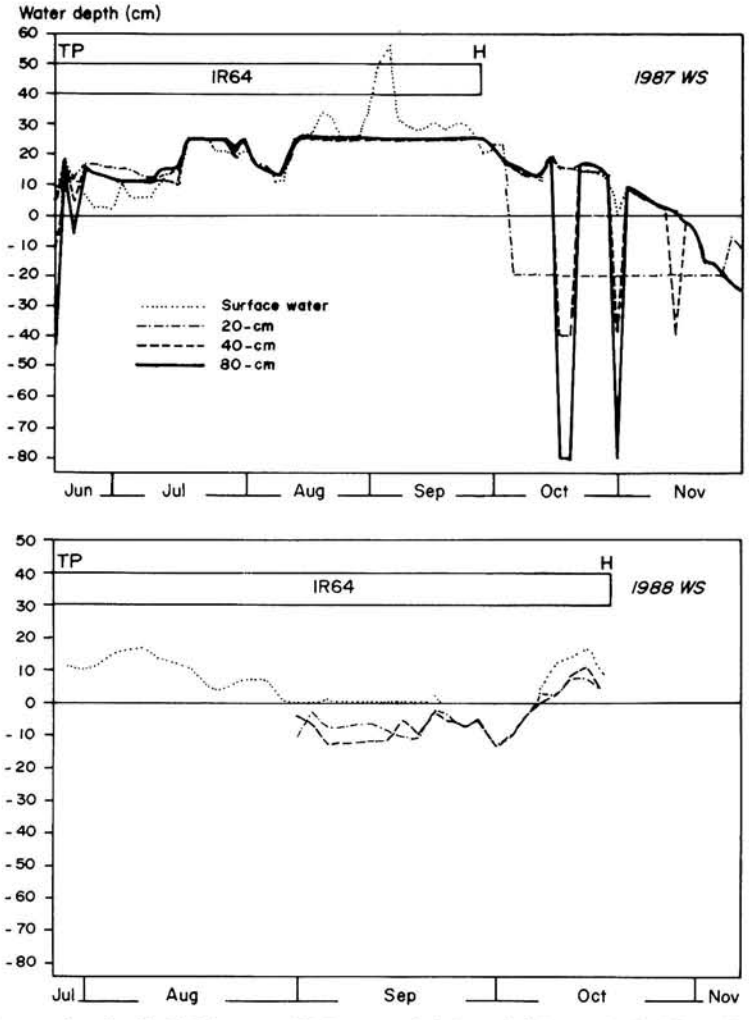


7. Hydrographs and rice crop duration for IDP 1, stratum I. Bacayao, Guimba, rainfed research site, Nueva Ecija, Philippines, 1987-88. TP = transplanting, H = harvest.

ing water varied in the different IDPs and land facets during the two WSs. In transect A (IDPs 1-5) the standing water in most of the fields remained for 20 d longer in 1988 than in 1987 as a direct result of the variation in rainfall.

The rate of loss of standing water is an important parameter in rainfed ricelands. From measurements of standing water every 2 d, the number of days required for a specific depth of water to naturally disappear was analyzed. Segments of the hydrological data set without significant rainfall (e.g., <8 mm) were selected to calculate the daily water loss rate. The result was then used to determine the surface water retention index (SWRI), defined as the number of days for a 50-mm depth of ricefield water to be lost through evapotranspiration, seepage, and percolation.

SWRI varied among the IDP's and strata (Table 8). It also differed between the two years. In stratum I the average SWRI ranged from zero to 4.4 d in 1987, and from zero to 12.5 d in 1988. IDPs 1 and 10 gave a SWRI close to zero because they could retain standing water for only a short time. The IDRs in stratum II showed average values ranging from 5 to 6.25 d in 1987, and from 7.5 to 15 d in 1988. Water retention persisted longer in 1988 by a factor of 2.4-4.2 d compared with that in 1987 in strata I and II. In stratum III, SWRI was



8. Hydrographs and rice crop duration for IDP 6, stratum III. Bacayao, Guimba, rainfed research site, Nueva Ecija, Philippines, 1987-88.

Table 8. Average surface water retention index (SWRI) in the IDPs in Bacayao, Guimba, Nueva Ecija, Philippines, 1987-88 WS.

Land facet	IDP[a]	SWRI (d)	
		1987	1988
Stratum I	1	0	4.4
	2	2.2	5.4
	9	4.4	12.5
	10	3.2	0
Stratum II	3	6.25	7.5
	4	5.3	7.5
	7	5.65	7.5
	8	5	15
Stratum III	5	19	15
	6	36.85	15.7

[a]IDP 7-10 had supplemental irrigation during critical periods in 1987. IDP 1, 2, and 9 had supplemental irrigation in 1988.

consistently more than 15 d in both years.

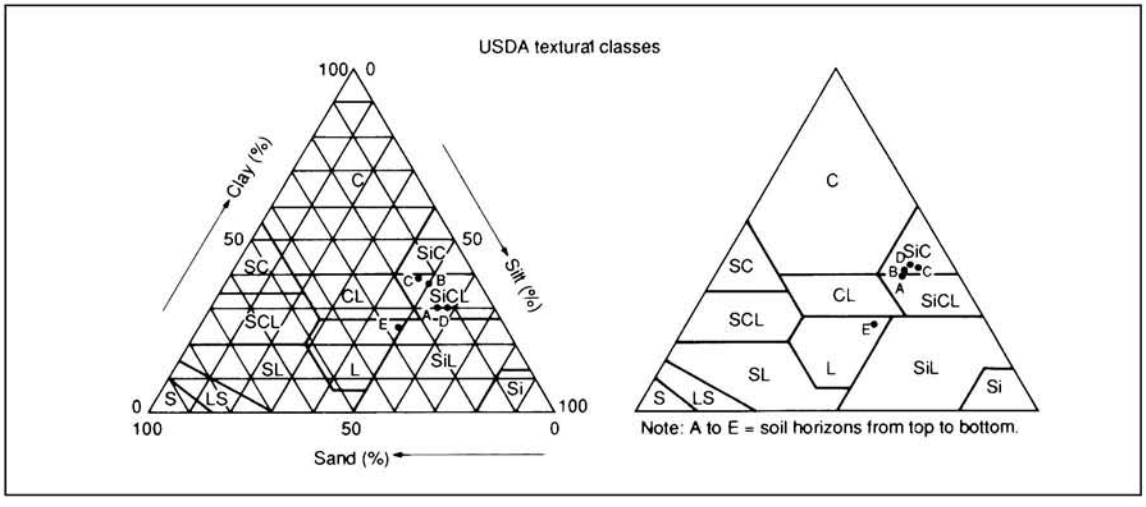
Two soil types were identified and mapped within the research sites, namely Tagulod and Padapada series. Basic differences between the two soils included physiographic position, drainage, and flooding hazard.

Profile pits representing the two soil types were characterized. One was dug in stratum II in Bacayao, mapped as Tagulod, while the other was between Bantug and Makatkatoit on a Padapada soil. The laboratory data on the profile samples are shown in Table 9, including an elaboration of the soil texture distribution in the USDA textural triangle.

Available K and P contents were low. Zn was also deficient, although topsoil pH was about 6.0. However, pH increased abruptly to neutral or slightly alkaline below the plow layer.

Table 9. Physical and chemical properties of the rainfed lowland site, Guimba, Nueva Ecija, Philippines. Plow layer: L = low, VL = very low, H = high, D = deficient, M = medium.

	Chemical characteristics							
	Pit 1 Bacayao				Pit 2 Makatkatoit			
	(0-12) Plow layer	(12-30) Plow pan	(30-50) Subsoil	Status (av)	(0-12) Plow layer	(12-30) Plow pan	(30-50) Subsoil	Status (av)
pH (1:1 H_2O)	6.0	6.8	7.4		6.3	6.9	7.1	
Organic C (%)	1.28	0.48	0.31	L	0.17	0.44	0.29	VL
Total N (%)	0.092	0.042	0.029	VL	0.096	0.039	0.031	VL
CEC (meq/100 g)	23.3	27.00	31.00	H	29.3	30.7	33.2	H
Available P (Olsen)	3.3	1.4	nil	L	8.9	3.5	0.61	M
Exchangeable K (meq/100 g)	0.088	0.112	0.113	L	0.208	0.188	0.192	M
Available Zn	0.57	0.15	0.06	D	0.34	0.10	0.12	D



The surface soil physical properties could be reasonably favorable for prerice or postrice upland crops. The topsoil was loamy, except the Padapada soil, which was silty clay. During the time of observation, the Padapada soil had wide and deep cracks. The Tagulod soil showed only slight surface cracking. Both soils, however, had a well-developed plow pan within 15-cm depth.

Cropping pattern. All farmers used modern rice varieties in the rainfed areas of Bacayao. In 1987, IDP 7 (stratum II) and IDP 10 (stratum I) were planted to IR42 and IR36, respectively. IR64 was used in the other observation fields. In 1988, however, all IDPs were planted to IR64. The cropping pattern was predominantly rice - fallow. In 1986, 90% of the total farm area (250 ha) within Bacayao followed this pattern; 10% was planted to string bean, mungbean, watermelon, or tomato as second crops after rice, especially on stratum I, where the soil has good friability.

All farmers applied fertilizers though at variable rates depending on their cash situations.

Rainfed land types. By consolidating the landform, hydrology, soils, and other relevant environmental attributes of the area, the three strata were tentatively classified into rainfed land types. The associated environmental descriptors of the land types (II, III, and IV) are presented in Table 10. The land type designations correspond to a general classification developed for rainfed ricelands in the Cagayan Valley.

Rainfed land type II, represented by stratum III, has a relatively long hydrological year. Of the three land types, double rice cropping could probably have potential only in land type II within the area. However, very limited areas occurring at the site correspond to land type II.

Land type III is basically unfavorable rainfed, characterized by severe drought stress threat during the cropping season. In Guimba, however, this

Table 10. Physical environmental attributes, and present and suggested cropping patterns of 3 rainfed land types identified in the lowland rice-growing areas. Bacayao, Guimba, Nueva Ecija, Philippines.

Environmental parameter	Rainfed land type[a]		
	II	III	IV
Land facet	Drainageway (stratum III)	Levee (stratum I)	Plain (broad alluvial terrace) (stratum II)
Drainage	Poor internal and surface drainage	Fair internal drainage, good surface drainage	Fair to poor internal and surface drainage
Hydrological year	Jun-Dec; surface and subsurface flow from upper catchment extends the hydrological year	Relatively short (Jul-Oct); water regime depends on direct rainfall and limited surface and interflow	Medium (Jun-Nov); water regime depends on direct rainfall and runoff from an upper facet, if any
Submergence threat	Short-term (2-3 d), crop submergence frequent	No submergence threat	No submergence threat
Drought threat	Slight to occasionally moderate	Moderate to severe	Moderate drought stress threat
Soil types	Padapada silty clay or clay loam	Tagulod silty clay loam, Quingua silty clay loam	Tagulod silty clay loam
Current cropping pattern	Rice - fallow	Rice - fallow; patches of beans, watermelon, vegetables after rice	Rice - fallow
Suggested cropping pattern	WSR - TPR	DSR - mungbean	WSR - mungbean

[a] Land type description corresponds to the classification of rainfed land types into 6 classes in the Cagayan Valley. Types I, V, and VI were not observed at the Guimba research site. TPR = transplanted rice, WSR = wet seeded rice, DSR = dry seeded rice (modern varieties).

threat may be only moderate in this land type. The short hydrological year (4 mo) may allow a short-duration upland crop after rice, but very early establishment of the main crop is necessary. Stratum I represents this land type.

Land type IV corresponds to stratum II, which has a slightly longer hydrological year than land type III. The drought threat is moderate but could easily be offset during favorable rainfall years because of the tendency to accumulate runoff from the upper areas. The present cropping pattern consists of a single rice crop. Abrupt onset of the rainy season can usually cause difficulty for a prerice crop because of the waterlogging threat. A postrice cropping strategy is, therefore, potentially feasible in this land type.

Cropping systems program

Analysis of the social and economic environment

Agricultural Economics Department; Bhutan Department of Agriculture; National Center for Applied Research on Rural Development, Madagascar; Ministry of Agriculture, Cambodia; and Ministry of Agriculture and Forestry, Laos

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RICE FARMER KNOWLEDGE AND PRACTICES IN MADAGASCAR

Agricultural Economics Department and National Center for Applied Research on Rural Development, Madagascar

Rice research in Madagascar's Central Highlands (where there are 600,000 ha of rainfed and irrigated lowland rice) is concerned with varietal improvement and with crop and nutrient management. Production problems for resource-poor farmers include poor soils, poor drainage and irrigation systems, and lack of inorganic fertilizers.

Agroecosystems were characterized and farmer rice production practices and knowledge examined as part of the collaborative Madagascar-IRRI program.

Farmers classify ricelands by landscape position, and soils by color and texture (Table 1). They match a range of rice cultivars and management strategies to land and soil resources, and they evaluate the results in terms of yield.

Our collaborative research targets small, resource-poor farmers and builds upon their selection of crops and cultivars, adaptation of management practices to local conditions, and technical knowledge underlying the practices. The research involves

- basic characterization of local ecosystems (hydrologies, soils);
- screening traditional and improved rice cultivars appropriate for the different rice microenvironments;
- a systems approach to developing farmer-adoptable technologies (e.g., for improved

Table 1. Land and soil types and qualities in the Central Highlands, Madagascar, according to farmers. 1988.

Malagasy	English	Comments
	Landscape position	
Tany vary	Riceland	Irrigated and rainfed
Heniheny	Wider lowland plain	Small alluvial valleys
Lohasaha	Narrow upper valley	Upstream courses
Ambony toerana	Upper	Upper terraces
Tanjona	Upper, cap	Upland "island" in ricefield
Tanety	Upland	Areas adjacent to ricefields
	Soil color	
Tany manga	Blue/grey	Humic gley or gley mineral hydromorph; need to spade; rich
Tany mainty	Black	Rich, clayey
Tany mainty	Black	Poor, peaty or waterlogged
Tany mavo	Yellow	Poor
Tany fotsy	White	Sandy, less labor, lower yield
Tany mena	Red	Upland soil, add to peat
	Soil texture	
Tany dilatra	Clayey	Richer
Tany fasika	Sandy	Poorer
Tany fompitra	Deep, peaty	Peaty or water upwelling
Tany horaka	Muddy	No need to plow or spade
Tany fotaka	Mud	Plain mud
Honahona/heniheny	Soft, boggy	Lowland plain, alluvial valley
	Other soil characteristics	
Mandrevo	Deep	Peaty soil or spring
Loharano	Spring, source	Water upwelling in ricefield
Tany manta	Uncooked, unripe	Infertile, peat being treated
Mihareraka	Tired	From fertilizer use, cropping
Tany masaka	Cooked, fertile	Fertile, treated peat soil
Mafana	Hot	More fertile soil
Mangatsiaka	Cold	Cold or poor soil
Ranontambiazina	Red-brown scum	Possibly Fe^{++} scum
Tany tofan	Added soil	Upland soil added to peat
Sakamainty	Rainfed	Rainfed lowland

nutrient management);
- building on farmer knowledge and practices;
- meaningful farmer participation, including, but not limited to, on-farm research; and
- strengthening national research capabilities.

CHARACTERIZATION OF AGROECOSYSTEMS AND FARMER PRACTICES AND KNOWLEDGE IN CAMBODIA

Agricultural Economics Department and Ministry of Agriculture, Cambodia

Agroecosystems were characterized and farmer rice production practices and knowledge examined as part of the design of a collaborative research program with Cambodia.

Cambodia's average rice yield (1.2 t/ha) is the lowest in Asia. Of the country's 1.8 million ha of rice, 80% is rainfed lowland. Farmers were interviewed in 3 provinces representing 8% of the national area, 24% of the population, 20% of the rice area, and 22% of rice production.

Different rice ecosystems were examined. Problems faced by resource-poor farmers in the rainfed lowlands include poor soils, drought in upper ricefields and flooding in lower ricefields, labor scarcity, and lack of such inputs as inorganic fertilizers. More positively, traditional varieties (TVs) suffer from relatively few pests and diseases; and farmers have developed various means to cope with their resource-poor circumstances.

Farmers carefully match a wide range of rice cultivars and management practices to landscape positions and hydrologies. Most of their land is upper riceland (*dey kpous*) with 0-15 cm water and sandy (*ksach*) or silty with sand (*dey lbay ksach*) soil. Middle or "normal" (*dey tommada*) riceland has 15 cm water and sandy to sandy clay soil (*dey kanding leah ksach*). If not waterlogged or if crops are not flooded out, lower ricelands (*dey trapaing, dey chumrau*) are the most productive. These lands have earlier and longer lasting water of 30-80 cm and from sandy to silty (*dey lbop*) soil or sandy mixed with clay (*dey ath leah ksach*) soil (Table 2).

Long-duration, photoperiod-sensitive TVs flowering in December and adapted to medium-long flooding of various depths up to 50 cm accounted for about 1 million ha in 1986-87. Photoperiod-insensitive, short-duration modern varieties (MVs, especially IR36 and IR42) or weakly sensitive, short- to medium-duration TVs are now planted in shallow rainfed or partially irrigated areas in the wet season (WS). Reported MV yields were about 2.0 t/ha in WS and 2.5 t/ha in the dry season (DS). TV yields were 0.6-3.0 t/ha.

Table 2. Cambodian farmers' classification of rainfed lowland land and soils. 1988.

Khmer	English	Equivalent
	Landscape position, relative water depth	
Kpous	High, shallow, normal for MVs	0-15 cm water
Tommada	Middle fields, normal for TVs	10-30 cm water
Chumrau, thip, trapaing	Lower, deep	30-80 cm water
	Soil texture	
Dey ksach	Sand	Sand
Dey lbop	Silt	Silt
Dey ath	Clay	Clay
	Textural class	
Dey ksach	Sandy soil	All of the sand group
Dey ath	(Infertile) clay soil	Clay
Dey ath leah ksach	Sandy clay	Sandy clay
Dey kanding leah ksach	Sandy-silty clay	Silty clay, silty clay loam
Dey lbay ksach	Silt and sand	Silt loam
	Soil tilth or bulk density	
Reng	Hard/compacted	
Tun	Soft/friable	

STRATEGIES FOR RICE OUTPUT GROWTH IN CAMBODIA

Agricultural Economics Department

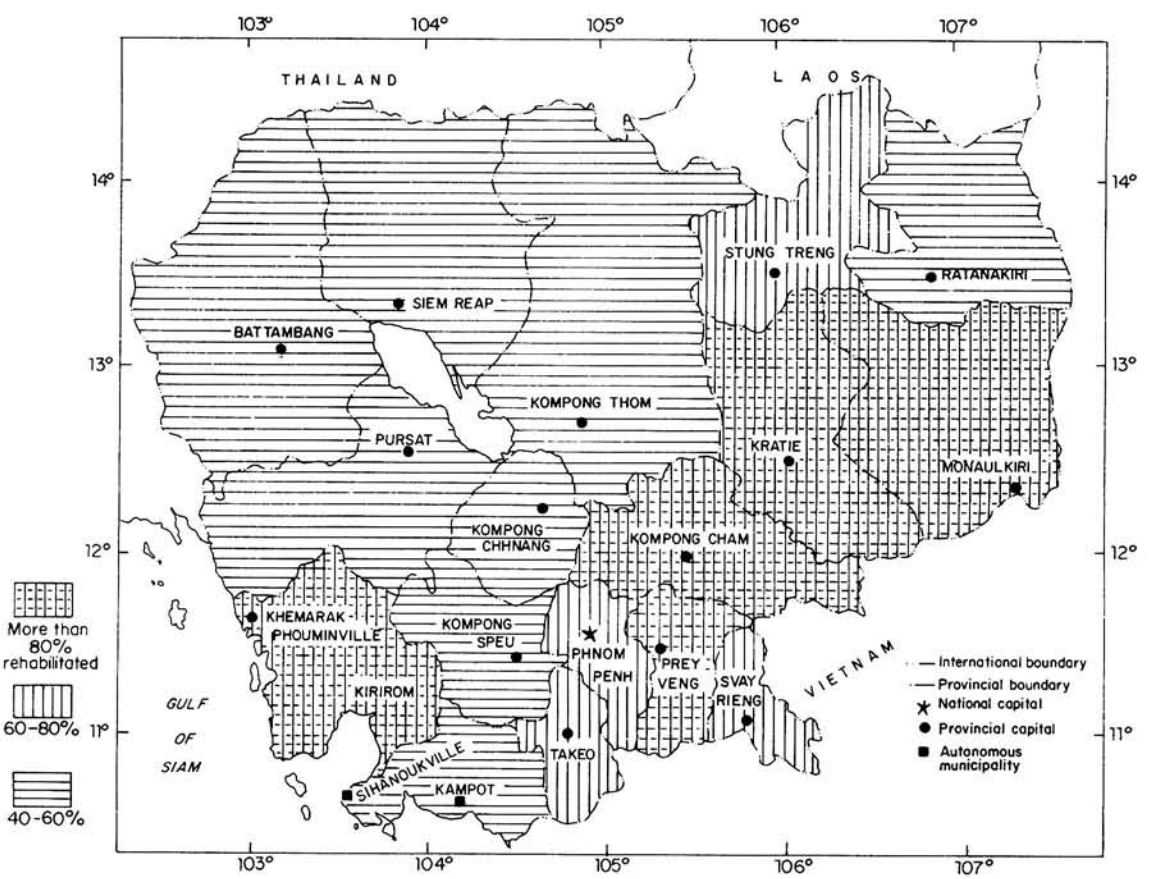
Two possible strategies for increasing rice output in Cambodia are to expand the area under cultivation and to intensify cropping in the existing cultivated area. The first is possible by rehabilitating riceland abandoned during the war years and by reclaiming land that can be converted to ricefields. The second would occur through yield improvements on currently cultivated riceland.

Output growth through area expansion. The current rice area falls short of that in prewar years by approximately 800,000 ha. This is the

extent of the land that can be rehabilitated. The area available for rehabilitation is unequally distributed across provinces. In the more densely populated areas such as the southeastern delta provinces, the area available for rehabilitation is extremely small (Fig. 1). On the other hand, sparsely populated areas such as Battambang have more than 50% of the 1966 rice area available for rehabilitation.

Area expansion under existing technology levels requires labor and draft power, both of which are severe constraints to area expansion beyond current levels. The best estimate of the current rural population of Cambodia is around 7.5 million people, of which only about 35% are in the labor force (males and females between 16 and 60 yr), given the large number of small children in the population. Current cultivated land reflects this reality. In all provinces, currently available labor is adequate or more than adequate for cultivating existing riceland. On the other hand, if current labor is matched to potential riceland in each province, a labor constraint prevents further rehabilitation in the northwestern provinces of Battambang, Siem Reap, and Pursat, and in the southeastern province of Svay Rieng. The total land available for rehabilitation in these 4 provinces is 447,000 ha, 79% of the total riceland available for rehabilitation.

During the war years, draft animal numbers were severely reduced, and the population is now being rebuilt. There are currently 1.2 million draft animals in the country. There is currently a shortage in four provinces: Battambang, Ratanakiri, Prey Veng, and Takeo. (Except for Ratanakiri, the draft shortages in these provinces are made up by tractors.) Draft animal rental rates range from 1 d of plowing exchanged for 1-2 d of trans-



1. Rice area rehabilitated since 1979, Cambodia.

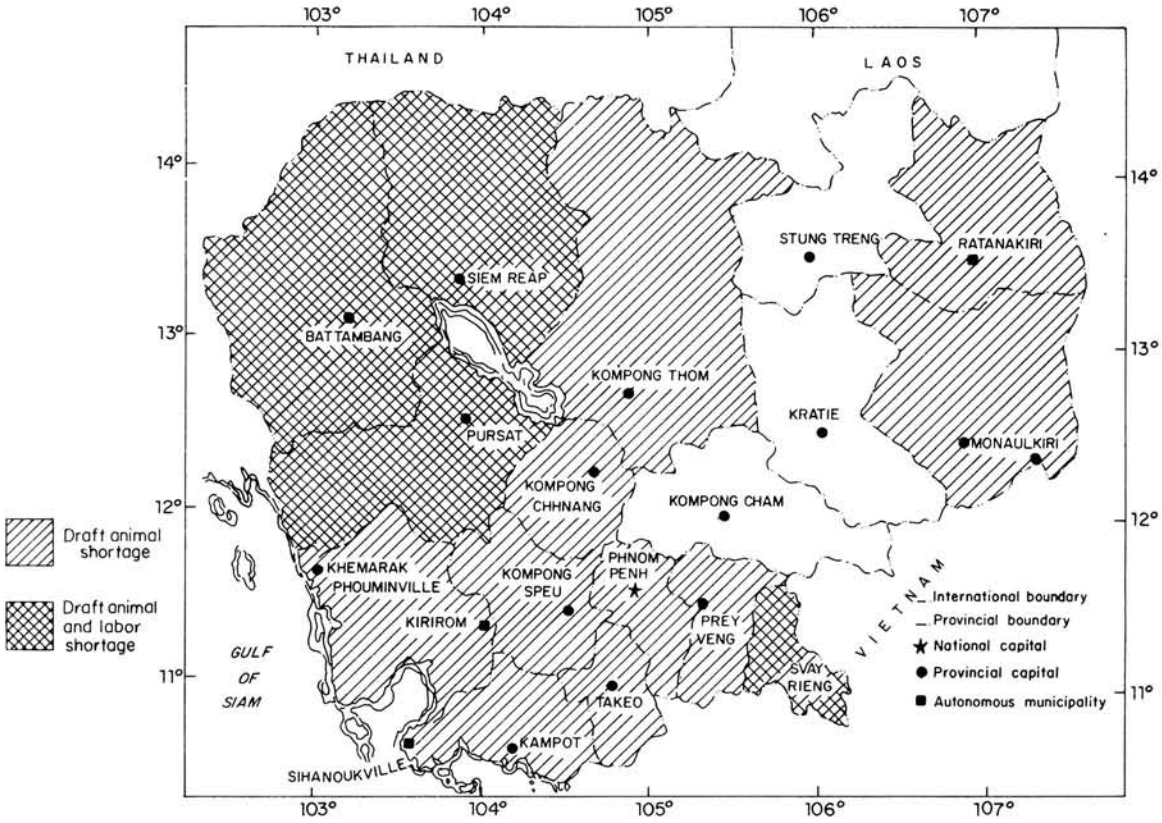
planting labor to 50-100 rieles (US$0.30-0.60) cash payment/day. Draft animal shortages constrain area expansion in 14 of 17 provinces (Fig. 2). Draft animal shortages constrain the rehabilitation of 500,000 ha of abandoned riceland, which is more than 85% of the riceland available for rehabilitation.

Can tractors be used to substitute for animal draft power for area expansion? Suppose we say (optimistically) that a tractor can cultivate 50 ha of land within a land preparation period. Even to cultivate an additional 200,000 ha, then, would require 4,000 tractors. This means that the current national fleet of 1,225 tractors must be increased 4 times, which would require unrealistic foreign exchange resources.

The strategy of output growth through area expansion is thus severely constrained by shortages of labor and draft power that are not likely to be alleviated in the near future. Area expansion through the rehabilitation of abandoned riceland will occur as returning refugees are integrated into Cambodian society and as today's children grow up and enter the labor force.

Output growth through cropping intensification on current riceland. More intensive use of existing riceland and consequent yield increases will come through improvements in one or more of the following: 1) soil fertility maintenance, 2) water control, and 3) seed supply.

Soil fertility maintenance. In rainfed and irrigated environments, soil fertility maintenance is an important constraint to yield improvement. Over the last few years, Cambodia has imported 20,000-25,000 t of urea and amophos annually. If fertilizer application were restricted to MVs, and using a short-term estimate of 250,000 ha of potential MV area, the average N application would have been 37-46 kg/ha, compared with 85 kg/ha in Central Luzon, Philippines. Further increases



2. Provinces with draft animal and labor shortages under potential riceland, Cambodia.

in fertilizer imports are severely restricted by a lack of foreign exchange.

The primary alternative for maintaining fertility levels is the increased use of organic fertilizers. Farmers reported applying farmyard manure (FYM), and some mentioned the use of green manure (GM) such as *Chromalaena odorata*. FYM is prepared using rudimentary techniques and is applied at 1-2 cartloads/ha (100-200 kg/ha). There is an active manure market, with a cartload of manure selling for 30-40 rieles (US$0.17-0.22). Given the small number of animals, supplies are inadequate. The quality of FYM can be improved substantially by using better composting techniques and by adding other organic matter. GM can be effectively introduced into the Cambodian rice farming system, and research is needed on the types of GM to introduce, methods of incorporation, etc. Further work also needs to be done on appropriate legume - rice systems.

Water control and irrigation as constraints to intensification. DS irrigation requirements should be assessed. Approximately 120,000-125,000 ha of DS rice are currently cultivated, being irrigated by pumps and by gravity systems. There are 4,500 small pumps in Cambodia, but the percentage of these in good working condition is low, and their capability is consequently low. Questions that need to be answered are: 1) At what capacity is the current irrigation system operating, i.e., how much more area can be cultivated without additional irrigation investments? and 2) What is the nature of further irrigation investments, and are these worthwhile?

Seed supply of modern and traditional varieties. In shallow rainfed and some medium-deep rainfed areas, the constraint to the adoption of MVs is seed availability. Seed is currently multiplied at research stations throughout the country. The current area under MVs is 161,000 ha, with a short-term potential for expansion to 250,000 ha over the next few years. The distribution of MVs by province is given in Figure 3. The potential can be easily met, but beyond this any further expansion of MVs will depend on the provision of seed and the maintenance of soil fertility through organic means. Over the longer term, the area under MVs may reach 400,000 ha, assuming that half the area under semiseasonal varieties is converted to MVs.

Before the war, there were several hundred rice varieties in Cambodia adapted to particular microenvironments. Many of these locally adapted varieties were lost during the war years. Now, farmers are trying to re-adapt varieties to their particular microenvironments.

CHARACTERIZING AGROECOSYSTEMS AND FARMER RICE PRODUCTION PRACTICES AND KNOWLEDGE IN LAOS

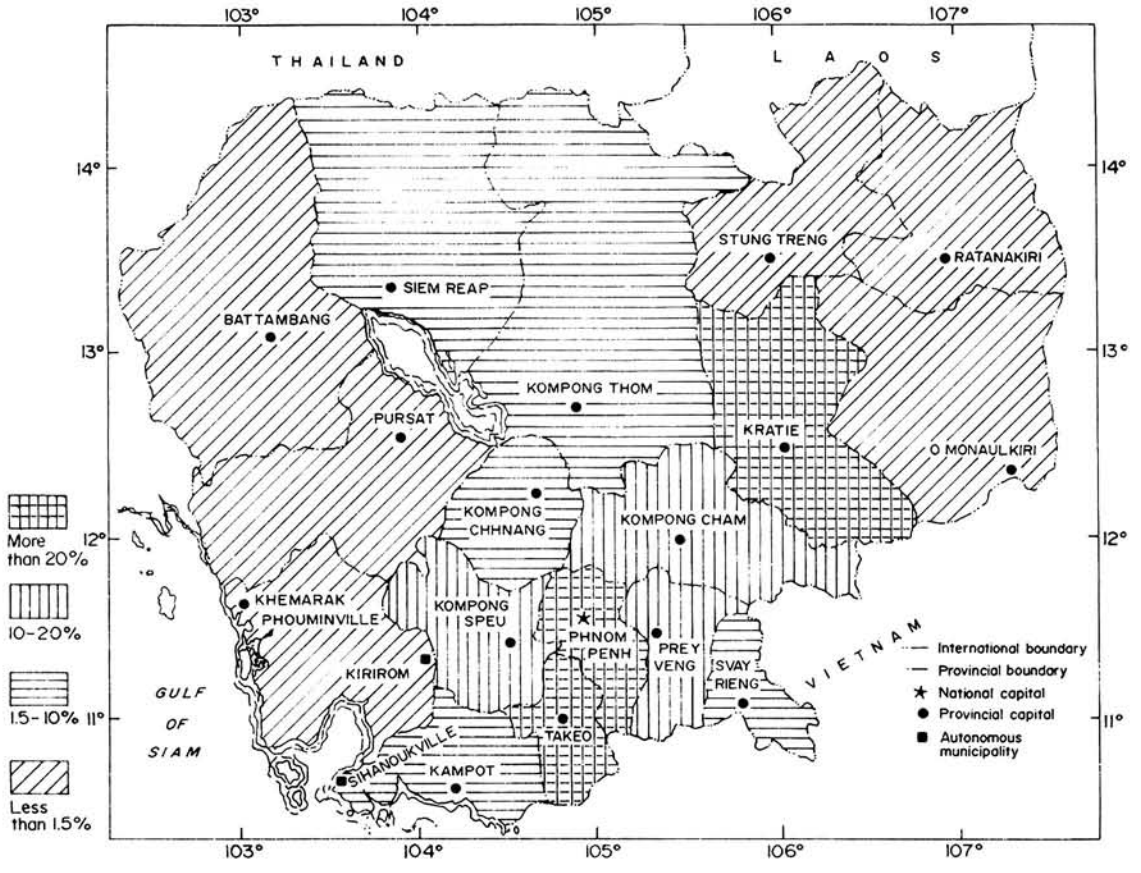
Agricultural Economics Department and Ministry of Agriculture and Forestry, Laos

The Lao Government and IRRI agreed to cooperate to improve the productivity of Lao rice-based farming systems. Research to characterize agroecosystems and farmer rice production practices and knowledge was conducted in Laos at the project design stage.

Laos' area of 237,000 km^2 includes 20% lowland alluvial plain and terrace, 50% hilly lands, and 30% mountainous areas. Almost 50% of the country is forested. The population is 3.85 million, and population density is 16 persons/km^2. Since only 740,000 ha or 3.1% of the area is cultivated, cropped land per person is a low 0.2 ha. Rice is grown on 644,000 ha (87% of the cropped area). Cultivars are largely glutinous (85% of the rice area) and traditional (>95% of the rice area).

Although rice production increased at 3.4% per yr in 1974-84, and at >5% per yr in 1980-86 – reaching 1.45 million t in 1986 – the government reported overall rice deficits for 1977, 1978, 1979, and 1983 (based on 180 kg milled rice required per person). Production in the largely rainfed rice environments is susceptible to climatic fluctuation. Flooding was a problem in 1978 and 1982 in the central and southern rice areas. Drought was a problem in 1977, 1982, 1983, and 1987, especially in the northern shifting cultivation areas. Rice production dropped to 1.0-1.1 million t in drought years. In 1982, severe drought affected the northern provinces, and flooding was a problem in the south.

Rainfed lowland rice is predominant in the central and southern provinces and accounts for



3. Percentage area planted to IR varieties, by province, Cambodia, 1986.

373,000 ha (58% of the national rice area) and about 75% of national production. Officially reported yields (1984-87) averaged 2.7 t/ha. Flooding and submergence in lower ricefields and drought in upper ricefields are among the main production problems.

Crop-cut samples were taken from lower, middle, and upper ricefields in Savannakhet Province in 1988 WS. The country suffered extreme drought in that season, and sampled yields were 40% less than preseason farmer expectations (Table 3).

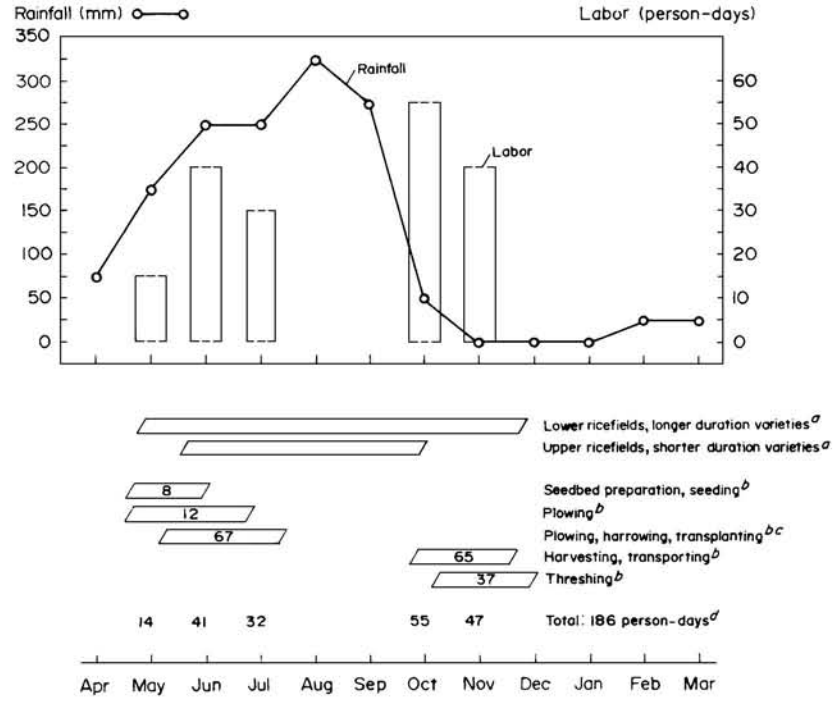
Rainfall and rice-cropping labor were plotted (Fig. 4) for Laos' rainfed lowlands.

Research in the rainfed lowlands should seek submergence-tolerant varieties; should build upon farmers' locally adapted management of upper, middle, and lower ricefield cultivars; and should work to improve low-input nutrient cycling systems.

Table 3. Yields from crop cuts in farmers' fields, drought-affected 1988 WS, and farmer-reported "normal" yields, lowland rainfed area in southern Laos.

Method of estimation	Yield (t/ha) at given landscape position		
	Lower	Middle	Upper
Crop-cut sample means (t/ha)	1.7	1.4	1.0
Farmer-reported normal (t/ha)	2.8	2.3	1.7
Reduction (%)	39	39	41

An irrigated DS crop is produced on up to 12,000 ha (1.8% of rice area), 50% of which is located on the Vientiane Plain. Although the government estimated that 600,000 ha nation-



4. Rainfall distribution and approximate labor distribution for 1 ha rainfed lowland rice, Savannakhet, Laos. [a] Time range from seeding to harvest for lower ricefields and longer duration cultivars, and for upper ricefields with shorter duration cultivars; flowering is Aug-Sep. [b] Total person-days of labor for 1 ha indicated within box showing general period in which activity takes place. [c] Second plowing, harrowing, pulling, transporting, and transplanting are done on small areas each day. [d] Approximate person-days of labor per month for 1 ha.

wide could be irrigated, water management and maintenance problems contribute to minimal DS yield gains. The irrigated area accounted for only 2% of national production, with official yields of 2.7 t/ha for 1984-87. Work in irrigated areas should determine why DS yields are low and should test appropriate cultivar and management combinations.

Upland shifting cultivation is predominant in the northern provinces, accounts for 42% of rice area (271,000 ha) and 23% of production, and is practiced by an estimated 1 million persons. Officially, yields averaged 1.3 t/ha for 1984-87. Drought, weeds, and other pests are major rice production problems. The Lao Government wants to reduce the slash-and-burn area by 30% by 1990 in the belief that the practice 1) affects 100,000 ha of virgin forest and 300,000 ha of secondary forest per year, and 2) is causing deforestation and watershed degradation.

Shifting cultivators face serious weed problems and must allocate more labor to weed control as field fallow periods are reduced (Table 4). Research on shifting cultivation should try to improve fallow management and build on farmers' weed control strategies. Farmers' participatory work on land and soil conservation for more permanent rice-based farming systems would follow.

RICE-BASED CROPPING SYSTEMS IN THE WANGDI-PUNAKHA VALLEY, BHUTAN

Agricultural Economics Department and Department of Agriculture, Bhutan

As part of the IRRI-Bhutan Farming Systems project, a farm-level survey was conducted in the Wangdiphodrang-Punakha Valley of Bhutan to 1) provide a base to measure the impact of the national rice program, 2) document current meth-

ods of rice production, and 3) identify research priorities. This valley is the most important rice-producing region in the country.

The dominant field crops in the valley are rice in summer and wheat, mustard, and buckwheat in winter. Local rices are broadly classified as Maap (red rice) or Kaap (white rice). Kaap rice dominated at low elevations (more than 60% land use), while Maap accounted for 92% of the rice area in the upper elevations (>1,500 m).

The average yield of Maap and Kaap rice was 3.5 t/ha at low and 3.3 t/ha at high elevations. There was no significant difference between cultivar yield within elevations. The most important determinant of rice yield is land quality: rice yield averaged 3.8 t/ha on the best quality land, 3.3 t/ha on medium-quality land, and 2.2 t/ha on poor quality land.

Rice production is labor intensive: some 280 d/ha is used to grow the crop (from seedbed preparation through to grain and straw storage), with more than 40% spent on harvesting, threshing, and associated operations. Few purchased inputs are used; major inputs are household-farm produced: owned seed, bullock power, human labor (mainly women), and compost.

Rice production is dominantly for subsistence, with more than 75% of the rice produced being consumed by the household. However, there was a strong positive and significant correlation between rice sales and farm size, a 1% increase in rice area being associated with a 1.1% increase in rice sales.

Research leading to technology that reduces labor constraints (e.g., mechanical threshers, improved weed control, and possibly direct seeding) appears attractive to rice farmers. Similarly, agronomic research to ensure the long-term stability of more intensive rice-based systems (fertility management, identification and assessment of insect and disease damage, and development of response strategies) must continue to be promoted. An increase in rice production may increase the marketed surplus, implying that rice prices and market development may become a more pressing issue for the government.

Table 4. Labor for 1 ha or 50 kg seed of upland rice per different fallow length or cover vegetation, Luang Prabang, Laos. 1988.

Operation	Labor requirement (person-days) with cover vegetation of		
	Second cropping (*Mimosa*/*C. odorata*)	4-yr fallow (secondary forest)	6-yr fallow (bamboo forest)
Cutting brush and trees	–	27	40
Cutting weeds	22	–	–
Burning	3	10	8
Weeding	31	20	25
Fencing	–	11[a]	–
Planting	30	22	42
Weeding	85	30	30
Weeding	169	70	70
Weeding	24	–	20
Harvesting	22	46	55[b]
Threshing, hauling	13	–	–
Total	399	236	290
Yield			
t/ha	1.3	1.4	1.2
kg/person-day	3.3	5.9	4.1

[a] Domestic animals and wild pigs are a problem. [b] Grain is stripped in the field by hand.

Cropping systems program

Pest control in rice-based cropping systems

Plant Pathology, Entomology, and Agronomy Departments

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DISEASES

Plant Pathology Department

Development of vesicular-arbuscular mycorrhizae in association with cropping patterns. Three cropping patterns, namely, maize - peanut (CP1), rice - peanut (CP2), and maize - fallow (CP3), were used to determine the effect of cropping sequence on the population of indigenous, vesicular-arbuscular mycorrhizal (VAM) fungi in P-deficient (Olsen P= 4.3-5.0 ppm), acidic (pH 4.2-4.6) soils at 3 locations: Plaridel, Patrocinio, and Compact Farm in Claveria, Misamis Oriental, Philippines. The population of VAM fungi was estimated by the most probable number (MPN) method using UPLRi-5 rice as a nurse plant (Table 1).

The indigenous VAM fungal population varied with cropping pattern, location, and time. The highest population occurred in November, after maize harvest and at rice crop maturity. Plaridel contained the highest fungal population (9.8 propagules/g soil), followed by Compact Farm (2.5) and Patrocinio (1.6) (Fig. 1). CP1 supported more VAM fungi than CP3 in Plaridel and Compact Farm, but CP3 supported more VAM fungi than CP1 in Patrocinio; the least VAM fungi were recorded in CP2 at all locations. *Glomus* spp. dominated the VAM spore population in Plaridel; *Gigaspora* was predominant in Patrocinio and Compact Farm. CP1 supported the highest spore population, followed by CP3, then CP2. Cropping pattern influenced the relative abundance of spore type.

A pot experiment studied the effectiveness of Plaridel VAM fungi using Pn 4 peanut. Inoculation of peanut with the indigenous VAM spores increased shoot and pod dry weight in natural and steam-sterilized soil.

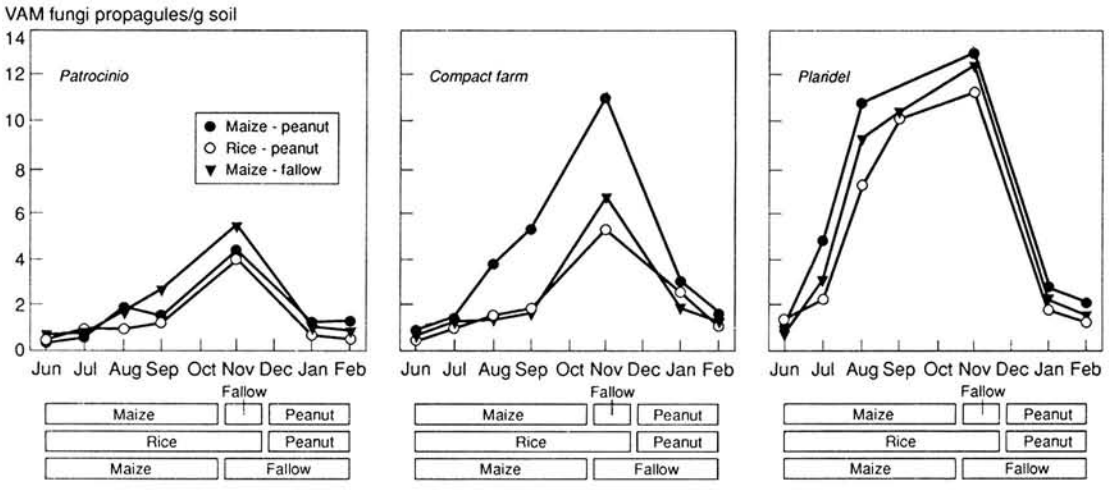
The field study on the residual effect of inoculation of the first crop of IPB 1 maize with *Glomus mosseae* on the succeeding crop of Pagasa 1 mungbean was done in fumigated and nonfumigated soils (pH 5.3) with moderate available P (Olsen 23 ppm). *G. mosseae* increased maize yield by 28% in the natural soil. The maize inoculation apparently carried inocula to mungbean planted after maize but failed to increase root colonization and yield. Fresh inoculation of mungbean with *G. mosseae* increased yield by 20% over the uninoculated treatment.

The interactions between *G. mosseae* and *Bradyrhizobium* spp. in mungbean, and between *G. mosseae* and *Rhizoctonia solani* in IPB 1 maize were studied using a split-root method. Concurrent inoculation of *G. mosseae* and *Bradyrhizobium*

Table 1. Relative abundance of VAM fungal spores at different stages of 3 cropping patterns at 3 sites.[a] Claveria, Misamis Oriental, Philippines, 1988.

Cropping pattern	VAM fungal spores (%)								
	Initial (June)			At rice harvest (November)			At peanut harvest (February)		
	Gig.	Glo.	Aca.	Gig.	Glo.	Aca.	Gig.	Glo.	Aca.
					Plaridel				
Maize - peanut	21 a	68 a	11 a	33 a	46 a	21 b	47 a	41 a	12 b
Rice - peanut	20 a	57 a	23 a	26 a	29 c	45 a	62 a	18 c	20 a
Maize - fallow	21 a	61 a	18 a	37 a	37 b	26 b	56 a	28 b	16 b
					Patrocinio				
Maize - peanut	70 a	16 a	14 a	50 a	31 b	29 b	84 a	10 a	6 a
Rice - peanut	75 a	14 a	11 a	45 a	7 c	48 a	90 a	3 a	7 a
Maize - fallow	76 a	22 a	2 b	44 a	47 a	9 c	85 a	11 a	4 a
					Compact Farm				
Maize - peanut	60 a	27 a	13 a	59 a	37 a	4 c	88 a	7 b	5 c
Rice - peanut	66 a	19 a	15 a	40 a	32 a	28 a	71 a	9 b	20 a
Maize - fallow	68 a	21 a	11 a	55 a	31 a	14 b	58 b	28 a	14 b

[a] Av of 4 replications. Actual value presented, arc sine /x transformed value analyzed. Within a site, means in a column followed by a common letter are not significantly different at the 5% level by DMRT. Gig. = *Gigaspora* spp., Glo. = *Glomus* spp., Aca. = *Acaulospora* spp.

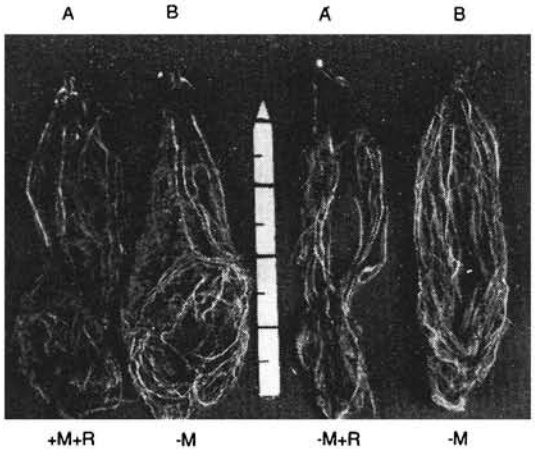


1. Change in VAM fungal population with time in 3 cropping patterns. Claveria, Misamis Oriental, Philippines, 1988.

spp. in a split root increased dry matter (DM) and grain weight. Nodule weight was higher in the mycorrhizal root than in the nonmycorrhizal root or in a P (30 mg/kg soil)-supplied root (Fig. 2).

R. solani multiplied less in the mycorrhizal root than in the nonmycorrhizal root, and reduced sclerotial production and root colonization by *G. mosseae* when both were in the same portion of the split root.

In determining the effect of interrupting the symbiotic relationship between *G. mosseae* and IR64 rice, mycorrhizal rice was found to invest less dry matter in the leaf and to have less unfilled grain than nonmycorrhizal rice. Benomyl treatment at 65 d after emergence (DE) changed the DM distribution of mycorrhizal rice, increased leaf weight and unfilled grain weight, and decreased filled grain weight.



2. Effect of *Rhizoctonia solani* (+R) on mycorrhizal (+M) and nonmycorrhizal (-M) portion of split roots (A and B) of IPB 1 maize, IRRI, 1988. *G. mosseae* was inoculated at seeding, *R. solani* at 35 d after seeding (DAS). Root harvest was at 65 DAS.

INSECTS

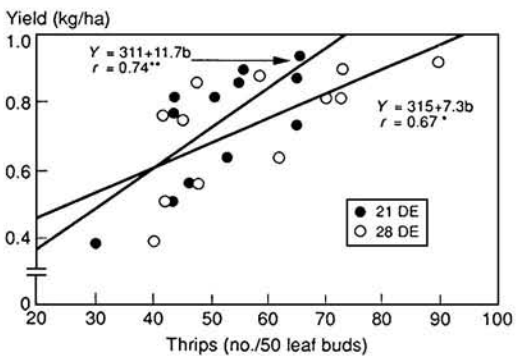
Entomology Department

Control of thrips on mungbean. Thrips are most difficult to control on mungbean, and even high rates and frequencies of conventional insecticides fail to control them adequately. Without at least 80% control it is difficult to know the extent of the yield loss caused. Preflowering sprayings of 11 insecticides showed deltamethrin, methiocarb, triazophos, and carbosulfan permitting the highest yields (Table 2). Omethoate, oxamyl, and formetanate also performed well in terms of yield. Often the highest thrips populations were associated with the highest yields (Fig. 3). Probably mungbean can tolerate thrips damage if damage from other insects is controlled. Thrips also select and multiply fastest on the most vigorous plants, and feed within leaf buds; better growing plants have more leaf buds and therefore more thrips. Deltamethrin may give high yields because it controls the other preflowering insects the best, and the crop tolerates thrips damage.

Table 2. Insecticide evaluation against thrips on mungbean planted after lowland rice.[a] Zaragoza, Nueva Ecija, Philippines, 1988 dry season (DS).

Treatment[b]	Yield (t/ha)
Deltamethrin	0.9 a
Methiocarb	0.9 a
Triazophos	0.9 a
Carbosulfan	0.9 a
Omethoate	0.8 a
Oxamyl	0.8 a
Formetanate	0.8 a
Profenofos	0.7 ab
Methomyl	0.6 b
Formothion	0.6 b
BPMC	0.5 bc
Untreated	0.4 c

[a] *Thrips palmi*. Av of 4 replications. All treatments including the untreated were sprayed with 0.25 kg ai monocrotophos EC/ha at 2 d after crop emergence (DE). [b] All insecticides were applied at 0.75 kg ai/ha at 9, 16, and 23 DE, except deltamethrin at 0.03 kg ai/ha.



3. Linear relationship of yield and abundance of thrips on mungbean on 2 sampling dates. Zaragoza, Nueva Ecija, Philippines, 1988 dry season (DS).

Chemical control on mungbean. Mungbean offers promise as a dry season (DS) third crop after two rice crops in irrigated areas of Central Luzon, Philippines. Yields reach 0.8-1.0 t/ha on residual soil moisture without fertilizer if insects are controlled. Yield loss from insects in 1988 DS was typical—71% (yield was 1.0 t/ha in protected and 0.3 t/ha in untreated plots) (Table 3). Differential treatments revealed that, of the total yield loss, 69% came during postflowering and 21% during preflowering.

The recommended insecticide practice of four low-dosage, well-timed sprays yielded 0.8 t/ha, slightly below the damage-free yield potential. Reducing the dosage of deltamethrin from 15 to 11 g ai/ha to economize showed an insignificant yield depression. However, spraying against pod borer with 3 low-dosage (7 g ai/ha) applications of deltamethrin and substituting a seed treatment for the 2 preflowering sprays showed a slight yield benefit over the recommended practice. Monocrotophos was superior to the isofenphos seed treatment in flea beetle and beanfly control. Improvement in preflowering control is therefore needed. The dominant pod borer was the bean lycaenid *Catochrysops cnejus* which can be controlled with either 2 (22 g total ai/ha) or 3 (21 g total ai/ha) deltamethrin sprays. Three sprays showed a slight yield advantage.

Use of agrochemicals in Nueva Ecija. Control technologies have better chances of success if they match existing farmer practices with regard to targets, thresholds, timing, etc. Forty farmers were interviewed at 2-wk intervals to determine their usage of fertilizers, herbicides, and insecticides during the 1987 wet season (WS). Each farm averaged 1.7 ha with a reported yield of 3.9 t/ha. The most commonly grown cultivars, determined by area planted, were IR42 (39%), IR66 (20%), IR64 (19%), and "IR68" (a selection) (15%). All farmers used fertilizer at an average cost of $31/ha, applying N, P, K, and $ZnSO_4$ at 60, 14, 10, and 8 kg/ha, respectively. The most common form of N was urea, used by 51% of the farmers. Farmers normally split N application into two. The application of fertilizer matched that recommended by researchers well, with the exception of K, which was not necessary according to fertilizer trials. Zn deficiency is common in the area, and perhaps greater amounts should have been used.

Only 26% of farmers applied herbicide—a low frequency. Those who did spent an average of $7/ha and applied herbicide 1.2 times. The most common herbicides were 2,4-D G (0.71 kg ai/ha) (applied by 50%) and piperophos + 2,4-D (0.30 kg ai/ha) (25%).

Most farmers (92%) used insecticides, averaging 1.7 applications/ha valued at $10/ha. The most common insecticides were monocrotophos (0.17 kg ai/ha) (29%), cypermethrin (0.02 kg ai/ha) (21%), chlorpyrifos + BPMC (0.15 kg ai/ha) (16%), MIPC (0.06 kg ai/ha) (12%), and mono-

Table 3. Development of chemical control technology for Pagasa 1 mungbean using the partitioned yield loss method.[a] Zaragoza, Nueva Ecija, Philippines, 1988 DS.

Flea beetle[b] (no. holes/plant) 14 DE	Beanfly[c] (no. larvae + pupae/35 plants) 21 DE	Thrips[d] (no./50 leaf bud terminals) 21 DE	Pod borer[e] (%)		Yield[f] (t/ha)
			Damaged flowers 48 DE	Damaged pods 58 DE	
Complete control: at preflowering, 0.5 kg ai monocrotophos EC/ha + 0.5 kg ai formetanate WP/ha at 2, 9, 16 DE; at postflowering, 30 g ai deltamethrin EC/ha at flowering (50% flower set) and at 10 and 20 d later					
11.5 a	0 a	56 a	4.8 a	7.2 a	1.0 a
Preflowering protection omitted					
27.6 c	16 cd	97 bc	8.8 ab	8.6 ab	0.7 b
Postflowering protection omitted					
14.9 ab	0 a	120 cd	40.0 c	45.6 c	0.4 c
Untreated check					
30.5 c	11 bc	95 abc	48.8 c	40.2 c	0.3 c
Recommended practice: at preflowering, 0.25 kg ai monocrotophos EC/ha at 2 and 12 DE; 15 g ai deltamethrin/ha at flowering (50% flower set) and 10 d later					
23.6 bc	4 ab	122 cd	7.6 ab	10.0 ab	0.8 b
Alternative practice 1: at preflowering, 0.25 kg ai monocrotophos EC/ha at 2 and 12 DE; 11 g ai deltamethrin/ha at flowering (50% flower set) and 10 d later					
23.6 bc	4 ab	127 cd	17.20 b	11.4 ab	0.8 b
Alternative practice 3: at preflowering, isofenphos seed treatment 0.25 kg ai/ha; 7 g ai deltamethrin/ha at flowering (50% flower set) and at 10 and 20 d later					
10.3 a	21 d	151 d	12.0 ab	10.4 ab	0.9 ab

[a] Av of 5 fields (replications). DE = days after crop emergence. [b] *Medythia suturalis:* 35 plants sampled. [c] *Ophiomyia phaseoli:* 35 plants sampled. [d] *Thrips palmi:* 50 leaf bud terminals sampled. [e] *Catochrysops cnejus:* 50 flowers, 100 pods, 300 seeds sampled. The most dominant pod borer. [f] From 20-m^2 cut.

crotophos + cypermethrin (0.06 kg ai/ha) (12%). Most farmers applied insecticide when they saw insect damage (49%) or insects (39%) rather than following preventive scheduling (12%).

Seed treatment on mungbean. Several insecticides show promise as seed treatments for controlling preflowering insects. Furathiocarb had the greatest efficacy against flea beetle and beanfly, followed by carbofuran ST at 0.25 kg ai/ha (Table 4). The yields were similar among the four chemicals tested. There is a savings of half the amount of insecticide and labor over that required by foliar sprays in the recommended practice. A final coating of dry cassava flour on the seed slurry protects

Table 4. Insecticide seed treatment for controlling preflowering pests of mungbean.[a] Zaragoza, Nueva Ecija, Philippines, 1988 DS.

Insecticide[b]	Flea beetle[c] (no. feeding holes/plant) 9 DE	Beanfly[d] (no. larvae + pupae/plant) 21 DE	Yield[e] (t/ha)
Carbosulfan 35 ST	8.5 b	8.6 bc	1.0 a
Furathiocarb 40 DS	3.7 a	3.4 a	1.1 a
Isofenphos 40 SD	15.0 c	10.2 c	1.1 a
Carbofuran 35 ST	9.2 b	4.8 ab	1.1 a
Untreated	24.3 d	9.6 bc	0.7 b

[a] Av of 5 replications. DE = days after crop emergence. [b] 0.25 kg ai/ha (seeding rate 25 kg/ha). Seeds coated with cassava paste + insecticide + flour prior to seeding. [c] *Medythia suturalis*: 35 plants sampled. [d] *Ophiomyia phaseoli*: 20 plants sampled. [e] 10-m^2 cut.

the hands of the farmer from direct contact with chemical during sowing. The trial received a blanket postflowering application of insecticide.

WEEDS

Agronomy Department

Cropping sequence. A trial was conducted to determine the effects of weed control practices in the first crop on tillage requirements and grain yields of succeeding crops, composition of weed flora, crop intensification, and economics.

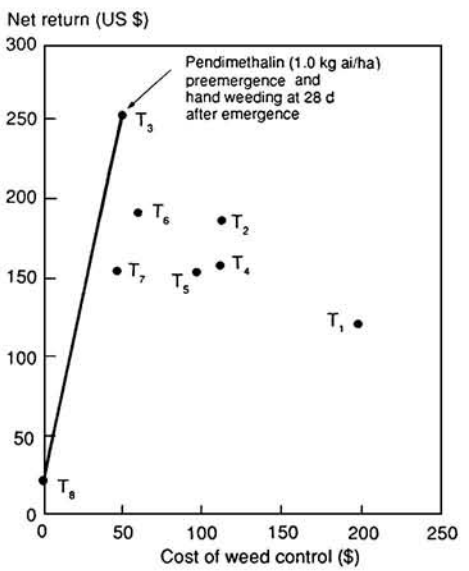
Upland rice. In upland rice, land preparation consisted of two plowings and three harrowings using animal power.

The weed species in the experimental plots, in order of dominance, were *Digitaria setigera, Borreria laevis*, and *Rottboellia cochinchinensis. R. cochinchinensis* became more important at the later stages of crop growth.

All weeding treatments significantly reduced weed weight at all sampling times (Table 5). Increasing the number of weeding operations, which reduced weed weight, did not increase the number of productive tillers. Grain yields were significantly lower when interrow cultivation plus hand weeding (IRC + HW) was done at 14 and 28 DE than when there were 3 or more weeding operations.

The cost of labor for weeding was high, ranging from US$46 to 96/ha and US$111 to 114/ha for 2 and 3 weeding operations, respectively (Table 6). Despite the high weeding costs, all weeding treatments except HW five times gave acceptable net returns and marginal benefit-cost ratios (MBCRs). Preemergence application of pendimethalin at 1.0 kg ai/ha plus HW at 28 DE gave the highest net return and MBCR (Table 6), and was dominant over the other treatments in terms of net return at a given cost of weed control (Fig. 4).

Maize. Two tillage levels were used for maize establishment. Plots that were weed-free after harvest of the rice crop were not plowed. A furrow



4. Dominance curve of weed control practices in UPLRi-7 rice. Ane-i, Claveria, Misamis Oriental, Philippines, 1987 wet season (WS). (See Table 6 for key to treatments.)

Table 5. Weed weight and number of productive tillers of UPLRi-7 upland rice as affected by weed control practice. Ane-i, Claveria, Misamis Oriental, Philippines, 1987 wet season (WS).

Treatment[a]	Weed weight (g/m²)			Productive tillers (no./m²)	Grain yield (t/ha)
	48 DE	75 DE	120 DE		
HW at 14, 28, 45, 60, & 110 DE	5.7 ab	4.3 a	13.3 a	71 a	2.9 a
HOEW + HW at 14, 28, & 45 DE	4.8 a	21.9 b	80.5 bc	75 a	2.8 a
Pendimethalin (1.0 kg ai/ha) & HW at PE & 28 DE	8.6 b	25.4 b	65.7 b	65 a	2.8 a
IRC + HW at 14 & 28 DE + HW at 45 DE	7.2 ab	35.4 b	102.5 c	69 a	2.5 a
HW at 14 & 28 DE	24.3 c	109.0 c	169.6 d	68 a	2.3 ab
HOEW + HW at 14 & 28 DE	27.3 c	107.9 c	194.4 d	63 a	2.3 ab
IRC + HW at 14 & 28 DE	36.2 c	182.9 c	208.4 d	63 a	1.9 b
No weeding	317.7 d	470.3 d	347.3 e	34 b	0.2 c

[a] HW = hand weeding, DE = d after emergence, HOEW = hoe weeding, PE = preemergence, IRC = interrow cultivation.

Table 6. Cost and return analyses of weed control practices.[a] Ane-i, Claveria, Misamis Oriental, Philippines, 1987 WS.

Treatment	Cost (US$/ha)			Return[b] (US$/ha)		MBCR[c]
	Labor and power	Material	Total variable	Gross	Net	
Upland rice						
1. HW at 14, 28, 45, 60, & 110 DE	198	–	198	325	127	1.5
2. HOEW + HW at 14, 28, & 45 DE	114	–	114	314	200	2.6
3. Pendimethalin (1.0 kg ai/ha) & HW at PE & 28 DE	27	23	50	314	264	5.8
4. IRC + HW at 14 & 28 DE + HW at 45 DE	111	–	111	280	169	2.3
5. HW at 14 & 28 DE	96	–	96	258	162	2.5
6. HOEW + HW at 14 & 28 DE	56	–	56	258	202	4.2
7. IRC + HW at 14 & 28 DE	46	–	–	213	167	4.2
8. No weeding	–	–	–	22	22	–
Maize						
A. Furrow and plant						
1. HW at 14, 28, 45, & 60 DE	74	–	74	177	103	2.4
2. IRC + HW at 14 & 28 DE + HW at 45 DE	58	11	69	109	40	1.6
3. HOEW at 14, 28, & 45 DE	40	–	40	82	42	2.1
4. Spot weeding at 45 DE	12	–	12	163	151	13.6
B. Plow, harrow, furrow, and plant						
5. HW at 14 & 28 DE	65	–	65	136	71	2.1
6. IRC + HW at 14 & 28 DE	27	11	38	109	71	2.9
7. HOEW at 14 & 28 DE	44	–	44	68	24	1.5
8. No weeding	–	–	–	–	–	–
Cowpea						
1. HW at 14 & 28 DE	33	–	33	151	118	7.5
2. HW at 14 DE	26	–	26	148	122	17.4
3 IRC + HW at 14 & 28 DE	47	–	47	115	68	2.1
4. IRC + HW at 14 DE	33	–	33	104	71	3.6
5. HOEW + HW at 14 & 28 DE	37	–	37	101	64	2.5
6. HOEW + HW at 14 DE	29	–	29	90	61	3.6
7. HOEW at 14 DE	21	–	21	61	40	–

[a]US$1 = ₱20.00. [b]Gross return = grain yield X unit price in US$ (rough rice = $0.14/kg, maize = $0.17/kg, cowpea = $0.45/kg); net return = gross return – total variable cost in US$. [c]MBCR = marginal benefit-cost ratio. For upland rice and maize = (gross return of treatment – gross return of untreated plot)/total variable cost; for cowpea = (gross return of treatment – gross return of HOEW treatment)/(total variable cost of treatment – total variable cost of HOEW treatment).

was opened for planting (zero tillage). The remaining plots were plowed once and harrowed twice, with 2 d between harrowings. The zero-tillage plots were established 10 d before the tilled plots.

Weed growth was greater in the tilled plots than in the zero-tillage plots. Soil disturbance stimulated the growth of *R. cochinchinensis* which accounted for 71% of the total weed weight. *Ageratum conyzoides* was the most important weed in the zero-tillage plots, accounting for 33% of the total weed weight.

All weeding treatments in the tilled plots significantly reduced weed weight, with corresponding increases in grain yield (Table 7). In the zero-tillage plots, 3 or more weedings reduced weed weight compared with spot weeding at 45 DE but failed to give corresponding increases in grain yield.

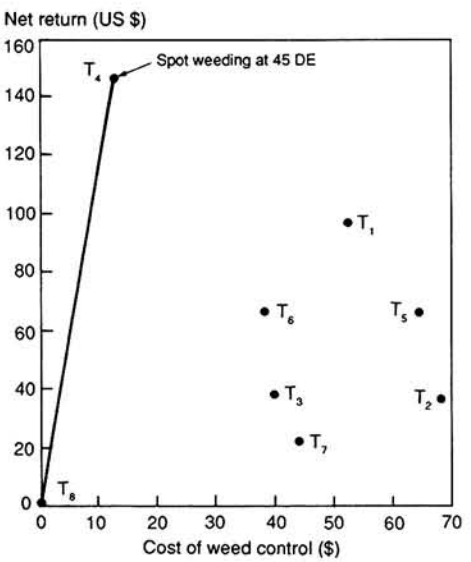
Grain yields were low because of drought. Irrespective of tillage level, HW 2 or 3 times and spot weeding at 45 DE gave the highest grain yields. Spot weeding cost the least (US$12/ha), resulted in the highest net return (US$151/ha) and MBCR (13.6) (Table 6), and was dominant over the other weeding treatments in net return at a given cost of weed control (Fig. 5). All treatments except IRC + HW at 14 and 28 DE plus HW at 45 DE, and hoe weeding at 14 and 28 DE, gave acceptable MBCRs.

Cowpea. Cowpea was established in all plots

Table 7. Grain yield of IPB 1 maize and weed weight as affected by weed control practice and tillage level.[a] Ane-i, Claveria, Misamis Oriental, Philippines, 1987 WS.

Treatment	Weed weight (g/m²)		Grain yield (t/ha)
	45 DE	75 DE	
Furrow and plant			
HW at 14, 28, 45, & 60 DE	7.5 a	1.4 a	1.3 a
IRC + HW at 14 & 28 DE + HW at 45 DE	14.3 ab	7.2 b	0.8 a
HOEW at 14, 28, & 45 DE	21.1 bc	32.5 c	0.6 a
Spot weeding at 45 DE	42.0 c	15.6 c	1.2 a
Plow, harrow, furrow, and plant			
HW at 14 & 28 DE	4.1 a	9.7 a	1.0 a
IRC + HW at 14 & 28 DE	7.0 ab	21.7 b	0.8 ab
HOEW at 14 & 28 DE	13.7 b	33.1 b	0.5 b
No weeding	137.3 c	354.5 c	0.0 c

[a] In a column, within each tillage level, means followed by a common letter are not significantly different at the 5% level by DMRT.



5. Dominance curve of weed control practices in IPB-1 maize. Ane-i, Claveria, Misamis Oriental, Philippines, 1987 WS. (See Table 6 for key to treatments.)

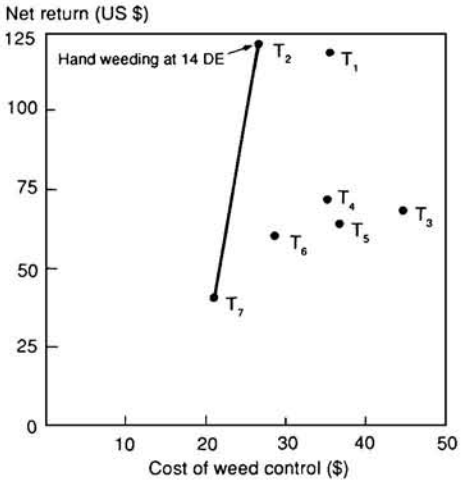
except those that were not weeded during the previous crop, which were left as a weedy fallow.

The total weed weight before the first weeding operation at 14 DE was low, indicating the effectiveness of the weed control practices in the maize crop (Table 8). Weed weights at 43 DE were significantly reduced by 2 weeding operations, but this did not necessarily result in significantly increased grain yield – there was a drought and weed pressure was low. However, the grain yields obtained from the plots that were hoe weeded at 14 DE were significantly lower than those from the plots that were hand weeded once or twice. All treatments gave acceptable MBCRs (Table 6). Based on the hoe weeding treatment at 14 DE, HW at 14 DE gave the highest net return at a given cost of weed control (Fig. 6).

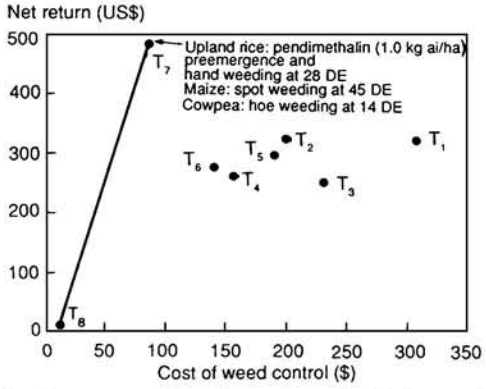
Table 8. Weed weight and grain yield of IT82D-889 cowpea as affected by weed control practice in zero tillage establishment. Ane-i, Claveria, Misamis Oriental, Philippines, 1988 DS.

Treatment	Weed weight (g/m²)		Grain yield (t/ha)
	13 DE	43 DE	
HW at 14 & 28 DE	1.9 b	3.0 a	0.4 a
HW at 14 DE	2.9 ab	7.5 bc	0.4 a
IRC + HW at 14 & 28 DE	3.2 ab	3.4 ab	0.3 ab
IRC + HW at 14 DE	6.0 a	14.1 c	0.3 ab
HOEW + HW at 14 & 28 DE	2.8 ab	2.4 a	0.3 ab
HOEW + HW at 14 DE	3.3 ab	11.6 c	0.3 ab
HOEW at 14 DE	5.7 ab	17.8 c	0.2 b

Upland rice + maize + cowpea. Preemergence application of pendimethalin at 1.0 kg ai/ha plus HW at 28 DE in upland rice, zero tillage for maize establishment plus spot weeding at 45 DE, and zero tillage establishment for cowpea plus hoe weeding at 14 DE resulted in the lowest cost of weed control (US$86/ha) and the highest net return (US$483/ha) and MBCR (7.6) (Table 9). This sequence was also dominant in terms of net return at a given cost of weed control (Fig. 7).



6. Dominance curve of weed control practices in IT82D-889 cowpea. Ane-i, Claveria, Misamis Oriental, Philippines, 1987 WS. (See Table 6 for key to treatments.)



7. Dominance curve of weed control practices in rice - maize - cowpea cropping sequence. Ane-i, Claveria, Misamis Oriental, Philippines, 1987 WS. (See Table 6 for key to treatments.)

Although the third weeding operation in upland rice did not significantly increase grain yield, weed weight was greatly reduced at harvest. This allowed the early establishment of the second crop in the zero-tillage plots and reduced the cost of land preparation by 77%. Early establishment of the second crop also allowed the planting of short-duration cowpea as a third crop, thus increasing cropping intensity.

Table 9. Combined cost and return analyses of weed control practices in an upland rice - maize - cowpea cropping sequence.[a] Ane-i, Claveria, Misamis Oriental, Philippines, 1987 WS.

Treatment[b]	Total variable cost[c] (US$/ha)	Return[d] (US$/ha)		MBCR[e]
		Gross	Net	
1. a. HW at 14, 28, 45, 60, & 110 DE				
b. HW at 14, 28, 45, & 60 DE				
c. HW at 14 & 28 DE	309	629	320	2.1
2. ab. HW at 14 & 28 DE				
c. HW at 14 DE	201	524	324	2.7
3. ab. IRC + HW at 14 & 28 DE + HW at 45 DE				
c. IRC + HW at 14 & 28 DE	231	484	253	2.1
4. ab. IRC + HW at 14 & 28 DE				
c. IRC + HW at 14 DE	157	419	262	2.8
5. a. HOEW + HW at 14, 28, & 45 DE				
b. HOEW at 14, 28, & 45 DE				
c. HOEW + HW, 14 & 28 DE	193	490	296	2.6
6. a. HOEW + HW at 14 & 28 DE				
b. HOEW at 14 & 28 DE				
c. HOEW + HW at 14 DE	143	422	280	3.1
7. a. Pendimethalin (1.0 kg ai/ha) & HW at PE & 28 DE				
b. Spot weeding at 45 DE				
c. HOEW at 14 DE	86	569	483	7.6
8. ab. No weeding				
c. Weedy fallow	14	22	8	–

[a] US$1 = ₱20.00. [b] a = applied to upland rice, b = applied to maize, ab = applied to upland rice and maize crops, c = applied to cowpea. [c] Total cost of weed control in an upland rice - maize - cowpea cropping sequence plus the cost of land preparation between crops. [d] Gross return = grain yield X unit price (rough rice = $0.14/kg, maize = $0.17/kg, cowpea = $0.45/kg); net return = gross return – total variable cost. [e] MBCR = marginal benefit-cost ratio = (gross return of treatment – gross return of untreated plot)/(total variable cost of treatment – total variable cost of untreated plot).

Undersowing upland rice with forage legumes. The ability of forage legumes to suppress weed growth and provide supplementary N to upland rice was studied in Claveria, Misamis Oriental. The three forage legumes sown with upland rice were *Stylosanthes guianensis, Lablab purpureus*, and *Macroptilium atropurpureum*. Three N levels—0, 25, and 50 kg/ha—and 2 weeding regimes—HW 2 and 3 times—were superimposed across the forage legume treatments. N was applied to upland rice only. A plot without forage legume was included as a check.

Weed weights at 45 DE were not affected by the forage legumes when no N was applied (Table 10). When N was applied, however, the plot without the forage legume had the lowest weed weight.

Yields were not increased by adding N or undersowing a forage legume (Table 10). In fact, yields with *S. guianensis* and *L. purpureus* at 0 and 25 kg N/ha were lower than those without forage legume because the two legumes grew vigorously and competed with the crop. At the highest N level, the crop was able to overcome the competitive effects of the legumes.

In another trial, the effects of undersowing of the same forage legumes in one rice crop on weed growth and yield of the succeeding rice crop were studied. When no N was applied, weed weights at 14 DE were significantly greater when the previous crop was undersown with *S. guianensis* than when there was no legume. At 40 DE after two HW, there was no difference in weed weight between treatments. Yield was not affected by the undersowing of legumes.

Green manure. Four green manure (GM) crops (*Leucaena leucocephala, Helianthus annuus, Chromolaena odorata*, and *Gliricidia sepium*) were incorporated at 10 t/ha (fresh weight) during land preparation to determine their effects on weeds, seedling damage due to insect pests, nematodes,

Table 10. Average weed weight and grain yield of UPLRi-5 upland rice as affected by N level and forage legumes.[a] Cabacungan, Claveria, Misamis Oriental, Philippines, 1987 WS.

Forage legume	Nitrogen level (kg/ha)		
	0	25	50
	Weed weight (g/m²)		
None	20.6 a	9.3 b	16.1 b
Stylosanthes guianensis	25.3 a	22.9 a	30.5 a
Lablab purpureus	23.0 a	20.4 ab	20.8 a
Macroptilium atropurpureum	26.9 a	17.6 ab	31.0 a
	Yield (t/ha)		
None	3.7 ab	3.9 a	3.6 a
S. guianensis	3.2 c	3.2 c	3.5 a
L. purpureus	3.4 bc	3.5 bc	3.6 a
M. atropurpureum	3.9 a	3.7 ab	3.6 a

[a] Av of 2 weeding treatments. In a column within a parameter, means followed by a common letter are not significantly different at the 5% level by DMRT.

Table 11. Effect of green manure on weeds, plant height, and grain yield of upland rice UPLRi-5 at 2 weeding levels.[a] IRRI, 1988 WS.

Treatment	Weed density (no./m²) at 5 WE	Weed weight (g/m²)		Plant height (cm) at 6 WE	Yield (t/ha)
		5 WE	9 WE		
	Hand weeded at 2, 4, and 6 WE				
Leucaena leucocephala	161 a	24 a	20 a	76 a	2.4 a
Helianthus annuus	159 a	25 a	33 a	73 a	2.1 ab
Chromolaena odorata	152 a	36 a	29 a	71 a	2.0 ab
Gliricidia sepium	143 a	31 a	17 a	75 a	2.0 ab
Weed-free fallow	175 a	28 a	21 a	59 b	1.5 bc
Weedy fallow	192 a	25 a	36 a	54 b	1.0 c
	Unweeded				
L. leucocephala	248 a	182 a	990 a	70 a	0
H. annuus	291 a	190 a	781 a	76 a	0
C. odorata	259 a	210 a	939 a	71 a	0
G. sepium	264 a	218 a	873 a	78 a	0
Weed-free fallow	268 a	183 a	743 a	72 a	0
Weedy fallow	389 b	168 a	796 a	60 b	0

[a] In a column within a weeding treatment, means followed by a common letter are not significantly different at the 5% level by DMRT. WE = wk after emergence.

and on upland rice (UPLRi-5) performance. A weed-free fallow and a weedy fallow were included as checks. There were two weeding levels: unweeded and hand weeded at 2, 4, and 6 wk after emergence (WE). No fertilizer was applied.

The treatments had no effect on rice stand, seedling damage due to insect pests, nematode populations, or rice tiller production. All GM crops increased rice plant height at 6 WE (Table 11). In the unweeded plots, the number of weeds was fewer in the plots where the GMs were incorporated than in the weedy fallow plot. However, there were no differences in weed weight at 5 and 9 WE. The number and weight of weeds among treatments did not differ when the plots were hand weeded.

Rice produced no yield in all unweeded plots because weed competition was intense (Table 11). In the hand-weeded plots, yields were greater with incorporated GMs than in the weedy fallow.

Cropping systems program

Design and evaluation of cropping patterns

Multiple Cropping and Agricultural Economics Departments

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- Farmer-managed evaluation of alternative cropping systems in an upland environment with acid soil **470**
  - Agronomic performance **470**
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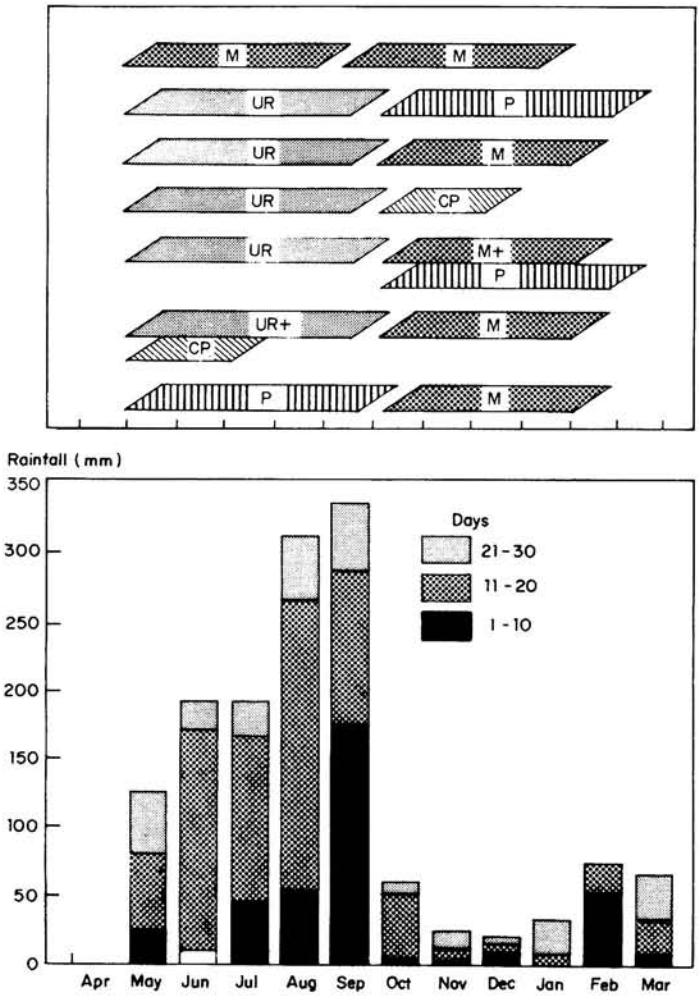
ACID UPLAND ENVIRONMENT

Multiple Cropping and Agricultural Economics Departments

Farmer-managed evaluation of alternative cropping systems in an upland environment with acid soil (*Multiple Cropping and Agricultural Economics*). *Agronomic performance* (*Multiple Cropping*). Seven cropping patterns were designed and evaluated under farmer management in crop year (CY) 1987-88 in Claveria, Misamis Oriental, Philippines. The patterns were suggested by the results in CY 1985-86 and CY 1986-87 (Annual reports for 1986 and 1987). Major features were crop intensification in acid upland environments, and the diversification of the current monocrops of rice and maize to cereal - legume patterns. Maize (IPB Var 1), rice (UPLRi-5), cowpea (IT82D-889), and peanut (UPL-PN4) were the major component crops. Mungbean was deleted from the patterns because of its sensitivity to acid. Only two-crop sequences were designed, since soil moisture had proven inadequate for a third crop. To check crop yield variation due to natural soil fertility, test fields were categorized into low and moderate fertility levels before distributing the cropping patterns.

A methodological innovation was the attempt to develop a protocol for evaluating patterns with two cash flow constraints: 1) low cash flow, which



1. Monthly rainfall and proposed cropping pattern, Claveria, Misamis Oriental, Philippines, 1987-88. M = maize, UR = upland rice, P = peanut, CP = cowpea.

is less than twice the current farmers' input level, and 2) a moderate cash flow level that provides some input flexibility above the farmers' level. The moderate level selected was approximately four times the farmers' cash investment. These levels were lower than those used in previous years.

The proposed patterns and the corresponding monthly rainfall are presented in Figure 1. Rainfall was favorable in CY 1985-86, but the succeeding 2 yr were characterized by late onset and early cessation of rainfall, with midseason drought stress. In CY 1987-88, planting of the first crop began on 3 June – 3-4 wk beyond the scheduled cutoff date – because rains were delayed.

Mean grain yields of the component crops are presented in Table 1. Rice and maize yields were substantially reduced by the drought stress in late August. Rice yield was further reduced by blast disease during the rice reproductive phase. The severity of disease incidence was scored, with a maximum leaf infection of 50%. Fields classified as having moderate soil fertility did not consistently give higher crop yields than those with low fertility, presumably because of the overriding effects of drought and diseases. Among the first crops, only maize and intercropped rice exhibited a yield increase from low to moderate cash flow level. Peanut had very low yields because of poor seed emergence and the occurrence of unfilled pods. In the intercrop system, low rice yields due to drought were augmented by moderate cowpea yields.

The second crops were established late regardless of the first crop species. Several fields were left unplanted, while the rest produced extremely low yields as a result of terminal drought due to the very early end of the wet season (WS).

Cowpea produced stable yields as a first crop across years, but production was constrained by the market outlet. High-yielding maize varieties also produced good yields, but they required higher fertilizer input than other crops. Rice (UPLRi-5) had excellent yields (3.5 t/ha) during the first CY but was substantially affected by drought and diseases during the succeeding 2 yr.

Shorter duration rice varieties may reduce the drought risk to the succeeding crop. Efforts to test this hypothesis are now in progress with a new generation of upland rice cultivars. The results of

Table 1. Mean grain yield of the first crop components of the cropping patterns at 2 cash flow (CF) levels. Claveria, Misamis Oriental, Philippines, 1987-88.

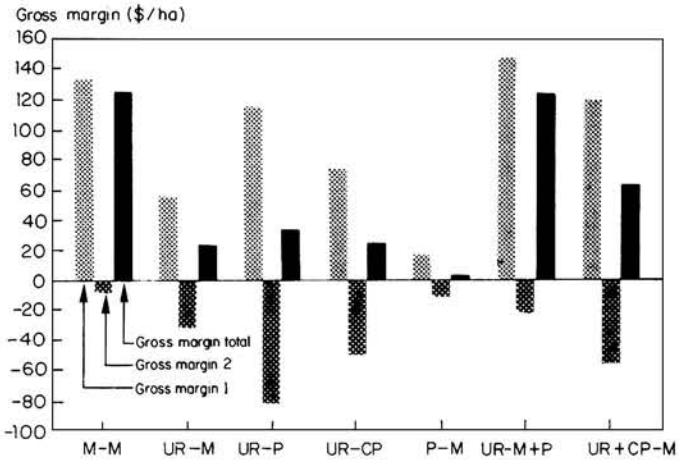
Crop	Variety	Sites[a] (no.)	Yield (t/ha)	
			Low CF	Moderate CF
	First crop			
Upland rice (UR)	UPLRi-5	41	1.6	1.7
Maize	IPB Var 1	11	2.0	2.4
Peanut	UPL PN4	4	0.2	0.1
UR intercrop	UPLRi-5	6	0.6	1.3
Cowpea intercrop	IT-82D-889	6	0.7	0.2
	Second crop			
Cowpea	IT-82D-889	3 (4)	0.0	0.1
Maize	IPB Var 1	15 (16)	0.2	0.2
Peanut	UPL PN4	3 (4)	0.1	0.1
Maize intercrop	IPB Var 1	3 (4)	0.2	0.3
Peanut intercrop	UPL PN4	3 (4)	0.1	0.1

[a]Number of fields harvested. Numbers in parentheses are number of fields planted. Failures were due to drought.

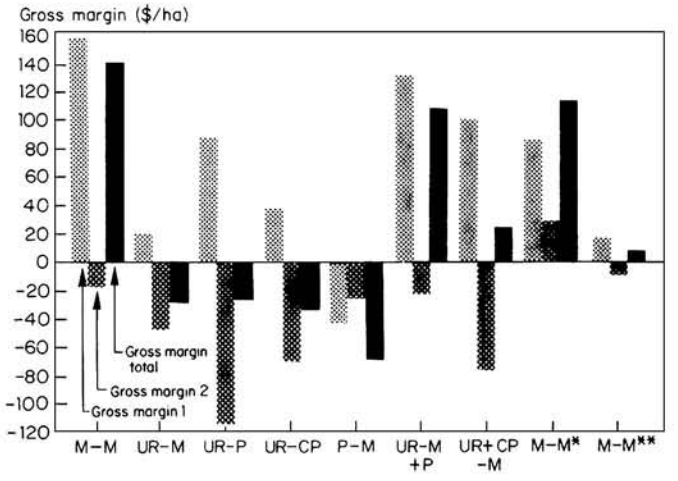
the three CYs indicate that the drought risk of a second crop established starting in late October is greatly increased with a delayed first crop. Fallowing a field previously planted to upland rice is very common. For production of a late WS second crop, low input levels and early-maturing cultivars are necessary for profitability. Fields may also be seeded to drought-resistant green manure legumes instead of leaving them fallow.

Assessing economic viability (Agricultural Economics). Severe drought incidence during the second crop cycle of CY 1987-88 reduced the total returns above variable costs (RAVC) for all cropping patterns tested (Fig. 2, 3). This implies that the gross revenue of the second crop was not sufficient to cover labor, power, and material costs of production and, necessarily, labor was paid below the existing wage. Therefore, farmers adopting any of these patterns would have been better off had they not planted a second crop and simply worked as hired farm laborers. In reality, however, farmers cannot predict drought such that, more often than not, they suffer heavy losses when it occurs.

The profitabilities of the tested patterns and the farmer's pattern were evaluated using enterprise budgeting applying farmer-effective prices (Table 2). Under the low cash situation, M-M(E) had the highest RAVC ($125/ha) from a produc-



2. Gross margin of alternative cropping patterns, low cash flow constraint. Claveria, Misamis Oriental, Philippines, 1987-88.



3. Gross margin of alternative cropping patterns, moderate cash flow level, Claveria, Misamis Oriental, Philippines, 1987-88. * = based on improved variety, ** = based on farmers' variety.

tion increase of 0.84 t/ha over the farmer's traditional M-M (F) pattern based on farmers' variety. This was achieved with a 15% reduction in total investment, implying higher technical efficiency of the tested pattern. The UR-M+P (E) pattern had approximately the same net gain; however, this was attained with 47% increase in cost over the farmer's pattern. The M-M(E) and UR-M-P(E) patterns dominated the rest of the patterns tested.

Under moderate cash management, the M-M(E) and farmer's improved maize technology based on improved variety, M-M (F), dominated the rest of the patterns. The most profitable pattern, M-M(E), involved only 22% increase in total investment, improved total production by 1.4 t/ha, and raised net gain from $8/ha to $142/ha. Compared with the farmer's improved maize technology, M-M(E) had almost the same level of investment ($202/ha vs $206/ha); however, the latter increased net gain by more than 25%. Opportunities thus exist for improving farmers' income under the prevalent M-M pattern by improving their production efficiency.

The labor profiles of the farmer's traditional pattern and those of the tested patterns are shown

Table 2. Costs and returns[a] of various cropping patterns on experimental (E) and farmers' (F) plots. Claveria, Misamis Oriental, Philippines, 1987-88.

Cropping pattern[b]	Sites (no.)	Yield (t/ha)		Costs ($/ha)			Gross return[c] ($/ha)	Return above variable costs[d]	Coefficient of variation (%)	Rates of return ($/$) to		MBCR[g]
		Crop 1	Crop 2	Labor and power	Materials	Total variable				Labor and power[e]	Materials[f]	
Low cash												
M-M (E)	11	1.95	0.22	128	15	143	268	125	90	2.0	9.3	-3.6
UR - M (E)	20	1.34	0.12	152	27	179	202	23	189	1.2	1.9	2.5
UR - P (E)	7	1.98	0.12	227	89	316	349	33	61	1.1	1.4	1.2
UR - CP (E)	7	1.45	0.03	163	25	188	212	24	115	1.2	2.0	1.9
P - M (E)	4	0.17	0.23	137	34	171	174	3	302	1.0	1.1	-0.9
UR - M+P (E)	7	2.19	0.18 + 0.07	208	41	249	370	122	45	1.6	4.0	2.4
UR+CP - M (E)	6	0.58 + 0.72	0.00	229	34	263	324	61	310	1.3	2.8	1.6
Moderate cash												
M - M (E)	11	2.42	0.33	145	62	207	348	142	64	2.0	3.3	4.6
UR - M (E)	20	1.34	0.16	159	77	236	208	-28		0.8	0.6	0.5
UR - P (E)	7	2.10	0.12	236	155	391	365	-26		0.9	0.8	0.8
UR - CP (E)	7	1.45	0.05	167	83	250	217	-33		0.8	0.6	0.5
P - M (E)	4	0.14	0.28	134	74	208	139	-68		0.5	0.1	-1.0
UR - M+P (E)	7	2.38	0.27 + 0.08	220	89	309	417	109	71	1.5	2.2	1.7
UR+CP - M (E)	6	1.32 + 0.21	0.00	149	74	223	247	24	180	1.2	1.3	1.3
M - M (F)[h]	5	1.70	0.69	173	29	202	317	115	126	1.7	5.0	4.2
M - M (F)[i]	18	0.80	0.53	153	16	169	177	8	45	1.1	1.5	

[a] $1 = 21 pesos. [b] Cultivars: cowpea, IT-82D-889; upland rice, UPLRi-5; maize, IPB Var 1; P = peanut. E indicates designed patterns with researcher consultation on management practices; F indicates a prevalently grown pattern with no researcher involvement (i.e., control). [c] Based on net yield, i.e., corrected for 17% harvester and thresher share + 3% losses. [d] Gross return – total variable cost. [e] Gross return – material posts/labor and power costs. [f] Gross return – labor and power costs/material cost. [g] MBCR = marginal benefit-cost ratio = (gross return of potential pattern – gross return of prevalent pattern) ÷ (total variable cost (TVC) of potential pattern – TVC of prevalent pattern). [h] Based on improved variety. [i] Based on farmers' variety.

in Table 3. Total labor use under the most profitable pattern, M-M(E), was 174 person-days/ha, which was 30% higher than in M-M(F). The highest labor use was with UR-P (E), utilizing 59% of the total farm supply. As in CY 1986-87, labor utilization during the year was low because of the decline in farm activities as a result of the drought during the second crop. Under the drought, M-M(F), M-M(E), and UR+CP-M(E) had the most even distribution of labor use. The cropping pattern experiments in 1987-88 suggest that, under the drought stress characteristic of upland Claveria, the farmers' prevalent M-M(F) pattern and the test M-M(E) pattern give higher net benefits and provide more even distribution of labor use. This would partly explain farmers' continuing preference for their existing M-M pattern.

Cowpea as the legume component in acid upland cropping systems (*Multiple Cropping*). Diversification of the traditional low-input cassava or cereal monocrop into cereal - legume sequences that can sustain soil productivity through nutrient cycling is constrained in acid upland areas by the sensitivity of legumes to acid soils. Our evaluation of several legumes for adaptation to the acid upland environmental complex in Claveria, Misamis Oriental, indicated that cowpea is more tolerant of acid soils and more acceptable to farmers than mungbean, soybean, pigeonpea, sword bean, or lablab. We therefore tested cowpea as a component of different cropping patterns and examined the cultural requirements of these patterns.

Cowpea was evaluated as a monocrop or intercrop component in two fields differing in inherent soil fertility and pH: a field with relatively lower fertility (pH 4.6, 1.92% organic C, 0.15 meq exchangeable K/100 g, 9.8 ppm Bray 2 available P) and one with higher fertility (pH 5.0, 1.94% organic C, 0.27 meq exchangeable K/100 g, 14.5 ppm available P). The following cropping patterns were evaluated: 1) cowpea followed by maize (CP - M); 2) upland rice followed by maize (UR - M); 3) an intercrop of upland rice and cowpea at a 2:1 row ratio, with maize relayed into the vacant rows after cowpea harvest (UR + CP/M); and 4) a monocrop of rice with 1 skip row (unplanted) alternating with 2 rice rows, with maize planted into the skip row at the same time as treatment 3. N fertilizer was applied as a subplot treatment within each cropping pattern at rates of 0 and 30 kg N/ha. The cultivars were IT82D-889 cowpea, UPLRi-5 upland rice, and IPB Var 1 maize.

N application had no significant effect on the growth and yield of any crop in the patterns.

Table 3. Use of labor in experimental cropping patterns in Claveria, Misamis Oriental, Philippines, 1987-88.

	Cropping pattern							
	M-M (E)	UR-M	UR-P	UR-CP	P-M	UR-M+P	UR+CP-M	M-M(F)[a]
Annual labor requirement								
Person-days	174	216	314	222	165	283	308	133
% of available supply	33	41	59	42	31	54	58	25
Monthly use of labor: % of available supply								
Jan	0	0	0	0	0	0	17	18
Feb	37	0	0	0	0	0	17	1
Mar	17	0	0	0	0	0	0	15
Apr	0	13	23	26	0	23	17	20
May	44	34	0	23	6	0	45	18
Jun	41	71	68	64	62	68	45	30
Jul	24	11	10	165	136	11	122	18
Aug	91	136	182	0	0	182	236	13
Sep	68	4	7	6	0	9	0	118
Oct	52	43	0	0	102	0	68	23
Nov	19	104	335	134	69	261	58	16
Dec	0	74	88	88	0	89	74	13
Coefficient of variation (%)	83	108	166	132	149	153	109	114

[a] Based on improved variety.

Therefore, the results were arranged across N level. The monocrop cowpea grain yields ranged from 0.9 to 1.5 t/ha (Table 4). The grain yields of the intercropped cowpea were 58 and 80% of the sole cowpea yields in the low and moderate fertility fields, respectively. In both fields, the intercropped rice yields were about 70% of the sole rice yields.

The land equivalent ratios for the intercrop of rice and cowpea varied from 1.25 to 1.51 between the low and moderate levels, respectively, suggesting a positive interaction in resource utilization. The rice in the skip row treatment gave a yield similar to that of the rice + cowpea intercrop in both fields, and between 65 and 74% of sole rice crop yields (Table 4). Thus, rice yields were reduced by about 1/3 whether 1/3 of the field area was occupied by a legume intercrop or by blank rows. This suggests that the only significant effect of the legume on the rice is accounted for by the field area it occupied.

No evidence of direct positive or negative effects such as net N transfer from the legume to the cereal was seen. Conversely, there was no indication of net competition by the cowpea for nutrients, water, or light. Maize relayed into the rows vacated by the cowpea after harvest was unsuccessful, apparently because of severe shading by the adjacent 85-d-old rice and competition for nutrients. The sole maize planted after harvest of the 130-d sole rice crop underwent severe terminal stress. Maize yields were much lower than when maize followed the 65-d-old sole cowpea crop. The early harvest of cowpea allowed the subsequent maize to escape late season drought stress. Both crops in the CP-M sequence had successful grain yields, thus giving this pattern the highest gross income.

The data in Table 4 suggest that it is advantageous agronomically and economically to produce cowpea as a monocrop rather than as an intercrop. The CP-M pattern had the highest gross return in both fields, and the yield of maize following cowpea was higher than when maize followed the UR + CP intercrop. Thus, cowpea shows potential as a cash crop for upland farmers.

Seldom is a cash crop the crop grown exclusively on the entire farm. The requirement for a stable source of cereal grain for food dictates that a substantial area of the farm should be planted to rice or maize in the early WS. Thus, a relevant issue is the comparative benefits of planting cowpea as a monocrop or as an intercrop when cowpea will cover only a portion of the farm.

Table 5 addresses the issue of optimizing the returns on a whole farm basis when both rice and cowpea are to be grown in early WS. Intercropping cowpea with rice was of modest positive advantage according to data from both the low and moderate fertility fields. The advantage in gross returns ranged from 4 to 11% when maize was grown sequentially following the UR + CP intercrop. Thus, when cowpea is to be grown on only a portion of the farm, intercropping it with

Table 4. Grain yield, land equivalent ratio (LER),[a] and gross income of component crops of cropping patterns in 2 fields. Claveria, Misamis Oriental, Philippines, 1987-88.

Crop sequence	Low fertility field crop component				Moderate fertility field crop component			
	CP	UR	M	LER	CP	UR	M	LER
				Grain yield (t/ha)				
CP-M	1.55	–	1.6	1.00	1.00	–	3.18	1.00
UR+CP/M	0.90	2.42	0	1.23	0.79	1.35	0.69	1.51
UR+blank/M	–	2.59	0	0.47	–	1.24	1.20	0.65
UR-M	–	3.48	0	1.00	–	1.90	1.46	1.00
				Gross income[b] (US$)				
CP-M	437.7	–	237.6	675.3	282.5	–	454.9	737.0
UR+CP/M	256.9	320.3	0	577.1	225.4	192.4	99.1	517.0
UR+blank/M	–	369.3	0	369.3	–	177.1	171.3	348.4
UR-M	–	501.3	0	496.6	–	271.0	208.3	479.3

[a] LER = land equivalent ratio, calculated for the first crop season in the sequence. [b] Gross income was computed at local market prices of $0.28/kg cowpea and $0.14/kg maize or rice.

Table 5. Optimizing gross returns on a 3-ha upland farm planted to rice and cowpea in early WS and maize in late WS.[a] Claveria, Misamis Oriental, Philippines, 1987-88.

Case	Area planted[b] (ha)	Pattern	Gross return[c] ($/area planted)	
			Low fertility	Moderate fertility
Monocrop	1	CP-M	675.29	737.38
	2	UR-M	993.14	958.57
Total			1668.43	1695.95
Intercrop + relay crop	3	UR+CP/M	1731.43 (+4)	1551.00 (– 8)
Intercrop[d]	3	UR+CP/M	1731.43 (+4)	1878.43 (+11)

[a] Data from Table 4. [b] Area planted to each crop in all patterns was the same, since the intercrop was 2/3 rice + 1/3 cowpea. [c] Values in parentheses are the percentage increase in gross returns above the returns to monocropping. [d] This pattern was not actually tested. Monoculture maize yields following the intercrop are assumed to be the same as those in the UR-M pattern.

rice may be slightly superior to cultivating it as a monocrop. This is because the cowpea intercrop produces much more per unit area planted to it without seriously affecting the yield of the companion rice crop.

The compatibility of rice and cowpea grown together in the intercrop is a function of the cultivar used. The very early-maturing (60-d) cowpea cultivar IT82D-889 is not as competitive as more indeterminate and late-maturing cultivars, and is a key element in the success of companion cropping with rice. The advantage of intercropping was much reduced when a following crop of maize was to be grown, because maize performance was much superior when planted after sole cowpea. The data do not suggest a practical advantage of rice + cowpea intercropping in the prevalent cropping system.

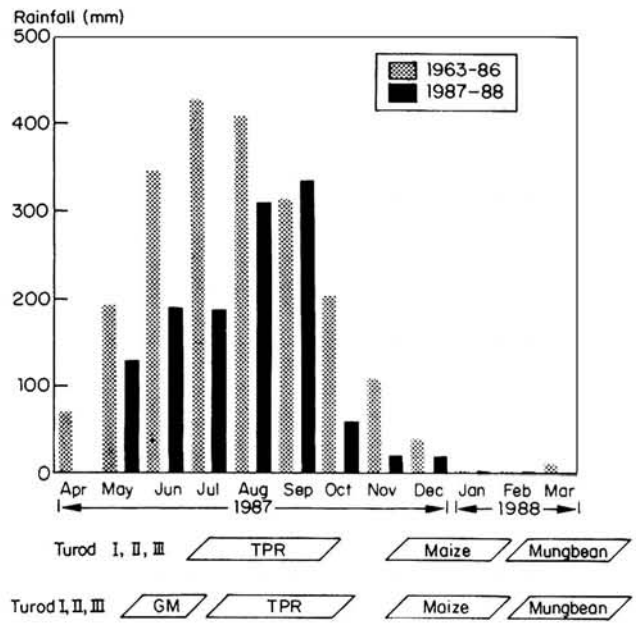
PARTIALLY IRRIGATED LOWLAND ENVIRONMENT

Multiple Cropping and Agricultural Economics Departments

Evaluation of alternative cropping systems in a partially irrigated environment. Details concerning the site and research methodologies for this project were reported previously (Annual reports for 1984 and 1985). The designed cropping patterns and weather are summarized in Figure 4. The objectives of the project were to diagnose the constraints on crop intensification and diversification in a partially irrigated environment with a deep tubewell as the water source, and to develop component technologies to improve the productivity of farmers' land, labor, and capital.

Transition season maize on turod. The mean yield of maize in 9 cropping pattern test fields using the hybrid SMC 305 was 5.71 t/ha, an increase of 1.23 t/ha over the 1986 yield and 3.11 t/ha over the 1984 yield. The yield increase over 4 yr of testing was due to improvements in land preparation technologies, fertilizer and irrigation management, and pest control. Because of the increased maize yields, the local Land Bank Office in Guimba, Nueva Ecija, extended credit loans to farmers who would plant maize as the second crop following WS rice. Credit was not extended to farmers who opted to plant rice instead of maize. Maize yield from farmers' fields averaged 4.8 t/ha compared with an average rice yield of 2.5 t/ha. Consequently, the irrigation fee payment by farmers who planted maize was 100%, which compared favorably with that of farmers who planted rice.

Transition season rice on lungog. A major constraint to the intensification of irrigated rice-based cropping systems in Central Luzon is the low yield potential observed when a second rice crop is established in the October-December transition period. Previous studies have indicated that low solar radiation, cool temperature, and high windspeed during the late vegetative and reproductive phases are contributing factors. Since tillering is reduced during this season, increased plant density might increase transition rice yields.



4. Designed cropping patterns graphed against mean monthly rainfall in a partially irrigated environment, Guimba, Nueva Ecija, Philippines, 1987-88. TPR = transplanted rice, GM = green manure.

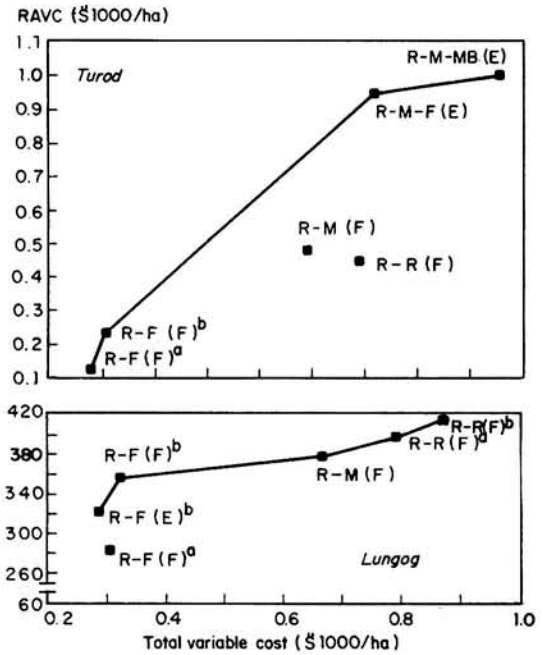
An experiment was conducted to study the performance of IR64 under three N levels and four planting distances. Closer planting (20x15 and 15 x 15 cm) produced higher grain yield than the recommended 20 x 20 cm, but the increase was not significant.

Late dry season mungbean on turod. Mungbean following maize was tested during the dry-to-wet transition period. The mean yield of mungbean was 0.91 t/ha. The late establishment of maize delayed mungbean planting by about 1 mo. Thus, harvest was postponed from late May to early June. Early WS rains decreased the number of primings and the seed quality of mungbean.

Dry season rice. The mean yield of IR64 from 12 fields in the command area of groundwater pump 108 was 4.6 t/ha. Although Zn deficiency was suspected, application of 20 kg $ZnSO_4$/ha had no significant effect on rice yields. NPK fertilizer treatments were superimposed on 10 fields. The results showed no significant effect of P and K on IR64 yield. The optimum N level was 60 kg N/ha – lower than that commonly applied by farmers.

It is now consistently observed that the level of nutrients applied by farmers in this area is substantially higher than that found to be optimum through agronomic research. This suggests that overapplication of inputs may be developing an "input wastage gap" among irrigated rice farms. We are investigating this to verify the presence of this gap and to determine its likely causes. The phenomenon would suggest a strong imperative to seriously investigate more efficient fertilizer input levels and application practices as a means of reducing production costs and raising profitability.

The net revenue of each cropping pattern is plotted against the total variable cost in Figure 5. In turod, it is most profitable for farmers to shift from the R-F(F)^a pattern (based on rice varieties except IR64) to R-F(F)^b (based on IR64), then to R-M-F(E) and R-M-MB(E). R-F(F)^b gave the highest marginal benefit-cost ratio (MBCR) (4.83), followed by R-M-F(E) (2.54) and R-M-MB(E) (2.13). R-M-MB(E) and R-M-F(E) gave lower MBCRs because the increase in RAVC–5 times higher than R-F(F)^a–was offset by a corresponding increase in total variable cost–4 times higher than R-F-(F)^a. In lungog, it is most profitable to shift from R-F(E)^b to R-F(F)^b and R-R(F)^a. Among all patterns, R-F(E)^b gave the second lowest RAVC due to low yield and high variable cost.

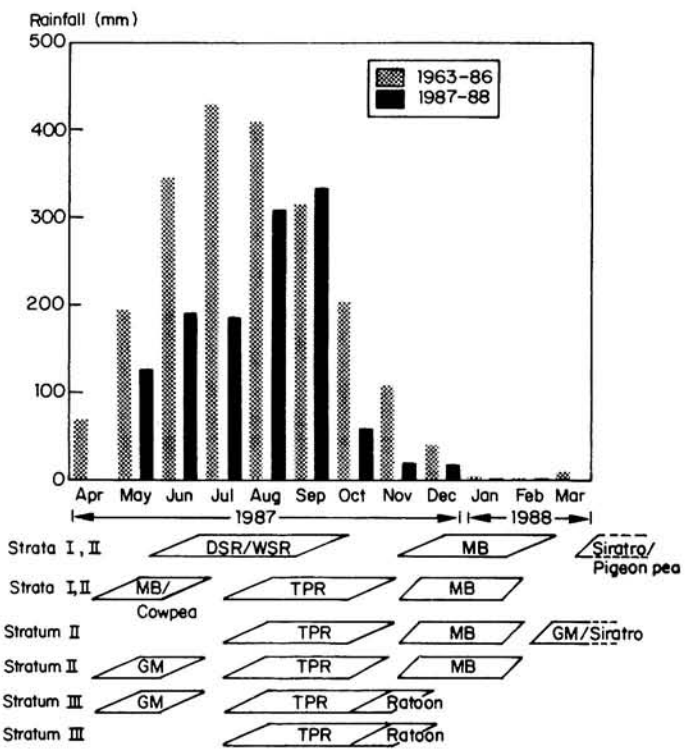


5. Net revenue curves for various cropping patterns. Bantug, Nueva Ecija, Philippines, 1987-88.

FAVORABLE RAINFED LOWLAND ENVIRONMENT

Multiple Cropping and Agricultural Economics Departments

Evaluation of alternative cropping systems for favorable rainfed lowland conditions. Research at the favorable rainfed lowland key research site started during 1987 WS. The site is located within the contiguous villages of Bacayao, Santo Cristo, and San Roque, Guimba, Nueva Ecija, in Central Luzon. The physical environment of the location is analyzed in the section entitled Analysis of the Physical and Biological Environment. Three main land facets were identified: 1) stratum I, which includes the gradually sloping convex level starting from the uppermost portion of the landscape; the ricefield drop height is around 5 cm, an indication of good drainability and greater susceptibility to drought; 2) stratum II, representing the nearly level to slightly concave areas below stratum I in the landscape; and 3) stratum III, corresponding to drainageway depressions and their headwater branches.



6. Designed cropping patterns graphed against mean monthly rainfall for the rainfed environment in Guimba, Nueva Ecija, Philippines, 1987-88. DSR = dry seeded rice, WSR = wet seeded rice, MB = mungbean, GM = green manure, TPR = transplanted rice. Broken lines = crop failure.

The present cropping pattern is a single crop of transplanted rice (TPR). The use of modern rice cultivars, e.g., IR64, reduces crop duration substantially, but has not resulted in greater crop intensification. The major research issue is the potential for greater crop intensification by adding a prerice or postrice crop. This involves an understanding of farmers' present resource use and of the economic situation. It also requires estimates of the labor and power profiles of alternative cropping patterns.

A total of 24 farmer cooperators – 8 from each of the 3 strata – were involved in testing of the designed cropping patterns. The patterns and 1987 weather are summarized in Figure 6, specifically by land facet.

The onset of the rainy season was delayed in 1987, and below average rainfall in June and July greatly delayed the establishment of WS TPR. Because of very dry soils after rice harvest, the upland crops designed to follow WS rice were not planted.

In a field planted to dry seeded rice, which was harvested early (mid-October), four upland crops were established under zero and full tillage levels. Mungbean, cowpea, and sorghum yielded much better with full tillage land preparation than with zero tillage (Table 6). In another researcher-managed cropping pattern trial, mungbean and sorghum outyielded four other upland crops (Table 7).

Figure 7 shows the net revenue curves for various cropping patterns tested at the Bacayao site. Due to water stress, the cropping patterns in the strictly rainfed areas gave lower RAVCs than those tested in the area with supplemental water from the shallow well pump. In the rainfed area, the optimal shift is from R-F(E)^b (based on IR64) to R-F(F)^b. R-F(E)^c (based on IR64) with green manure gave a negative RAVC (-212) due to crop failure. In the rainfed area with supplemental irrigation, however, the most profitable is for farmers to shift from R-F(E)^b (based on IR64) to R-F(F)^b. In both areas, shifting from R-F(F)^b (based on IR64) to any of the experimental and other farmers' cropping patterns generally gave low MBCR (<2.0), mainly due to low increases in net returns and high increases in variable costs.

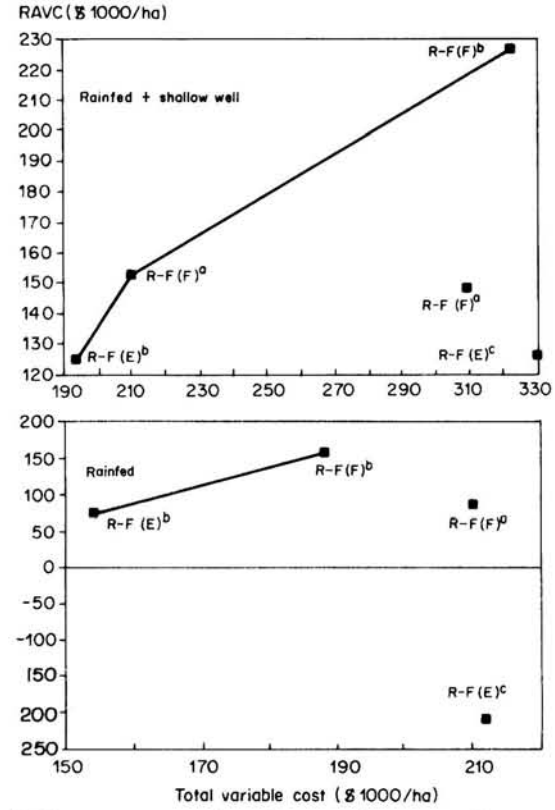
Table 6. Mean yield of upland crops following early dry seeded rice under 2 tillage levels for the upland crops. Rainfed environment in Guimba, Nueva Ecija, Philippines, 1987 transition season.[a]

Crop	Yield (t/ha)	
	Zero tillage	Full tillage
Mungbean	0.28	0.76
Cowpea	0.39	1.44
Sorghum	0.60	2.00
Green maize	0	0.48

[a] Av of 4 replications.

Table 7. Mean yield of upland crops following rice in a researcher-managed cropping pattern. Rainfed environment in Guimba, Nueva Ecija, Philippines, 1987 transition season.

Crop	Yield (t/ha)
Mungbean	1.14
Sesame	0.19
Peanut	0
Sorghum	1.94
Pigeonpea	0.40
Green maize	0



7. Net revenue curves for various cropping patterns. Bacayao, Guimba, Nueva Ecija, Philippines, 1987-88.

Cropping systems program

Selecting and testing varieties for rice-based cropping systems

Rice Farming Systems Program and Multiple Cropping Department

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SELECTING AND TESTING UPLAND CROP CULTIVARS FOR RICE-BASED FARMING SYSTEMS

Rice Farming Systems Program

Upland crop varieties bred and selected from the University of the Philippines at Los Baños (UPLB) Institute of Plant Breeding (IPB)-IRRI collaborative project, national programs involved in the Asian Rice Farming Systems Network (ARFSN), and international agricultural research centers were evaluated before and after wetland rice. The crops tested were mungbean, cowpea, bush sitao, soybean, peanut, pigeonpea, maize, and sorghum. IPB collects germplasm and does the hybridization, screening, and selection, while IRRI multiplies seed and distributes the materials to various farming systems sites in the ARFSN.

Mungbean. Thirty-four new mungbean accessions from India, Indonesia, Thailand, and Pakistan were collected, bringing the total germplasm collection to 6,577. Two thousand five hundred forty cultivars were put in an observational nursery before and after wetland rice (1,290 before rice and 1,250 after rice) at UPLB and Pangasinan State University. From each screening, 100 lines were selected for a preliminary yield trial (PYT) at both locations. From these successive evaluations, 20 outstanding lines were put in an advanced yield trial (AYT). Five selections (IPB-M82-17-32, IPB-M82-16-70, IPB-M82-17-52, IPB-M82-2-19, and IPB-M82-21-2) were outstanding at both locations in the postrice test, giving grain yields of 1.1-1.2 t/ha. The check variety Pag-asa-5 yielded 1.0 t/ha. In the prerice test, five lines—IPB-M82-21-4, IPB-M82-20-13, IPB-M82-2-43, IPB-M82-17-32, and IPB-M82-2-55—were selected for inclusion in the international trials of the ARFSN. Their mean grain yield ranged from 1.2 to 1.3 t/ha, with IPB-M82-21-4 as the top yielder.

Screening for sources of tolerance for drought and waterlogging and for resistance to major insect pests and diseases was also done at IPB. For drought and waterlogging tolerance, three types of experiments were conducted: preliminary screening, a verification trial, and a multilocational trial. In 1988, 100 lines were selected from the preliminary screening of 342 lines for drought tolerance. Bases for selection were grain yield and plant vigor during stress. From a verification trial of 81 entries, 15 lines also showed high tolerance for drought. IPB-M82-17-32 obtained the highest grain yield of 2.88 t/ha, followed by IPB-M82-21-16 (2.32 t/ha), IPB-M82-16-35 (2.18 t/ha), and IPB-M82-2-49 (2.08 t/ha). Pag-asa-5, the check variety, yielded the lowest with 0.33 t/ha. In the multilocational trial at four Philippine locations (IPB, Los Baños; Ilagan, Isabela; La Granja, Negros Occidental; and Batac, Ilocos Sur), 4 entries were outstanding: IPB-M79-13-98 (1.42 t/ha), Pag-asa-3 (1.40 t/ha), IPB-M79-9-82 (1.30 t/ha), and IPB-M79-6-11 (1.26 t/ha). In the screening for waterlogging tolerance, preliminary trials with 348 entries and verification trials with 37 entries are in progress.

To screen for insect and disease resistance, preliminary and confirmatory tests were conducted. In the preliminary screening, all entries in the observational nursery, PYTs, and AYTs were rated against the naturally occurring major insect pests and diseases in the experimental area. Materials that were resistant to moderately resistant were evaluated further in a confirmatory test. For insect resistance screening, a confirmatory test of 40 entries revealed 6 entries with resistance to beanfly (2 with high and 6 with moderate resistance). The preliminary and confirmatory tests for pod borer and leaffolder did not give conclusive results because insect populations were low. For disease screening, 359 mungbean lines were evaluated in the confirmatory test for Cercospora leaf spot. Six lines showed high and 145 moderate resistance to the disease.

At IRRI, 12 promising selections from IPB, the Asian Vegetable Research and Development Center (AVRDC), and national programs were evaluated before and after wetland rice. Before rice, Kampangsaen from Thailand had the highest yield of grain (1.39 t/ha) and fodder dry matter (DM) (5.51 t/ha). Other promising selections in terms of grain production were IPB-M80-36-33 (1.31 t/ha), IPB-M81-4-55 (1.23 t/ha), and IPB-M81-4-19 (1.20 t/ha). IPB-M80-21-36 and IPB-M79-12-179 were the other top yielders of fodder DM, both producing 5.05 t/ha. After rice, IPB-M79-13-60 (Pag-asa-5) gave the highest grain yield (0.87 t/ha), followed by MG-50-10A(G) (0.84 t/ha) and IPB-M79-13-29 (0.80 t/ha). IPB-M79-13-29 also gave the highest fodder DM yield (1.0

t/ha). These varieties matured in 60-65 d.

Cowpea. Twelve promising cowpea varieties from IPB and the International Institute of Tropical Agriculture (IITA) were evaluated before wetland rice. IT-82D-889 gave the highest green pod yield (5.47 t/ha), followed by IT-82D-892 (4.99 t/ha), CES-41-6 (4.68 t/ha), and IT-82D-699 (4.58 t/ha). CES-41-6 also gave the highest dry bean yield (1.30 t/ha). IT-82D-699 produced the highest fodder DM yield (7.84 t/ha) after 3-4 pickings of dry pods. Other high fodder-producing entries were IT-82E-19 (6.01 t/ha) and IT-82D-892 (5.89 t/ha). IT-82D-889 yielded only 3.97 t fodder DM/ha. These varieties matured in 65-70 d.

Ten bruchid-resistant and 10 aphid-resistant lines from IITA were also evaluated after wetland rice. Among the bruchid-resistant lines, IT-84D-460 gave the highest grain yield (1.50 t/ha), followed by IT-84S-2246-4 (1.24 t/ha) and IT-84S-275-9 (1.23 t/ha). The top grain yielders among the aphid-resistant lines were IT-84S-2246-4 (1.34 t/ha), IT-83S-728-5 (1.23 t/ha), and IT-84S-275-9 (1.22 t/ha). These varieties matured in 70-75 d.

Bush sitao. Ten bush sitao varieties from UPLB, IITA, and national programs were tested before rice. The most promising entries were BS[1] (6-14R × AS) and BS[3] (6-14R × AS), which yielded 7.21 and 5.97 t/ha of green pods and 4.03 and 4.46 t/ha of fodder DM, respectively, after 6-8 pickings of fresh pods. They matured in 70 d.

Soybean. Twenty-two soybean accessions from Thailand and AVRDC were collected during the year. A PYT of 100 lines selected from the previous year's observational nursery was planted after wetland rice at UPLB and Pangasinan State University. Twenty-one lines were selected and entered in an AYT at both locations. Yields ranged from 76 to 225 kg/ha at UPLB and from 1,057 to 2,136 kg/ha at Pangasinan. The low yields at UPLB were due to waterlogging from the early vegetative to the flowering stage. Five lines (IPB-SY82-178-1, IPB-SY82-178-19, IPB-SY82-9, IPB-SY82-167-67, and IPB-SY82-178-121) were selected for testing in the ARFSN.

Of the 200 lines mass-screened for waterlogging tolerance the previous year, 15 were evaluated in a verification trial at UPLB. B-3037 obtained the highest yield of 1.30 t/ha, followed by GC-60030-4 (1.10 t/ha) and B-3039 (0.97 t/ha). UPL-SY-2, the check variety, gave the lowest yield of 0.22 t/ha. For drought tolerance, 15 entries selected from the preliminary trial were planted at IPB and the Ilagan Experiment Station, Isabela. At IPB, yield range was low because of pod borer damage and photoperiodicity in some entries, since planting was done in mid-February, when relatively long day periods usually prevail. Grain yield from B-3039 was highest with 0.58 t/ha, followed by Acc-770 (0.40 t/ha). At Ilagan, TGX-311-14C yielded the highest (2.51 t/ha), followed by IPB-SY-178-12 (2.50 t/ha) and BTP #13 (1.90 t/ha).

Of 682 entries mass-screened for insect resistance during the year, 295 showed a promising level of resistance (172 entries with resistance to leaffolder and 123 entries with resistance to pod borer). B-3039, B-3036, and Acc-53 were among the entries that showed moderate resistance to pod borer, while MTD-10 and IPB-SY-138-29 exhibited high and moderate resistance to leaffolder, respectively. In the preliminary screening for disease resistance, two resistant lines—IPB-SY-83-35-19 and IBP-SY-83-52-10—exhibited a hypersensitive type of resistance to soybean rust. In the advanced trial after rice, IPB-SY-82-218 was moderately resistant to rust. Three lines—IPB-SY-83-46-3, IPB-SY-83-46-7, and IPB-SY-83-61-3—were rated as resistant to bacterial pustule in the preliminary trial, but none was resistant in the advanced trial.

At IRRI, 16 early-maturing and 15 medium-maturing varieties from IPB, IITA, AVRDC, and Illinois (USA) were evaluated after rice under zero tillage. Among the early varieties, which matured in 75-80 d, UPL-SY-2, the variety used in cropping pattern testing, gave the highest grain yield (1.82 t/ha). Other promising entries were AGS-160 (1.71 t/ha) and AGS-124 (1.41 t/ha). Among the medium-maturing group (85-95 d), TGX-888-485 and TGX-52-4D from IITA were the top grain yielders.

Ten medium-maturing and eight late-maturing varieties were also tested after upland rice during the dry season (DS). Yields ranged from 0.81 to 1.86 t/ha in the medium-maturing group, with TGX-996-28E as the top grain yielder. UPL-SY-4, the check variety, yielded 1.42 t/ha. In the

late-maturing group, the check variety L-114 gave the highest grain yield (2.43 t/ha), followed by TGX-297-01F with 1.66 t/ha. These varieties matured in 115 d.

Peanut. Thirty-four new peanut accessions from Indonesia, China, and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) were collected during the year. Ninety-one selections from the previous year's screening were evaluated in yield trials (67 in PYT and 27 in AYT) after rice at UPLB and Pangasinan. Yields in both trials were abnormally low and it was decided to retest them in the 1988 postrice season.

The PYT of 144 entries and the verification trial of 18 entries for drought tolerance were conducted during 1987-88 DS. Twenty lines were selected in the PYT and five in the verification trial. Bases for selection were yield and plant vigor during stress. All entries included in the observational nursery, PYT, and AYT were also rated against the naturally occurring major disease and insect pests of peanut. From these screenings, 15 entries were confirmed resistant and 43 moderately resistant. Confirmatory tests for Cercospora leaf spot showed 50 lines with high and 116 with moderate resistance. Preliminary screening for leafhopper also resulted in the selection of 55 lines with moderate resistance. Ten of the 55 also exhibited moderate resistance to defoliators and pod borers.

Twelve peanut varieties from IPB and national programs were evaluated after wetland rice under zero tillage at IRRI. The top yielders of shelled peanut were IPB-PN-46-12 (1.47 t/ha), IPB-PN-2-25 (UPL-PN-6) (1.44 t/ha), and IPB-PN-48-90 (1.38 t/ha). In fodder DM production, IPB-PN-48-90 was the most promising entry, with 2.28 t/ha. Other promising varieties were IPB-PN-42-14 (2.20 t/ha of fodder DM), UPL-PN-4 (2.13 t/ha), and IPB-PN-46-12 (2.04 t/ha).

An observational nursery of 23 early-maturing lines from Thailand was also tested before rice at IRRI. Shelled bean yields obtained were low, primarily because waterlogging at maturity caused rotting of the pods even though they were planted on top of ridges. ICGS (E)-56, an ICRISAT-bred line, gave the highest bean yield of 0.36 t/ha, followed by local checks from Thailand: Nongbuadaeng (0.35 t/ha) and Nakomsongkhon (0.33 t/ha). MGS-7 × SM 1-5 gave the highest fodder DM yield (3.34 t/ha). Other good fodder producers were UPL-PN-4 (3.24 t/ha) and Nongbuadaeng (3.13 t/ha). The crop was harvested in 95 d.

Pigeonpea. Twelve pigeonpea cultivars from Australia and ICRISAT, and 14 introductions from ICRISAT were evaluated for grain and fodder production after wetland rice at IRRI. The trials were planted with zero tillage. In the first group of materials, the top grain yielders were ICPL-6 (1.63 t/ha), ICPL-81 (1.51 t/ha), and ICPL-87 (1.45 t/ha). ICPL-87 also gave the highest fresh fodder yield (12.33 t/ha), followed by TC (FC)J-1 (12.00 t/ha) and ICPL-6 (11.53 t/ha). ICPL-6 had taller plants (134 cm) than ICPL-87 (92 cm). Among the introductions, the top grain yielders were ICPL-87 (1.03 t/ha) and ICPL-86003 (0.79 t/ha). The top producers of fresh fodder were ICPL-87046 (15.87 t/ha) and ICPL-86005 (13.33 t/ha); however, they gave the lowest grain yield.

Maize. Twelve varieties from IPB, the Centro Internacional de Mejoramiento de Maiz y Trigo, and national programs were tested after rice under zero tillage. IPB Var 1 and 2, the varieties used in cropping pattern testing, were the top yielders with 2.64 and 2.67 t grain/ha and 2.30 and 2.80 t stover DM/ha, respectively. Both varieties had average plant height of 175 cm and matured in 105 d.

Sorghum. Twelve sorghum varieties from IPB and ICRISAT were evaluated after rice under zero tillage. The top grain yielder was ICSV-126, with 4.05 t/ha. It produced a dry stover yield of 6.74 t/ha. Other promising varieties were SPV-475 and ICSV-163, which yielded 3.35 and 3.33 t grain/ha and 6.97 and 9.53 t dry stover/ha, respectively. UPL-SG-5, the variety used in cropping pattern testing, yielded 2.84 t grain/ha and 6.0 t dry stover/ha. ICSV-126, SPV-475, and ICSV-163 matured in 120 d, 15 d later than UPL-SG-5.

Two international adaptation trials composed of 25 hybrids and 25 inbred varieties from ICRISAT were also evaluated under zero tillage after wetland rice. Among the hybrids, ICSH-138 was the top grain yielder with 3.50 t/ha, followed by ICSH-9 (3.42 t/ha), ICSH-106 (3.41 t/ha), and ICSH-162 (3.40 t/ha). UPL-SG-5, the check entry, yielded 2.52 t/ha. Among the varieties, CSH-11 gave the highest grain yield of 4.33 t/ha. Other

high-yielding varieties were ICSV-298 (4.11 t/ha), ICSV-233 (3.95 t/ha), and ICSV-110 (3.93 t/ha).

CHEMICAL ANALYSIS OF FODDER FROM UPLAND CROPS

Rice Farming Systems Program

In the varietal testing of upland crops in ARFSN, we also determined the percentage of crude protein and crude fiber in the fodder after grain harvest. These crop residues are good sources of feed during DS, when other fodder is very limited.

Samples of mungbean, bush sitao, cowpea, and sweet potato from the 1987 and 1988 trials were analyzed by the Institute of Animal Science of UPLB. Crude protein and crude fiber percentages in mungbean varied significantly among varieties. Crude protein was highest in IPB-M80-21-36 (13.9%) and Pag-asa-5 (13.5%). Crude fiber was lowest in variety 7715 (33.9%) from Bangladesh and Pag-asa-5 (36.2%). IPB-M80-21-36, Pag-asa-5, and 7715 had grain yields of 1.14, 1.09, and 0.88 t/ha, respectively.

In cowpea, the highest crude protein content was obtained in IT-82E-18 (13.0%), followed by that in IT-82D-892 (12.9%) and IT-82D-889 (12.4%). Crude fiber was lowest in IT-82E-16 (36.9%) and IT-82D-755 (37.8%). IT-82D-889 had the third lowest percentage of crude fiber (38.4%) and the highest grain yield (0.90 t/ha) among the varieties tested. However, it produced lower fodder DM yield (4.0 t/ha) than the other varieties that had yielded 6.0 t residues/ha.

In bush sitao, EG BS_2 and IT-81D-1228-14 gave the highest crude protein content (14.0%). IT-81D-1228-10 and IT-81D-1228-12 had the lowest crude fiber content (31.1%). These varieties yielded 3-5 t of fresh pods/ha after 6-8 pickings. BS_1 (6-14R × AS), which gave the highest fresh pod yield (7.2 t/ha), had 12.2% crude protein and 32.4% crude fiber.

In sweet potato, differences in the crude protein and crude fiber contents of the vines were also significant. V2-1 from the Visayas State College of Agriculture, Leyte, gave the highest crude protein content (12.9%), followed by Kinabakab (12.0%) from Bicol, Philippines. Crude fiber content was lowest in G145r-4 (25.2%). V2-1, which also gave the highest marketable tuber yield (12.2 t/ha), had 31.2% crude fiber content.

VARIETAL EVALUATION OF CULTIVARS FOR RICE-BASED FARMING SYSTEMS

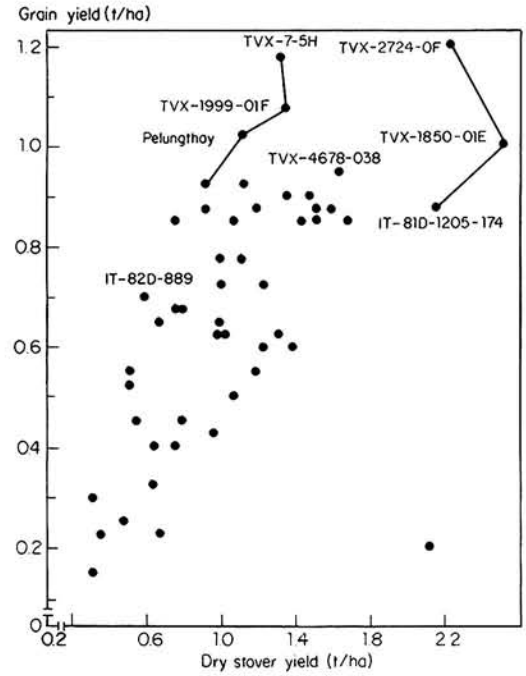
Multiple Cropping Department

Soybean, sorghum, pigeonpea, and sunflower cultivars were evaluated for yield potential after rice during 1987-88 DS. For soybean, 32 cultivars were evaluated. They were classified into early and medium maturity groups. The top seed yielders among the early-maturing varieties were UPL-SY-2, AGS-160, AGS-124, and EG-SY-73. Among the medium-maturing varieties, the superior entries were TGX-888-48D, TGX-562-4D, Willis, and TGX-239-17E. Among the 12 promising sorghum cultivars tested, the top seed yielders were ICSV-126, SPV-475, ICSV-163, CS-110, and ICSV-138 and the top dry fodder yielders were ICSV-163, ICSV-138, DK-64, and SPV-475. Potential cultivars for high yield of both seed and dry fodder were SPV-475, ICSV-163, and ICSV-138. The 26 pigeonpea cultivars evaluated were grouped into two sets: promising varieties from previous evaluation at IRRI, and newly introduced genotypes. The highest grain and fodder yielders among the promising varieties were ICPL-6, ICPL-81, and ICPL-87. Among the newly introduced genotypes, ICPL-87 and ICPL-86003 were the top grain yielders, and ICPL-86005 and ICPL-87046 were the top fodder yielders. Of five sunflower cultivars evaluated, IHA-93 produced the highest seed yield.

COWPEA CULTIVAR SELECTION FOR UPLAND RICE CROPPING SYSTEMS

Multiple Cropping Department

Fifty cowpea entries were evaluated in an upland field with pH 4.3 at the Claveria key research site to identify specific cultivars for contrasting niches in upland cropping systems. Cultivars TVX-7-5H, TVX-1999-01F, and Pelungthay, in the upper left of Figure 1, exhibited high grain yield and low stover weight. They may be superior for intercropping with rice, since they can produce high yields but offer relatively low competition to the adjoining rice. Pelungthay had the least biomass among the entries that exceeded a grain yield of 1 t/ha; its growth duration is as short as that of the current elite cultivar IT-82D-889. TVX-2724-0F, TVX-1850-01E, and IT-81D-1205-174, on the



1. Relationship between grain and dry stover yields of 50 cowpea cultivars evaluated at Claveria acid upland key research site, Misamis Oriental, Philippines, 1987 wet season.

frontier of the upper right of Figure 1, were identified for both grain and stover (dual purpose). Other than benefits from grain yield, these varieties would contribute superior amounts of crop residue, which could be used as DS animal feed or plowed down for green manure (GM). Several cultivars were found superior to IT-82D-889, the entry that has been superior in research studies for the past 4 yr.

IDENTIFICATION OF SUITABLE FORAGE AND GRAIN LEGUME SPECIES FOR HIGHLY ACID SOILS

Multiple Cropping Department

Twenty-five entries of leguminous species were evaluated on a highly acidic soil (pH 4.5, 6.3-8.0 ppm Bray 2 P) in Cavinti, Laguna, Philippines, to identify genotypes most suitable for intercropping or sequential cropping (for grain legume entries) and most suitable as GM cover crops to improve soil fertility or as animal fodder.

The study was conducted as three experiments differing in fertility level:

Table 1. Mean total dry matter yield (TDMY), nodule count, and plant vigor score at flowering, and days to flowering of entries from testing to identify suitable forage or grain legume species for acid soils (low fertility) in Cavinti, Laguna, Philippines, 1988 WS.

Cultivar	Nodule count at flowering		TDMY at flowering		Days to flowering		Plant vigor[a]
	Rank	no.	Rank	t/ha	Rank	no.	
Lablab (Rongai)	19	5	20	0.34	21	158	9
Stylosanthes C136	1	42	8	4.73	20	148	4
Clitorea ternatea	–	–	–	–	–	–	9
Desmanthus virgatus	–	–	–	–	–	–	9
Siratro (local)	15	6	16	1.08	6	64	7
Stylosanthes humilis	2	25	7	5.62	4	61	4
Rice bean	7	15	14	1.98	5	63	6
Centrosema 5277	11	9	3	7.07	17	129	1
Stylosanthes C184	5	18	9	4.30	18	133	4
Jack bean	4	20	11	2.98	7	64	4
Centrosema brazilianum	21	4	6	6.02	12	97	4
Moth bean	–	–	–	–	–	–	9
Stylosanthes copitata	18	5	2	10.00	13	100	1
Siratro (Thai)	10	10	15	1.61	8	66	6
Centrosema (local)	16	6	5	6.08	16	131	4
Lablab (Hiworth)	14	6	19	0.53	14	104	9
Stylosanthes hamata	9	13	18	0.70	3	56	3
Sword bean	17	5	10	3.00	9	67	6
Stylosanthes macrocephala	13	6	1	11.00	11	95	3
Centrosema 5586	20	4	4	7.04	19	133	3
Stylosanthes ceca	–	–	–	–	–	–	9
Lablab (local)	12	7	21	0.17	15	120	7
Cowpea TVX-1948-01F	6	16	12	2.88	2	53	3
Pigeonpea QPL-72	8	14	13	2.69	10	78	4
Adzuki bean	3	22	17	1.00	1	47	5

[a] Visual scores based on *Standard evaluation system for rice*: 1 = excellent, 9 = very poor.

- Low fertility: zero fertilizer
- Moderate fertility: 15 kg P + 1 t lime/ha
- High fertility: 45 kg P + 3 t lime/ha

In the low fertility level experiment, the top five producers of biomass at flowering were *Stylosanthes macrocephala, S. copitata, Centrosema* 5277, *Centrosema* 5586, and a local *Centrosema* (Table 1). They varied in total dry matter yield (TDMY) from 6.08 to 11.00 t/ha. These production levels were very much superior to that of most other species tested. Lablab was poorly adapted to the chemical conditions of the site.

At the moderate fertility level, the top five TDMY producers at flowering were cowpea CV TVX-1948-01F, three accessions of *Stylosanthes* (C184, *humilis,* and *copitata*), and *Centrosema* 5586 (Table 2). Four of these same entries (except for *Stylosanthes* C184) were also the top performing entries at the high fertility level (Table 3). At the high fertility levels, *S. copitata* yielded 20.4 t/ha dry matter in 103 d (Table 3).

The top 10 biomass producers (average of three levels of fertility) are shown in Table 4, together with the top 10 nodulating entries. The entries with superior biomass production at flowering were mostly forage legumes (*Stylosanthes* and *Centrosema*), while the top nodule counts were also more frequent among the grain legumes.

TDMY and nodule count of entries in general increased with increasing fertility. Some entries showed a constant biomass production regardless of fertility level, e.g., *Stylosanthes* C136, *S. humilis*, jack bean, *Centrosema brazilianum*, local *Centrosema*, and sword bean. *S. macrocephala* decreased biomass production at flowering with increasing fertility. Cowpea entries such as TVX-1946-01F had below-average biomass production without fertilization, but the response to moderate or high P and lime was outstanding. *S. copitata* and *Centrosema* 5586 were among the top five in all three fertility environments.

Table 2. Mean TDMY, nodule count, and plant vigor score at flowering, and days to flowering of entries from testing to identify suitable forage or grain legume species for acid soils (moderate fertility) in Cavinti, Laguna Philippines, 1988 WS.

Cultivar	Nodule count at flowering		TDMY at flowering		Days to flowering		Plant vigor
	Rank	no.	Rank	t/ha	Rank	no.	
Lablab (Rongai)	20	6	9	5.54	22	153	5
Stylosanthes C136	10	16	10	5.04	21	144	1
Clitorea ternatea	–	–	–	–	–	–	9
Desmanthus virgatus	–	–	–	–	–	–	9
Siratro (local)	12	14	20	1.37	8	57	5
Stylosanthes humilis	2	56	4	8.46	5	53	3
Rice bean	6	30	17	2.00	6	56	5
Centrosema 5277	18	8	16	2.11	20	135	3
Stylosanthes C184	1	62	2	13.60	17	119	1
Jack bean	5	30	12	2.95	9	63	3
Centrosema brazilianum	7	23	6	7.12	13	96	5
Moth bean	22	4	14	2.58	2	45	4
Stylosanthes copitata	9	16	5	7.20	14	104	1
Siratro (Thai)	16	9	18	1.53	7	56	6
Centrosema (local)	15	9	7	6.22	18	132	3
Lablab (Hiworth)	21	4	13	2.69	16	108	4
Stylosanthes hamata	8	22	22	0.40	4	53	3
Sword bean	3	36	11	3.38	10	63	3
Stylosanthes macrocephala	13	12	8	5.82	12	94	3
Centrosema 5586	17	9	3	9.91	19	132	3
Stylosanthes ceca	–	–	–	–	–	–	9
Lablab (local)	19	8	21	0.80	15	105	3
Cowpea TVX-1948-01F	11	16	1	14.00	3	52	2
Pigeonpea QPL-72	14	11	15	2.46	11	76	3
Adzuki bean	4	31	19	1.47	1	42	4

Table 3. Mean TDMY, nodule count, and plant vigor score at flowering, and days to flowering of entries from testing to identify suitable forage or grain legume species for acid soils (high fertility) in Cavinti, Laguna, Philippines, 1988 WS.

Cultivar	Nodule count at flowering		TDMY at flowering		Days to flowering		Plant vigor
	Rank	no.	Rank	t/ha	Rank	no.	
Lablab (Rongai)	14	14	15	3.05	24	155	4
Stylosanthes C136	9	23	14	3.63	23	145	2
Clitorea ternatea	7	25	23	0.51	2	49	5
Desmanthus virgatus	20	4	8	5.84	13	77	5
Siratro (local)	16	14	19	2.08	10	69	5
Stylosanthes humilis	2	64	4	9.46	12	72	3
Rice bean	3	45	16	2.69	6	55	4
Centrosema 5277	11	18	5	8.40	21	134	3
Stylosanthes C184	1	93	6	7.17	19	132	2
Jack bean	6	35	9	5.25	7	56	3
Centrosema brazilianum	8	25	11	4.69	15	100	3
Moth bean	23	4	21	1.20	3	50	3
Stylosanthes copitata	10	19	1	20.40	17	103	1
Siratro (Thai)	15	14	18	2.12	8	56	3
Centrosema (local)	20	7	7	6.58	20	132	3
Lablab (Hiworth)	18	11	17	2.25	16	102	3
Stylosanthes hamata	17	13	10	4.83	5	52	2
Sword bean	4	40	13	3.88	9	57	3
Stylosanthes macrocephala	22	5	24	0.27	14	95	7
Centrosema 5586	21	6	3	10.00	22	136	2
Stylosanthes ceca	–	–	–	–	–	–	9
Lablab (local)	13	15	20	1.66	18	104	6
Cowpea TVX-1948-01F	12	16	2	18.10	4	50	1
Pigeonpea QPL-72	19	10	12	4.20	11	72	3
Adzuki bean	5	39	22	0.86	1	42	3

Table 4. Top 10 among 25 entries of forage or grain legume according to TDMY and nodule count at flowering from testing to identify species for acid soils in Cavinti, Laguna, Philippines, 1988 WS.[a]

	Total dry matter at flowering				Nodule count at flowering		
Rank	Cultivar	t/ha	SES score	Days to flowering (no.)	Cultivar	no.	Days to flowering (no.)
1	*Stylosanthes copitata*	12.53	1	102	*Stylosanthes* C184	58	128
2	TVX-1948-01F	11.66	1	52	*Stylosanthes humilis*	48	62
3	*Centrosema* 5586	8.98	2	134	Adzuki bean	31	44
4	*Stylosanthes* C184	8.36	2	128	Rice bean	30	58
5	*Stylosanthes humilis*	7.85	3	62	Jack bean	28	61
6	*Centrosema* (local)	6.29	3	132	Sword bean	27	62
7	*Centrosema brazilianum*	5.94	3	98	*Stylosanthes* C136	27	146
8	*Centrosema* 5277	5.86	3	133	*Centrosema brazilianum*	17	98
9	*Stylosanthes macrocephala*	5.70	3	95	*Stylosanthes hamata*	16	54
10	*Stylosanthes* C136	4.47	3	146	TVX-1948-01F	16	52

[a] Av of high, moderate, and low fertility levels. High fertility = 45 kg P + 3 t lime/ha, medium fertility = 15 kg P + 1 t lime/ha, and low fertility = zero input.

Cropping systems program

Agronomic management in rice-based cropping systems

Multiple Cropping Department; Rice Research Institute, Thailand; and Rice Farming Systems Program

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GREEN MANURE - RICE

Multiple Cropping Department and Rice Research Institute, Thailand

Effect of seeding rate and incorporation age of *Sesbania rostrata* on performance of the following rice crop (*Multiple Cropping and Rice Research Institute, Thailand*). Field experiments to develop production systems for *Sesbania rostrata* as a green manure (GM) crop in sequence with rainfed lowland rice were initiated through the Regional Rainfed Lowland Rice Project in the 1987 wet season (WS). Research was conducted at the regional experimental farm of the Ubon Rice Research Center (URRC); at an on-farm research site in Ban Khu Khat, a rice-growing village in Ubon Province about 28 km northwest of URRC; and at the 5 regional subcenters of the Rice Research Institute in Northeast Thailand. Basic management practices for the various experiments were similar. The trials at URRC and in Khu Khat were conducted on Roi Et series soil, a member of the fine, kaolinitic, acid family of Low Humic Gley Soils (Thai national classification system), or Aeric Paleaquults. Soil pH in the top 15-cm depth ranged from 4.1 to 4.7; organic C was 0.071-0.330%; total N was 0.018-0.050%; cation exchange capacity was 0.516-0.967 meq/100 g air-dried soil (ads); and Bray P was 2.6-14.0 ppm. Soil particle size range was 2-18% clay, 21-53% silt, and 29-74% sand. These values, which are indicative of extreme soil infertility, plus the erratic rainfall are responsible for the very low rice yields in Northeast Thailand (1.3 t/ha average).

Several approaches to the problem of producing a substantial quantity of GM biomass and accumulated N to increase rice yields in the sandy loam, infertile ricelands of Northeast Thailand were considered: increasing the plant density of the GM crop, lengthening its growth duration, and stimulating its growth by applying nutrients.

Biomass production and N accumulation of *S. rostrata*, and its effect on rainfed transplanted rice (TPR) were determined with GM planted at 3 seeding rates (15, 30, and 60 kg/ha) and soil-incorporated at 2 ages (46 and 61 d after seeding [DAS]). In addition, 22 kg P/ha was broadcast in 2 treatments to evaluate the stimulatory effect of P on GM. One unweeded and two weed-free fallow plots (without GM) were also tested using a randomized complete block design (RCBD) with four replications.

The GM was cut at ground level, coarsely chopped into 8- to 12-cm lengths, and incorporated with a hoe during soil puddling; 22 kg P/ha and 42 kg K/ha were likewise incorporated in the 3 control plots. All plots were kept flooded after GM incorporation until about 10 d before rice harvest.

RD15 rice seedlings (25 d old) were transplanted at 3 seedlings/hill, with hills spaced at 25 × 25 cm. One of the weed-free fallow plots received 50 kg N/ha as urea topdressed 1/3 at 23 d after transplanting (DT) and 2/3 at panicle initiation (PI). The GM plots, which did not receive K before rice, were topdressed with 42 kg K/ha to equalize the K application. The GM and rice crops were adequately protected from insects and weeds. A chrysomelid beetle of the genus *Monolepta* fed on the sesbania foliage, but this was adequately controlled with malathion.

Growth of sesbania was distinctly slower in Northeast Thailand than on fertile alluvial rice soils in the Philippines. P application and increased growth duration (61 vs 46 DAS) did allow considerably greater sesbania plant height and biomass accumulation (Table 1). The higher total dry matter yield (TDMY) resulted in significantly higher N, P, and K accumulation in the plant tissues. P application increased sesbania tissue P levels by 5-8 times over the unfertilized sesbania. Dry weed biomass in the unweeded control treatment was 0.87 t/ha, producing 9 kg N/ha. The minimum N contribution of the sesbania was 18 kg N/ha, contained in a biomass of 0.46 t/ha.

When GM was incorporated early (46 DAS), N accumulation was low (<25 kg/ha) unless P was applied. But when incorporation was delayed to 61 DAS, N accumulation ranged from 76 to 116 kg/ha. The low seeding rate (15 kg/ha) produced substantial N accumulation as long as incorporation was delayed.

The increase in rice grain yield due to GM incorporation ranged from 42 to 158% over the weed-free fallow treatment without N. Grain yield increase due to inorganic N application was 103%

Table 1. Plant height; total dry matter yield (TDMY); and N, P, and K accumulation in *Sesbania rostrata* as influenced by age, seeding rate, and applied P. Ubon Rice Research Center, Thailand, 1987 wet season (WS).

Treatment			Plant density (no. X 1000/ha)	Plant height (cm)	TDMY (t/ha)	Accumulation (kg/ha)		
S. rostrata		Fertilizer[b] (kg/ha)						
Age[a] (DAS)	Seeding rate (kg/ha)					N	P	K
46	15	0	533	33	0.46	18	0.62	7
46	30	0	920	38	0.69	16	0.94	7
46	30	22 P	850	76	1.72	66	4.53	23
46	60	0	1763	32	0.85	24	1.13	10
61	15	0	637	83	2.77	76	3.02	20
61	30	0	1237	86	4.02	86	3.90	20
61	30	22 P	1220	126	5.08	116	8.70	38
61	60	0	2226	63	3.38	100	3.00	20
Weeds (from unweeded fallow control)			–	–	0.87	9	1.65	14
Age at incorporation								
46 DAS			1017	44	0.93	31	1.80	12
61 DAS			1330	89	3.81	95	4.65	24
Seeding rate								
15 kg			585	58	1.62	47	1.82	13
30 kg			1057	81	2.88	71	4.52	22
60 kg			1995	47	2.11	62	2.06	15
SE			96	8	0.52	13	0.76	4
CV (%)			12	17	34	32	35	32

[a]DAS = days after seeding. [b]Applied to *S. rostrata*.

Table 2. Grain yield; TDMY; and N, P, and K accumulation in RD15 rice as influenced by applied fertilizers and *S. rostrata* age and seeding rate. Ubon Rice Research Center, Thailand, 1987 and 1988 WS.

Treatment				Grain yield (t/ha)	TDMY (t/ha)	1987 accumulation (kg/ha)			1987 N responses		
No.	*S. rostrata*		Fertilizer[a] (kg/ha)			N	P	K	Efficiency (kg grain/ kg N applied)	Utilization (kg grain/ kg N uptake)	Recovery (%)
	Age (DAS)	Seeding rate (kg/ha)									
T1	46	15	0	1.6	5.18	31	6.8	83.8	29.0	56.6	50.0
T2	46	30	0	1.5	3.02	20	4.4	34.7	29.5	23.0	12.5
T3	46	30	22 P	2.5	5.98	38	8.9	67.3	21.1	86.9	24.0
T4	46	60	0	1.8	4.03	27	5.6	49.2	32.2	15.2	20.8
T5	61	15	0	2.4	5.77	39	6.2	74.8	17.2	77.0	22.4
T6	61	30	0	2.2	5.50	45	6.7	54.8	19.9	50.0	26.7
T7	61	30	22 P	2.8	5.72	47	10.1	67.2	9.9	68.4	21.6
T8	61	60	0	2.6	5.88	48	8.3	66.2	15.3	58.5	26.0
T9: fallow, weed-free, 0-22-42 NPK				1.1	3.70	22	4.2	53.9	–	–	–
T10: fallow, unweeded, 0-22-42 NPK				1.4	2.99	21	5.0	39.5	27.1	-30.0	-11.1
T11: fallow, weed-free, 50-22-42 NPK				2.2	4.12	34	7.1	45.0	22.2	92.5	–
SE				0.2	0.89	4.4	0.9	18.3			

[a]Applied to *S. rostrata*. K at 42 kg/ha was also applied to rice in T1-T8.

(Table 2). P application to sesbania as well as delaying incorporation of the crop by 15 d (from 46 to 61 DAS) significantly increased rice grain yield and N and P accumulation. This suggests that P applied to GM may be more effective than the same amount applied to rice. The rice yield response to unfertilized, incorporated weeds was not significant.

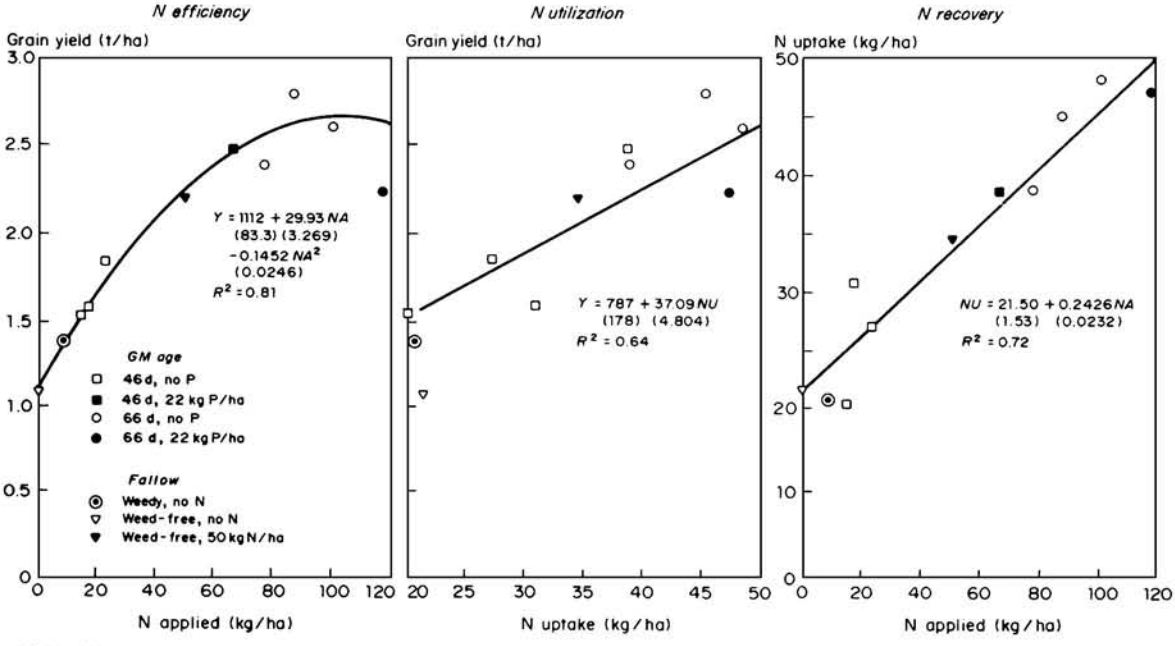
Grain yield increased curvilinearly with GM or applied inorganic N (Fig. 1). Grain production was about 30 kg/kg N applied. Grain yield was estimated to be optimum at 2.7 t/ha when N applied was 103 kg/ha. N utilization and N recovery exhibited linear responses. Apparent N recovery was 24.3%, with the soil supplying 21.5 kg N/ha.

Increasing the sesbania seeding rate did not significantly affect rice grain yield or TDMY, suggesting that 15 kg seed/ha is adequate at the site. Grain yields were higher with 15 kg seed/ha if incorporation of GM was delayed to 61 DAS than with 30 or 60 kg seed/ha and incorporation at 46 DAS. *S. rostrata* seed is a scarce commodity (at least at present). Therefore, seeding rates should be minimized where possible. Optimum rates will depend on the age at expected incorporation. It will be useful to test seeding rates lower than 15 kg/ha in further work in Northeast Thailand.

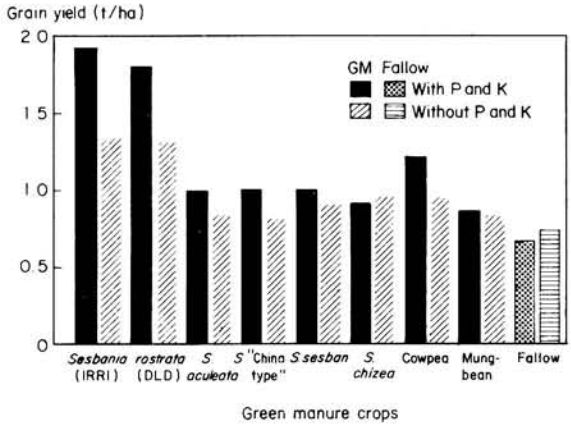
Evaluation of eight green manure cultivars (*Multiple Cropping*). The GM potentials of five *Sesbania* species (*S. aculeata, S. sesban, S. chizea, Sesbania* "china type," and two accessions of *S. rostrata* from the Department of Land Development, Thailand, and from IRRI) were compared at URRC. Cowpea and mungbean were included in the test as alternative dual-purpose legumes for prerice grain and GM production. The crops were evaluated under 2 fertilizer levels (with and without 22 kg P/ha and 42 kg K/ha) as main plots. The GM accessions were arrayed as subplot treatments, with a fallow control plot. Subplots were 5 × 5 m with 4 replications.

The crops were drilled (30 kg seed/ha) in rows 40 cm apart. The P and K fertilizers were applied in bands about 8 cm from the rows at seeding. Soil waterlogging due to frequent rains and to poor surface and internal drainage affected the emergence and growth of cowpea and mungbean, which turned yellow and wilted; the mungbean eventually died. With the exception of the two *S. rostrata* accessions, which were only slightly affected, the other species turned pale green and exhibited depressed growth. Stem nodulation on *S. rostrata* appeared normal, was sparse on *S. aculeata*, and was completely absent in the other species.

At 61 DAS, the GM crops were cut at ground level, chopped to pieces, and incorporated in the soil. All plots were then kept flooded. Thirty-



1. N efficiency, utilization, and recovery from *S. rostrata* green manure (GM) grown at 2 seeding rates and P levels and incorporated at 2 ages. URRC, Thailand, 1987 wet season (WS).



2. Rice yields from GM grown with and without P (22 kg/ha) and K (42 kg/ha), URRC, Thailand, 1987 WS. DLD = Department of Land Development, Thailand.

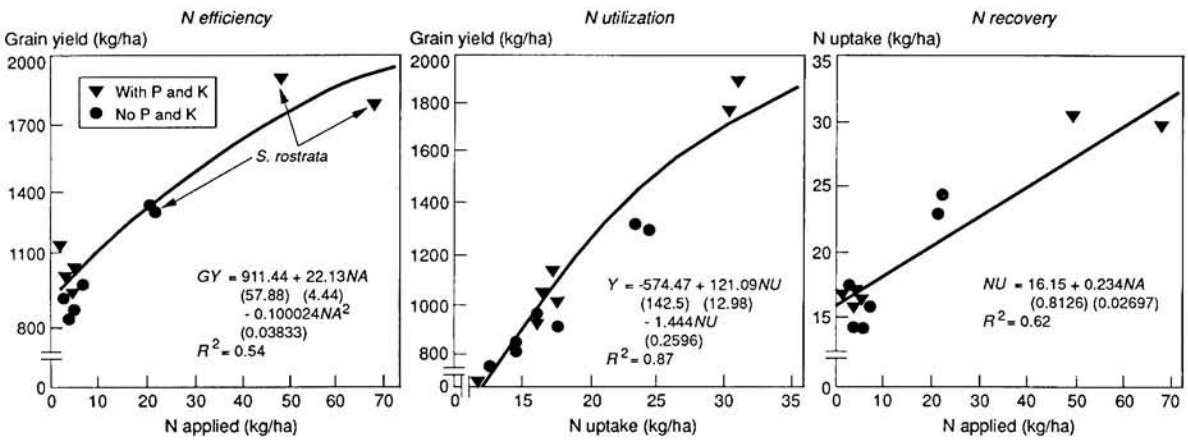
nine-day-old KDML 105 rice seedlings were transplanted in 25- × 25-cm hills at 3 seedlings/hill. No further inorganic fertilizer was applied to the rice. Weeds and insect pests were adequately controlled. A 12-m^2 sampling area was used for grain and TDMY estimates at maturity.

Plant height, TDMY, and N accumulation at the time of incorporation were highest in *S. rostrata*, regardless of fertilizer management. Plant height, N content, N yield, and TDMY of *S. rostrata* treatments were significantly greater than those of the *S. aculeata* treatments. Application of P and K increased plant height, N yield, and TDMY only in *S. rostrata* treatments. Susceptibility to excessive soil moisture suppressed the response of the other species to the added P and K. Mean TDMY across GM species was 0.91 t/ha in the fertilized treatment and 0.59 t/ha in the unfertilized treatment. Mean N accumulation values were 21 kg/ha in the fertilized treatment and 10 kg/ha in the unfertilized treatment. N accumulation in the fertilized *S. rostrata* was 2.4 times that in the unfertilized.

Highest rice grain yield, TDMY, plant height, and N accumulation were obtained with fertilized *S. rostrata*, followed by unfertilized *S. rostrata* (Fig. 2).

N effects and responses by regression analysis are shown in Figure 3. Computed apparent N recovery was 23.4%, with 16.2 kg N/ha derived from the soil. Both N efficiency and N utilization showed quadratic N responses. The grain-to-N ratio was about 22:1. The low N efficiency response was probably associated with the flooded soil conditions, which markedly reduced GM biomass production and N accumulation even in the P- and K-fertilized treatments.

S. rostrata showed distinct superiority over the other *Sesbania* species evaluated in the waterlogged conditions of the experiment. There were no significant differences in the overall performance of the two *S. rostrata* accessions. In this situation, the grain legume crops were unadapted. Further comparisons over a greater range of soil and hydrological conditions are needed for broader inferences to be made. This initial



3. Efficiency, utilization, and recovery of N from GM grown with and without P (22 kg/ha) and K (42 kg/ha). URRC, Thailand, 1987 WS.

test suggests that *S. rostrata* has strong superiority when excess water is a usual condition before rice.

Methods of green manure establishment (*Multiple Cropping*). The use of GM to enhance rice yield is feasible only if GM establishment does not strain the monetary and labor resources of the farmer. An experiment was set up in a farmer's field in Ban Khu Khat, Ubon, Thailand, to develop a practical, low-input management system for a prerice GM crop and to determine the response of the subsequent rice crop to GM establishment method. Bunded plots (4 × 4 m) were laid out in RCBD with 4 replications. *S. rostrata* seeds were broadcast at 15 and 30 kg/ha in plowed and unplowed plots, or drilled in rows. The broadcast seeds were not harrowed in. In the zero tillage treatments where the seeds were drilled, shallow furrows were made every 40 cm. The seeds were covered after hand drilling. Two unweeded, fallow control plots were maintained.

Initial growth was slow because of drought stress. At 31 DAS, 22 kg P/ha and 42 kg K/ha were broadcast to stimulate sesbania growth. The sesbania was harvested, chopped, and incorporated on 20 August (63 DAS), when enough rainwater had accumulated and farmers in adjacent fields were transplanting their rice.

Thirty-six-day-old seedlings of KDML 105 were transplanted the next day at 3 seedlings/hill (25- × 25-cm spacing). In 1 of the control plots, 50 kg N/ha as urea was split-applied (1/3 at 22 DT and 2/3 at PI); none was applied in the other. Grain yield and TDMY were estimated from a 6-m^2 sample area in each plot at maturity.

Sesbania plant population at 18 DAS, and plant height and TDMY at 63 DAS were significantly affected by establishment method. Drilling the seeds in furrows was most successful in establishing a high plant population. The germinating seedlings in the broadcast treatments were subjected to more severe drought stress because they were exposed on the soil surface. At incorporation, however, TDMY and N accumulation were highest in the plowed-and-broadcast treatments. This was apparently the result of better rooting conditions and higher mineralized nutrient availability in the tilled soil. Average N accumulated by sesbania was significantly higher when 30 kg seed/ha was used.

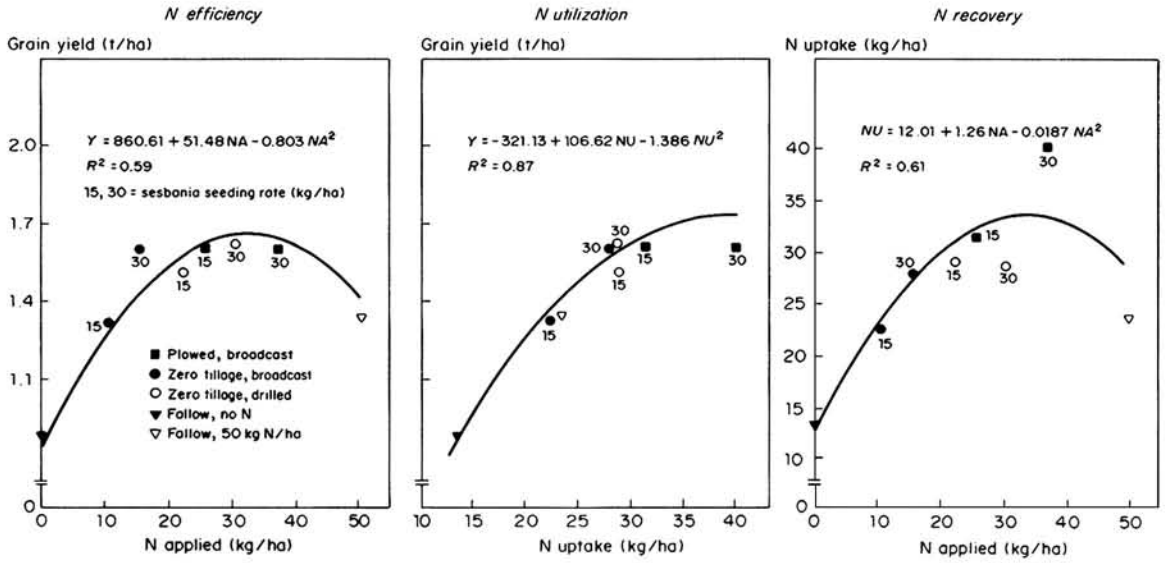
The rice grain yields were similar (av 1.5 t/ha) regardless of sesbania seeding rate or method of establishment, suggesting that N accumulation per sesbania plant tended to be equalized by greater biomass per plant in treatments with lower plant density. GM gave significantly higher grain yields than the fallow control treatment with no N. Yields with GM and inorganic N were similar.

N efficiency and recovery with GM were higher in this experiment than in that with inorganic N application (Fig. 4). Grain yields were optimum at about 32 kg/ha of applied N and an N uptake of 38 kg/ha.

The data suggest that establishment of sesbania with zero tillage is a feasible alternative to conventional land preparation. Rainfed farmers in Northeast Thailand normally plow twice before planting rice: once after the early rains wet the soil, and again immediately before transplanting. A viable management system for a sesbania - rice sequence should also require no more than two plowings. If the sesbania can be established by zero tillage, the two tillage operations can be reserved for 1) incorporating the GM, and 2) final preparation for rice transplanting 2-3 wk afterward.

Fertilization strategy for green manure - rice cropping systems (*Multiple Cropping*). Nutrient management in a GM - TPR cropping system should consider whether inorganic fertilizer and farmyard manure (FYM) are more effectively applied to the GM to promote its biomass production, or directly to the subsequent rice crop. Given the extremely infertile soils in most of Northeast Thailand, it was hypothesized that applying FYM, which farmers traditionally practice in the region, or P fertilizer to prerice sesbania would significantly improve its biomass and N accumulation, thereby enhancing nutrient availability to the rice crop more than if these materials were applied directly to the rice.

Four nutrient management levels were applied as main plot treatments to prerice *S. rostrata*: 1) no fertilizer, 2) 13 kg P/ha, 3) FYM (3 t dry weight/ha), and 4) weed-free fallow control (no sesbania). Subplot treatments imposed on



4. Efficiency, utilization, and recovery of N from sesbania GM established under different methods. Khu Khat, Ubon Province, Thailand, 1987 WS.

the succeeding rice crop were 1) no inorganic fertilizer, 2) 50 kg N/ha, 3) 50-23-25 kg NPK/ha, and 4) 3 t FYM/ha. The combination of 4 nutrient management levels on the sesbania and 4 on the rice resulted in 16 treatments.

The experiment was conducted at six rice research stations in the northeast – Ubon, Khon Kaen, Chumpae, Surin, Pimai, and Sakhon Nakhon – as well as in a farmer's field in Ban Khu Khat, Ubon Province. Conducting the trial at seven locations permitted evaluation of the rice responses to the GM system across a range of soil and climatic environments. At each site the experiment was laid out using a split-plot design with three replications.

S. rostrata was seeded (30 kg/ha) after incorporating the P and FYM in the respective plots. Growth durations of the GM at incorporation ranged from 48 to 70 d. GM was incorporated at each site when enough rainwater had accumulated for puddling. The GM was cut into small pieces, scattered uniformly in the plots, and worked into the soil during puddling after applying the inorganic fertilizers and FYM for the rice.

KDML 105 rice was transplanted in 25- × 25-cm hills at 3 seedlings/hill. Weeds and insects were adequately controlled. Sampling areas for grain yield ranged from 3 to 9 m^2.

Rice grain yields without GM or inorganic fertilizer ranged from 0.5 t/ha in Ban Khu Khat, which is characterized by fine, sandy loam soil, to 2.8 t/ha in Surin, where fine clayey soils dominate (Table 3). Severe neck blast (Bl) infection in treatments with inorganic N, especially in combination with GM, severely depressed yields in Khu Kat. In Khon Kaen, 50-100% lodging occurred in the inorganic-N treatments. Severe drought stress reduced all yields in Chumpae and Sakhon Nakhon. TDMYs were likewise affected (Table 4).

Except in Chumpae, GM had a significant positive effect on rice grain yield. Sesbania - rice without fertilization increased rice yield by 0.9 t/ha (54%) above fallow - rice (2.5 t/ha vs 1.6 t/ha). The yield difference between the 2 cropping patterns across all nutrient levels was 0.6 t/ha (29%). Main plot treatments 2 and 3 tested the effect of supplying sesbania with either P or FYM as a supplement to the amounts to be applied on the subsequent rice crop. The fertilized sesbania generally appeared more vigorous and exhibited better growth than the comparable treatments

Table 3. Soil nutrients applied to *S. rostrata* and rice (KDML 105) and their effects on rice grain yield at 7 locations in Northeast Thailand, 1987 WS.

Treatment	Nutrients[a] (kg NPK/ha) applied to		Grain yield[b] (t/ha)							
	S. rostrata	Rice	URRC	Khu Khat	Chumpae	Khon Kaen	Sakhon Nakhon	Pimai	Surin	Mean
1	0-0-0	0-0-0	1.9	0.7	1.6	3.0	1.3	3.3	4.3	2.5
2		50-0-0	2.7	0.9	2.6	1.9[f]	1.2	4.3	4.4	2.8
3		50-13-25[c]	2.6	1.3	2.0	2.3[f]	1.5	4.4	4.3	2.8
4		FYM	2.1	1.0	1.4	3.8	1.0	3.3	4.1	2.6
5	0-13-0[d]	0-0-0	2.3	0.4[e]	1.5	3.6	1.4	3.5	4.2	2.7
6		50-0-0	2.8	1.3	2.4	2.4[f]	1.4	4.6	3.7	2.9
7		50-13-25[c]	2.9	1.3	2.2	2.0[f]	1.8	4.9	4.1	2.9
8		FYM	2.3	0.9	1.7	3.7	1.0	3.5	4.3	2.7
9	FYM	0-0-0	2.6	1.2	1.2	4.1	1.6	3.5	4.4	2.8
10		50-0-0	2.5	1.1	2.4	1.9[f]	1.6	4.6	3.8	2.7
11		50-13-25[c]	2.6	1.0	2.4	2.0[f]	2.2	4.8	4.2	2.9
12		FYM	3.1	1.2	1.5	3.8	1.3	3.8	4.3	2.9
13	Fallow	0-0-0	1.1	0.5	1.3	1.9	1.4	2.0	2.8	1.6
14		50-0-0	1.8	0.7	2.3	2.2	1.6	4.0	3.0	2.3
15		50-13-25[c]	2.5	1.1	2.1	2.2	1.7	4.1	3.3	2.5
16		FYM	1.1	0.8	1.7	2.2	1.2	2.4	2.6	1.8
Mean			2.3	1.0	1.9	2.7	1.4	3.8	3.9	

[a]FYM = farmyard manure at 3 t dry weight/ha. [b]Means of 3 replications at each site. [c]50-22-42 at URRC and Khu Khat. [d]0-13-25 at URRC and Khu Khat. [e]With severe neck blast incidence. [f]Severe lodging in plots with inorganic N.

Table 4. Soil nutrients applied to *S. rostrata* and rice (KDML 105) and their effects on rice TDMY at 7 locations in Northeast Thailand, 1987 WS.

Treatment	Nutrients[a] (kg NPK/ha) applied to		TDMY[b] (t/ha)							
	S. rostrata	Rice	URRC	Khu Khat	Chumpae	Khon Kaen	Sakhon Nakhon	Pimai	Surin	Mean
1	0-0-0	0-0-0	5.0	1.8	4.4	8.8	3.5	7.1	14.4	6.4
2		50-0-0	7.0	2.3	7.3	6.9	3.5	12.4	16.8	8.0
3		50-13-25[c]	7.3	3.5	7.3	9.0	4.1	11.3	17.2	8.5
4		FYM	5.2	2.2	4.3	9.1	3.5	7.2	16.1	6.8
5	0-13-0[d]	0-0-0	7.3	2.0	4.5	8.3	3.1	6.4	13.4	6.4
6		50-0-0	7.3	3.3	7.4	8.8	3.6	11.2	11.8	7.6
7		50-13-25[c]	8.1	4.0	6.6	7.8	3.9	11.8	13.0	7.9
8		FYM	6.1	2.4	4.1	10.3	3.8	7.2	17.0	7.3
9	FYM	0-0-0	8.1	3.0	3.3	9.1	3.6	6.9	18.5	7.5
10		50-0-0	9.6	4.0	6.7	6.7	4.6	12.0	17.2	8.7
11		50-13-25[c]	8.9	4.2	6.4	6.8	5.4	11.4	18.4	8.8
12		FYM	8.6	3.6	4.0	9.0	4.0	8.0	14.9	7.4
13	Fallow	0-0-0	2.9	1.2	3.3	3.9	2.5	3.4	6.8	3.4
14		50-0-0	4.1	1.9	7.0	7.1	2.9	7.5	8.4	5.6
15		50-13-25[c]	5.7	2.6	6.5	8.2	3.2	9.1	9.3	6.4
16		FYM	2.8	2.3	3.8	4.1	3.0	4.5	5.6	3.7
Mean			6.5	2.8	5.4	7.7	3.6	8.6	13.7	

[a]FYM at 3 t dry weight/ha. [b]Means of 3 replications at each site. [c]50-22-42 at URRC and Khu Khat. [d]0-13-25 at URRC and Khu Khat.

without added nutrients. Single degree of freedom contrasts among the main plot treatments (averaged over all subplots) showed no significant benefits of fertilization on sesbania except in Surin. The yield increments among main plots 2 and 3 compared with main plot 1 were < 0.2 t/ha.

Rainfed farmers typically apply FYM but little or no inorganic N. Comparing treatments 9 and 4 indicates that FYM was slightly but not significantly more stimulatory to rice yield when applied to the sesbania (2.8 t/ha vs 2.6 t/ha). There was an advantage at five of the seven sites; the effect was not observed at the two sites with severe drought.

Sesbania (treatment 1) was observed to be a superior substitute for FYM on rice (treatment 16) when no other fertilization was supplied. Yields with sesbania were higher at five of seven sites. FYM applied directly to the rice crop showed no significant effect on grain yield when compared with the fallow unfertilized treatment, except in Chumpae.

The grain yield increase when P and K were applied to the rice was significant at five of six sites. The effect of 50 kg inorganic N/ha was significant at 2 of 6 sites.

Optimum interval between green manure incorporation and rice transplanting (*Multiple Cropping*). A very long interval between GM incorporation and rice transplanting may reduce nutrient availability to the rice crop from the decomposing GM. Too short an interval may lead to toxic effects on the rice seedlings, a distinct hazard in light-textured soils with low buffering capacity.

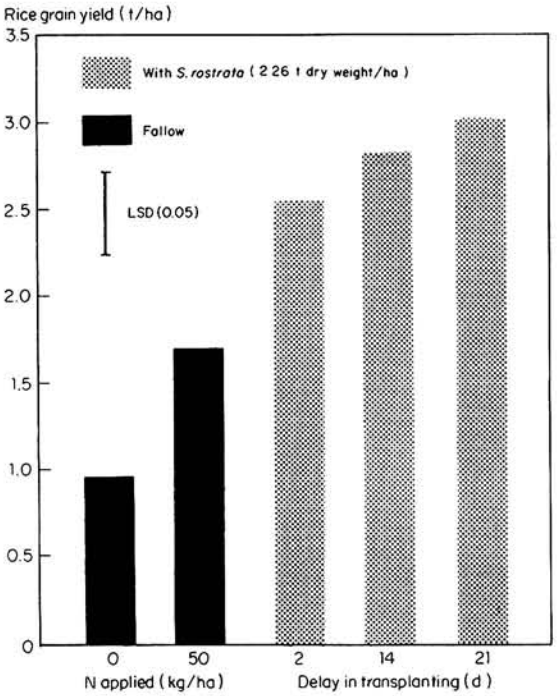
The effect of the duration of the interval between *S. rostrata* incorporation and rice transplanting on the performance of the rice crop was studied in a field experiment with 5 treatments that included 3 intervals (2, 14, and 21 d) and 2 control treatments (unweeded fallow, with and without inorganic N applied to the rice). Bunded plots (5 × 5 m) were laid out in RCBD with 3 replications.

Twenty-two kg P/ha and 42 kg K/ha were broadcast and soil-incorporated in the GM plots. *S. rostrata* was broadcast seeded (30 kg/ha) on 3, 11, and 22 June and soil-incorporated in situ (equivalent to 2.26 t dry weight/ha in all GM plots) on 23 July, 31 July, and 11 August, respectively. This schedule enabled the rice seedlings to be transplanted on the same day, with the GM at the same age (50 d), while varying the time between GM incorporation and rice transplanting. The amount of incorporated biomass was equalized across treatments to reduce the effect of variations in *S. rostrata* growth. The incident weeds, together with 22 kg P/ha and 42 kg K/ha, were also incorporated on 11 August in the 2 control plots. The plots were kept flooded after incorporation.

Thirty-six-day-old seedlings of rice cultivar KDML 105 were transplanted on 13 August at a spacing of 25 × 25 cm, with 3 seedlings/hill. Dead and dying hills were replanted at 5 DAS after scoring for their incidence. One control plot received 50 kg N/ha as urea (1/3 at 20 DT and 2/3 at PI); the other received no N. Weeds and insect pests were adequately controlled. Samples for rice grain yield and TDMY were harvested from a 12-m^2 area.

GM (2.26 t dry matter [DM]/ha) provided 76 kg N/ha to the rice and significantly increased grain yield (Fig. 5), TDMY, plant height, productive tillers, and 1000-grain weight (Table 5). The grain increase due to the application of 50 kg inorganic N/ha was also significant. However, the increase over the zero N control treatment was only 0.76 t/ha, whereas the GM benefit averaged 1.82 t/ha. Sesbania incorporated 21 d before rice transplanting tripled the unfertilized grain yield. There was a marked tendency for rice growth subsequent to transplanting to be depressed in the 2-d interval treatment, with a significant negative effect on seedling vigor and seedling survival (Table 5). However, grain yield from this treatment after replanting the missing hills was still 159% higher than that from the control treatment. Average straw weights were more than double those observed with inorganic N application, and four times those without N. The increased residue, if left in the field, may elevate the soil organic matter level, or increase the dry season (DS) fodder available to ruminant livestock.

Rainfed rice farmers normally plow twice and transplant immediately after the second plow-



5. Effect of inorganic N application and interval between GM incorporation and rice (KDML 105) transplanting. URRC, Thailand, 1987 WS.

ing. These data suggest that immediate transplanting after GM incorporation is possible, but a delay between the two operations is optimal. Such a delay would allow sufficient time for GM decomposition. The final harrowing and rice transplanting operations are more time-consuming and less convenient in soil with freshly incorporated GM. A delay as long as 21 d does not appear to have negative effects on total nutrient availability.

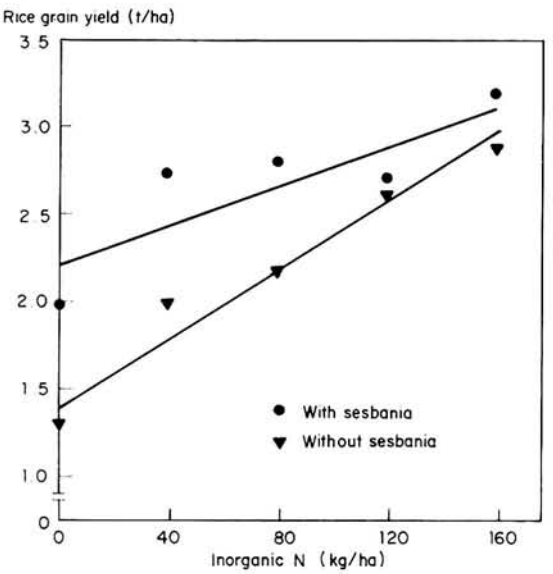
Rice response to inorganic nitrogen in the presence or absence of green manure (*Multiple Cropping*). The N substitution effect of *S. rostrata* was studied in a farmer's field in Ban Khu Khat, Ubon, Thailand, by determining the yield response of rainfed rice to applied inorganic N with and without a prior GM crop. The trial was laid out in a split-plot design with 2 main plot treatments (with and without sesbania) and five subplot treatments (0, 40, 80, 120, and 160 kg N/ha as urea) imposed on the subsequent rice crop. The trial was replicated 4 times with bunded plots of 4 × 4 m. Sesbania was broadcast at 30 kg seed/ha. Because of sparse plant stand due to low rainfall after initial seedling emergence, sesbania was replanted by drilling the seeds in 40-cm rows and later topdressing with 22 kg P/ha and 42 kg K/ha to promote biomass production. The GM was harvested at 51 DAS when the plots became flooded by rains. Because the sesbania crop stand and growth were erratic, the biomass harvested from each plot was pooled by replication and then applied in equal amounts (an average of 0.58 t dry biomass/ha) to all GM plots within a replication.

Rice (RD15) was transplanted in all plots at 25- × 25-cm spacing, 3 seedlings/hill. The desig-

Table 5. Effect of interval between *S. rostrata* incorporation and rice (KDML 105) transplanting on some rice characters.[a] Ubon Rice Research Center, Ubon, Thailand, 1987 WS.

Interval (d)	*S. rostrata* TDMY (t/ha) at 50 DAS	N applied to rice (kg/ha)	Seedling mortality[b] (5 DT)	Seedling vigor rating[c] at		Plant height at maturity (cm)	TDMY (t/ha)		Straw weight (t/ha)	Productive tillers (no./hill)	1000-grain weight (g)
				18 DT	29 DT		55 DT	Maturity			
2	3.93	76[d]	3.55 (11.0)	5.7	4.3	128	1.95	6.97	4.44	9.7	26.9
14	12.56	76	1.89 (6.2)	3.7	2.3	120	2.67	7.67	4.82	9.3	26.6
21	14.45	76	0.98 (0.5)	1.0	1.0	129	2.30	8.36	5.34	9.7	26.9
Fallow	–	0	1.30 (0.6)	7.0	9.0	91	0.46	2.22	1.24	4.7	23.9
Fallow	–	50[e]	0.88 (0.3)	7.7	7.0	97	0.62	3.89	2.15	8.3	24.9
CV (%)			23	22	15	8	25	16	20	11	2
LSD (0.05)			0.76	2.1	1.4	16	1.38	1.73	1.36	1.8	1.09
LSD (0.01)			1.1	3.0	2.0	25	2.00	2.51	1.98	2.4	1.58

[a]Means of 3 replications. [b]Transformed data. Figures in parentheses are the actual percentages. [c]1-9 scale where 1 = extra vigorous, 9 = plants very weak and small. [d]Supplied by *S. rostrata*. Amount incorporated was equalized across treatments. [e]As urea.



6. Grain yield as influenced by sesbania GM and applied inorganic N. Ban Khu Khat, Ubon Province, Thailand, 1987 WS.

nated amount of inorganic N (as urea) was broadcast, 1/3 at 22 DT and 2/3 at 3 d before PI. Weeds and insects were adequately controlled. Plant samples, grain yield, and TDMY were obtained from the central 6 m^2 of each plot.

Rice grain yields in both the GM and fallow treatments increased linearly as applied inorganic N levels were increased (Fig. 6). The N replacement effect of sesbania was equivalent to an additional 80 kg N/ha when the inorganic N level was less than or equal to 80 kg N/ha. That is, yields from inorganic N applied at 80, 120, and 160 kg/ha were equivalent to yields obtained from sesbania plus 0, 40, and 80 kg inorganic N/ha, respectively. In the absence of inorganic N, the green manured rice yield was 53% higher than the fallow treatment yield.

TDMY, plant height, number of productive tillers, and N, P, and K uptake were significantly greater in the GM treatments (Table 6). These characters generally increased with increasing applied N, regardless of the presence or absence of GM.

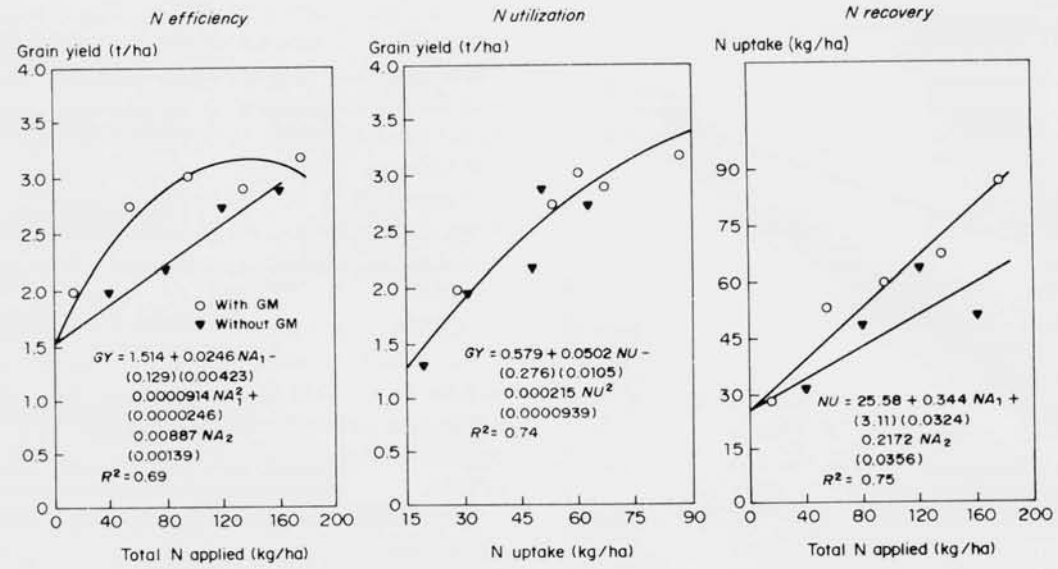
Regression analysis showed a higher N efficiency with GM (Fig. 7). Grain yield with GM increased curvilinearly and was estimated to be optimum at 135 kg N/ha. Higher N efficiency was associated with higher N recovery. N utilization with GM and that without were similar.

Comparative efficiency of sesbania green leaf manure and inorganic nitrogen on transplanted rice and residual nitrogen responses by a second rice crop (*Multiple Cropping*). A field experiment compared the N efficiency of inorganic and GM N, and combinations of both, on TPR. *S. rostrata* grown in an adjacent field for 45 d was used as

Table 6. Effect of GM and applied inorganic N on some rice (RD15) plant characters. Ban Khu Khat, Ubon Province, Thailand, 1987 WS.

N applied to rice (kg/ha)			TDMY (t/ha) at maturity		Plant height (cm)		Total tillers (no./hill)		Productive tillers (no./hill)		Total uptake by rice (kg/ha)					
											N		P		K	
Inorganic	GM	Total	With GM	No GM	With GM	No GM	With GM	No GM	With GM	No GM	With GM	No GM	With GM	No GM	With GM	No GM
0	15	15	4.27	2.39	102	92	8	6	8	6	28	19	6	3	46	24
40	15	55	5.84	3.94	120	106	11	8	10	8	53	31	10	6	106	41
80	15	95	6.98	5.67	114	105	10	10	10	9	60	48	9	8	104	78
120	15	133	6.91	5.87	111	106	10	9	10	8	66	63	11	8	99	62
160	15	175	8.03	5.45	111	112	10	10	10	10	86	50	13	10	111	51
Mean			6.61	4.65	111	104	9.6	8.9	9.4	8.2	59	42	10	7	93	51
SEa[a]			0.59		2.10		0.17		0.38		4.28		0.69		9.83	
SEb[a]			0.63		5.65		0.59		0.65		4.70		0.75		10.95	
CV (%)																
(a)			33		6		6		14		27		26		43	
(b)			22		7		9		10		19		18		30	

[a]SEa = standard error for treatment comparisons among N levels within a GM treatment. SEb = standard error for treatment comparisons among the same or different N levels across GM treatments.



7. Efficiency, utilization, and recovery of N from sesbania GM with and without inorganic N applied, Ban Khu Khat, Ubon Province, Thailand, 1987 WS.

green leaf manure (GLM). N applied was computed as the product of DM and percent N content of the GLM biomass. GLM N at 0, 40, 80, and 120 kg/ha was applied to the rice crop. N at the same rates was applied as urea. The other N source was a combination of urea and GLM at equal amounts of N. The three N sources were randomized as main plots over the four replications, and the N rates as subplots were randomly allocated to the main plots in a split-plot design. All N, regardless of source, was applied at transplanting to eliminate the confounding effect of different application times. Soil properties of the experimental field are shown in Table 7.

Grain yield, TDMY, and N uptake as influenced by N source and rate are summarized in Table 8. Grain yield responded significantly to increasing applied N. Grain yield increases of 1.2, 1.8, and 2.0 t/ha over the control treatment, resulted from application of 40, 80, and 120 kg N/ha, respectively, regardless of N source. GLM, urea, and the combination of both were not significantly different across N rate. However, urea and GLM + urea outperformed GLM alone in terms of TDMY and N uptake.

Regression models were used to examine N efficiency, utilization, and recovery responses (Fig. 8). The yield response effects of N source were not significant and therefore were not partitioned as separate responses in the regression analysis. Similar grain yield responses to applied N and N uptake from different sources were evident. This suggests similar efficiency when inorganic N is replaced with equivalent GM N. The optimum yield was estimated to be 4.4 t/ha when applied N was 112 kg/ha, regardless of N source. Apparent N recovery varied with respect to N source (Fig. 8). GLM, urea, and GLM + urea resulted in about 19, 32, and 58% N recovery, with 36 kg N/ha coming from the soil.

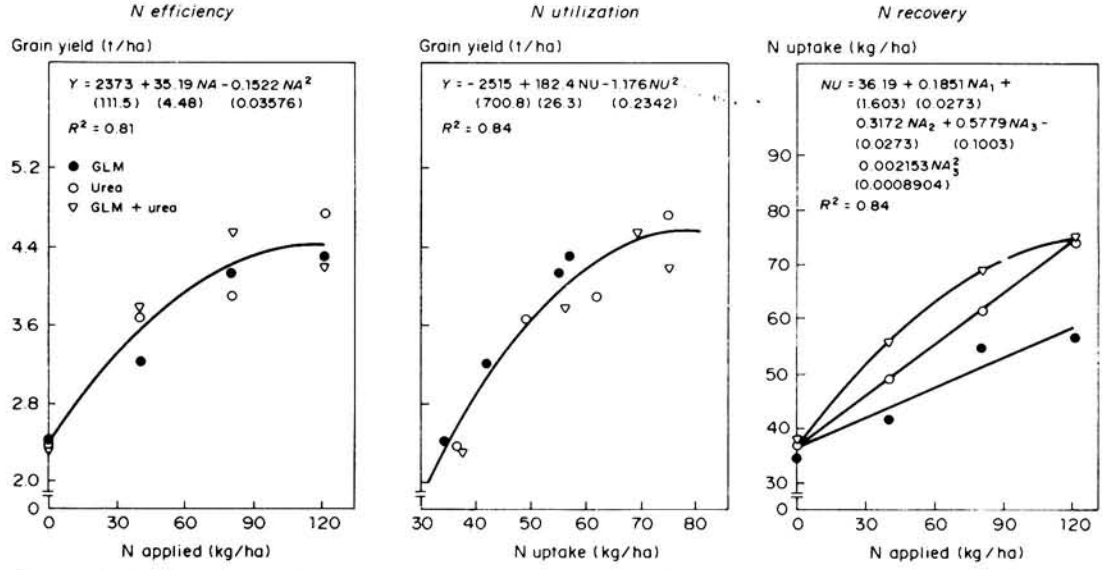
The response of a second rice crop to unrecovered N is presented in Table 9. Unrecovered N was computed as the difference between incorporated GLM and/or inorganic N and apparent N recovery (N yield of GLM and/or inor-

Table 7. Soil properties of the experimental site. IRRI, 1988 WS.

Attribute	Concentration
pH	6.0
Total N (%)	0.12
Organic C (%)	0.95
Available Olsen P (ppm air-dried soil)	25.0
Available K (meq/100 g air-dried soil)	1.21
CEC (meq/100 g air-dried soil)	34.2

Table 8. Grain yield, TDMY, and N uptake of transplanted rice as influenced by source and rate of applied N. IRRI, 1989 WS.

N source	Grain yield (t/ha)					TDMY (t/ha)					N uptake (kg/ha)				
	0 N	40 N	80 N	120 N	Mean	0 N	40 N	80 N	120 N	Mean	0 N	40 N	80 N	120 N	Mean
Green leaf manure	2.4	3.2	4.1	4.3	3.5	6.21	7.18	9.53	8.93	7.96	34	42	55	57	47
Urea	2.4	3.7	3.9	4.7	3.7	6.80	8.64	11.90	13.51	10.21	36	49	61	74	55
Green leaf manure + urea	2.3	3.8	4.6	4.2	3.7	7.86	10.27	11.13	12.12	10.35	37	55	68	74	59
Mean	2.4	3.6	4.2	4.4	3.6	6.96	8.70	10.85	11.52	9.51	36	49	61	68	54
SE_1			0.25					1.23					4.53		
SE_2			0.27					1.15					4.49		



8. Comparative N efficiency, N utilization, and apparent N recovery of transplanted rice from GLM and/or urea application. IRRI, 1988 WS.

ganic treatment minus the N yield of unfertilized treatments of the main crop). Additional N was applied in this experiment, which followed the previous WS trial.

The average yield response to unrecovered N from fertilized treatments was a nonsignificant 0.4 t/ha over the control. Likewise grain yield, TDMY, N uptake, or unrecovered N showed no significant variation due to N source. However, the corresponding N uptakes of 34, 36, and 33 kg/ha from 40, 80, and 120 kg N/ha application, regardless of N source, were significantly higher than that of the control plot at 28 kg N/ha.

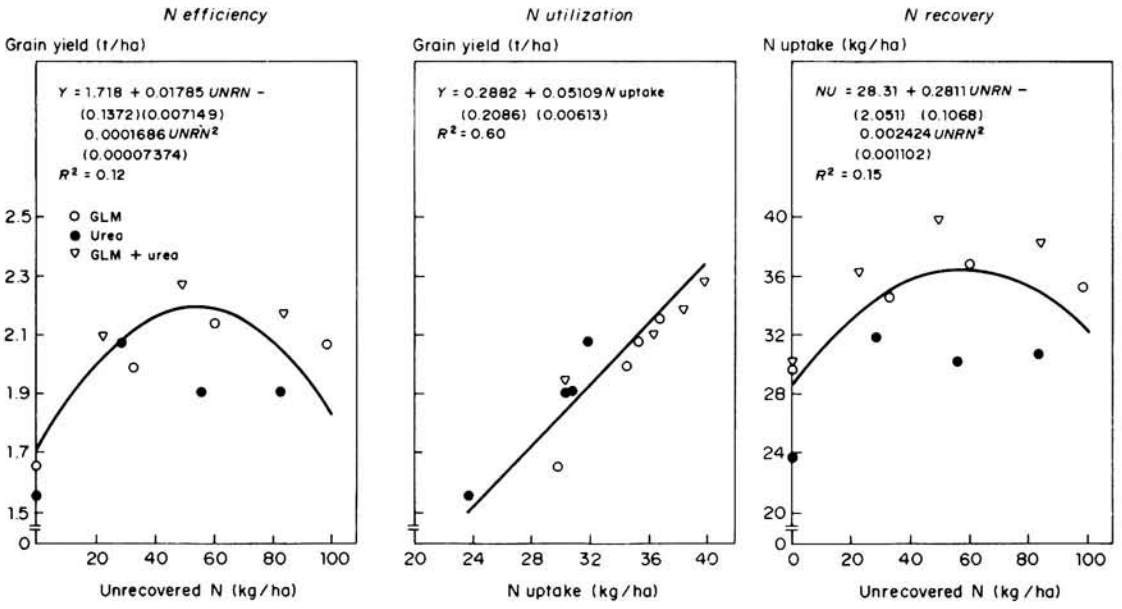
Significant differences of 27, 55, and 58 kg unrecovered N/ha were obtained from 40, 80, and 120 kg N/ha application regardless of N source. Average unrecovered N from GLM was slightly higher (47 kg/ha) than from urea (41 kg/ha) or their combination (38 kg/ha), which were statistically comparable.

Grain yield responses to unrecovered N, and N uptake and apparent N recovery are illustrated in Figure 9. Grain yield increased linearly with N uptake but decreased with higher unrecovered N. Grain yield was estimated as optimum at 2.2 t/ha when residual N was 53 kg/ha. These optimum values were less than 50% of the grain and N yields obtained from the previous main crop.

Productivity and profitability of intercropping *Sesbania rostrata* with cowpea at different row

Table 9. Response of transplanted rice to unrecovered N from organic and inorganic N applications. IRRI, 1989 DS.

N source	Grain yield (t/ha)					TDMY (t/ha)					N uptake (kg/ha)					Unrecovered N (kg/ha)				
	0 N	40 N	80 N	120 N	Mean	0 N	40 N	80 N	120 N	Mean	0 N	40 N	80 N	120 N	Mean	0 N	40 N	80 N	120 N	Mean
Green leaf manure	1.7	1.5	2.1	2.1	2.0	5.06	4.90	5.17	4.90	5.00	30	35	37	35	34	0	33	60	98	47
Urea	1.6	2.1	1.9	1.9	1.9	3.84	4.57	4.68	4.53	4.41	24	32	30	31	29	0	28	55	83	41
Green leaf manure + urea	1.9	2.1	2.3	2.1	2.1	4.27	5.37	5.27	5.13	5.01	30	36	40	38	36	0	21	48	83	38
Mean	1.7	2.1	2.1	2.0	2.0	4.39	4.95	5.04	4.85	4.81	28	34	36	35	33	0	27	55	88	57
SE_1			0.34					0.68					4.62					4.91		
SE_2			0.38					0.78					5.28					5.70		



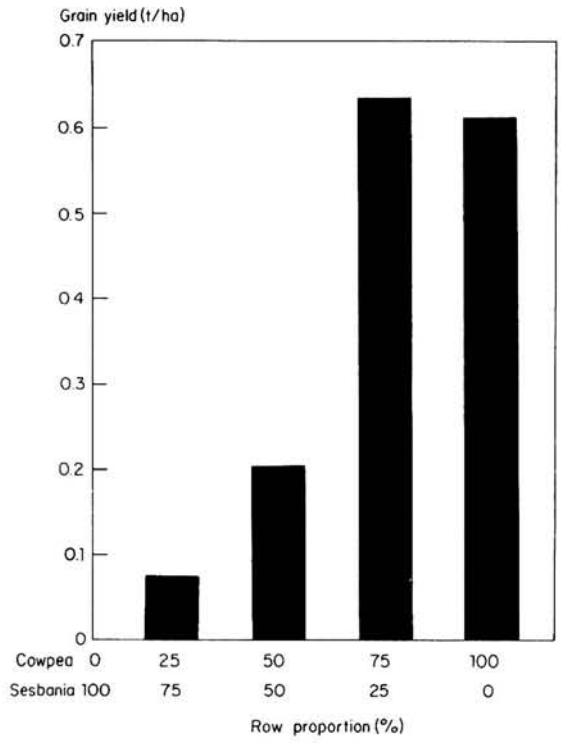
9. Rice response to unrecovered N from organic or inorganic sources. IRRI, 1989 DS.

proportions as source of organic nitrogen for transplanted rice (*Multiple Cropping*). A field trial examined the effect of intercropping sesbania with cowpea (variety IT-82D-89) at various row ratios on the yield of cowpea and the subsequent response of TPR to the N contributed by the legume residue. Cowpea:sesbania row-crop proportions were 0:100, 25:75, 50:50, 75:25, and 100:0. Three fallow plots were maintained during the grain legume - sesbania growing period and were reserved for 3 N rates – 0, 60, and 120 kg/ha – for the following rice. The sesbania was clipped at 35 cm above the ground at 36 d after planting as a source of forage and to reduce its suppressive effect on the cowpea crop, which was intended primarily for grain production.

The grain yield of cowpea as influenced by the row proportion of the sesbania intercrop is presented in Table 10. The depressive effects on cowpea yield of increasing sesbania row proportion were significantly different. Increasing cowpea rows relative to sesbania from 25 to 75% increased grain yield by 565 kg/ha at 75:25 and 100:0 cowpea:sesbania row combination. Grain yields of cowpea were comparable at 635 and 616 kg/ha, and were found optimum at a 75:25 row ratio (Fig. 10).

Combined dry herbage of sesbania regrowth plus cowpea residue was highest (10.67 t/ha) at 50:50 row ratio. The corresponding N accumulation was 281 kg/ha. The sesbania monocrop, however, significantly outyielded the cowpea monocrop in both herbage and N yield.

Rice grain yield, TDMY, and N uptake are shown in Table 11. Single degree of freedom



10. Effect of row proportion on cowpea grain yield, IRRI, 1988 DS. Values are means of 4 replications.

comparisons were used to compare treatment means. The effects of organic N and GM N were comparable in terms of grain yield and TDMY, but both N species significantly outyielded the control treatment in all the attributes. Green

Table 10. Grain yield of cowpea, total dry herbage yield, and N accumulation of cowpea and sesbania as influenced by intercropping proportion. IRRI, 1988 DS.

Row proportions of cowpea: sesbania (%)	Grain yield (kg/ha)	Forage of 36-d clipping (t/ha)	Green manure dry herbage (t/ha)	N accumulation (kg/ha)
0:100	–	1.11	4.23	104
25:75	70	1.45	8.42	185
50:50	206	1.64	10.67	281
75:25	635	0.58	8.62	182
100:0	616	–	2.66	44
CV (%)	37	15	18	18

Table 11. Grain, total dry matter, and N yields as affected by inorganic and green manure N fertilizer on transplanted rice. IRRI, 1988 WS.

Treatment[a]	Grain yield (t/ha)	Total dry matter (t/ha)	N uptake (kg/ha)
T1 Fallow, 0 kg N/ha	2.2	6.78	43
T2 Fallow, 60 kg N/ha	2.8	10.45	67
T3 Fallow, 120 kg N/ha	3.8	12.62	95
T4 100% SR: 0% CP	3.1	11.17	80
T5 75% SR: 25% CP	2.9	11.30	77
T6 50% SR: 50% CP	3.4	11.06	66
T7 25% SR: 75% CP	2.9	11.14	68
T8 0% SR:100% CP	3.1	10.10	69
SE	0.26	1.24	6.84
CV (%)	11.8	16.6	13.7

[a] CP = cowpea, SR = *Sesbania rostrata*.

manure N treatments (e.g., T4-T6) did not significantly affect grain, DM, and N yields, but these attributes increased markedly with higher rates of organic N applied.

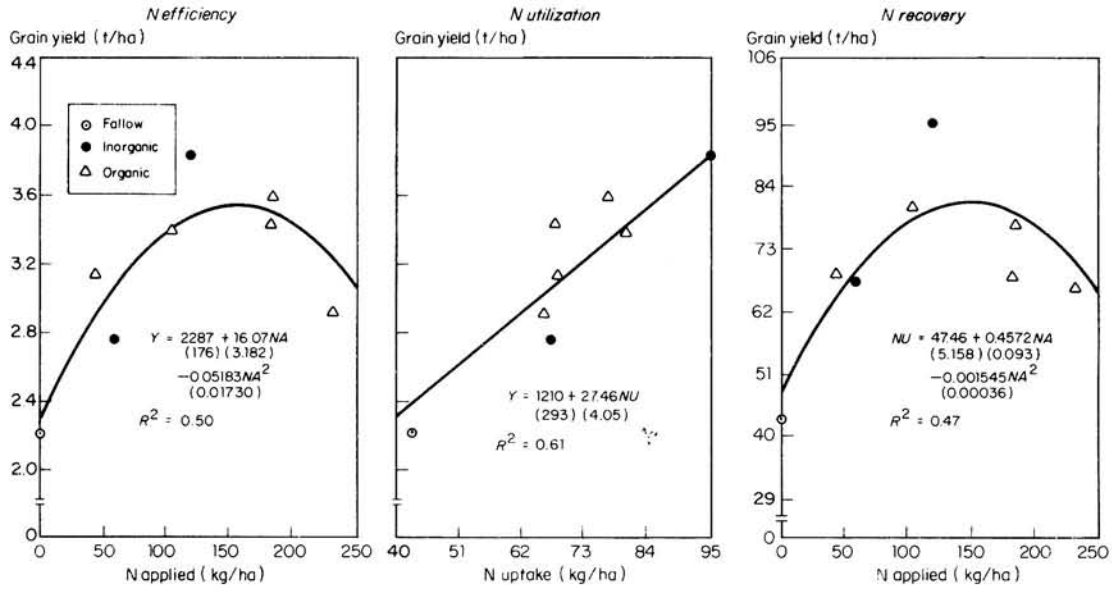
Regression models were used to examine N efficiency (Fig. 11). Inorganic N treatments showed a curvilinear response of grain yield and N uptake to N applied. N recovery was linearly related to N applied. In the overall model, however, the depressive effect on grain yield of applied N was associated more with the excessive amounts of N coming from the GM. Grain was estimated to be optimum at 3.5 t/ha when the applied N was 155 kg/ha. N recovery was about 45%, with the soil supplying approximately 47 kg N/ha.

These findings indicate the potential of intercropping GM with grain legumes to increase productivity without sacrificing arable areas intended for grain legume or other cash crop production. In terms of rice grain yield, GM N can replace as much as 100 kg N/ha from inorganic fertilizer.

Since the recovery was low, a considerable amount of N was unrecovered. Hence, a second rice crop was planted in the same field to determine the response to residual N.

The marginal rate of return was computed for undominated treatments (those that provided the highest net income per unit of investment) (Table 12). Application of 120 kg N/ha resulted in recovery of $2.79 for every dollar invested in inorganic N. Shifting from inorganic N to GM N from the cowpea monocrop residue gave a marginal rate of return of $2.53. Part of the return was attributed to income from the cowpea yield. However, cowpea with a sesbania intercrop at 75:25 further increased the marginal rate of return to $3.57. The net benefit curve with respect to variable cost (Fig. 12) shows the profitability of intercropping sesbania with cowpea in an optimum row crop proportion of 75:25.

Effect of grain legumes, *Sesbania rostrata* green manure, and nitrogen fertilizer on rice - wheat - legume systems (*Multiple Cropping*). *Transplanted rice.* Continuous cropping of cereals (rice - rice or rice - wheat) tends to reduce the sustainability of the cropping system. Grain legumes and GM legumes are alternative sources of biologically fixed N and increased organic matter in rice-based cropping systems. A field experiment compared the response of rice to GM, mungbean residue, and inorganic N fertilizer. Mungbean (Pagasa 1) was sown on 15 April and *S. rostrata*

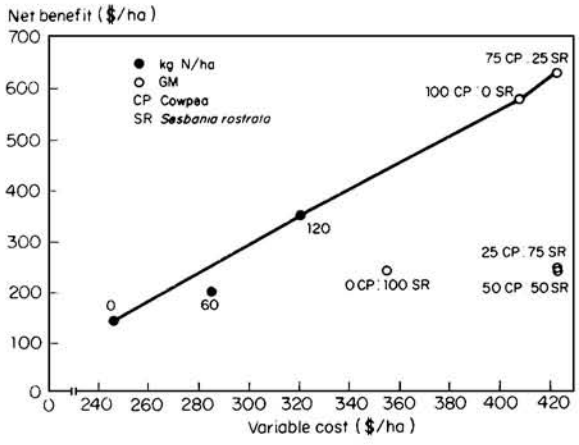


11. N efficiency, N utilization, and N recovery from organic and inorganic N applications. IRRI, 1988 WS.

Table 12. Computed marginal rate of return of undominated treatments. IRRI, 1988 WS.

Treatment[a]	Variable cost	Net benefit ($/ha)	Marginal rate of return ($/$)
0 kg N/ha	245.90	145.55	2.79
120 kg N/ha	320.30	353.20	2.53
100% CP:0% SR	408.85	577.40	3.57
75% CP:25% SR	422.95	627.82	

[a] CP = cowpea, SR = *Sesbania rostrata*.



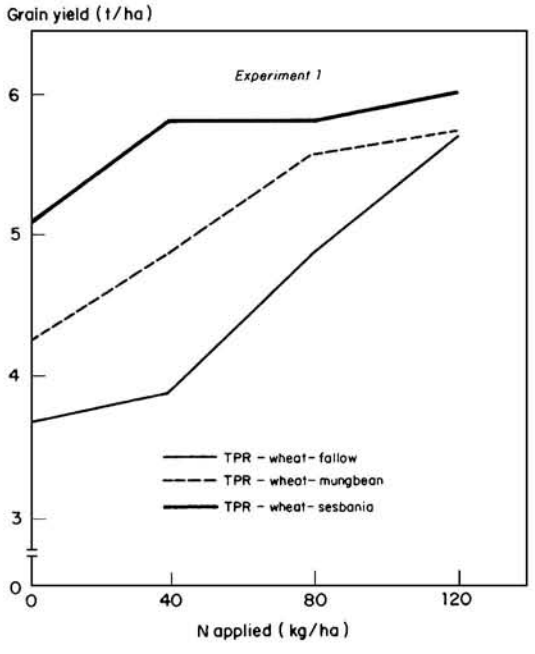
12. Net benefit curve from application of organic and GM N to transplanted rice, IRRI, 1989 WS. Dominated treatments are shown below the curve.

on 3 May. The date of planting was staggered so that at mungbean harvest, sesbania for incorporation would be 45 d old. Mungbean (0.55 t grain/ha) was harvested on 10 Jun 1988. The mean dry matter yields of mungbean, weedy fallow, and sesbania at 4 N rates were 2.8, 2.4, and 3.9 t/ha, respectively. The N contents of the materials during incorporation were 9, 26, and 58 kg N/ha, respectively. Two-thirds of the N was applied on 21 June. Eighteen-day-old rice (IR66) seedlings were transplanted on 22 Jun 1988. The remaining 1/3 N was applied on 25 Jul 1988.

With the use of *S. rostrata*, rice yields increased by 1.4 and 0.8 t/ha, respectively, over unweeded fallow and mungbean residue. Rice yield with *S. rostrata* GM application combined with 40 kg N/ha of inorganic N fertilizer was comparable to that obtained with 120 kg N/ha applied in unweeded fallow and 80 kg N/ha applied to mungbean plots, respectively (Fig. 13). These results suggest that an input of 80 kg N/ha can be saved, without reducing rice yield, by adopting a sesbania GM - rice cropping system.

Wet seeded rice. Under irrigated environments, cropping intensity in rice-based cropping systems could be increased by wet seeded rice (WSR). Wet seeding saves time for raising seedlings in the seedbed and shortens the turnaround time between the harvest of the DS crop and the establishment of a WS rice crop.

A second experiment determined the response of WSR to GM and inorganic N fertilizer. Mungbean (Pagasa) was sown on 15 April and *S. rostrata* on 3 May. Mungbean (0.38 t grain/ha) was harvested on 14 Jun 1988. The mean dry matter yields at 4 N rates were 2.8 t/ha for mungbean, 2.3 t/ha, for weedy fallow, and 3.9 t/ha for *S. rostrata*. The N contents of the materials during incorporation were 29, 31, and 54 kg/ha, respectively. Two-thirds of the N was applied on 22 Jun 1988. Presoaked rice seed (IR66) was sown on 23 Jun 1988 using the drum seeder de-

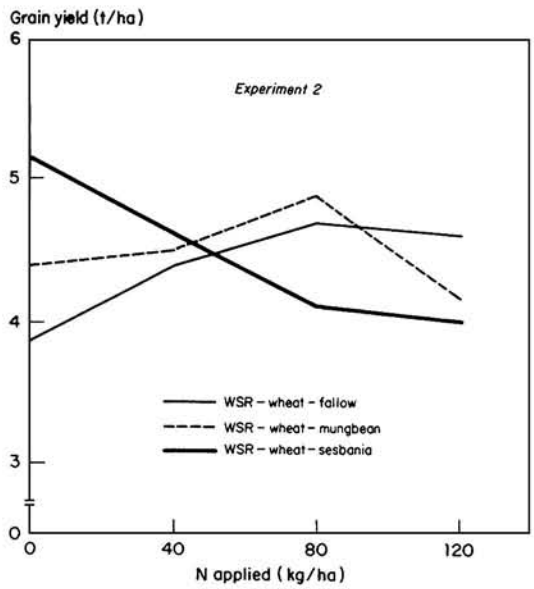


13. Yield of rice planted after weedy fallow, *Sesbania rostrata*, and mungbean at 4 N rates. IRRI, 1988 WS. TPR = transplanted rice

veloped by the Agricultural Engineering Department. The remaining 1/3 N was applied on 28 Jul 1988.

With the use of *S. rostrata*, rice yields increased by 1.2 and 0.7 t/ha, respectively, over the unweeded fallow and mungbean residue (Fig. 14). Lodging caused severe yield reduction of WSR, especially in *S. rostrata* plots. The degree of lodging increased with increasing N level. Without inorganic N fertilizer, rice yield achieved from *S. rostrata* GM plots was similar to that from weedy fallow receiving 120 kg N/ha and from mungbean plots receiving 120 kg N/ha. These results suggest that an input of 120 kg N/ha can be saved, but without reducing rice yield, by adopting a GM - WSR cropping system.

Effect of pigeonpea biomass incorporation on transplanted rice in a rice - legume system (*Multiple Cropping*). Pigeonpea is a drought-resistant crop that has the growth characters to produce large amounts of biomass on residual soil moisture and limited rainfall during the postrice DS. Regrowth biomass from a ratooned pigeonpea crop grown after rice was incorporated as GM to quantify the root, shoot, and combined root and shoot effects on TPR, and to determine N substitution with and without inorganic N to the rice crop. In GM plots, the pigeonpea crop was cut at ground level and divided into roots and shoots. Roots were left in the plots as the root treatment, while shoots were chopped and uniformly applied in the fallow plots as the shoot treatment. For the combined root and shoot treatment, chopped shoots were applied uniformly in the plots where the biomass was harvested, together with the roots. To determine N substitution, N rates of 0, 40, 80, and 120 kg N/ha were applied in the respective treatments. N was applied in 2 splits: 2/3 basally incorporated at transplanting, and 1/3 topdressed at PI. IR54 seedlings (28-d-old) were transplanted at 20- × 20-cm spacing at 3 seedlings/hill.



14. Yield of rice planted after a weedy fallow, *Sesbania rostrata*, and mungbean at 4 N rates, IRRI, 1988 WS. WSR = wet seeded rice.

There were significant treatment differences in dry matter, percent N, and N yield (Table 13). Dry matter yields varied from 2.32 to 10.12 t/ha. The corresponding N yields varied from 20 to 141 kg/ha. The highest percent N in the biomass was observed in the weedy fallow with 1.2%. Roots gave the lowest percent N with 0.8%. The high N percentage of the weeds was attributed to their composition, which was mostly *Mimosa pudica*, a legume.

Grain yield increased significantly with higher N accumulation in GM (Table 14). Combined root and shoot GM increased grain yield by 25%, and shoot GM increased yield by 22% over the fallow treatment. No significant difference in yield was observed between root and fallow treatments. Rice grain yield responded significantly to increasing inorganic N rate. The highest yield was

Table 13. Total dry matter, percent N, and N yield of weeds and different parts of pigeonpea crop incorporated as green manure.[a] IRRI, 1987 WS.

Green manure	Total dry matter (t/ha)	Nitrogen (%)	Nitrogen yield (kg/ha)
Fallow (weed)	3.54 b	1.2	68 b
Root	2.32 c	0.8	20 c
Shoot	9.75 a	1.4	136 a
Root and shoot	10.12 a	1.4	141 a
Mean	6.42	1.4	91
CV (%)	11.4		9.9

[a] Av of 4 replications.

Table 14. Grain yield of transplanted rice as affected by different parts of pigeonpea as green manure and inorganic N fertilization. IRRI, 1987 WS.

Green manure	Yield (t/ha) at nitrogen rates (kg/ha) of				Mean yield (t/ha)
	0	40	80	120	
Fallow	1.7	2.2	2.6	2.4	2.2
Root	1.7	2.2	2.3	1.7	2.0
Shoot	2.2	2.5	2.7	2.2	2.4
Root and shoot	2.3	2.7	2.7	2.1	2.4
Mean	2.0	2.4	2.6	2.1	2.3
CV (%)	22				

observed at 80 kg N/ha. N efficiency in this experiment was low, as the crop was damaged by a typhoon in the reproductive phase.

RICE - WHEAT

Multiple Cropping Department

Simulation of wheat yield potential under irrigated and rainfed conditions in Southeast Asia. The governments of most Southeast Asian countries have a growing interest in cultivating wheat. Since the water requirement of wheat is much less than that of rice, wheat is a potential DS crop. National plant breeding programs as well as the Centro Internacional de Mejoramiento de Maiz y Trigo have initiated varietal improvement programs to develop wheat varieties adapted to specific environments in the region. Presently available varieties yield 2 t/ha or more with irrigation.

We used a simulation model to establish the potential yields and rainfed yields of wheat following rice in Southeast Asia.

Potential grain yields at different latitudes and elevations. Wheat growth was simulated for latitudes 7° S, 0, 7° N, 14° N, 21° N, and 28° N at 0, 500, 1,000, 1,500, and 2,000 m elevation. The sowing date was assumed to be 25 June for 7° S; 25 December for the equator, 7° N, and 14° N; and 15 November for 21° N and 28° N. The simulated potential grain yields varied between 2.8 and 11.8 t/ha. The potential grain yields increased with the latitude and elevation.

To facilitate manipulation, the results of the detailed dynamic simulations were put into a regression equation relating grain yield (GY, in kg/ha) to latitude (LAT, in degrees) and elevation (ELV, in m):

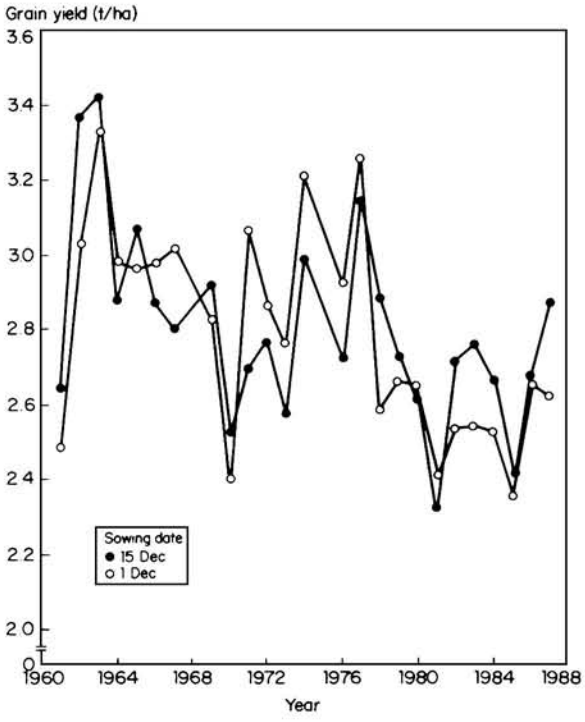
$$GY = 3005 - 66.8\,LAT + 7.36\,LAT^2 + 2.62\,ELV \quad (R^2 = 0.93)$$

The potential grain yield in Southeast Asia was shown to exceed 3.0 t/ha almost everywhere. At sea level, grain yield is 3.0 t/ha between 0 and 8° N; it increases to 5.0 t/ha at 21° N and 4.5 t/ha at 10° S. The potential grain yield increases with elevation at all latitudes. At 500-m elevation, the estimated potential grain yield is more than 5.0 t/ha for latitudes below 5° S and above 15° N. The potential exceeds 6.0 t/ha at 21° N and 5.7 t/ha at 10° S. At 1,000-m elevation, grain yield is 5.8 t/ha between 0 and 10° N, and increases up to 7.6 t/ha at 21° N. Grain yield increases with elevation and with latitude because of lower temperatures in the growing season.

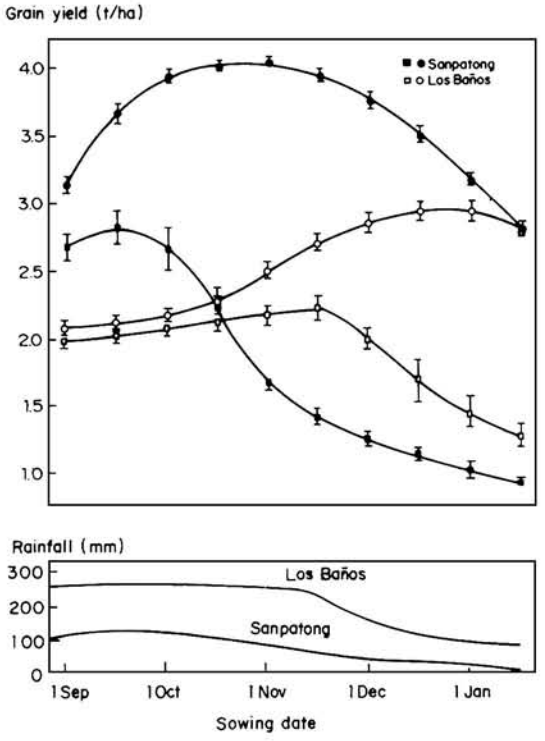
Stability of potential grain yields. An important trait indicating the suitability of a crop is the stability of its performance over the years. Yield stability refers here to the difference in yield level with a 75 and 25% probability of being exceeded in any year; the smaller the difference, the larger is the ability to quantify stability. The growth of wheat in Los Baños (14° 10' N) sown at 15-d intervals between 15 November and 30 January was simulated for 25 yr, using actual daily weather data. The year-to-year variations in grain yield for 15 December and 1 January sowing dates are plotted in Figure 15. The potential grain yield fluctuates between 2.3 and 3.4 t/ha for both sowings.

The potential yield of current wheat varieties is 3.0-5.5 t/ha in Southeast Asia. It is fairly stable over years and increases with elevation. Delayed wheat sowing will have little or no effect on the grain yield of irrigated wheat. Since the crop duration is less than 3 mo, wheat can fit very well in intensive cropping systems if it can be seeded at its optimal time.

There are 4.1 million ha of DS irrigated rice areas in Southeast Asia, mainly north of 15° N and south of 5° S. The potential yield of wheat in these areas is more than 4.0 t/ha. From a purely agronomic viewpoint, these areas are suitable for cultivating wheat.



15. Year-to-year variation in simulated potential grain yield of wheat sown in Los Baños, Philippines, on 15 December and 1 January. IRRI, 1988.



16. Effect of sowing date on water-limited wheat yields and its standard deviation in soils (□) in Sanpatong (Thailand) and Los Baños (Philippines). Also shown are the potential yields (o) and monthly rainfall.

Stability of rainfed potential grain yields. The effect of sowing date on rainfed wheat was simulated for Los Baños, Philippines, and Sanpatong, Thailand (18°45' N). The potential yield (with no water deficit) at Sanpatong is about 4.0 t/ha and is obtained for sowing dates between 1 October and 15 November. It decreases in later sowings to 2.8 t/ha by 15 January (Fig. 16). The grain yield of rainfed wheat, however, is sensitive to sowing date. The maximum rainfed yield is 2.7 t/ha for sowing between 1 September and 1 October, and subsequently decreases sharply. In Sanpatong and similar locations, 2.5 t grain yield/ha can be obtained when the sowing is completed before 5 October.

The year-to-year variation in rainfed yields has been determined for wheat sown on 1 December in Los Baños for the 25 yr. Because soil texture and rooting depth of the ricelands vary a great deal, three representative rice soils were considered—heavy clay, light clay, and loam—with a uniform texture for the whole profile. Maximum rooting depth was either 0.25, 0.5, or 1.0 m to mimic the presence of a root-impeding layer at different depths.

Frequency distribution analysis of wheat yields indicates that when the maximum rooting depth is 0.25 m—as in many rice soils with a compacted layer—grain yields are very low and highly unstable, irrespective of soil texture. In many years, no grain yield is produced, since the crop dies before flowering.

This model predicts that the gap between potential yields and rainfed yields is small when wheat is planted on a deep soil that is at field capacity. The latter condition can be ensured in the optimal planting period by not delaying wheat sowing once the rains have lessened and any waterlogging has disappeared. Simultaneously, if the soils are deep, relatively light-textured, and free of root-restricting layers, yields are fairly high and often close to the potential level.

Intercropped wheat and grain legume. Since tropical potential wheat biomass and yield are limited, intercropping wheat with a grain legume was hypothesized to be a means of maximizing resource use efficiency in rice - wheat systems. The total resource use by wheat may be less than the total available resources of light, nutrients, and water. Two field experiments at IRRI in 1988 DS investigated intercropping wheat (*Triticum aestivum*) with an adapted grain legume (soybean *Glycine max*). We determined the production potential of the intercrop and the grain and N yield sensitivity of intercropped wheat and soybean to row proportion. Studies on replacement series using upland rice and cowpea were reported earlier (Annual report for 1985).

Experiment 1 was conducted after TPR in a lowland field, and experiment 2 was in an upland field. The soils were moderately productive Tropudalfs (clayey isohyperthermic). The treatments were 2 monocultures and 4 intercrops in a 12-row arrangement of a replacement series with wheat and soybean (wheat monoculture 100%; wheat 80%:soybean 20%; wheat 60%:soybean 40%; wheat 40%:soybean 60%; wheat 20%:soybean 80%; soybean monoculture 100%) replicated three times and arranged in RCBD. Experiment 1 was planted on 29 Jan 1988 and experiment 2 on 4 Jan 1988.

Wheat (variety UPLW-3) was seeded at 120 kg/ha, and the seeding rate was adjusted for area proportion. Soybean (dwarf experimental line G-2261) was overseeded and thinned to obtain rows of 10 plants/m. Row spacing was maintained at 25 cm. A fertilizer rate of 60 kg N/ha was applied basally in full dose only to the wheat. The crops were irrigated 4 times: at planting and at 15, 30, and 45 DAS.

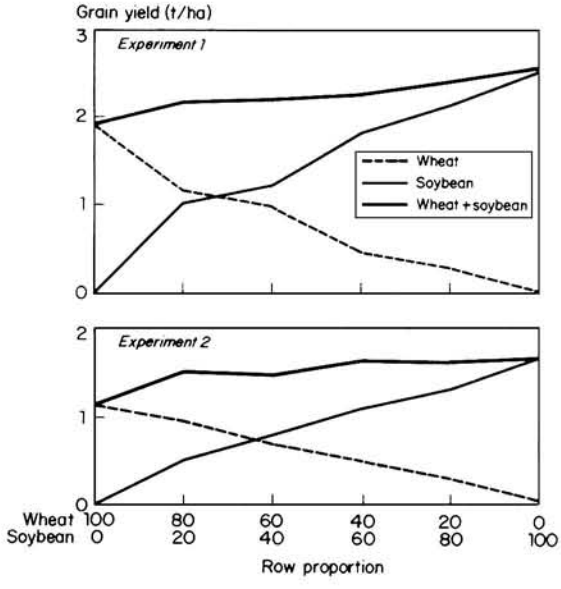
Wheat in the upland field matured earlier by 10 d than wheat in the lowland field. Wheat matured earlier than soybean by 4 d in both experiments. Grain yields were affected significantly by row proportion treatments. In experiment 1, wheat yield reduction was proportional to decreasing row proportion as soybean rows increased, except in 80:20 and 60:40 wheat:soybean proportions, where yields of both species were similar. In experiment 2, wheat yields were affected by treatments below 80% row proportion as soybean rows increased. Wheat yields were significantly reduced below 80% of wheat row proportion. Soybean yield increased significantly as wheat row proportion decreased. Soybean yields at 60 and 80% proportion were comparable to those of wheat (Fig. 17).

Crude protein yield is a function of grain yield as well as N concentration. Row proportion influenced the crude protein yields of both crops. Crude protein decreased with row proportion for both species (Fig. 18). The lowland field produced higher crude protein than did the upland field (experiment 2).

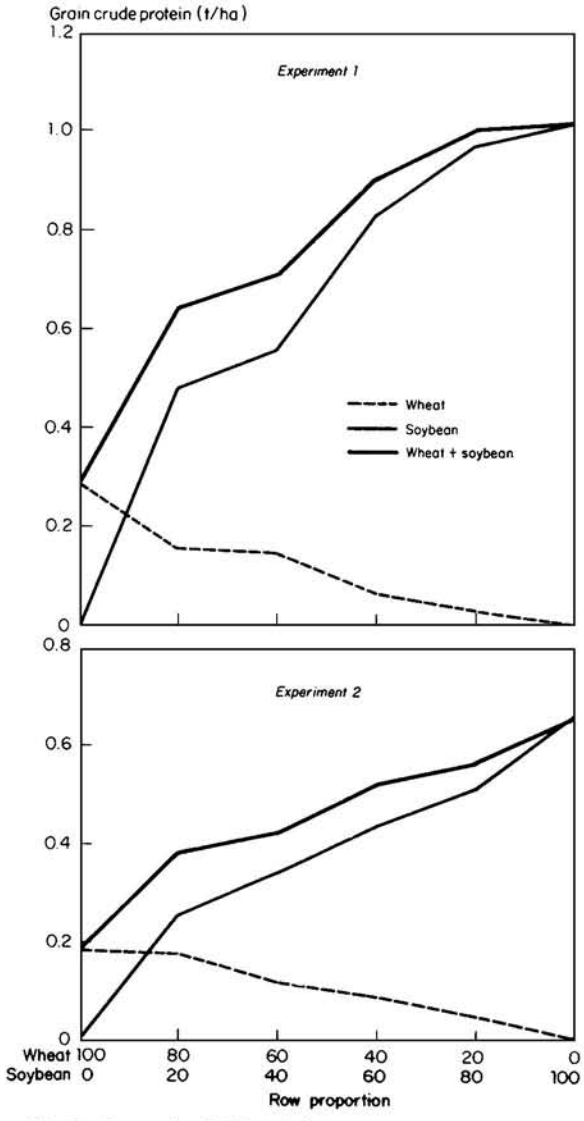
The land equivalent ratio (LER) is the land area required in monoculture to equal the yield of 1 ha of the intercrop. The LER varied between 1.0 and 1.2, indicating a slightly greater productivity of the intercrop.

In the lowland environment, the highest LER was influenced by the better growth of soybean in the 80:20 wheat:soybean row proportion (LER 1.2). In the upland environment, the highest LER was influenced by the better growth of wheat in the 80:20 wheat:soybean proportion (LER 1.0).

The competitive ratio, a recently proposed index, indicates the number of times by which



17. Grain yields of wheat and soybean intercrop in a replacement series. IRRI, January-April 1988 DS.



18. Crude protein yield in wheat and soybean intercrop in a replacement series. IRRI, January-April 1988 DS.

one intercrop is more competitive than the other, and is calculated as follows:

$$CR_a = \frac{L_a}{L_b} \times \frac{Z_b}{Z_a}$$

where CR_a = competitive ratio for species a in mixture b, Z_a, Z_b = proportions of species a and b in the mixture, and L_a, L_b = relative yields (intercrop-monocrop) of species a and b.

In the lowland environment, stored moisture in the soil helped the soybean become more competitive (CR = 2.92) than wheat. Soybean was not as tall as wheat, but it produced more lateral branches, which influenced adjacent rows of wheat through shading and reducing wheat density. To achieve greatest productivity, the optimum crop proportion was 80% wheat and 20% soybean or vice versa.

Effect of tillage and planting method on wheat grain yield. An experiment was designed to evaluate the performance of wheat sown under zero tillage and under conventionally tilled lowland soil and to compare the performance of the inverted-T seeder and hand-drill sowing at three N fertilizer levels. The experiment was conducted in a lowland field at IRRI in 1988 DS on a silty clay soil (pH 6.5, 1.03% organic C, 0.12% total N, 18 ppm available P [Olsen], bulk density 1.65). Treatments were 3 N fertilizer rates (0, 45, 90 kg N/ha) as main plots. Tillage practices (zero = no tillage; conventional = one plowing followed by rototilling to obtain well-tilled seedbeds) and two sowing methods (hand drill on furrow prepared by a dragstick or "lithao," and inverted-T seeder) were subplots. The experimental design was a 2 × 2 factorial in a split plot with 3 replications. At planting, conventional tillage was done when soil moisture permitted.

The crop was maintained as rainfed from sowing, but was later given a lifesaving irrigation at flowering (4 Mar 1988). Pests and diseases were adequately controlled.

Grain yield, TDMY, number of spikes, grain weight, and plant height were all significantly increased by N rate (Table 15). Tillage treatment did not affect yield. The inverted-T seeder gave yields superior to those with the hand drill, but the two were similar in TDMY response. Plants were taller in inverted-T plots. Although the number of spikes was slightly higher with the hand-drilled method at the same N level, this was offset by bigger seed size in the inverted-T treatment. Planting by inverted-T seeder resulted in a uniform crop stand, which encountered a lower level of drought stress than did hand drilling. The superiority of the inverted-T seeder was due to favorable seed placement where residual soil moisture was available for wheat growth.

Table 15. Effect of N fertilizer, tillage, and planting method on grain yield, TDMY, yield components, and plant height of wheat.[a] IRRI, 1988 DS.

N rate (kg/ha)	Planting method	Grain yield (t/ha)	Total dry matter (t/ha)	Spikes (no./m²)	1000-grain weight (g)	Plant height (cm)
0	Hand drill	0.9	2.1	231	29.0	44.5
	Inverted-T	1.1	2.3	236	30.5	47.3
45	Hand drill	1.1	2.6	294	29.0	47.6
	Inverted-T	1.3	2.8	238	29.4	50.7
90	Hand drill	1.5	3.5	264	29.1	56.2
	Inverted-T	1.6	3.5	242	30.2	57.6
SE		0.1	0.5	25.2	0.8	5.1
CV		11.8	19.7	10.3	3.4	12.3

[a]Means over 2 tillage treatments with 3 replications.

Tilled soil provided unfavorable soil conditions that prevented the buildup of weeds as the soil dried (Table 16). Dry weed weight also increased significantly as N fertilizer rate increased. Interactions of N × tillage × planting method were not significant.

Wheat variety trial in a postrice environment. The 20 highest yielding wheat varieties from the 1987 DS trials were evaluated after TPR in an irrigated environment in a lowland field to determine the potential yield and the adaptability of local and introduced wheat varieties in a tropical climate. The trial was sown in Los Baños on 30 Jan 1988 at a seeding rate of 120 kg/ha in 20-cm rows. The crop was irrigated three times.

Grain yields ranged from 0.7 to 2.1 t/ha. UPLW-2 wheat significantly outyielded all other local and foreign entries. UPLW-2 is agronomically adaptable for local cultivation despite the unusual rainfall and high temperature conditions prevailing during the growing season. The varieties were sown late because of frequent rain showers, thus exposing the crops to higher temperature, which hastened maturity, shortened plant height, and caused poor stand and grain development.

Table 16. Dry weed weight at 20 d after emergence as affected by N fertilizer tillage and planting method of wheat (UPLW-3).[a] IRRI, 1988 DS.

N rate (kg/ha)	Tillage practice	Dry weed weight (g/18 m²)
0	No tillage	174.25
	Tilled	19.75
45	No tillage	186.60
	Tilled	18.25
90	No tillage	256.10
	Tilled	48.85
SE		18.07
CV		18.9

[a]Means over 2 planting methods with 3 replications.

RICE - UPLAND CROPS

Rice Farming Systems Program

Response of sunflower under zero tillage to plant population density and row spacing after lowland rice. Sunflower is an oilseed with a growing market. In some Asian countries, it is a promising postrice crop. An experiment evaluated the response of sunflower after lowland rice under varying plant densities and row spacings and with zero tillage. The experimental design was a RCBD in split plots replicated three times. The experimental factors were row spacing of 50 and 75 cm as main plots and populations of 40,000, 60,000, 80,000, 100,000, and 120,000 plants/ha as subplots. Cultivar CLSUN-1 (selected in the Philippines) was drilled in open furrows and was thinned to achieve the desired plant population at 15 d after emergence (DE). N was applied at 80 kg/ha, 1/2 basal and 1/2 sidedressed at 40 DE. Supplemental irrigation was given at planting, and at 20 and 40 DE. Weeds were controlled by hand weeding.

At flowering, three plant samples per treatment in all replications were randomly picked for leaf area index (LAI) and DM determination. At maturity, 10 randomly selected plants from the center row of each plot were used for height and head diameter determination. Center rows were hand harvested, and plant stand counts were made. The heads were threshed and weighed.

Seed yield increased significantly from 1.09 to 2.19 t/ha when population increased from 40,000 to 120,000 plants/ha, regardless of row spacing. Biomass also increased significantly from 9.57 to 16.88, and TDMY from 2.65 to 6.82 t/ha. Likewise, increasing the plant population significantly increased plant height from 159 to 178 cm, and LAI from 1.52 to 3.33. Head diameter significantly decreased from 16.4 to 12.2 cm, and seed weight from 7.1 to 5.9 g as plant population increased from 40,000/ha to 120,000/ha.

Biomass and TDMY responded positively to increasing population density. Similar responses were observed in plant height and LAI.

CROP ESTABLISHMENT

Multiple Cropping Department

Effect of seeding rate and row spacing on the performance of the IRRI wetland drum seeder. The IRRI wetland drum seeder was developed to enable row-seeding of rice on puddled soil. The relative merits of the two row-width versions of the seeder need careful evaluation. A study using IR66 rice compared the effect of seeding rate (50 and 100 kg/ha) and row spacing (20 and 25 cm) on the performance of the seeder versus the broadcast method. The experiment was laid out in RCBD with three replications. Two models of the seeder with row spacings of 20 and 25 cm were used.

The time required for seeding was greatest for the 25-cm drum seeder at both seeding rates (Table 17). The 20-cm drum seeder was comparable to broadcasting in time required for seeding. Rice grain yields were similar at both seeding rates for the 25-cm drum seeder and were comparable to the yields obtained with both the 20-cm drum seeder and broadcasting at 100 kg/ha. TDMY was greater at the higher seeding rate for all seeding methods. The same trend was noted for total tillers, productive tillers, and panicle number. These observations account for the higher grain yields obtained with the higher seeding rate. The similar yields with the drum seeder suggest that the method does not affect crop performance but does contribute the advantage of easier interrow weed control.

Performance of new IRRI dryland seeders for legume establishment in tilled soil before rice. A study in a conventionally tilled lowland field previously planted to TPR evaluated the performance of three newly developed IRRI dryland seeders in establishing selected legume species before rice. Hand seeding in straight rows made by a lithao was the control.

In all crops, seeding was faster with the upland seeders than with hand seeding (Table 18). With cowpea, the manual seeder was significantly faster than the plow seeder but was comparable to the inverted-T seeder. For mungbean, the manual seeder was faster than the inverted-T seeder but was comparable to the plow seeder. No difference in seeding soybean was noted among the three seeders.

Differences in seedling emergence were significant at 16 DAS (Table 18). Cowpea emergence was significantly greater with hand seeding, the inverted-T seeder, and the plow seeder

Table 17. Seeding time, grain yield, and agronomic characters of broadcast seeded and drum seeded rice. IRRI, 1988 WS.

Seeding method	Seeding rate (kg/ha)	Row spacing (cm)	Time for seeding (min/56 m²)	Grain yield (t/ha)	TDMY (t/ha)	Total tillers (no./m²)	Productive tillers (no./m²)	Panicles (no./m²)
Broadcast	50	–	1.66 a	2.59 b	8.48 c	377 d	354 c	283 c
Broadcast	100	–	1.87 b	3.80 a	10.39 a	438 b	392 b	359 a
Drum seeded	50	20	1.87 b	2.46 b	8.35 c	359 e	333 d	278 c
Drum seeded	100	20	1.72 a	3.70 a	9.72 b	419 c	390 b	350 a
Drum seeded	50	25	2.37 c	3.73 a	9.60 b	413 c	384 b	296 bc
Drum seeded	100	25	2.31 c	3.87 a	10.58 a	477 a	438 a	310 b

Table 18. Planting time and seedling emergence in selected legumes using different planting methods.[a] IRRI, 1988.

Planting method	Planting time (min/21 m²)			Emergence count (seedlings/m)		
	Cowpea	Mungbean	Soybean	Cowpea	Mungbean	Soybean
Hand seeding	4.87	4.05	5.72	5.47 a	20.20 ab	6.90 a
Inverted-T seeder	2.05	2.08	2.26	4.47 a	22.57 a	7.10 a
Plow seeder	2.23	1.87	2.41	4.17 a	15.70 a	3.63 b
Manual seeder	1.76	1.73	1.78	2.43 b	11.02 c	2.77 b
Planting method mean square	6.22**	3.559**	9.80**	4.78*	77.96*	14.84**
Planting method F value	161.87**	230.39**	90.24**	7.16*	7.60*	56.76**
CV (%)	7.19	5.11	10.83	19.77	18.43	10.02
LSD (0.05)	0.39	0.25	0.66	1.63	6.40	1.02

[a] ** = significant at the 1% level, * = 5%.

than with the manual seeder. Mungbean emergence was superior with the inverted-T seeder, hand seeding, and the plow seeder to that with the manual seeder. Soybean emergence was greater with both hand seeding and the inverted-T seeder than with the manual seeder or plow seeder.

Both cowpea and mungbean had comparable plant counts with the four planting methods. For soybean, plant stand with hand seeding and the inverted-T seeder was significantly superior.

No differences were observed among planting methods in the grain yield of the three crops. In tilled prerice conditions, the performance of the dryland seeders was comparable to that of hand seeding. The only palpable advantage of dryland seeders is the reduction in time spent during seeding.

Influence of groove openers on mungbean and cowpea establishment in an untilled lowland ricefield using the multicrop inverted-T seeder. Two experiments were conducted on mungbean (CES 1D-21) and cowpea (IT-82D-889) to determine the effects of different groove openers on crop establishment with the multicrop inverted-T seeder (MITS). The experiments were simultaneously conducted in an untilled soil previously grown to lowland rice harvested 45 d earlier. The three groove openers—inverted-T, inverted-Y, and U-groove—gave significantly more emerged seedlings when attached to the MITS than did hand seeding. The three types of groove openers were comparable in the early establishment of the two legumes.

At maturity the MITS-sown plots had greater plant density than the hand-seeded plots. The inverted-T opener had a statistically greater mungbean stand than the U-groove, but not when compared with the inverted-Y. For cowpea, the stand with the inverted-Y opener also was superior to that with the other groove openers.

The plant heights at maturity of cowpea and mungbean were not influenced by seeding method. However, the two crops differed in their yield response to the seeding treatments. The seed yield of mungbean with the inverted-T opener was statistically greater than that with hand seeding, but the seed yields with both the inverted-Y and U-groove openers were comparable to that of the inverted-T. Cowpea seed yields were not statistically different for all the seeding methods.

Influence of seedling preparation on performance of the IRRI rice transplanter. Seedling management is an important determinant of the efficiency of mechanical rice transplanters. An experiment evaluated the performance of the IRRI rice transplanter using two methods of seedling preparation: a) seedlings in a mat, and b) washing the roots of seedlings 2 d before transplanting and allowing root regrowth (washed root method). A RCBD with four replications was used.

Transplanting with the IRRI transplanter was significantly faster using seedlings in a mat compared with using seedlings prepared through the washed root method (Table 19). The transplanter saved time compared with hand transplanting by three women. Both hand planting and mechanical transplanting of matted seedlings resulted in equally superior crop stands. Mechanical transplanting with washed roots resulted in

Table 19. Planting time, crop stand, grain yield, and agronomic characters of rice (IR66) established by hand transplanting and mechanical transplanter. IRRI, 1988 WS.

Planting method	Planting time (min/52.5 m²)	Crop stand (seedlings/m²)	Grain yield (t/ha)	TDMY (t/ha)	Productive tillers (no./m²)	1000-seed weight (g)	Plant height (cm)
Hand planting	20.90 a	30 a	3.88 b	9.50 a	379 b	21.4 a	85.2 b
Transplanter (mat)	11.34 c	29 a	4.12 a	9.92 a	409 a	21.2 a	86.7 b
Transplanter (washed root)	15.56 b	22 b	3.46 c	9.46 b	406 a	20.6 b	89.0 a

more missing hills. Rice grain yield was highest with the transplanter using seedlings in mats. TDMY was highest with the transplanter mat, but statistically similar to that with hand planting. No differences were observed in total tiller number and panicle number. However, more productive tillers were obtained with the transplanter (mat and washed method) than with hand planting. Seed weight was greater for hand planting and transplanter (mat). The transplanter (washed root) produced the tallest rice plants.

UPLAND RICE SYSTEM

Multiple Cropping Department

Production sustainability of rice-based rainfed upland cropping systems. Soil nutrients are depleted by continuous cereal monocropping and minimal fertilizer application. A production sustainability approach for rice-based upland areas was studied based on the theory of nutrient cycling through crop diversification into cereal - legume sequences. Five cropping patterns were established in the upland of Claveria, Misamis Oriental, Philippines, with an acid soil, and at IRRI, with a high-base status soil: WS upland rice preceded by maize, maize + peanut, pigeonpea + cowpea, pigeonpea + peanut, or fallow as DS crops. The cropping patterns aimed to determine the legume contribution to soil N relative to the cereal crop and the differential effects of the DS crop combinations on the performance of the succeeding rice crop.

Maize (IPB-VAR 1), cowpea (IT-82D-889), peanut (UPL PN4), and pigeonpea (QPL-72) were planted in different crop combinations during the postmonsoon rains in 1986. The legumes were not fertilized, but the maize crop received urea at the rate of 50 kg N/ha. Grain yield was determined from these crop combinations, and the residues were incorporated into the soil during land preparation for the following upland rice crop. Mean DM yield was 6.17 t/ha in Claveria but only 4.25 t/ha at IRRI because of drought stress. The amount of residue incorporated ranged from 2.5 to 4.7 t/ha at IRRI and from 3.8 to 5.3 t/ha in Claveria. The amounts of N offtake and N incorporated from the different crop combinations are shown in Table 20. Pigeonpea + peanut and pigeonpea + cowpea, which were unfertilized, had higher total N uptake than maize and maize + peanut, which received inorganic N. Except for the fallow, where weeds were incorporated without N offtake, all DS crop treatments supplied less N in their incorporated residue than was removed from the field through harvesting because N concentration was higher in the grain than in the stover. The incorporated residues contained from 6.9 to 58.7 kg N/ha, with the maximum N contribution from pigeonpea + peanut and the least from maize.

The succeeding rice crop (UPLRi-5) was planted in June 1987 under 0, 30, and 60 kg inorganic N/ha. The previous DS crop treatments were used as the main plot and the inorganic N levels on rice as subplots. The effects of the previous crop and the inorganic N on rice grain and TDMY at both sites are presented in Table 21. At IRRI, rice yields increased with inorganic N application but were not significantly affected by the preceding crop. In Claveria, the highest grain yield and TDMY were obtained from rice preceded by maize or maize + peanut, probably because of the residual effect of the inorganic N

Table 20. The fate of N from different dry season crops[a] after harvest at 2 upland sites, 1986.

Crops A + B	N (kg/ha)								N harvest index
	Crop A		Crop B		Total uptake	Total		Difference	
	Offtake	Incorporated	Offtake	Incorporated		Offtake	Incorporated		
				IRRI					
M	8.40	6.92			15.32	8.40	6.92	- 1.48	0.55
M + P	3.19	5.21	23.47	18.02	48.89	26.66	23.23	- 3.43	0.55
PP + CP	18.66	19.66	29.51	15.76	83.59	48.17	35.42	-12.75	0.58
PP + P	26.74	27.89	39.01	30.84	105.53	65.75	58.73	- 7.02	0.62
Fallow		Nil					Nil		
				Claveria					
M	31.05	18.79			49.84	31.05	18.79	-12.26	0.62
M + P	26.98	18.76	14.77	11.04	71.55	41.75	29.80	-11.95	0.58
PP + CP	25.57	26.90	46.49	20.56	119.52	72.06	47.46	-24.60	0.60
PP + P	30.20	29.58	29.17	23.14	112.09	59.37	52.72	- 6.65	0.53
Fallow	0.00	14.55			14.55	0.00	14.55	14.55	

[a]M = maize, P = peanut, PP = pigeonpea, CP = cowpea, fallow = weeds.

Table 21. Grain and total dry matter yields of rice as affected by the previous dry season crops and inorganic N in 2 upland sites, 1986.

Previous crop(s)	Grain yield (t/ha)				Total dry matter (t/ha)			
	0 N	30 N	60 N	Mean	0 N	30 N	60 N	Mean
				IRRI				
M	2.6	3.1	3.2	3.0	5.0	6.7	7.3	6.3
M + P	2.7	3.2	3.4	3.1	5.5	7.2	7.9	6.7
PP + CP	2.2	3.2	3.0	2.8	4.6	6.7	7.4	6.2
PP + P	2.7	3.6	3.6	3.3	5.0	6.7	7.5	6.4
Fallow	2.4	3.3	3.6	3.1	4.8	7.0	7.8	6.6
Mean	2.6	3.3	3.3		5.0	6.8	7.6	
SE_x : Crop		0.2				0.3		
N		0.1				0.1		
				Claveria				
M	3.2	3.3	3.2	3.2	5.3	6.3	6.7	6.1
M + P	2.8	3.2	3.1	3.0	4.6	5.6	6.0	5.4
PP + CP	1.8	2.4	2.2	2.1	3.6	4.8	5.3	4.6
PP + P	2.3	2.8	2.7	2.6	4.3	4.4	5.7	4.8
Fallow	1.8	2.5	2.6	2.3	3.6	4.5	5.4	4.5
Mean	2.4	2.8	2.7		4.3	5.1	5.8	
SE_x : Crop		0.2				0.4		
N		0.1				0.2		

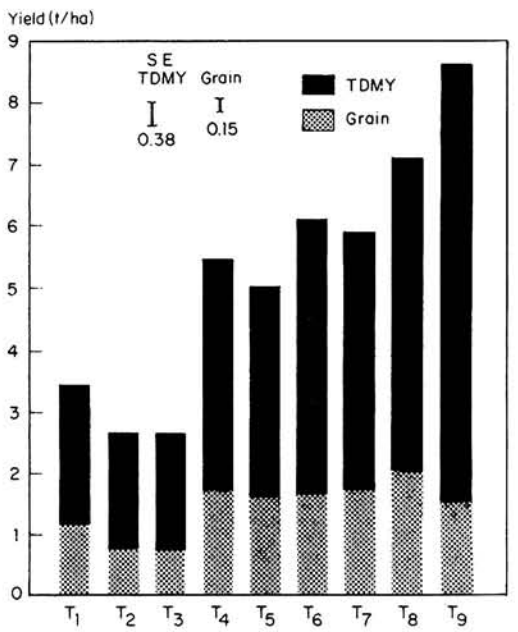
fertilizer applied to these crops. Inorganic N increased rice yields except when the preceding crops were maize or maize + peanut. Legumes returned more N to the soil than the cereal through residue incorporation. However, a positive effect of the previous legume crops on rice yield was not observed regardless of the total legume biomass produced. Patterns with pigeonpea showed a significant adverse effect in reducing grain yield and and TDMY of the following rice crop.

Fertility management for upland rice on acid soils. One of the many problems associated with improving and sustaining upland rice production in acid infertile soils is lack of appropriate fertility management techniques for acid soils.

This study was conducted during three seasons (1985, 1986, 1987) in Barangay Mahipon, Cavinti, Laguna. The site has rolling topography (maximum rains from July to December or January) with annual rainfall of 3,300 mm/yr, with clayey Palehumult soil with pH 4.0. Several combinations of organic and inorganic fertilizer and lime were evaluated to investigate the effects on upland cultivar UPLRi-5.

The 1985 trial was characterized by a long drought period in the vegetative phase and severe neck blast (Bl) incidence during early grain filling. Grain yields varied significantly from about 0.7 to 2.0 t/ha, while TDMY varied from 2.3 to 8.4 t/ha (Fig. 19). Applying N alone (35 N and 70 N) significantly reduced grain yield and TDMY, apparently because of an induced N:P imbalance. Treatments with added P (T4-T9) produced higher TDMY and grain yield than the control and N alone treatments. Treatments composed of NPK + lime (T7-T9) produced the highest grain yields. The grain yield of T8 (70 N + 20 P + 20 K + 2000 lime) at 2.0 t/ha was significantly higher than those of all other treatments. TDMY was maximum in T9 (70 N + 20 P + 20 K + 2000 lime + 3000 chicken manure). This treatment had the most vigorous and tallest plants, but at harvest neck Bl and leaf scald damage were most severe, substantially lowering grain yield.

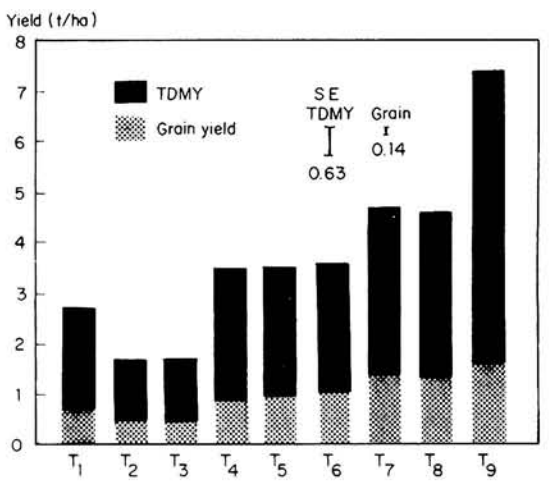
The 1986 trial was characterized by excessive rainfall (>3800 mm from June to November) and number of rainy days (85%). These conditions enhanced the prevalence of whitebacked planthoppers, which increased in population in the late reproductive phase together with neck Bl incidence. Grain yield and TDMY of this trial were lower than in the 1985 trial. Yields varied from 0.4 to 1.6 t/ha, while TDMY ranged from 1.66 to 7.45 t/ha (Fig. 20). Treatment 9 produced the highest TDMY and grain yield (7.45 and 1.6 t/ha, respectively), significantly higher than all the other treatments. As in the first trial, the effects of P and lime were demonstrated in the 1986 trial, and N application alone considerably



Fertilizer added (kg/ha)

	T1	T2	T3	T4	T5	T6	T7	T8	T9
N	-	35	70	70	35	70	70	70	70
P	-	-	-	20	10	20	20	20	20
K	-	-	-	-	10	20	20	20	20
Lime	-	-	-	-	-	-	500	2000	2000
Manure	-	-	-	-	-	-	-	-	3000

19. Grain yield and TDMY of UPLRi-5 as affected by fertility level under acid upland soils of Cavinti, Laguna, Philippines, 1985 WS.



Fertilizer added (kg/ha)

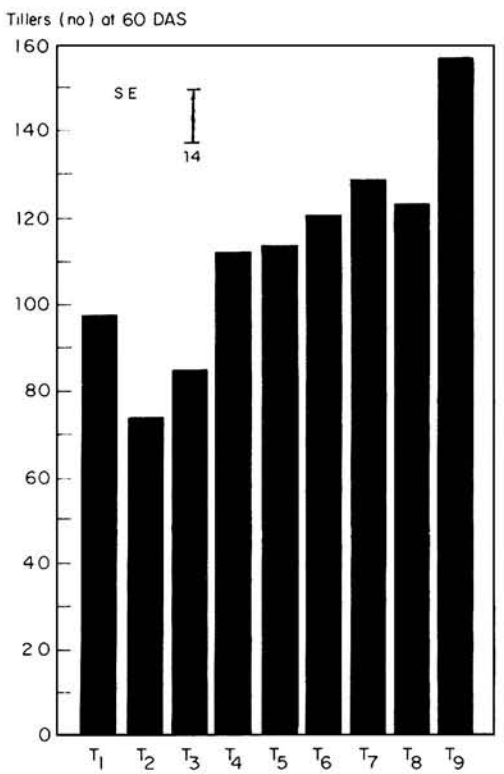
	T1	T2	T3	T4	T5	T6	T7	T8	T9
N	-	35	70	70	35	70	35	70	70
P	-	-	-	20	10	20	40	20	40
K	-	-	-	-	10	20	20	20	20
Lime		-	-	-	-	-	500	2000	2000
Manure		-	-	-	-	-	-	-	3000

20. Grain yield and TDMY of UPLRi-5 as affected by fertility level under acid upland soil conditions of Cavinti, Laguna, Philippines, 1986 WS.

reduced TDMY and grain yield compared with the control. The high-fertility treatments (T4-T9) showed vigorous growth from the seedling stage to harvest. The trend in tiller count at 60 DAS (Fig. 21) was also observed in other yield components.

The 1987 WS trial was characterized by relatively favorable weather with evenly distributed rainfall. Grain yield varied from 1.1 to 2.3 t/ha, and TDMY varied from 4.42 to 7.34 t/ha.

The added P treatments (T4-T9) produced grain yield and TDMY significantly higher than in the zero P treatments. This trend was corroborated by the TDMY at 65 DAS. Higher P levels were more effective than high lime rates in stimulating rice growth. There were fewer filled grains per panicle in T8 (20 P) than in the two other limed treatments (T7 and T9), which received 40 P. Although yields were significantly higher in the lime treatments (T7-T9) than in the no-lime treatments, response to the amount of lime was not positive (Table 22).



21. Tiller count/0.25 m² at 60 DAS of UPLRi-5 at different fertility levels (T1-T9 were described in Figure 20) under acid upland conditions of Cavinti, Laguna,Philippines, 1986 WS.

Table 22. Grain yield, TDMY, and number of grains per panicle of rice cultivar UPLRi-5 grown at different levels of fertility on acid upland soils of Cavinti, Laguna, Philippines, 1987 WS.

Treatment	Grain yield (t/ha)	TDMY (t/ha)	Filled grains (no./panicle)
1. Control	1.5 d	4.92 c	55.03 e
2. 35 kg N/ha	1.3 de	5.06 bc	51.11 f
3. 70 kg N/ha	1.1 e	4.42 c	52.36 ef
4. 70 kg N/ha + 20 P/ha	1.5 d	5.66 b	66.21 b
5. 35 N + 10 P + 10 K	1.9 bc	6.88 a	60.60 cd
6. 70 N + 20 P + 20 K	2.0 bc	7.08 a	61.71 c
7. 35 N + 40 P + 20 K + 0.5 t/ha lime	2.3 a	6.64 a	65.38 b
8. 70 N + 20 P + 20 K + 4.0 t/ha lime	1.9 bc	7.34 a	58.94 d
9. 70 N + 40 P + 20 K + 4.0 t/ha lime + 3.0 t/ha chicken manure	2.1 ab	7.04 a	70.60 a
SE	0.3	0.73	3.52

Lime, nitrogen, phosphorus, and inoculant requirements of cowpea. A study at the Claveria key research site determined whether cowpea would respond to *Rhizobium* inoculation on the prevalent acid soils. The effect of inoculation was tested in the presence and absence of N, P, and lime.

Cowpea had a profuse natural nodulation, which was not further increased by *Rhizobium* inoculation. A sufficient rhizobial population may have been present from the cowpea crop planted the previous year at the trial site. The untreated crops had 1.1 t grain yield/ha and 2.5 t TDMY/ha. The application of 3 t lime/ha significantly increased grain yield by 27% and TDMY by 33%. Solo application of inoculant, 25 kg N/ha, or 13 kg P/ha had no significant effect on grain yield or TDMY. However, combining them with lime increased TDMY by 54% above the control treatment, but did not significantly increase grain yield, probably due to terminal drought stress.

Cropping systems program

Preproduction testing of improved cropping patterns

INTEGRATED NUTRIENT AND PEST MANAGEMENT IN IRRIGATED AND RAINFED LOWLAND RICE SYSTEMS **520**
Irrigated lowland **520**
Rainfed lowland **522**

INTEGRATED NUTRIENT AND PEST MANAGEMENT IN IRRIGATED AND RAINFED LOWLAND RICE SYSTEMS

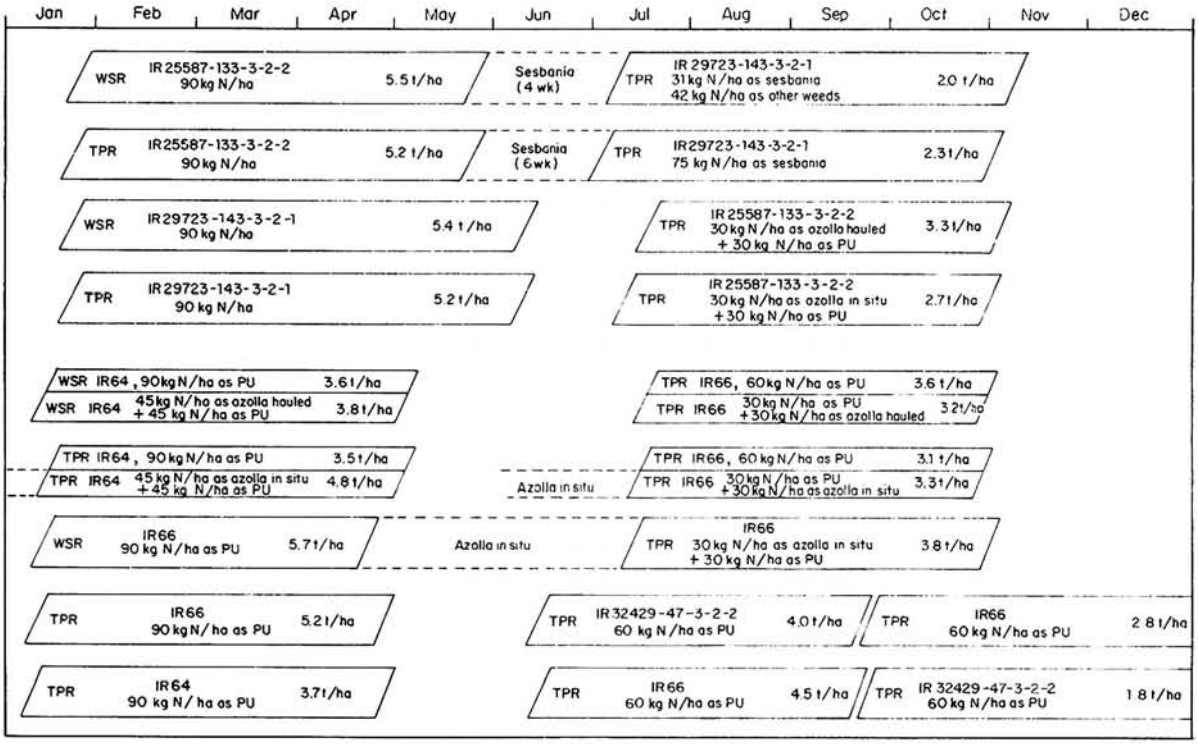
Irrigated lowland. Thirteen rice croppings and three methods of nutrient management were evaluated during the wet season from June to December 1988 to identify cost-efficient alternative technologies in irrigated lowland rice-based systems (Fig. 1).

The second rice crops, following the dry season (DS) crops, matured in September and escaped the typhoons. Grain yields of 4.0-4.5 t/ha were obtained (Fig. 1). Crops harvested late in October until December were adversely affected by strong winds and persistent rains during the reproductive phase, hence the low grain yields of 1.8-3.8 t/ha. Nevertheless, croppings were still profitable, with net margins of $59-$429/ha (Table 1).

Direct production cost with prilled urea (PU) application was as low as $110/ha per cropping, but increased when either sesbania or azolla green manure (GM) was applied basally (Table 2). Application of 60 kg N/ha as PU was very economical, entailing a cost of only $16-$19/ha (Table 1).

Four weeks of sesbania biomass production enabled the fixation of free atmospheric N_2. This incorporated 31 kg N/ha into the soil and allowed other weeds to grow with it, thus contributing 42 kg N/ha. Six weeks of sesbania production fixed and incorporated 75 kg N/ha and completely competed with other weeds. Sesbania manuring incurred a cost of $52-$59/ha (Table 1, Fig. 1).

Azolla treatments cost $26-$40/ha. Basal incorporation of 30 kg N/ha from azolla combined with 30 kg N/ha as PU recorded at least 48% to at most 150% more N than PU applied alone. Azolla propagation required good management. Its incorporation was difficult during persistent precipitation. With minimum water supply, azolla incorporation was difficult. Floating azolla, by its mulching effect, adversely affected newly transplanted dapog rice seedlings, more so with immediate rains and inadequate drainage just after



1. Alternative integrated nutrient management in irrigated lowland rice-based systems, IRRI, 1988. WSR = wet seeded rice, TPR = transplanted rice, PU = prilled urea.

Table 1. Economic analysis and profitability of integrated nutrient and pest management in second and third transplanted rice (TPR) crop in irrigated lowland rice-based systems.[a] IRRI, 1988 WS.

Cropping[b]	Yield (t/ha)	Gross return ($/ha)	Variable cost ($/ha)						Net margin ($/ha)
			Land preparation	Seed and crop establishment	Fertilization	Weed control	Harvesting	Irrigation	
TPR IR29723-143-3-2-1[b] 31 kg N/ha as sesbania 4 wk 42 kg N/ha as other weeds 4 wk	2.0	328	61	46	52	40	47	23	59
TPR IR29723-143-3-2-1[b] 75 kg N/ha as sesbania 6 wk	2.3	377	70	46	59	34	54	23	91
TPR IR25587-133-3-2-2[b] 30 kg N/ha as azolla hauled 30 kg N/ha as PU	3.3	541	52	41	40	33	77	23	275
TPR IR25587-133-3-2-2[b] 30 kg N/ha as azolla in situ 30 kg N/ha as PU	2.7	443	40	46	23	32	63	23	216
TPR IR66[b] 60 kg N/ha as PU	3.4	566	54	49	18	20	81	23	321
TPR IR66[b] 30 kg N/ha as azolla hauled 30 kg N/ha as PU	3.2	525	49	53	26	44	75	23	245
TPR IR66[b] 30 kg N/ha as azolla in situ 30 kg N/ha as PU	3.4	566	48	46	32	23	81	23	313
TPR IR32429-47-3-2-2[c]	4.0	656	38	38	19	15	94	23	429
TPR IR66[d] 60 kg N/ha as PU	2.8	459	44	44	17	45	66	–	242
TPR IR66[c]	4.5	738	29	38	16	34	105	23	493
TPR IR32429-47-3-2-2[d] 60 kg N/ha as PU	1.8	295	41	44	16	45	42	–	106

[a] US$1.00 = ₱21.33. [b] Harvested October-November. PU = prilled urea. [c] Harvested September. [d] Harvested December.

Table 2. Economic analysis of second and third rice croppings harvested at different periods in irrigated lowland rice-based systems.[a] IRRI, 1988 WS.

Treatment[b]	Gross return ($/ha)	Cash outflow[c] ($/ha)	Net margin ($/ha)	Return on investment (%)
TPR IR29723-143-3-2-1 2d crop Sesbania 4 wk (October-November)	328	199	129	65
TPR IR29723-143-3-2-1 2d crop Sesbania 6 wk (October-November)	377	209	168	80
TPR IR25587-133-3-2-2 2d crop Azolla hauled (October-November)	541	166	375	226
TPR IR25587-133-3-2-1 2d crop Azolla in situ (October-November)	443	141	302	214
TPR IR66 2d crop PU (October-November)	566	141	425	301
TPR IR66 2d crop Azolla hauled (October-November)	525	172	353	205
TPR IR66 2d crop Azolla in situ (October-November)	566	149	417	280
TPR IR32429-47-3-2-2 2d crop PU (September)	656	110	526	478
TPR IR66 3d crop PU (December)	459	150	309	206
TPR IR66 2d crop PU (September)	728	117	611	522
TPR IR66 2d crop PU (December)	295	146	149	102

[a] US$1.00 = ₱21.33. [b] All at 60 kg N/ha. [c] Land preparation, seed and crop establishment, fertilization, and weed control.

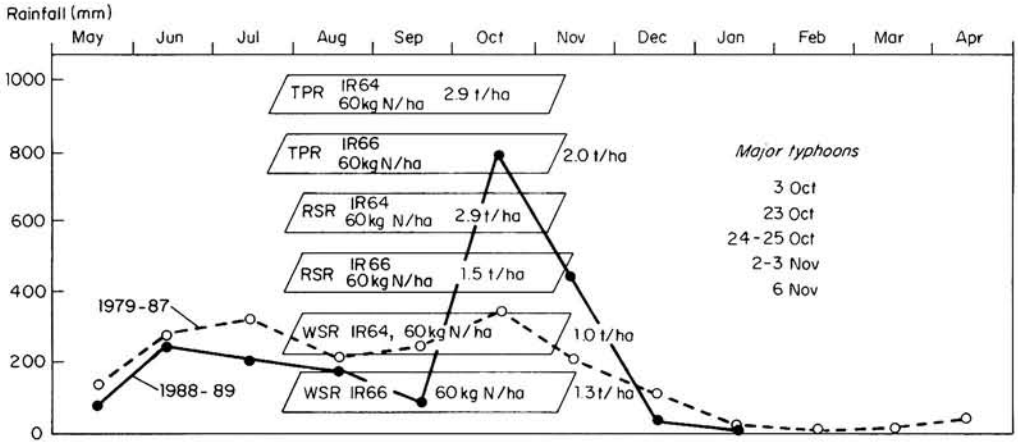
establishment. On the other hand, well-drained fields made thorough leveling difficult—thus favoring weed growth on higher portions—rendered preemergence herbicides inefficient, and increased the cost of weed management.

Sesbania and azolla in situ required 6 wk to propagate. Either of these GM crops prolonged turnaround time. Both of them were seen to have potential as organic N source for rice-based farming (see recommendations).

Rainfed lowland. Three weed control technologies involving two rice varieties, three cropping establishment methods (Fig. 2), and four weed management levels were evaluated from July to November 1988 for efficiency and economic feasibility under rainfed lowland rice-based systems.

Rainfall distribution was erratic when compared with the average rainfall from 1979 to 1987. Consequently, all treatments suffered from lack of water during the first half of the crop growth duration. Excessive rainfall and detrimental wind currents hit the crops during the reproductive phase. Rainfall was low in August at 186 mm, much lower in September at 90 mm, but was extremely high in October at 801 mm (Fig. 2). Lack of water during the early vegetative phase caused the preemergence herbicides to be ineffective. This water stress condition favored the emergence of creeping weeds *Cynodon dactylon* and *Polytrias amaura*.

Transplanted (TPR) IR64 and row seeded (RSR) IR64 outyielded the same treatments used on IR66. In contrast, wet seeded (WSR) IR64 grain



2. Alternative croppings for rainfed lowland rice-based systems, IRRI, 1988. RSR = row seeded rice.

Table 3. Economic analysis of WSR, TPR, and RSR and profitability of 2 rice varieties in rainfed lowland rice-based systems.[a] IRRI, 1988 WS.

Treatment	Yield (t/ha)	Gross return ($/ha)	Variable cost ($/ha)					Net margin ($/ha)
			Land preparation	Seed and crop establishment	Fertilization	Weed[b] control	Harvesting	
TPR IR64	2.9	476	58	43	15	120	68	172
TPR IR66	2.0	344	60	43	15	154	57	15
RSR IR64	2.9	476	59	25	18	144	68	162
RSR IR66	1.5	258	59	25	18	123	37	16
WSR IR64	1.0	172	61	26	21	167	24	−127
WSR IR66	1.3	224	61	26	21	100	32	−16

[a] US$1.00 = ₱21.33. [b] TPR received 0.75 kg ai butachlor/ha + 0.5 kg ai 2,4-D/ha at 4 d after transplanting, RSR received 0.45 kg ai sofit/ha at 3 d after seeding, WSR received 1.0 kg ai butachlor/ha at 3 d before seeding. One manual weeding operation done at 25 d after planting.

yield (1.5-2.9 t/ha) was inferior to that of WSR IR66 (Table 3, Fig. 2). TPR IR64 gained $162-$172/ha while TPR IR66 net margin was $15-$16/ha. Both WSR IR64 and WSR IR66 incurred losses of $16-$127/ha (Table 3).

IR66 reduced weed production more than did IR64 across all herbicide preemergence treatments. There were more weeds in RSR than in WSR, but more weeds in TPR than in RSR. WSR IR66 allowed 0.3 t weed dry matter yield/ha at 25 d after planting, while WSR IR64 allowed 0.5 t/ha (Table 4). As in WSR IR66, RSR IR66 allowed 0.3 t weeds/ha, while RSR IR66 allowed 0.8 t/ha for the same duration. TPR IR66 yielded 0.7 t weeds/ha, while TPR IR64 with 0.9 t/ha was the most weedy treatment.

When rainfall became limiting, neither preemergence herbicide nor manual weeding was economically advantageous for WSR establishment. WSR IR64 earned $15/ha, while WSR IR66 lost $25/ha with preemergence herbicide application (Table 5). WSR IR64 could have gained $48/ha without weed control instead of only $15/ha, while WSR IR66 could have saved $33/ha in addition to farmer's earnings for land preparation, crop establishment, and harvesting labor employment.

An unnecessary and uneconomical second manual weeding, which incurred $132-$188/ha added investment, increased grain yield by only 0.4 t/ha in TPR IR66, 0.3 t/ha in WSR IR64, and 0.1 t/ha in WSR IR66 (Table 5).

Recommendations for this situation follow:

- Grow only two rice crops in a year for maximum profit. A third rice cropping produces very minimal income.
- Whenever three rice crops are grown, grow two early-maturing, high-yielding rice varieties in succession during dry season and time the second harvest before heavy rains or typhoons are likely to occur. The third rice crop in the pattern should be resistant to diseases and lodging.
- Grow azolla in situ during the vegetative growth phase of the preceding rice crop in preparation for green manuring of the following crop, to minimize management and hauling costs.
- Produce low-cost farm-grown sesbania seed in a nursery with concrete flooring at row intervals of 1-1.5 m for easy collection of mature shattered seeds that can be swept at harvest time.
- Preemergence herbicides and manual weeding for WSR in rainfed lowland rice-based systems are not advisable with limited rainfall. When water is adequate, one weeding may be done and as early as possible.
- Mechanical or manual weeding, or both, for TPR and RSR are advisable when water is sufficient.

Table 4. Grain yield and weeds (oven-dry weight) harvested from TPR, RSR, and WSR plots as affected by weed management level in rainfed lowland rice-based systems. IRRI, 1988 WS.

Treatment[a]	Grain yield (t/ha)	Weed dry matter yield[b] (t/ha)		
		25 DAP	50 DAP	100 DAP
TPR IR64				
Chemical and mechanical	2.3	0	0	0.6
Mechanical and manual	2.9	0.9	0	0.7
Manual once	2.9	0.9	0	0.5
Manual twice	2.9	0.9	0.7	0.5
TPR IR66				
Chemical and mechanical	1.7	0	0	0.8
Mechanical and manual	3.2	0.7	0	0.6
Manual once	2.0	0.7	0	0.4
Manual twice	2.4	0.7	0.7	0.3
RSR IR64				
Chemical and mechanical	1.3	0	0	0.4
Mechanical and manual	1.9	0.8	0	0.4
Manual once	2.9	0.8	0	0.6
Manual twice	2.4	0.8	0.8	0.5
RSR IR66				
Chemical and mechanical	1.1	0	0	0.4
Mechanical and manual	1.3	0.3	0	0.4
Manual once	1.5	0.3	0	0.4
Manual twice	1.9	0.3	0.6	0.4
WSR IR64				
Chemical and mechanical	1.1	0	0	0.6
Mechanical and manual	1.1	0.5	0	0.3
Manual once	1.0	0.5	0	0.3
Manual twice	1.3	0.5	0.9	0.3
WSR IR66				
Chemical and mechanical	0.9	0	0	0.6
Mechanical and manual	1.1	0.3	0	0.3
Manual once	1.3	0.3	0	0.4
Manual twice	1.4	0.3	0.6	0.3

[a] Chemical weed control as preemergence herbicides, mechanical weeding as manually operated rotary weeder.
[b] DAP = days after planting.

Table 5. Profitability of TPR, RSR, and WSR at different weed management levels in rainfed lowland rice-based systems.[a] IRRI, 1988 WS.

Treatment	Yield (t/ha)	Gross return ($/ha)	Variable cost ($/ha)		Net margin ($/ha)
			Weed[b] management	Other inputs	
TPR IR64					
Chemical and mechanical	2.3	377	34	184	159
Mechanical and manual	2.9	476	103	184	189
Manual once	2.9	476	86	184	206
Manual twice	2.9	476	154	184	138
TPR IR66					
Chemical and mechanical	1.7	279	34	175	70
Mechanical and manual	3.2	525	108	175	242
Manual once	2.0	328	120	175	33
Manual twice	2.4	394	188	175	31
RSR IR64					
Chemical and mechanical	1.3	213	52	170	-09
Mechanical and manual	1.9	312	70	170	72
Manual once	2.9	476	92	170	214
Manual twice	2.4	394	151	170	73
RSR IR66					
Chemical and mechanical	1.1	180	45	139	-04
Mechanical and manual	1.3	213	126	139	52
Manual once	1.5	246	78	139	29
Manual twice	1.9	312	132	139	41
WSR IR64					
Chemical and mechanical	1.1	180	33	132	15
Mechanical and manual	1.1	180	0	132	48
Manual once	1.0	164	134	132	-382
Manual twice	1.3	213	188	132	-107
WSR IR66					
Chemical and mechanical	0.9	148	33	140	-25
Mechanical and manual	1.1	180	0	140	40
Manual once	1.3	213	67	140	06
Manual twice	1.4	230	115	140	25

[a] US$1.00 = ₱21.33. [b] Chemical weed control as preemergence herbicides, mechanical and manual weeding at 25 DAP, second manual weeding at 50 DAP.

Engineering technologies

Agricultural Engineering and Multiple Cropping Departments; University of the Philippines at Los Baños; Philippine Department of Agriculture, Department of Trade and Industry, and National Manpower and Youth Council; and University of Hohenheim, Germany

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The Agricultural Engineering Department is oriented toward technologies and coordinated systems that will elevate human dignity, reduce drudgery, improve efficiency, and raise profitability in farming. The program of the Department is broader than just mechanization; it includes the application of the science and practices of engineering to all areas of concern and relevance to engineering in a rice-dependent agriculture.

LAND PREPARATION

Agricultural Engineering Department

Improvements to the PT3 power tiller. Machine designs need to be regularly upgraded to avoid design obsolescence and keep up with changing demands. The PT3, IRRI's largest pedestrian tractor, has been through a transmission design simplification and upgrading stage. A pair of dog clutches and an RC 60 chain in the final drive were installed on the PT3 with modified rotary tiller attachment. The modified unit was placed on a test program in both lowland and upland fields; no failure in the transmission was encountered. The unit was also assessed for incorporating sesbania under upland conditions. During these tests, the rotary blades were replaced with slasher blades on a cylindrical hub designed to minimize winding of the tall green manure (GM) crop around the rotating assembly. The modification was successful in preventing wrapping.

When used on fallowed dry soil, frequent breakage of the rotary tiller blades and some loosening of blade sockets were observed. The rotary tiller transmission chain had also stretched excessively, indicating that the chain was overloaded under those soil conditions. These tests indicated the limitations of the machine on fallowed dry soil.

The modified design of the steering clutches and the intermediate drive of the rotary tiller performed satisfactorily in 200 h of field testing (Fig. 1).

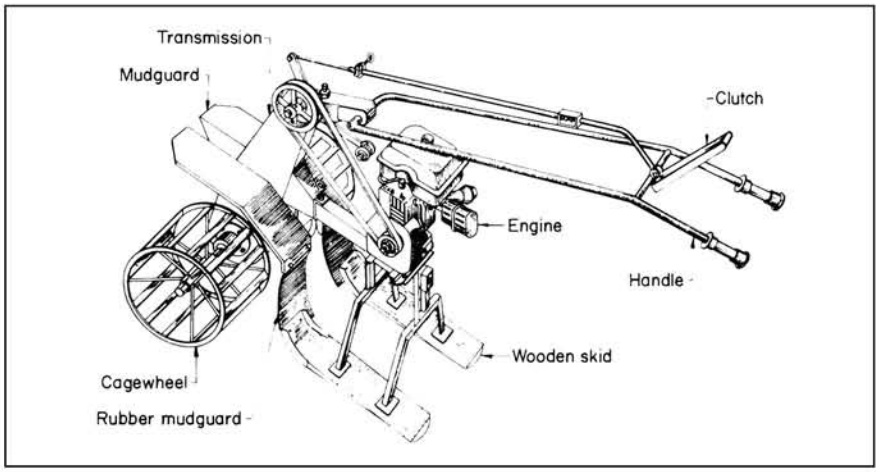
PT6—a new small power tiller. A small power tiller, the PT6, was designed, incorporating certain novel features. The prototype has transmission reduction ratios ranging from 10.13 to 11.11, depending on the sprockets used, for better chain life. The transmission casing was designed to fit RC 40/50, RC 50/50, RC 40/60, and RC 50/60 chain and sprocket combinations in the transmission. The sprocket-shaft assembly was simplified for easier assembly and changing of components. The casing was redesigned such that oil leaks from the transmission, a persistent problem in most local tillers, are avoided. The casing can be fabricated in small shops without using a press and dies.



1. Green manure incorporation for upland. IRRI, 1988.

The prototype weighs 105 kg, including its 5-hp gasoline engine, and has a moldboard plowing capacity of 11 h/ha for an average fuel consumption of 1.48 liters/h. Harrowing with a comb harrow took 7.7 h/ha and fuel consumption of 1.4 liters/h with a 7.5-hp gasoline engine. Tests were successfully conducted with a 2-disc plow using the 5- and 7.5-hp gasoline engines and with a 4-hp diesel engine.

The new design can be readily converted into a hydrotiller by transferring the engine to the rear and adding a pair of wooden skids. "Road speed" (130-150 rpm) is used on the axle shaft. Initial tests of the setup (Fig. 2), which will be called the



2. Transformer power tiller, PT6. IRRI, 1988.

"Transformer," indicated the design has good potential for such operations. Further testing is required before release of the PT6 to manufacturers.

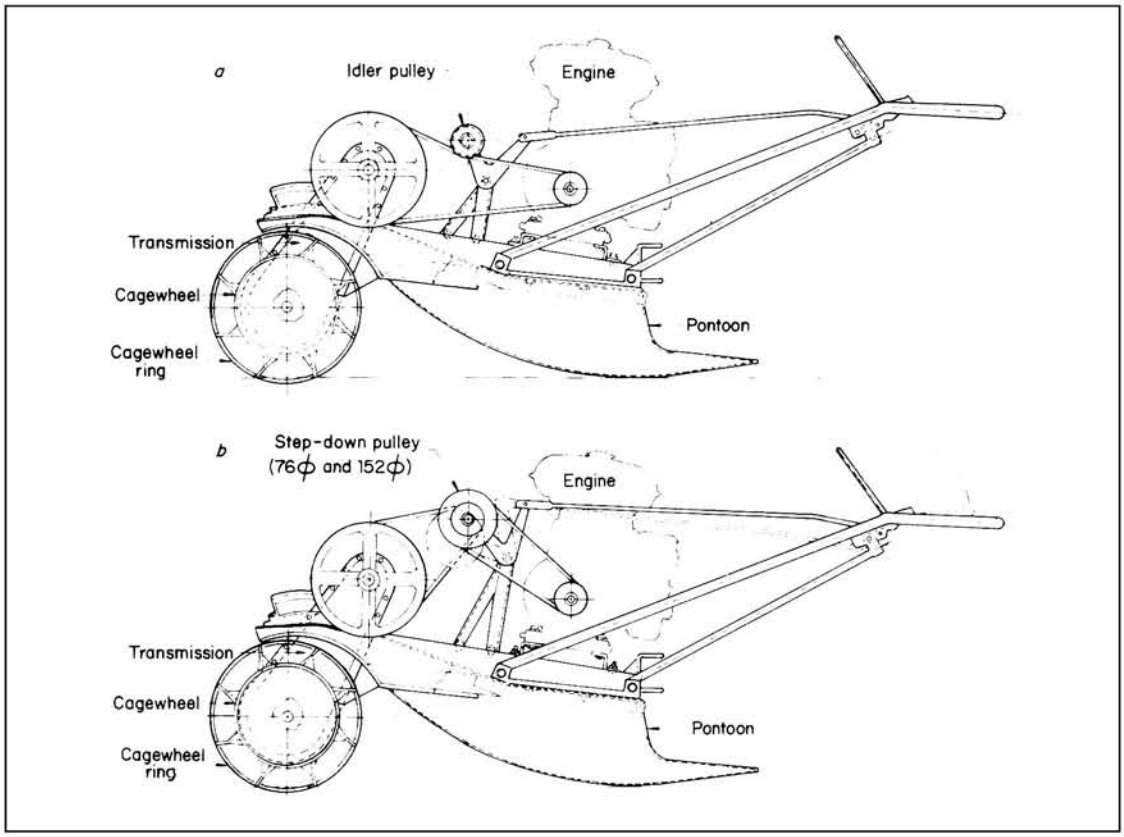
Hydrotillers. A floating rototiller that can puddle fields uniformly with fewer operations and can reduce costs accordingly was developed under the earlier Philippine Department of Agriculture-IRRI Program for Small Farm Equipment Development. IRRI's hydrotiller has twin hulls or pontoons for effective planing through puddled soil, unlike the single-hull floating tillers, which create canals or furrows on puddled soil and thereby require additional leveling operations. The hydrotiller was tested and proven highly effective in incorporating GM, weeds, and residues. It can incorporate sesbania even up to a crop height of 2 m (Fig. 3).



3. Tall sesbania incorporation with hydrotiller. IRRI, 1988.

Previous tests on the hydrotiller concentrated on functional performance compared with single-float commercial floating tillers and indicated better performance of the IRRI hydrotiller, especially in ease of handling, due to its balanced design. The design was subsequently released to selected manufacturers. Very recent comparative field tests between an IRRI hydrotiller and a manufacturer's hydrotiller were conducted to determine the operating forces and to assess drive trains. Both machines were similar, but the IRRI prototype had a modified clutching mechanism using an idler pulley, while that of the commercial model (CM) hydrotiller used the original design, an overcenter engine mount clutch. The idler pulley clutching system was chosen because it gave flexibility in choice of engines and better balance to the machine in operation. The distance between the engine and the cagewheel of the IRRI prototype was also longer than in the CM. Upward and downward forces to control depth of cut of the cagewheel, acceleration of the machine, and sideward force to control the machine's direction during tilling and headland turning were monitored.

To facilitate road transport, an intermediate reduction pulley was designed as an attachment for the hydrotiller, to be placed between the engine drive and the transmission input pulley. The intermediate pulley (Fig. 4) actuates in the pivot bushing of the removed idler clutch and stretches



4. Hydrotiller setup for field operation (a) and transport (b).

the belts when engaged for power transmission, but loosens when disengaged. This pulley was made quickly removable, to enable the operator to restore the original idler clutch when the hydrotiller is needed for puddling or residue incorporation.

Different shapes of hulls or pontoons for floating tillers were evaluated under laboratory conditions, as part of a graduate student project at IRRI, to provide criteria for optimizing designs for wetland conditions. The study revealed that the drag resistance of hulls was significantly influenced by the weight on the hull and by the hull length-to-width ratio (L:W). When the hulls operated at a shallow sinkage (less than 4-5 cm, with ground pressure of 5.7-6.9 kPa), drag resistance was not much affected by compaction in soft soil.

The drag of the elliptical hull changed when the hull was moved from hard to soft soil, but the difference was not significantly affected by soil compaction. The elliptical shape proved better suited to a wider range of soil conditions than other types of hulls, without adverse effects on mobility. Although all L:Ws of the elliptical-shaped hull considered (1.3-2.3) ensured stable operation and low drag, the lowest ratio gave the least drag.

At least 10 Philippine manufacturers have subsequently begun commercial production of the IRRI hydrotiller design, and overseas interests are being developed.

CROP ESTABLISHMENT

Agricultural Engineering and Multiple Cropping Departments

Plow drum seeder (*Agricultural Engineering*). The plow-mounted drum seeder, developed for use in minimum tillage systems, was redesigned to re-

duce its cost to $15 or less and its weight to not more than 5 kg.

Field tests on the attachment for hill metering (Fig. 5) showed that seed, particularly rice, that became wedged between the drum and the cover either was milled or jammed the drum. Transparent tubing was installed on the discharge hole of the cover to direct seed to the furrow bottom within a narrow band width. The metering cover was made detachable for drill seeding of rice or smaller seed, to avoid jamming. The clamp adaptor was also improved by wrapping a rubber band around the plow handle before clamping for better grip. An optional furrow closer was incorporated to cover the seed. The telescopic arrangement was extended and fitted with a handle for convenient lifting of the whole assembly at headlands.

Manual upland seeder (*Agricultural Engineering and Multiple Cropping*). The manual upland seeder was designed as a low-cost, lightweight machine for manual operation or to be animal drawn for rice and legumes. Its design was further modified.

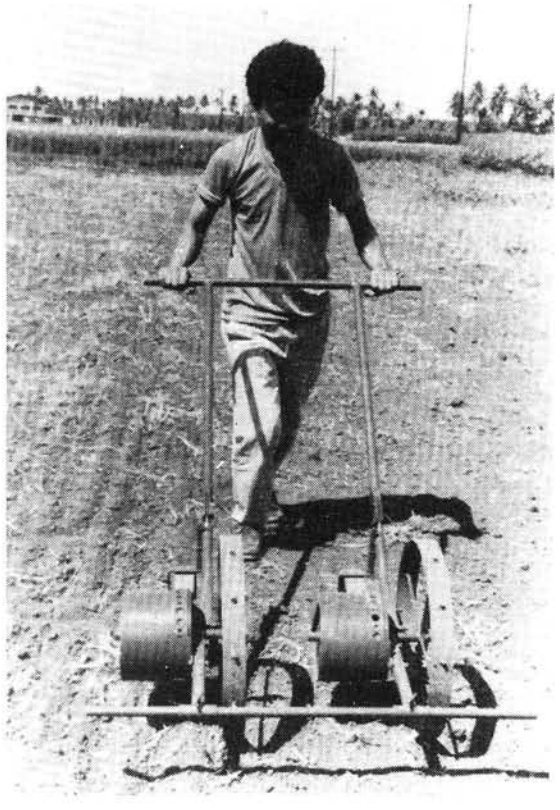
The seeder (Fig. 6) utilizes the same seed metering device as the plow drum seeder. It has a narrow, parabolic furrow opener with transparent flexible tubing to deliver the metered seed into the furrow just before the soil moves back to cover the seed. An optional presswheel trails behind the delivery tube to close the furrow and ensure good seed-soil contact.

In initial tests, the push-type seeder performed well on well-prepared soil. However, in fields with clods > 5 cm in diameter, the seeder was unstable, and clods often jammed between the furrow opener blade and ground wheel. Seeds were also not adequately covered because they bounced in cloddy soils during furrowing.

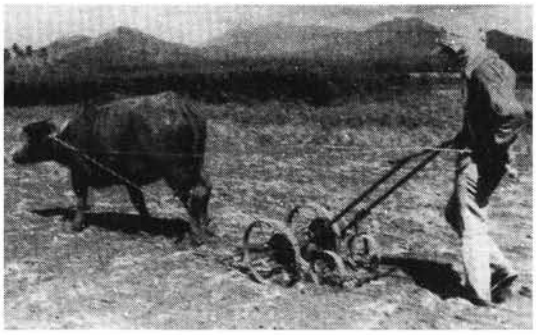
A two-row seeder pulled by a water buffalo (Fig. 7) performed as well as did the push-type machine. A laboratory test on drum metering will



5. Plow drum seeder. IRRI, 1988.



6. Manual upland seeder. IRRI, 1988.



7. Two-row upland seeder. IRRI, 1988.

be conducted to evaluate seeding performance with various seeds.

IRRIGATION AND WATER HANDLING

Agricultural Engineering Department, University of the Philippines at Los Baños, and Philippine Department of Agriculture

Evaluation of the treadle (tapak-tapak) and rower pumps (*Agricultural Engineering and University of the Philippines*). A test comparison was conducted, in collaboration with the Agricultural Machinery Testing and Evaluation Center of the University of the Philippines at Los Baños, of the treadle and rower pumps to evaluate their technical and ergonomic performance.

The treadle pump required more leg force to operate than the hand-operated rower pump (Table 1, 2). However, the treadle pump had a higher output than the rower pump. Heartbeat measurements of the operators of the two pumps were about the same, indicating no substantial difference in overall operational effort.

Small electric pumps for supplementary irrigation (*Agricultural Engineering and Philippine Department of Agriculture*). With the progress of rural electrification in developing countries in view, the Agricultural Engineering Department, in collaboration with the Bureau of Plant Industry of the Philippine Department of Agriculture, developed small electric pumps to help small farmers in rainfed lowland areas tap groundwater during dry periods. The IRRI "Wattmiser" self-priming electric pump series can provide supplemental irrigation for 1-3 ha of rice using a matching single-phase electric motor from 0.37 to 1.13 kW (Table 3). The pump's impeller is 115 mm in diameter but can be supplied in varying widths (Fig. 8) to suit different flow rates and electric motor sizes. A Wattmiser pump powered by a 0.56-kW motor can lift about 225 liters water/min against an operating head of 6 m.

In a test in northern Luzon, a 0.56-kW IRRI Wattmiser operating in a tubewell cost about US$0.10/h to operate, while a pump driven by an engine consuming 1 liter gasoline/h cost about US$0.32 for the same water output. Farmers like the Wattmiser, not only because of its low purchase price (40-50% lower than imported models of the same output), but also because they can pay for energy through monthly electric bills. A manufacturer in Manila has started mass-producing Wattmiser pumps.

Flowmeter for testing pumps (*Agricultural Engineering*). An important variable in evaluating water pumps is output capacity. This is obtained by measuring the amount of water that flows into a calibrated container within a predetermined period. A flowmeter was developed to obtain accurate data by fewer persons during testing of

Table 1. Volumetric efficiency of tapak-tapak and rower pumps at different static heads. IRRI, 1988.

Parameter	Volumetric efficiency at 4 static heads							
	Treadle pump				Rower pump			
	3 m	4 m	5 m	7 m	3 m	4 m	5 m	7 m
Strokes per minute (no.)	39.48	34.74	31.89	30.31	29.78	29.92	30.34	26.46
Discharge (liters/min)	95.82	62.82	59.22	59.22	45.62	37.20	37.20	35.40
Volume (liters) per stroke	2.42	1.81	1.85	1.95	1.53	1.49	1.22	1.37
Piston displacement (liters)	3.93	3.93	3.93	3.93	2.09	2.09	2.09	2.09
Volume efficiency (%)	61.83	46.05	47.23	49.62	73.08	71.79	58.48	64.11

Table 2. Average increase in heartbeat rate of 3 operators after 15 min of pumping at different static heads. IRRI, 1988.

Static head (m)	Heartbeat rate					
	Treadle pump			Rower pump		
	Before	After	Ratio	Before	After	Ratio
3	73	113	1.55	77	105	1.36
4	80	105	1.31	78	106	1.36
5	70	93	1.32	74	98	1.32
7	76	110	1.45	71	104	1.46

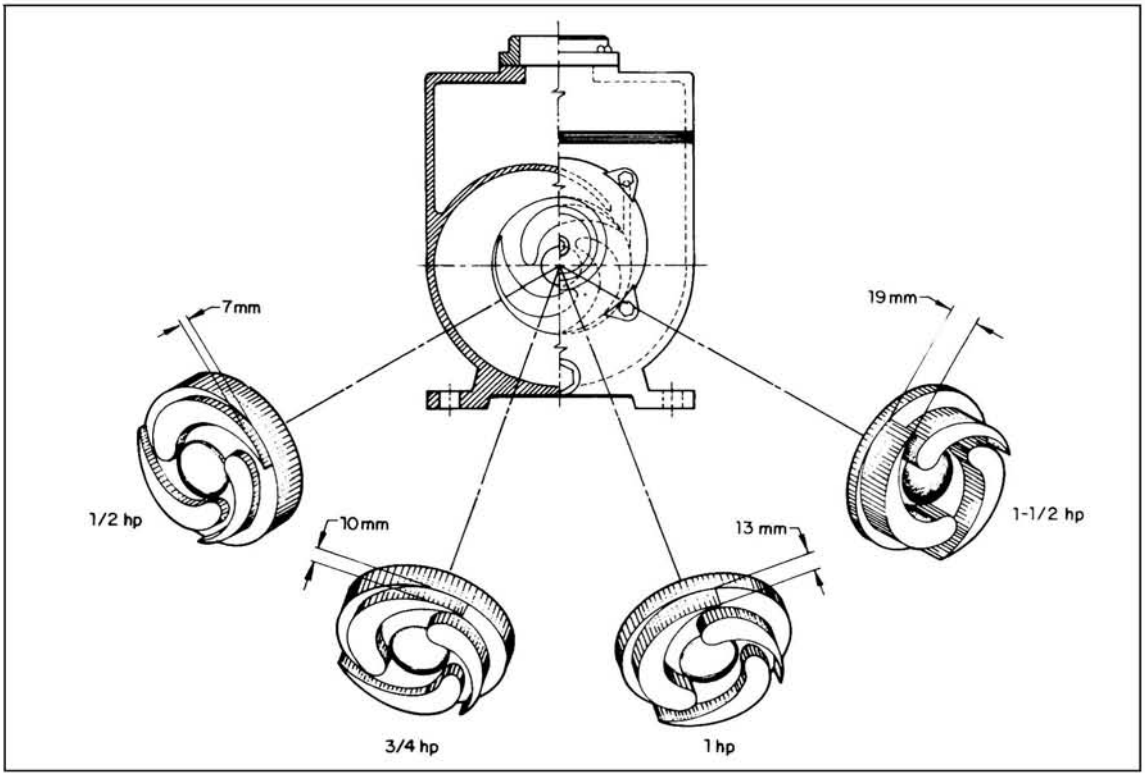
Table 3. Selecting a Wattmiser pump for use on clay loam soil. IRRI, 1988.

Model	Motor size (kW)	Area serviced (ha) at 8 m lift			
		12 h	16 h	20 h	24 h
WM 50	0.37	0.5	0.7	0.8	1.0
WM 75	0.56	1.0	1.3	1.7	2.0
WM 100	0.75	1.5	2.0	2.5	3.0
WM 150	1.13	2.0	2.7	3.3	4.0

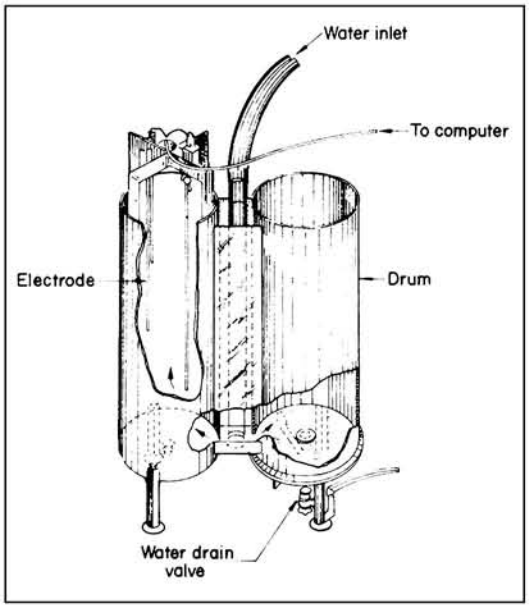
IRRI's hydraulic ram. A sensor, placed in the container of known volume, sends a signal to the data acquisition computer (IBM PC) when the container is full.

The container consists of two vertical cylindrical drums coupled together as shown in Figure 9. The flowing water to be measured is delivered to an inlet pipe placed inside the space between the drums. Water flows into the bottom of the container to keep the water surface level and stable. The space between the drums also serves as a stilling tank to prevent turbulence. Water from this space flows smoothly inside the two drums, which are provided with a 4-cm-width opening from the bottom up to 3 cm below the top level of the tank.

Time is measured accurately by four electrodes at preselected levels occupying equal spaces in one of the drums. Each electrode has a 4.5-V battery connected in series to the analog input terminal of the data acquisition computer. An Omnidata Polycorder model 516 C with 10-chan-



8. IRRI Wattmiser impeller dimensions for different motor hp. IRRI, 1988.

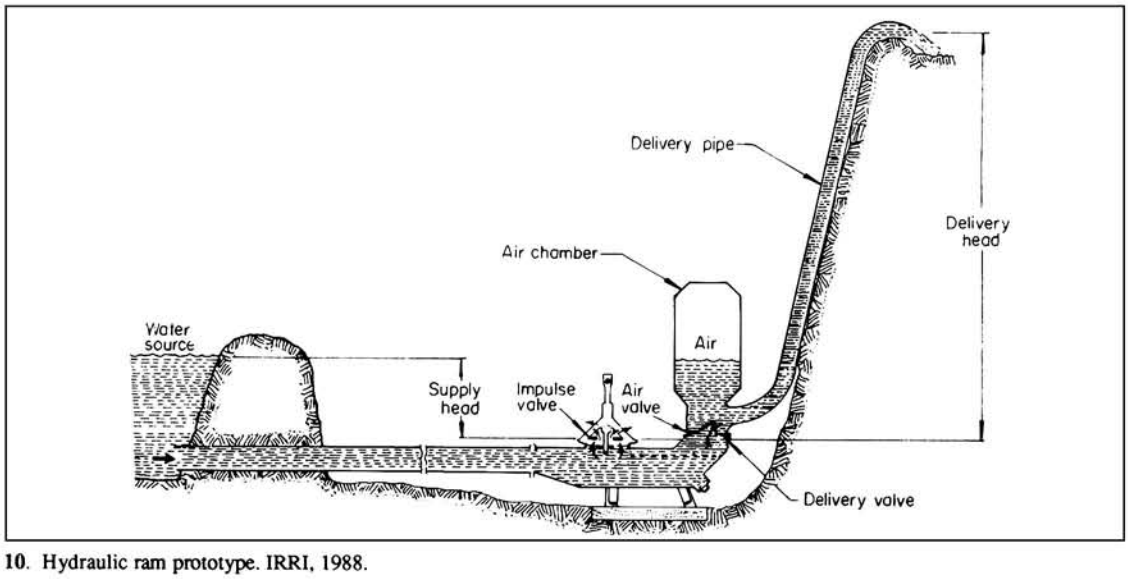


9. Water flowmeter assembly. IRRI, 1988.

nel analog input of 5 V is used. The body, made of galvanized steel sheeting, serves as the fifth electrode connected to the common and low-level ground terminal of the Polycorder. The electrode and water, as electrical conductors, serve as the switch component of the circuit so that, when flowing water touches any electrode, the 4.5-V battery connects directly to the input of the Polycorder. The Polycorder has an internal preprogrammed timer so that when there is an input signal higher than 3 V it will simultaneously record and store in its memory the time elapsed. The longest electrode measures the reference time, while the other three electrodes measure flow for three replications. The Polycorder is also programmed so that when water reaches all electrodes the flow in liters per minute is computed, displayed on the screen, and stored. When the measurement is finished and one drum is full, water is removed through a quick discharging mechanism installed in the other drum.

Hydraulic ram (*Agricultural Engineering*). Although hydraulic rams have been manufactured by foundries for many years, there is surprisingly little published data on the design. A commercial catalog of hydraulic rams for models with a minimum delivery of 75 liters/min, the minimum required for supplementary irrigation for 1 ha of riceland, revealed that the rams were designed for higher supply and delivery heads than a supply head of 1.2 m and 6-m delivery head—the practical design criteria for rice farmers in Asia.

A project was initiated to design a portable hydraulic ram to deliver 75-150 liters/min at a supply head of 1.0-1.2 m and a 5-m delivery head. A 190-mm hydraulic ram prototype was fabricated from USG 14 steel sheeting with a resulting weight of 41 kg (Fig. 10).



10. Hydraulic ram prototype. IRRI, 1988.

Tests were conducted using a computer data acquisition system and appropriate transducers, strain gauges, weirs, and a special flowmeter. The test parameters monitored included supply head, delivery head, length of supply pipes, diameter of supply pipes, valve clearance, and valve weight. Data sets were generated for prospective users of hydraulic rams.

Animal-driven pump (*Agricultural Engineering*). Draft animals are 10 times more powerful than humans and can pump more water in a shorter time; however, there has been little detailed research on animal-powered irrigation pumps for tubewells.

Two prototypes of a 2-stage epicyclic sprocket power transmission were designed and fabricated with speed ratios of 1:15 and 1:28.5. The drive head concept (Fig. 11) was designed for a water pump, rice thresher, grain cleaner, rice huller, or grain mill, or for use on a low-lift tubular pump by a single water buffalo.

Initial design testing determined the optimum sizes of pump bore and stroke length for both prototypes.

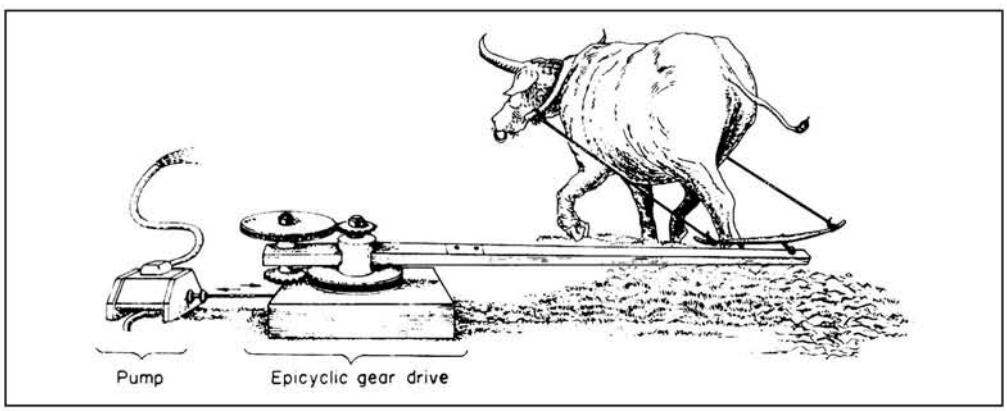
The first prototype was limited to water pumping less than a 3-m head with the 15-cm (6-in) nominal bore. The second prototype gave a head of 5 m. Further design tests were done to compare the performance of 13- and 15-cm (5- and 6-in) bores at different stroke lengths (Table 4). A 15-cm (6-in) bore and stroke lengths of 127 and 152 mm required pulling forces greater than sustained water buffalo operating capability. A 13-cm (5-in) bore pump was optimum at similar stroke length, generating a flow rate ranging from 0.108 to 0.18 m^3/min.

A pedal thresher was tested for possible adoption and modification using the animal-driven power gear. The results indicated a pulling force requirement of 98-490 N, which is well within the pulling capacity of an average water buffalo.

HARVESTING

Agricultural Engineering Department

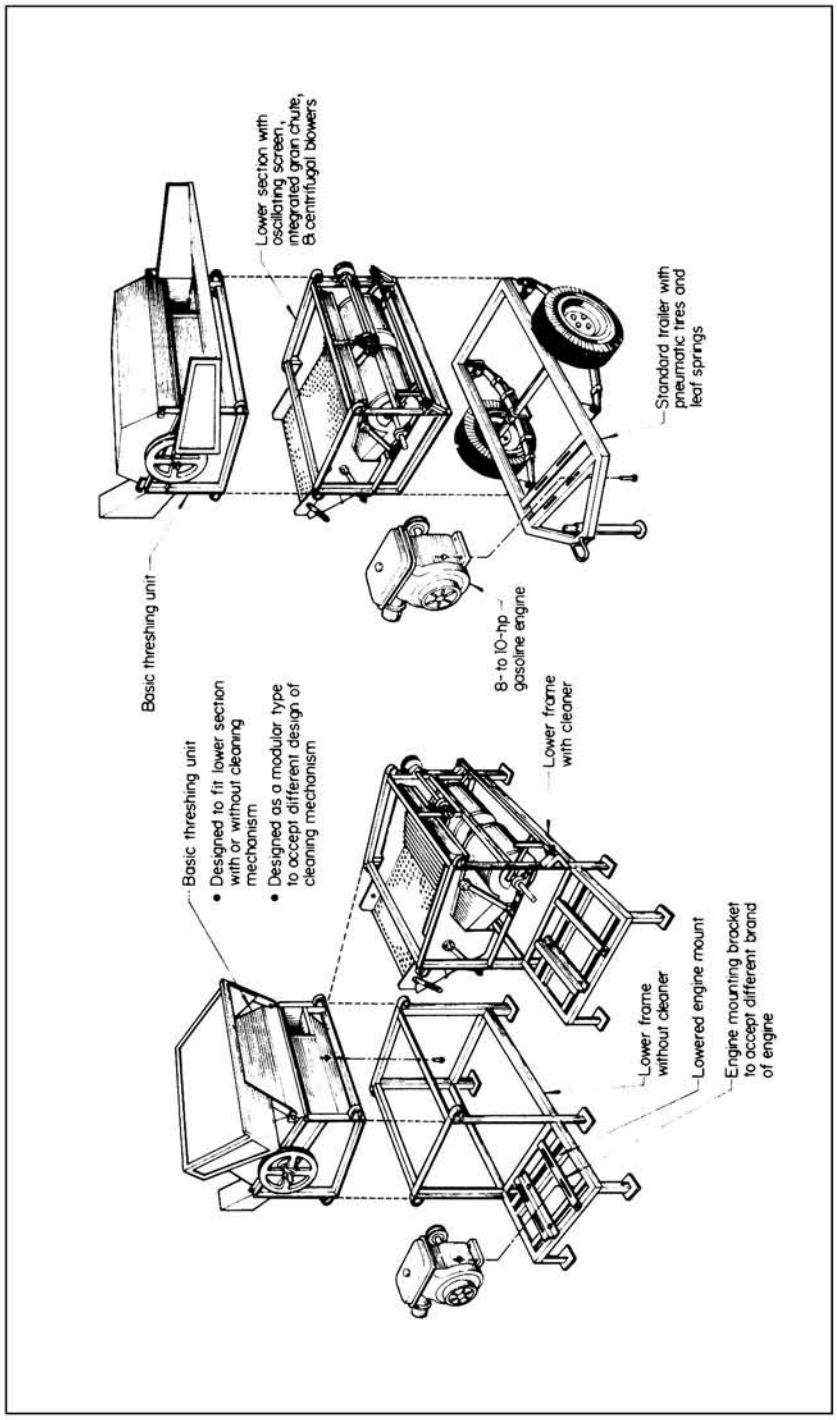
Improved portable thresher, the "modular thresher." Since the first IRRI portable thresher (TH6 model) was released more than a decade



11. Animal-driven pump. IRRI, 1988.

Table 4. Design test results of 13- and 15-cm (5- and 6-in) bore double-acting water pumps at 3 stroke lengths (transmission ratio = 1:28.5). IRRI, 1988.

Stroke length (mm)	Discharge (m^3/min)		Arm speed (RPM)		Stroke speed (stroke/min)		Pulling force (N)	
	13 cm	15 cm	13 cm	15 cm	13 cm	15 cm	13 cm	15 cm
101.6	0.12	0.18	1.80	2.60	51.3	74.1	278.3	392-686
127.0	0.13	–	1.28	1.53	36.5	43.6	372.4	> 882
152.4	0.48	–	2.55	1.53	72.7	43.6	399.8	> 882



12. Improved modular-type portable thresher. IRRI, 1988.

ago, adoption has been widespread. It has been conservatively estimated that 300,000 units have been manufactured. A very recent report from Vietnam indicates that there are 60,000 axial-flow threshers in the Mekong Delta alone. Some manufacturers have incorporated features or have modified the basic design to improve its performance. The original design has also been continuously improved by IRRI, and blueprints continue to be sent to interested manufacturers. The same axial-flow threshing, throw-in feeding, open threshing cylinder is retained in the modular thresher (Fig. 12).

Design specifications of the modular thresher to replace the TH6 are as follows:

Target threshing capacity	600-800 kg/h
Separation loss, maximum allowable	0.3%
Rice straw length	40-60 cm
Purity of threshed grain	85-92%
Target weight	120-180 kg
Estimated power requirement	3.7-6 kW
Calculated peripheral velocity	17-19 m/s
Concave length	77 cm
Angle of concave wrapping	202°

The concave was a larger angle of wrap (202°) and is divided into two sections, the first section comprising an aggressive rasp bar designed to have a varying clearance between the concave bars and the cylinder peg tooth. The second section has a standard grill made of round bars. Optional concaves can be provided for multicrop threshing. A semihexagonal cover with spiral guide vanes was adopted for easier fabrication. The tip diameter of the thrower paddle and the angle of discharge were increased to throw the straw farther. The engine was mounted low to reduce vibration. The main feature of this model, however, is its adaptability to different cleaning systems. The cheapest basic module has no cleaning mechanism, but blowers and screen, with or without pneumatic tires and leaf springs (trailer type), can be assembled on the basic unit without modifications (Fig. 12, right).

Two prototypes of the basic threshing module (without grain cleaner) were fabricated in early July, and initial testing showed that the basic modular thresher can effectively thresh up to 1.5 t/h of short-straw rice (60 cm) and about 0.7-1.0 t/h of long-straw rice (80 cm). However, the separation losses ranged from 1.0 to 2.2%.

The grain cleaner module was also completed and tested. Average capacity was about 820 kg cleaned grain/h. Hopper capacity is approximately 80 kg.

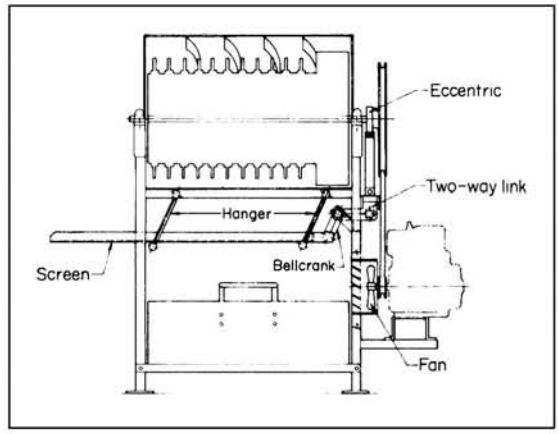
When the grain cleaner module was directly attached to the basic threshing unit (Fig. 13), at higher throughputs grain overflowed at the end of the oscillating screen. The total weight of the modular thresher with oscillating grain cleaner was 257 kg with a 10-hp engine. This weight exceeded our target.

Several modifications are being undertaken:

- counterpegs to be installed in the concave to reduce separation loss,
- redesign for weight reduction, and
- increased screen area for better cleaning efficiency.

Foot-powered thresher. A prototype of a foot-powered hold-on thresher with longer drum, able to accommodate up to four operators simultaneously, was designed and fabricated. This machine will be tested coupled to the animal-driven transmission power take-off.

Cross-flow fan for axial-flow thresher. The conventional paddlewheel fan commonly used in the axial-flow thresher has an uneven airflow discharge, which is less than ideal for the cleaning mechanism. The use of two identical fans mounted



13. Simplified oscillating grain cleaner setup for TH6 thresher. IRRI, 1988.

side by side with a common shaft partially solved the problem for larger threshers, but this approach requires more materials and a more complex inlet shutter for controlling airflow.

A project was initiated to substitute a cross-flow fan, which gives a more uniform air velocity pattern at the outlet, for the existing paddlewheel fan. A cross-flow fan (Fig. 14) with 28-cm diameter and 77-cm-long rotor was fabricated, tested, and compared with the existing twin conventional fan. Initial results showed that the twin conventional fan has lower efficiency and requires more power than the prototype cross-flow fan with underslung inlet.

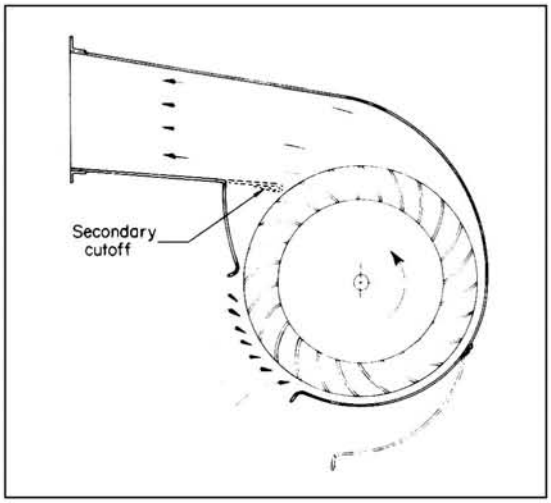
POSTHARVEST TECHNOLOGIES

Agricultural Engineering Department and University of Hohenheim, Germany

Solar tunnel dryer. A solar tunnel dryer designed at the University of Hohenheim, Germany, under a joint project with IRRI was built and tested (Fig. 15) to gather data on its performance characteristics in the tropics. Under adverse weather conditions the dryer was able to dry wet rice to moisture contents suitable for safe short-term storage.

The reduction of moisture content was faster with sun-drying because of the more frequent mixing and the thinner rice layer; however, drying capacity (defined as weight of rice dried on 1 m^2 in 1 h) was consistently higher for the solar tunnel dryer.

The overall efficiency of the solar tunnel dryer was at least 7% higher than that for sun-drying. Milling recovery for samples from both sun-drying and solar tunnel tests ranged from 70.4 to 73.4% (showing no significant difference), because the adverse effects of sun-drying were minimized by maintaining a thin drying rice layer and frequent mixing, as suggested by earlier studies. However, not all operators are careful enough to minimize fissuring when sun-drying on the pavement. Overdrying and grain damage have been noted in down-the-road monitoring surveys of pavement drying.



14. Cross-flow fan for thresher. IRRI, 1988. Rotor is 25.4 cm (10 in) o.d.

ENGINEERED PEST CONTROL

Agricultural Engineering Department

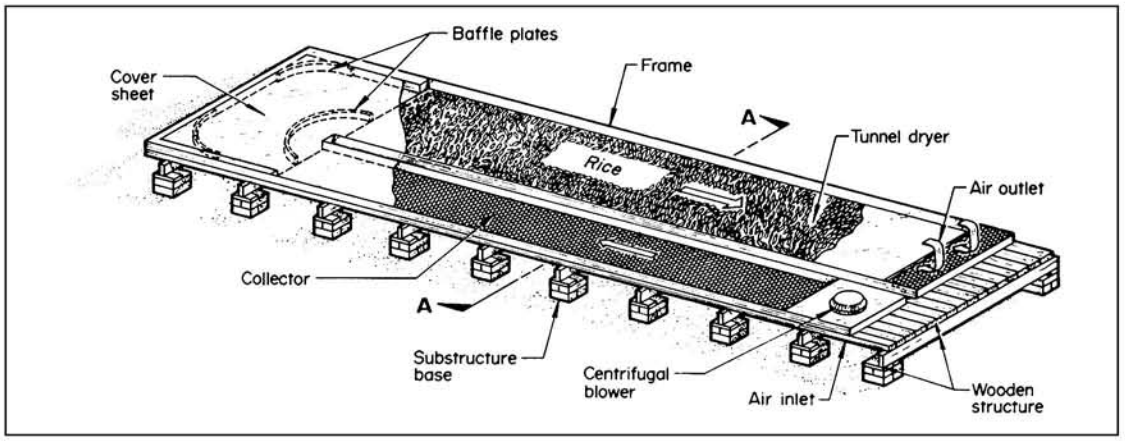
Rats, birds, and the golden snail continue to be major problems for rice farmers in the Philippines, and the rice rat is a problem worldwide. In the absence of biological agents, the Agricultural Engineering Department has embarked upon a program to help develop mechanical (nonchemical) methods to reduce pest damage. This approach is called engineered pest control (EPC).

The EPC attack on pests has commenced along several lines:

- improved designs of flame throwers for controlling rats and for coagulating snail egg masses,
- using lethal and nonlethal electrified wire, and
- using mechanical devices for trapping, collecting, and disposing of rats, nuisance birds, and snails.

This work is intended to be nonharmful to the environment, species-specific, and such that resistance cannot be developed by the target pests. Human safety is of primary concern. The field test program on these developments has just commenced.

Preliminary indications are that the use of the hydrotiller will reduce the golden snail population by half in one pass. This unexpected side benefit will be explored more thoroughly in statistically controlled experiments.



15. Solar tunnel dryer. IRRI, 1988.

ENGINEERING LIAISON AND TRAINING

Agricultural Engineering Department, Philippine Department of Trade and Industry, National Manpower and Youth Council, and Department of Agriculture

Liaison with Philippine Government. We conducted training seminars on manufacturing of appropriate agricultural equipment in collaboration with the Philippine Department of Trade and Industry and the National Manpower and Youth Council in

- Region X—in Cagayan de Oro City
- Region I—in Isabela, Cagayan
- Region VI—in Iloilo City

The lectures included interpretation of drafting plans and blueprints, some techniques of fabrication, applications, maintenance, and operation of agricultural machines.

Field machinery demonstrations and farmer training efforts were likewise conducted in collaboration with BPI engineers in localities assigned to the Department of Agriculture-IRRI Mechanization Program.

Liaison with manufacturers. At the end of 1988, a cumulative total of 326 collaborating manufacturers had been in touch with the Agricultural Engineering Department over the years. We estimate that currently 100 of these Philippine manufacturers are still actually in business and making IRRI-designed machines. In 1988, we mailed approximately 0.5 t of blueprints to enquirers worldwide free of charge.

A number of pieces of equipment, built locally to IRRI designs and specifications, were shipped overseas on behalf of sister institutions and the Food and Agriculture Organization during the year. In addition, the developmental workshop provided technical services to other departments of IRRI in design and fabrication of such items as a vacuum chamber, microtome soil samplers, centrifugal dewaterer, rice mill, fertilizer injector, insect traps, pollen separator, and soil samplers.

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We continued our training and educational programs in collaboration with national agricultural research systems. During the year, 517 scientists from 49 countries participated in these programs.

RESEARCH-ORIENTED PROGRAMS

Visiting scientist, postdoctoral scientist, and collaborative research scientist program. During the year, 65 senior scientists and young Ph Ds from 22 countries worked on various research projects at IRRI. Nineteen of them were designated visiting scientists, 32 postdoctoral scientists, and 14 collaborative research scientists and special research fellows (Table 1, 2).

These scientists came to IRRI to study in greater depth, and with the modern research facilities of IRRI, a research problem of significance to the rice ecosystem in their respective countries. While honing their research skills and interests in the field, they also contributed to the research activities of the Institute.

Degree program. The degree program continues to be an important component of IRRI's training programs. It directly addresses itself to the development of highly trained scientific manpower in the various national programs, particularly in countries where graduate education in agriculture is not yet well developed. IRRI collaborates with more than 30 agricultural universities all over the world in the graduate degree training of its scholars. In 1988, agreements were signed with Assam Agricultural University in India, the Universidad Federal de Pelotas in Brazil, and the Colegio de Post-Graduados in Mexico.

During the year, 83 Ph D and 55 MS scholars were in residence at IRRI (Table 1, 2). They represented 29 countries and more than 20 agricultural universities all over the world. The majority of the degree scholars are enrolled under the IRRI-University of the Philippines at Los Baños (UPLB) collaborative graduate program. They are guided in their academic programs by IRRI scientists, who are affiliate members of the UPLB Graduate Faculty, and their UPLB advisers, who jointly compose the scholars' graduate advisory committees. The rest of the scholars conduct their thesis research at IRRI after completing their courses at their university.

Table 1. Distribution of scholars and fellows by country.[a] IRRI, 1988.

Country	Scholars and fellows (no.)					
	VS1	PDS	CRS/ SpRF	Ph D	MS	ND
Asia						
Bangladesh	1	2	–	15	6	1
Bhutan	–	–	–	–	1	1
China	–	–	4	14	12	4
India	11	9	1	4	–	1
Indonesia	–	–	–	1	–	–
Iran	–	–	–	1	2	3
Japan	–	2	–	2		
Korea, Rep. of	–	2	1	7	1	4
Malaysia	–	–	–	–	–	1
Myanmar	1	–	–	2	8	
Nepal	–	1	–	9	–	–
Pakistan	–	2	–	6	–	–
Philippines	–	6	1	2	3	1
Sri Lanka	2	–	–	1	2	1
Thailand	2	–	–	2	11	2
Vietnam	–	–	–	1	1	6
Africa						
Egypt	–	3	–	1	–	–
Ghana	1	1	–	1	1	–
Kenya	–	–	1	–	–	–
Madagascar	–	–	–	–	3	2
Nigeria	1	1	–	–	–	–
Sierra Leone	–	1	–	–	–	–
Sudan	–	–	–	–	1	–
Tanzania	–	–	–	1	–	–
Latin America						
Brazil	–	–	–	–	1	–
Cuba	–	–	–	–	–	1
Mexico	–	1	–	–	2	–
Europe						
Belgium	–	–	1	1	–	–
Bulgaria	–	–	–	–	–	1
France	–	–	–	3	–	–
Germany, Fed. Rep. of	–	–	4	5	–	–
Netherlands	–	–	1	1	–	6
Switzerland	–	–	–	1	–	1
United Kingdom	–	–	–	1	–	–
North America						
Canada	–	–	–	1	–	–
United States	–	1				
Total	19	32	14	83	55	36

[a] VS1 = visiting scientist 1, PDS = postdoctoral scientist, CRS = collaborative research scientist, SpRF = special research fellow, Ph D = doctoral fellow, MS = masteral scholar, ND = nondegree student.

Nondegree training program. Thirty-six scientists from 16 countries participated in hands-on, apprenticeship-type training in the various departments and programs of IRRI.

Table 2. Distribution of scholars and fellows by department. IRRI, 1988.

Department	VS1	PDS	CRS/SpRF	Ph D	MS	ND
Agricultural Economics	1	2	–	7	5	3
Agricultural Engineering	1	1	–	–	7	–
Agronomy	–	4	2	8	9	2
Entomology	2	2	4	10	6	4
Cereal Chemistry	–	1	–	–	–	1
Communication and Publications	–	–	–	1	1	4
Experimental Farm	–	–	–	–	–	1
IRTP	2	3	–	1	1	1
IRGC	–	–	1	–	–	–
Library and Documentation Center	–	–	–	–	–	1
Plant Breeding	3	6	1	16	1	5
Plant Pathology/Seed Health Unit	3	6	3	8	3	6
Plant Physiology	1	3	–	5	2	1
Multiple Cropping/Rice Farming Systems Program	2	–	2	10	6	3
Soil Microbiology	3	–	–	3	1	1
Soils	–	2	1	3	1	1
Statistics	–	–	–	1	3	1
Training and Technology Transfer	–	1	–	2	–	–
Water Management	–	1	–	3	3	1
Overseas	1	–	–	5	6	–
Total	19	32	14	83	55	36

NONDEGREE COURSES

In 1988, IRRI offered 9 regular and 10 special short-term courses. The numbers of participants, by region and country, are given in Tables 3 and 4.

Regular courses. *Agricultural Engineering (AEC).* This 2-wk course complements IRRI's on-farm machinery development program and is offered to cooperators of IRRI's farm machinery program. It includes all aspects of design, manufacture, and field testing of IRRI-designed machines and develops the participants' competence in the operation and maintenance of appropriate machines.

Cropping Systems (CSTC). This 21-wk course enhances the research and extension capabilities of workers involved in cropping systems and development programs through theoretical and practical training in intensified, diversified multiple cropping techniques. A 2-wk training on research and extension project implementation and management is included and conducted in collaboration with the Research Management Center of UPLB. This was the last time the course will be offered on a regular basis. It will be integrated with the course on the socioeconomic aspects of farming systems and taught as a holistic farming systems course in the future.

Genetic Evaluation and Utilization (GEU). This 16-wk course complements IRRI's GEU research program and trains agricultural scientists in rice germplasm improvement and management. It covers the various types of rice culture, techniques of screening for varietal resistance or tolerance, as well as hybridization methods and evaluation of progenies.

Integrated Pest Management (IPM). This 18-wk course teaches integrated pest control strategies that consider the interaction of crop management, ecological factors, and the environment to effect crop protection. It emphasizes cost-efficient management strategies that rely on natural biological and environmental occurrences.

International Network on Soil Fertility and Sustainable Rice Farming (INSURF). This 16-wk course replaces the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) course. It provides participants with skills and concepts for promoting soil health for sustainable high yields and reducing production costs through increased input efficiency and by replacing purchased inputs with farm-produced ones.

Irrigation Water Management (IWMT). This 6-wk course enhances the engineering, agronomic, economic, socioinstitutional, and communication

knowledge and skills associated with sound irrigation water management principles and practices, proper identification of field-level water problems, and development of approaches to solve them.

Training and Technology Transfer (T3C). This 12-wk course trains professionals involved in training or technology transfer programs in the latest concepts and skills in developing human resources and disseminating technology. It em-

Table 3. Participants in regular short-term courses, by country and course.[a] IRRI, 1988.

Country	Participants (no.)									
	AEC	CSTC	GEU	IPM	INSURF	IWMT	T3C I	T3C II	WSTC	Total
East Africa										
Egypt	4									4
Madagascar		2						2	1	5
Sudan	1									1
Tanzania		2	1		1					4
Zambia									1	1
Subtotal	5	4	1	0	1	0	0	2	2	15
West Africa										
Benin			1							1
Burkina Faso				1						1
Cameroon			1		1					2
Ghana		1			1					2
Liberia		1			1					2
Nigeria	3				1				1	5
Sierra Leone		1	1	1						3
Subtotal	3	3	3	2	4	0	0	0	1	16
Asia										
Bangladesh		1		2		2		2	1	8
Bhutan		1	1		1	3		5		11
Brunei				1					1	2
Cambodia		3	1							4
China	4	1	4	1	3		6		2	21
India				2			4			6
Indonesia	1					2				3
Korea, Rep. of				1						1
Laos		2		2	1					5
Malaysia						2				2
Pakistan			1							1
Philippines	1	1		2		5			1	10
Sri Lanka	2	6		1		2	5			16
Thailand	1	2	1	2	2				1	9
Vietnam		3	2	3	1	2			1	12
Subtotal	9	20	10	17	8	18	15	7	7	111
Latin America/Caribbean										
Brazil			1							1
Cuba					1					1
Mexico	1								1	2
Subtotal	1	0	1	0	1	0	0	0	1	4
Middle East										
Iran			1			1				2
Turkey			1							1
Subtotal	0	0	2	0	0	1	0	0	0	3
Total	18	27	17	19	14	19	15	9	11	149

[a] AEC = Agricultural Engineering, CSTC = Cropping Systems, GEU = Genetic Evaluation and Utilization, IPM = Integrated Pest Management, INSURF = International Network on Soil Fertility and Sustainable Rice Farming, IWMT = Irrigation Water Management, T3C = Training and Technology Transfer, WSTC = Weed Science.

phasizes components of needs assessment and curriculum development, training media, methodologies, and the evaluation of training programs. It implements a team concept in training and culminates in a training program that is designed by a team. The course is conducted twice a year.

Weed Science (WSTC). This 10-wk course trains scientists in the design and implementation of weed science research programs that are integrated with other aspects of crop production to reduce yield losses and maximize profits while protecting the environment. This course is offered every 2 yr.

Special courses. *Data Base Management for Genetic Resources (DBMGR).* This 10-wk course addressed the increasing need for germplasm exchange among national and international cen-

Table 4. Participants in special short-term courses, by country and course.[a] IRRI, 1988.

Country	Participants (no.)											
	DBMGR	GEU-RFL	GRCM	IAFSR	PARSM	PTR	RPC-IC	RPC-MG	SHTR	SSARP	VIDL	Total
East Africa												
Kenya									1			1
Madagascar								12				12
Tanzania									1			1
Subtotal	0	0		0	0	0	0	12	2	0	0	14
West Africa												
Guinea-Bissau						1						1
Liberia									1			1
Niger						1						1
Nigeria		2							1			3
Zaire						1						1
Subtotal	0	2		0	0	3	0	0	2	0	0	7
Asia												
Bangladesh		3	1	3					1	4		12
Cambodia							13					13
China, except Taiwan	3		2						1	8		14
China, Taiwan			1									1
India	2	3							1	4		10
Indonesia	1		1	1	2				2	4	1	12
Korea, Rep. of			1							4		5
Laos		2					3					5
Malaysia									1			1
Nepal									1			1
Pakistan									1		1	2
Philippines	1			1	2				2			6
Sri Lanka	1		1	2					1			5
Thailand	1	2	1		1				1		1	7
Vietnam		1	1						1			3
Subtotal	9	11	9	7	5	0	16	0	13	24	3	97
Latin America/Caribbean												
Brazil									1			1
Colombia									1			1
Subtotal	0	0	0	0	0	0	0	0	2	0	0	2
Total	9	13	9	7	5	3	16	12	19	24	3	120

[a] DBMGR = Data Base Management for Genetic Resources, GEU-RFL = GEU on Rainfed Lowland Rice, GRCM = Genetic Resources Conservation and Management, IAFSR = Impact Assessment of Farming Systems Research, PARSM = Physical Aspects of Soil Management in Rice-based Cropping Systems, PTR = Prosperity Through Rice for African Scientists, RPC-IC = Rice Production Course for Indochinese, RPC-MG = Rice Production Course for Madagascans, SHTR = Seed Health Testing of Rice, SSARP = Simulation and Systems Analysis for Rice Production, VIDL = Varietal Improvement of Dryland Legume Crops for Rice-based Farming Systems.

ters by providing data base workers with expertise in computer systems and software relevant to germplasm work. The participants were provided with practical experience in techniques for characterizing, evaluating, and selecting genetic material; statistical and analytical procedures for analyzing genetic resources data; and IRRIGEN, an IRRI-developed microcomputer data base system for genebanks.

GEU on Rainfed Lowland Rice (GEU-RFL). This 15-wk course gave the participants an opportunity to learn basic methods for improving rainfed lowland rice, with emphasis on interdisciplinary activity and on-farm research. The course was concluded with a 1-wk field training session in Northeast Thailand.

Genetic Resources Conservation and Management (GRCM). This 9-mo course provided participants with theoretical and practical aspects of genetic conservation in relation to rice improvement. Prior to coming to IRRI for the actual training, the participants spent 3 mo in field collection of native cultivars and wild species of rice in their home countries.

Impact Assessment of Farming Systems Research (IAFSR). This 6-wk course was conducted as an activity of the Asian Rice Farming Systems Network in assessing the impact of farming systems research in Bangladesh, Philippines, Indonesia, and Sri Lanka. It familiarized participants with computer-based data management techniques to assess the impact of farming systems research; to utilize computer statistical packages to analyze data; to prepare the final study report for presentation at the end of the course; and to observe the conduct of the impact study in the Philippines.

Physical Aspects of Soil Management in Rice-Based Cropping Systems (PARSM). This 8-wk course gave junior scientists practical and theoretical training in the design and conduct of experiments associated with measurement methods for soil-physical management of rice - legume cropping systems.

Prosperity Through Rice (PTR) for African Scientists. On the request of the Food and Agriculture Organization (FAO) of the United Nations, this 40-d course was arranged to expose 3 African scientists to different rice-based technologies currently demonstrated in the PTR Demo Center at IRRI and some selected sites in the Philippines for possible application to African conditions.

Rice Production Course for Indochinese (RPC-IC). This 19-wk course was conducted as part of the IRRI-Indochina Project funded by the Australian Government to assist in the improvement of the agricultural economies of the Indochinese countries. The course was designed to continue developing an in-country team of Cambodian agriculturists who can lead and assist in the introduction and examination of modern rice technologies in Cambodia. In addition to the 13 Cambodians, 3 Laotians attended the course.

Rice Production Course for Madagascans (RPC-MG). This 17-wk course was designed to address irrigation, rice technology transfer, and extension needs for Madagascar. The participants, 7 extension chiefs and 5 junior researchers, were exposed to participatory management in irrigation systems through a 3-wk training session conducted by the College of Engineering of Central Luzon State University. They were instructed in the fundamental principles of teaching and learning as well as principles of extension in technology transfer. A third of the course was devoted to the transfer of important rice production concepts and practices. The course concluded with a case study and extension campaign for transferring irrigation parameters from the extension service to farmer-cooperators.

Seed Health Testing of Rice (SHTR). This 7-wk course trained technicians and laboratory scientists in detecting and identifying seedborne rice pathogens. It was jointly coordinated by IRRI and the Danish Government Institute of Seed Pathology for Developing Countries under the sponsorship of the Danish International Development Agency.

Simulation and Systems Analysis for Rice Production (SSARP). This 8-wk course aimed to develop a critical mass of scientists at national research stations and agricultural universities who can implement systems analysis and simulation of rice production. The course, attended by six teams of four researchers each, provided instruction on how modeling can improve research and extension work in rice production. It was jointly coordinated by IRRI and two institutions from the Netherlands: the Theoretical Production Ecol-

ogy Department of the Wageningen Agricultural University and the Centre for Agrobiological Research.

Varietal Improvement of Dryland Legume Crops for Rice-Based Farming Systems (VIDL). This 17-wk course was taught in cooperation with the Institute of Plant Breeding of UPLB. It acquainted the participants with aspects of varietal improvement research for rice-based farming systems such as hybridization, selection, and evaluation of material under actual field conditions; and screening of varieties against waterlogging, drought tolerance, and disease and pest resistance. The course included visits to on-farm trials in the Philippines and concluded with a 1-wk field visit in Thailand.

INSTRUCTIONAL RESOURCE DEVELOPMENT

Development of learner-driven courseware materials—in print-on-paper, slide-tape, and interactive computer-aided instruction formats—continued. At the end of the year, the status of courseware material development was as follows:

- *Print-on-paper*
  - Guidebooks: 2 published; 2 forthcoming
  - Basic skills series: Rice production (33 titles)—English edition published, French edition forthcoming; GEU—6 titles published, 6 titles forthcoming; T3C—10 titles forthcoming
  - Manuals: T3C objectives manual being revised
- *Slide-tape modules* (a complete module consists of a script, slide set, taped audio, and booklets). Rice production—4 titles completed, 3 completed except for booklet component, 1 with script and slide set; scripts of 45 titles edited and reviewed by content experts. Cropping systems—1 title completed, 2 with scripts and slide sets; scripts of 6 titles edited and reviewed by content experts.
- *Interactive computer-aided instruction* (script, content frame, lesson, and interactive components). Rice production—2 titles completed, 9 completed except for interactive components; scripts and content frames of 19 titles and scripts of 28 titles finished.

INSTRUCTIONAL RESEARCH

A study assessed the impact of IRRI short-term training on the alumni in terms of professional growth, utilization of knowledge and acquired skills, and job productivity. Respondents were 330 former trainees in 8 short-term courses who had completed their training in 1977-86. Responses were gathered using a 43-item mailed questionnaire. Analysis of results used frequency distribution, percentages, and summated means. Impact was assessed by way of a 5-point scale to measure training influence and usefulness.

Aspects of professional growth considered in this study were promotion, change in job responsibility, membership in professional societies, and professional advancement (Table 5). Training influence on all these aspects, except for membership in professional societies, was rated above the median.

In terms of knowledge utilization, usefulness of training to the job was rated high, as well as

Table 5. Training impact on professional growth of alumni of IRRI short-term training program, 1977-86.

Item	Affirmative response (no.)	Distribution (no.) over scale						Summated mean
		No response[a]	1 None	2	3	4	5 Very much	
Promotion	180	2	18	24	50	53	33	3.29
Changed responsibilities	199	4	12	14	55	77	37	3.51
Membership in professional societies	133	0	51	30	25	15	12	2.30
Professional advancement	307	23	6	14	64	114	86	3.62
MS/Ph D	82	0	3	3	20	34	22	3.84
Training/seminars	235	0	3	11	53	96	72	3.95
Subscriptions	80	0	1	5	14	33	27	4.00

[a]Some respondents indicated an affirmative response but did not answer the follow-up question about degree of effect.

knowledge and skills gained and used on the job (Table 6). The training was rated relatively high in influence on decisionmaking and ability to influence organizational decisionmaking on the part of the respondents.

Again, usefulness of training was rated high in providing tools for conducting training programs (seminars, workshops, conferences) and extension or production programs (Table 7).

COURSE TRANSFER TO NATIONAL PROGRAMS

The second shuttle training program in Bhutan was implemented in East, South, and West Bhutan. Five training courses in rice production with components on communication and extension strategies were attended by 126 agricultural extension officers, project managers, and extension agents of the Department of Agriculture and 12 diploma students of the National Agricultural Training Institute. The courses were conducted by 5 Bhutanese extension officers who had trained in T3C at IRRI in 1986. They were assisted by two training staff members of the Training and Technology Transfer Department in a program to institute a "train-the-trainor" concept with national systems.

ALUMNI NEWSLETTER

The IRRI Alumni Newsletter printed its maiden issue in January 1988. The second issue was printed in July 1988. A total of 10,000 copies were circulated to alumni and other friends of IRRI.

SCHOLARS AND FELLOWS WHO COMPLETED TRAINING IN 1988

The following scholars and fellows completed training in 1988. Those marked with one asterisk completed the MS degree; two asterisks indicate completion of the Ph D degree. Universities of those who completed degrees are noted after their topics.

Visiting scientists 1

U Tin Aung. Myanmar. Studies on the influence of root lesion nematode *Pratylenchus zeae* on the growth and yield of rice, and on various cropping patterns

Abdul A. Kareem. India. Botanical pest control in rice-based cropping systems with emphasis on the potential and use of neem derivatives against insect pests and diseases of rice

M. K. Majumder. India. Genetic and breeding investigations on cold tolerance characteristic in rice

N. F. C. Ranaweera. Sri Lanka. Evaluation of benefits from farming systems research in the ARFSN; marketing in farming systems research

Anake Topark-Ngarm. Thailand. Forage research in farming systems

Postdoctoral scientists

Candida Adalla. Philippines. Inheritance of resistance to green leafhopper

Rizk Aidy. Egypt. Genetics of blast resistance

Moon Soo Cho. Republic of Korea. Studies on pollen culture of indica and japonica rices

Virgilio Gayanilo. Philippines. Paddy sundrying studies

Ghulam Jilani. Pakistan. Plant derivatives as protectants against insect pests of stored paddy rice

Nilufer Hye Karim. Bangladesh. Studies on regeneration of rice through anther culture

R. Kaushik. India. Genetic analysis of amylose content in rice

Soon Chul Kim. Republic of Korea. Adaptation strategies of several lowland weed species

K. P. Palanisami. India. Efficiency and equity in irrigation system management

Claro Q. Torres. Philippines. I. Assessment of yield loss due to rice blast; II. Development of rice blast model

Rodolfo Undan. Philippines. Agrohydrologic and farming practice analysis of the floodprone rice areas of the Bicol River Basin

Collaborative research scientists and fellows

Hae Chune Choi. Republic of Korea. Analysis of rice cold tolerance

A. Ghosh. India. Serodiagnosis of rice viruses and its application in virus research

Rolf Maurer. Federal Republic of Germany. Development of a solar dryer for rice

Hubertus Johannas Maria Nilwik.* Netherlands. Stability analysis of rainfed rice cultivars in Northeast Thailand. Agricultural University of Wageningen

Aart Osman. Netherlands. Partial resistance in rice germplasm to blast and bacterial blight

Table 6. Training impact on aspects of knowledge utilization of alumni of IRRI short-term training program, 1977-86.

Item	Affirmative response (no.)	Distribution (no.) over scale					Summated mean
		1 Not useful	2	3	4	5 Very useful	
Usefulness of training for job	330	0	11	38	113	168	4.33
Making better decisions	316	1	12	77	156	70	3.89
Influence in organizational decisionmaking	324	16	45	95	113	55	3.45
		No. under indicated percentage					
		<10	11-20	21-30	31-40	>40	
Percent knowledge or skills used	330	10	30	46	70	174	4.12

Table 7. Training impact on job productivity of alumni of IRRI short-term training program, 1977-86.

Item	Affirmative response (no.)	Distribution (no.) over scale						Summated mean
		No response[a]	1 Not useful	2	3	4	5 Very useful	
Produced publications	191	0	6	28	60	60	37	3.49
Books	23	1	0	0	6	10	6	4.00
Research papers	150	4	4	21	49	50	22	3.45
Popular articles	64	2	3	9	17	14	19	3.62
Reviews	41	2	0	2	13	15	9	3.79
Training materials	40	3	0	5	11	9	12	3.76
Conducted training (seminars, workshops, conferences)	191	3	2	12	23	61	90	4.18
Conducted extension and production programs	155	1	3	12	23	50	66	4.07
Consultancy work	49	0	0	1	4	19	25	3.62
Total impact on productivity	283	0	0	16	87	100	80	3.85

[a]Some respondents indicated an affirmative response but did not answer the follow-up question about degree of effect.

Annemieke de Vos. Netherlands. Partial resistance in rice germplasm to blast and bacterial blight

Peter G. Watson.* United Kingdom. Rainwater harvesting and conservation for rice and other crops in a rainfed drought-prone environment. Silsoe College

Special research fellows

S. H. Choi. China. Molecular genetics of *Xanthomonas*

Shen Ying. China. Genetics of blast fungus

Zhao Qiangji. China. Ecological analysis of cropping systems in rainfed and irrigated rice environments

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Thelma Bernardo. Philippines. Effect of new technology on seasonal migration

Tapash Kumar Biswas.** India. Nitrogen dynamics and nitrogen-15 balance in lowland rice as affected by green manure and urea application. Indian Agricultural Research Institute

Ganesh Dahal.** Nepal. Transmission of tungro-associated viruses by field and selected colonies of *Nephotettix virescens* (Distant) and their mode of feeding on some selected cultivars. University of the Philippines at Los Baños (UPLB)

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rice. Bangladesh Agricultural University

Mohan Dey.** Bangladesh. Instability in Bangladesh rice production. UPLB

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Kevin Gallagher.** United States. The effect of host plant resistance on the microevolution of the rice brown planthopper *Nilaparvata lugens* and the Malayan black bug *Scotinophara coarctata*. University of California at Berkeley

Abdul Haqqani.** Pakistan. Water use, growth and yield of water-stressed and irrigated mungbean (*Vigna radiata* L. Wilczek) at different growth and planting densities. UPLB

Huang Yongming. China. Genetics of background resistance to bacterial blight

Farhad Jameel.** Bangladesh. Agricultural knowledge flows: a systems analysis and its application to the design of an operational model for Bangladesh. Cornell University

P. S. John.** India. Nitrogen recovery in rice-based cropping systems through cowpea green manure, crop residue and fertilizer nitrogen management. Indian Agricultural Research Institute

Ravindra C. Joshi.** India. Seasonal abundance of rice arthropods; influence of varietal resistance and synthetic pyrethroid. UPLB

Je Kyu Kim.** Republic of Korea. Agro-physiological studies on low tillering rice: an ideotype for raising grain yield potential. UPLB

Buddhi Khadge.** Nepal. Symbiotic competence of *Glomus mosseae* in a rice-based cropping system. UPLB

Md. Ashraf Khan.** Bangladesh. Alternative hosts of tungro-associated viruses and their possible roles in tungro epidemics. UPLB

Woon Kye Ki. Republic of Korea. Use of anther culture in the production of rice varieties resistant to blast

R. Vijaya Kumar.** India. Screening for wide compatibility gene(s) in rice. Andhra Pradesh Agricultural University

A. C. Lahai.** Sierra Leone. The effect of host passaging on the relative parasitic fitness of isolates of *Pyricularia oryzae* Cavara on rice. UPLB

Ghulam Nabi Mir.** India. Inheritance of bacterial leaf blight resistance in rice cultivars. Andhra Pradesh Agricultural University

Alfredo Navarro.** Philippines. Potassium, zinc, calcium and magnesium interactions in lowland rice. UPLB

Abdus Salam.** Bangladesh. Studies on the photoperiod sensitivity gene in rice (*Oryza sativa* L.). UPLB

Mohammad Salim.** Pakistan. Physical stresses and varietal resistance in rice: effect of white-backed planthopper, *Sogatella furcifera* (Horvath). UPLB

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Bandarupalli Sivaprasad.** India. Diffusion mechanisms associated with ammonia volatilization in lowland rice. Indian Agricultural Research Institute

K. Tedia.** India. Crop water use, root distribution, plant growth and seed yield of soybean genotype as influenced by water stress and tillage. Indian Agricultural Research Institute

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Hari K. Upadhyaya.** Nepal. Labor market effects of modern rice technology in favorable and unfavorable production environments. UPLB

Helen Wedgewood. United Kingdom. Grain quality

Zhang Zhitao. China. Variations in mating signals in field-collected BPH populations in the Philippines and China

Research scholars

Golafshany Jafar Babapour. Iran. Grain quality

Do Van Xe. Vietnam. IRRISTAT and other microcomputer applications in agricultural research

U Moe Hein.* Myanmar. Effect of nitrogen, size and number of sclerotia on rice sheath blight disease severity. UPLB

Hoang Thi Hoa. Vietnam. Library and documentation management and procedures

Sang Yeol Kim.* Republic of Korea. Seed dormancy and developmental pattern of *Commelina benghalensis* Linn. UPLB

Birgit Kramer. Federal Republic of Germany. Epidemiology and control of rice blast in upland rice

Li Goufu.* China. Variability in flowering to maturity duration in rice. UPLB

U Maung Maung Lay.* Myanmar. Studies on the interaction between *Xanthomonas campestris* pv. *oryzae* and *Gerlachia oryzae* on the rice plant. UPLB

Le Xuan Cuoc. China. Assessment of resistance to blast in some rice isolates

Mario L. R. Mesquita.* Brazil. Influence of land preparation and weed control methods on weed growth and yield of upland rice. UPLB

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Pensee Nantasomsaran.* Thailand. Effect of cultivar and cultural practices on weed control in upland rice (*Oryza sativa* L.). Kasetsart University

Chumnong Nartsomboon.* Thailand. Studies on herbicidal control of weeds in upland rice. Kasetsart University

Gorban Ali Nematzadeh.* Iran. Gene action and combining ability for yield and quality characters in rice. University of Tarbiyat Modarres

Ana Victoria Perez-Padron. Cuba. Studies on the effect of different growth regulators on callus induction in indica and japonica rices

Kiril Perfanov. Bulgaria. Applied methods of rice breeding and rice anther culture techniques

Pham Van Luyen. Vietnam. Graphics and audiovisual production

Phi Manh Hung. Vietnam. Graphics and audiovisual production

Wichitra Phonyiem.* Thailand. Data transformation for disease data in rice. UPLB

Ran Bahadur Rai. Bhutan. Rice breeding and varietal testing

Razakariaramanna. Madagascar. Agrometeorology and weather data processing for rice research in Madagascar

Oraphan Rirermsoonthorn.* Thailand. Effects of soil moisture regime and phosphorus source on phosphorus nutrition and rice growth in acid soils. Kasetsart University

U Than Sein.* Myanmar. Evaluation of different metering devices for multi-crop seeding. UPLB

Tahere Azhiri Sigari. Iran. Heat treatment to increase callus induction efficiency in anther culture

Yaghoub Sigari.* Iran. Effects of heterosis on salinity tolerance in rice. Gregorio Araneta University Foundation

U Khin Soe.* Myanmar. Diallel analysis on callus formation and plant regeneration in anther culture of Burmese rices. UPLB

Suree Srivantanyakul.* Thailand. Quality traits in selection for crosses with RD 19. Kasetsart University

Nguyen Van Suan. Vietnam. Hybrid rice production

U Aye Thaw.* Myanmar. Studies on cultural management practices for sunflower grown after wetland rice. Central Luzon State University

U Chit Thein.* Myanmar. Effect of planting date and method of tillage on grain yield potential of wheat under rainfed and irrigated conditions. UPLB

Tran Xuan Phuc. Vietnam. Graphics and audiovisual production

Trinh Ngoc Vinh.* Vietnam. Effect of the hull shapes of the floating power tiller on its performance under wetland conditions. UPLB

Wang Ziming.* China. Inheritance of partial resistance to leaf blast (*P. oryzae*) in some rice varieties. UPLB

R. A. Wijasena.* Sri Lanka. The influence of seeding methods on early growth and development of short-term annuals in rice-based cropping systems. Post-Graduate Institute, University of Sri Lanka

Butranu Woothisak.* Thailand. Inoculum distribution and inoculum potential of *R. solani* relating to multiple cropping. UPLB

Jingyuan Xia.* China. Computer simulation of the population dynamics of the yellow stemborer, *Scirpophaga incertulas* (Walker). UPLB

Yong Ye Zhihua.* China. Resistance to white-backed planthopper *Sogatella furcifera* (Horvath) in elite lines of *Oryza sativa* and *Oryza officinalis* crosses. UPLB

Longyue Zhao.* China. An economic evaluation of the returns to hybrid rice research in China. UPLB

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Regular courses

AEC (Agricultural Engineering)

China
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Ebrahim, Ahmed Osama
El-Behery, Ahmed Abd El-Khalik
Radwan, Hanafi Mohamed

Indonesia
Darmono

Mexico
Marquez-Cabrera, Fernando

Nigeria
Ekeh, Anthony Ngamdi
Okeke, Joseph Okechukwu
Onuigbo, Ignatius M.C.

Philippines
Rotor, Paul Victor, Jr.

Sri Lanka
Mohamed Haniffa, Mohamed Ghouse
Wewala Walauwe, Vinodhan Wewala

Sudan
Abdelgadir, Babiker Elamin

Thailand
Im-prasertsuk, Kijja

CSTC (Cropping Systems)

Bangladesh
Alauddin, Md.

Bhutan
Sharpchop, Karchung

Cambodia
Meng, Try
Pheng, Huot Chin
Sam, Im

China
Zhang, Yanzhi

Ghana
Tetebo, Lawrence Ofosu

Laos
Phanmanivong, Khamphone
Sayaphet, Sida

Liberia
Miller, John V.

Madagascar
Rabemananiara, Dorothee I.A.
Ramiaramanana, Danielle M.V.H.

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Seno, Nenita S.

Sierra Leone
Kamara, Bombolai A.K.

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Ratnayaka, Handunneththi H.
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Muliahela, Leonard M.E.
Runkulatile, H.H.E.

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Muangmool, Prakasit

Vietnam
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Quoc, Huynh Tran
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GEU (Genetic Evaluation and Utilization)

Benin
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Bhutan
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Brazil
Correira Farias, Francisco

Cambodia
Sothat, Leng

Cameroon
Gabriel, Meli

China
Han Chun-Lei
Hua Zetian
Li Ren-hua
Wang Lian-fang

Iran
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Pakistan
Rabbani, Ashiq

Sierra Leone
Lahai-Hilton, Heinrich Alfred

Tanzania
Msomba, William Solomon

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Hongto, Kriangsak

Turkey
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Vietnam
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INSURF (International Network on Soil Fertility and Sustainable Rice Farming)
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Yang Nanchang
Zhang Dan

Cuba
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Ghana
Dogbe, Wilson

Laos
Kongdara, Khampai

Liberia
Harding, Melville B.

Nigeria
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Tanzania
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Boondown, Somsak
Chinapan, Withoon

Vietnam
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IPM (Integrated Pest Management)
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Burkina Faso
Nacro, Souleymane

China
Wang Wen-Lai

India
Nanda, Umakanta
Patil, Anandrao Pandurang

Korea, Republic of
Shin, Dong-Bum

Laos
Vongprachanh, Bounnhong
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Philippines
Rueda, Prescilla J.
Sadumiano, Amador S.

Sierra Leone
Kamara, Bassiru Ibrahim

Sri Lanka
Pemadasa, Kebed Duwa Gamage

Thailand
Chiengwattana, Nalinee
Thongdeethae, Somsak

Vietnam
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Toan, Nguyen Dau
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IWMT (Irrigation Water Management)
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Kunzang
Sharma, Lok Nath

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Yanti, Suli

Iran
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Sim, Kok Kee
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Damasco, Catalino S., Jr.
de Guzman, Romeo A.
Francisco, Cecilia M.
Lorenzo, Alfredo F.

Sri Lanka
Selvanathan, Nadarajah
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Loan, Nguyen Thi Hong
Truong, Minh Chanh

T3CI (Training and Technology Transfer I)
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Wang Bogi
Xing Zhichen
Zhangju
Zhou Xia
Zhou Xing-liang

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Ronald, Yelagada Mani John
Singh, Mahabir
Singh, Surendra Pal

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Annakkage, H.K.D.A.P.S.
Piyadasa, Munasingha K.G.
Ratnasiri, Abeykoon Jalath
Wijesena, Ilimbe Vidanalage
Wijeweera, Witharana P.J.

T3CII (Training and Technology Transfer II)
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Rahman, Md. Mansur

Bhutan
Gurung, Hari
Kujur, S.C.
Mongar, Padam Lal
Rai, Indra Man
Tamang, Lal Bahadur

Madagascar
Abel Ratovo, Henri Lucien
Rasoafalimanana, Mbolarinosy

WSTC (Weed Science)
Bangladesh
Mridha, Md. Abdul Jalil

Brunei
Lakim, Mohd. Salleh Abd.

China
Shuai Songmao
Xue Guang

Madagascar
Rakotobe, Andriamanana Oliva

Mexico
Esqueda-Esquivel, Valentin Alberto

Nigeria
Bassey, Akinfenwa-Donus E.U.

Philippines
Evangelista, Ma. Chona S.

Thailand
Varinruk, Boondit

Vietnam
Dan, Hoang Van

Zambia
Syankwilimba, Ian S.K.

Special courses

DBMGR (Data Base Management for Genetic Resources)
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India
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Dhua, Sudhi Ranjan

Indonesia
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Philippines
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Sri Lanka
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GRCM (Genetic Resources Conservation and Management)
Bangladesh
Zeenat, Zarina

China
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Indonesia
Hamdani, Muslimah

Korea, Republic of
Lim, Sang-Jong

Sri Lanka
Silva, Laddu Sumanadasa

Thailand
Vutiyano, Chawewan

Vietnam
Quynh, Nguyen Thi

GEU-RFL (GEU on Rainfed Lowland Rice)
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Ahmed, Helal Uddin
Ali, Md. Gaus
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India
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Singh, Udai Pratap
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Laos
Manivong, Viengsavanh
Sipaseut

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Akinremi, Jacob Akinpelu
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Thailand
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Sunanwongse, Attapol

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IAFSR (Impact Assessment of Farming Systems Research)
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Indonesia
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Philippines
Medialdia, Ma. Theresa S.

Sri Lanka
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Kahingalage, Lal de Silva

PARSM (Physical Aspects of Soil Management in Rice-Based Cropping Systems)
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PTR (Prosperity Through Rice)
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Niger
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Zaire
Lukumba, Tshibambe

RP-IC (Rice Production Course for Indochinese)
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Bontot, Chheang
Chanthou, Chuon
Chhan, Hang Chham
Chhoeun, Kong
Ith, Sarun
Kan, Chhim
Moeun, Sim
Nhan, Chak
Pochun, Teav
Rany, Kim
Thary, Leng
Tonleng, Sam
Yon, Kim

Laos
Sensombath, Thongsao
Souksavat, Chanthavong
Taixayavong, Khampeu

RP-MG (Rice Production Course for Madagascans)
Madagascar
Andre
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Lalanekenarisoa, Nenee T.
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Ramonjy, Arison Eugene
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Ranoro-Sahondra, Yvette G.
Ravaoarimanana, Lucie
Ravaoarimino, Josephine M.I.
Razafindramonjy, Jean Bonheur
Razafinirina, Irene Olga
Saholiarilala, Berthine M.L.

SHTR (Seed Health Testing of Rice)
Bangladesh
Nahar, Kamrun

Brazil
Alves Ferrari, Wilma

China
Xu Zhixin

Colombia
Huertas Davey, Carlos Alberto

India
Majumdar, Amitava

Indonesia
Kadir, Triny Surjani
Rukmanto

Kenya
Movogo, Melxadesk Enana

Liberia
Wilson, J. Wleh

Malaysia
Hashim, Marzukhi

Nepal
Thapa, Birendra Jung

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Sri Lanka
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Tanzania
Maingu, Tasiana Zakaria

Thailand
Jirawongse, Suwanit

Vietnam
Tam, Tran Thi Minh

SSARP (Simulation and Systems Analysis for Rice Production)
Bangladesh
Akanda, Md. Shamsul Islam
Biswas, Jiban Krishna
Quader, S.M. Belayetul
Sattar, Sk. Md. Abdus

China
Cheng Shihua
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India
Budhar, Mathur Nedumaran
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Raju, Natesan
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Indonesia
Hidayat, Achmad
Makarim, Abdul Karim
Moeljopawiro, Sugiono
Rahayu, Aay

Korea, Republic of
Jeong, Yee-Geun
Lee, Chul-Won
Lee, Moon Hee
Shin, Jin-Chul

VIDL (Varietal Improvement of Dryland Legume Crops for Rice-Based Farming Systems)
Indonesia
Mejaya, Imade Jana

Pakistan
Ghafoor, Abdul

Thailand
Promdeerat, Tinnakorn

International collaboration

International Rice Testing Program

International Rice Testing Program; Plant Physiology, Soils, and Multiple Cropping Departments; and Library and Documentation Center

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The International Rice Testing Program (IRTP), a collaborative network funded by the United Nations Development Programme for the worldwide exchange and evaluation of elite rice germplasm, emphasizes the utilization of the genetic diversity of the rice plant. The following sections summarize 1) results of the 1987 nurseries, for which data were received and analyzed in 1988 (detailed results are published separately in IRTP annual nursery reports), and 2) activities in 1988.

1987 NURSERY RESULTS

International Rice Testing Program

IRTP composed 1,550 sets of 25 types of nurseries—14 for cultural types, 10 for stress tolerance, and 1 for grain quality—and distributed them to 49 countries collaborating in the IRTP network.

Yield nurseries. Outstanding entries for the three maturity groups of irrigated rices—the International Rice Yield Nursery-Very Early (IRYN-VE), -Early (IRYN-E), and -Medium (IRYN-M)—are listed in Tables 1, 2, and 3. Some rices performed well in several regions. The yield and yield components by site and region are given in the detailed IRTP annual nursery reports, published separately. Varietal differences in stability of performance were evident among the high-yielding entries. For example, both BR316-15-4-4-1 and IR68 (IR28224-3-2-3-2) were among the five highest yielders in IRYN-M. But BR316-15-4-4-1 showed a greater degree of stability (Fig. 1).

Table 1. Best performing entries in the 8th International Rice Yield Nursery-Very Early (IRYN-VE) based on overall and regional mean yield, 1987.

Region and number of trials	Designation	Origin	Days to heading	Yield (t/ha)
Overall, 25	IR66	IRRI	94	5.1
	IR31785-58-1-2-3-3	IRRI	82	5.0
	IR50	IRRI	87	5.0
	BG1203	Sri Lanka	90	4.9
	IR39357-133-3-2-2-2	IRRI	87	4.9
	IR41996-118-2-1-3	IRRI	89	4.9
East Asia, 4	IR29725-40-3-2-3	IRRI	104	6.7
	IR39357-133-3-2-2-2	IRRI	100	6.7
	C1136-3	Philippines	101	6.6
	IR50	IRRI	103	6.5
	BG1203	Sri Lanka	106	6.4
Southeast Asia, 9	BG731-2	Sri Lanka	81	4.2
	IR66	IRRI	85	4.2
	IR39357-133-3-2-2-2	IRRI	78	4.2
	BG1203	Sri Lanka	80	4.1
	IR41996-118-2-1-3	IRRI	79	4.1
South Asia, 8	IR31785-58-1-2-3-3	IRRI	82	5.7
	IR66	IRRI	93	5.5
	IR41996-118-2-1-3	IRRI	89	5.3
	BG1203	Sri Lanka	90	5.2
	IR50	IRRI	88	5.2
West Asia and North Africa, 2	IR31785-58-1-2-3-3	IRRI	91	7.1
	BG731-2	Sri Lanka	104	7.0
	IR29692-117-1-2-2	IRRI	96	7.0
	IR25898-60-2-3	IRRI	94	6.9
	IR66	IRRI	105	6.9
	IR41996-118-2-1-3	IRRI	101	6.9
Sub-Saharan Africa, 2	IR31779-19-3-3-2-2	IRRI	80	5.1
	IR66	IRRI	86	4.3
	IR50	IRRI	84	4.1
	IR32429-47-3-2-2	IRRI	84	3.9
	C1158-7	Philippines	84	3.8
	IR39357-133-3-2-2-2	IRRI	84	3.8
	IR39385-124-3-3-2-3	IRRI	82	3.8

Table 2. Best performing entries in the 15th International Rice Yield Nursery-Early (IRYN-E) based on overall and regional mean yield, 1987.

Region and number of trials	Designation	Origin	Days to heading	Yield (t/ha)
Overall, 30	S818b-10-2	Indonesia	102	4.8
	Chianung sen yu 26	Taiwan, China	102	4.6
	IR32843-92-2-2-3	IRRI	98	4.5
	IR35546-17-3-1-3	IRRI	99	4.5
	IR35366-40-3-3-2-2	IRRI	100	4.5
East Asia, 5	Chianung sen yu 26	Taiwan, China	104	5.7
	Lei Zhong 124	China	97	5.6
	S818b-10-2	Indonesia	105	5.6
	Taichung sen yu 223	Taiwan, China	103	5.4
	DR33	Pakistan	106	5.3
	IR35366-40-3-3-2-2	IRRI	102	5.3
Southeast Asia, 10	IR32843-92-2-2-3	IRRI	91	4.3
	IR35546-17-3-1-3	IRRI	90	4.2
	S818b-10-2	Indonesia	95	4.2
	IR34615-4-2-3	IRRI	92	4.1
	IR31805-20-1-3-3	IRRI	93	4.0
South Asia, 8	IR35546-17-3-1-3	IRRI	106	4.5
	SPRLR76102-26-1-1	Thailand	115	4.5
	S818b-10-2	Indonesia	107	4.5
	Chianung sen yu 26	Taiwan, China	107	4.4
	IR32419-44-2-3-2	IRRI	100	4.4
	IR35366-40-3-3-2-2	IRRI	106	4.4
West Asia and North Africa, 1	S818b-10-2	Indonesia	115	9.8
	IR25840-83-3-2	IRRI	108	8.8
	IR24632-206-3-2-2	IRRI	110	8.7
	S287b-39-1-3	Indonesia	111	8.7
	IR31802-48-2-2-2	IRRI	103	8.6
Sub-Saharan Africa, 3	SPRLR76102-26-1-1	Thailand	102	4.4
	IR31805-20-1-3-3	IRRI	100	4.3
	IR32843-92-2-2-3	IRRI	98	4.3
	IR35546-17-3-1-3	IRRI	96	4.3
	IR64	IRRI	96	4.3
	S818b-10-2	Indonesia	100	4.3

Table 3. Best performing entries in the 15th International Rice Yield Nursery-Medium (IRYN-M) based on overall and regional mean yield, 1987.

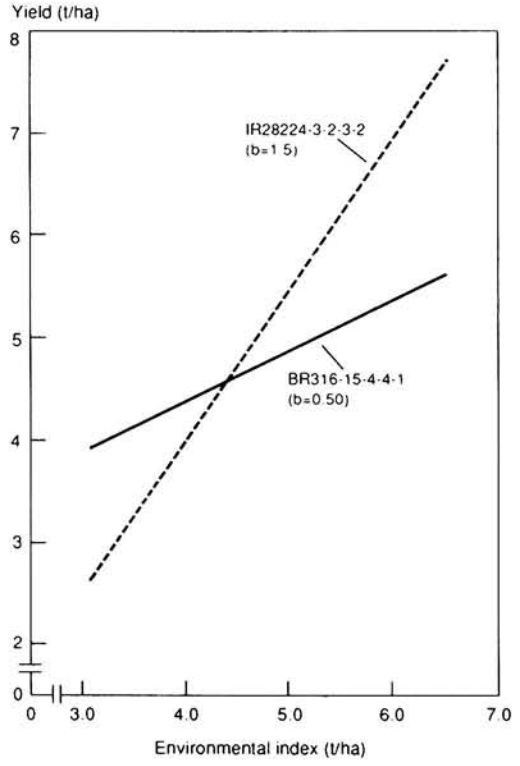
Region and number of trials	Designation	Origin	Days to heading	Yield (t/ha)
Overall, 16	BG380-2	Sri Lanka	101	5.2
	S499b-28	Indonesia	103	5.0
	BW293-2	Sri Lanka	106	4.8
	IR70	IRRI	108	4.8
	BR316-15-4-4-1	Bangladesh	99	4.6
	IR68	IRRI	100	4.6
	Seberang	Malaysia	110	4.6
East Asia, 1	C1333-4	Philippines	130	5.8
	S499b-28	Indonesia	120	5.6
	DR29	Pakistan	120	5.2
	IR31809-83-3-2-2	IRRI	130	5.2
	BG380-2	Sri Lanka	128	5.1

continued on next page

Table 3 continued.

Region and number of trials	Designation	Origin	Days to heading	Yield (t/ha)
Southeast Asia, 6	BG380-2	Sri Lanka	92	5.4
	BR316-15-4-4-1	Bangladesh	89	5.1
	UPR254-85-1-TCA3	India	88	5.0
	DR29	Pakistan	90	4.9
	S499b-28	Indonesia	94	4.9
South Asia, 7	BG380-2	Sri Lanka	105	4.8
	S499b-28	Indonesia	108	4.8
	BW293-2	Sri Lanka	110	4.7
	Seberang	Malaysia	114	4.7
	IR70	IRRI	113	4.6
Sub-Saharan Africa, 2	IR68	IRRI	103	6.3
	BW293-2	Sri Lanka	105	6.1
	BG380-2	Sri Lanka	101	6.1
	S499b-28	Indonesia	105	6.0
	IR70	IRRI	109	5.7

Tables 4 and 5 show yields of the best performing entries in the two rainfed shallow water yield nurseries: early (IRRSWYN-E) and medium (IRRSWYN-M). The highest yielding entries in the nurseries for two maturity groups of upland rices—early (IURYN-E) and medium (IURYN-M)—are given in Tables 6 and 7.



1. Regression of yields of 2 selected varieties on site means (25 varieties, 13 sites), IRYN-M, 1987.

Observational nurseries. The best performing entries in the IRTP observational nurseries—IRON, IRRSWON, IURON, IRDWON, IFRON, and ITPRON—based on their overall phenotypic acceptability ratings, are given in Table 8. A number of entries were resistant to or tolerant of one or more important stresses at trial sites.

Nurseries for specific stresses. Tables 9 and 10 list the best performing entries in nurseries established for specific stresses. Insect nurseries were those for brown planthopper (IRBPHN), whitebacked planthopper (IRWBPHN), and stem borer (IRSBN). Disease nurseries were those for ufra nematode (IRUSS), bacterial blight (IRBBN), rice blast (IRBN), and rice tungro (IRTN). Nurseries for other stresses were those for salinity and alkalinity (IRSATON), acid upland and acid lowland soils, and cold tolerance (IRCTN).

1988 NURSERY DISTRIBUTION

International Rice Testing Program

A total of 1,217 sets of 25 types of IRTP nurseries (14 cultural types, 10 for stress tolerance, and 1 for grain quality) were composed and distributed to 46 countries in the IRTP network (Table 11). In Asia, 928 sets went to national programs. Sub-

Table 4. Best performing entries in the 7th International Rice Rainfed Shallow Water Yield Nursery-Early (IRRSWYN-E) based on overall and regional mean yield, 1987.

Region and number of trials	Designation	Origin	Days to heading	Yield (t/ha)
Overall, 13	IR46	IRRI	107	3.6
	CR213-1002	India	120	3.5
	IR21015-80-3-3-1-2	IRRI	105	3.5
	IR21567-9-2-2-3-1-3	IRRI	112	3.5
	IR21573-2-1-2-2-2-1	IRRI	110	3.5
	IR26933-16-2-3	IRRI	103	3.5
	IR33380-60-1-2-2	IRRI	116	3.5
	IR33383-23-3-3-3	IRRI	104	3.5
East Asia, 1	IR8073-65-6-1-1E-P2	IRRI	123	9.4
	IR13240-39-3-3-3-P1	IRRI	116	8.6
	IR21015-80-3-3-1-2	IRRI	115	8.6
	IR4563-1-1-3-6-1E-P1	IRRI	121	8.6
	IR46	IRRI	130	8.2
Southeast Asia, 5	IR33380-60-1-2-2	IRRI	104	3.2
	IR21015-80-3-3-1-2	IRRI	94	3.1
	IR33383-23-3-3-3	IRRI	95	3.1
	IR8073-65-6-1-1E-P2	IRRI	95	3.1
South Asia, 6	IR21567-9-2-2-3-1-3	IRRI	117	3.8
	IR21573-2-1-2-2-2-1	IRRI	114	3.6
	CR213-1002	India	126	3.5
	IR33380-60-1-2-2	IRRI	120	3.4
	IR33383-23-3-3-3	IRRI	105	3.4
Sub-Saharan Africa, 1	IR31429-14-2-3	IRRI	110	4.2
	IR26933-16-2-3	IRRI	109	4.1
	IR46	IRRI	108	4.0
	IR8073-65-6-1-1E-P2	IRRI	115	3.9
	CR213-1002	India	108	3.7

Table 5. Best performing entries in the 7th International Rice Rainfed Shallow Water Yield Nursery-Medium (IRRSWYN-M) based on overall and regional mean yield, 1987.

Region and number of trials	Designation	Origin	Days to heading	Yield (t/ha)
Overall, 13	IR13146-45-2	IRRI	112	3.0
	IR13146-45-2-3	IRRI	115	3.0
	IR31662-34-1-2	IRRI	117	3.0
	Mahsuri	Malaysia	116	3.0
	OR142-99	India	119	3.0
	SPT7106-2-3-3-1	Thailand	109	3.0
Southeast Asia, 9	IR31662-34-1-2	IRRI	110	3.2
	SPT7106-2-3-3-1	Thailand	103	3.2
	IR13146-45-2	IRRI	106	3.1
	IR13146-45-2-3	IRRI	106	3.1
	OR142-99	India	112	3.1
South Asia, 4	Mahsuri	Malaysia	129	3.1
	BRB34-74-3	Bangladesh	139	2.9
	OR142-99	India	133	2.8
	IR13146-45-2	IRRI	125	2.7
	IR13146-45-2-3	IRRI	132	2.6

Table 6. Best performing entries in the 13th International Upland Rice Yield Nursery (IURYN-E) based on overall and regional mean yield, 1987.

Region and number of trials	Designation	Origin	Days to heading	Yield (t/ha)
Overall, 21	IR25588-7-3-1	IRRI	75	2.4
	NDR97	India	72	2.1
	CR222-MW10	India	77	2.0
	UPR103-80-1-2	India	78	2.0
Southeast Asia, 10	IR25588-7-3-1	IRRI	70	2.3
	NDR97	India	67	2.2
	CR222-MW10	India	73	2.0
	RAU4028-2	India	60	2.0
	TNAU6464	India	75	2.0
	UPR103-80-1-2	India	74	2.0
	IET1444	India	76	2.0
South Asia, 7	IR25588-7-3-1	IRRI	81	2.4
	IR9729-67-3	IRRI	73	2.2
	NDR97	India	77	2.1
	RAU4028-2	India	74	2.1
	ADT31	India	85	2.0
	CR222-MW10	India	80	2.0
Sub-Saharan Africa, 3	BG367-4	Sri Lanka	85	2.2
	IRAT133	Ivory Coast	68	2.0
	ADT36	India	81	1.9
	IR25588-7-3-1	IRRI	77	1.8
	IR10198-66-2	IRRI	77	1.7
Latin America, 1	IR25588-7-3-1	IRRI	68	4.2
	NDR84	India	71	4.1
	UPR103-80-1-2	India	71	4.0
	NDR97	India	65	3.9
	NDR83	India	76	3.8

Table 7. Best performing entries in the 13th International Upland Rice Yield Nursery-Medium (IURYN-M) based on overall and regional mean yield, 1987.

Region and number of trials	Designation	Origin	Days to heading	Yield (t/ha)
Overall, 6	BR319-1	Bangladesh	88	3.1
	B3016b-Tb-260-3-2-1-1-3	Indonesia	85	3.0
	B3622F-Tb-14-2	Indonesia	85	2.9
	C894-7	Philippines	96	2.9
	IR26957-86-2	IRRI	100	2.9
	IR43	IRRI	98	2.9
Southeast Asia, 4	B3016b-Tb-260-3-2-1-1-3	Indonesia	82	3.3
	B3622e-Tb-14-2	Indonesia	85	3.3
	BR319-1	Bangladesh	83	3.1
	B3622e-Tb-5-4-4	Indonesia	82	3.1
	IR26957-86-2	IRRI	98	3.1
	IR43	IRRI	96	3.1
South Asia, 1	C894-7	Philippines	106	3.5
	Bala Late Mutant	India	90	3.4
	BR319-1	Bangladesh	105	3.4
	IR43	IRRI	105	3.4
	B3016b-Tb-260-3-2-1-1-3	Indonesia	99	3.1
Sub-Saharan Africa, 1	IRAT110	Ivory Coast	72	2.9
	IRAT114	Ivory Coast	72	2.9
	BR319-1	Bangladesh	90	2.6
	B3906d-14-ST-16-48-3	Indonesia	81	2.5
	C894-7	Philippines	94	2.5
	ITA212	IITA	100	2.5

Table 8. Entries that received the best phenotypic acceptability ratings in the 1987 observational nurseries.

Nursery and number of trials	Designation	Origin	Av phenotypic acceptability score	Av days to heading
International Rice Observational Nursery (IRON), 36	IR35295-82-2-1-3-2	IRRI	4.3	99
	IR32876-54-2-2-2	IRRI	4.5	99
	IR42015-83-3-2-2	IRRI	4.6	88
	IR31851-96-2-3-2-1	IRRI	4.6	93
	BG731-2	Sri Lanka	4.7	94
	IR29725-117-2-3-3	IRRI	4.7	94
	IR39357-45-3-2-3	IRRI	4.7	88
	Tainung sen Glutinous 2	Taiwan, China	4.7	95
International Upland Rice Observational Nursery (IURON), 30	IR29429-B3-B-1-4	IRRI	4.7	90
	RR20-5	India	5.0	72
	CNA762069	Brazil	5.0	72
	B3906D-14-ST-16-48-3	Indonesia	5.1	84
	UPLRi-5	Philippine	5.1	95
	S431B-5-1	Indonesia	5.1	83
	CR222-MW10	India	5.2	77
	B3906D-13-13-ST-37	Indonesia	5.2	85
International Rice Rainfed Shallow Water Observational Nursery (IRRSWON), 16	IR21567-9-2-2-3-1-3	IRRI	3.8	107
	IR13146-45-2-3	IRRI	3.8	113
	BR425-189-1-6-1-2	Bangladesh	4.0	110
	CN836-3-10	India	4.1	117
	IR21567-9-2-2-2-1	IRRI	4.1	111
	IR33356-14-3-1-3	IRRI	4.1	114
	IR48526-44-1-1	IRRI	4.3	116
	Pankaj	India	4.3	118
	SPT7106-2-3-3-1	Thailand	4.3	113
International Rice Deepwater Observational Nursery (IRDWON), 7	Tilakkachari	India	3.0	143
	B5309d-23d-Mr-6-1	Indonesia	3.4	119
	B2433b-Kn-10-1-1-1	Indonesia	3.8	129
	B4259-48-1-3-1-3	Indonesia	4.0	133
	B5332-13d-Mr-4-2	Indonesia	4.0	125
	B5332-13d-Mr-5-2	Indonesia	4.0	131
International Floating Rice Observational Nursery (IFRON), 2	Leb Mue Nahng 111	Thailand	2.0	138
	BR222-B-191-3-2	Bangladesh	2.0	128
	BR523-168-2	Bangladesh	2.0	125
	DWC-B-283	Bangladesh	2.0	120
	HTAFR77012-3	Thailand	3.0	135
International Tide-Prone Observational Nursery (ITPRON), 1	B5354-5d-Mr-1	Indonesia	3.0	95
	IR13149-71-3-2-3	IRRI	3.0	99
	IR28840-01-1	IRRI	3.0	99
	IR9288-B-B-B-252-1-2-2-1	IRRI	3.0	93

Saharan Africa received 129 sets. Forty-two nursery sets went to national programs in West Asia and North Africa. One hundred two sets went to 12 countries in Latin America, and 16 sets to 3 countries in Europe. Sources of entries in the 1988 IRTP nurseries distributed around the world are in Table 12.

USE OF IRTP ENTRIES

International Rice Testing Program

National rice improvement programs continued using IRTP materials. A total of 207 entries were used as donors in hybridization programs (Table 13), and 33 entries were selected for further yield testing. Most frequently used entries in national follow-up trials are listed in Table 14.

Three IRTP entries were released in Bhutan in 1988: BR153-2B-10-1-3, which originated from Bangladesh; IR64 from IRRI; and Takanenishiki from Japan.

Table 9. Best performing entries in the 1987 insect and disease nurseries.

Nursery[a]	Trials (no.)	Entries rated tolerant
IRBPHN	15	IR13427-45-3-1-2-2-2, IR17494-32-2-2-1-3, IR27316-78-3-3, IR29725-109-1-2-1, IR31809-83-3-2-2, IR32822-2-2-3-2, IR32829-5-2-2, IR32830-23-2-2, IR35323-93-1-3-1
IRWBPHN	13	Bahbolon, Chemparan Pandi, IR13427-45-3-1-2-2-2, IR27316-6-2-2, IR64, Mushkan 41, Valsara Champara
IRSBN		
Vegetative phase Greenhouse	2	Bahbolon, BPT1235, W1263, IR13427-40-2-3-3-3-3, IR13427-45-3-1-2-2-2
Field	4	W1263, IR28150-84-3-3-2, IR32307-107-3-2-2, IR32429-47-3-2-2, IR32429-68-3-3-3
Heading stage Field	4	CO27, GH147 (m), 40 Krad 89, HTAFR77043-2, IR2035-117-3, IR28154-101-3-2
IRUSS	2	BR539-17-4-3-3-1, Rayada 16-06, Shada Pankaich, CNL319, NC492, Dalbao
IRBN	20	Kataktara DA2, IR24632-34-2, IR29506-60-3-3-2, IR32307-12-2-1-2, IR32720-138-2-1-1-2, IR328533-185-3-2-2, IR37721-3-3-3-3-1, IR39326-9-2-2-3
IRBBN	26	AC19-1-1, Camor, IR29341-85-3-1-3, Kachamota, RP2151-173-1-8, RP2151-21-22, RP2151-40-1
IRTN	3	ARC11554

[a] IRBPHN = International Rice Brown Planthopper Nursery, IRWBPHN = International Rice Whitebacked Planthopper Nursery, IRSBN = International Rice Stem Borer Nursery, IRUSS = International Rice Ufra Screening Set, IRBN = International Rice Blast Nursery, IRBBN = International Rice Bacterial Blight Nursery, IRTN = International Rice Tungro Nursery.

Table 10. Best performing entries in the 1987 IRTP soil and low temperature stress screening nurseries.

Nursery[a]	Trials (no.)	Entries rated tolerant
IRSATON Salinity	14	Bhurarata 4-10, BR51-282-8, B2433b-Kn-10-1-1-1, Nona Bokra
Alkalinity	4	IR33238-25-2-3-2, IR22083-105-3-3-3-3
Acid Upland	2	Djoweh, IET1444, UPLRi-5, UPR103-80-1-2
Acid Lowland	5	IR9764-45-2-2, Kajalsail
IRCTN	28	Akiyutaka, Suweon 303, JKAU(K)450-126-10, No. 11

[a] IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery, IRCTN = International Rice Cold Tolerance Nursery.

MONITORING VISITS AND PLANNING MEETINGS

International Rice Testing Program

The 1988 monitoring tours and workshops organized by IRTP stimulated the collaborative efforts of rice scientists in the world toward genetic enhancement of rice (Fig. 2). The IRTP Advisory Committee met in Bangkok in October (Fig. 3).



2. IRTP Cold Tolerance Monitoring Tour participants observing a breeder's plot in Tublay, Philippines, September 1988.



3. The IRTP Advisory Committee, composed of rice scientists from selected countries, met in Bangkok in October 1988 to review achievements and formulate strategies for the program.

Table 11. IRTP nurseries dispatched from IRRI in 1988.

Region and country	Nurseries for different cultural types[a]																		Screening for specific stresses											Total
	Yield								Observational																						
	IRYN-VE	IRYN-E	IRYN-M	IURYN-E	IURYN-M	IRRSWYN-E	IRRSWYN-M	IRDWYN	IRON-VE	IRON-E	IRON-M	IURON-E	IURON-M	IRRSWON-E	IRRSWON-M	IRDWON	IFRON	ITPRON	IRCTN	IRSATON	ACID LOWLAND	ACID UPLAND	IRBN	IRBBN	IRTN	IRBPHN	IRWBPHN	IRSBN	IRSGON	
East Asia																														
China	2	6	1	1		1		1	6	7	5	3	2	2	1	2	1		3	2			11	6		8	4	2	1	78
Japan	1																		2				1							4
Korea, Republic	1								3	1	1								4	2			4	1		1	1			19
Taiwan, China	1	1							1	1	1												1	1		1	1	1		10
Southeast Asia																														
Indonesia												1	1			1	1	1	1	1	2	1	2	1	1			1		15
Malaysia		3	3			2	2			1	2			2	2					1	2		1	1	1	1	1	1	1	27
Myanma	1	1	1	2			2					1		1	1	2		1	1	2	1	1	2	2		1	1	2	1	27
Philippines	2	2	2	11	11	3	3		4	4	3	13	13	6	6	1	1	2	3	4	2	2	1	1	2	1	1	1		105
Thailand	6	5	4	1	3	4	4		3	3	3	3	3	2	2	4	5		4	2	1	1	8	6	3	2	1	4	2	87
Vietnam	8	8	6	3	4	1	2	4	7	8	6	2	2	2	1	3	2	2	2	3	4	1	4	4	2	7	3	3	4	108
South Asia																														
Bangladesh	4	3	1	2		2	2	2	4	4	2	3		4	4	4	4	1	4	3		1	4	3	4	1	1			67
Bhutan	1	1	1				1		1	1	1			1	1				4		1								2	16
India	19	16	16	13	6	4	8	6	13	8	11	16	9	1	8	9	4		13	9	2	2	15	14	6	10	9	9	6	262
Nepal	4	4	5	3	3	2	2		1	1	2	3	3	1	1				4			1	7	4		1		3		55
Pakistan	2	2	4							2	2								1	3			1				2	2		21
Sri Lanka				2	1				4	4	4	1	1						1	5	3		1							27
West Asia and North Africa																														
Afghanistan	1	1							1	1									1				1					1	1	8
Egypt	2	2		2					2	2						3	3			2			2							20
Ethiopia	1			1	1			1	1			1																		6
Iran	1								1										1				1					1	1	6
Turkey									1											1										2
Sub-Saharan Africa																														
Cameroon			1								1								3										2	7
Kenya				1	1							1	1																	4
Liberia																					2									2
Mali																1	1													2
Nigeria	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	2	3	2	2	2	3	2	2			1	1	67
Sierra Leone						1	1		1	1				1	1			1		1	1		1							10
South Africa	1																													1
Tanzania	1	1	1	2	2	1	1		1	2	1	2	1	2	1				3	1			1							24
Zaire				1								1	1										1							4
Zimbabwe												2	2						2			2								8

continued on next page

Table 11 continued.

Region and country	Nurseries for different cultural types[a]																		Screening for specific stresses												Total
	Yield								Observational																							
	IRYN-VE	IRYN-E	IRYN-M	IURYN-E	IURYN-M	IRRSWYN-E	IRRSWYN-M	IRDWYN	IRON-VE	IRON-E	IRON-M	IURON-E	IURON-M	IRRSWON-E	IRRSWON-M	IRDWON	IFRON	ITPRON	IRCTN	IRSATON	ACID LOWLAND	ACID UPLAND	IRBN	IRBBN	IRTN	IRBPHN	IRWBPHN	IRSBN	IRSGON	
Latin America																															
Argentina										1	1																				2
Belize		2	1						1			1	1																		6
Brazil	1	1							1	1		1	1						1				2								9
Chile									1														1								2
Colombia									2	2	2	2	2									1	1								12
Dominican Republic									1	1	1	1	1						1	1											7
El Salvador									1														1	1							3
Guatemala									1	1	1	1	1										1								6
Honduras		1																					3								4
Mexico	1	4	1	1	3	1	1		2	3	3	3	3	1	1				3	2	1	1	3								38
Panama									1	1	1	1	1										1								6
Peru	1	2																		2			2								7
Europe																															
Hungary									1			1							1												3
Italy	1								1	1	1								1				1								6
Spain	1	1	1						1	1	1									1											7
Total	67	70	50	49	38	25	32	17	72	66	59	67	52	29	33	31	23	10	67	50	24	16	89	47	21	34	25	32	22	1217

[a]IRYN-VE = International Rice Yield Nursery-Very Early, IRYN-E = International Rice Yield Nursery-Early, IRYN-M = International Rice Yield Nursery-Medium, IURYN-E = International Upland Rice Yield Nursery-Early, IURYN-M = International Upland Rice Yield Nursery-Medium, IRRSWYN-E = International Rice Rainfed Shallow Water Yield Nursery-Early, IRRSWYN-M = International Rice Rainfed Shallow Water Yield Nursery-Medium, IRDWYN = International Rice Deep Water Yield Nursery, IRON-VE = International Rice Observational Nursery-Very Early, IRON-E = International Rice Observational Nursery-Early, IRON-M = International Rice Observational Nursery-Medium, IURON-E = International Upland Rice Observational Nursery-Early, IURON-M = International Upland Rice Observational Nursery-Medium, IRRSWON-E = International Rice Rainfed Shallow Water Observational Nursery-Early, IRRSWON-M = International Rice Rainfed Shallow Water Observational Nursery-Medium, IRDWON = International Rice Deep Water Observational Nursery, IFRON = International Floating Rice Observational Nursery, ITPRON = International Tide-Prone Rice Observational Nursery, IRCTN = International Rice Cold Tolerance Nursery, IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery, ACID LOWLAND = Acid Lowland Soils Screening Set, ACID UPLAND = Acid Upland Soils Screening Set, IRBN = International Rice Blast Nursery, IRBBN = International Rice Bacterial Blight Nursery, IRTN = International Rice Tungro Nursery, IRBPHN = International Rice Brown Planthopper Nursery, IRWBPHN = International Rice Whitebacked Planthopper Nursery, IRSBN = International Rice Stem Borer Nursery, IRSGON = International Rice Slender Grain Observational Nursery.

Table 12. Origin and types of entries in the 1988 IRTP nurseries dispatched from IRRI.

Nursery	Sets dispatched (no.)	Entries (no.)	Entries (no.) from					
			National programs		IARCs[a]			Germplasm bank
			Improved	Traditional	IRRI	CIAT	IITA	
IRYN-VE	67	24	11	0	13	0	0	0
IRYN-E	70	24	11	0	13	0	0	0
IRYN-M	50	24	15	0	9	0	0	0
IURYN-E	49	18	16	0	2	0	0	0
IURYN-M	38	23	16	0	6	0	1	0
IRRSWYN-E	25	19	9	0	10	0	0	0
IRRSWYN-M	32	21	13	0	8	0	0	0
IRDWYN	17	13	8	0	5	0	0	0
IRON-VE	72	14	7	0	7	0	0	0
IRON-E	66	83	51	0	30	2	0	0
IRON-M	59	105	75	0	8	22	0	0
IURON-E	67	30	20	8	1	0	0	1
IURON-M	52	63	18	3	37	0	4	1
IRRSWON-E	29	16	8	1	7	0	0	0
IRRSWON-M	33	111	66	1	40	0	1	3
IRDWON	31	136	51	0	84	1	0	0
IFRON	23	21	16	2	3	0	0	0
ITPRON	10	55	27	2	25	0	0	1
IRCTN	67	73	51	6	6	1	0	9
IRSATON	50	97	26	2	69	0	0	0
Acid Lowland	24	83	23	1	51	3	5	0
Acid Upland	16	63	20	1	34	5	2	1
IRBN	89	157	91	10	54	1	1	0
IRBBN	47	110	52	6	50	0	0	2
IRTN	21	84	45	1	35	0	0	3
IRBPHN	34	76	42	1	29	0	0	4
IRWBPHN	25	55	26	2	24	0	0	3
IRSBN	32	44	11	2	27	0	0	4
IRSGON	22	31	24	0	6	1	0	0
Total	1217	1673	849	49	693	36	14	32

[a] International agricultural research centers.

Table 13. Utilization of 1988 IRTP nursery entries.[a]

Region and country	Entries (no.) used for			
	Hybridization	Yield testing		
		Local	State	National
East Asia				
China	71	14	12	–
Korea, Republic	18	–	–	–
Taiwan, China	12	–	–	–
Southeast Asia				
Philippines	11	–	–	–
Thailand	48	20	–	–
Vietnam	33	71	5	3
Latin America				
Dominican Republic	–	–	–	58
Europe				
Spain	14	15	–	–
Total	207	120	17	61

[a] Based on data received as of 3 Jan 1989.

Table 14. 1988 IRTP entries most frequently included in national follow-up trials.

Entry	Origin	Nursery source
AT77-1	Sri Lanka	IRYN-VE
BG731-2	Sri Lanka	IRYN-VE
BG850	Sri Lanka	IRON
B5322B-PN-1-MS-1-KP-1	Indonesia	IRON
B5322B-PN-1-MS-83	Indonesia	IRON, IRTN
B5322B-PN-19-MS-27-KP-1	Indonesia	IRON
B5322B-PN-2-MS-3-NG-2	Indonesia	IRON
C731067	Taiwan, China	IRBPHN, IRBBN
Duansan	China	IRON
IR31787-85-3-3-3-2	IRRI	IRYN-VE
IR31805-20-1-3-3	IRRI	IRYN-E
IR31851-96-2-3-2-1	IRRI	IRON
IR31868-64-2-3-3-3	IRRI	IRON, IRBN, IRTN
IR32429-47-3-2-2	IRRI	IRYN-VE, IRBN, IRTN, IRBBN, IRWBPHN
IR32876-54-2-2-2	IRRI	IRON
IR35295-82-2-1-3-2	IRRI	IRON
IR35311-25-2-1-3	IRRI	IRON
IR35366-40-3-3-2-2	IRRI	IRYN-E, IRTN, IRBPHN, IRSBN, IRWBPHN, IRBBN
IR35546-17-3-1-3	IRRI	IRYN-E
IR36	IRRI	IRYN-E, IRON, IRBN, IRBPHN
IR39357-133-3-2-2-2	IRRI	IRYN-VE, IRBN, IRTN, IRBBN
IR41985-98-3-1-3-2	IRRI	IRYN-E
IR42068-22-3-3-1-3	IRRI	IRYN-E
IR44595-70-2-2-3	IRRI	IRYN-E
IR44657-49-2-2-2-2	IRRI	IRON
IR46027-3-1-2-2-3	IRRI	IRON
IR66	IRRI	IRYN-VE, IRON, IRBN, IRBPHN, IRSBN, IRBBN, IRWBPHN
Kaohsiung sen yu 272	Taiwan, China	IRON
Luke 3	China	IRYN-E
Pusa 205	India	IRON
Pusa 570-8-2-2	India	IRON
Si-pi 692033	Taiwan, China	IRYN-E
S818b-10-2	Indonesia	IRON

The meeting, which was attended by 18 scientists from national programs, IRRI, and the West Africa Rice Development Association (WARDA), reviewed the 1988 trial results and formulated plans for 1989. The monitoring tours and workshops organized in 1988 were as follows:

- Cold Tolerant Rice Monitoring Tour in the Philippines, Thailand, India, and Republic of Korea; 25 Sep-7 Oct 1988
- Rainfed Lowland Monitoring Tour in Thailand, Cambodia, and Vietnam; 6-19 Dec 1988
- IRTP-Africa monitoring and study group meetings
  a. Upland Rice in Ivory Coast, 26 Aug-3 Sep
  b. Upland/Inland Swamp Continuum (Fe toxicity) in Liberia and Sierra Leone, 5-11 Sep
  c. Irrigated Sahel Ecology in Burkina Faso, 24-30 Sep
  d. Hydromorphic/Inland Swamp in Nigeria, 10-14 Oct
  e. Rice Yellow Mottle Virus in Niger and Nigeria, 31 Oct-4 Nov
- IRTP-Latin America workshops and meetings
  a. Rice Group Meeting in Central America, 21-25 Mar
  b. Rice Breeders' Workshops for Tropical South America, 8-10 Aug

c. IRTP Conference for Latin America, 11-12 Aug
d. Advisory Committee Meeting, 13 Aug

The observations and recommendations relative to these monitoring tours and workshops are published separately.

IRTP IN AFRICA

International Rice Testing Program

The number of nurseries for IRTP-Africa—a collaborative program of IRRI, the International Institute of Tropical Agriculture, WARDA, and African national programs—has increased considerably since 1985 (Table 15). Three hundred thirty-one nursery sets were distributed in 1988 (Table 16). The promising entries from the 1985-87 IRTP-Africa nurseries are listed in Table 17.

IRTP IN LATIN AMERICA AND THE CARIBBEAN

International Rice Testing Program

IRTP-Latin America and the Caribbean is a joint program of IRRI, the Centro Internacional de Agricultura Tropical (CIAT), and national programs in the region. In 1988, 99 sets of IRTP-Latin America nurseries were distributed (Table 18). Entries for 1988 nurseries originated from national programs of Latin America, CIAT, and Asia. Thirty-four percent of the total entries were nominated by various national programs.

Eleven introduced entries were released as varieties by various countries in Latin America during 1987-88 (Table 19). Regional meetings held in 1988 strengthened collaboration among rice researchers in Latin America. Future strategies and recommendations were formulated to improve the efficiency of IRTP-Latin America operations.

IRTP HOT-SPOT SCREENING FOR LOW TEMPERATURE STRESS

International Rice Testing Program and Plant Physiology Department

Although the high-elevation areas in Korea are all potential hot-spot sites for cold tolerance screening, the Chuncheon Substation was selected for the excellent facilities available there. At this site, water temperature can be regulated, while air temperature is generally low during the reproductive phase, which makes screening for cold tolerance at heading ideal. Greenhouse facilities are also available to check the results obtained under field conditions. The facilities are provided by the Rural Development Administration, Korea, and additional screenings are often conducted at Unbong or Jinbu, high-altitude areas in Korea.

In 1988, 477 entries from the following IRTP nurseries were screened for cold tolerance in Chuncheon: 1988 IRCTN (73), 1987 IURYN-M (38), 1987 IURYN-E (21), 1988 IURYN-M (14), 1988 IURYN-E (9), 1988 IURON (72), 1988 Acid Upland (41), 1987 Acid Upland (71), 1987 IURON (138). Many upland rice areas on mountain slopes and valleys are affected by low temperature, hence the need to screen the IRTP upland nurseries for cold tolerance for better knowledge of their reactions to low temperature.

The outstanding entries from the cold tolerance screening nursery and the observational yield trial were nominated to the 1989 IRCTN. The entries came from various national programs and from the IRRI breeding program.

Table 15. Distribution of IRTP-Africa nursery sets, 1985-88.[a]

Year	Upland			Irrigated			Rainfed lowland	Blast	RYMV[b]	Total
	AYT	ON	PSS	AYT	ON	PSS	PSS	ON		
1985	45	36	12	45	37	13	–	–	–	188
1986	50	46	25	46	43	20	–	–	–	230
1987	50	45	21	61	48	19	–	–	–	244
1988	65	53	25	71	50	28	26	17	6	331
Total	210	180	83	223	178	70	26	27	6	993

[a]AYT = advanced yield trial, ON = observational nursery, PSS = preliminary screening set. [b]A collaborative research trial on rice yellow mottle virus (RYMV); a regular nursery is planned for 1989.

Table 16. Distribution of IRTP-Africa nurseries in 1988.[a]

Country	Sets (no.)									
	Upland			Irrigated			Rainfed lowland	Blast ON	RYMV[b]	Total
	AYT	ON	PSS	AYT	ON	PSS	PSS			
Belgium	4	–	–	4	–	–	–	–	–	8
Benin Republic	1	1	–	1	1	–	1	1	–	6
Burkina Faso	1	1	–	1	1	–	–	1	1	6
Burundi	2	1	1	5	3	–	1	–	–	13
Cameroon	2	3	2	3	2	2	1	1	–	16
Colombia	–	1	1	–	1	–	–	–	–	3
Congo	2	–	–	2	–	–	–	–	–	4
Egypt	–	2	2	–	–	–	–	–	–	4
Ethiopia	1	1	–	1	1	–	–	–	–	4
Gambia	3	1	1	2	1	–	–	–	–	8
Ghana	4	5	1	3	3	1	3	2	–	22
Guinea	3	2	1	1	1	–	1	–	–	9
Guinea Bissau	4	5	–	2	3	–	1	–	–	15
Ivory Coast	5	5	3	3	1	–	1	1	1	20
Kenya	2	1	1	2	1	–	1	1	–	9
Liberia	2	2	2	3	3	3	1	1	–	17
Malawi	–	–	–	2	2	1	1	1	–	7
Mali	1	1	–	–	–	–	–	–	–	2
Niger	–	–	–	–	–	–	–	–	1	1
Nigeria	7	6	4	12	6	3	7	2	2	49
Rwanda	1	1	1	3	2	2	1	1	–	12
Senegal	2	2	1	3	3	2	1	1	–	15
Sierra Leone	2	1	–	3	2	1	1	1	1	12
Solomon Islands	1	–	–	1	–	–	–	–	–	2
Somalia	1	1	–	1	1	–	–	–	–	4
Sudan	1	1	–	1	1	–	–	–	–	4
Tanzania	2	3	2	6	6	1	1	1	–	22
Togo	1	1	1	1	1	–	1	–	–	6
Uganda	2	1	–	–	–	–	–	–	–	3
Zaire	4	1	–	1	–	–	–	–	–	6
Zambia	3	2	1	3	3	2	2	2	–	18
Zimbabwe	1	1	–	1	1	–	–	–	–	4
Total	65	53	25	71	50	18	26	17	6	331

[a] AYT = advanced yield trial, ON = observational nursery, PSS = preliminary screening set. [b] A collaborative research trial on rice yellow mottle virus (RYMV); a regular nursery is planned for 1989.

IRTP HOT-SPOT SCREENING FOR ADVERSE SOILS TOLERANCE

International Rice Testing Program and Soils Department

Acid Upland. At Balagbag, San Dionisio, Iloilo, Philippines, we screened 290 upland rice varieties for tolerance for drought, rice blast, and overall adverse soil and climatic conditions. Of the promising entries, 24 were nominated for inclusion in the IURYN and Acid Upland Screening Set of IRTP nurseries for multilocation testing:

Aus 454 (C)	IR47686-7-2-1
B3622E-TB-5-4-4	IR47686-12-3-2-1
B3623G-TB-46	IR47691-27-2-2
CT6510-19-2-1	IR45199-B-B-B-2
CT6510-21-3-3	IR45199-B-B-B-3
CT6510-24-1-1	IR45199-B-B-B-5
CT6510-24-1-3	IR45221-B-B-B-14
CT6516-23-2-7	IR45222-B-B-B-4
CT6633-19-2-3	IR45222-B-B-B-10
CT6727-11-2-1	IR37532-B-B-B-5-3
IR47682-9-1-B	IR38547-B-B-B-3-2
IR47686-4-4-B-2	IR52812-CP128-C3-21-2-1

Table 17. Promising entries in Africa from the 1985-87 IRTP-Africa nurseries.

Nursery[a]	Entries
AIRAT	BG400-1, BG90-2, IR46, ITA212, ITA306
AURAT	IRAT104, IRAT161, IRAT170, ITA305, ITA315
AIRON	BR153-2B-10-1-3, BW348-1, IR1346, IR18348-36-3-3, IR19661-150-2-2-2-1, IR211141-24-2, IR3880-10, ITA302, TOX714-1-204-1-101-3, TOX902-5-103-3-101-2
AURON	IRAT109, IRAT133, IRAT136, IRAT147, ITA116, ITA118, ITA130, ITA187, TOX1012-12-28, TOX475-NIB1-KN1-LS3
AIRPSS	Bouake 189, B4140C-PN-186-28-KP-2, CP3-C2, C1252-9, IR2042-178-1, IR21015-72-3-3-3-1, IR21820-154-3-2-2-3, IR22082-41-2, IR28128-45-3-3-2, TOX902-5-102-2-103-101
AURPSS	IRAT156, IRAT168, IR14632-22-3, M55, TOX1010-21-5-12-4, TOX955-208-2-102

[a]AIRAT = African Irrigated Rice Advanced Trial, AIRON = African Irrigated Rice Observational Nursery, AIRPSS = African Irrigated Rice Preliminary Screening Set, AURAT = African Upland Rice Advanced Trial, AURON = African Upland Rice Observational Nursery, AURPSS = African Upland Rice Preliminary Screening Set.

All these entries have drought tolerance and phenotypic acceptability scores of 4.5.

Inland iron-toxic soils. About 180 rices put together by IRTP were evaluated for tolerance for acid soil conditions having Fe toxicity, P deficiency, and low pH in San Dionisio, Iloilo, Philippines. The soils used in this trial had properties similar to those of soils in mass screening and yield trials. Of the 11 promising lines at this site, 4 were outstanding—B4414F-MR-6-3, IR32453-20-3-2-2, IR34686-179-1-2-3, and X72-7-15—and were nominated for inclusion in the Acid Lowland and

Table 19. Rice varieties released in Latin America, 1987-88.

Name	Releasing country	Pedigree
	From introduced material	
Ajuricaba	Brazil	F2205 F4 (CNA1051)
Alto Mayo 88	Peru	P4519F3-5-2M
Apatzingan A87	Mexico	P2231F4-45-1B
BR-IRGA 414	Brazil	P793-B4-38-1T (CL selection14)
Cabacu	Brazil	Mutation IRAT79
Cimarron	Venezuela	Taichung sen yu 23
IAC238	Brazil	P3299F4-7-1
IAC242	Brazil	P2399F4-33-2
ICTA Motagua	Guatemala	P3304F4-5-1B
ICTA Quirigua	Guatemala	P2231F4-138-2-3
Mearim	Brazil	TOM1-3 (mutation OS-6)
	From locally generated material	
Guapore	Brazil	CNA/511-12-B-14 (CNA4172)

Table 18. Distribution of 1988 IRTP-Latin America nurseries.

Germplasm group tolerance for	First semester		Second semester		Total	
	Lines (no.)	Sets (no.)	Lines (no.)	Sets (no.)	Lines[a] (no.)	Sets (no.)
	For favorable moisture environments					
Blast only[b]	80	14	81	6	108	20
Blast combined with hoja blanca and vector	14	4	15	1	18	5
Fe toxicity	—	—	18	1	18	1
Earliness	29	2	48	8	49	10
Fe toxicity and earliness	—	—	11	4	11	4
Fungal diseases[c] only	50	30	48	5	72	35
Fungal diseases combined with hoja blanca and vector	10	5	10	1	13	6
Subtotal	—	55	—	26	—	81
	For unfavorable moisture environments					
Fungal diseases and acid soils	50	12	50	6	50	18
Total	—	67	—	32	—	99

[a]This number does not agree with semester totals because some lines were common to both semesters. [b]This row represents the total number of lines available for this environment at a given time, since all combinations include blast tolerance. [c]Blast, narrow brown leaf spot, leaf scald, brown spot, and glume discoloration.

IRON screening and IRYN sets of IRTP for multilocation testing. All these lines have vegetative vigor and phenotypic acceptability scores of 2-4, and grain yield of about 200 g/m^2.

Saline soils. We characterized 270 rice entries at 3 sites in farmers' fields in Santo Rosario, Lanjagan, and Pili, Ajuy, Iloilo, Philippines, used as hot-spot testing sites for saline and acid sulfate soil conditions. Twenty-seven varieties that obtained a score of 4 or better at all sites were nominated to be included in IRSATON and the acid lowland screening sets of IRTP for multilocation testing:

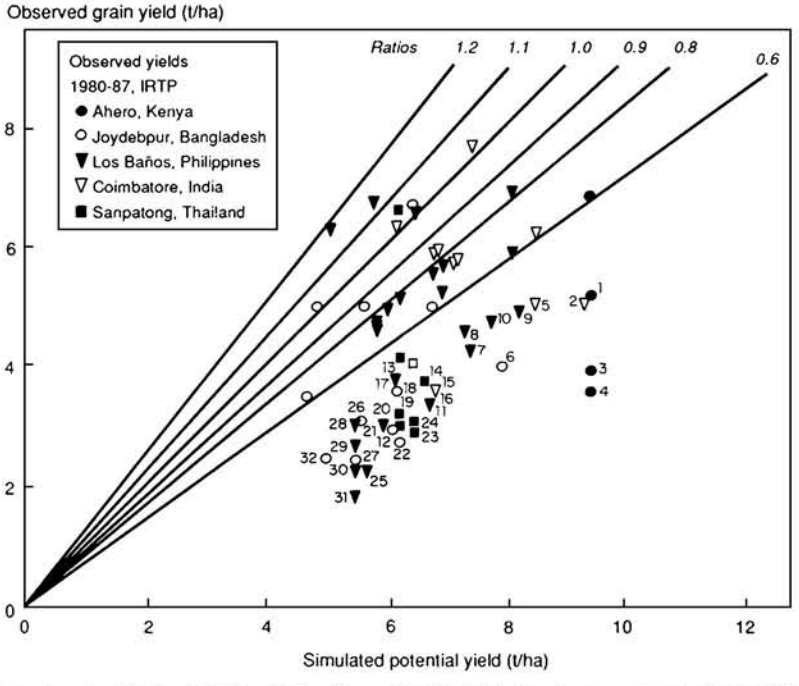
IR21178-43-1-2-2-2
IR2608-4-2-1-3-3
IR30146-26-3-2-3
IR31238-474-3-P1
IR4111-13-1-1-2
IR4111-113-1-2-1-2
IR42207-93-22-2-1-2
IR42207-94-2-4-3
IR42244-37-1-2-2
IR42371-26-6-2-1
IR42266-81-5-3-2
IR43034-22-3-2-3-3
IR43342-10-1-1-3-3
IR43449-SKN-522-3-1-3
IR37255-21-3-3-2
IR37263-6-1-3-3-1-2
IR46706-27-3-3
IR47606-37-2-3
IR31375-5-2-1-3
IR37250-44-2-1-1-2-2
IR54742-24-38-10
IR46346-KKN-8-2-1-2
IR42998-124-3-1-1
IR42998-155-2-3-2
IR43016-14-3-3-3
IR46463-CPA-3-2-2-3
TCP6533-8

In addition, eight lines from Bangladesh were found promising under these soil conditions: BR1818-2B-4-1-1, BR1818-2B-12-2-1, BR1818-2B-15-2-1, BR1818-2B-26-5-2, BR1878-10-1-1-4, BR1878-15-1-4-1, BR1818-16-1-4-4, and BR2576-2B-6-5.

LITERATURE DISSEMINATION TO IRTP NETWORK

Library and Documentation Center and International Rice Testing Program

In 1988, the library broadened the scope of its literature dissemination program through the already established linkage and network of IRTP. This places the library in direct position to answer the information needs of more than 800 rice scientists involved in varietal improvement, located at more than 300 research stations in 55 rice-growing countries around the world.



4. Simulated and actual grain yield for 65 trials at 5 locations of IRTP, 1988. Numbers represent individual trials with actual yields less than 60% of potential production.

USING SIMULATION MODELING TO SUPPORT TESTING OF VARIETIES IN MULTILOCATION TRIALS

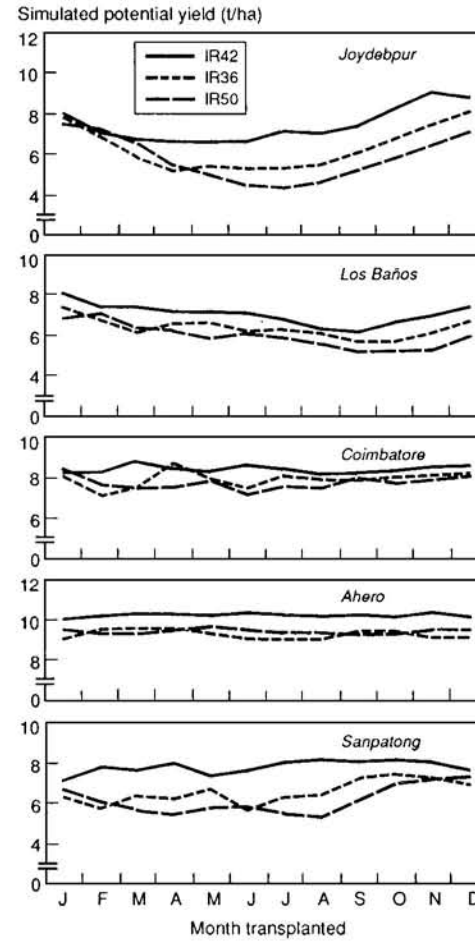
International Rice Testing Program and Multiple Cropping Department

IRTP and its collaborative rice breeders are searching for tools that permit more efficient screening and comparison of performance of varieties across locations and years. We investigated how simulation can support evaluation of crop performance in multilocation trials of IRTP. Potential productivity of three varieties in five environments was simulated. These varieties represent three maturity groups: very early (IR50), early (IR36), and medium (IR42). Potential yields were calculated as a function of actual solar radiation, maximum temperature, and minimum temperature, all other factors being nonlimiting. Some field observations were used to calibrate the rate of progress toward flowering.

The period to flowering and to maturity was simulated well across all sites. Yields simulated for transplanting throughout the year show seasonality related to temperature and radiation variations. The model simulates crop development and potential yield over a range of conditions rather well. Comparing actual yields in 65 trials with potential yields showed that only about half of the experimental yields were roughly similar to simulated values, while actual yield was less than 60% of potential production in the other cases (Fig. 4). Reasons for this yield gap vary in an irregular manner from year to year and site to site (e.g., pest and disease pressure, soil constraints, suboptimal fertilization).

A weather generation program was used to create weather patterns for 20 yr whenever historic records were too short. Expected potential yields for 25%, 50%, and 75% probability levels were derived (e.g., Fig. 5). This puts values for a particular year in a long-term perspective.

To apply crop simulation, a minimum set of weather and crop data is required. We recommend resumption of weather data reporting by cooperators. A few additional data on key cultivars at specific sites must be collected.



5. Expected potential yields for 50% probability levels in 3 rice maturity groups: IR50 (very early), IR36 (early), and IR42 (medium) at 5 IRTP sites based on simulations with 20 yr of generated weather data for Joydebpur (Bangladesh), Coimbatore (India), Ahero (Kenya), and Sanpatong (Thailand), 1988. For Los Baños, Philippines, 20 yr of historic weather data are used.

International collaboration

International Network on Soil Fertility and Sustainable Rice Farming

International Network on Soil Fertility and Sustainable Rice Farming

INTEGRATED USE OF INORGANIC AND ORGANIC NITROGEN FERTILIZERS **576**
Irrigated rice **576**
Rainfed lowland rice **578**
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LONG-TERM FERTILITY TRIALS **578**
Irrigated rice **578**
SOIL FERTILITY MANAGEMENT OF ACID UPLAND SOILS (pH<5) **580**

Eighty-three INSURF trials were conducted in the 1987-88 cropping seasons at 64 sites in 9 countries. Of these, 29 trials were on the integrated use of inorganic and organic N fertilizers in irrigated rice; 17 were long-term fertility trials in irrigated rice; 16 concerned soil fertility management of acid upland soils for rice; 12 were on N fertilizer efficiency trials in irrigated rice and 4 on rainfed lowland rice; and 5 compared hand- and machine-applied N fertilizers in irrigated rice.

In 1988, 144 sets of experimental fertilizers and fieldbooks were sent to 44 collaborators in 13 participating countries. Seven collaborative research trials were conducted, as follows:

- Integrated use of inorganic and organic N fertilizers
  - irrigated rice (second in series)
  - rainfed lowland rice (first in series)
  - upland rice (first in series)
- Long-term fertility trial
  - irrigated rice (second in series)
  - rainfed lowland rice (first in series)
  - upland rice (second in series)
- Soil fertility management of acid upland soils (pH <5, second in series)

The current research focus on integrated nutrient management and long-term fertility trials in the major rice environments is the response of the newly organized INSURF network to the two pressing challenges of 1) promoting soil health for sustainable rice production, and 2) reducing production cost through input use efficiency and substituting farm-produced inputs for purchased inputs. INSURF is developing appropriate integrated nutrient management systems involving chemical and biofertilizers, and is looking into the long-term effects of inorganic fertilizers in intensive rice-based cropping systems as well as long-term trends in grain yield. The socioeconomic impact of various soil fertility management strategies including those for adverse soils is also a major concern. The whole scheme of INSURF research is aimed at developing relevant soil fertility management technologies for the major rice ecosystems that will maintain present or future yield levels and at the same time preserve or enhance the soil resource for the next generations.

The N fertilizer efficiency trials and the trials comparing hand- and machine-applied N fertilizers were still conducted by interested collaborators in 1988. Although optional, some collaborators conducted these trials as part of maintenance research or to address some site-specific issue.

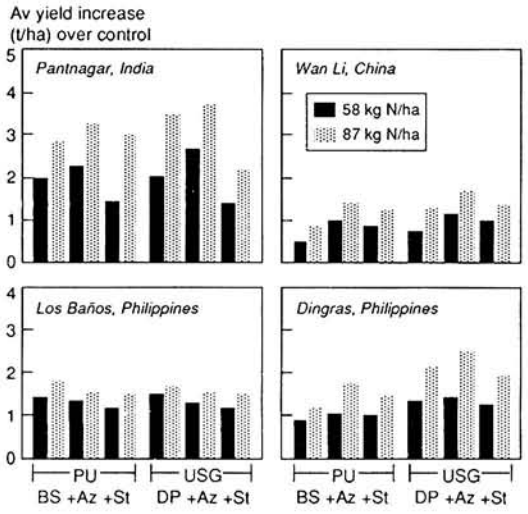
In 1988, INSURF initiated subnetworks to tackle major research priorities. Each subnetwork involves a lead center in a mature national system that has attained strength in a specific area directly related to INSURF's priorities.

INTEGRATED USE OF INORGANIC AND ORGANIC N FERTILIZERS

Irrigated rice. During the 1987-88 cropping seasons, 18 trials on integrated nutrient management for irrigated rice were conducted at 10 sites in 5 countries. This long-term trial was initiated in 1984 to evaluate the effectiveness of inorganic N fertilizers applied alone or in combination with biofertilizers (1/3 to 1/2 of N requirement) such as azolla and rice straw and to determine their long-term effects on soil fertility. At least six sites in five countries are still continuing, and some are already in their fourth or fifth year of continuous intensive cropping.

A significant response to N was observed at most sites. The performance of deep-placed (DP) urea supergranules (USG) was superior to that of best split (BS) application of prilled urea (PU) even when combined with biofertilizers. Average responses at 15 sites in 6 countries showed that inorganic N as PU BS or USG DP with azolla or rice straw produced yields comparable to those with inorganic sources alone. At certain sites such as Pantnagar, India; Wan Li, China; and Dingras, Philippines, inorganic N + azolla performed even better than inorganic N alone (Fig. 1). On the other hand, the performance of inorganic N + rice straw was inferior to that of inorganic N + azolla at several sites. At one site (Coimbatore, India) inorganic N + rice straw gave higher yields than the combination of inorganic N + azolla.

Responses to N and the effectivity of inorganic/organic N combinations were largely dependent on key environmental parameters such as soil characteristics. In some trials, the advantage of



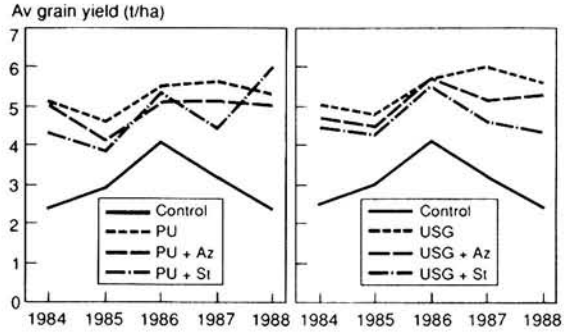
1. Average yield response of irrigated rice to inorganic and organic N combinations at 4 sites in 4 countries. First trial on integrated use of inorganic and organic N in irrigated rice, INSURF, 1984-88. PU = prilled urea, BS = best split, Az = azolla, St = rice straw, USG = urea supergranules, DP = deep-placed.

integrated nutrient management was more apparent at higher N rates. Constraints on the availability of biofertilizers such as azolla may force the farmer to consider alternative organic materials. This was actually observed at a few sites.

Changes in key soil properties were studied at the Los Baños (Philippines) site after 10 successive rice croppings (1984-88) (Table 1). For the topsoil layer (0-20 cm depth), increases in soil organic matter, available P, and available Zn were observed. The soil improvements were more obvious in plots where biofertilizers were applied. Similar changes were observed for the subsoil layer.

Trends in grain yield also varied across sites. In Los Baños, yields initially increased, but after the third year, dry season (DS) yields gradually decreased (Fig. 2). In Wan Li, China, yields of inorganic and organic N combinations tended to increase, while yields due to inorganic fertilizer alone tended to decrease (Fig. 3).

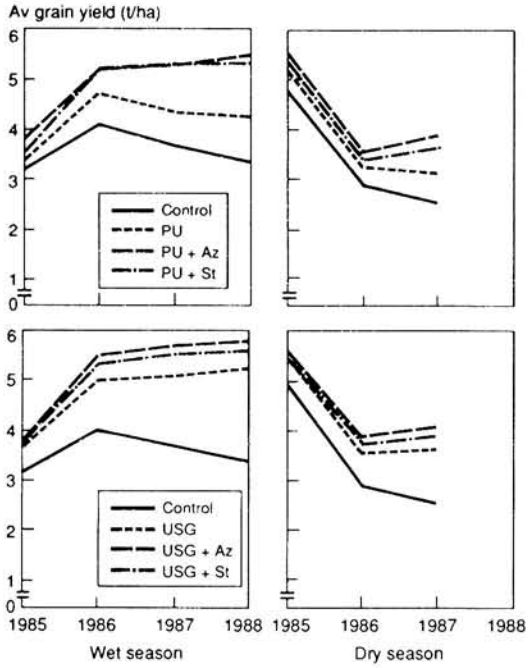
Preliminary results for the second trial on integrated use of inorganic and organic N (a modification of the first trial) showed similar yield increases for USG DP and PU + green manure (GM) at five of nine sites in four countries. GM species used in the 12 trials conducted were *Sesbania*



2. Dry season grain yield trends in the first trial on integrated use of inorganic and organic N fertilizers in irrigated rice conducted at IRRI, Los Baños, Philippines, 1984-88. N rate = 58 kg/ha.

Table 1. Changes in soil characteristics (0-20 cm depth) after 10 consecutive croppings in the first trial on integrated use of inorganic and organic N at Block 421b, IRRI, Los Baños, Philippines. INSURF, 1984-88.

Treatment	pH	Organic matter (%)	CEC (meq/ 100 g)	Total N (%)	Available P (Olsen) (ppm)	Exchangeable K (meq/ 100 g)	Available Zn (ppm)
Original condition	5.9	3.25	35	0.16	19	1.7	1.0
After 10 croppings							
Control	5.9	3.06	32	0.16	33	1.7	1.8
PU	5.8	3.41	32	0.18	34	1.6	1.4
USG	5.8	3.38	32	0.17	34	1.6	1.4
PU + azolla	5.6	3.48	33	0.18	36	1.7	1.6
PU + straw	5.6	3.67	32	0.18	38	1.8	1.5
USG + azolla	5.8	3.48	32	0.18	36	1.7	1.4
USG + straw	5.8	3.32	32	0.17	35	1.7	1.6

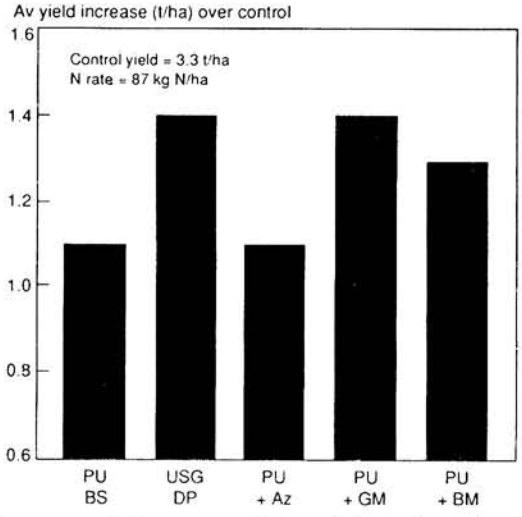


3. Grain yield trends in the first trial on integrated use of inorganic and organic N fertilizers in irrigated rice conducted at Wan Li, Fujian Province, China. 1985-88. N rate = 58 kg/ha.

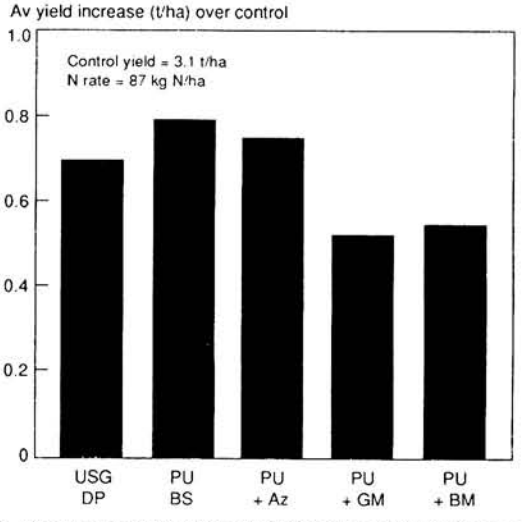
aculeata and *S. rostrata*. Among the fertilizers used, GM gave the best average yields (Fig. 4). PU + farmyard manure (FYM, in this case cattle dung) and PU + azolla performed better than PU BS, but this was not consistent for all sites.

Rainfed lowland rice. From the preliminary results of 5 trials at 4 sites in 3 countries, PU + azolla gave the highest average yield of 3.9 t/ha, comparable to PU BS (Fig. 5). USG DP gave a slightly lower yield of 3.8 t/ha. PU + GM and PU + FYM were not as effective as PU + azolla in these preliminary rainfed lowland trials.

Upland rice. Initial trials at two upland sites in Claveria, Philippines, were done during the 1988 wet season (WS). Two inorganic sources, PU and ammonium sulfate at 60 kg N/ha, were tested. Three GM species—*Cassia* sp., *Gliricidia sepium*, and *Helianthus annuus* (wild sunflower)—were tested in combination with PU (GM satisfied 1/2 of the total N requirement). For two sites, average grain yields of PU + *Helianthus* and PU + FM (poultry manure) were comparable to that of PU alone (Fig. 6).



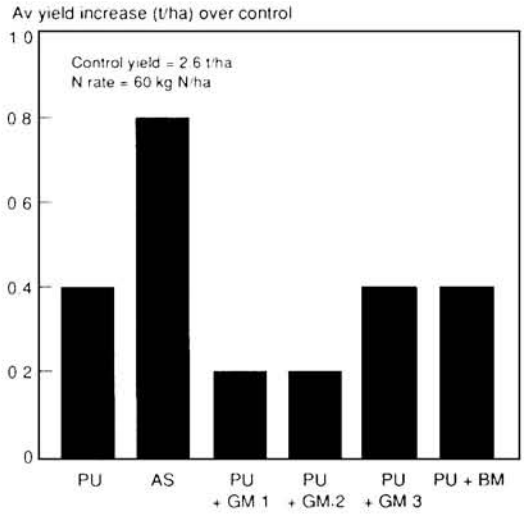
4. Average yield response of irrigated rice to inorganic and organic N combinations in 12 trials at 9 sites. Second trial on integrated use of inorganic and organic N in irrigated rice, INSURF, 1987-88. BM = barnyard manure.



5. Average yield response of rainfed lowland rice to inorganic and organic N combinations in 5 trials at 4 sites. First trial on integrated use of inorganic and organic N in rainfed lowland rice, INSURF, 1988 WS.

LONG-TERM FERTILITY TRIALS

Irrigated rice. This trial began in 1976 to monitor the effects of continuous chemical fertilizer application and intensive cropping on soil health and yield stability. With the current thrust on sustain-



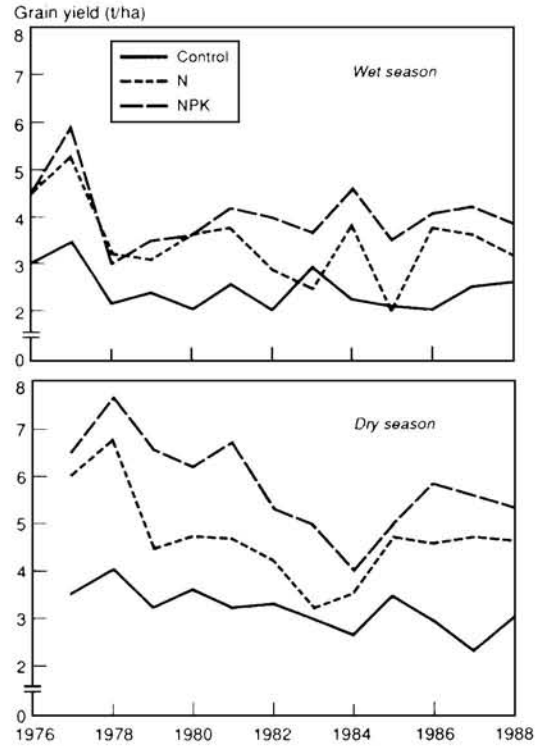
6. Average yield response of upland rice in 2 trials at 2 sites in Claveria, Philippines, 1988 WS. First trial on integrated use of inorganic and organic N in upland rice. PU = prilled urea, AS = ammonium sulfate, GM 1 = *Cassia* sp., GM 2 = *Gliricidia sepium*, GM 3 = *Helianthus annuus*, BM = barnyard manure.

able rice production systems, the long-term fertility trial becomes a vital component of the INSURF program.

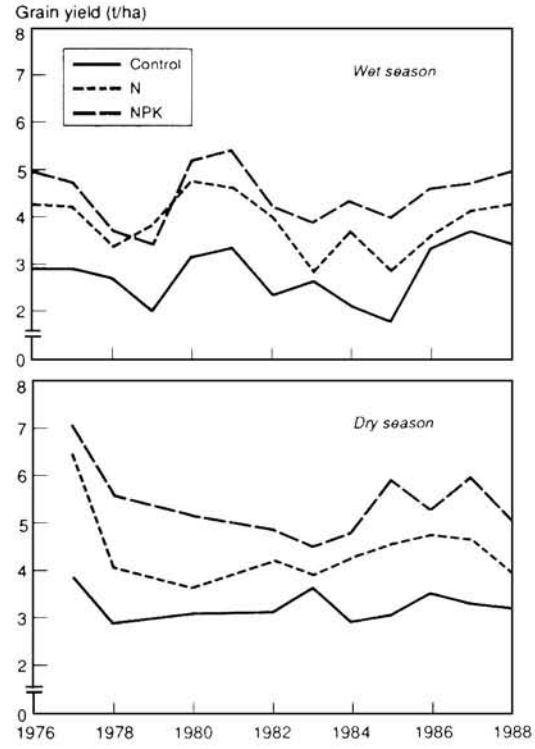
The trial is being conducted at 10 sites in 4 countries. Four sites in the Philippines and Indonesia are already in their 12th year; those in China and India are more recent. Interim results are presented here.

In Luisiana, Philippines, on an acidic Aquic Dystropept soil, yields on unfertilized and fertilized plots continued to decline gradually (Fig. 7). The slight increase observed beginning in 1984 DS may have been due to a change in variety. In Tanay, on a calcareous Vertic Tropaquept soil, yields were also declining, but not as markedly as in Luisiana (Fig. 8). The positive influence of P on grain yield was also observed in recent years, although not consistently.

Soil analyses done after 12 yr of continuous cropping in Luisiana and Tanay showed no significant changes in the soil pH, total N, exchange-



7. Grain yield trends during wet and dry seasons over 12 yr of continuous trials in Luisiana, Philippines. First international long-term fertility trial in irrigated rice, INSURF, 1976-88.



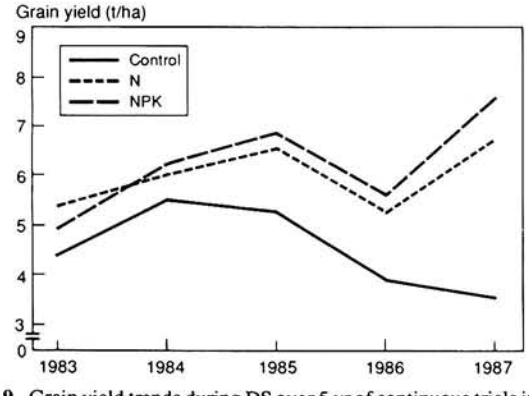
8. Grain yield trends during wet and dry seasons over 12 yr of continuous trials in Tanay, Philippines. First international long-term fertility trial in irrigated rice, INSURF, 1976-88.

able Ca, or available Zn of both soils. N remains the major limiting nutrient; however, the role of P in sustaining yields is becoming increasingly important. Without replenishment by P fertilizers, the available P of control plots in high-pH Tanay soil has gone below 10 ppm Olsen P and that in low-pH Luisiana soil has gone below 20 ppm Bray II P. P levels in fertilized plots were not as depleted; P content was higher by 2-4 ppm in fertilized plots in Luisiana.

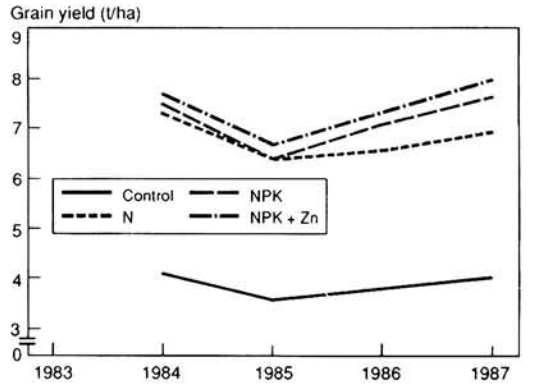
In Maros, Indonesia (Typic Tropaquept), grain yields tended to increase during DS and decrease during WS. N was the major limiting nutrient; the addition of P, K, and Zn did not significantly improve grain yields.

In Guanshanping and Shipai, China, yield trials were erratic, and no trend was yet discernible. DS yields for the unfertilized control in Qingpu declined gradually (Fig. 9). In Pantnagar, India (Fluvaquentic Haplaquoll), high grain yields were largely due to N, although responses to P, K, and Zn seem to have increased with time (Fig. 10).

The second long-term fertility trial in irrigated rice started in 1988 WS at five sites in four countries. The trial includes an inorganic/organic fertilizer treatment and provides for site-specific treatments, determined by the collaborator, to deal with site-specific problems. Initial results showed that nutrients such as S and Zn in addition to NPK can further increase yields at some sites. In Coimbatore, India, and Kyaukse, Myanmar, the use of biofertilizers had a positive effect on grain yield.



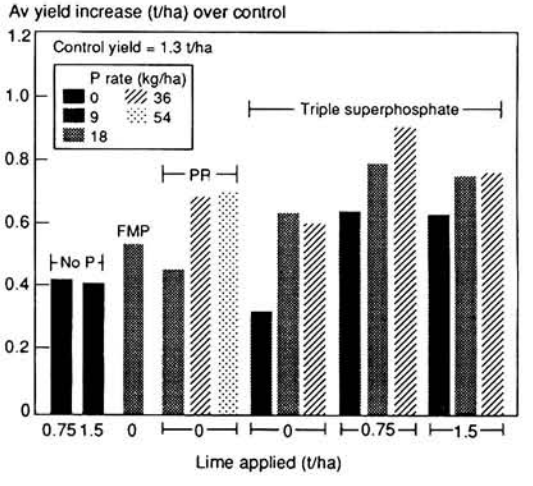
9. Grain yield trends during DS over 5 yr of continuous trials in Qingpu, Shanghai, China. First international long-term fertility trial in irrigated rice, INSURF, 1983-87.



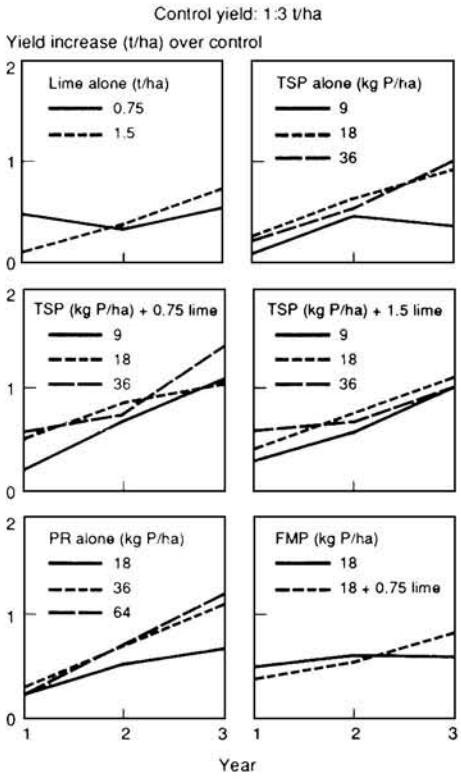
10. Grain yield trends during WS over 4 yr of continuous trials in Pantnagar, Uttar Pradesh, India. First international long-term fertility trial in irrigated rice, INSURF, 1984-87.

SOIL FERTILITY MANAGEMENT OF ACID UPLAND SOILS (pH<5)

The interactions between 3 P sources—triple superphosphate (TSP), less soluble phosphate rock (PR), and fused magnesium phosphate—and lime, and their long-term effects on rice yield were tested in 12 trials at 4 acid upland sites in the Philippines and Myanmar from 1984 to 1988. Three kinds of PR were used: Christmas Island PR, Citraphos, and Morocco PR. Lime was ap-



11. Average yield response of rice in 10 trials conducted at 3 acid upland sites in the Philippines during 1984-88 WS. First international trial on soil fertility management of acid upland soils (pH <5) for rice, INSURF, 1984-88. FMP = fused magnesium phosphate, PR = phosphate rock.



12. Yield response trends over 3 consecutive years of upland rice to various treatments in the P x lime interaction trials in Cavinti and Claveria, Philippines. First international trial on soil fertility management of acid upland soils (pH <5) for rice, INSURF, 1988.

plied at 0.75 and 1.5 t/ha and band-placed near the drilled seeds.

Average responses from trials conducted in Cavinti (Orthoxic Palehumult) and Claveria (Ultic Haplorthox) showed TSP as the best P source with or without lime (Fig. 11). At the same P rate, TSP + 0.75 t lime/ha performed better than TSP alone or TSP + 1.5 t lime/ha. PR sources gave lower yields than TSP during the first few years; with time, however, yields increased with increasing levels of PR applied (Fig. 12). Upland rice was more responsive to P application; in later years, however, yields due to lime alone also improved. In Cavinti and at the more fertile site in Claveria, yields with lime alone gradually increased after three consecutive years of lime application. The results indicate that both P and lime are essential to increasing yields in strongly acidic upland soils.

Table 2. Changes in pH and Bray II P of the topsoil layer (0-20 cm) at 2 acid upland sites in the Philippines.

Treatment	Cavinti (Orthoxic Palehumult)		Claveria I (Ultic Haplorthox)	
	pH	Bray II (ppm)	pH	Bray II (ppm)
Original condition	4.4	6.7	4.6	9.8
	After 4 croppings		*After 3 croppings*	
Control	4.4	6.1	4.3	4.9
TSP alone (36 kg P/ha)	4.9	7.0	4.6	6.2
Lime alone (1.5 t/ha)	4.8	6.1	4.7	5.0
TSP + lime (36 kg P/ha + 1.5 t/ha)	4.7	7.1	4.6	7.7

Soil analyses done for both sites showed no substantial improvement in soil pH even after 4 yr of continuous cropping (Table 2). In Cavinti, Bray II P slightly increased in plots with TSP but was still below the critical minimum level. In Claveria, soil P decreased even with fertilized plots; with the unfertilized control, soil P was depleted to a greater extent.

International collaboration

Asian Rice Farming Systems Network

Rice Farming Systems Program; Training and Technology Transfer, Agricultural Economics, Multiple Cropping, and Entomology Departments; University of the Philippines at Los Baños; Philippine Department of Agriculture; Kasetsart University, Chiang Mai University, Khon Kaen University, Prince of Songkla University, and Department of Agriculture, Thailand; Agency for Agricultural Research and Development, Indonesia; Bangladesh Rice Research Institute; Department of Agriculture, Nepal; Indian Council for Agricultural Development; Pakistan Agricultural Research Council; Management of Agricultural Research and Technology Group; and Department of Agriculture, Sri Lanka

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IMPACT OF FARMING SYSTEMS RESEARCH **593**

In the Asian Rice Farming Systems Network (ARFSN), scientists from IRRI and 15 nations work together to increase food production by identifying more productive rice-based farming systems. Countries collaborating in the network are Bangladesh, Bhutan, China including Taiwan, India, Indonesia, Republic of Korea, Madagascar, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand, and Vietnam. The methodology developed collaboratively over time for on-farm research is used in most of the countries. A national coordinator or leader represents each country in the ARFSN Working Group, which meets annually. The working group determines priority areas for collaborative research.

In addition to doing farming systems research (FSR), national programs are extending the technologies identified. Bangladesh, Sri Lanka, Indonesia, Philippines, Nepal, and Thailand are implementing the preproduction and production phases of the technologies developed at various locations. The Philippines, for example, is now reorienting commodity production programs such as "Masagana 99" (rice) and "Maisagana" (maize) to a farming systems perspective to increase farm production and income.

Collaborative research activities in the network include cropping systems research, rice - wheat cropping systems, women in rice farming, crop - livestock farming systems, varietal testing of upland crops, long-term cropping patterns, fertilizer studies, and farm implements for intensive systems. A study to assess the impact of FSR involving six countries is also under way.

VARIETAL TESTING OF UPLAND CROPS BEFORE AND AFTER RICE

Rice Farming Systems Program

Materials for varietal testing came from the breeding programs of the Institute of Plant Breeding (IPB), Philippines; Field Crops Research Institute, Thailand; Central Research Institute for Food Crops, Indonesia; and other national programs involved in the network. Cowpea and soybean entries came from IRRI screening in collaboration with the International Institute of Tropical Agriculture (IITA). Pigeonpea came from IRRI screening in collaboration with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Maize entries came from the International Maize and Wheat Improvement Center (CIMMYT), IPB, and other national programs (Thailand, Indonesia, and Myanmar).

In 1988, we distributed 47 trials for prerice evaluation (15 mungbean, 15 cowpea, 4 bush sitao, 5 soybean, 3 peanut, 3 maize, 1 sorghum, and 1 pigeonpea) and 101 trials for postrice evaluation (20 mungbean, 20 cowpea, 5 bush sitao, 22 soybean, 16 peanut, 7 maize, 5 sorghum, and 6 pigeonpea) to Nepal, Myanmar, Thailand, Cambodia, Bhutan, Pakistan, Indonesia, Sri Lanka, Vietnam, India, and Philippines.

The most promising varieties in the trials conducted before and after rice during the 1987-88 cropping pattern year in Thailand, Myanmar, and Philippines are presented in Tables 1 and 2.

We also increased seeds of 44 mungbean, 15 cowpea, 5 bush sitao, 18 soybean, 16 peanut, 7 sorghum, 5 pigeonpea, and 4 maize lines or varieties from IPB, ICRISAT, IITA, CIMMYT, and national programs (Thailand, Pakistan, Myanmar, and Indonesia).

CROP - LIVESTOCK PROJECT

Rice Farming Systems Program and Institute of Animal Science, University of the Philippines at Los Baños

The main objective of the component technology research on forage crops is the search for suitable forage species and proper cultural practices to increase animal feeds in rice-based farming systems. The research has been carried out in two environments based on strategies of growing forage crops.

Rainfed upland. Two intercropping experiments (cereal + forage legume and grain legume + forage legume) were conducted to evaluate intercropping effects on food and forage production. One experiment involved 16 intercropping combinations of 4 cereal crops (UPLRi-5 upland rice, XC#1 maize, UPLSG5 sorghum, and pearl millet) and 4 forage legumes: *Desmanthus virgatus*, *Stylosanthes guianensis* (CIAT 136), *Macroptilium atropurpureum* cv. siratro, and *Centrosema macrocarpum*. Another was intercropping of four

Table 1. Upland crop varieties better than the local check or highest yielding across locations in the Asian Rice Farming Systems Network when planted before wetland rice, 1987-88 cropping pattern year.

Test site	Mungbean		Cowpea		Peanut		Soybean grain	Field maize	
	Grain	Fodder	Grain	Fodder	Grain	Fodder		Grain	Fodder
Philippines	IPB M79-13-29	IPB M79-13-29	IT82D-889	IT82E-16	–	–	–	–	–
	IPB M79-9-82	VC 1973 A	IT82D-755	TVX 1850-01E					
	Pag-asa 3	IPB M79-9-82	IT82D-892	IT82D-787					
				IT82D-755					
Thailand	IPB M79-9-82	–	–	–	–	–	AGS 129	–	–
	VC 2768 A						EG SY-73		
	Uthong 1						SJ-4		
Myanmar	M-19-19	IPB M79-13-29	–	–	Hung Mei-chao	IPB PN-42-14	–	Ranjuna	Comayagua 8130
	Uthong 1	IPB M79-9-82			JL-24	IPB PN-2-25		Yezin 8401	IPB Var 2
	Padishewa	Uthong 1			IPB M79-2-25	M-10		Early DMR Comp 1	Early DMR Comp 1
	IPB M79-9-82								

grain legumes (Pag-asa 3 mungbean, All Season cowpea, CES 2-25 peanut, and UPL-Sy2 and SJ-5 soybean) and four forage legumes: *Clitoria ternatea*, pigeonpea (*Cajanus cajan*), *Centrosema*, and siratro.

Cereal grain yields in cereal + forage legume combinations were not significantly different from their monocrop yields. Cereal grain yield was highest with cereal intercropped with *Desmanthus*. Among forage legume intercrops, *Stylosanthes* gave the highest fodder yield of 10.97 t/ha, while *Centrosema, Desmanthus*, and siratro yielded 8.76, 7.18, and 4.58 t/ha, respectively. In the grain legume + forage legume intercropping, grain yields of the first grain legume crops were likewise significantly different ($P < .05$) among intercrop combinations. Forage dry matter yields of intercrops were also highly significant with pigeonpea, 1.96 t/ha; *Desmanthus*, 0.20 t/ha; siratro, 0.28 t/ha; and *Clitoria*, 0.52 t/ha. Crop grain and residue yields in the second cropping season were lower, but forage yields were higher than in the first cropping. The whole year forage yield of each species was 7.67 t/ha for *Desmanthus*, 5.40 t/ha for *Clitoria*, 5.18 t/ha for pigeonpea, and 3.57 t/ha for siratro.

From November 1987 to May 1988, two similar experiments involving grain legume + forage legume intercropping were conducted in farmers' fields. In Bacnotan, La Union, Philippines, four main crop grain legumes (Pag-asa 5 and IPB-M79-13-29 mungbean and IT82D-889 and TVX 2724-01F cowpea) were grown with two forage legume intercrops (siratro and *Desmanthus*). In Trece Martires, Cavite, Philippines, Pag-asa 5 mungbean, IT82D-889 cowpea, QPL-72 pigeonpea, and IPB-Pn-2-25 peanut were the grain crops, and siratro and *Centrosema macrocarpum* were the intercrops. Results in Trece Martires indicated that the grain and crop residue yields of the food crops were not reduced under intercropping compared with the monocrops. Pigeonpea gave the highest yield, with 0.79 t grain/ha and 3.03 t dry matter (DM)/ha. For the intercrop forages, siratro outyielded *Centrosema* in most intercroppings. The highest forage yield, 2.89 t DM/ha, was obtained from the peanut + siratro combination. In Bacnotan, intercropping did not reduce grain yields of all main crops. In addition, crop yields of cowpea

Table 2. Upland crop varieties better than the local check or highest yielding across locations in the Asian Rice Farming Systems Network when planted after wetland rice, 1987-88 cropping pattern year.

Crop	Philippines	Thailand	Myanmar
Mungbean			
Grain	IPB M79-13-60 IPB M79-13-29 IPB M79-9-82	Uthong 1 Kampangsaen VC 2762-B-45-2B IPB M79-13-29	–
Fodder	IPB M79-13-60 IPB M79-13-29 VC 2762-B-45-2B	VC 2762-B-45-2B IPB M79-13-60 Uthong 1	–
Cowpea			
Grain	TVX 2907-02D IT82E-18 TVX 2724-01F	IT82E-16 Vita 4 CES 41-6	TVX 2907-02D IT81E-16 TVX 2724-01F
Fodder	Vita 4 TVX 2907-02D TVX 2724-01F	–	–
Peanut			
Grain	IPB PN-46-12 IPB PN-2-25 IPB PN-48-90 EG PN-18	Hong Mei-chao JL-24 IPB PN-2-25	UPL PN-4 IPB PN-42-14 IPB PN-2-25
Fodder	IPB PN-42-12 IPB PN-48-90 UPL PN-4 IPB PN-46-12	JL-24 IPB PN-48-90 IPB PN-2-25	IPB PN-42-14 Tainan EG PN-18
Soybean			
Grain	UPL SY-2 AGS 160 AGS 124 EG SY-73	TGX 536-02D TGX 311-23D Improved Pelican	Willis TGX 311-23D TGX 888-48C
Pigeonpea			
Grain	ICPL 6 ICPL 81 ICPC 87	ICPC 142 ICPC 187 QPL 72	–
Fodder	ICPL 87 TC(FC)J-1 ICPL 6 QPL 72	ICPL 6 QPL 72 ICPC 142	–
Field maize			
Grain	IPB VAR 2 IPB VAR 1 CIAT B130 Early Thai Comp	Early Yellow Pop'n Muneng 8331 N 53006	–
Fodder	IPB VAR 1 IPB VAR 2 CIAT B130 Early Thai Comp	Early Yellow Pop'n N 53006 IPB VAR 2	–
Sorghum			
Grain	ICSV 126 SPV 475 ICSV 163 CS 110	–	ICSV 138 ICSV 163 ICSV 159
Fodder	ICSV 163 ICSV 138 DK 64	–	ICSV 159 ICSV 138 ICSV 163

intercropped with either siratro or *Desmanthus* were higher than those of monocrops. Intercrop forage yields did not differ significantly, ranging from 2.70 to 4.25 t DM/ha.

D. virgatus, a high-protein leguminous species, was evaluated under different cutting regimes (30-, 50-, and 100-cm cutting heights and 30-, 45-, and 60-d cutting intervals) for herbage production.

Data from 1 yr revealed no significant differences in herbage yield among cutting intervals within any cutting height. However, yield increased significantly when the plants were cut at 100-cm height. Fresh herbage yield was highest (130.7 t/ha per yr or 38.7 t DM/ha) at 100-cm cutting height and 45-d cutting interval. At 50-cm and 100-cm cutting height, the 45-d cutting interval gave a higher herbage yield than either the 30- or 60-d interval. Leaf and stem ratios of the cut material indicated that at longer cutting intervals, leaf proportions become lower. The shattering of older, more mature leaves resulted in more stems at harvest.

Six grasses and five legume species similar to those previously tested on ricefield bunds (Annual report for 1987) were tested under rainfed upland conditions at IRRI. Cuttings and root stocks for the grasses, and seeds for the legumes were used for establishment. First herbage harvesting for forage was 60 d after establishment for grasses and 90 d for legumes. Succeeding harvests were made at 45-d intervals. The total forage yields of the grasses and legumes are presented in Table 3. Among the grasses tested, *Andropogon gayanus* gave the highest forage DM yield of 21.6 t/ha (73.7 t fresh weight/ha). Fresh forage yield (80.6 t/ha) of *Setaria splendida* was highest, but when converted to DM, the yield was third after *A. gayanus* and *Paspalum plicatulum*. Forage DM yields of the legumes ranged from 6.7 to 18.4 t/ha, *D. virgatus* giving the highest. All forage legumes except *D. virgatus* were affected by a leaf rot disease during wet season (WS), causing decreases in forage yield.

Rainfed lowland. In the lowland where there is no standing water, forage crops can be grown

Table 3. Grain, crop residue, and forage yields of cereal + forage legume intercropping on upland. IRRI, 1987-88.

Intercropping	Dry matter yield[a] (t/ha)					
	During 1st cereal crop			During 2d cereal crop		
	Grain	Residue	Forage	Grain	Residue	Forage
Upland rice monocrop	0.94 a	1.82 a	–	0.02 a	0.75 a	–
Rice + siratro	1.13 a	2.28 a	1.27	0.10 b	0.58 a	1.20
Rice + *Centrosema*	1.22 a	2.30 a	1.12	0.01 b	0.21 a	2.01
Rice + *Stylosanthes*	1.20 a	2.34 a	1.30	0.05 b	0.44 a	4.15
Rice + *Desmanthus*	1.47 a	2.60 a	0.77	0.05 b	0.51 a	1.73
Maize monocrop	1.54 a	5.97 a	–	1.14 a	3.58 a	–
Maize + siratro	0.84 a	3.93 bc	0.11	0.49 a	2.82 ab	0.95
Maize + *Centrosema*	1.19 a	3.75 c	0.80	0.57 a	1.40 bc	2.63
Maize + *Stylosanthes*	1.36 a	5.28 ab	0.18	0.88 a	1.78 bc	3.97
Maize + *Desmanthus*	1.68 a	5.20 ab	0.21	0.96 a	0.59 c	1.22
Sorghum monocrop	3.28 ab	9.08 a	–	2.00 a	2.08 a	–
Sorghum + siratro	3.38 ab	8.15 a	0.10	2.04 a	2.33 a	0.96
Sorghum + *Centrosema*	2.53 b	7.51 a	0.28	1.82 a	1.87 a	0.82
Sorghum + *Stylosanthes*	3.75 ab	7.57 a	0.33	1.16 a	1.90 a	0.92
Sorghum + *Desmanthus*	4.35 a	10.10 a	0.04	2.22 a	1.60 a	0.80
Pearl millet monocrop	1.03 a	4.43 a	–	–	–	–
Pearl millet + siratro	1.21 a	4.05 a	0.08	–	–	0.83
Pearl millet + *Centrosema*	0.86 a	3.57 a	0.45	–	–	2.36
Pearl millet + *Stylosanthes*	1.59 a	4.30 a	0.46	–	–	4.62
Pearl millet + *Desmanthus*	1.27 a	4.09 a	0.23	–	–	1.50

[a]Within each group of cereals, values in a column followed by the same letter are not significantly different at the 5% level by DMRT.

alone or integrated with food crops in many cropping patterns. The ricefield in its prerice or postrice period and the ricefield bund were used to conduct several trials on forage monocropping and food + forage intercropping.

At IRRI, a rice - forage grass cropping pattern trial to evaluate forage production during the rice fallow period in a ricefield and the means of weed control for the subsequent rice crop was started in 1986. The first year's (1986-87) results were reported previously (Annual report for 1987). In the second growing season (December 1987 to June 1988) the grasses *Brachiaria mutica, S. splendida, S. anceps* var. nandi, and *Echinochloa picta* yielded 32.3, 28.2, 25.0, and 19.4 t fresh forage/ha from 4 cuttings, which were similar to the first year's yields. Grain and straw yields of the subsequent rice crop were not affected by the prior establishment of forage grass.

The evaluation of rice varieties that have dual-purpose potential (forage and grain) was repeated in 1988 at IRRI. The results were different from those obtained previously. IR70, with 3.6 t grain/ha when not cut for forage and 2.2 t grain/ha when cut, and 4.65 t fresh forage/ha was the best variety in 1988, compared with IR34 in 1987. Differences in grain yield between the cut and uncut treatments ranged from 0.1 to 1.5 t/ha (IR74). Fresh forage yields obtained from cutting the rice plants were 3.27-5.33 t/ha.

An intercropping experiment of varied cowpea plant densities with siratro and *Desmanthus* was conducted at IRRI in January to June 1988. Two successive cowpea crops were grown with one continuous crop of the forage legume. During the first cowpea crop, grain yields of cowpea ranged from 1.02 to 1.67 t/ha, which were significantly different among plant densities. Forage yields of siratro and *Desmanthus* (0.1-0.3 t DM/ha) were not affected by the varying plant density of cowpea; however, siratro yielded a little better than *Desmanthus* during the first 12 wk. Grain yields of the second cowpea crop were about half those of the first crop, and the differences in yield among plant densities were less. Forage yields during the second cowpea crop increased (0.89-2.98 t DM/ha), since the plants were bigger and better established. *Desmanthus* yielded higher than siratro at this stage.

PROSPERITY THROUGH RICE PROJECT - PHASE 2

Training and Technology Transfer Department and University of the Philippines at Los Baños

IRRI and the University of the Philippines at Los Baños (UPLB) continued to collaborate in demonstrating and providing leadership in rice farming systems methods that maximize rice yield and in methods of postharvest crop management and scientific use of biomass. The project in the four outreach countries – Bangladesh, Indonesia, Sri Lanka, and Thailand – made satisfactory progress in introducing, testing, and demonstrating improved farming systems and postharvest and biomass utilization technologies in the pilot areas. While a complete impact assessment of the project is not yet possible, some positive changes in levels of production, income, labor use, knowledge, and use of technologies could be observed at some pilot sites.

The project, after 1 1/2 brief years of implementation, has triggered positive interactions among disciplines and agencies in putting together available information and technologies in the pilot villages. It has enhanced institutional cooperation and helped strengthen multidisciplinary attempts to demonstrate possible options that can increase farmers' income and employment opportunities in rice-based farming systems communities.

In 1989, the project will continue its regular activities but will focus more on technologies that were identified as workable and acceptable to farmers in the pilot villages. Some of the technologies gaining wide acceptability at the sites follow:

Bangladesh. Promising technologies were use of BR14 for irrigated boro season and BR20 and BR21 for rainfed aus season (gave 30-40% better yield than farmers' varieties like Pajam and IR8); an improved stove (chula), which is fuel-efficient and very cheap and emits less smoke; pedal threshers and rotary weeders; and backyard chicken raising.

Indonesia. Promising technologies were use of IR48 for the gogo rancah (direct seeding) system and Cisadane and GH277 (Improved Cisadane) for irrigated areas; addition of KCl and $(NH_4)_2SO_4$ to N and P fertilizer to obtain high yield; Supra

Insus fertilizer recommendation for irrigated areas; gogo rancah in lieu of transplanted rice in rainfed areas; simple farm equipment like serrated sickles, pedal threshers, storage facilities, winnowers, liners, hoes, and weeder; mushroom production; and silage enrichment.

Sri Lanka. Cost-reducing technologies were improved dapog nurseries, mechanical transplanters, weeders, integrated pest management (IPM), and the quick decomposition method for straw as organic fertilizer; straw for mushroom culture, handicrafts, and enriched cattle feed; pedal threshers and IRRI drum-type dryers; introduction of a sandwich crop between the maha and yala seasons; and changing of rice - rice and rice - fallow to more profitable rice - other food crop patterns.

Thailand. Promising technologies were village rice mill and rice byproduct utilization for backyard swine and chicken raising; integrated farming systems involving rice - fish, chicken, assorted vegetables, and a new rice variety (RD6); and shallow and deep wells that augment water for intensive vegetable production and backyard fishponds.

WOMEN IN RICE FARMING SYSTEMS PROGRAM

Agricultural Economics, Multiple Cropping, and Entomology Departments; University of the Philippines at Los Baños; Philippine Department of Agriculture; Kasetsart University, Chiang Mai University, Khon Kaen University, Prince of Songkla University, and Department of Agriculture, Thailand; Agency for Agricultural Research and Development, Indonesia; Bangladesh Rice Research Institute; Department of Agriculture, Nepal; Indian Council for Agricultural Research; Pakistan Agricultural Research Council; and Management of Agricultural Research and Technology Group

One of the main activities of the Women in Rice Farming Systems (WIRFS) Program was a training and planning workshop held 2-11 May 1988 at IRRI. The workshop brought together 40 social and biological scientists from national agricultural institutes and universities from the Philippines, Thailand, Indonesia, Bangladesh, Pakistan, India, and Nepal. The participants evaluated the status of efforts to consider the needs of rural women in designing rice farming systems projects, reviewed methods for integrating women's concerns into ongoing and future FSR, and presented plans for action-research activities. Technologies relevant to rural women were discussed, and a field practicum was conducted in selected villages in Pangasinan, Philippines.

In 1986, the WIRFS network of seven countries was organized at IRRI. It was agreed that technologies and mechanisms for incorporating WIRFS issues into FSR would be developed at several key ARFSN sites and other sites under national agricultural research systems (NARS). The activities focus on four general areas: women and technology development, women and extension, the impact of new technologies on women and the household, and sensitization of policymakers and women. The ultimate aim of WIRFS is to institutionalize concerns for women's roles in agricultural research and extension programs dealing with rice farming systems. The major thrust of the collaboration is to include women's concerns in rice FSR methodology from site description to technology development and dissemination. The basic elements are to

- quantify women's roles in rice-based farming systems; describe the technologies they use; identify their constraints, potentials, and needs; and recommend options for improvement;
- design, test, and adapt the best available technologies tailored to the needs of women in experimental village-based programs or at ongoing FSR sites; and
- promote the necessary training and other support programs for women to enable them to participate actively in technology development and to derive benefit from technological innovations.

Several existing cropping and farming systems sites have been selected as key sites. Comparative analyses of female labor participation across agricultural systems will also be examined using the farming systems perspective.

Philippines *(Agricultural Economics Department, University of the Philippines at Los Baños, and Philippine Department of Agriculture). Santa Barbara, Pangasinan (rainfed and partially irrigated).* In 1986, the role of women was taken into account in two villages in Pangasinan, Philip-

pines: Malanay (partially irrigated) and Carosucan (rainfed). Information describing employment, income, credit, expenditures, and food consumption was analyzed to assess the effects of technologies on men, women, and children:

- *Labor utilization in crop production.* Table 4 shows male and female labor contributions to crop production. Female labor comprised 14% of the total WS labor in rice production in the partially irrigated area and 17% in the rainfed area. Pulling seedlings and winnowing were handled exclusively by women, while transplanting, land preparation, application of chemicals, threshing, and hauling were performed by men. Hired labor was an important labor source in Malanay, and exchange labor was common in Carosucan. Female hired labor for rice was higher in Malanay (114 h/ha) than in Carosucan (56 h/ha), while exchange female labor was higher in Carosucan (39 h/ha) than in Malanay (4 h/ha). The contribution of family female labor was higher in Carosucan. About 569 h/ha were utilized for mungbean production: 65% were contributed by male adults and 35% by female adults. Land preparation and spraying (up to seven times) were done by men, while planting, harvesting, and threshing were performed predominantly by women. Marketing, storage, and seed selection were women's responsibilities.
- *Income.* Average annual household income at the partially irrigated site was slightly higher ($674) than at the rainfed site ($637) (Table 5). On a monthly basis, this was below the national average of $70 in 1987 among rice farmers, and far below the national target of $100 by 1992.
- *Farm income.* Farm income consisted of sales from crops and livestock. Rice was the main crop at both sites; however, income from nonrice crops and livestock (including swine and poultry) was important in sustaining family income. In Carosucan, 50%

Table 4. Labor utilization, by gender, in crop production. Santa Barbara, Pangasinan, Philippines, 1988.[a]

Source	Labor utilization (h/ha)		
	Malanay	Carosucan	
	Partially irrigated rice	Rainfed rice	Mungbean
Family			
Male	445.87 (93)	544.78 (91)	246.73 (73)
Female	31.62 (7)	55.45 (27)	91.69 (27)
Exchange			
Male	24.72 (85)	156.55 (80)	11.89 (100)
Female	4.27 (15)	39.00 (20)	
Hired			
Male	428.93 (79)	128.93 (70)	111.67 (51)
Female	113.70 (21)	56.32 (30)	106.67 (49)
Total	1049.11	1062.03	568.65
Male	889.52 (86)	886.03 (83)	370.29 (65)
Female	149.59 (14)	176.00 (17)	198.36 (35)

[a] Figures in parentheses are percentages.

Table 5. Average cash income per household, Santa Barbara, Pangasinan, Philippines, 1986-87 crop year.

Source of income	Income[a] (US$)	
	Malanay	Carosucan
Farm income		
Crop sales		
Rice	250 (84)	55 (37)
Glutinous rice		55 (37)
Legumes	12 (4)	30 (20)
Vegetables/fruits	36 (12)	6 (4)
Mushrooms		4 (3)
Subtotal	298 (44)	150 (23)
Livestock sales		
Carabao or cattle	46 (32)	48 (60)
Swine	98 (67)	3 (4)
Poultry	9 (1)	29 (36)
Subtotal	146 (22)	80 (12)
Off-farm income		
Male wages	31 (57)	14 (79)
Female wages	23 (43)	4 (21)
Subtotal	54 (8)	18 (4)
Nonfarm income		
Male earnings	54 (30)	81 (21)
Female earnings	73 (41)	32 (8)
Remittances, pensions, or lottery	49 (28)	242 (62)
Others (rents, etc.)		34 (9)
Subtotal	176 (26)	389 (61)
Total	674 100	637 100

[a] For 16 households in Malanay (partially irrigated) and 15 in Carosucan (rainfed). Figures in parentheses are percentages.

of the total rice income was derived from the sale of IR65, a high-yielding glutinous rice variety introduced by the project. Legumes (mungbean and cowpea) grown after rice contributed 20% to the total crop income in Carosucan. Cowpea, fruits, and vegetables, grown on a limited scale during the dry season (DS), contributed 3%. Cowpea, mungbean, and other homegrown vegetables were women's responsibilities. Mushroom production, recently introduced to women at the rainfed site, contributed only about 3% to total crop income.

Livestock income, which included that from swine and poultry (both women's responsibility), comprised 22% of the total household income in Malanay and 12% of that in Carosucan. In Malanay, income from swine fattening was higher than from large animals. In contrast, at the rainfed site income from sales of large animals (cattle) was higher than that from swine. Backyard poultry raising was an important source of cash in Carosucan. In general, because production and marketing decisions concerning large animals were handled by men, men controlled the income from such endeavors. Women controlled the income obtained from swine and poultry. Swine raised for fattening were acquired by women through the *paiwi* sharing system, while poultry was owned.

- *Off-farm income.* The female contribution comprised 43% of total off-farm income at the partially irrigated site and 21% at the rainfed site. Pulling of rice seedlings was done exclusively by women, while transplanting was done by men. Although no differences existed in cash wages between men and women, the wage rate depended on skill and efficiency.
- *Nonfarm income.* Incomes of men and women from nonfarm sources were equally important in Malanay. Men engaged in carpentry, fishing, etc. during the off-rice season. Women worked in petty trading, etc. In Carosucan, men normally performed construction work outside the village during DS. Women bought and processed glutinous rice from September to October when demand was high. Remittances from abroad were also important for a majority of the farm households (Table 5).
- *Credit.* Women were the major recipients of informal loans at both sites (Table 6). Large animals (carabao and cattle) owned by men were used as collateral. Informal loans were obtained before land preparation and crop establishment and were paid in rough rice at harvest. At the rainfed site, informal loans were used for food and daily household expenditures rather than for inputs for rice production. Before the harvest in August, when rice supplies were depleted, women borrowed rice through a credit arrangement called *tampa*. Rice worth $15 was repaid with 150 kg of rough rice (worth $22.50) following harvest. This was equivalent to interest of 10% per mo. If input loans were obtained from rice dealers, the interest rate was 12.5% per mo. Farm households were caught in a vicious cycle of borrowing rice during lean months and repaying at harvest at interest rates of 10-20% per mo. Thus rice producers were also net purchasers of rice. A strong women's organization and a credit scheme to finance income-generating activities should be explored to give women access to credit at lower interest rates (Table 6).

Table 6. Percentage of credit borrowed, by purpose and by borrower, Santa Barbara, Pangasinan, 1986-87 crop year.[a]

Item	Malanay		Carosucan	
	Formal	Informal	Formal	Informal
Purpose				
Crop production	79	51	41	18
Household	21	40	37	73
Repayment of credit		9	22	9
Total	100	100	100	100
Borrower				
Wife alone	82	76	3	77
Husband alone	7	13	42	18
Both	11	11	55	5
Total	100	100	100	100

[a]For 16 households in Malanay (partially irrigated) and 15 in Carosucan (rainfed).

Claveria, Misamis Oriental (upland). Women's roles were assessed at the Claveria, Misamis Oriental, cropping systems site (upland acid soil environment) in 1986-87. Preliminary analysis showed that women were involved predominantly in harvesting, postharvest operations, and marketing of rice and nonrice crops. This study also examined economic and noneconomic factors that influenced decision making in rural households concerning agricultural production and postproduction activities. Techniques such as ethnographic history, time allocation by direct observation, ethnographic interviews with participant observation, and recall surveys of food consumption were tested in the study.

Guimba, Nueva Ecija (irrigated and rainfed). Guimba, Nueva Ecija, is an IRRI cropping systems research site. Two villages, one irrigated and one rainfed, were selected as study sites for WIRFS. At the rainfed site, mungbean, a drought-tolerant crop, had potential for growing after rice. However, insect damage before harvest and during storage was a constraint to expanded mungbean production. Seed selection, marketing, and storage of mungbean were predominantly women's responsibilities. A survey of methods used in mungbean storage revealed the use of indigenous materials for controlling insects during storage. Experiments on the use of indigenous materials for pest control during seed storage are being conducted by the Multiple Cropping and Entomology Departments.

Studies will be conducted to quantify the roles of women in household, farm, and nonfarm activities as well as to examine the likely implications of new technologies on women's labor and income.

Trece Martires, Cavite (upland). A benchmark socioeconomic survey was conducted in Lapidario, Trece Martires. It showed that women play important roles in upland rice and nonrice crop production and in swine fattening. Based on this survey, integrated crop and animal experiments, e.g., swine - cowpea - sweet potato, were done to improve existing swine fattening practices.

Leyte, Eastern Visayas (upland). In 1986, the Farming Systems Development Project in Eastern Visayas conducted a study on gender roles in upland crop production in selected villages. The study revealed that women were involved in planting (dibbling), weeding, harvesting, drying, storage, marketing, and processing. Care and management of small ruminants and poultry were done predominantly by women. Although womens roles were identified, no efforts were made to involve women in designing technologies.

Thailand *(Agricultural Economics Department; Kasetsart University, Chiang Mai University, Khon Kaen University, Prince of Songkla University; and Department of Agriculture, Thailand).* The technology and training needs of rural women are being addressed through FSR activities under the Thailand Farming Systems Research Institute. Four sites were selected to represent different ecosystems.

Amphoe Phrao, Chiang Mai (irrigated lowland and upland). In 1987, a study on the differential roles of men and women was conducted by social scientists from Chiang Mai University and staff from the Farming Systems Research and Development Unit of the Department of Agriculture in Chiang Mai. The study showed that women were involved in both lowland and upland crop production operations, marketed farm products, and raised poultry. Backyard poultry raising had potential for increasing women's income. Based on this study, three subprojects were proposed to integrate women's concerns into the FSR activities: a) poultry husbandry technology, b) marketing study, and c) impact study.

Ban Pai, Khon Kaen (rainfed lowland and upland). In this crop - livestock project, labor and income contributions of men, women, and children were reanalyzed. Based on this study, sericulture, which is done predominantly by women, has potential for increasing household income, particularly during DS. Thus, technology in mulberry production and sericulture is being introduced to rural women in this village. This is a collaborative project between Farming Systems Research and Development Unit of the Department of Agriculture in Khon Kaen and social scientists from Khon Kaen University.

Indonesia *(Agricultural Economics Department and Agency for Agricultural Research and Development, Indonesia).* An intercountry workshop was sponsored by the Central Research Institute for Food Crops (CRIFC), Bogor, Indonesia, and Bogor Agricultural University to discuss the integration of womens concerns into FSR sites. At present, a data base on labor and income contributions by

gender and age, and on decision making is being generated to provide a basis for technology generation and transfer. Five major target areas of research have been established:

- Batumarta, South Sumatra (an upland transmigration area), with focus on the role of women in crop - livestock systems
- Sukamandi, West Java (an irrigated lowland area), with focus on the role of women in rice - fish systems
- Sukarami, West Sumatra (an upland transmigration area), with focus on the role of women in upland areas
- Maros, Sulawesi (rainfed lowland and upland areas), with focus on a comparison between active and nonactive women in agriculture
- Upper river watersheds in Central and East Java with focus mainly on the role of women in developing farming systems and soil conservation.

Pakistan *(Agricultural Economics Department, Pakistan Agricultural Research Council, and Management of Agricultural Research and Technology Group).* A study undertaken in 34 irrigated and rainfed villages in Barani revealed four major activities in rice farming where women were actively involved: a) preharvest; b) harvesting, processing, and management of field crops; c) storage and handling of food grains; and d) livestock care and management. Efforts to improve women's status in farming systems were discussed at a workshop held 12-14 Jan 1988 on the role of women in FSR. A diagnostic study at the Fatehjang FSR site was conducted by the Pakistan Agricultural Research Council and the Management of Agricultural Research and Technology Group to identify women's roles and needs.

IMPACT OF FARMING SYSTEMS RESEARCH

Agricultural Economics Department; Agency for Agricultural Research and Development, Indonesia; Bangladesh Rice Research Institute; University of the Philippines at Los Baños; Department of Agriculture, Sri Lanka

A study in 1987-88 assessed the impact of FSR in four participating countries: Indonesia, Bangladesh, Philippines, and Sri Lanka. The Agricultural Economics Department studied the impact of the FSR program in Oton-Tigbauan, Iloilo. The objectives of the study were specifically to

- locate the new technology within a farming systems framework and determine the extent to which it has been adopted;
- determine the degree to which this new technology increased real incomes of farmers and their purchasing power;
- measure the degree to which this increased purchasing power has helped enhance nutritional and educational levels of farm families, and the extent of capital asset accumulation;
- examine the influence FSR has within NARS and the impact it has had on research management and policy;
- study the role support institutions play in responding to the new technology package;
- recommend policy directions that could influence the future of FSR activities; and
- develop a cost-effective but robust methodology that can be employed by national programs using a microcomputer to measure the impact of such research programs.

A review workshop to present the results was held at IRRI, 24-28 Apr 1988. The main conclusions from the study were that there is a definite need to clearly identify technology adopters and nonadopters; and there is ambiguity in current definitions, particularly since farmers change adoption patterns regularly. In Iloilo, rainfed farmers who were adopting the technology were better off than they had been in 1975-80, during which time the traditional rice - fallow technology was practiced; in Banda Aceh, Indonesia, farmers adopting the new rice - soybean technology performed better, while in Sri Lanka there was no significant difference between adopters and nonadopters.

The study brought out the need to develop methodologies for impact studies and also to clearly identify categories of adopters and nonadopters. Consequently, a six-country study involving Bangladesh, Nepal, Indonesia, Sri Lanka, Thailand, and Philippines, funded by IDRC, will be carried out in 1989-91.

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COUNTRY REPORTS

Various departments

We briefly review some of IRRI's collaborative work with various national programs. Examples of the range of research activities undertaken follow. Other collaborative projects are discussed earlier in this annual report under the various program areas.

Bangladesh. IRRI and the Bangladesh Rice Research Institute (BRRI) have pursued collaborative rice research and training activities since June 1973. Funding was agreed upon for Phase III of the Rice Research and Training Project to cover the period from January 1988 through June 1992. The project provides for two resident scientists: a research systems specialist/IRRI representative and a rice farming systems specialist.

A major part of the project concerns training. During 1988, one BRRI scientist completed a postdoctoral fellowship at IRRI, and one fellowship was begun. Three Ph D scholarships were completed, five were continuing, and four were started during the year. Two MS scholarships were completed and two were continuing. Nineteen BRRI scientists participated in short-term training courses, and 26 in workshops or meetings at IRRI. In Phase III there are slots for 12 Ph D and 2 MS scholarships abroad and for 16 Ph D and 4 MS scholarships in Bangladesh.

During the year, BRRI and IRRI scientists collaborated on 15 projects, mostly under the BRRI/IRRI project umbrella. Two projects, Prosperity Through Rice-II and the Rainfed Rice Project, required special approval from the Government of Bangladesh. There were 26 visits of IRRI scientists to Bangladesh during the year to support these activities.

The research support through the project relates mostly to rice breeding and germplasm collection, irrigation and water management, integrated pest management, and farming systems research. A collaborative research initiative on women in rice farming was started during the year.

The collaborative research included studies on irrigation management to intensify cropping systems and more efficient use of available water. The collaborative research under Prosperity Through Rice concentrated on the nonflooded areas of Central Bangladesh. Introduction of improved rice varieties produced 17-26% increases in grain yield and as much as a 5% increase in straw yield over those of farmers' varieties. These whole-farm studies have shown the need to increase biomass production for animal feed, fuel, and soil fertility purposes.

An experiment at the Comilla Regional Station compared the total cropping pattern yields for three aus transplanting dates using four aus varieties or lines and six aman cultivars. The field duration of the aus cultivars negatively affected total yield, with the effect increasing as the date of transplanting was delayed. BR21 followed by photoperiod-sensitive BR716-7-2-1-1 yielded higher than the recommended cropping sequences BR1 - BR11 (transplanting BR11 before 30 August) and BR1 - Nizersail (transplanting Nizersail in September). The rainfall distribution for the second rice crop was favorable, with minimal water stress.

The extent of adoption of cropping systems technology and its impact on farm productivity, technology, income, and consumption patterns were assessed at two rainfed lowland sites. The Kamalganj site was characterized by a rice surplus, remoteness, and limited diversity of income. Sitakunda, on the other hand, had a rice deficit, ready access to major markets, and greater diversity of farm and off-farm income.

In Kamalganj, adopters achieved more than 0.5 t more total production/ha and higher net returns than nonadopters. However, fertilizer use was approximately one-third of the recommended rate. For Sitakunda, adopter production was 1.9 t/ha higher than that of nonadopters, and net returns were similarly higher. Adoption in Sitakunda of cropping systems technology was lower than in Kamalganj, but fertilizer levels were higher, as was total production. The level of credit at both sites was negligible.

The level of technology adoption as measured by varietal sequence, fertilizer level, and cropping intensity was significantly higher for smaller farmers and was positively correlated with total production and net return on cash invested.

The income base from other farm enterprises and off-farm employment was far higher for Sitakunda, with rice production contributing only

27% of total income compared with 58% for Kamalganj. Cash investment in agriculture was four times higher in Sitakunda. The lower income base in Kamalganj resulted in a cash squeeze for purchase of inputs, causing lower rice production.

An initial implication of the results of the study is that, for sites dominated by a single income source such as rice production, crop diversification and development of other enterprises may be important components for increasing both income and production. Coupled with this is a major need to address infrastructure support.

Bhutan. The IRRI-Bhutan Rice Farming Systems Project has been supported since 1984 through a grant from the International Development Research Centre (IDRC) of Canada. In 1988, emphasis continued to be placed on strengthening Bhutan's human resources in rice research and development. Two members of the IRRI training staff spent 1 mo in Bhutan to assist the Department of Agriculture in planning and implementing a series of rice production refresher courses for 138 senior and field-level extension personnel. The in-country training was initiated by a team of five Bhutanese who had been trained at IRRI in 1986 in the Training and Technology Transfer Course. Other important activities in Bhutan during 1988 included a successfully implemented consultancy and training program on the production of mustard after rice, and the initiation of collaborative studies on integrated pest management (IPM).

A major highlight in 1988 was the release of three rice varieties by the National Variety Release Committee of the Department of Agriculture: BR153-2B-10-1-3, released as BR153 for the low-altitude southern foothills (150-600 m above sea level [asl]); IR64, released as IR64 for the medium-altitude valleys (1000-1500 m asl); and Takanenishiki, released as No. 11 for the high-altitude areas (1500-2400 m asl). All three were introduced, tested, and evaluated with the support of IRRI.

Cambodia. The Cambodia-IRRI Project, supported by the Australian International Development Assistance Bureau (AIDAB), addresses three of the main constraints affecting Cambodian agriculture: 1)inadequate human resources, 2) inadequate research infrastructure, and 3) ineffective technology transfer. From August to December 1988, 13 agricultural officers from Cambodia (including 3 women) participated in a special rice production training course at IRRI. A team of three IRRI scientists will take up residence in Phnom Penh in early 1989. The development of the Cambodian Rice Research and Development Institute (CARRDI) site in Prateah Lang (18 km from Phnom Penh) is receiving priority attention. An experiment station development specialist spent 2 mo in Cambodia in late 1988 to produce the CARRDI master plan. The Cambodian Government has requested IRRI to identify a suitable donor or consortium of donors to support the development of CARRDI.

Caribbean. *Regional conference.* Following the work plan for the Caribbean Rice Improvement Network (CRIN) approved by the Technical Advisory Committee of the Consultative Group on International Agricultural Research for 1988, a monitoring tour and a regional conference were held in Trinidad and Guyana, 27 October to 2 November 1988. The participants were from Jamaica (1), Trinidad (2), Guyana (2), Surinam (3), and CRIN (4). The objectives of the monitoring tour and conference were to promote interaction among the researchers of the Caribbean area, to identify common problems of rice in countries of the region, and to define common strategies for obtaining solutions to these constraints.

In Trinidad, the Centeno Experiment Station and Caroni Limited were visited, along with several farmers' fields where hoja blanca disease was observed in varieties Starbonnet and CICA8. The St. Patrick County Agricultural Extension Service facilities were also toured. The participants learned about rice problems that farmers confront, like flooding (40-60 cm height), field pollution with oil, lack of drainage and irrigation, and nonavailability of suitable varieties for the location.

In Guyana, blast (Bl) was reported in 1988; in some West Coast Demerara fields, yield losses averaged 35%. No data were available on the area affected. The nonavailability of resistant varieties, lack of machinery for land preparation and harvesting, and almost nonexistent agricultural extension were identified as the main constraints to rice production.

At the end of the monitoring tour, the regional conference was held at the headquarters of the National Agricultural Research Institute of Guyana. Seven papers were presented concerning rice production constraints in the Caribbean region.

Technology transfer. An agreement among 10 rice farmers, CRIN, and the Rice Research Center of the Dominican Republic (CEDIA) was signed to apply an improved technological package for rice production. The technological components were land preparation, seeding rate, weed control, fertilization, and pest control. Two planting systems were used: mechanized transplanting and direct seeding.

With mechanized transplanting, 4 plots of 3 ha each averaged 7.1 t/ha compared with the 4.6 t/ha average of the 3 previous years in the same plots. The yield difference was 52.3%, and the total production cost per hectare was reduced by 19.4% (Table 1).

Six plots of 3 ha each were direct seeded using the CRIN-CEDIA technology. In this case, the yield increased only 4.0% over the farmers' 3-yr average yield; however, the production costs were reduced by 15.7% (Table 1).

The cost-to-benefit relationship was US$0.17 for mechanized transplanting and US$0.11 for direct seeding.

Regional varietal trial. In coordination with CEDIA and CRIN, regional varietal testing was set up in the Dominican Republic. The study evaluated 10 promising lines and 5 check varieties that were seeded at 4 locations (El Pozo, Juma, Cruce Esperanza, and San Juan de la Maguana) during the second half of 1988.

Among the 10 lines, P3831F3-RH38-8-1M-J182 was the best performer, since it outyielded the best 2 check varieties, Juma 57 and Juma 58, at 2 locations (Juma [7.7 t/ha] and San Juan de la Maguana [7.6 t/ha]) by 1.1 t/ha. On the other hand, these two check varieties were the maximum yielders in Cruce Esperanza and El Pozo, with 6.5 and 7.1 t/ha, respectively.

Among the remaining lines, P3790F4-13-1B was the best performer, with an average yield of 6.1 t/ha and 133 d to maturity, which represented a 15-d difference in earliness compared with the 2 best checks.

The sister lines P4729F2-30-1-J2 and P4729F2-2-J198 also outyielded Juma 57 and Juma 58 by 0.3 t/ha, but only in Juma, with the advantage to the lines that matured between 6 and 14 d earlier than the checks.

In 1989, regional varietal testing will continue to identify suitable lines for release as varieties for each location.

China. IRRI's collaborative work with China involves the Chinese Academy of Agricultural Sciences; Chinese Academy of Agricultural Mechanization Sciences; Academia Sinica; National Laboratory for Plant Genetics Engineering; Development Research Institute, Research Center for Rural Development of the State Council of the People's Republic of China; 14 provincial academies; and 6 agricultural colleges and universities. Collaborative research priorities are IPM, sustainable agriculture, hybrid rice, biotechnology, and germplasm conservation and utilization.

Egypt. IRRI continues to collaborate with rice researchers in Egypt through a contract with the Egyptian Ministry of Agriculture financed by the United States Agency for International Development and centered at the Rice Research and

Table 1. Economic analysis of 2 technologies for rice production under 2 planting systems in the Dominican Republic, Caribbean Rice Improvement Network, 1988.

Planting system[a]	Production costs (US$/ha)	Cost reduction (%)	Yield (t/ha)	Yield increase (%)
Mechanized transplanting				
CRIN-CEDIA technology	398.57	19.4	7.1	52.3
Farmers' technology	494.30	–	4.6	–
Direct seeding				
CRIN-CEDIA technology	367.16	15.7	6.0	4.0
Farmers' technology	435.66	–	5.8	–

[a]CRIN = Caribbean Rice Improvement Network, CEDIA = Rice Research Center, Dominican Republic.

Training Center (RRTC) in Sakha. Germplasm and breeding lines are exchanged. IRRI provides a winter nursery and technical help when requested, and IRRI trains Egyptian scientists at various levels.

In 1988, four Egyptian scientists attended short courses at IRRI, and three were assigned to IRRI for 1-yr postdoctoral work in the Plant Breeding, Agronomy, and Entomology Departments. Seven IRRI scientists visited Egypt, and four Egyptian scientists and managers visited IRRI.

Plant breeding. Over the last decade, a continuous stream of Bl-resistant, high-yielding varieties has been developed, and the two most recently released lines, Giza 175 (GZ1394-10-1) and Giza 181 (IR1626-203), were recommended for cultivation in 1988. They have Bl resistance, short duration, short stiff straw, high yield potential, and good grain quality. The 2 wk saved by early maturity allows more intensive cropping, particularly more berseem production over winter. In on-farm demonstration trials (12 sites of 4 ha each), Giza 175 and Giza 181 yielded 10.2 and 11.2 t/ha, respectively.

Several breeding lines combine Bl resistance with desirable agronomic and grain quality characteristics, and some salinity tolerance has been identified: IR25571-31-1, IR29725-22-3, IR25582-32-3, IR25898-60, GZ2069-1-2-2, GZ2122-5-8-1, and GZ2310-5-10. GZ2175-5-6, a very promising line evaluated on a large scale in farmers' fields in 1988, gave an average yield of 11.3 t/ha.

Plant pathology. Besides developing Bl-resistant lines, efforts are under way to explore other methods of mitigating the disease in the Nile Valley. Disease management methods include decreasing the primary source of inoculum in a given system. Research has been initiated to elucidate the ecology of the Bl pathogen. Results indicate that infected seed, seed debris, and rice straw, which is traditionally stored on rooftops for fuel, all readily harbor the pathogen for a period of 10-12 mo and can act as the primary inoculum for the subsequent season. Preliminary results show that the seedborne primary inoculum may be effectively controlled by seed treatment. Systemic seed dressing protected the seedlings for 5 wk after seed treatment. Some effective systemic fungicides are tricyclazone, benomyl, and thiophanate (at 4 g/kg of seed). Also, Bl in nurseries transmitted by diseased seed could be effectively controlled by applying granular fungicides at 20 kg/ha 20 d after seeding (DAS).

Agronomy and extension. The agronomy program in Sakha studies fertilizer use efficiency, water use efficiency, and IPM. Research in Egypt and at IRRI has shown that up to 50% of N fertilizer (usually urea) applied to flooded rice is lost. The utilization percentage can be increased by applying the total amount of N needed in two or three splits over the active growing season. The technology has been developed for flooded transplanted rice (TPR) but not for direct seeded rice (DSR). Hence, IRRI scientists have collaborated with scientists of RRTC to study the N balance (losses) of various fertilizer treatments comparing TPR and DSR. The ^{15}N analyses are done at IRRI. Yields of DSR can be as high as those of TPR provided that herbicides are used within 2 wk after seedling emergence from DSR.

The field surveillance program identified few production constraints for rice in the delta in 1988 aside from the approximately 20% of the area that has varying amounts of saline or alkaline soil and water problems. Giza 181 showed more susceptibility to saline soil and Zn deficiency than did other varieties during tillering but recovered at later growth stages. Responses to Zn fertilizer were shown in demonstration plots in saline and alkaline soil areas. Bl was noticed on traditional varieties Giza 171, Giza 172, and Reiho in isolated areas, but its detrimental effect was minimal in 1988. Stem borer *Chilo agamemnon* was recorded in large numbers in isolated areas, especially on Giza 175. In spite of these constraints the average yield from farmers' fields was estimated to be 6.0 t/ha, the highest in the history of rice production in Egypt. Rice area in the delta was 10% lower than in the previous few years, but the total production on about 400,000 ha will approach a record. This is due to more areas receiving better seed supplies, earlier planting, and careful execution of recommended practices under the eyes of RRTC-trained and -supervised extension workers. On the average, the Egyptian farmer produces the highest rice yield in the world, but only about 20% of them use all recommended practices to come near the demonstrated potential of the on-farm research trials (10.1 t/ha). Thus, the majority of the rice area of the delta

needs better seed, timely inputs of fertilizer and pesticides, timely irrigation, and overall intensive management to increase yields.

India. The Indian Council of Agricultural Research-IRRI collaborative research programs continued in the areas of germplasm improvement, crop and resource management, socioeconomic research, international networks, scientist exchange, and communication and publications. The major collaborative research effort, however, centered around the special rice research project in Eastern India: rainfed rice production in deepwater, shallow lowland drought-prone and shallow lowland flood-prone, and upland environments (see later in this section).

Varietal improvement, crop establishment, nutrient management, and manual irrigation technology programs were introduced in farmers' fields with an on-farm research approach. Several promising varieties and soil and crop management technologies were identified and were adopted by the farmers, resulting in increased production.

Besides directly improving rice productivity, conducting experiments under farmers' environments helps to increase the efficiency and effectiveness of the rainfed rice research process in two ways: first, in adopting the existing technology and/or contributing to the development of alternative technologies for targeted groups of farmers; and second, in providing feedback to the experiment station in setting research priorities, planning, and programming. Thus, an attempt is being made to integrate experiment station and on-farm research into a coherent program focused on rainfed farmers' needs.

Indonesia. Staff of the Agency for Agricultural Research and Development and IRRI collaborated in the collection of germplasm from West Java: 30 populations of *Oryza rufipogon*, 12 of *O. officinalis*, 2 of *O. granulata*, and 11 varieties of *O. sativa*. For irrigated rice improvement, replicated yield trials evaluated elite breeding lines with multiple resistance to diseases and insects. Emphasis was on superior grain quality conditioned by intermediate amylose content and intermediate gelatinization temperature. Breeding lines originating from crosses of *O. sativa* and *O. officinalis* are being evaluated.

In breeding for peat soils, two locations in South Kalimantan were used: Unit Tatas for potential acid sulfate soils, and Belandean for acid sulfate, direct tidal wetlands. We screened traditional varieties from West Africa and advanced IR lines. In Unit Tatas, 8 West African varieties were better than local check varieties; in Belandean, 15 West African varieties performed well. Seven West African varieties were selected for hybridization. IR26708-2-2-3-1-1, IR30217-4-3-2-3, and IR31376-1-2-1-1 were selected for further testing.

Although Sukamandi soil (Vertic Tropaquults in association with Typic Plinthaquox) is low in available P, continuous application of triple superphosphate (TSP) has gradually increased P accumulation. Trials on P sources in the wet season (WS) and dry season (DS) showed no response to application.

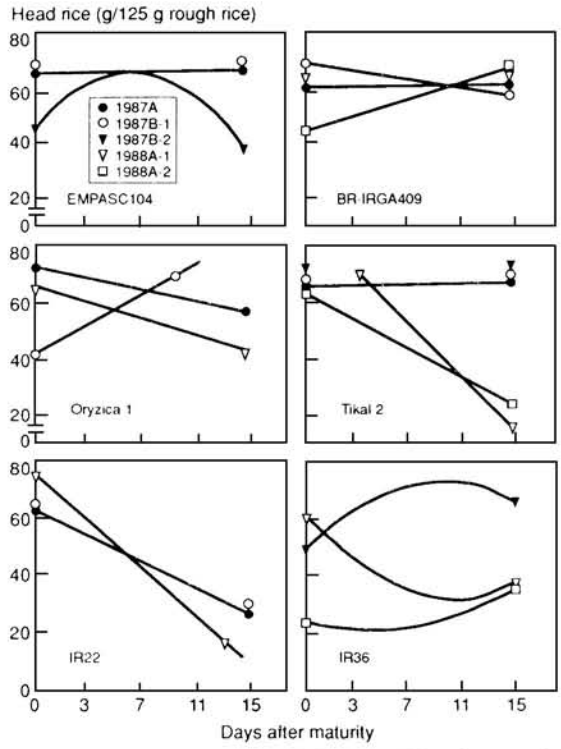
Evaluation of hybrid rices was hampered by the high frequency of sterile plants due to the instability of IR54752 A. However, populations of IR54752 A grown at 500 m asl in Kuningan were more uniform than those grown in Sukamandi. Success in developing rice hybrids now seems to depend primarily on the availability of a stable cytoplasmic male sterile (CMS) line, high outcrossing rate, and resistance to major pests and diseases.

Laos. During 1988, IRRI undertook a project identification and design study in Laos in preparation for a major country project expected to commence in mid-1989. Financial support for this study as well as for the training of eight Lao scientists and agricultural officers was provided by the Australian Government. Several IRRI scientists visited Laos during 1988 to discuss priorities of the Lao Government in rice research and development, and to jointly identify the possible role of IRRI. Rice farming communities in Luang Prabang (upland), Vientiane (rainfed lowland and irrigated), and Savannakhet (rainfed lowland) were studied, and constraints and research priorities were identified.

A project proposal was being finalized in late 1988 that would focus on the development of appropriate low-cost technologies in the uplands and rainfed lowlands and would develop human resources in rice research and development.

Latin America. Our collaboration with the Centro Internacional de Agricultura Tropical continued with an experiment on screening methods for tolerance for delayed harvesting.

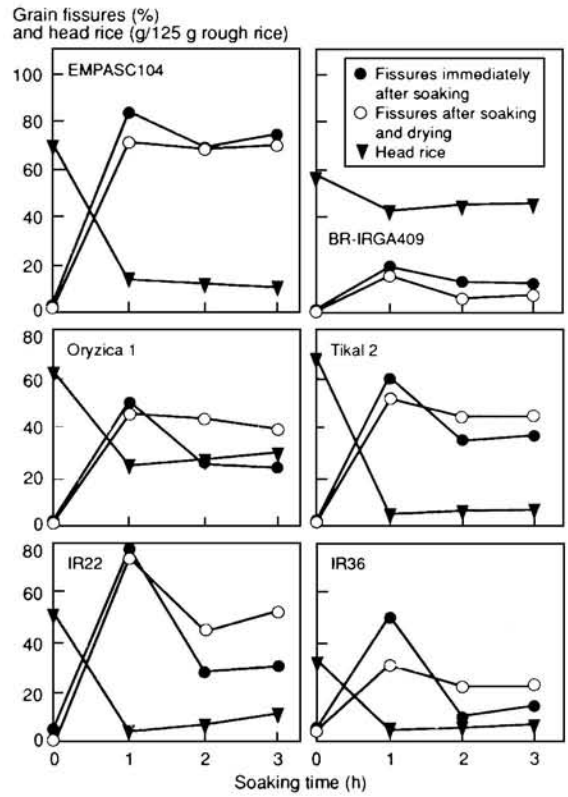
Milling evaluations under delayed harvest are expected to predict varietal performance at the farm level more accurately, since this is a common stress reducing head rice yields under actual farming conditions. Large environmental effects greatly reduce the precision of direct varietal evaluations. However, in spite of strong seasonal effects there were genotypic differences in the reaction to 2-wk harvest delays of a group of rice varieties with similar growing cycles (Fig. 1). Head rice yields of IR22 were much more susceptible to delayed harvest than those of EMPASC104, BR-IRGA409, Oryzica 1, or Tikal 2. One planting brought up a difference within this last group, suggesting that BR-IRGA409 has larger tolerance. IR36 did not show consistent performance, suggesting a strong seasonal effect. Tikal 2 was also very susceptible to seasonal changes. Using these observations, we grouped the varieties into four categories: resistant – BR-IRGA409; moderately resistant (MR) – EMPASC104 and Oryzica 1; moderately susceptible (MS) – Tikal 2; and susceptible – IR22 and IR36.



1. Milling recovery of 5 rice varieties under delayed harvest in Palmira, Colombia.

To have a reliable screening method, nongenetic effects should be minimized. For that reason we investigated controlled treatments to predict field performance under delayed harvest. We found soaking the rice grain for 3 h too harsh on head rice yields, since it grouped the varieties in only 2 classes. With shorter soaking and measuring grain fissuring (in 200 rough rice grains) as well as head rice yield (in 125 g of rough rice), we observed that for all varieties maximum fissuring is attained after 1 h of soaking, regardless of measuring time, and that a sharp reduction in head rice yield is also observed at that soaking time (Fig. 2). EMPASC104 and IR22 had the maximum number of fissures, while the head rice yields of BR-IRGA409 and Oryzica 1 were the least affected by soaking.

We tested the possibility of using milling and fissuring under soaking to predict the observed field classification of varieties under delayed harvest. Discriminant analysis indicated that head rice yield and number of grains fissured after 2 h of soaking could classify samples in the same



2. Effect of grain soaking time on fissuring and head rice yield.

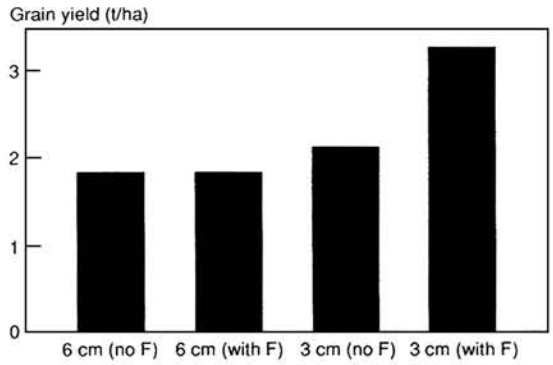
groups as those in the field classification nearly 90% of the time. Misclassifications observed included only MR classified as MS and vice versa.

Madagascar. The breeding program screened introductions and Malagasy varieties for cold tolerance, Fe toxicity, and P deficiency tolerance and identified materials tolerant of all these stresses. These local and elite materials were crossed, and 184 F_1 lines were grown out. Additionally, 24 F_2 populations were being screened for these stresses. After several years of on-station and on-farm testing, the Centre National de la Recherche Appliquée au Rural Developpement (FOFIFA) recommended the prerelease advancement of Rojomena 271/10 (Acc. 2822), Tainan 3 (2067), and Acc. 473 for the High Plateau. FOFIFA and IRRI breeders and agronomists also collaborated in increasing cropping intensity by testing varieties for ratooning and double cropping.

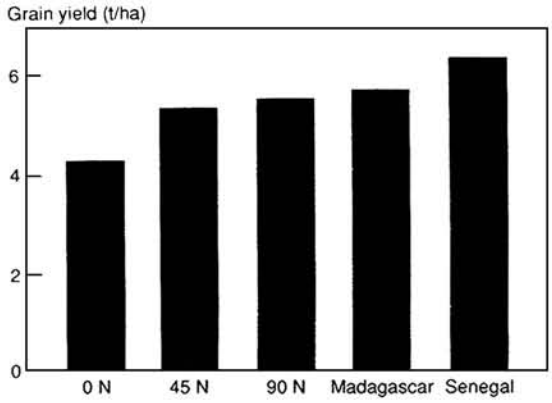
Fertilizers are expensive but necessary for the High Plateau. P fertilizers are not very efficiently utilized on some of the more P-fixing, Fe-toxic soils. Agronomists found that dipping the roots of seedlings in a slurry of soil, water, and TSP is about 30% more efficient than broadcasting and incorporating TSP. Many farmers do not apply fertilizer. Agronomists found that some of these farmers may transplant too deeply and thus do not realize any benefit from applying fertilizer (Fig. 3).

On the Marovoay plain, water is too deep during the rainy season to grow rice on about 12,000 ha. Thus, only an irrigated DS crop is grown after the floodwater subsides. Breeders introduced and identified several deepwater rice (DWR) varieties (e.g., SPR7297-432-1-2-1 and IR763-11-2-2-3) that produce 4.5 t/ha and could be grown in the presently fallowed 12,000 t/ha, permitting double cropping. For DS, IR36 and IR38 regularly yielded 4-5 t/ha and were recommended for prerelease testing.

In Tanandava, Tche Kouai, Taichung 178, HB96, IR20, IR36, and IR38 were recommended for prerelease testing. In this area, an indigenous variety of *Sesbania rostrata* grows naturally. Agronomists found that both the indigenous and Senegalese *S. rostrata* can be used as a substitute for expensive urea fertilizer (Fig. 4).



3. Effect of depth of transplanting and 60-26-50 kg NPK fertilization (F) on yield of Chianan 8 in farmers' fields, Manjakandriana, Madagascar, 1988.



4. Effect of N and incorporation of *S. rostrata* var. Madagascar and var. Senegal on grain yield of Tohe Koual, Tanandava, Madagascar, 1988 WS.

In Lac Alaotra, FOFIFA recommended the release of B54/b/kn/112/2/2 (Acc. 2787) and Tche Kouai, and recommended the prerelease testing of Acc. 1601 and Acc. 1634. Agronomists were conducting on-farm rice-based cropping systems research in the rainfed and upland areas.

Myanmar. Funded by the Consortium for International Development and, starting in 1989, by IDRC, the Myanmar-IRRI Farming Systems (MIFS) Project is a cooperative research activity between the Myanmar Agricultural Corporation and IRRI. The objectives are to improve crop varieties for rice farming systems with emphasis on export quality rice; to develop harvest technology for better crop quality; to develop cost-effi-

cient rice farming systems technology including crop and livestock research and on-farm cropping pattern trials; to expand research on animal-drawn implements for rice farming; and to train Myanmar scientists in rice farming.

Six of the Myanmar scholars sent to IRRI under the MIFS Project returned to Myanmar in April 1988 with the MS degree. Two Ph D scholars and one MS scholar were still at IRRI completing their degrees.

In close collaboration with 60 Myanmar agricultural scientists and extension workers, the MIFS Project conducted its rice farming research at 19 sites and research stations throughout Myanmar. Eleven new promising cropping patterns were identified at three sites:

Site	*Pattern*
Yezin	Peanut - TPR - cowpea
	Peanut - TPR - chickpea
	Peanut - TPR - black gram
	Peanut - Maize - TPR
Patheingyi	Mungbean - TPR
	Sesamum - TPR
	Cotton - TPR
Prome (North Nawin)	TPR - chickpea
	TPR - sunflower
	Mungbean - cotton
	Peanut - cotton

The highlight of the year's program was the demonstration to farmers that *S. rostrata* green manure has been proven as a urea substitute in rice production if incorporated at least 2 mo after emergence (Table 2, 3).

The MIFS Project small-scale mechanization program modified the IRRI-designed lowland rice drum seeder for sowing upland crops after rice; arranged to power the TH-7 thresher with ani-

Table 2. Agronomic data on rice variety Manawthuka as affected by *S. rostrata* green manure incorporation at different days after emergence.[a] Myanmar, 1988.

Green manure incorporation (DE)[b]	Yield (t/ha)	Panicles (no./m²)	Straw yield (t/ha)	Lodging index[c]	Plant height (cm)	Bearing culms (no./hill)
30	5.2 d	348.50 c	13.64 c	1.25 c	90.94 c	13.02 c
45	5.9 c	382.17 b	14.44 c	2.25 b	96.09 b	14.43 b
60	6.9 a	419.08 a	17.84 a	4.17 a	101.28 a	16.56 a
45 + 14 kg N/ha	6.3 b	375.08 bc	16.61 b	2.17 b	97.43 b	14.58 b
CV (%)	4.35	8.66	9.14	34.90	2.60	8.36

[a] Av of 4 replications. [b] DE = days after emergence. [c] *Standard evaluation system for rice* scale of 1-9: 1 = no lodging, 9 = more than 80%.

Table 3. Rice yields of on-farm demonstrations of *S. rostrata* as green manure for rice. Aye Swe, Than Khae, Yan Thein, Myint Soe, Sein Ni, and San San Myint, Myanmar, 1988.

Site	Yield (t/ha)[a]				Rice variety
	GM+N	GM	N	Control	
Thayetkon (PMA)	3.2	2.5	2.9	2.1	Manawthuka
Kyaukchet (PMA)	4.5	3.8	3.7	3.1	Manawthuka
Seinsapin (PMA)	6.2	5.4	5.3	3.2	Palethwe
Taikkyi	3.6	3.4	3.5	3.6	Shwewatun
Taikkyi	3.5	3.3	3.4	3.4	Shwewatun
Daik-U	4.1	3.9	4.1	2.8	IR50
Daik-U	3.8	3.4	3.5	2.9	Shwewatun
Daik-U	3.3	3.3	3.2	2.8	Shwewatun

[a] N = urea fertilizer, 42.5 kg N/ha split; green manure (GM) = 25 kg/ha, plowed under at 45 DE; GM+N = GM + 31 kg urea/ha at panicle initiation or 15 kg N/ha at 40 d after transplanting.

mals by means of a gear drive device; continued improving the animal-drawn no-tillage slit seeder for sowing crops after rice; and demonstrated the uses of the cono-puddler and cono-weeder in rice farming. Through extension work, the Project continued demonstrating the effective use of the TH-7 thresher and IRRI-designed rice reapers.

The rice varietal improvement component identified AC-1951 from India and SPR-7284-57-5 from Thailand, from International Rice Testing Program (IRTP) nurseries, for release to farmers – AC-1951, locally named Shwenan-1, for favorable rainfed lowlands, and SPR-7284-57-5, with the local name of Shwese-2, for irrigated lowlands. In 1988, 27 IRTP nurseries at 13 stations and 4 International Network for Sustainable Rice Farming trials at 8 sites were being coordinated by this program in Myanmar.

The MIFS Project showed that milling and head rice recoveries are varietal characteristics (Table 4). This study also indicated that traditional rices have better recovery than high-yielding varieties. Poor rice grain quality and low head rice recovery are caused by threshing delays, which are related to the grain moisture status in the field (Table 5). Delayed threshing favors head rice yield as long as the relative humidity is low. A diagnostic survey of postharvest practices in four rice-producing townships was under way to determine which practices adversely affect milling and lower head rice recovery and to determine the cost efficiency options of different approaches for improving postharvest management of rice at the farm level.

The MIFS Project also arranged the translation into Myanmar and the printing of 3,000 copies of *Helpful insects, spiders, and pathogens* for farmers. In addition, *A farmer's primer on growing cowpea on riceland*, *A farmer's primer on growing soybean on riceland*, and 12 farming systems training modules were being translated into Myanmar for use in training agricultural technicians.

A farming systems agronomist/project leader was in residence in Myanmar. He also acted as the IRRI representative.

Philippines. A collaborative project of the University of the Philippines at Los Baños Institute of Plant Breeding (IPB) and IRRI is accelerating the development and selection of upland crop cultivars for the prerice and postrice environments, a project coordinated through the Asian Rice Farming Systems Network (ARFSN). Germplasm comes from several international institutes (viz., the International Institute of Tropical Agriculture [IITA], International Maize and Wheat Improvement Center, Asian Vegetable Research and Development Center [AVRDC], and International Crops Research Institute for the Semi-Arid Tropics [ICRISAT]). IPB does the germplasm collection, hybridization, screening, and selection of mungbean, soybean, and peanut, while IRRI does the seed multiplication and distribution of test materials to various farming systems sites in the network for evaluation before and after wetland rice.

In 1988, IPB collected and screened, before and after rice, 2,540 cultivars of mungbean from AVRDC and national programs; 912 soybean cultivars from AVRDC, IITA, and Thailand; and

Table 4. Milling recovery and head rice of 3 traditional and 3 high-yielding rices with different grain types.[a] Myanmar, 1988.

Variety	Grain type	Milling recovery (%)	Head rice (%)
Traditional			
Shwedingar	Long	68.34 b	45.12 c
Pawsanbaykya	Medium	72.38 a	60.05 a
Shannyein	Short	71.86 a	58.38 ab
High-yielding			
Singakere		65.33 c	42.12 d
Manawthuka		63.09 d	47.68 c
Palethwe		71.33 a	55.72 b
CV (%)		2.49	6.82

[a] Av of 4 replications.

Table 5. Grain moisture content at harvest, head rice, and milling recovery of 6 rice varieties at 3 threshing delays after harvest.[a] Myanmar, 1988.

Days after harvest	Grain moisture content (%) at harvest	Head rice (%)	Milling recovery (%)
0	22.68 a	52.07 a	68.55 b
14	15.54 b	50.00 b	67.91 b
28	13.91 c	52.47 a	69.81 a
CV (%)	4.51	6.82	2.49

[a] Av of 4 replications.

269 peanut cultivars from ICRISAT, Indonesia, and China for adaptation before and after rice. These cultivars were screened for yield potential, maturity, tolerance for drought and excessive moisture, and resistance to major insect pests and diseases. At present, promising lines of these crops have been identified, and they are being utilized in hybridization work. IRRI also screened and evaluated, for use before and after rice, accessions of mungbean, cowpea, bush sitao, soybean, peanut, pigeonpea, maize, and sorghum from IPB, national programs, and international centers. ARFSN distributed 47 trials of 8 crops for prerice evaluation and 101 trials for postrice evaluation.

Thailand. Several new projects, including socioeconomic research and biological agents for the control and management of rice pests, were initiated. In DWR, significant progress was made in introducing early-maturing crops for preflood production. Methods to establish upland or early rice intercrops with DWR were evaluated. Fertilizer management, weed control, and yield evaluation techniques were assessed.

Results with a small-plot technique to test the response of DWR to fertilizers were similar to results from trials in farmers' fields. The variability of yield measurements was tested using border effect experiments. The aim was to make early generation yield trials more efficient. Using plant samples and N analysis gave more satisfactory results in N uptake studies than using normal yield measurements. The technique showed the pattern of responses to flooding under different soil conditions.

This was the sixth year for the Thailand-IRRI breeding nurseries for rainfed lowland rice, and 84 advanced lines were evaluated at 6 stations in the northeast. Advanced lines from the shuttle breeding program were grown in farmers' fields in Ban Khu Kad. Alternative methods of direct seeding, including using small hand-operated planters, were evaluated at experiment stations and in farmers' fields. Both wet and dry seeding were compared with transplanting.

Interpretations of the soils and landscape of one village were carried out using four topographical transects. Soils and hydrology were mapped in relation to farmer cropping practices and yields. This work will help to identify constraints to higher yields and to more intensive cropping systems. Soil fertility work focused on P nutrition of rice in acid and acid sulfate soils, and on the effects of P sources with varying citrate solubility. The research design involved P-sorption isotherms and soil chemical properties in relation to P source. The results will be used to develop a cost-efficient, low-input technology for rainfed lowland rice production.

Vietnam. In March 1988, the Government of Australia approved a grant to IRRI of US$387,000 over 3 yr for support of nondegree training and collaborative research. During 1988, collaboration in water management was initiated with the University of Agriculture and Forestry (UAF), Ho Chi Minh City; fertilizer use efficiency with the Institute of Soils and Fertilizer, University of Cantho (UC), and UAF; and socioeconomics with UAF. Research on varietal and agronomic improvement in DWR continued during 1988 in collaboration with the Cuu Long Delta Rice Research Institute and UC.

JAPAN-IRRI COLLABORATIVE PROJECT ON BACTERIAL BLIGHT

Plant Breeding and Plant Pathology Departments

IRRI continued research on bacterial blight (BB) as part of the Low Input Cultivation Technology Under Irrigated Conditions Project in close collaboration with the Tropical Agriculture Research Center (TARC), Ministry of Agriculture, Forestry and Fisheries, Japan. The project is funded by the Government of Japan.

Development of international differentials for bacterial blight (*Plant Breeding and Plant Pathology*). Using BB races from the Philippines at IRRI and races from other Asian countries at TARC, we are developing near-isogenic lines for use as international differentials. These lines each have single resistance genes in an identical genetic background. By the end of 1988, 12 genes for BB resistance had been identified in Japan and at IRRI. Three varieties—IR24, Toyonishiki, and Milyang 23, which are indica, japonica, and indica/japonica derivatives, respectively—were used as the recurrent parents for developing the near-isogenic lines. At year's end we had BC_4F_4 or later generations with *Xa-1*, *Xa-3*, *Xa-4*, *xa-5*, *Xa-7*, *xa-*

8, *Xa-10*, and *Xa-11* and had named them IR-BB1 to IR-BB211 (Table 6). Near-isogenic lines with either *xa-13* or *Xa-14* were in the BC_4F_1 to BC_4F_3.

Inheritance of resistance (*Plant Breeding*). To identify the chromosome locations of genes *Xa-7* and *xa-8*, trisomic analysis was carried out using four races (races 1-4) (Table 7), but the chromosome on which these genes are located had not yet been identified. The results show that *Xa-7* is located on neither chromosome 6 nor 8. Similarly, *xa-8* is not located on chromosome 1, 3, 6, 9, or 10. We are carrying out trisomic analysis using the other trisomic lines.

Rice varietal groups based on the reaction to Philippine races (*Plant Breeding*). We did seedling tests of varieties from the International Rice Germplasm Center using four Philippine races (races 1-4). Race 5 was also used in screening varieties from China (including Taiwan Province), because variety TN1 from Taiwan is resistant to race 5 and has *Xa-14*. In 1988, 3,711 varieties from China, 900 from Taiwan, 1,109 from Nepal, 926 from Pakistan, and 2,228 from the Philippines were tested at the seedling stage. Sixty-six varieties from China and 7 varieties from Taiwan were found to have *Xa-14*.

Table 6. Near-isogenic lines with resistance genes for bacterial blight (BB) developed at IRRI and TARC, 1988.

Gene	Donor parent	Near-isogenic lines from given recurrent parent[a]		
		IR24	Toyonishiki	Milyang 23
Xa-1, Xa-12	Kogyoku	IR-BB1 (t)	IR-BB101 (t)	IR-BB201 (t)
Xa-3	Chugoku 45	IR-BB3	IR-BB103	IR-BB203
Xa-4	IR20	IR-BB4	IR-BB104	IR-BB204
xa-5	IR1545-339	IR-BB5	IR-BB105	IR-BB205
Xa-7	DV85	IR-BB7	IR-BB107	IR-BB207
xa-8	PI231129	IR-BB8	IR-BB108	IR-BB208
Xa-10	Cas 209	IR-BB10	IR-BB110	IR-BB210
Xa-11	IR8	IR-BB11	IR-BB111	IR-BB211
xa-13	Bhadoia 648	BC_4F_3	–	–
	BJ1	BC_4F_1	BC_2F_1	BC_2F_1
Xa-14	TN1	BC_4F_1	BC_4F_1	BC_4F_1

[a] (t) = tentative designation, because *Xa-1* and *Xa-12* have not yet been established to be either identical or different.

Table 7. Trisomic analysis of *Xa-7* and *xa-8* genes. IRRI, 1988.

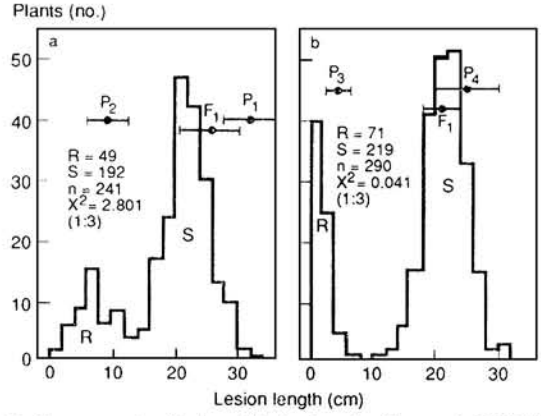
Cross[a]	Chromosome no.	Lines (no.) with given reaction to BB			χ^2	
		R	S	Total	3:1	1:3
Triplo 6/IR-BB7	2n	144	50	194	0.061	
	2n+1	92	38	130	1.241	
Triplo 8/IR-BB7	2n	171	46	217	1.673	
	2n+1	55	20	75	0.111	
Triplo 1/IR-BB8	2n	38	134	172		0.775
	2n+1	16	34	50		1.307
Triplo 3/IR-BB8	2n	52	108	160		4.800
	2n+1	17	58	75		0.217
Triplo 6/IR-BB8	2n	45	124	169		0.239
	2n+1	24	51	75		1.960
Triplo 9/IR-BB8	2n	35	96	131		0.206
	2n+1	27	62	89		1.352
Triplo 10/IR-BB8	2n	61	169	230		0.284
	2n+1	24	66	90		0.133

[a] Triplo lines had been bred to IR24 background because IR36, the original triplo line's background, had gene *Xa-4*.

After the seedling test, only selected resistant varieties were inoculated at booting to identify their resistance gene. At booting, 1,008 varieties from Vietnam, Cambodia, and China (including Taiwan were tested and classified based on the reaction pattern to Philippine races (Table 8). Four varieties from Vietnam and one variety each from Cambodia and China showed the same reaction pattern as that of Cas 209. This shows that *Xa-10* is also distributed outside Myanmar. We screened about 1,500 Myanmar varieties using 6 races and found 159 to be resistant. Of these, 47 varieties have *Xa-10* alone, and 4 have both *Xa-4* and *Xa-10*.

Mutation breeding for resistance to bacterial blight (*Plant Breeding*). To increase the genetic resources for resistance to BB, we undertook a program on mutation breeding. IR24, susceptible to all Philippine races, was treated with 1mM N-methyl-N-nitrosourea (MNU) by soaking panicles at the single cell stage of embryogenesis; 2,739 M_2 lines were inoculated with isolate PXO 112 (race 5). Two lines, XM5 and XM6, segregated for resistance; they were resistant to all races in the Philippines (Table 9). To date, only a few varieties carrying both *xa-5* and *xa-13*, like BJ1, are known as resistant to all Philippine races.

To study the inheritance of resistance in these two mutant lines, they were crossed with IR24. The reactions of the F_1 and F_2 plants to BB races suggested that both mutant lines have single recessive genes for BB resistance (Fig. 5). Allelism tests with three known recessive genes showed that the mutant gene was independent of *xa-5*, *xa-8*, and *xa-13* (Table 10). These results show that the resistance gene in these mutant lines is a new recessive one.



5. Frequency distribution of lesion length with race 6 (PXO 99) in F_2 populations from the crosses of IR24(P_1)/XM5(P_2) and XM6(P_1)/IR24(P_2). IRRI, 1988. R = resistant, S = susceptible.

Table 8. Estimated variety group of varieties tested at booting against 4 BB races, 1988.

Origin	Total entries (no.)	Entries (no.) in estimated variety group				
		Java 14 (*Xa-3*)	TKM6 (*Xa-4*)	DZ192 (*xa-5*)	Cas 209 (*Xa-10*)	Others
Vietnam	69	17	17	2	4	29
Cambodia	158	10	14	37	1	96
China	598	218	39	37	1	303
Taiwan, China	183	86	34	0	0	63
Nepal	261	60	24	117	12	48
Pakistan	119	1	35	55	2	26

Table 9. Reaction of mutant lines to 6 BB races. IRRI, 1988.

Mutant or cultivar	Lesion length (cm)					
	Race 1 PXO 61	Race 2 PXO 86	Race 3 PXO 79	Race 4 PXO 71	Race 5 PXO 112	Race 6 PXO 99
XM5	7.2	7.6	6.2	9.2	9.5	10.7
XM6	7.0	4.2	3.3	6.2	6.1	4.7
IR24	34.5	30.7	33.9	31.4	33.3	30.4

Table 10. Allelism tests between mutants and known recessive genes.[a] IRRI, 1988.

Cross	Segregation of genotypes in F_2						
	Mutant + recessive gene	*xa-5*	*xa-8*	*xa-13*	Susceptible	χ^2	P
XM5/IR-BB5 (*xa-5*)	61	50			153	0.520 (4:3:9)	0.70-0.80
XM5/IR-BB8 (*xa-8*)	48		63		156	8.835 (4:3:9)	0.01-0.02
XM5/BJ1 (*xa-5, xa-13*)	74	41		29	115	2.498 (19:9:9:27)	0.30-0.50
XM6/IR1545 (*xa-5*)	42	41			132	3.592 (4:3:9)	0.10-0.20
XM6/PI231129 (*xa-8*)	50		60		157	6.485 (4:3:9)	0.10-0.20
XM6/BJ1 (*xa-5, xa-13*)	85	32		42	119	1.839 (19:9:9:27)	0.50-0.70

[a] All F_1 plants were susceptible to the 6 races.

YIELD OF F_1 RICE HYBRIDS IN KOREA

Plant Breeding Department

Seven experimental rice hybrids, developed collaboratively by the Korea-IRRI Hybrid Rice Program, were evaluated along with seven male parents including the best check varieties in Suweon, Iri, and Milyang, Korea. Hybrids, in general, yielded 1.0-1.8 t/ha higher than the inbred cultivars at the 3 locations (Table 11). The two best hybrids—IR54756 A/Iri 362 (10.8 t/ha) and IR54756 A/Suweon 332 (10.5 t/ha)—were significantly higher yielding than the best yielding inbred cultivars—Suweon 294 (9.1 t/ha), Iri 361 (9.1 t/ha), and Suweon 318 (9.0 t/ha).

ON-FARM RAINFED RICE RESEARCH IN EASTERN INDIA

Multiple Cropping Department

Eastern India, comprising the states of Assam, West Bengal, Bihar, Orissa, eastern Uttar Pradesh, and eastern Madhya Pradesh, accounts for 23 million ha (57%) of the total rice area in India but contributes only about 46% of the grain production. About 85% of the rainfed upland and 65% of the lowland rice of India taken together account for 70% of the total rice area in eastern India, having rice yields ranging from <1.0 to 1.5 t/ha, the upper limit being the national average. In its effort to improve global rice yield, IRRI launched a collaborative on-farm research project on rainfed rice in eastern India. The project covers 15 centers representing the major rainfed ecosystems: upland, lowland, and deepwater. Adopting the methodology of farmer participation, on-farm trials were conducted in 300 farmers' fields during 1988 WS. At the upland trial site, Ranchi, Bihar, test line RAU4045-10 recorded a grain yield of 3.4 t/ha, with 100-d crop duration; the local check Brown Gora yielded 1.8 t/ha and matured in 97 d.

RAU4045-10 yield was 50% higher with 20 kg N/ha (2.4 t/ha) and 90% higher with 40 kg N/ha.

In a rainfed lowland environment (50-70 cm water depth) in Moshra, NC492, a tall indica selection from local germplasm, recorded 4.1 t grain yield/ha compared with 2.1 t/ha from a popular local variety, Suo Kalma.

The deepwater project site Gopalnagar in West Bengal experienced deep flooding (130 cm) at 20-25 DAS in the third week of June 1988. Local rice cultivars Najani, Meghi, and Kalma were severely damaged. Three plots that suffered total crop failure were selected to plant 55-d-old seedlings of IET9003 and NC492 in the third week of July after the recession of the floodwater. Grain yields ranging between 1.7 and 3.5 t/ha were obtained from the postflood rice crop compared with yields up to 0.8 t/ha in the flood-damaged plots sown with farmers' varieties.

Table 11. Yield of experimental rice hybrids, male parents, and check varieties in replicated yield trials conducted in Suweon, Iri, and Milyang, Korea, 1988.

F_1 hybrid or inbred variety	Yield (t/ha)			
	Suweon	Iri	Milyang	Mean
Hybrids				
IR54756 A/Iri 362	11.8	10.8	9.8	10.8
IR54756 A/Suweon 332	10.6	11.0	9.9	10.5
IR54756 A/Suweon 294	10.8	10.1	9.4	10.1
IR54756 A/Suweon 287	10.1	10.2	9.4	9.9
IR54756 A/Suweon 325	10.4	9.1	9.8	9.8
IR54756 A/Iri 361	11.6	7.9	9.5	9.7
IR54756 A/Suweon 318	10.7	9.3	8.8	9.6
Mean	10.9	9.8	9.5	10.1
Inbreds				
Suweon 287	7.5	8.3	7.9	7.9
Suweon 294	9.0	9.4	8.9	9.1
Suweon 318	9.2	9.2	8.7	9.0
Suweon 325	6.9	7.6	7.1	7.2
Suweon 332	7.4	8.8	7.0	7.7
Iri 361	8.6	9.7	–	9.1
Iri 362	8.1	9.2	6.5	7.9
Mean	8.1	8.9	7.7	8.3
LSD (0.05)	1.1	1.0	0.8	

RESEARCH ON INTEGRATED PEST MANAGEMENT FOR DEEPWATER RICE FARMING SYSTEMS AND DEVELOPMENT OF RICE - FISH CULTURE IN WEST BENGAL, INDIA

Entomology Department

Field surveys conducted in different areas of West Bengal showed that yellow stem borer *Scirpophaga incertulas* was the major pest of DWR, causing up to 61% stem damage at the ripening and mature stages. Other insect pests of economic importance that were found in surveys are hispa, leaffolder, and whorl maggot in the early elongation stage, and ear-cutting caterpillar (*Mythimna* sp.) and rice stink bug during ripening. Parasitoids and predators occurring in DWR were isolated from sweepnet and suction samples.

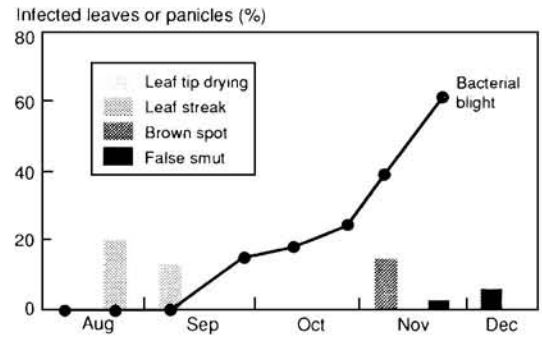
Surveys of farmers' cultural practices revealed that more than 30% of the farmers followed crop rotation. However, only 18% adopted some pest control measures. Twenty-two percent of the farmers burned stubble at the close of winter. Only 7% of the farmers undertook rice - fish culture.

An empirical map was prepared showing the distribution by district of DWR areas in eastern India. In West Bengal it was 460,000 ha, which was about 9% of the net rice area.

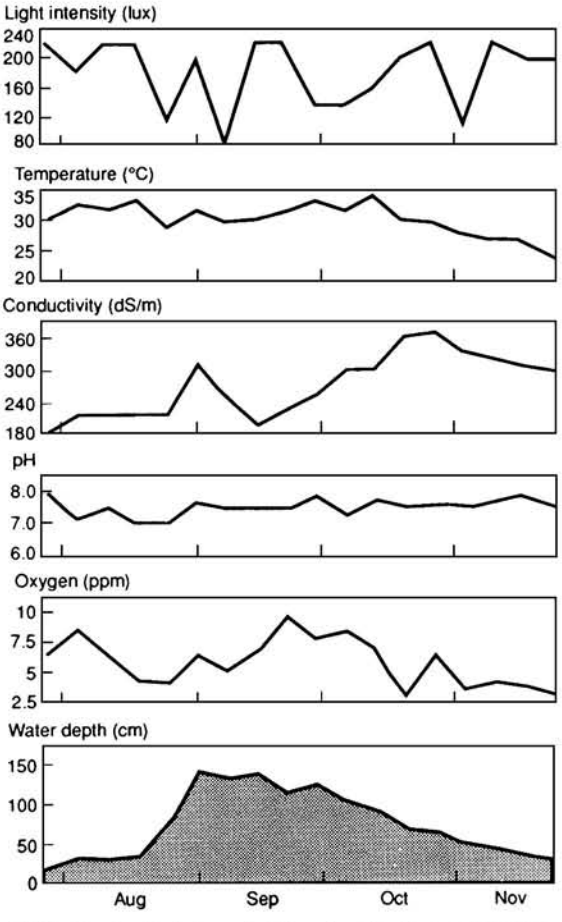
Field surveys showed that BB was the major disease, causing 60% infection at the flag leaf stage (Fig. 6). Brown spot, false smut, and kernel bunt were also recorded at ripening.

From the International Rice Ufra Screening Set (IRUSS 1987), Rayada 16-06, Rayada 16-09, Bazail-65, and CNL 319 were found to be resistant to ufra infestation.

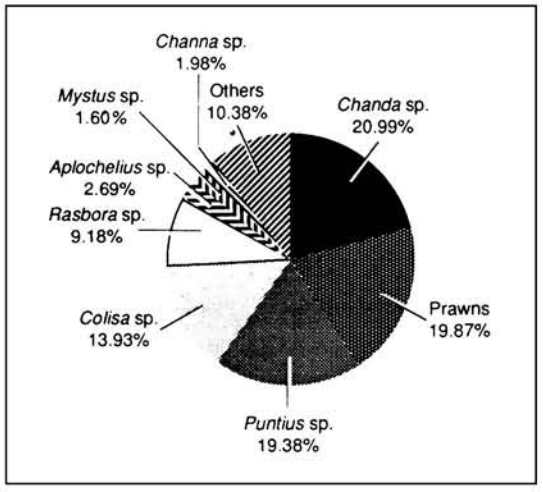
Supplementary fish feed in DWR fields increased fish production by an average of 40% (significant at the 5% level by *t*-test), with a cost-



6. Incidence of infected leaves and panicles in a deepwater ricefield in Kedarnagar, West Bengal, 1987.



7. Physicochemical characteristics of water from a deepwater ricefield in Pearapur, Hooghly, West Bengal, 1988.



8. Composition of total catch of wild fish and prawns from a deepwater ricefield in Pearapur Village, West Bengal, India, 1987 WS.

to-benefit ratio of 1:4. There was, however, no marked evidence that the presence of fish increased DWR production or vice versa. Dried poultry droppings elicited better fish growth than composted cow dung.

Ecological studies of the aquatic environment, with special reference to plankton and benthos, of a large DWR field in Pearapur (near Chinsurah) were carried out to determine the DWR field's suitability for fish culture. The main physical features of the field were measured with standard equipment at weekly intervals between 0900 and 1000 h at 10 cm below the water surface and at 10 cm above the bottom—except light intensity, which was measured on the water surface beneath the plant canopy (Fig. 7). Plankton (phytoplankton and zooplankton) and macroorganisms (arthropods, mollusks, and fish) were sampled weekly; periphyton and benthic organisms were measured monthly. The wild fish population was estimated during 1987-88 kharif using bamboo traps at several locations and emptied after every 24 h throughout the season. Thus, the dominant aquatic flora and fauna of the field could be assessed. The composition of the total catch of wild fish and prawns from the field was also estimated (Fig. 8).

The performance of grass carp *Ctenopharyngodon idella* (Val) was tested along with DWR at three locations; the fish fingerlings were released in the field when the rice plants were strongly rooted. There was no damage to rice plants, and the fish grew reasonably well. It could not be established, however, that this species can control weeds in DWR fields.

A simple method to control crab, a major DWR pest, was worked out.

International collaboration

Technology sharing

Various departments

COMMUNICATION AND PUBLICATIONS **612**
- Publications **612**
- Editing and publication training course **612**
- Research on the role of women in rice science **612**

COOPERATIVES AND NETWORKS **612**
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CONFERENCES, WORKSHOPS, AND MEETINGS **613**

COMMUNICATION AND PUBLICATIONS

Communication and Publications Department

Publications. About 150,000 copies of major IRRI publications were distributed during 1988. Of these, almost 37,000 were in English; the others were translations generated through our copublication program.

Of the English publications, 40% were distributed free, mostly to key libraries in less developed countries. Almost all translations were sold or sponsored by donor funds.

Ten books and one map in English were released. An additional six translations of IRRI publications were copublished by national programs. The section on Publications and Seminars has a full listing.

Five issues of the *IRRI reporter*, 6 issues of the *International rice research newsletter* (IRRN), and the IRRN *Subject index* and *Index of varieties, cultivars, and lines* for 1988 were distributed to 12,000 rice workers and 3,050 libraries in 151 countries. One issue of the *International azolla newsletter,* two of the *Deepwater rice newsletter*, three of the *Hybrid rice newsletter*, one of the *Rice genetics newsletter,* and two of the *IRRI alumni newsletter* were published. Six issues of the *IRRI research paper series* came out.

Thirty news releases were written and distributed; four were also distributed in Spanish and French.

Seven issues of *Rice abstracts*, which IRRI began publishing jointly with CAB International in 1986, were distributed. The Asian Development Bank has provided a grant to support 1,100 *Rice abstracts* subscriptions for key agricultural libraries in less developed countries for 3 yr.

Editing and publication training course. A 2-wk EdPub course for 25 editors was held in June in Bangkok at the invitation of the Department of Agriculture of Thailand.

Research on the role of women in rice science. Previous studies on women in rice have documented the role of women in farming but not the role of Asian professional women in rice science. Thus, we conducted a benchmark analysis to measure the personal and professional background of women and their roles in rice science.

A total of 9,400 female and male recipients of IRRI publications from 155 countries were taken from the IRRI computerized mailing list for a gender comparative analysis. Women made up 12% of the individual subscribers to IRRI publications; 83% were from Asia. Males dominated the postgraduate degree holders. But it is encouraging that most of the females were between the ages of 21 and 30 (41% of the male recipients were above 40 years old). Not much difference was found in the problem areas in which each group showed interest.

For a more detailed analysis, 205 women from 19 countries in Asia were selected and classified by geographic region (Table 1). Most of the women were below the age of 35. Half had postgraduate degrees. More than 40% worked for national research organizations, and 50% were involved primarily in research. Although the primary interest area of Asian women was pest management (diseases, insects, and weeds), women worked on various problem areas.

Information from the study reinforces the argument for strengthening linkages between and among agencies, among professional women, and between professional women and rural women in agricultural and rural development.

COOPERATIVES AND NETWORKS

Integrated Pest Management Project. We continued collaborating with the Food and Agriculture Organization Intercountry Program for Integrated Pest Control for Rice in South and Southeast Asia and with country programs in the development of integrated pest management (IPM). These collaborations included:

- training on IPM concepts for subject matter specialists in Indonesia, Malaysia, the Philippines, and China;
- workshop to improve pest surveillance in Malaysia;
- workshops to enhance IPM implementation programs in China and the Philippines; and
- strategic extension campaign for control of the golden apple snail in the Philippines.

Our research on yield losses and compensation due to pests helped in the adjustment of

Table 1. Personal and educational backgrounds of 205 Asian women. IRRI, 1988.

Factor	Region (%)			
	Southeast Asia	South Asia	East and West Asia	All
Highest degree				
Ph D	6	25	28	19
MA/MS	27	38	28	31
BA/BS	62	20	32	39
Diploma	1	12	8	7
Other	4	5	4	4
Total	100	100	100	100
Discipline				
Agronomy	34	22	5	23
Plant Breeding	6	11	28	12
Chemistry	3	0	0	1
Crop Management	6	7	3	6
Engineering	3	1	7	3
Entomology	13	18	18	16
Nutrition	0	1	5	2
Pathology	9	6	10	8
Physiology	4	9	7	6
Social Science	4	20	10	12
Soil Science	18	5	7	11
Total	100	100	100	100
Age				
<25	12	5	4	8
25-34	46	60	24	45
35-44	32	19	33	28
45-55	10	11	29	15
>55	0	5	10	4
Total	100	100	100	100
Av (age)	33	34	41	36
Professional activities				
Policy/planning	10	16	16	13
Research	50	48	54	50
Teaching	19	19	17	19
Extension	12	7	2	8
Farming	3	6	3	4
Other	6	4	8	6

thresholds for the rice leaffolder and stem borers.

Cooperative for research on problem soils. Research activities of the Cooperative for Research on Problem Soils continued during 1988 at cooperating institutions in India, Indonesia, Pakistan, Sri Lanka, and Thailand. For details, see the sections on the Integrated Germplasm Evaluation and Utilization Program.

The third meeting of the Cooperative was held in Indonesia on 20-27 August. The theme was rice cultivation on peat soils. Scientists from cooperating institutions and IRRI gained first-hand information about the prospects and problems associated with the use of peat soils for rice cultivation. Indonesian scientists described the peat soils research program of Indonesia including the extent, distribution, and chemical and physical properties of peat soils; development project; land use systems; varietal improvement research; pests and diseases; soil and water management; and socioeconomic problems. After a field visit to peat soil areas in South Kalimantan, researchable issues mutually beneficial to all countries were discussed, and a plan of work was prepared. The cooperative's research program was also reviewed.

CONFERENCES, WORKSHOPS, AND MEETINGS

The following conferences, workshops, and meetings were held in 1988.

January

20-22	Annual Meeting of the Rockefeller Foundation Program on Rice Biotechnology
28-29	Thailand-IRRI Collaborative Research Planning Meeting (Thailand)

February

1- 3	AARD-IRRI Collaborative Research Planning Meeting (Indonesia)

March

14-18	International Workshop on Bacterial Blight of Rice
21-25	Workshop on Rice - Fish Farming Systems Research and Development (Thailand)
21-25	Korea-IRRI Collaborative Project RDA-IRRI Joint Planning Session
28-30	Egypt Project Planning Meeting (Egypt)

April

4- 8 Workshop on Establishing Priorities in Rice Postharvest Research

25-30 Impact of Farming Systems Research in Selected Asian Countries

May

2-11 Women in Rice Farming Systems Training and Planning Workshop

June

13-14 Rice Grain Quality and Marketing Workshop

August

15-19 Crop Animal Farming Systems Workshop (Malaysia)

22-27 Third Meeting of the Cooperative for Research on Problem Soils (Indonesia)

23-30 China-IRRI Collaborative Project Joint Planning Session

September

5- 7 Strategy Review Panel I Meeting

8-10 Strategy Review Panel II Meeting

14-20 Acid Upland Rice Systems Internetwork Traveling Workshop

25- 7 Oct IRTP Cold Tolerance Monitoring Tour (Thailand, Philippines, and India)

October

30- 6 Nov Prosperity Through Rice Project Evaluation and Country Site Visit (Thailand)

November

7-11 1988 International Rice Research Conference: "Component Technology for Rice Farming Systems - An Overview"

12-15 19th Asian Rice Farming Systems Working Group Meeting

14-15 IRRI-Sri Lanka Collaboration Research Planning Meeting

15-18 Strategy Review Panel III Meeting

28- 6 Dec ICAR/IRRI International Conference on Appropriate Technology for Rural Women: Future Strategies and Linkages with Development Systems (India)

December

2- 5 UNDP-BNF Advisory Committee Meeting (Thailand)

6-13 International Symposium on Paddy Soil Fertility (Thailand)

8-19 IRTP Monitoring Tour on Photoperiod-Sensitive Rainfed Lowland Rice (Thailand, Vietnam, and Cambodia)

12-16 Workshop on Botanical Pest Control in Rice-Based Cropping Systems

20 Review and Planning Meeting of IRRI-IIMI Collaborative Project (Irrigation Management for Rice-Based Farming Systems)

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LIBRARY AND DOCUMENTATION CENTER

The 1987 supplement to the *International bibliography of rice research* was released in 1988. The 842-page volume contains 8,523 citations on technical rice literature. Also included is a list of rice literature translations acquired during the year. An additional 131 serial titles were scanned for the compilation. The bibliography is arranged according to subject matter and has author and keyword indexes.

The following publications were also issued in 1988:

- Theses and dissertations on rice available in the library of the International Rice Research Institute, 1988 supplement
- 12 issues of Library list of recent accessions (January to December 1988)

All the publications were distributed, without charge, by the library to more than 600 libraries and documentation centers in the rice-producing world. Many were also sold to subscribers.

At the end of 1988, the Rice Literature Search System, which became operational in 1985, had roughly 130,000 rice literature entries. All the original documents representing these citations are in the library's book and periodical collection. In addition, the library acquired AGRICOLA, a computerized bibliographic data file on CD-ROM laser disks. Both literature retrieval services are being utilized to reply to worldwide requests for information on rice science and cognate disciplines.

Circulation of tables of contents of newly received journals, to keep scientists informed of the latest publications on rice, was continued within IRRI and to several stations in Indonesia, Bangladesh, and Africa. Citations of Japanese and Chinese publications were also forwarded to CAB International (CABI) for inclusion in the CABI database. The library also sent to CABI the original documents for abstracting.

In 1988, the library broadened the scope of its literature dissemination program through the already established linkages and networks of the International Rice Testing Program (IRTP), the Asian Rice Farming Systems Network, and the International Network on Soil Fertility and Sustainable Rice Farming. This permits the library to directly answer the information needs of an additional 350 key rice scientists in national agricultural research systems (NARS); there are now linkages with as many as 375 research workers at 217 sites in 104 countries. Consequently, there was a marked increase in the number of inquiries, particularly from India, Bangladesh, Madagascar, and Indonesia. Assistance in library organization and management, and in selecting and processing special materials such as microforms, maps, pamphlets, and ephemera was also given.

Lectures in literature searching and library use, and library tours were given to IRRI scholars, trainees, and visitors. Computer literature searches, purchase of textbooks, binding of theses and dissertations, and provision of certificate folders were also handled by the library.

Researchers and students from the Los Baños community, Metro Manila, and Central Luzon used the library facilities. The demands were not for rice literature alone, but for other disciplines as well.

At the close of 1988, the monograph collection (books, pamphlets, reprints, and translations) totaled 85,783. Serial titles had reached a maximum of 3,656 during the year, but a few were excluded at year's end. Maps and microforms were also added.

During the year, the library continued sending input sheets of its serial holdings to the International Crops Research Institute for the Semi-Arid Tropics for the preparation of a union catalog of serials of international agricultural research center libraries.

EXPERIMENTAL FARM

The concrete bridge near series 100 was renovated, creating a spillway to reduce soil erosion in the adjacent plots and to make it easy for vehicles to pass during typhoons without danger of being carried away by floodwaters.

A tractor shed was constructed at the back of the farm machinery shop to ease the congestion of tractors and farm implements at the entrance of the farm shop and also to protect the tractors from rain.

Fields Mainit I and Mainit II were given back to the University of the Philippines at Los Baños as per agreement.

In 1988, the Experimental Farm planted 38.11 ha for seed multiplication and rice for milling; the rice was given to IRRI employees as Christmas gifts and as donations to flood victims in three barangays of Los Baños and four barangays of Bay, Laguna. The following varieties and selections were planted: IR66, IR68, IR70, IR72, IR74, and IR841.

During the year, 28,233 rats were killed in IRRI fields by electric fences, baiting, trapping, and flame throwing operations.

A total of $438,013 was spent for contract labor, 58.2% of which was for planting and weeding, 36.2% for bird boys, and 5.6% for land preparation (Table 1). The use of hydrotillers, which can plow and harrow at the same time, resulted in savings of $6,223 compared with expenses in 1987 for land preparation.

In 1988 we realized $44,334 from sales of seed, rough rice for milling, milled rice, and other farm produce (Table 2).

Table 1. Expenses for contract labor by the Experimental Farm, 1988.

Operation	Expense	
	₱	$
Land preparation (carabao and machine)	₱ 519,539.01	$ 24,495.00
Planting and weeding	5,405,865.47	254,873.43
Bird boys	3,374,854.24	158,644.70
Total	₱9,290,258.72	$438,013.13

Table 2. Experimental Farm income for 1988.

Item	Quantity (kg)	Value	
		₱	$
Seed			
IR54	10.00	45.00	2.12
IR56	5.00	22.50	1.06
IR60	12.00	58.40	2.75
IR64	15.00	67.50	3.18
IR66	17,884.00	118,550.10	5,589.34
IR68	4,376.00	26,110.60	1,231.05
IR70	6,094.00	33,501.80	1,579.52
IR72	8,043.00	50,683.00	2,389.58
IR74	6,384.00	40,423.80	1,905.88
IR841	110.00	495.00	23.33
Rough rice for milling	32,545.99	97,637.97	4,603.39
Milled rice	72,889.20	379,915.89	17,912.11
Milled IR841	2,272.52	15,907.60	750.00
Glutinous rice	10,519.70	104,837.90	4,942.95
Soybean (feed)	1,346.00	2,692.00	126.92
Sesbania seed	25.00	375.00	17.68
Supersweet maize seed	4.00	60.00	2.82
Flint maize (feed)	343.00	872.10	41.11
Mongo	217.00	3,255.00	153.46
Supersweet maize (green)		28,575.00	1,347.24
Glutinous maize (green)		12,414.90	585.33
Rejected supersweet maize (feed)		667.50	31.47
Rice bran		704.00	33.19
Jute sacks		16,633.60	784.23
Vegetables			
Cabbage		894.00	42.14
Eggplant		141.18	6.67
Baby maize		2,692.00	126.92
Gabi		279.00	13.15
Pole sitao		1,009.68	47.60
Okra		15.00	.70
Cucumber		692.10	32.63
Tomato		97.00	4.57
	Total	₱940,326.12	$44,333.97

As of December 31, 1988, the seed room had 7,599 kg of seed valued at $1,713.

ANALYTICAL SERVICE LABORATORIES

Output and efficiency. In 1988, the Analytical Service Laboratories (ASL) performed 132,076 analyses on 74,698 samples for 71 parameters (Table 3). With a staff of 22 plus nearly 6,000 h of overtime and emergency hired help, ASL averaged 2.7 analyses/h of work or 22 min/analysis. These figures are close to those of the previous years.

In addition to analytical services, the Radioisotope Laboratory provided facilities for the following experiments that involved radiotracers:

- Studies on decomposition of ^{14}C-labeled rice straw in tropical flooded soils (Soils Department)
- Determination of differential rates of insecticide penetration, metabolism, and anticholinesterase activity in the brown planthopper *N. lugens* and its predator, the wolf spider *L. pseudoannulata* (Entomology Department)
- ADP/UDP sucrose synthase and ADP/UDP glucose pyrophosphorylase in developing rice grain of starch mutants (Cereal Chemistry Department)
- Sulfur transformation in lowland rice soils from two ^{35}S-tagged fertilizers as influenced by water management (Agronomy Department)
- Effect of fertilizer application method on fate of N and S from urea-elemental S and urea-ammonium sulfate mixtures (Agronomy Department)
- Reduction of sulfate to sulfide (Agronomy Department)
- Oxidation of elemental sulfur to sulfate (Agronomy Department)

Computerization. In planning the computerization program of ASL, the steps involved in routine analysis were evaluated to identify the processes that should be given priority on the basis of technical feasibility, benefits, and costs. Recognized as priority items were chemical analysis, data processing, report generation, record keeping, and file management.

An inexpensive computer system designed to capture "time critical" analog data simultaneously from four data sources used in chemical analysis and to process those data was installed and tested. The system consists of off-the-shelf hardware and software, plus four application programs customized for the unique needs of ASL.

Table 3. Analytical services completed at IRRI in 1988.

Sample type	Samples (no.)	Determinations (no.)
Chemical Analysis Laboratory		
Plant	37,733	72,103
Soil	3,170	17,556
Floodwater/solution	18,731	25,953
Fertilizer	62	123
Mass Spectrometry Laboratory		
^{15}N	8,843	8,843
Radioisotope Laboratory		
Oxidation and counting	6,159	7,498
Total	74,698	132,076

The Technicon AutoAnalyzers, which are used for colorimetric analysis, were the data sources for which the computer system was designed. The basic AutoAnalyzer equipment automates sampling, dilution, mixing, chemical reaction, and detection of color intensity, which is directly proportional to the concentration of the element concerned. Detection of color intensity is manifested as an electrical signal, which is registered as a tracing on the recorder chart. This tracing shows a series of peaks corresponding to the samples analyzed. Before the computer system was installed, data processing was a tedious operation that consisted of measuring the height of each concentration peak and computing the analyte concentration for each sample. With the new computer system, data processing became automated as well.

Hardware. The voltage output of the AutoAnalyzer is captured by an early generation 64-kilobyte NorthStar Horizon microcomputer with a 15-megabyte hard disk. An analog-to-digital converter card (Dual Systems AIM-12) was installed in the computer to convert the voltage signals from the AutoAnalyzers to digital information that the computer understands. Because of the limited capacity of the NorthStar, we designated it to handle the data logging function only. A second computer, a 640-kilobyte Mitac Titan, an IBM AT-compatible with enhanced graphic capabilities, is used to process data. Data transfer from the NorthStar to the Mitac is via serial com-

munications using an RS-232 cable and a null modem adapter because of incompatible disk formats.

Software. Data capture and communication between the computers cannot be achieved with hardware alone; appropriate programs are needed to control those operations. We developed four application programs in-house and selected two commercially available utility programs to control signal capture by the NorthStar, data transfer from the NorthStar to the Mitac, and data processing by the Mitac. For signal capture, we wrote two programs, "AC5" and "RTS," in Microsoft BASIC-80 (release 5) for the NorthStar. These programs provide for multichannel access, optimized sampling rates, and tolerance for systems failures. We selected "PIP," a CP/M utility, to enable the NorthStar to transmit data, and "Crosstalk XVI" (Microstuf, Inc.) to enable the Mitac to receive data. For data processing, we wrote two additional programs, "STR" and "FAStPRO(DPM)," in Turbo Basic for the Mitac. With the help of computer graphics, these programs allow the user to interact with the computer in calibration, evaluation of the standard curve, sample peak identification, computation of analyte concentrations, and generation of reports in text file and hard copy (Fig. 1).

Data obtained and processed by the computerized system agree closely with the data calculated from peak heights read visually from the strip chart recorder.

PESTICIDE RESIDUE LABORATORY

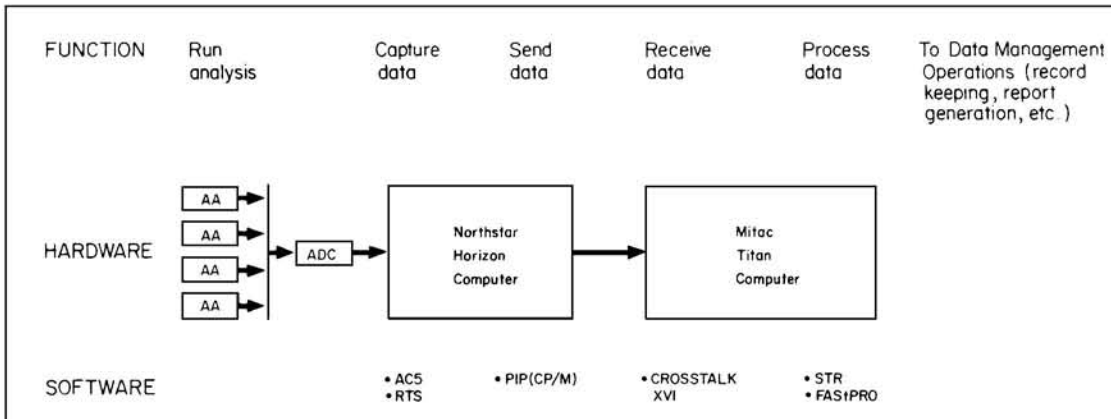
The Pesticide Residue Laboratory received 1,104 samples in 1988. Of these, 133 were submitted for complete analysis: 116 from the Experimental Farm Waterways Runoff Monitoring Project, 13 from the Water Management Department for analysis for organophosphate and carbamate residues in runoff from farmers' fields, and 4 rice grain samples from the Experimental Farm for monocrotophos (Table 4).

The bulk of the pesticide residue samples received—802 extracts of pesticide-treated insects—

Table 4. Analyses performed by the Pesticide Residue Laboratory, 1988.

	Complete analysis (no.)	GLC[a] injection only (no.)
Monocrotophos	133	
BPMC	129	
Butachlor	129	
Carbaryl	129	
Carbofuran	129	
Chlorpyrifos	129	
Diazinon	129	
Isoprocarb	129	
Acephate	129	342
Aldrin		56
Dieldrin		56
Methamidophos		342
Propaphos and metabolites		404
Others		169
Total	1165	1369

[a]GLC = gas liquid chromatography. Aldrin → dieldrin. Acephate → methamidophos. Propaphos→metabolites.



1. Schematic illustration of the IRRI Analytical Service Laboratories data acquisition system. AA = AutoAnalyzer, ADC = Analog-to-Digital Converter.

were for injection and quantitative analysis only. These samples were from metabolic degradation studies on acephate (342), propaphos (404), and aldrin (56), being conducted by a doctoral candidate in the Entomology Department.

One hundred sixty-nine nonpesticide analyses were performed on epicuticular wax extracts submitted by the Plant Breeding Department.

PHYTOTRON

The phytotron was used for 63 projects of 8 departments. Plant Breeding had the most projects (17), followed by Plant Physiology (15).

Of the 7 types of growth rooms, the glasshouses (naturally lighted) provided more than 75% of the total available space and reached an occupancy rate of 91% in 1988 (Table 5). Occupancy averaged 96% in the artificially lighted cabinets (KG, HNL, Conviron Bench) and more than 77% in the naturally lighted cabinets (KB, SA-L). The darkrooms posted an average of 78% occupancy. Overall occupancy was less by 1% than the average of 1987 (88%). Most of the studies lasted more than 60 d. A downtime of 2.5 d between experiments was recorded.

The aeroponic equipment in Glasshouse 3 was intermittently used for 135 d by the International Rice Germplasm Center for screening root characters.

Table 5. Occupancy of growth rooms in the IRRI phytotron, 1988.

Growth rooms	Total floor area (m^2)	Occupancy (%)
6 glasshouses (naturally lighted)	240.00	91
12 SA-L cabinets (naturally lighted)	18.72	77
4 KB cabinets (naturally lighted)	1.76	78
11 KG cabinets (artificially lighted)	15.84	91
1 Conviron Bench (artificially lighted)	4.46	97
1 HNL cabinet (artificially lighted)	3.06	100
5 darkrooms	32.50	78

The phytotron used more than $254,000 for its operation in 1988. More than 56% of this amount was spent for electricity and diesel fuel, and the remainder for maintenance.

The entire facility was used from January to October and was closed in November and December for annual maintenance. It was operated without any technical problem despite 40 power interruptions lasting a total of 218 h.

The phytotron provided services for 129 requests of other departments for the use of the cold room, leaf area meter, oven, and other instruments. It also entertained numerous visitors, trainees, and student groups.

Preparations were made for the installation of ultraviolet-B facilities in Glasshouse 1 in connection with IRRI's program on global warming and environmental changes.

SEED HEALTH UNIT

During the year, the Seed Health Unit (SHU) processed 586 foreign seed requests and 124 requests for 1,217 IRTP nursery sets for phytosanitary certification. The seed packets covering the foreign seed requests totaled 52,651, weighed 1,199 kg, and were sent to 68 countries; 74,652 seed packets constituted the IRTP nursery sets, which were sent to 46 countries. Hot-water treatment (HWT) was given to 14,581 seed packets (2,848 kg) for 1988 IRTP nursery sets sent to countries where HWT of rice seeds is a pre-import requirement. Processing for 1989 IRTP nursery preparation started in June 1988 with a total of 1,224 seed lots submitted for visual inspection, 1,596 seed lots (1,615 kg) for removal of *Tilletia barclayana* (kernel smut)-contaminated seeds, and 2,521 seed lots for test of germination after HWT.

Routine seed health testing (RSHT) for outgoing seeds was conducted on 4,314 official seed lot samples and on 45,873 unofficial samples. The major seedborne organisms in outgoing seeds were *Trichoconis padwickii*, affecting 98% of tested seed lots, followed by *Curvularia* spp., 91%; *Sarocladium oryzae*, 74%; *Gerlachia oryzae*, 39%; *Drechslera oryzae*, 24%; and *Fusarium moniliforme*, 12% (Table 6). *Tilletia barclayana* and *Aphelenchoides besseyi* affected 4% each of the tested seed lots, while *Pyricularia oryzae* was found in only 0.2%. *Cercospora oryzae* and *Nakataea sigmoideum* were

Table 6. Routine seed health test results of 1988 outgoing seeds with and without treatment.

Pathogen	With treatment[a]			Without treatment[b]		
	Affected seed lots (%)	Detection level (%)	Mean value (%)	Affected seed lots (%)	Detection level (%)	Mean value (%)
Pyricularia oryzae	0	0	0	0.2	1 - 2	1.2
Drechslera oryzae	2.4	1 - 2	1.1	23.9	1 - 28	2.1
Gerlachia oryzae	0	0	0	38.8	1 - 55	2.6
Sarocladium oryzae	0	0	0	73.7	1 - 71	5.9
Fusarium moniliforme	0	0	0	12.3	1 - 13	1.3
Trichoconis padwickii	1.2	1 - 3	1.4	97.7	1 - 89	21.7
Curvularia spp.	2.9	1 - 3	1.1	90.9	1 - 96	11.6
Tilletia barclayana[c]	0.4	1 - 4	2.0	4.1	1 - 98	11.2
Aphelenchoides besseyi[d]	0	0	0	4.3	1 - 107	9.5

[a] 1704 samples. [b] 2610 samples. [c] *Tilletia barclayana*-contaminated seeds were rejected for certification. [d] Actual nematode count.

not detected. RSHT for treated seed lots showed effective elimination of the seedborne pathogens except for the partial effects of fungicides benomyl and mancozeb on a few seed lots having deep-seated infection by *D. oryzae, Trichoconis padwickii,* and *Curvularia* spp. (Table 6).

Eighty-eight incoming seed shipments originating from 26 countries covering 6,752 seed packets were processed for post-entry clearing. The largest shipment was received in late November from Korea, with 3,798 seed packets for seed increase. Total tested seed lots were 6,408, with 449 seed lots supplying official samples; 344 seed lots were so limited that samples could not be drawn. RSHT of the official samples revealed the following seedborne pathogens: *T. padwickii* affecting 17% of tested seed lots; *Curvularia* spp., 10%; *Tilletia barclayana* contamination, 9%; *D. oryzae*, 8%; *A. besseyi*, 7%; *S. oryzae*, 4%; *G. oryzae*, 1%; *F. moniliforme*, 1%; and *P. oryzae*, 0.2% (Table 7). Among the quarantine objects observed in the incoming seed shipment were storage insects or insect damage affecting 13.8% of total seed lots, and 10 weed species in 1.7% of the seed lots (Table 8).

All seed lots (incoming and outgoing) were subjected to standard seed treatment of fumigation with phosphine, hot-water treatment at 52-57 °C for 15 min, slurry treatment with benomyl and mancozeb at 0.3% by seed weight except when importing country regulations stated otherwise. Fungicide slurry treatments of IRTP materials were done by IRTP after SHU had performed HWT.

Table 7. Routine seed health test results of 1988 incoming seeds received with and without treatment (449 samples).

Pathogen	Affected seed lots (%)	Detection level (%)	Mean value (%)
Pyricularia oryzae	0.2	2 - 2	2.0
Drechslera oryzae	8.0	1 - 72	8.2
Gerlachia oryzae	1.1	1 - 9	1.7
Sarocladium oryzae	4.0	1 - 25	4.2
Fusarium moniliforme	0.9	1 - 8	1.5
Cercospora oryzae	0	0	0
Nakataea sigmoideum	0	0	0
Trichoconis padwickii	16.7	1 - 95	25.8
Curvularia spp.	10.2	1 - 75	12.2
Tilletia barclayana[a]	9.1	1 - 83	13.5
Aphelenchoides besseyi[b]	6.9	1 - 344	26.0

[a] *Tilletia barclayana*-contaminated seeds were rejected from shipment. [b] Actual nematode count.

Crop health inspection was done on 5,942 varieties planted during the dry season (DS) and wet season (WS) in the post-entry quarantine area and other designated plots. Diseases observed on plants from incoming seeds were not of an introduced nature. The most common disease was sheath rot, affecting 15% of the varieties in DS; bacterial leaf streak and leaf scald affected 16 and 11% of the varieties, respectively, during WS (Table 9).

All these certification activities for incoming and outgoing rice seeds were supervised by the Plant Quarantine Service, Bureau of Plant Industry, Philippines.

In response to a recommendation made at the International Workshop on Rice Seed Health (March 1987, at IRRI), the First International Course on Seed Health Testing of Rice was sponsored by the Danish International Development Agency and was jointly coordinated by IRRI and the Danish Government Institute of Seed Pathology for Developing Countries. It was held at the SHU 17 Oct-2 Dec 1988, and was attended by 19 representatives from 17 countries of Asia, Africa, and Latin America. Identification and detection techniques for major seedborne pathogens of rice including fungi, bacteria, and nematodes were demonstrated, discussed, and evaluated by the participants. The techniques were based on current knowledge and are very useful tools in plant quarantine, testing rice seed for seedborne infections, and routine seed health assessment. Ten participants came from plant quarantine services, three from seed testing laboratories, and six from research institutions.

Table 8. Incoming rice seed shipments for 1988 and conditions observed.

Item	no.	%
Country of origin	26	
Shipments (no.)	88	
Seed lots (no.)	6,752	
Total weight (kg) of seed lots	273.06	
Shipments covered by phytosanitary certificates	47	53
Shipments without phytosanitary certificates	41	47
Shipments with		
Declared treatments	25	28
Undeclared treatments	12	14
No treatments	51	58
Seed lots with		
Soil	341	5.1
Storage insects or insect damage	933	13.8
Sitophilus spp.	194	2.9
S. cerealella	264	4.0
Rhizopertha dominica	258	3.8
Cryptolestes ferrugineus	45	0.7
Tribolium spp.	45	0.7
Liposcelis entomophilus	7	0.1
Weed seeds		
Echinochloa spp.	26	0.4
Rottboellia cochinchinensis	24	0.4
Paspalum sp.	7	0.1
Scirpus sp.	7	0.1
Ischaemum rugosum	21	0.3
Digitaria sp.	5	0.1
Panicum sp.	2	0.1
Unidentified (3 spp.)[a]	21	0.3
Smutted seeds	4	0.1

[a]Weed species being identified by Plant Quarantine Service, Bureau of Plant Industry, and Agronomy Department, IRRI.

COMPUTER SERVICES

The Computer Services Department (CSD) provided high levels of support to research scientists and administrative staff during 1988. Response time averaged 0.1 s; resource availability index, 69%; and system availability, 99.23%.

We are approaching a 1-to-1 ratio of microcomputers to researchers. Secretaries, administrative assistants, and research support staff have a similarly high ratio of microcomputers. We had 540 microcomputers in total at year's end.

We acquired ORACLE, a fourth-generation software package. It is a versatile, relational database management system, well suited to IRRI's research requirements. The Genetic Evaluation and Utilization database and World Rice Statistics database are now run under ORACLE.

CSD was instrumental in acquiring and installing the McCormack and Dodge Millenium Financial System.

Table 9. Percent of entries affected by rice diseases in the crop health inspection of incoming seeds[a] and seed multiplication plots intended for export. IRRI, 1988 dry and wet seasons.

Season	Entries (no.)	Percent of entries affected[b]												
		RTV	GSV	RSV	ShR	ShB	NBLS	LSc	WLS	Bl	BLS	BB	BShR	FS
Dry	3498	6.2	0.1	0.74	15.4	0.7	2.9	0.3	0.2	0.1	4.2	0.1	6.1	0.1
Wet	2444	2.4	0	0	2.8	2.3	0.5	11.3	0	3.2	16.1	0.4	8.8	0.8

[a]Diseases observed on plants originating from incoming seeds were not of an introduced nature. [b]RTV = tungro, GSV = grassy stunt, RSV = ragged stunt, ShR = sheath rot, ShB = sheath blight, NBLS = narrow brown leaf spot, LSc = leaf scald, WLS = white leaf streak, Bl = blast, BLS = bacterial leaf streak, BB = bacterial blight, BShR = brown sheath rot, FS = false smut.

Voice and data communication were improved by the installation of a microwave facility that connects IRRI to 10 international direct dial voice lines and 2 digital data lines. In 1989, the facility will be expanded to 20 voice lines. With the planned installation of a Public Automated Branch Exchange (PABX) in 1989, voice communication will improve considerably. The data channels on the new microwave facility will help IRRI disseminate its research findings and databases to NARS and others.

COMMUNICATIONS SUPPORT

The Communication and Publications Department (CPD), in addition to its editorial, information, distribution, and research functions, provides in-house communication support services to IRRI programs. These include typesetting, art and design, printing, and audiovisual services.

CPD printed 20 million pages of text in-house in 1988 (not including the printing of books and major periodicals, which are contracted out). More than 16,000 original slides were produced, and 92,000 slides were duplicated. About 6,000 pieces of black-and-white artwork were drawn, and about 55,000 black-and-white photos were developed.

Nine displays were prepared. Thirty-three news releases were written, plus four radio programs and three television "spots" promoting integrated pest management.

Publications and seminars

PUBLICATIONS

Under Institute publications are listed the 14 major books and 1 map produced by the Communication and Publications Department, 4 of which were copublished in 6 multilanguage editions; 6 monographs in the IRRI Research Paper Series on a variety of topics; and 7 periodicals. Subsequent sections list the output of individual scientists by department and additional bibliographies produced by the Library and Documentation Center.

Institute publications

Major publications

Fundamentals of rice crop science [in Japanese], by S. Yoshida. 316 p.
Helpful insects, spiders, and pathogens -- friends of the rice farmer [Cebuano, Khmer, and Gujarati editions], by B.M. Shepard, A.T. Barrion, and J.A. Litsinger. 136 p.
IRRI highlights 1987. 84 p.
Human geography of rice in South Asia. (booklet and map)
Genetic manipulation in crops. 446 p.
Filipino women in rice farming systems. 408 p.
Rice seed health. 362 p.
Conditions for azolla. (map)
History of IRRI: an adventure in applied science [in Chinese]. 270 p.
Rice ratooning. 279 p.
A farmer's primer on growing rice [Oualof edition], by B.S. Vergara. 221 p.
Green manure in rice farming: sustainable agriculture. 378 p.
A farmer's primer on growing upland rice, by M.A. Arraudeau and B.S. Vergara. 282 p.
Annual report for 1987. 640 p.
Proceedings of the 1987 International Deepwater Rice Workshop. 633 p.

Research Paper Series

131. Rice cultivar variability in tolerance for accelerated aging of seed, by S.B. Siddique, D.V. Seshu, and W.D. Pardee. 7 p.
132. Yield constraints and fertilizer management in shallow rainfed transplanted and broadcast seeded lowland rice in the Philippines, by S.K. De Datta, F.V. Garcia, W.P. Abilay, Jr., and J.M. Alcantara. 14 p.
133. Rice harvesting systems in Central Luzon and Laguna revisited, by Y. Hayami, E. B. Marciano, and L.M. Bambo. 15 p.
134. Electrophoretic variation of isozymes in plumules of rice (*Oryza sativa* L.)—a key to the identification of 76 alleles at 24 loci, by J. C. Glaszmann, B.G. de los Reyes, and G. S. Khush. 14 p.
135. Simulation of rice leaffolder population dynamics in lowland rice, by E.A. Benigno, B.M. Shepard, E.G. Rubia, G.S. Arida, F.W.T. Penning de Vries, and J. Bandong. 8 p.
136. Rice agroecosystems, farmer management, and social organization in Kampuchea: a preliminary assessment and research recommendations, by S. Fujisaka. 16 p.

Periodicals

International rice research newsletter, Vol. 13, nos. 1-6, plus Subject index
International azolla newsletter, Vol. 4, no. 1
Deepwater rice, Nos. 13-14
Hybrid rice newsletter, Vol. 2, nos. 1-3
Rice genetics newsletter, Vol. 5
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SEMINARS

Thursday seminars and special seminars cover a wide range of topics. Saturday seminars report ongoing IRRI research. Unless otherwise stated, the speakers were IRRI staff members.

Thursday seminars

Genetic evaluation and hormonal regulation of internodal elongation of deepwater rice. Dr. K. Takahashi, visiting scientist; Ms. A. M. Mazaredo, research assistant; Mr. A. Aguilar, research aide; and Dr. B. S. Vergara, plant physiologist and head, Plant Physiology Department.

Image analysis and measurement of soil structure. Dr. A. J. Ringrose-Voase, consultant, Soils Department.

Global agriculture at the crossroads. Dr. M. S. Swaminathan.

Inventory of one's life (coping with stress). Dr. L. Lapuz, psychiatrist, Medical City General Hospital, Pasig, Metro Manila.

School on the air: a farmer's primer on growing rice. Dr. T. H. Stuart, assistant professor, Institute of Development Communication, University of the Philippines at Los Baños, College, Laguna.

Crop diversification - the World Bank's perspective. Mr. S. Bharghouti, irrigated crops advisor, Agriculture and Rural Development Department, World Bank, Washington, D. C.

Genetics of resistance to bacterial blight in rice. Dr. T. Ogawa.

Effect of plant resistance on microevaluation of the brown planthopper. Dr. K. Gallagher, collaborative research fellow, Entomology Department.

Iron chlorosis on calcareous soils. Dr. K. Mengel, soil scientist, Justus Liebig University, Germany.

Identification and inheritance of sheath blight resistance in rice. Dr. B. J. Hoff, visiting scientist, Plant Breeding Department.

Technological change and land reform in the Philippines. Dr. K. Otsuka, visiting scientist, Agricultural Economics Department.

Thinking like an editor, or, too simple to be scientific? Mr. I. Montagnes, visiting editor, Communication and Publications Department.

IRRI's novel approaches to technology dissemination. Dr. F. Cariño, extension adviser, Communication and Publications Department.

Target-oriented project planning (TOPP). Mr. C. Catapang, project director, Cebu Community Development Project.

Role of gender in technology development. Dr. H. Feldstein, Codirector, The Gender and Agriculture Project of the Population Council, New York.

Perennial (cash) crops in the small farm sector: a review. Dr. N. Mateo, postdoctoral fellow, Rice Farming Systems Program.

Why does rice die at 5 °C? Dr. J. Wilson, visiting scientist, Plant Physiology Department.

Hepatitis B. Dr. R. Olveda, head, Research and Training, Research Institute of Tropical Medicine, Alabang.

Enhanced biodegradation of soil-applied pesticides. Dr. L. Somasundaram, Iowa State University, USA.

Varietal development for rainfed lowland rice in Chinsurah, India. Dr. S. Mallik, postdoctoral fellow, Plant Physiology Department.

What makes networks work - if they do! Dr. D. G. Faris, visiting scientist, Rice Farming Systems Program.

Agricultural engineering: potential program. Dr. W. J. Cochran, agricultural engineering consultant, Food and Agriculture Organization.

Expert systems. Dr. G. C. Krajcsik.

Biotechnology in rice virus research: present status and prospects. Dr. T. Omura, plant virologist and senior researcher, Laboratory for Virus Disease Control, Department of Plant Protection, National Agriculture Research Center, Tsukuba, Japan.

Strengthening agriculture in Nepal through the Agricultural Research and Production Project. Dr. R. Q. Lacsina, research station management specialist, Agricultural Research and Production Project, Winrock International, Kathmandu, Nepal.

A farming systems research and extension approach to rainfed agricultural development. Dr. I. A. Craig, farming systems specialist, Northeast Agricultural Project, Khon Kaen, Thailand.

In search of a new land reform paradigm for the Philippines. Dr. Y. Hayami, professor, School of International Policies, Economics and Business, Aoyama Gakuin University, Shibuya-ku, Tokyo, Japan.

Tungro disease: problems and prospects. Dr. H. Hibino.

Genetics of endosperm mutants in rice. Dr. R. P. Kaushik, postdoctoral scientist; and Dr. G. S. Khush, principal plant breeder and head, Plant Breeding Department.

IIRR: 60 years in rural development. Dr. A. de Jesus, executive vice president, International Institute for Rural Reconstruction, Silang, Cavite.

Neem derivatives for management of insect pests of rice and mungbean crops in the Philippines. Dr. A. Abdul Kareem, visiting scientist, Entomology Department.

Simulation of soybean growth and water use. Dr. F. W. T. Penning de Vries, visiting scientist, Multiple Cropping Department.

When cultures collide—the IRRI experience. Dr. S. S. Mina, postdoctoral fellow, Training and Technology Transfer Department.

SAWAH—a model for simulating soil-water dynamics in rainfed lowland ricefields. Dr. H.F.M. Ten Berge, associate scientist, Simulation and Systems Analysis for Rice Production (SARP), Centre for Agro Biological Research, Wageningen, The Netherlands.

Energetics for rice yield improvement: accomplishment and future outlook. Dr. S. Akita.

Guidelines for preparing proposals for submission to ADB. Dr. N. Amirasinghe, senior sector planning specialist, Agriculture Department (West), Asian Development Bank, Roxas Boulevard, Metro Manila.

Nematode parasites of rice: perspective, targets, objectives. Dr. J.C. Prot, visiting scientist, Plant Pathology Department.

Allelopathic effects of natural compounds. Dr. N. H. Fischer, professor, Department of Chemistry, Louisiana State University, USA.

Towards designing a new plant type for direct seeded flooded rice culture. Dr. M. Dingkuhn, visiting collaborative scientist; Dr. H. F. Schnier, visiting collaborative scientist; and Dr. S. K. De Datta, principal scientist and head, Agronomy Department.

Saturday seminars

Measurement of denitrification loss in lowland ricefields. Dr. S. K. De Datta, principal scientist and head; Dr. R. J. Buresh, visiting scientist; Ms. E. V. Flordelis, senior research assistant; and Ms. M. I. Samson, research assistant, Agronomy Department.

Cono puddlers, a new approach for energy efficient rotary puddling. Mr. R. C. Bautista.

A fish and vegetable grower for all seasons. Dr. R. E. Huke, visiting scientist, Agricultural Economics Department.

Biometrical procedure for detecting probable duplicates in a rice germplasm bank. Dr. A. I. N. Gironella, postdoctoral scientist, Statistics Department.

Paddy sun-drying studies. Dr. V. G. Gayanilo, postdoctoral fellow, Agricultural Engineering Department.

Development of the hydrotiller. Mr. H. T. Manaligod.

Technology development for rice-based farming systems in Southern Bhutan. Mr. A. R. Samiano.

Statistical analysis of data from intercropping experiments. Mr. K. Rahim, research fellow, Statistics Department.

Test type reference and test performance: do they match? Mr. J. del Carmen.

Physical stresses and varietal resistance in rice: effect on whiteback planthopper *Sogatella fur-*

cifera (Horvath) (Homoptera: Delphacidae). Mr. M. Salim, research fellow; and Dr. R. C. Saxena, entomologist, Entomology Department.

Toward understanding the genetic mechanism for cold tolerance characteristics in rice. Dr. M. K. Majumder, visiting scientist; and Dr. D. V. Seshu, plant breeder and coordinator, International Rice Testing Program.

Green leafhopper "biotypes" and tungro transmission in the Philippines. Mr. G. Dahal, research fellow; Mr. V. Aguiero, senior research assistant; Dr. H. Hibino, plant virologist, Plant Pathology Department; and Dr. R. C. Saxena, entomologist, Entomology Department.

Nitrogen absorption pattern of rice plants grown under different conditions. Dr. G. Wada.

Wide compatibility in rice (*Oryza sativa* L.). Mr. R. Vijaya Kumar, research fellow; and Dr. S. S. Virmani, plant breeder, Plant Breeding Department.

Blast resistance in tropical lowland rice cultivars. Mr. B. A. Estrada, Mr. J. M. Bandong, and Dr. J. M. Bonman.

Fertility trends of F_1 upland rice crosses. Ms. A. V. Alzona, research assistant; and Mr. M. A. Arraudeau, visiting plant breeder, Plant Breeding Department.

Physiological aspects of heterosis in F_1 rice hybrids. Ms. L. C. Blanco, research assistant; Dr. S. Akita, plant physiologist; and Mr. C. K. Kim, research fellow, Plant Physiology Department.

Resistance to bacterial blight of rice. Ms. C. Vera Cruz and Dr. T. W. Mew.

Results of screening and observational trials of upland rice at Cavinti, Laguna. Mr. E. Sison, research assistant; and Mr. M. A. Arraudeau, visiting plant breeder, Plant Breeding Department.

Rice breeding for cold tolerance in Korea. Dr. C. H. Kim, visiting plant breeder, Plant Breeding Department.

Disease modeling to improve management decisions. Dr. P. S. Teng.

The collection and conservation of wild relatives of rice. Dr. D. A. Vaughan.

Toward stabilizing yield of upland rice. Dr. T. T. Chang and Ms. G. C. Loresto.

Arthropod food webs of major insect pests of rice. Mr. A. T. Barrion and Dr. J. A. Litsinger.

Status of the study of chemical basis of resistance to the rice plant to leaffolders and stem borers. Dr. P. Caballero, postdoctoral scientist; and Dr. B. O. Juliano, chemist and head, Cereal Chemistry Department; Dr. Z. R. Khan, associate entomologist; and Dr. R. C. Saxena, entomologist, Entomology Department; and Dr. F. J. Zapata, tissue culture specialist, Plant Breeding Department.

Evaluating biological control agents against insect pests of rice. Ms. R. M. Aguda and Dr. B. M. Shepard.

Grain filling in rice as affected by size and position of source and sink. Dr. J. K. Ahn, former research fellow; Mr. G. F. Pateña, research assistant; and Dr. B. S. Vergara, plant physiologist and head, Plant Physiology Department.

Probability of each spikelet occurring in a rice panicle. Mr. G. F. Pateña and Dr. B. S. Vergara.

Resistance of *Oryza* sp. to rice thrips *Stenchaetothrips biformis* (Bagnall) (Thysanoptera: Thripidae). Ms. E. B. Medina and Dr. R. C. Saxena.

Effects of neem seed bitters on planthopper and leafhopper pests of rice and their predators. Ms. E. M. Boncodin, Ms. B. P. Rueda, and Dr. R. C. Saxena.

Excess water problems in rice cultivation. Dr. S. I. Bhuiyan.

Flooding hazards in lowland rice areas and farm-level strategies for their alleviation. Mr. M. M. Agua, senior research assistant; Dr. S. I. Bhuiyan, agricultural engineer and head; Dr. R. C. Undan, former postdoctoral scientist, Water Management Department.

Irrigation water quality and sustainability of rice production: the Agno River Basin case. Mr. A. R. Castañeda and Dr. S.I. Bhuiyan.

Direct measurement of ammonia volatilization and denitrification losses in flooded tropical rice. Ms. W. N. Obcemea, senior research assistant; Mr. J. G. Real, research assistant; Ms. M. I. Samson, research assistant; Dr. S. K. De Datta, principal scientist and head; and Dr. R. J. Buresh, visiting scientist, Agronomy Department.

Rice panicle development stages as indications of grain yield. Mr. N. Senanayake, research fellow; and Dr. S. K. De Datta, principal scientist and head, Agronomy Department.

Weed research in relation to management strategies for controlling weeds in ricefields. Dr. K. Ampong-Nyarko, postdoctoral scientist; and Dr. S. K. De Datta, principal scientist and head, Agronomy Department.

Integrated use of organic and inorganic fertilizers in lowland rice-based cropping systems. Mr. R. T. Rosales and Dr. C. P. Mamaril.

Drought stress index for rice. Ms. E. B. Yambao and Dr. K. T. Ingram.

Effect of water overflowing from herbicide-treated plots on herbicide performance. Mr. E. M. Castin and Dr. K. Moody.

Basin irrigation design for upland crops in ricelands. Dr. D. J. Moridis and Mr. M. M. Alagcan.

Electrophoretic analysis of genetic variation in brown planthopper *Nilaparvata lugens* (Stal) (Homoptera: Delphacidae) and green leafhopper *Nephotettix virescens* (Distant) (Homoptera: Cicadellidae) in the Philippines. Mr. C. G. Demayo, senior research assistant; and Dr. R. C. Saxena, entomologist, Entomology Department, IRRI; and Dr. A. A. Barrion, assistant professor, University of the Philippines at Los Baños.

Characterization of IRRI farm soil and irrigation water properties, nutritional disorders, and rice yields. Ms. M. T. C. Cayton, Ms. N. U. Autor, and Mr. R. Y. Reyes.

Computer guided classification of soils based on soil taxonomy. Mr. R. Y. Reyes and Ms. C. M. Chavez.

Special seminars

Rice research and production in tropical Australia. Mr. A. K. Borrell, research agronomist, Queensland Department of Primary Industries, Australia.

Analysis and planning of tropical farming systems. Dr. L. Stroosnijder, coordinator, NUFFIC, UNIBRAW, LUA Soil Science Project, Brawijaya University, Malang, Indonesia.

Rice and global atmospheric change. Dr. J. S. Hoffman, U.S. Environmental Protection Agency; and Dr. A. Teramura, botanist, University of Maryland, USA.

Rice response to global changes in carbon dioxide concentration. Dr. J. T. Baker, assistant research scientist, Institute of Food and Agricultural Sciences, University of Florida, USA.

Heavy metal contamination of soils and vegetation in Metro Manila. Dr. E. Pfeiffer and Dr. J. Freytag, Institute of Soil Science, University of Hamburg, West Germany.

Supersensitivity and superresistance of rice plants to oxygen stress. Prof. B. B. Vartapetian, K. A. Timiriazev Institute of Plant Physiology, Academy of Sciences, USSR.

WARDA—its present state of set-up and future strategy. Dr. E. Terry, director general, WARDA, Bouaké, Ivory Coast.

Simulation of soybean growth and water use. Dr. F.W.T. Penning de Vries, visiting scientist, Multiple Cropping Department.

Computer simulation of the population dynamics of the yellow stem borer *Scirpophaga incertulas* (Walker). Mr. Jingyuan Xia, research fellow, Multiple Cropping Department (IRRI-SARP Project).

Mechanisms of resistance in sorghum to stem borers. Prof. K.N. Saxena, program leader, Crop Test Research Program, International Centre of Insect Physiology and Ecology, Nairobi, Kenya.

Viruses as insect pest control agents with special reference to the tropics. Dr. P. F. Entwistle, Institute of Virology, Oxford, UK.

Weather data generation. Ir. D. Jansen, collaborative research fellow, Multiple Cropping Department (IRRI-SARP Project).

Gene transfer techniques in higher plant. Dr. J. Schell, Max Planck Institut fuer Zuechtungsforschung, Federal Republic of Germany.

Weather-related variability in potential production of rice. Ms. C. H. Reyes.

Development of a comprehensive classification for rice ecosystems. Ms. E. Bowles, affiliate research fellow, Rainfed Environments, Multiple Cropping Department.

Staff changes

January

Dr. Anil Deolalikar, Department of Economics, Harvard University, USA, joined IRRI as visiting scientist in the Agricultural Economics Department.

Dr. Kiyoshi Takahashi, visiting scientist, Plant Physiology Department, left after completion of his assignment.

Dr. Guy J. D. Kirk, former postdoctoral research assistant, Department of Plant Sciences, University of Oxford, UK, joined IRRI as associate soil chemist in the Soils Department.

Dr. Monkumbo S. Swaminathan, director general, retired.

Dr. Kong Luen Heong, former senior research officer (entomologist/ecologist), Central Research Laboratories, MARDI Serdang, Malaysia, joined the Institute as associate entomologist in the Entomology Department.

February

Dr. Klaus Lampe, former senior advisor to GTZ-General Management, Federal Republic of Germany, became IRRI's new director general.

Dr. Anil Deolalikar, visiting scientist in Agricultural Economics Department, left after completing his assignment.

Dr. Donald G. Faris, coordinator, Asian Grain Legume Network, Andhra Pradesh, India, joined the Institute as visiting scientist, Rice Farming Systems Program.

March

Dr. Greg J. Wells rejoined the Institute as interim IRRI representative in Cambodia for three months in the Training and Technology Transfer Department.

Dr. Devinder Sharma, consultant, Communication and Publications Department, left after completing his assignment.

Dr. Robert E. Huke, professor of Geography at Dartmouth College, New Hampshire, USA, and Mrs. Eleanor Huke, visiting scientists, Agricultural Economics Department, left after completing their assignment.

Dr. Tsugufumi Ogawa, plant breeder, Plant Breeding Department, left after completing his assignment.

Ms. Jill Marie Sullivan, consultant, Training and Technology Transfer Department, left after completing her assignment.

April

Dr. Ryoichi Ikeda, former plant breeder, Department of Rice Research, Tohoku National Agricultural Experiment Station, Ministry of Agriculture, Forestry and Fisheries, Japan, joined IRRI as plant breeder, Plant Breeding Department.

May

Dr. Clive W. F. Lightfoot, former research fellow, Cornell University, joined IRRI as visiting scientist, the Rice Farming Systems Program.

Ms. Vrinda Kumble of the Editorial Consultant Services, New Delhi, India, joined IRRI as visiting editor in the Communication and Publications Department.

Dr. Greg J. Wells, interim IRRI representative in Cambodia, left after completing his assignment.

June

Dr. Lloyd R. Bostian, professor, Department of Agricultural Journalism, University of Wisconsin-Madison, joined IRRI as visiting scientist in the Communication and Publications Department.

Dr. Bert J. Hoff, visiting scientist, Plant Breeding Department, left after completing his sabbatical leave.

Dr. Donald G. Faris, visiting scientist, Rice Farming Systems Program, left after completing his assignment.

Ms. Vrinda Kumble, visiting editor, Communication and Publications Department, left after completing her assignment.

July

Dr. James A. Litsinger, entomologist, Entomology Department, left for a one-year study leave

at the Oregon State University, Corvallis, Oregon, USA.

Ms. Jill Marie Sullivan rejoined IRRI as consultant on the IRRI-Cambodian Project in the Training and Technology Transfer Department for six months.

Dr. Yujiro Hayami, professor of Economics, School of Politics, Economics and Business, Aoyama Gakuin University, Japan, joined IRRI as visiting scientist in the Agricultural Economics Department.

Dr. Peter A. C. Ooi, senior entomologist, CAB International, Institute of Biological Control, Malaysia, joined IRRI as visiting scientist in the Entomology Department.

Dr. John Hardie, Office of Planning and Evaluation, International Development Research Centre, joined IRRI as consultant in the Director General's Office.

Dr. Nimal F. C. Ranaweera, Agricultural Economics Department, was appointed associate visiting scientist in the Agricultural Economics Department.

Dr. Nicolas Mateo, associate visiting scientist, Rice Farming Systems Program, left after completing his sabbatical leave.

Dr. John C. Flinn, agricultural economist and head, Agricultural Economics Department, left for a one-year study leave at Harvard University, USA.

Dr. Joseph K. Campbell, visiting agricultural engineer and acting department head, Agricultural Engineering Department, left after completing his assignment.

August

Dr. Graeme R. Quick, former director of Agricultural Engineering, New South Wales Department of Agriculture, Australia, joined IRRI as agricultural engineer and head of the Agricultural Engineering Department.

Dr. Lloyd R. Bostian, visiting scientist, Communication and Publications Department, left after completing his assignment.

Dr. Virgilio R. Carangal, agronomist and head, Rice Farming Systems Program, left for a one-year study leave at the Oregon State University, USA.

Dr. Hiroyuki Hibino, plant pathologist, Plant Pathology Department, left afer completing his assignment.

Dr. Yujiro Hayami, visiting scientist, Agricultural Economics Department, left after completing his assignment.

Dr. William P. Gormbley joined IRRI as consultant to the Director General, and left on 27 August after completing his assignment.

Dr. Jean-Claude Prot, ORSTOM scientist, joined IRRI as visiting scientist in the Plant Pathology Department.

September

Dr. B. Merle Shepard, entomologist and head, Entomology Department, resigned.

October

Mr. Sean E. O'Connor, computer hardware coordinator, Computer Services Department, resigned.

Dr. Manuel S. Rosero, IRRI liaison scientist for Latin America, left after completing his assignment.

November

Dr. Harry J. Nesbitt joined IRRI as agronomist and team leader, IRRI-Cambodia Project.

Dr. Hisatoshi Kaku, senior researcher, Tropical Agriculture Research Center, joined IRRI as visiting scientist in the Plant Pathology Department.

Dr. Shigemi Akita, plant physiologist, Plant Physiology Department, left after completing his assignment.

December

Dr. John Hardie, consultant to the Director General, left after completing his assignment.

Dr. William P. Gormbley joined IRRI as consultant to the Director General and left on 17 December after completing his assignment.

Dr. Ram Chet Chaudhary, former rice specialist, Federal Agricultural Coordinating Unit, Regional Office, Federal Department of Rural Development, Nigeria, joined IRRI as plant breeder, IRRI-Cambodia Project.

Ms. Jill Marie Sullivan, consultant, Training and Technology Transfer Department, left after completing her assignment.

Dr. Peter A. C. Ooi, visiting scientist, Entomology Department, left after completing his assignment.

Dr. Robert E. Huke, professor of Geography at Dartmouth College, New Hampshire, USA, and Mrs. Eleanor Huke joined IRRI as visiting scientists in the Agricultural Economics Department.

Dr. Keith Moody, agronomist, Agronomy Department, left for a one-year study leave at the University of Hawaii at Manoa.

Dr. Ram K. Pandey, visiting scientist, Rice Farming Systems Program, left after completing his assignment.

Finances

Summary of financial support to IRRI core and to special and collaborative projects received in 1988.[a]

	Amount (US$)			
	Core		Special and collaborative projects	Total
	Unrestricted	Restricted		
Details of sources of support from grants				
Asian Development Bank			450,600	450,600
Australia	629,644		966,378	1,596,022
Belgium			135,235	135,235
Canadian International Development Agency	1,482,421		20,085	1,502,506
Denmark	405,175		142,092	547,267
European Economic Community		2,050,830		2,050,830
Finland	249,180			249,180
France		206,120		206,120
Federal Republic of Germany	564,462	169,339	53,262	787,063
India	**111,921**			111,921
International Bank for Reconstruction and Development	1,950,000			1,950,000
International Development Research Centre		79,459	427,569	507,028
International Fund for Agricultural Development			2,117	2,117
Iran			83,065	83,065
Italy	**387,402**	**800,000**	220,000	1,407,402
Japan		5,691,103	2,049,564	7,740,667
Republic of Korea Office of Rural Development			98,000	98,000
The Netherlands		150,756	110,974	261,730
Norway	127,684			127,684
Organization of Petroleum Exporting Countries			108,671	108,671
Philippines	**137,196**		28,951	166,147
Rockefeller Foundation		**136,600**	249,183	385,783
Spain	29,990			29,990
Stabilization Mechanism Fund (CGIAR)	1,150,000			1,150,000
Sweden	552,787		21,959	574,746
Swiss Development Cooperation		**671,282**		671,282
United Kingdom Overseas Development Administration	1,546,396		21,600	1,567,996
United Nations Development Programme		**1,815,200**		1,815,200
United States Agency for International Development		**4,128,028**	1,757,856	5,885,884
Miscellaneous research grants			66,782	66,782
Funds reimbursed under collaborative research program				
Food and Agriculture Organization			23,000	23,000
International Center of Insect Physiology and Ecology		**44,926**		44,926
International Fertilizer Development Center			45,086	45,086
International Food Policy Research Institute			107,393	107,393
United States Department of Agriculture/University of Minnesota			9,080	9,080
University of Giessen			35,030	35,030
University of Hamburg			23,610	23,610
Total	9,324,258	15,943,643	7,257,142	32,525,043

[a] Receipts are accounted for on a cash basis. Amounts shown in boldface differ from 1988 pledges from grantors in that they may reflect 1987 or 1989 pledges received in 1988, or may not reflect the full amount of 1988 pledges that are anticipated to be received in 1989. Also, the Government of France (through the research organizations ORSTOM and IRAT) provided IRRI the services of four resident scientists; the value of their services cannot be quantified.

Weather summary

The 1988 annual rainfall totals were 2,465 mm for the dryland (upland) site and 2,458 mm for the wetland (lowland) site (Table 1). These values were 394 mm higher than normal for the dryland site and 437 mm higher than normal for the wetland site. A 2-mo dry period occurred in February and March (Fig. 1). The longest dry spell experienced was 14 d (26 Nov to 9 Dec). The longest wet spell, 13 d, occurred from 1 to 13 October at the dryland site. Because of 3 tropical storms—Seniang, Toyang, and Unsang—October was exceptionally wet, with 791 mm rainfall at the dryland site and 811 mm at the wetland site.

The average solar radiation was 16.1 MJ/m^2 per d at the dryland and wetland sites (Table 1). Solar radiation was highest in May—20.9 MJ/m^2 per d at the dryland site and 20.3 MJ/m^2 per d at the wetland site. Lowest solar radiation was in October (10.6 MJ/m^2 per d) at the dryland site and in November (10.5 MJ/m^2 per d) at the wetland site.

The average daily temperatures were 31.7 °C maximum and 23.7 °C minimum at the dryland site, and 30.9 °C maximum and 23.6 °C minimum at the wetland site (Table 1).

Windspeed measured at 2 m above the ground was highest in December (2.0 m/s) at both the dryland and wetland sites (Table 1). The lowest windspeed was in August and September, with 1.0 m/s at the dryland site and 0.9 m/s at the wetland site.

Total evaporation from the class A pan was 1,698 mm at the dryland site and 1,607 mm at the wetland site (Table 1, Fig. 2).

Of the 20 tropical cyclones that passed through the Philippine area of responsibility during 1988, 9 affected Los Baños. Of five destructive typhoons, four affected Los Baños, namely Biring (29 May-3 Jun), Unsang (21-26 Oct), Welpring (1-5 Nov), and Yoning (5-8 Nov).

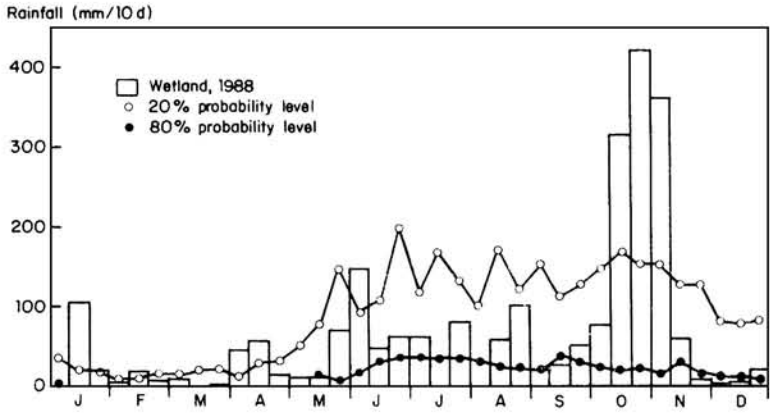
Monthly weather data are summarized in Table 1 for the dryland site, the wetland site, and eight outreach and cooperating stations in the Philippines during 1988.

Table 1. Monthly weather data for IRRI outreach and cooperating stations in the Philippines, 1988.[a]

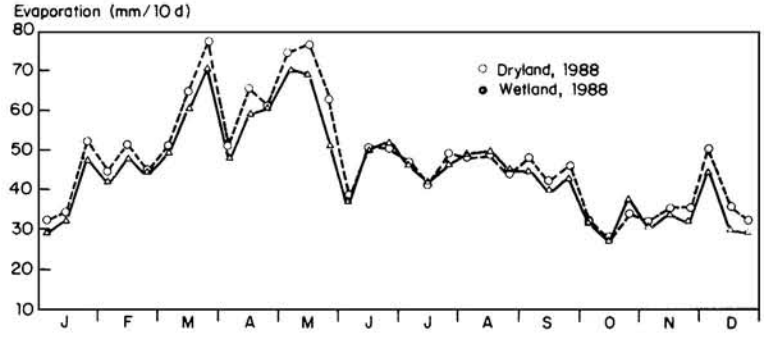
Item	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual total or daily average
							Rainfall (mm/mo)						
Banaue (16°58'N, 121°02'E)	238	336	118	196	255	245	433	383	475	698	313	78	3768
Betinan (07°54'N, 123°27'E)	32	57	84	117	224	495	315	308	393	328	269	84	2706
Cavinti (14°17'N, 121°30'E)	517	273	64	495	209	366	393	409	231	1367	813	198	5335
Claveria (08°38'N, 124°55'E)	33	72	66	63	70	154	180	193	242	549	256	103	1981
Guimba (15°39'N, 120°47'E)	1	2	0	14	127	236	439	220	131	406	84	8	1668
IRRI-Dryland (14°13'N, 121°15'E)	234	26	6	136	73	226	227	183	80	791	452	31	2465
IRRI-Wetland	221	29	10	113	93	256	183	190	101	811	422	30	2458
MRRTC (15°45'N, 120°56'E)	8	31	0	27	86	217	428	211	300	438	62	9	1817
Solana (17°39'N, 121°41'E)	80	61	12	62	93	47	196	174	99	214	193	84	1315
Visayas Experiment Station (10°32'N, 122°34'E)	22	27	14	111	151	414	342	223	236	462	319	40	2361
							Evaporation (mm/mo)						
Banaue	88	84	129	114	130	127	131	126	107	80	66	49	1231
Betinan	132	108	100	140	110	112	114	114	125	117	113	102	1387
Cavinti	105	119	178	163	172	127	137	136	115	77	91	88	1508
Claveria	154	128	178	176	186	132	142	138	131	129	121	106	1721
Guimba	162	164	190	203	195	169	152	143	134	116	148	165	1942

IRRI-Dryland		117	139	192	176	212	138	136	142	136	92	101	117	1698
IRRI-Wetland		108	132	180	166	189	137	133	142	127	96	95	102	1607
MRRTC		164	176	209	178	175	158	175	166	152	111	140	154	1958
Solana		112	105	187	176	214	205	176	175	156	115	82	83	1786
Visayas Experiment Station		159	166	192	172	178	123	153	161	131	109	127	128	1799
							Temperature (°C)							
Banaue	Max	23.5	23.3	26.3	26.3	28.1	27.1	27.1	27.5	26.6	24.7	23.4	20.5	25.4
	Min	16.9	16.6	17.0	18.3	19.5	19.4	18.8	19.0	19.3	19.2	17.4	14.1	18.0
Betinan	Max	33.2	33.1	34.0	32.2	31.5	30.4	29.2	31.1	30.4	29.6	30.6	30.4	31.3
	Min	21.3	22.0	22.6	22.9	23.3	22.5	22.0	22.1	22.1	22.0	22.0	20.8	22.1
Cavinti	Max	26.7	27.1	28.9	29.8	31.0	30.1	29.4	29.9	29.9	27.5	26.0	24.5	28.4
	Min	20.5	20.1	20.1	21.0	22.1	22.3	22.1	21.9	20.4	20.6	19.5	15.6	20.5
Claveria	Max	29.0	28.3	29.6	29.7	30.2	28.8	28.4	28.1	28.7	28.4	27.7	25.9	28.6
	Min	20.9	20.9	21.1	22.4	22.5	22.1	21.7	21.7	21.4	21.3	21.3	20.2	21.5
Guimba	Max	33.4	33.3	34.5	36.5	37.0	33.5	33.6	33.3	33.2	31.4	31.6	30.7	33.5
	Min	20.7	21.1	20.5	22.8	23.8	23.3	23.6	24.0	23.7	23.5	22.2	19.1	22.4
IRRI-Dryland	Max	30.3	31.5	32.8	33.1	35.1	32.4	31.9	32.6	32.7	30.1	29.4	28.6	31.7
	Min	23.3	22.7	23.0	24.5	25.4	24.3	24.2	23.9	23.9	23.6	23.8	21.8	23.7
IRRI-Wetland	Max	29.5	30.5	31.2	32.3	33.8	31.8	31.6	32.0	32.1	29.6	28.8	27.3	30.9
	Min	23.2	22.6	22.7	24.3	25.2	24.3	24.2	23.9	24.0	24.0	23.6	21.2	23.6
MRRTC	Max	31.8	31.4	32.2	32.6	33.3	31.8	31.5	32.0	32.7	30.1	31.1	30.0	31.7
	Min	22.2	22.7	22.2	23.9	24.8	24.3	25.0	24.6	24.1	23.6	22.4	20.1	23.3
Solana	Max	29.1	29.6	32.8	33.5	36.3	35.0	33.8	33.8	33.7	30.2	27.5	25.7	31.8
	Min	22.5	21.6	22.5	23.6	24.8	24.6	24.3	24.5	24.4	24.3	22.4	19.3	23.2
Visayas Experiment Station	Max	31.3	31.9	33.8	34.4	34.2	31.3	31.5	31.8	32.1	30.2	30.5	29.5	31.9
	Min	23.9	24.0	24.3	25.1	25.7	24.5	24.3	24.6	23.8	23.0	22.8	22.5	24.0
							Solar radiation (MJ/m^2)							
Banaue		14.7	14.7	20.8	18.0	19.4	19.3	19.6	19.6	16.8	11.5	11.9	11.7	16.5
Betinan		17.1	13.5	13.8	M	M	M	M	M	M	M	M	M	M
Cavinti		14.7	18.3	21.0	19.3	19.7	16.1	M	M	12.5	7.4	6.4	M	15.0
Claveria		19.0	16.0	20.0	20.9	20.9	17.2	18.6	17.4	20.0	17.3	17.8	14.2	18.3
Guimba		22.4	25.1	26.7	26.7	24.6	23.9	22.9	22.0	24.3	17.6	21.5	20.6	23.2
IRRI-Dryland		13.9	17.6	20.0	19.1	20.9	17.0	16.6	17.9	17.1	10.6	11.0	11.8	16.1
IRRI-Wetland		13.9	18.3	20.3	19.2	20.3	17.0	16.7	17.8	16.8	10.6	10.5	11.5	16.1
MRRTC		22.0	24.7	26.6	27.5	24.7	23.6	24.1	26.0	25.4	19.1	20.3	20.1	23.7
Solana		11.4	10.6	21.0	18.8	20.8	21.3	19.0	20.7	17.9	14.4	11.3	10.4	16.5
Visayas Experiment Station		18.0	19.7	21.7	21.1	19.0	15.8	17.1	18.7	16.6	14.4	15.4	14.8	17.7
							Windspeed (m/s)							
Banaue		0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.5	0.4	0.5	0.4	0.3	0.5
Betinan		0.7	0.7	0.9	0.9	0.7	0.6	0.6	0.7	0.7	1.0	0.8	0.7	0.8
Cavinti		2.2	2.1	2.1	2.0	1.7	1.5	1.5	1.1	0.8	1.4	3.0	3.0	1.9
Claveria		1.3	1.2	1.4	1.4	1.3	1.1	1.0	0.8	0.8	1.0	0.6	0.4	1.0
Guimba		2.3	1.8	1.2	1.9	1.6	1.1	0.9	0.8	0.6	1.4	2.3	3.0	1.6
IRRI-Dryland		1.5	1.5	1.5	1.5	1.7	1.4	1.3	1.0	1.0	1.4	1.9	2.0	1.5
IRRI-Wetland		1.4	1.4	1.6	1.4	1.5	1.3	1.1	0.9	0.9	1.2	1.8	2.0	1.4
MRRTC		M	M	M	M	M	M	M	M	M	M	M	M	M
Solana		0.7	0.9	1.0	1.0	1.1	1.1	1.0	0.9	0.8	0.8	0.8	0.9	0.9
Visayas Experiment Station		1.3	1.6	1.9	M	1.2	1.0	1.1	0.7	0.7	1.4	1.8	1.5	1.3

[a] M = missing data.



1. Rainfall and rainfall probability at 20 and 80% levels by 10-d period. IRRI, 1988.



2. Evaporation by 10-d period. IRRI, 1988.

- Genetic evaluation and utilization (GEU) program
- Management of rice pests
- Water management
- Soil and crop management
- Climatic environment and rice
- Consequences of new technology
- Cropping systems program
- Engineering technologies
- Training programs
- International collaboration

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