THE INTERNATIONAL RICE RESEARCH INSTITUTE

ANNUAL REPORT FOR 1974

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THE INTERNATIONAL RICE RESEARCH INSTITUTE
LOS BAÑOS, LAGUNA, PHILIPPINES P.O. BOX 933, MANILA, PHILIPPINES.

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About this report

This thirteenth annual report covers the work accomplished during the 1974 calendar year. The various sections of the report deal with the interdisciplinary approach to problem areas.

The department (or departments) which performed the research is (or are) identified in italics in parentheses following the topic heading, i.e., "Machinery Development and Testing" *(Agricultural Engineering Department).* In those cases where more than one department cooperated in a particular major problem area, where only one of the departments carried out one phase of the research, the department is identified in italics following the name of this subtopic. For example, the departments of Agronomy, Agricultural Economics, and Statistics cooperated in a major project "Quantifying Effects of Biological Inputs" *(Agronomy, Agricultural Economics, and Statistics Departments),* and where the Statistics Department bore single responsibility for one phase of this effort, the name of that department follows the subtopic thus, 'Management package experiments at IRRI' *(Statistics).*

Data in the report are given in metric units, e.g. "t/ha" means metric tons per hectare. Unless otherwise stated, "control" means untreated control, grain yield is calculated as rough rice at 14 percent moisture, and protein content is calculated as a percentage of brown rice at 14 percent moisture. A single asterisk (*) means significant at the 5-percent level, a double asterisk (**) means significant at the 1% level, *but* if value for a control is given, a single asterisk means significantly different from the control at the 5% level and a double asterisk means significantly different from the control at the 1% level.

The system for indicating pedigrees uses a slant bar (/) rather than the multiplication sign (×). For example IR22 × IR24 is now written IR22/IR24. The sequence of crosses is indicated by the number of slant bars: (IR22 × IR24) × CR94-13 is now written IR22/IR24//CR94-13. The fourth and further crosses are designated /4/, /5/, and so on. Backcrosses are indicated by a superscript numeral.

The report frequently mentions three fundamental types of rice culture. Upland culture means rice grown without irrigation in fields without bunds. Rainfed paddy culture means rice grown without irrigation but in fields that are bunded, to impound rainfall. Irrigated or flooded culture means rice grown with irrigation in bunded fields.

A detailed table of contents is furnished at the beginning of each major section, in addition to the general table of contents at the beginning of the report. The thumb index on the back cover provides quick access to each section. To use it, bend the book in half and follow the margin index to the page with the black-edge marker.

4×10^9

Sometime in 1975, a mother will give birth to a very significant child – our planet's 4-billionth human being. The earth's population will then be on its way to the 5-billion level, expected in the mid-1980's. Even if family planning programs cut the birth rate thereafter to two children per family, the 6-billionth person will arrive well before the year 2000.

The 4-billionth child will likely be born in Asia, where more than half of the world's people already live, and will probably eat rice, the region's staple food. Millions of others in Africa and Latin America also depend on this crop for much of their nutrition.

The exploding population rate grimly dictates the world's food requirements, especially for rice. For the rice-growing countries are already the most crowded in the world, and their rates of population growth are among the highest.

A truly formidable challenge faces those involved in the worldwide struggle to produce more rice. In Asia alone, farmers must produce 5 million more tons of rice in 1975 than in 1974, even to maintain the current meager per-capita consumption. This annual increase in demand is about *1½ times the total annual rice production of the world's largest exporter, the United States.*

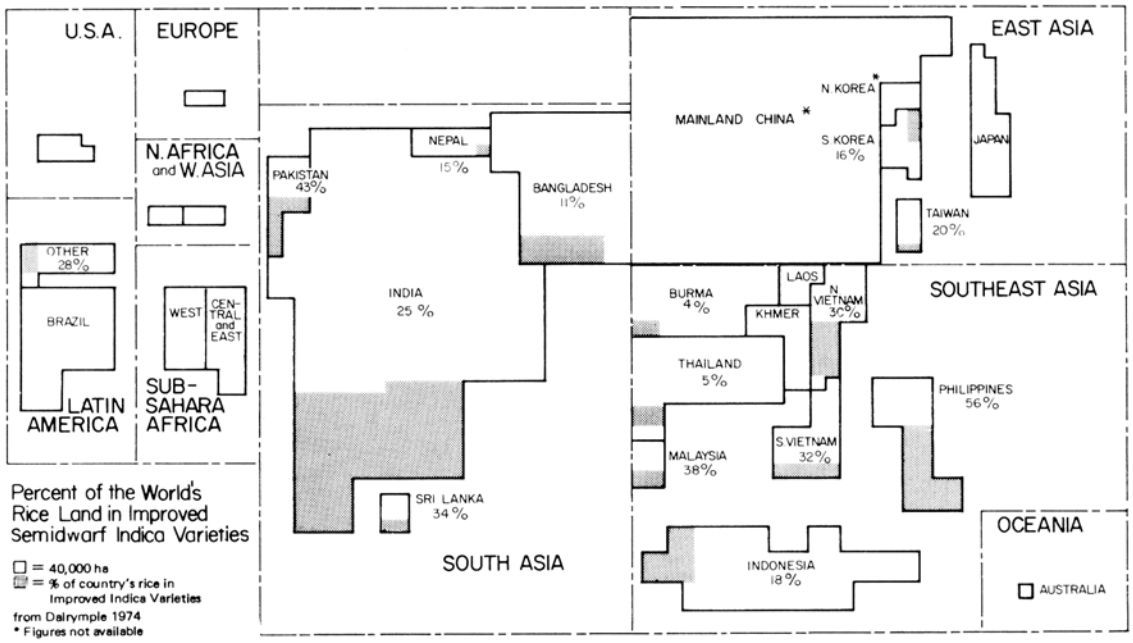
Over the next decade, worldwide rice production must increase by at least 30 percent just to maintain current (and inadequate) levels of consumption. Otherwise, chances are high for widespread hunger and even famine.

Most of the extra rice must be produced without bringing more land into cultivation, because most arable land is already being farmed in the rice-growing nations.

To the casual observer, the change in the global food outlook is surprising. The new rice and wheat varieties in the 1960's seemed to many a panacea. The term "green revolution" was coined to describe how the new "miracle" seeds could free the world from the ugly specter of hunger. To many, man seemed well on his way to solving his oldest problem, food production.

But the drougnts, floods, and pest epidemics of the early 1970's, combined with a steady increase in population, awakened the world to the fact that the struggle to produce food had just begun. Remarkable as the new rices were, they would not grow equally well under all growing conditions. In fact, these modern varieties were quite unsuitable for vast regions of deep water, drought, injurious soils, and cold temperatures. This partly explains why today, farmers use the improved seeds in only about a fourth of the world's rice-growing areas (fig. 1).

The major thrust of rice scientists in the next decade must be to develop improved rices and associated technology for small farmers in regions of adverse ecological conditions, to help them produce more food from limited land.



1. About 25 percent of the world's rice land is now planted to improved rice varieties. Scientists hope to extend the Green Revolution by developing improved varieties and technologies for the other regions.

The role of science and technology

During the past year, we at IRRI have given considerable thought to how we can more effectively help the world's small farmers increase their rice production.

We know that farmers have adopted the new varieties on only about a fourth of the world's rice land. Even in some countries where the new rices are widely grown, rice production has increased far less than anticipated.

We also know that on a substantial portion of the world's rice land – estimates range from half to three-fourths – farmers can't increase production much because no improved varieties and technology are available that are suited to their areas.

We have concluded that to be more effective, we must take three steps:

First, we must *work closely with farmers to determine their constraints.* We must find out why they have not adopted the new technology, or if they have adopted it, why their yields are so low;

Second, we must organize our internal research and training programs to encourage *interdisciplinary attacks on farmers' problems* in the field; and

Third, we must better *couple* our research and development programs with those of cooperating scientists and educators in the rice-growing countries, *for theirs is the ultimate task of developing and adapting the technology needed to feed a hungry world.*

We made some progress in each of these areas in 1974. These efforts complemented the traditional flow of new varieties and technology from the fields, greenhouses, and laboratories of the Institute.

IDENTIFYING FARMERS' YIELD CONSTRAINTS

In 1974, we intensified and expanded our research to better understand what prevents small farmers from producing yields as high as we know are attainable with the new technology.

We are concerned with both bio-physical and socioeconomic factors (fig. 2). The bio-physical aspect of the yield gap indicates *what* inputs are missing. It measures the extent to which yields would increase if farmers would use improved varieties, apply optimum levels of fertilizers and pesticides, correct soil problems, and use the best cultural practices. The socioeconomic analysis indicates *why* the farmer may not be using the bio-physical technology. Reasons may include input costs, market prices, inadequate knowledge, inadequate credit, or traditional beliefs.

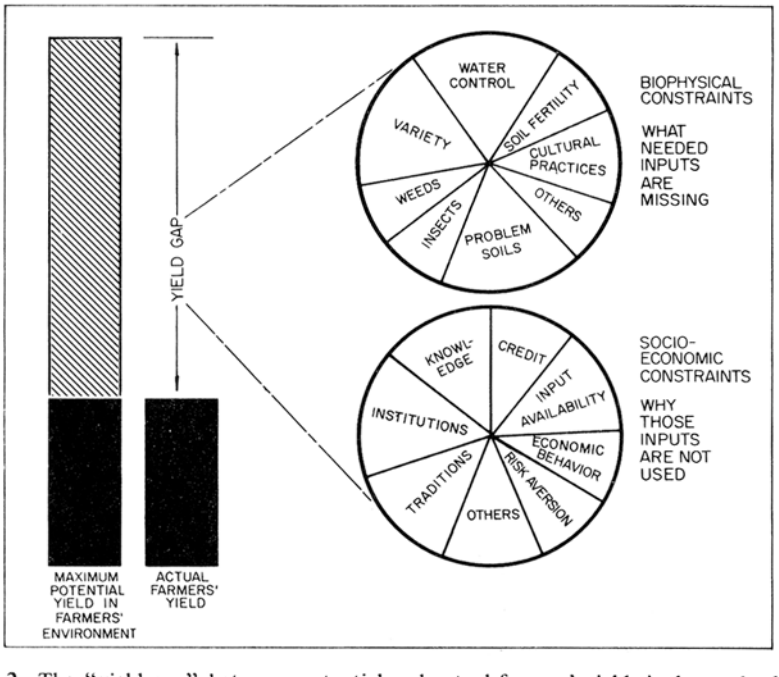
Because the yield-gap factors differ from area to area, an important aspect of our program is developing and sharing reliable research methodology to help local scientists in many nations identify local production constraints, so they can then overcome them.

Our research shows that diseases and insects are obviously major constraints to rice yields. In six experiments on farmers' fields in Laguna province, Philippines, for example, insect damage reduced yields by an average of almost 1.7 t/ha (Table 1).

Other major constraints are inadequate water and weed control, and inadequate fertilizer use.

INTER-DISCIPLINARY RESEARCH

We continued to develop and formalize *interdisciplinary* team attacks on rice production problems in 1974. Our reasoning is simple: the problems that face small farmers are varied and complex. No single discipline – nor any single research institution – has the ability to tackle them. Only a team effort, each scientist contributing his specialized knowledge and skills, can produce the wide range of varieties and technology needed to really intensify food production.



2. The "yield gap" between potential and actual farmers' yields is due to both biophysical and socioeconomic constraints.

Table 1. Comparative yield constraints from each of three inputs when the other inputs were held at farmers' level or at a high level (average of 6 locations). Laguna province, Philippines, 1974 dry season.

Level of other inputs	Increase (t/ha) from		
	Insect control	Weed control	Fertilizer
Farmers' level	1.68**	0.23	0.91**
High level	1.04**	0.50	0.66**

**Highly significant increase.

Our two largest teams are those concerned with the Genetic Evaluation and Utilization (GEU) program and with the Cropping Systems program. Together, they account for more than half of IRRI's total research and training efforts. The GEU program illustrates how the approach is being used.

Genetic Evaluation and Utilization (GEU) Program. The GEU program is an interdisciplinary rice improvement effort, linked with similar national programs in Asia, Africa, and Latin America, to jointly develop and evaluate improved rices and technology for all rice-growing areas. The GEU program builds on the success of the semidwarf varieties that have so remarkably increased production in those areas where farmers are assured of water control and adequate chemical inputs.

Despite these productivity increases, the Green Revolution technology has bypassed many other less prosperous areas. The semidwarf rices developed at IRRI are unsuitable for many vast "deep water" regions of Thailand, Bangladesh, India, Burma, Indonesia, and Vietnam. Similarly, high-yielding rices are needed for the salty soils of coastal marshes and of irrigated land in arid regions, and for the drought-prone regions where upland rice is grown. The improved rices developed for all areas must be resistant to major insects and diseases.

The GEU teams. Through the GEU program, nine interdisciplinary teams of plant breeders and problem-area scientists, such as pathologists, entomologists, agronomists, and soil chemists, are working together to develop rices that are genetically adapted to each of the major types of growing conditions in which rice is produced.

The problem areas for which GEU teams are seeking improved rices are:

- agronomic characteristics;
- resistance to insects;
- resistance to diseases;
- resistance to drought;
- tolerance to adverse soils;
- tolerance to deep water and floods;
- tolerance to extreme temperatures (cold or hot);
- grain quality; and
- higher levels of protein

To develop improved rices, each team first identifies varieties that can withstand the major constraints to rice production within its specific problem area. Through crossbreeding, they develop large numbers of experimental lines that are resistant or tolerant to these constraints, and that have other favorable characters as well (particularly high and stable yield potential and pest resistance).

Each team member brings his specialized background knowledge into the breeding and evaluation program.

The drought-tolerance team, for example, consists of geneticists, plant breeders,

agronomists, and plant physiologists; it works closely with the disease- and insect-resistance teams. In much the same manner that pest-resistant varieties were developed, the drought team is now screening, breeding, and testing to develop rices that can withstand moisture stress. They determine the abilities of traditional Asian and African varieties to survive drought, and cross them with other rices of higher yield potential. They promptly make promising lines available to cooperating scientists in regions of drought to evaluate in rigid screening trials.

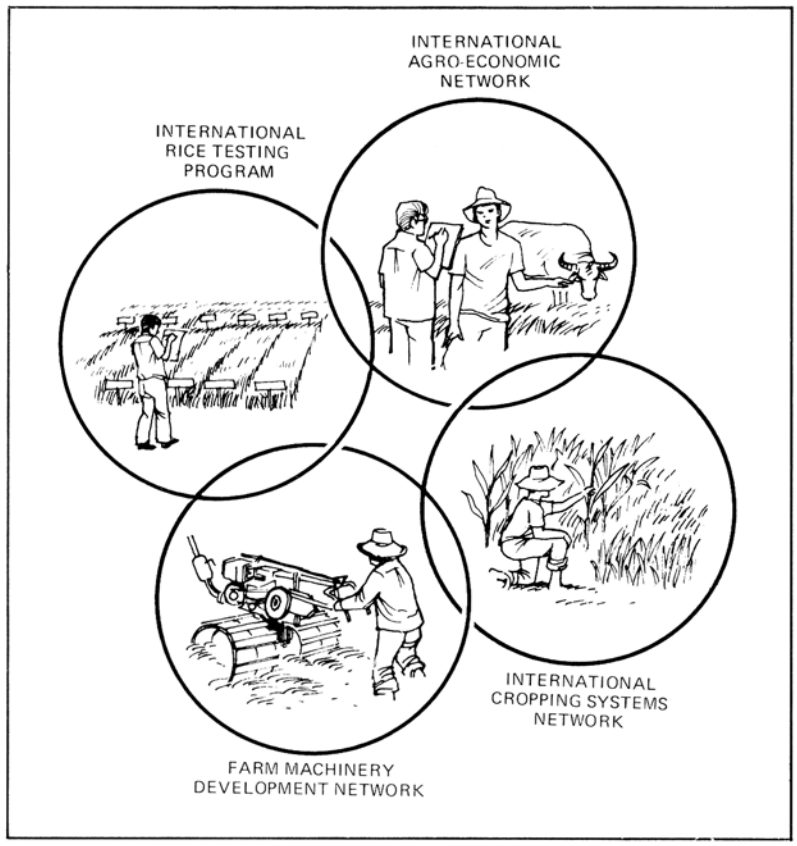
NETWORKS

The third major thrust at IRRI is to initiate and expand international networks, uniting the research and development efforts of scientists from a number of cooperating countries.

Four such collaborative networks have been established among cooperating biological and social scientists across the rice-growing world: 1) the International Rice Testing Program, which is the evaluation component of an international GEU effort; 2) the International Agro-Economic Network; 3) the International Cropping Systems Network; and 4) the Agricultural Machinery Development Network (fig. 3).

International Rice Testing Program (IRTP). Elite rices generated by the GEU program and by national rice improvement programs are evaluated under a worldwide range of environmental conditions through the IRTP (fig. 4).

Each national program can nominate its best parent materials, breeding lines, and



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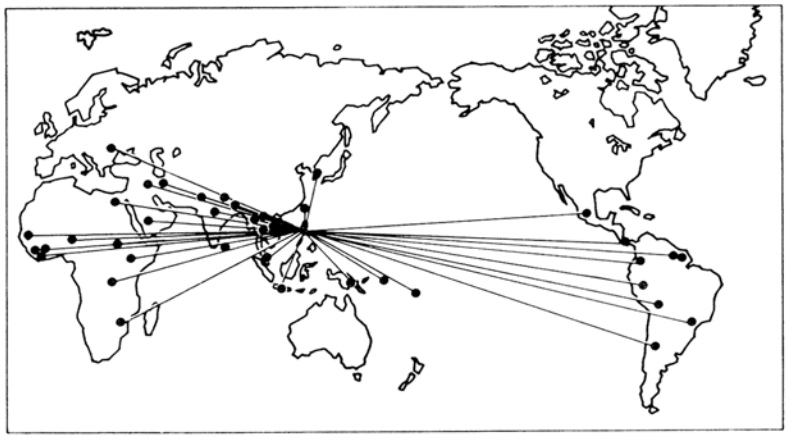


4. Elite rices developed through national programs and through IRRI's Genetic Evaluation and Utilization program are evaluated in about 40 nations through the International Rice Testing Program.

varieties for global evaluation in the 12 yield and/screening nurseries (Table 2). Additional problem-area nurseries may be initiated as the need arises.

Worldwide testing shows how different rices react to diverse pests, diseases, and environmental conditions, and speeds up the identification of rices with yield stability. It spreads new germ plasm to broaden the genetic base of the world's rice crop.

The operation of the program is quite simple. IRRI, as IRTP coordinator, receives seeds of varieties or lines that cooperators in national centers have nominated for inclusion in the program. We multiply the seed and then compile it into sets, which are distributed to cooperators in country programs. The field tests are run by scientists in national programs who are familiar with local environmental conditions and with the habits, customs, and resources of local farmers.

Table 2. Nurseries in the International Rice Testing Program (IRTP).

YIELD:
International Rice Yield Nursery – early-maturing (IRYN-Early)
International Rice Yield Nursery – medium-maturing (IRYN-Medium)
International Upland Rice Yield Nursery (IURYN)

SCREENING:

Observational:
International Rice Observational Nursery (IRON)
International Upland Rice Observational Nursery (IURON)

Disease:
International Rice Blast Nursery (IRBN)
International Rice Sheath Blight Nursery (IRSHBN)
International Rice Tungro Nursery (IRTN)

Insect:
International Rice Brown Planthopper Nursery (IRBPHN)
International Rice Gall Midge Nursery (IRGMN)

Other Stresses:
International Rice Salinity Tolerance Observational Nursery (IRSTON)
International Rice Cold Tolerance Nursery (IRCTN)

These scientists evaluate and record how each rice yields and how each reacts to adverse biological factors, such as diseases, drought, or cold. Results are used within each national program, and duplicate sets of data from all locations are sent to IRRI to be rapidly analyzed, compiled, published, and distributed. Rice scientists around the world then study the information, select the best materials for their programs, and request seed.

The program's effectiveness is largely determined by the way that cooperators use the germ plasm and test information to strengthen their national programs.

International Rice Agro-Economic Network (IRAEN). IRRI is collaborating with scientists in several rice-growing countries to develop methodology to monitor problems that slow down the farm adoption of improved rice varieties and technology through the IRAEN.

Economists and agronomists in Indonesia, Thailand, and the Philippines are coordinating research through the IRAEN. They conduct experiments on farmers' fields, survey farmers to determine biological and socioeconomic constraints, analyze markets and input prices, and relay their findings back to scientists in national research programs and at IRRI. Other nations are expected to participate in future research.

The agro-economic teams are trying to determine answers to such problems as why rice production has substantially increased in many regions where the new varieties are planted, but not in others.

Or, why many farmers who have accepted the new rice varieties do not use accompanying chemical inputs and cultural practices. These farmers' yields may have increased, but they still lag far behind potential yields proved possible in experiments.

Once answers are determined, the scientists can then tailor research to develop the varieties and technology to overcome the production constraints.

The network is a step toward an international system through which scientists can continuously monitor the adoption of improved rice technology, and can devise strategies to speed adoption. From the knowledge gained through the network, sceintists will evaluate the probable impact of alternative research and development strategies.

The International Agro-Economic Network has the following objectives:

- to develop and use procedures to identify the physical, social, and economic factors that influence the adoption and efficient use of improved rice technology;
- to define and, where practical, test alternative strategies for alleviating constraints and increasing rice production;
- to develop and use procedures to assess the distribution of benefits of the new technology (what impact the technology has on income, income distribution, and employment among various classes of farmers and agricultural laborers);
- to undertake collaborative research in cooperating nations;
- to help train researchers in national programs to identify constraints that hold down the yields in their own countries; and
- to improve communication among scientists of different disciplines concerned with the application of new rice technology.

By cooperating in the International Agro-Economic Network, scientists hope to gain the knowledge to be able to recommend ways by which national rice improvement programs can increase their impact on small farmers' fields.

International Cropping Systems Network. Although rice is generally the stable crop of small farmers in Asia, it is seldom their only food crop. Farmers can intercrop, or follow, rice with other food crops such as corn, soybean, mung, sweet potato, cassava, or sorghum.

Through the International Cropping Systems Network, scientists are testing different cropping patterns in farmers' fields in Bangladesh, Indonesia, Vietnam, and the Philippines.

Scientists are also evaluating for intensive farming schemes, varieties of crops such as rice, sorghum, soybean, peanut, sweet potato, and cowpea.

The first priority is to develop cropping systems slanted to small farmers in upland and rainfed areas. Most of these farmers are subsistence, but research shows that their potential to produce more food can be substantially raised.

To ensure that the technology developed will be within the management capabilities of small farmers, cropping systems research trials are conducted in farmers' fields, under farmer management.

The experimental sites represent the environmental conditions of specific "agro-climatic zones," or areas of similar soil, climatic, and cultural conditions. Knowledge gained at each experimental site can then be shared and used throughout the agro-climatic zone, speeding the transfer of technology among nations.

The scientists determine the biological parameters – the growth durations, fertility requirements, and food production potentials – of different crops. Then, on the farms, they fit together compatible combinations of food crops and develop farming schemes to raise the income levels of small farmers.

Because we are studying *rice-based* farming patterns, the Cropping Systems Network must be coordinated with the GEU and with the International Rice Testing programs, and the Agro-Economic and Farm Machinery Development Networks.

Cropping patterns revolve around the best available rice varieties for each agro-climatic zone. As scientists continue to shorten the growth durations of improved rices, the farmers' potential to produce more food increases. For example, modern varieties such as IR28 and IR30 mature in 115 days – from 1 to 2 months earlier than traditional varieties. The short growing seasons leave the farmer adequate time and soil moisture during the late monsoon season to grow other crops.

Work plans for the network are developed jointly with scientists from cooperating national programs. A cropping systems working group has met at IRRI to determine common guidelines for cooperative research.

Farm Machinery Development Network. To intensify food production, farmers in the developing nations need tools and technology to speed certain production practices, such as land preparation, threshing, and drying. The need will increase as more farmers shift to short-season varieties and multiple cropping.

Much of the machinery developed for large-scale farming in the more developed countries is not suited to the needs of farmers in the rice-producing nations. The machines may be too costly and complex. Or, they may be far too large to meet the needs of farmers with less than 10 ha. Furthermore, they cannot be economically manufactured in low volume in the developing countries because they are designed for capital-intensive mass production. They are hard to service and to maintain because of difficulties in obtaining spare parts.

To help fill this technology gap, IRRI cooperates with a network of national research organizations, manufacturers, and engineers in Asia, Latin America, and Africa.

The philosophy of the network is to develop appropriate mechanization technology for small farms and to encourage local manufacture of suitable farm machines by small metalworking firms.

How the program works. IRRI scientists identify the most pressing production problems in farmers' fields and develop appropriate farm machines to overcome the production constraints.

To encourage local production, IRRI releases the designs free to cooperating manufacturers who want to produce and sell the machines.

Local manufacture of farm equipment generates employment. Equally important, indigenous production saves foreign exchange in the developing nations.

IRRI scientists maintain cooperative relationships with local manufacturers. We have found that small metalworking shops often modify the basic IRRI designs to better suit the machines to their specific local conditions.

IRRI provides ongoing technical consultation to ensure machine quality and performance.

Major research results

GENETIC IMPROVEMENT

During 1974, 14 IRRI lines were named as varieties – 11 by cooperating countries, and 3 by IRRI. This brings to at least 45 the number of varieties named from IRRI lines; 36 have been named by cooperators and 9 by IRRI.

All three of the varieties released by IRRI in 1974, IR28, IR29, and IR30, are early maturing, with resistance to major diseases and insects, good grain quality, and high yield potential (fig. 5). Because of their short growth durations, these varieties are especially suited for multiple cropping – the growing of successive crops of rice, or of rice followed by upland cash crops.

IR28, IR29, and IR30 are the first varieties that are highly resistant to grassy stunt virus, a serious disease in many countries. They inherit this resistance from *Oryza nivara,* a wild rice from India.

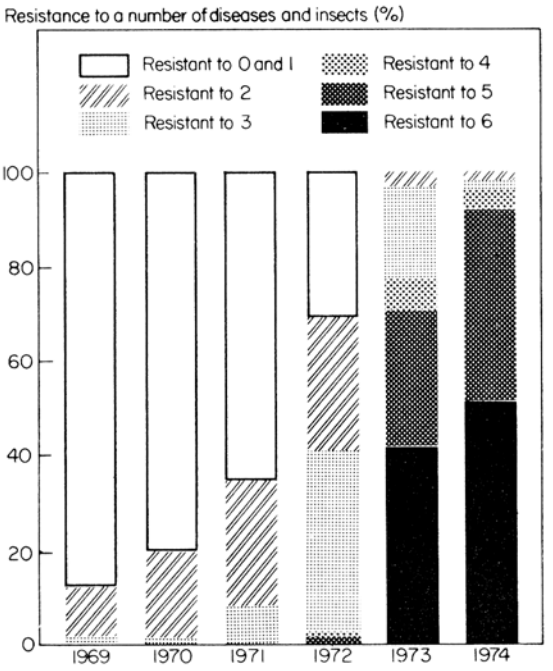
IR29 is the first IRRI variety with glutinous or waxy endosperm. It cooks soft and sticky, and can be used in special preparations, such as cakes and pastries. Glutinous rice is the staple food in Laos and northeast Thailand.

Farmer acceptance of IR26. Philippine farmers generally seem satisfied with the yielding ability and pest resistance of IR26 under field conditions. About 250,000 ha

Variety	Diseases				Insects			Soil problems			
	Blast	Bacterial blight	Grassy stunt	Tungro	Green leaf-hopper	Brown plant-hopper	Stem borer	Alkali injury	Salt injury	Zinc defi-ciency	Phos-phorus defi-ciency
IR8	MR	S	S	S	R	S	MS	S	MR	S	MR
IR5	S	S	S	S	R	S	S	S	MR	R	MR
IR20	MR	R	S	R	R	S	MR	S	MR	R	R
IR22	S	R	S	S	S	S	S	S	S	S	MR
IR24	S	S	S	MR	R	S	S	MR	MR	S	MR
IR26	MR	R	MS	R	R	R	MR	MR	MR	S	R
IR28	R	R	R	R	R	R	MR	MR	MR	R	R
IR29	R	R	R	R	R	R	MR	S	MS	R	R
IR30	MS	R	R	R	R	R	MR	MR	MR	R	MR

R = resistant MR = moderately resistant MS = moderately susceptible S = susceptible

5. IRRI's more recent varieties, IR26, IR28, IR29, and IR30, have broad resistance to major diseases and insects and to several soil problems.



6. The proportion of entries in the annual replicated yield trials with multiple resistance to insects and diseases is steadily increasing. More than 90 percent of the 1974 entries had at least moderate resistance to five or more major pests.

were planted in the Philippines during the 1974 wet season. As resistant material is widely planted, both brown planthopper populations and insecticide use for their control are declining.

At the time of its approval for cultivation in Vietnam, in late 1974, about 30,000 ha of IR26 had already been planted. IR26 is being multiplied in Indonesia, Sri Lanka, and Kerala state, India, and is being extensively tested in Burma, Bangladesh, India, Sri Lanka, and Indonesia.

IRRI lines named in other countries. Selected IRRI lines were found suited to a variety of ecological conditions and named as varieties in 1974. IR5-198-1-1 was named as ROK-6 in Sierra Leone, where it is adapted to growing under swampy lowland conditions. IR665-4-5-5 and IR841-63-5, which have long and slender grains of excellent quality, were released for cultivation in Brazil. IR747B2-6-3 and IR1614-138-3-1 were named as GPL 1 and GPL 2 in the British Solomon Islands. These two lines are resistant to brown planthoppers, a serious pest in that country. IR837-20-3-6 and IR837-46-2, two lines with excellent long and slender grains and high yield potential, were named as Redras Negras A74 and Bomoa A74 in Mexico. IR841-36-2, an early maturing line, was named Abbasi 72 in Pakistan. IR822-81-2 was released as CR1113 in Costa Rica, where it is highly resistant to blast. IR532E-208 was released for cultivation as N.G. 6637 in Papua, New Guinea. Malaysia approved for general cultivation IR5-250, a sister line of IR5 and Bahagia as SM1.

Breeding program. The crossing program was further expanded during 1974. Of the 2,849 crosses made, 1,762 were single crosses, 741 were topcrosses, and 346 were doublecrosses. We used several new sources of resistance to diseases and insects in 1974. Similarly, we crossed improved disease- and insect-resistant breeding lines with

several tall varieties that have high protein content or tolerance to drought, adverse soils, cold temperatures, or floods.

We grew F_2 populations from 316 cross combinations and grew 45,302 pedigree rows, most without chemical protection.

We evaluated the yield and protein content of 414 dry-season and 368 wet-season entries in the replicated yield trials, and of more than 1,000 breeding lines in the wet- and dry-season observational nurseries.

Progress on multiple insect and disease resistance. More than 90 percent of the lines in the 1974 replicated yield trials had at least moderate resistance to five or more of the major insects and diseases (fig. 6).

Outstanding selections with multiple resistance are being tested in various coordinated trials in the Philippines; many are also being tested in other countries through the International Rice Yield Nursery. Many sister selections of these lines have similar levels of disease and insect resistance. At least four of these lines are resistant to gall midge. Two of them, IR2153-26-3-5 and IR2153-43-2-5, are tolerant of salinity and another two, IR1702-74-3-2 and IR2070-747-6, are tolerant of iron toxicity. They vary in growth duration from 105 to 160 days. Plant statures also differ; some lines are taller than others. IR2061-213-2-17, like IR5, is of intermediate height and should be particularly adaptable to areas where farmers prefer intermediate-statured varieties.

Many of these lines are now serving as parents in the crossing programs.

Exchange of breeding lines. We continued to supply improved advanced breeding lines to scientists across the rice-growing world. We sent 11,492 packages of breeding lines to 57 countries in 1974.

EFFICIENCY OF CHEMICAL INPUTS

High prices of both fertilizers and pesticides add to the problems of all rice farmers, particularly those of low income. As a result, fertilizer use has leveled off or actually decreased. We expanded our research in 1974 to increase the efficiency of both fertilizers and insecticides so that farmers can get higher yields from lower applications.

Fertilizers. We concentrated urea in small mudballs and placed them about 10 cm deep in the soil beside newly transplanted seedlings (fig. 7). Using mudballs, we produced 8 t/ha of rice with 60 kg of nitrogen per hectare, compared with 6.6 t/ha using 100 kg N/ha when applied as a topdressing (the system generally used by farmers in the Philippines) (Table 3).

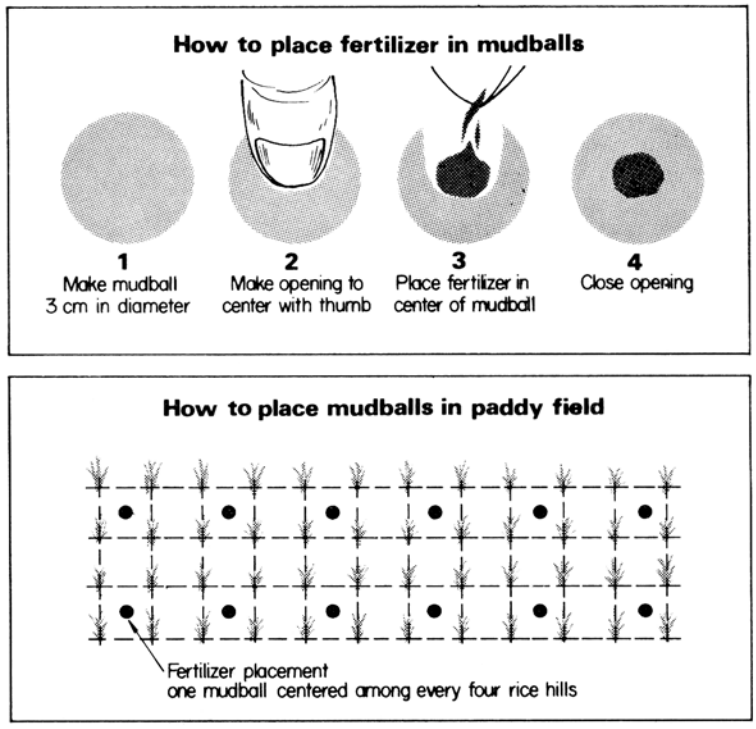
Fertilizer efficiency, or kilograms of grain produced per kilogram of fertilizer added, was considerably higher using the mudball placement technique than using the traditional topdressing or basal applications (Table 3). Concentrating the nitrogen and placing it deep enough in the paddy to prevent oxidation seems to reduce losses of this important nutrient.

The mudball technique has been tested not only at the IRRI farm but also in farmers' fields in the Philippines, and in India, Laos, Korea, and Thailand. Further tests are needed to fully exploit its practicality.

Insecticides. We further tested the root zone method of applying systemic insecticides in 1974. We used a modified grease gun to inject three insecticides into the root zone of young seedlings. Urea at the rate of 30 kg N/ha was concurrently injected into the root zone by the same procedure.

Only 1 kg/ha of insecticide applied in the root zone controlled insects as well as 8 kg/ha of carbofuran applied conventionally to the paddy water (Table 4).

Carbofuran residues were low in the paddy water following root zone application. The concentration of the insecticide in the roots and shoots reached a peak at about 20 days after treatment, but declined to a low level by 100 days. The efficiency of



7. Nitrogen fertilizer placed in a mudball and inserted about 10 cm beneath the soil surface gives significantly higher yields at lower fertilizer rates.

control was high during early growth and residual hazards were low in the harvested crop.

Application equipment. Despite the advantages of concentrating both nitrogen and systemic insecticides in the root zone, the labor required to produce the mudballs and to manually place the insecticides discourages their practical use.

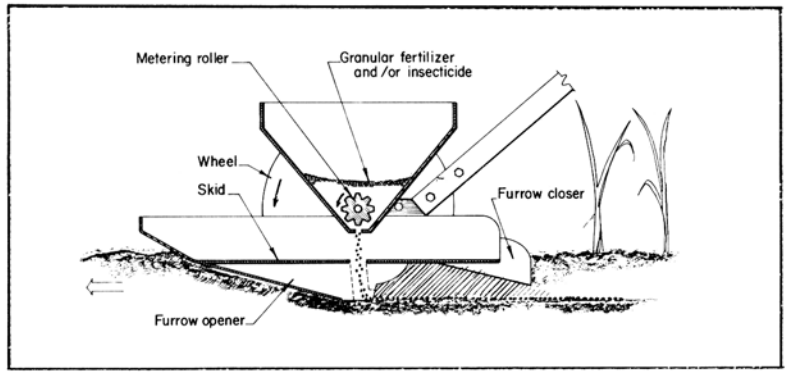
We are developing inexpensive, manually operated machines to apply both fertilizer and insecticide (fig. 8). The chemicals are applied in a band below the soil surface between the new seedlings. Preliminary results are encouraging; we are now improving the machine and the placement technique.

We have had large pellets of combined urea and insecticide prepared that can easily be placed in the rice root zone. We will continue our experiments to fully exploit the potential of deep placement of agricultural chemicals.

Varietal yield potential at low fertility levels. We are reassessing the yield potential

Table 3. Higher increases in yield were obtained with 60 kg/ha of nitrogen when concentrated in mudballs and applied to the rice root zone, than with 100 kg/ha applied by the topdressing method used by farmers. IRRI, 1974 dry season.

Fertilizer rate (kg N/ha)	Yield (t/ha) when N applied as		Efficiency of N (kg rice/kg N)	
	Mudball	Topdressing	Mudball	Topdressing
60	8.0	5.8	53	23
100	8.4	6.6	38	21



8. The granular chemical applicator opens a furrow, deposits the fertilizer or insecticide below the soil surface, and closes the furrow.

of different varieties at low fertility levels. We have found yield potential to be related to field resistance to lodging (the breaking of the stem or falling over as the plant approaches maturity). Because the traditional variety Peta lodges even at modest fertility levels, it yields poorly in the field. But when the plants are supported in the greenhouse to prevent lodging, Peta yields higher than widely grown IR20, especially at low fertility levels (Table 5).

We are seeking means to incorporate the higher yield potential at low fertility levels of Peta and other traditional varieties into lodging-resistant modern varieties.

Table 4. The effect of three insecticides injected into the root zone along with a urea slurry (30 kg N/ha) on the yield of IR26. IRRI, 1974 wet season.

Chemical	Placement	Rate (kg a.i./ha)	Yield (t/ha)
Chlordimeform	root zone	1	4.5
Cartap	root zone	1	3.9
Carbofuran	root zone	1	4.2
Carbofuran	paddy water	8	4.3
Control	–	–	3.0

Table 5. The relative yields of IR20 and Peta when lodging is permitted (as under field conditions) and when lodging is prevented under greenhouse conditions. IRRI, 1974.

Variety	Relative yields when			
	Lodging permitted (field)		Lodging prevented (greenhouse)	
	No N	High N	No N	High N
IR20	100	100	100	100
Peta	95	43	151	132

Research programs

GENETIC EVALUATION AND UTILIZATION (GEU) PROGRAM

Germ plasm conservation. Rice grows in remarkably diverse ecological and climatic conditions on every continent except Antarctica. One can find rice growing at altitudes of 2,400 meters (8,000 feet) in the Kashmir Valley; as a slash-and-burn hillside crop in Sarawak; in water 6 meters (20 feet) deep in the "floating rice" areas of Bangladesh; at least as far north as Central Czechoslovakia (50°N) and as far south as New South Wales in Australia (35°S) and Uruguay.

Scientists take advantage of this wide adaptation to combine, through plant breeding, desirable characters of rices from one area with those of other rices from half way around the world. But first, we must collect the seeds of diverse rices and conserve them so that their genes will be available for the testing and breeding programs. The collected seeds are catalogued and included in our germ plasm bank. Scientists in breeding programs in any nation can deposit and withdraw seeds of rices with outstanding genetic characteristics.

In 1974, almost 6,000 rices were added to the IRRI germ plasm bank. After duplicates and replacements were eliminated, 1,300 new accessions were actually entered. This brings the total number of accessions to about 35,000. The germ plasm bank also contains about 3,000 African entries, genetic testers, and wild taxa.

More than 3,000 varieties and lines were furnished by experiment stations from national rice collections in Asia, Africa, and Latin America. Major contributors were Japan and Bangladesh, but experiment stations in 10 other countries also entered rice varieties.

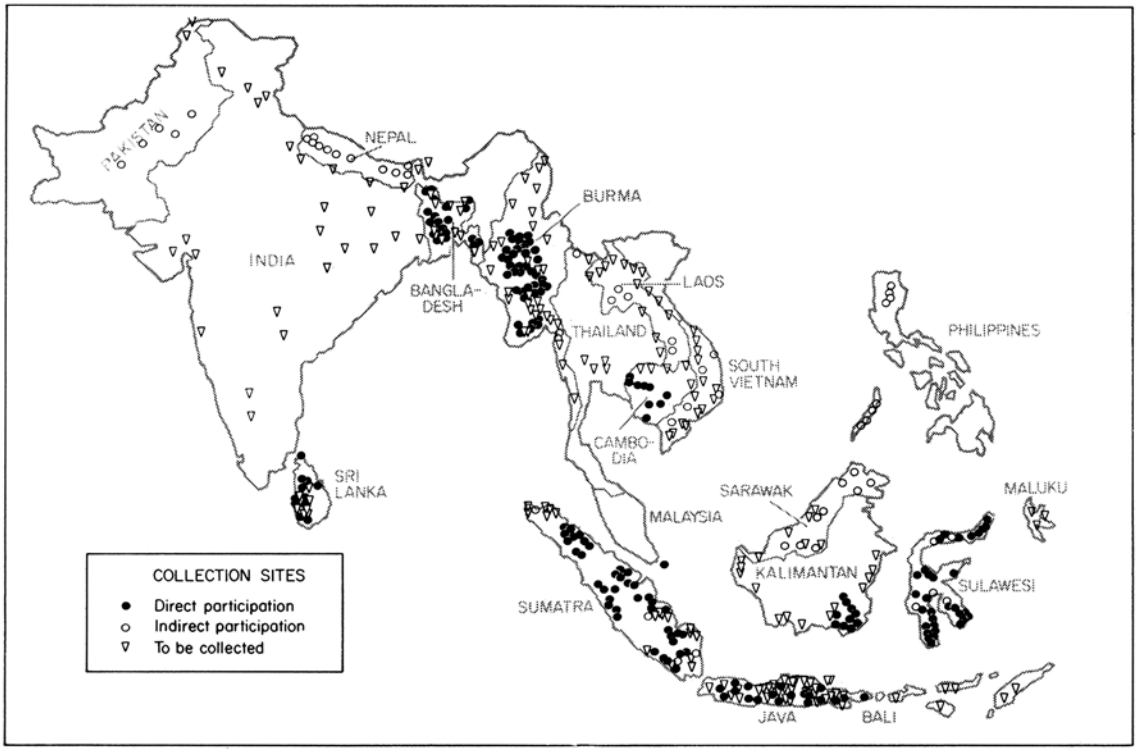
The IRRI field advisor on rice collection participated in field collection operations in Bangladesh, Burma, Indonesia, and Vietnam during 1974 and early 1975. About 1,400 samples were collected with IRRI's direct participation. Another 1,800 samples were gathered by national centers in five collaborating countries.

The IRRI director brought 38 cultivars on his return from a visit to China as a member of a U.S. plant science exchange group.

About 840 of the new samples are special types, bringing to almost 4,000 the rices collected in regions of particular environmental stress or with special characteristics

Table 6. More than 4,000 special types of rice varieties and wild taxa have been preserved in the IRRI germ plasm bank between July, 1972, and December, 1974.

Reported feature	Samples (no.)
Tolerance to salinity	124
Tolerance to acid soils (flooded)	150
Tolerance to alkaline soils	11
Upland types	2425
Floating types	518
High-elevation types	600
Resistance to nematodes	5
Escape from rodent damage	9
Aromatic types	89
Wild taxa	82
Total	4013



9. Sites of past and future germ plasm collection.

that breeding programs need: cold-tolerant rices from the mountains, drought-tolerant rices from rainfed and upland areas, salt-tolerant rices from coastal regions; floating rices; and aromatic types (Table 6).

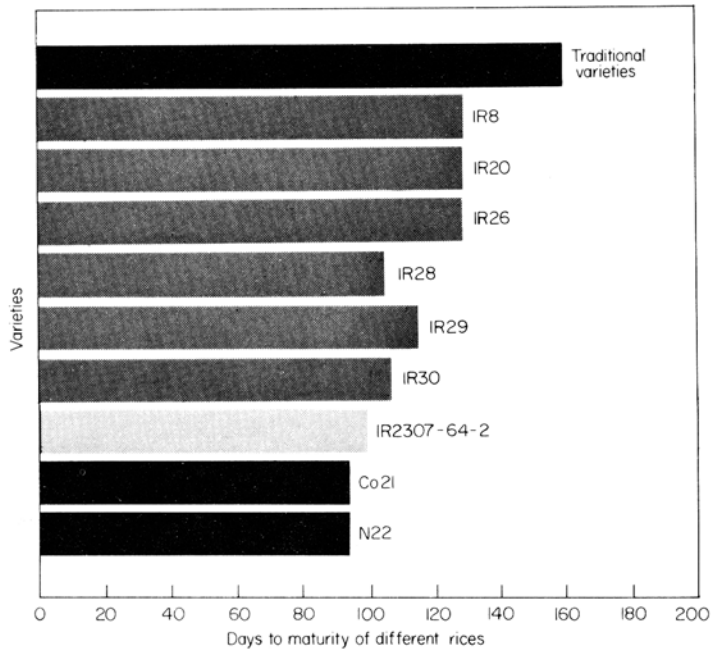
As a service to national rice breeding programs, we sent 2,600 seed samples to 43 countries in response to 142 requests. We furnished 167 seed packets of wild taxa.

The number of seed samples supplied internally to IRRI scientists tripled in 1974, reflecting the increased emphasis on problem-oriented breeding through the GEU program.

Since IRRI began field collection in 1971, 12 Asian nations have collaborated on the genetic conservation program (fig. 9). Hundreds of African rices *(O. glaberrima)* were collected and supplied by collaborating institutions in West Africa.

Further collection and conservation of rice genetic resources carries a high priority. Seeds of the traditional rices are disappearing as they are replaced by improved varieties and by changing cropping patterns. While these traditional varieties generally are agronomically inferior to their replacements, any one of them may have one or more remarkable genetic characteristics – particularly genes that enable them to resist or tolerate local environmental stresses (such as drought or injurious soils). These genetic sources must be conserved. Our objective is to collect as many as possible of the 100,000 to 150,000 rices in the world before they are lost to future generations.

Agronomic characteristics. The potential to increase food production by double or triple cropping places increased emphasis on high-yielding rice varieties that mature early. Two of our recent varieties, IR28 and IR30, mature from 15 to 30 days earlier than other IRRI varieties, and about 2 months earlier than most traditional varieties (fig. 10).

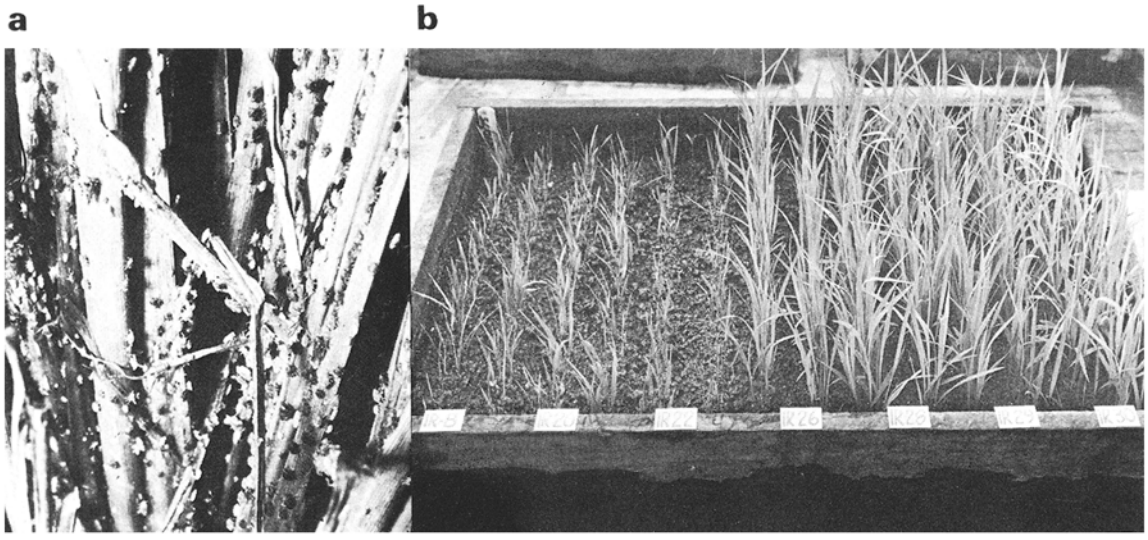


10. Most traditional rice varieties mature in 160 days or longer. IR8, IR20, and IR26 mature in 130 days; IR28 and IR30 mature in about 105 days. Some experimental lines, such as IR2307-64-2 mature in about 100 days. Varieties with even shorter growth durations are being used in IRRI's breeding program.

But still earlier varieties are being sought; we are evaluating a few lines that mature from 4 to 5 days earlier than IR28 and IR30.

To reach the goal of 95- or 100-day varieties, we have crossed our early maturing lines with several early lines from China, India, and Bangladesh. We are selecting progeny for early vigor and rapid tillering ability.

11. IR26 (left) has genetic resistance to a wide range of insects and diseases, so it grows well without pesticide protection. Rexoro and Taichung Native 1 (right) are susceptible and have been destroyed by rice pests. Genetic resistance decreases farmer's dependence on expensive pesticides.



12 a. The brown planthopper is becoming one of the most serious insect pests in Asia. **b.** These seedlings were caged with large numbers of brown planthoppers. IRRI's early varieties are susceptible but IR26, IR28, IR29, and IR30 are resistant.

We have also selected several lines of longer growth duration. We have crossed a photoperiod-sensitive line, IR1060-90-2, with our disease- and insect-resistant lines to develop high-yielding varieties that are sensitive to photoperiod.

Resistance to lodging remains a high priority, especially as we seek medium-statured varieties. Lines with excellent sturdy stems and lodging resistance are being crossed with lines that are resistant to major insects and diseases.

Resistance to insects and diseases. The first significantly improved rice variety that was resistant to insect pests was IR20, released in 1969.

IR20 spread rapidly during the Philippine tungro epidemic of 1971 because of its resistance to both tungro virus disease and its vector, the green leafhopper.

Similarly, IR26 is spreading fast today because of its even wider range of resistance (fig. 11), especially to most biotypes of the brown planthopper, which is becoming one of the most serious insect pests across Asia.

IRRI's newer varieties, IR28, IR29, and IR30, are resistant to brown planthoppers (fig. 12); highly resistant to grassy stunt virus disease (transmitted by brown planthoppers); and resistant to several other pests. In regions where they are suited, farmers are rapidly shifting to the more resistant varieties as they become available.

As the energy crisis forces up the price of pesticides, IRRI regards resistance to insects and diseases as essential – only pest-resistant experimental lines are considered for release as varieties. Concurrently, many national rice improvement programs are also adopting pest resistance as a breeding goal.

To identify newer and better sources of resistance to major insect and disease pests, IRRI entomologists, plant pathologists, and plant breeders continued to screen promising rice varieties and breeding lines from all over the world in 1974.

Screening for insect resistance. Entomologists and breeders on the GEU insect resistance team screened, crossed, and selected for genetic resistance to the following major insects: the brown planthopper, the green leafhopper, the white-backed planthopper, the striped stem borer, the yellow stem borer, and the whorl maggot (Table 7).

We also tested almost 3,000 varieties and lines in field experiments during the dry season *without pesticide protection,* and nearly 2,000 during the wet season. Natural

Table 7. Rices identified by screening trials as resistant to various insect pests of rice.[a] IRRI, 1974.

Insect	Varieties or lines (no.)	
	Tested	Selected as resistant or moderately resistant
Brown planthopper *(Nilaparvata lugens)*	5499	202[b]
Green leafhopper *(Nephotettix virescens)*	2876	306[b]
White-backed planthopper *(Sogatella furcifera)*	2259	164
Striped borer *(Chilo suppressalis)*	664	10
Yellow borer *(Tryporyza incertulas)*	2504	56
Whorl maggot *(Hydrellia philippina)*	4898	155

[a]Excludes screening of early generation breeding lines: 32,075 tested against brown planthoppers and 14,848 against green leafhoppers. [b]On further retesting, 17 varieties were highly resistant to brown planthoppers and highly resistant to green leafhoppers.

infestations of the following major pests were highest during these experiments: rice whorl maggots, stem borers, brown planthoppers, and accompanying virus diseases.

The most resistant rices identified in the field screening were re-tested for consistency of resistance in greenhouse and screenhouse trials.

The best rices were entered in the international screening nurseries for worldwide evaluation through the International Rice Testing Network.

By intercrossing varieties that are moderately resistant to the striped borer, we have produced progeny that are more resistant than any of the parents.

We made similar crosses to build resistance against the rice whorl maggot, for which we have found no distinct varietal resistance, even after evaluating more than 10,000 varieties over the past 4 years.

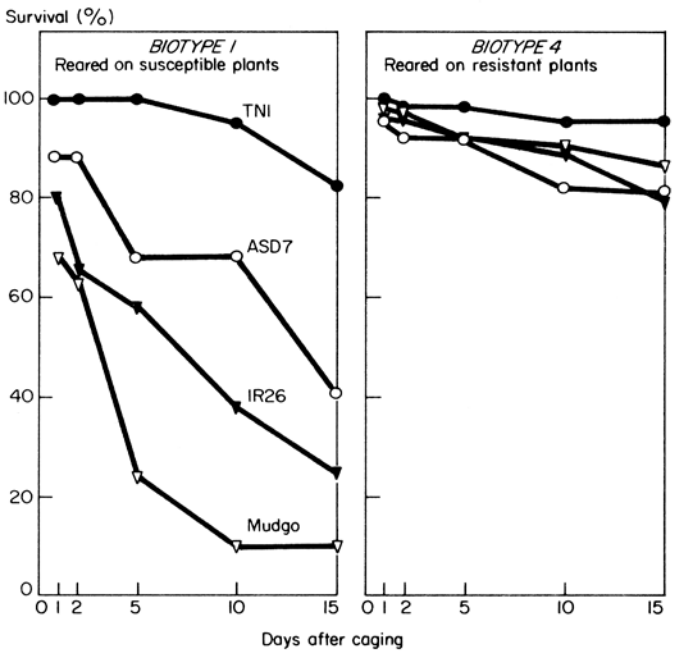
Intensive experiments have revealed that IR1820-52-2 is moderately resistant to the yellow borer. Moths laid fewer eggs on it than on other test varieties; of the larvae that hatched, fewer survived. Yellow borer incidence on this line was lowest in both screenhouse and field experiments.

During 1974, we identified many additional varieties that are resistant to brown planthoppers. The resistance of some, such as Kentjana from Indonesia and Bathurst from Sierra Leone, appears to be of a different nature than that of earlier identified resistant varieties. Although both Kentjana and Bathurst are only moderately resistant, they may provide alternative sources of resistance to Mudgo and ASD 7.

We are investigating the genetics of varietal resistance to insect pests and whether the resistance is due to biophysical or biochemical factors, or to both.

Brown planthopper biotypes. When selected varieties that are resistant to brown planthoppers were evaluated in the International Rice Testing Program, we found that brown planthopper populations in Kerala state, southern India, and Sri Lanka appeared to be of different biotypes than those in the Philippines and many other countries. Varieties that possess monogenic dominant resistance (for example, Mudgo) or monogenic recessive resistance (for example, ASD 7) to the brown planthopper reacted as susceptible in Kerala and in Sri Lanka. Most of the varieties identified so far as resistant to the brown planthopper are indigenous to Sri Lanka and southern India.

We proved that different biotypes can develop by collecting brown planthoppers from fields planted with resistant varieties and then rearing them for several generations on resistant plants in a greenhouse. This led to the development of three new biotypes,



13. The natural brown planthopper population at IRRI (Biotype 1) suffers high mortality when caged on resistant varieties ASD 7, IR26, and Mudgo, but thrives on the susceptible variety Taichung Native 1. It has high rates of survival, however, when caged on resistant varieties. Biotype 4 evolved when insects were collected from areas intensively planted with resistant varieties and then reared for several generations on resistant varieties.

including one that can survive on both ASD 7 and Mudgo (fig. 13). We are now using these biotypes to identify newer sources of resistance.

From these and other experiments, scientists hypothesize that if only a few pest-resistant varieties are planted intensively over wide areas, insect biotypes may develop through natural selection that can attack and feed on the formerly resistant varieties.

If the crop resistance is governed by a single pair of genes (monogenic or single-gene resistance), the possibility increases that insect biotypes will develop that can survive – and even thrive – on formerly resistant plants. When the resistance is governed by two or more pairs of genes (multigenic or multiple-gene resistance), the possibility lessens. We plan to stress the combining of several sources of resistance to each insect or disease, whenever possible, into single varieties.

Screening for disease resistance. We have screened 10,000 accessions of the germ plasm bank for resistance to blast fungus disease. Many were evaluated not only in the Philippines but also in 29 countries through the International Blast Nursery. About 1 percent were found to have a broad spectrum of blast resistance and 0.1 percent had a *very* broad spectrum of resistance.

We tested 3,705 varieties from the germ plasm bank in 1974 to identify new sources of resistance. Almost 20 percent – 717 varieties – reacted as resistant in the first test. The more resistant will be tested internationally through the blast nursery.

Several varieties that have consistently shown very broad spectrums of resistance over 11 years of testing in 30 countries are Tetep, Nang Chet Chuc, Tadukan, Mamoriaka, Carreon, Ram Tulasi (Sel), C46-15, and Dissi Hatif.

We continued to evaluate a standard scale that scientists in different countries can use to uniformly assess and rate resistance to sheath blight disease in field trials. This will become increasingly important as more scientists join international testing programs.

We screened more than 5,000 varieties and breeding lines for sheath blight resistance in both dry and wet seasons. Although many varieties were moderately resistant, we found no variety that was highly resistant or immune.

Sixty varieties were screened in the second International Sheath Blight Nursery in eight Asian countries: Korea, Indonesia, Taiwan, Malaysia, Philippines, Thailand, India, and Sri Lanka. We received 14 sets of test results.

A few varieties reacted differently in different test locations. These are being re-evaluated to determine if different races of the pathogen may exist.

Some tall varieties that were broadly resistant in many countries are Laka, Ta-poo-cho-z, Kam Bau Ngan, 46 Palman, and Dular. Semidwarf lines with moderately broad spectrums of resistance are IR1542-30-2-4, IR1544-340-6-1, IR883-12-1-3, IR1529-680-3-2, and IR3273-67 P.

We screened about 10,000 new cultivars from the germ plasm bank over two seasons for resistance to bacterial blight. One hundred sixty-three new cultivars were considered strongly resistant.

The inheritance of resistance to bacterial blight in several varieties and breeding lines was investigated, confirming that a single dominant gene governs resistance in some varieties (such as TKM6, Sigadis, and W1263) and a single recessive gene in others (BJ1, DZ192).

We identified for the first time a single recessive gene that controls resistance in IR1698, a progeny of Zenith.

Results from 20 of the 22 cooperating scientists conducting the Third International Bacterial Blight Nursery showed that the Indian lines from RP633 had the broadest spectrums of resistance. Varieties such as IR30 and IR26 were moderately resistant in most countries.

Using the improved mass screening method in greenhouses, we tested about 380,000 seedlings of 15,460 entries for tungro virus resistance in 1974. A total of 278 IR selections were classified as resistant. We are developing a field cage method of tungro screening.

We tested 156,000 seedlings, representing 8,029 entries, for resistance to grassy stunt in 1974. Some IR selections showed resistant reactions even when tested 18 times: IR1704-3-2-3, IR1737-19-7-8-3, and IR2035-708-3.

Drought resistance. The development of drought-resistant or drought-tolerant varieties continues to receive high priority, not only for upland rice, but also for rainfed, non-irrigated rice. Our aim is to combine the drought tolerance of traditional varieties adapted to rainfed cultures with the high-yielding potential and pest resistance of modern rices.

We have found remarkable differences in the response of traditional varieties to drought, using both greenhouse and field techniques (Table 8). Since 1971, more than a thousand crosses of drought-tolerant rices and improved breeding materials have been made; 800 in 1974.

Mass field screening. During the 1974 dry season, we screened more than 2,000 varieties and breeding lines from Asia, Africa, and Latin America in IRRI fields for resistance to drought.

Field resistance ratings were based on plasticity of leaf rolling and unfolding, death of leaves, degree of stunted growth, and effects on reproductive processes.

Table 8. Variation in drought ratings of varieties and lines using three screening techniques. IRRI, 1974.

Variety/line	Stress in		
	Water table box[a] (comparative yield)	Field	
		Relative plant ht[b]	Visual rating[c]
M1-48	100	(71)	R
E 425	47	(78)	MR
OS4	29	(68)	R
Miltex	78	(73)	I
Palawan	2	(68)	MR
IR5	33	(63)	MR
Azucena	30	(64)	MR
IR442-2-58	0	(59)	I
IR1529-680-3	0	(54)	I
IR20	0	(51)	S

[a]Constant water table maintained in water table box at 45 cm below surface. [b]Plant height under water stress relative to that under well-watered conditions. [c]Rated by Plant Breeding Department: R–resistant; MR–moderately resistant; I–intermediate; MS–moderately susceptible; S–susceptible.

The largest proportion of drought-resistant varieties was found among the traditional upland rices from Africa, followed by those from South America, and by hill rices from Laos. A good proportion of the early maturing varieties of Bangladesh were found resistant. The floating varieties of Southeast Asia were rated from moderately resistant to moderately susceptible.

Some early maturing and drought-resistant varieties that produced well-filled grains were N 22, Seratus Malam, Cartuna, Kap Nhay, Padi Tatakin, Rikuto Norin 21, Susono-mochi, Maligaya 5, Kinandang Patong, and Ba Djang Nhu.

Only a small percentage of the upland breeding lines that came from crosses of upland and lowland parents were found to be as drought resistant as the African upland parents (such as OS4).

Among the 567 breeding lines from upland nurseries, the largest number of resistant varieties came from crosses made in 1970 of African upland x semidwarf lowland rices.

Recovery from drought was recorded after watering the stressed plants. Most of the lowland varieties and lines recovered faster and to greater degrees than did the upland varieties and lines. We hope to combine drought resistance with the ability to recover from drought by further crossing and selection.

Performance in upland farmers' fields. During the 1974 wet season, we evaluated the performance of 81 experimental lines in upland farmers' fields in Batangas province, Philippines, and in several other countries in Asia and Africa. We also evaluated them for field resistance to diseases and insects, agronomic characteristics, and yield potential.

The high-yielding experimental lines were selected from earlier yield and observation trials and installed in six sites across the Philippines. Included were three maturity groups: early, intermediate, and late. An unusually long dry spell during the growing season provided an excellent opportunity to evaluate the experimental lines for drought reaction.

The three early maturing lines that were exposed to drought and that produced the highest average yields in farmers' fields were IR661-1-170 (2.9 t/ha), followed by

Table 9. The root-to-shoot ratios of 25 rice varieties, one sorghum variety, and one corn variety. IRRI, 1974.

Root:shoot ratio (mg/g)	Designation
209	Sorghum (Cosor)
146	Corn (Early Thai Composite)
101–120	Rikuto Norin 21, Azucena, OS4, E425, Palawan, Dular, Azmil, M1-48
81–100	C22-51, IR442-2-58, 81B25, Miltex, IR5, IR8, Jappeni Tungkungo, PI 215936
60–80	TN1, NARB, Bluebonnet, Peta, IR841-67-2, IR127-80-1, IR1529-680-3, H4
49	IR20

IR2031-729-3 (2.8 t/ha) and IR2035-227-1 (2.7 t/ha). IR1529-430-3, which produced the highest average yields (3.6 t/ha), had yielded highest among the 1973 entries, when the rainfall distribution was normal. Other high-yielding lines, which averaged about 3 t/ha, were IR1529-680-3, IR1529-677-2, IR1577-24-1, and IR2035-242-1.

Drought affected the late-maturing group most markedly. No line yielded better than the check, IR5.

At one of the Batangas test sites, two IR1750 lines (from African upland x IR20 crosses) produced 3.6 and 3.1 t/ha while the best local upland variety produced 1.9 t/ha.

Screening for drought tolerance. We developed a greenhouse technique to determine how different varieties respond to soil moisture stress at the early (vegetative) growth stage and at the later (reproductive) stage.

Under moisture stress during vegetative growth, the varieties matured a month later than the checks (which were not subjected to moisture stress). Plant height was reduced, but when relieved of moisture stress, the plants produced additional tillers and panicles that contributed to final yield. Early stress affected the percentage of unfilled grains in only a few varieties.

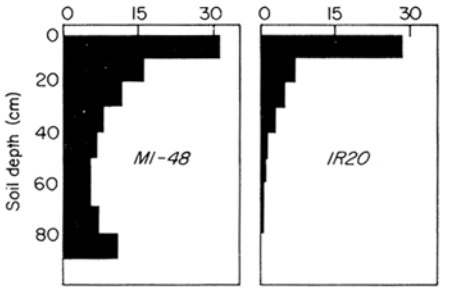
Moisture stress during the reproductive growth stage did not generally lengthen the maturity dates, but it did reduce yields of several lines by more than half. The promising lines are being further evaluated under field conditions.

Root studies. We compared the root systems of 25 rice varieties with those of sorghum and corn, two crops that are more drought resistant than rice. The root-to-shoot ratio of corn and sorghum was much higher than for the rices although the rices varied considerably in this trait (Table 9). IR20, a drought-susceptible variety, had a very low root-to-shoot ratio while a number of drought-resistant upland varieties had ratios approaching that of corn.

Drought-resistant varieties also had more deep roots and their roots tended to be thicker than the susceptible ones (fig. 14). The root distribution technique has been standardized and will be used to screen several hundred rices annually.

In general, tall rices tend to have larger and more extensive root systems but some short-statured rices also have extensive systems. This suggests that it should be possible to breed relatively short-statured rices with good root systems and with high drought resistance.

Tolerance to adverse soils. Adverse soils prevent the new varieties from delivering their full potential yields on about 40 million ha of rice land in the tropics.



14. The drought-resistant variety M1-48 has a higher root-to-shoot ratio and a higher proportion of deep roots than has a more drought-susceptible variety, IR20.

Another 40 million ha, climatically and physiographically suited to rice, lie uncultivated largely because of soil problems, including salinity, salinity-alkalinity, alkalinity, iron toxicity, toxicity of acid-sulfate soils, zinc deficiency, phosphorus deficiency, and the low productivity of peat soils.

With increasing population pressures, the rice-growing nations cannot afford to let these lands remain low in productivity or idle.

Because improving these lands by chemical amendments or by water management is too expensive for most developing countries, we are selecting and breeding for tolerance to the adverse soil conditions as a component of the GEU program.

During 1974, soil chemists and breeders refined a technique for screening large numbers of plants for salt tolerance. We screened 343 varieties and selections for tolerance to salinity, alkalinity, iron toxicity, zinc deficiency, and phosphorus deficiency (Table 10).

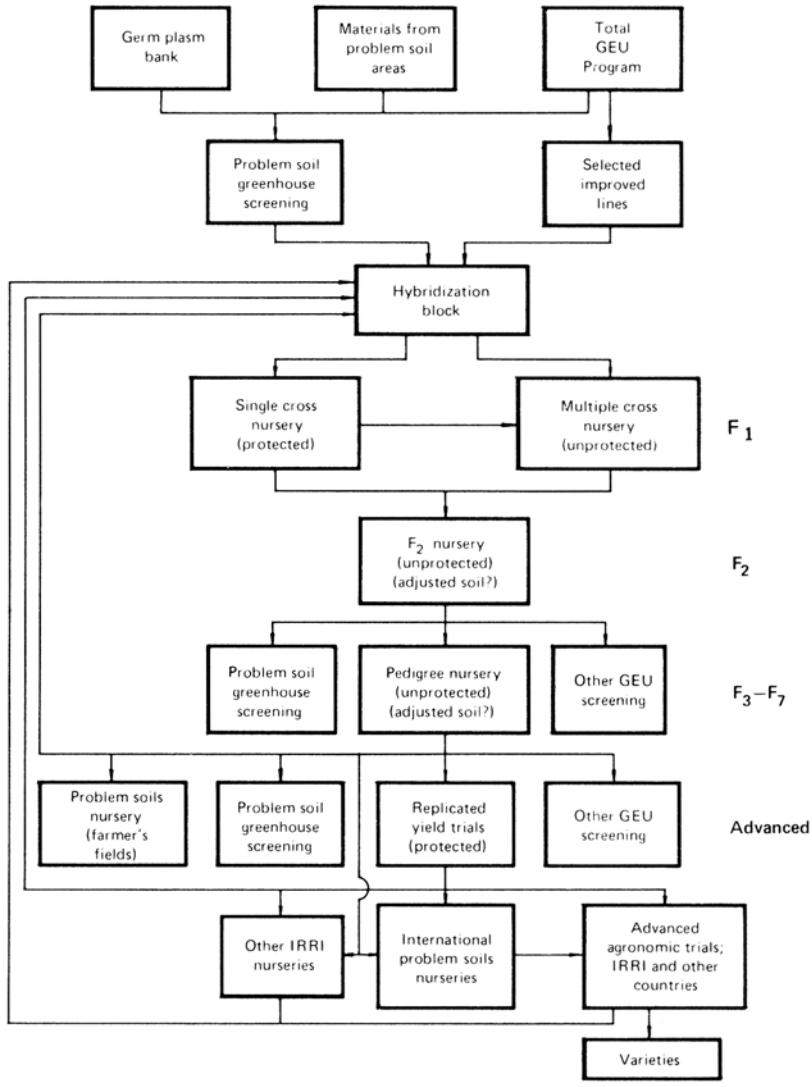
The complexity of the evaluation and breeding for problem soils is illustrated by fig. 15, which shows the flow of genetic materials through the steps needed to produce a new variety.

Salt tolerance. We emphasized salt tolerance in the GEU program because salinity is the most extensive soil problem. During 1973, we made numerous crosses with Pokkali, a low-yielding variety that farmers plant in coastal regions of India and Sri Lanka because it tolerates salinity and several other injurious soils. Pokkali has been a poor combiner, but we were able to select some salt-tolerant progeny of satisfactory agronomic type.

We refined and simplified the technique for screening varieties for salt tolerance. Of

Table 10. Sources of tolerance to soil problems. IRRI, 1974.

Soil problem	Sources of tolerance
Salinity:	BR4-10, Gottelu, Kalarata 1-24 (Karjat Research Station), Muskan 7, Nona Bokra, SR 26 B (Acc. 5908), Pokkali (Acc. 26869).
Alkalinity:	Pokkali (Acc. 26869), Benzer
Zinc deficiency:	IR30, IR2153-14-1, IR2153-15-1, Pokkali.
Phosphorus deficiency:	IR20, IR26, IR28, RD1, IR2061-214-2.



15. Flow of genetic materials through IRRI's GEU program to develop varieties adapted to adverse soils.

48 reportedly salt-tolerant varieties screened, only seven actually tolerated salinity. The lines IR2153-26-3-5, IR2153-43-2-5, and IR2035-290-2 tolerated salinity better than other improved varieties or lines tested.

The salt-tolerant IRRI lines are resistant to most of the major diseases and insects, and thus are potential varieties. But because they are all semidwarfs, they would not be suitable for most coastal saline areas where the water is too deep. We are making crosses with taller varieties for these coastal saline areas.

Alkalinity. Alkaline soils limit yields or prevent rice from being grown in many arid regions recently brought into production by irrigation in India, Pakistan, Iran, and other countries.

Twenty-four selections or varieties were tested for alkali tolerance in the greenhouse. Pokkali and Benzer were tolerant; IR2151-918-2, IR2153-96-1, IR30, IR2153-247-1, IR2153-276-1, and Kangni Torh were moderately tolerant.

In an outdoor replicated test in concrete tanks, Pokkali, IR2031-114-2, and M1 273 were least injured.

In a replicated field test in alkalized Maahas clay (pH 8.7), Pokkali and IR26 performed best.

Iron toxicity. Excess water-soluble iron limits rice yields on millions of hectares of strongly acid oxisols and acid-sulfate soils. Built-in tolerance to iron toxicity would be a boon to the poor people who grow rice on these soils.

We planted 2-week-old seedlings of 22 varieties or selections on a strongly acid oxisol that builds up more than 400 ppm iron in the soil solution a few weeks after submergence. Four weeks later, we scored the plants according to the severity of symptoms and found the following to be tolerant – Pokkali, IR30, IR2151-190-3, IR2153-96-1.

Zinc deficiency. Zinc deficiency occurs on alkali and calcareous soils and on continuously wet soils. In the Philippines alone, about 500,000 ha of soils have this nutritional disorder. About a third of the rice area of India and Pakistan is believed to exhibit some zinc deficiency. Varietal tolerance may be a simpler remedy than applying zinc to the soils or plants.

Using plant symptoms and yields relative to those of zinc-treated plants as our basis for comparison, we screened 100 varieties and selections in pots in screenhouse. IR28, IR29, and IR30 were as tolerant as were 10 experimental lines.

In an outdoor replicated test of 16 varieties on a zinc-deficient soil in concrete tanks, only IR1514A-E666 was tolerant.

Field tests of 20 entries at three locations in Laguna province, Philippines, indicated that IR20, IR1514A-E666, and IR2031-238-4 were tolerant.

Phosphorus deficiency. Phosphorus deficiency limits rice yields on millions of hectares of ultisols, oxisols, and vertisols. Because most of these soils are found in poor countries where farmers cannot afford to use large amounts of fertilizers, we are searching for varieties that can exploit and utilize soil phosphorus more efficiently than others.

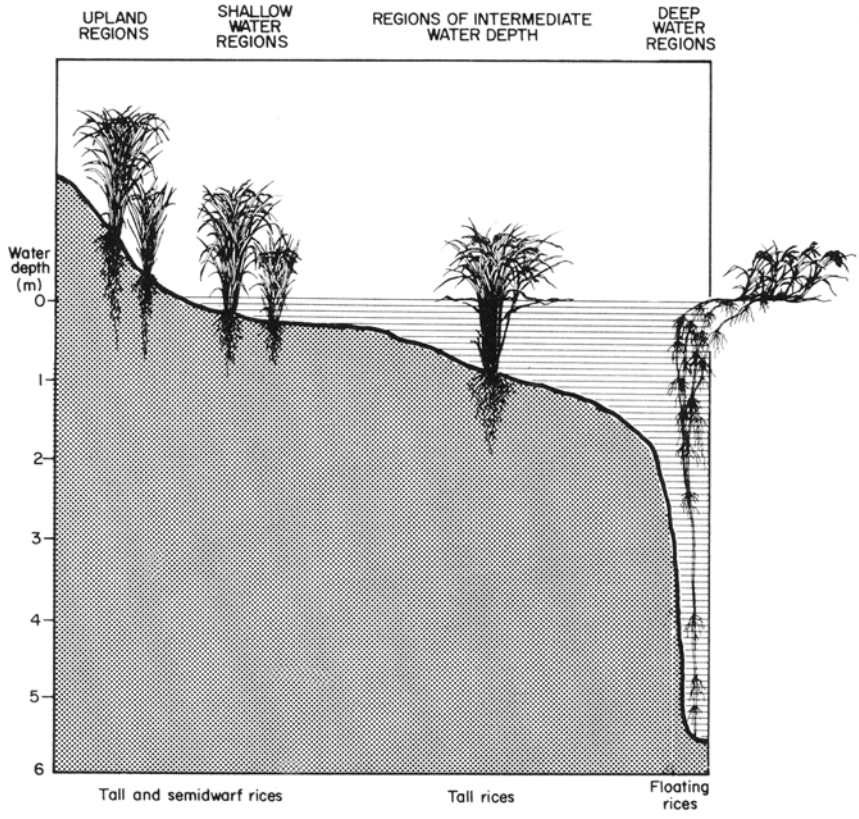
We grew 15 varieties or lines in a phosphorus-deficient ultisol (pH: 4.9; Olsen P: 1.2 ppm) in an outdoor trial. IR20, IR26, IR28, IR1514A-E666, IR1529-680-3, and IR2061-464-2 were tolerant.

In a replicated yield trial, we grew 30 varieties and experimental lines with and without 25 kg P/ha, over a basal dressing of N and K, on a phosphorus-deficient soil at Pangil, Laguna province, Philippines. Some varieties yielded more than 4 t/ha with no phosphate fertilizer, and yielded from 33 to 50 percent more when phosphate was applied.

IR26, IR2061-214-2, IR1529-680-3, IR944-102-2, and RD2 were classified as tolerant.

Deep water and flood tolerance. The new rice technology has bypassed the vast regions where farmers cannot control the water, and where water becomes too deep during the monsoon season for the semidwarf varieties. Estimates of such areas range from 25 to more than 40 percent of the world's rice land (fig. 16). Included in the deep water regions are the densely populated valleys and deltas of the mighty rivers of Asia – the Ganges, the Brahmaputra, the Godavari, the Irrawaddy, the Chao Phraya, and the Mekong. Only low-yielding indica varieties, tall enough to grow in deep water and to survive most floods, are available to farmers in these areas.

In the deepest areas, where water normally reaches from 1 to 6 meters, farmers grow special "floating" rice varieties. Over centuries, these varieties have developed genetic mechanisms that enable them to grow normally in deep water and to escape



16. The world's rice land classified by water regimes and predominant rice types.

flood submergence – their stems elongate as waters rise. But their yields are low.

About 10 percent of the rice land in Asia and Africa is planted in floating rices; another 20 or 30 percent is in tall non-floating varieties adapted to medium-deep water.

So far, the improved rice technology has not generally helped farmers in these areas; their yields have remained stagnant for decades or longer at 1 or 2 t/ha.

International cooperation. Improvement of the deep water and floating rices in the past was generally limited to identification of the better local strains. But today IRRI is working with scientists in India, Bangladesh, Thailand, Vietnam, and Indonesia to cooperatively develop improved varieties and cultural practices for the areas of deep water.

In 1974, we joined with the Ministry of Agriculture in Thailand in an expanded program of deep water rice research. Headquarters for the joint research effort is at the Huntra Deep Water Rice Research Center, 100 km north of Bangkok. Research is being done at the station and in cooperation with nearby farmers. Promising genetic materials developed at Huntra, at IRRI headquarters in Los Baños, and through national breeding programs will be shared with other rice improvement programs around the world.

We co-sponsored an International Seminar on Deep Water Rice at the Bangladesh Rice Research Institute (BRRI) in August, 1974. Groundwork for future cooperation among researchers working on deep water rice was set at this seminar.

17. The experimental line **T442-121-24**, a progeny of a cross of floating and semidwarf rice parents, elongates with rising water. It grows well in water more than 110 cm deep, while IR8 is completely submerged and killed, at the Huntra Deep Water Rice Research Center, Thailand.

Screening for deep water tolerance. Rices suitable for deep water and flood tolerance must elongate rapidly as the water rises (fig. 17) and must tolerate submergence in water for at least short periods of time. By December, 1974, we had screened 1,126 varieties to obtain information on these two characteristics.

We measured the rate of elongation of 20 varieties by completely submerging 40-day-old seedlings for 5 days. We recorded as much as 31 cm internode elongation during the first day (Table 11).

In other experiments, 144 varieties were screened for survival when submerged in deep water for 7 days. The internode length of 24 of these varieties increased by more than 40 cm. One variety, Habiganj Deep Water 1 from Bangladesh, elongated 70 cm during the 1-week period.

We compared the submergence survival of 479 varieties with that of a standard

Table 11. Varieties with rapid rates of internode elongation (selected from 20 varieties tested). IRRI, 1974.

Variety	Increase in internode length (cm)			
	24 h[a]	48 h	72 h	120 h
Boon Nahk	13	27	34	43
DW 6255	17	40	35	45
HBJ DW 8	27	35	46	44
Leb Muc Nahng 111	23	32	38	51
Nang Dum To	20	34	32	47
Khao Hawn	31	36	40	48
Nak Neva	24	39	36	46

[a]After submergence.

Table 12. Tolerance to submergence. Of 479 varieties submerged in water for 7 days at the seedling stage, eight had survival rates as high as the submergence-tolerant check variety, Nam Sagui 19, used as the basis for comparison. IRRI, 1974.

Comparative survival[a] (%)	Varieties (no.)
0–25	414
26–50	39
51–100	18
100+	8

[a]Comparative survival (%) = $\frac{\text{Survival (\%) of a variety}}{\text{Survival (\%) of Nam Sagui 19}} \times 100.$

check, Nam Sagui 19 from Thailand. Eight of them survived fully as well as the check variety (Table 12). These will be used in our crossing program to incorporate tolerance to periods of total submergence into higher yielding varieties with resistance to insects and diseases.

Tolerance to extreme temperature. Both cold and hot climates limit the adoption of improved varieties across the rice-growing world. Low temperatures are probably the greater limiting factor. We are just beginning to study the effects of heat stress on rice.

Cold tolerance. In mountainous regions of the tropics, and in the temperate rice-growing zones of the world, cold weather is a problem. On about 7 million ha in South and Southeast Asia alone, improved varieties cannot be grown because of low temperatures. This includes rice-growing valleys in Kashmir, Nepal, Pakistan, Indonesia, and the northern Philippines.

In 1974, we screened rices for cold tolerance in farmers' fields in the mountains, in special cold water tanks, and in cold growth rooms in the IRRI phytotron. We selected a steep area in Benguet, Mountain Province, Philippines, to study how varieties respond to cold temperatures and to identify plant characteristics to determine cold tolerance during the vegetative and reproductive stages of growth.

We planted a set of eight varieties at three sites: 1,210 m (3,819 ft), 1,070 m (3,461 ft), and 1,015 m (3,391 ft). This set was also planted at the IRRI farm and in phytotron cold rooms.

We measured the following physiological reactions: tiller number, plant height, panicle exsertion, sterility, grain yield, and growth duration.

We found that plant height seems to be the easiest and most consistent character to determine cold tolerance.

At 36 days after transplanting, China 1039, from Kashmir, was the tallest variety at the three sites in Benguet, at low temperature regimes in the phytotron, and in Los Baños fields.

The growth durations of the eight varieties were markedly greater at low temperatures than at higher Los Baños temperatures (Table 13). We found that the minimum temperature of a locality better indicates the delay in growth duration than does the average daily temperature.

The Kashmir variety China 1039 was most impressive, requiring only 137 days from seeding to harvest at Benguet. It also matured earlier in Los Baños fields and in cold growth rooms of the IRRI phytotron.

Plant breeding for cold tolerance. During the 1974 dry season, we evaluated 826 varieties and breeding lines for maturity, fertility, and agronomic traits, and grew 23

Table 13. Growth durations of eight test varieties grown under different temperature regimes[a] on farmers' fields at elevations of above 1,000 meters in Benguet, Philippines; in Los Baños fields; and in the IRRI phytotron. Cooperative experiment, Philippine Bureau of Plant Industry and IRRI, 1974.

Designation	Origin	Days from seedling to harvest in				
		Benguet (27.5°/ 15.7°C)	Los Baños (32°/ 25.6°C)	IRRI phytotron		
				32°/24°C	26°/18°C	20°/20°C
China	Kashmir	137	96	100	118	102
Fujisaka 5	Japan	137	98	97	108	103
Bengawan	Indonesia	181	142	152	156	154
IR8	IRRI	181	126	130	160	141
M1-48	Philippines	158	123	122	143	128
IR24	IRRI	158	119	119	147	130
IR667	Korea	158	107	111	130	124
Kulu	Australia	158	106	120	149	125

[a]Day/night temperature regimes.

F_2 populations in Benguet province. During the wet season, we evaluated 841 varieties and lines and grew 16 F_2 populations. Temperatures were about the same in wet and dry seasons, averaging 23°C and ranging from 16° to 29°C. Several typhoons severely damaged the nursery, making evaluation and selection difficult.

The materials were concurrently evaluated at IRRI for resistance to blast and bacterial blight diseases, tolerance of cold water, and various grain quality characters.

We selected 56 of the more promising varieties and lines and, cooperatively with the Philippine Bureau of Plant Industry (BPI), evaluated them during the 1974 wet season in the ancient Ifugao rice terraces of Banaue, Ifugao province, Philippines. Elevation is 1,200 m (3,876 ft).

We identified several cold-tolerant varieties and lines of suitable growth duration – short enough to permit, for the first time, the cultivation of two crops per year (Table 14).

These will be further evaluated on farmers' fields in the rice terraces during the 1975 wet season, and in other nations through the International Rice Cold Tolerance Nursery.

We continued to collect the better varieties and breeding lines from areas of cold temperature and to cross them with improved material at IRRI. Seed of 81 F_2 populations was available for distribution to requesting cooperators in national programs at the end of 1974.

Heat tolerance. High sterility has been reported in dry-season lowland crops in Cambodia. Thailand, and India. The same problems may occur in other countries where high temperatures and low relative humidities prevail during the dry season such as Pakistan, Iran, and countries of West Africa.

To investigate effects of high temperature on rice, we grew 10 varieties at three temperature regimes in the glasshouse rooms of the phytotron. These varieties cover a wide geographic distribution from 43°N (northern Japan) to the equator (Indonesia). The three day/night temperature regimes used were 29°/21°C, 32°/34°C, and 35°/ 27°C.

The response of three varieties of these temperature regimes is shown in fig. 18. Spikelet numbers were relatively unaffected by temperature differences. But the

Table 14. China 1039, an early maturing, cold-tolerant variety developed in Kashmir, was the most promising selection (from 56 entries) grown on the rice terraces at Banaue, Ifugao province, Philippines. Cooperative experiment, Philippine Bureau of Plant Industry (BPI) and IRRI, 1974 wet season.

Designation	Origin	Tillers (no.)	Plant (cm)	Days to heading	Panicle exertion (cm)
China 1039	Kashmir, India	11	85	84	3.0
Claket 520	Indonesia	9	67	87	2.5
JP 5	Pakistan	12	78	76	5.8
Kn-1h-214-1	Indonesia	7	83	90	1.5
Kn-1h-361-1-8	Indonesia	10	87	90	0.6
Sug	Kashmir, India	10	82	56	5.0
Kn-1b-361-1	Indonesia	10	78	87	1.3
Kn-1b-361-18	Indonesia	9	78	87	2.0
Kn-1b-361-B1K-2	Indonesia	8	76	87	2.8
Kn-1b-361-B1K-13	Indonesia	11	84	87	2.0
Kn-1b-361-B1K-22	Indonesia	11	83	92	1.1
Kn-1b-361-B1K-27	Indonesia	9	85	89	2.0
IR1846-300-1	IRRI	13	81	87	1.8
IR1846-314	IRRI	13	86	82	0.6
Fujisaka 5	Japan	12	56	86	3.0

percentage of filled grain and grain weight per plant were greatly reduced by the higher temperatures. IR8 seemed relatively unaffected by the higher temperatures.

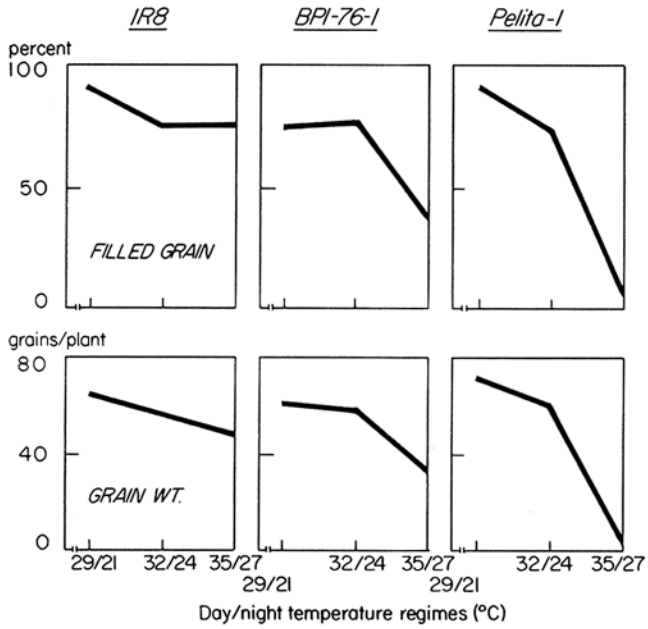
Grain quality. Amylose, a component of starch, partly determines the eating quality of rice. High-amylose rices, such as IR8, cook up light and fluffy, but the grains tend to harden as they cool. Low-amylose rices, such as IR24, are sticky and soft when cooked.

IRRI surveyed Asian consumers and found that most prefer rice of intermediate amylose content (20-25%). These rices cook moist, with grains that separate easily, but that do not harden. Because amylose content is under genetic control, the GEU grain quality team composed of breeders and cereal chemists, uses rices such as the Philippine variety C4-63 and BPI 121-407 in the crossing program, to incorporate superior grain quality and intermediate amylose content into future varieties.

But consumer preferences vary from region to region, so a range of rices with different amylose levels are also being developed.

Several breeding lines from crosses of BPI 121-407 have an improved plant type and intermediate amylose content but lack resistance to one or two of the important rice diseases or insects. These lines were used extensively in the hybridization program during 1973 and 1974. F_3 progenies from several of these crosses were evaluated during 1974 and were found to have intermediate amylose content as well as combined resistance to major diseases and insects. We hope that high-yielding varieties with intermediate amylose content will be available within a few years.

We have also started to screen breeding lines for gel consistency. All the breeding lines with low and intermediate amylose contents screened so far have soft gel consistency.

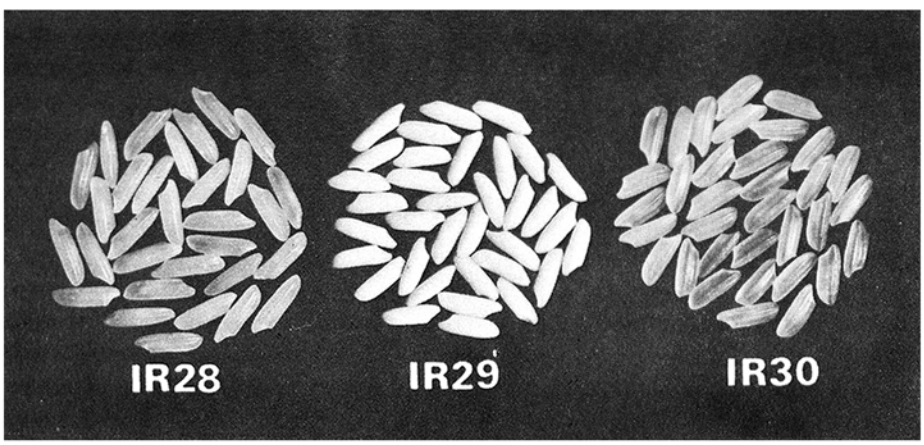


18. Higher temperature regimes significantly reduced the percentage of filled grains and the grain weight per plant of the varieties BPI-76-1 and Pelita I/1 in the IRRI phytotron. IR8 was affected less.

But high-amylose lines may have either soft, intermediate, or hard gel consistency. Because most of our breeding lines have high amylose content, we have screened them and identified many with soft or intermediate gel consistency. Several advanced lines of the crosses IR2070, IR2071, IR2151, and IR2153 have soft gel consistency.

Eating quality of IR28, IR29, and IR30. The eating quality of IR28 is comparable to that of IR22. IR28 has long, slender, and translucent grains (fig. 19). Its high amylose content and high gel consistency make it cook light and fluffy.

IR30 has soft gel consistency and is likely to gain wide consumer acceptance. It has high amylose content.



19. The grains of IR28 are long, slender, and translucent. IR29 is the first IRRI variety with glutinous or waxy grains. IR30 has medium-long, slender, and translucent grains.

Table 15. Promising breeding materials with brown rice protein contents at least 15 percent above that of IR20 and with yields at least equal to IR20. Wet and dry season average, IRRI, 1974.

Variety/line	Protein index	Yield index
BRJ1-5-B-7	122	104
IR480-5-7	121	109
IR2003-P3-3	124	100
IR2003-P16-7	119	104
IR2006-P12-12	120	112
IR2016-P-7-4	122	101
IR20 (check)	100	100

IR29 is the first IRRI variety with glutinous or waxy grains. Glutinous rice cooks soft and sticky. It is the staple food in Laos and northeast Thailand, and is used in special preparations, such as cakes and pastries, across Asia.

Increasing protein content. The world's affluent obtain vital protein through foods such as meat, eggs, and dairy products, but millions of the world's poor get most of their protein through rice. Any increases in the protein content of rice could affect millions.

Although the grains of most rices contain 7 percent protein, some are significantly higher. IRRI's chemists, plant breeders, statisticians, geneticists, and agronomists work on the GEU protein team toward a goal of increasing that level by 2 percentage points – from 7 percent up to 9 percent.

In 1974, breeders and agronomists evaluated 437 varieties and lines for protein content during the dry season and 368 during the wet season. Some of these lines with good yielding ability and pest resistance have significantly higher protein contents than existing varieties (Table 15).

The elite lines IR2031-724-2 and IR2153-338-3 performed consistently well in both seasons at two levels of added nitrogen fertilizer and two levels of management. They yielded at least as high as IR20, and had about 1 percentage point higher content of grain protein. The only major weakness of IR2031-724-2 is susceptibility to tungro virus disease; IR2153-338-3 is at least moderately resistant to all major pests.

Statisticians and breeders have determined "protein per seed" to be a promising criterion for selection in rice pedigree nurseries based on studies of F_3 seeds of the cross IR480-5-9 X IR1514A-E588 and of the 1974 replicated yield trials. Heritabilities associated with "protein per seed" were considerably higher and more stable than those associated with percent of brown rice protein. The studies imply that selection based on "protein per seed" is better than selection based on percent protein.

Agronomists applied defoliants to accelerate leaf senescence to determine if this would stimulate nitrogen transport from the leaves to the developing grains, thereby increasing protein content. The defoliant increased the grain protein content but unfortunately decreased the yield.

We found that the rate, time, and method of applying fertilizer all affect the protein content of rice (Table 16). Highest protein levels were obtained when the fertilizer was applied in split doses.

A study of enzymes of nitrogen metabolism in rice seedlings showed that they reached maximum levels per gram of fresh shoot or root at 7 to 10 days after germination. Rices that differ in grain protein content were verified to have similar levels of

Table 16. The effect of method of applying fertilizer on the average contents of brown rice protein of nine varieties. IRRI, 1974.

Nitrogen (kg/ha)	Method of application	Protein content[a] (%)		Yield (t/ha)	
		Dry season	Wet season	Dry season	Wet season[b]
0	–	7.8	7.0	4.1	3.9
150	Basal	8.7	8.7	7.6	4.9
150	Split[c]	9.4	9.4	7.8	5.2

[a]LSD (5%) = 0.6%. [b]Eight varieties. [c]70 kg/ha basal, 40 kg at 30 days after transplanting, and 40 kg at panicle initiation.

enzymes, indicating that reliable biochemical criteria for selecting grain protein are not applicable at the seedling stage.

High protein content *per se* was found not to be the major cause of the lower eating quality of a high-protein variety from Korea. This finding substantiates previous taste-panel evaluations of cooked rice of high- and low-protein sister lines.

Feeding trials using both raw rice in rats and cooked rice-based diets in preschool children indicated that the nutritional quality of the protein in high-protein rices was as good as that in ordinary rices.

MANAGEMENT OF PESTS

Disease control and management. We identified and classified 26 new pathogenic races of blast fungus disease *(Pyricularia oryzae)* in 1974, bringing the total number of races identified to 255.

We began to study how climatic factors, such as temperature, length and degree of wet period, and relative humidity, affect the disease in the tropics. We found that longer wet periods at lower temperatures favored infection (Table 17). Relative humidity did not affect colonization too much, although 85 percent RH was more favorable to the fungus than 50 percent.

We confirmed that rice plants grown in dry soil (50 centibars) and in very dry soil (75 cb) are more susceptible to blast than those grown under flooded conditions. The length of dew period was considerably greater under upland conditions (13 hours) than under lowland conditions (11 hours). The longer dew period may explain why blast is so common in upland rice.

In 1973, we first observed a particularly virulent strain of the bacterial blight pathogen, *Xanthomonas oryzae,* in Isabela province, Philippines. It partially breaks down the resistance of IR20 and other varieties that are resistant through dominant genes.

When we studied the more aggressive strain under field conditions in Isabela,

Table 17. Effect of temperature[a] and length of wet period on infection rate of blast fungus disease on the variety KTH 17. IRRI, 1974.

Wet period (h)	Blast lesions[b] (no./100 leaves)			
	21°/22°C	26°/28°C	32°/34°C	36°/37°C
4	0	0	0	0
8	49	46	4	3
12	285	116	12	4
24	1133	552	36	10

[a]Day/night temperature regimes in phytotron growth room. [b]Types 3 and 4.

Table 18. Comparative movement of the green leafhopper, which transmits tungro virus disease, on a resistant variety, IR8, and a susceptible variety, Taichung Native 1. IRRI, 1974.

Characteristic	Resistant (IR8)	Susceptible (TN1)
Insects that moved in 9 hours (%)	61	14
Movements per insect in 9-hour test (av. no.)	3.03	1.29
Av. duration of insect visit on seedling (h)	2.09	4.82

however, we found that it did not cause significant loss and does not presently appear to be a threat. Varieties with the recessive gene for resistance to bacterial blight (BJ2 and DZ192) remained resistant to this virulent strain.

We continued to study the epidemiology of tungro disease in 37 farmers' fields in Luzon, Philippines. Conditions tended to favor a tungro outbreak in Central Luzon in 1974 as populations of the insect vector, the green leafhopper *(Nephotettix virescens),* increased gradually until June. But extensive chemical control and heavy rains in August cut down the hopper population and no outbreak occurred.

We found that the transmission of tungro virus by green leafhoppers decreased when the temperatures were low because the insects' infectivity markedly decreased.

We artificially transferred insects from seedling to seedling under favorable temperature conditions and found that each insect infected only 40 seedlings per day. When the insects were caged with seedlings only, each insect infected 11 per day.

We studied the movement of tungro-viruliferous adults of green leafhoppers when caged with either IR8 (resistant to the insect) or Taichung Native 1 (susceptible). The insects moved more frequently on IR8 and remained on IR8 seedlings for a shorter period of time (Table 18). The insect apparently prefers the susceptible variety and feeds on it longer, thereby increasing the chances of viral infection.

An outbreak of grassy stunt virus disease occurred in Laguna province, Philippines, during 1973, but not in 1974. We compared the numbers of brown planthoppers *(Nilaparvata lugens),* the vector of grassy stunt, captured in light traps at the IRRI farm during the 2 years.

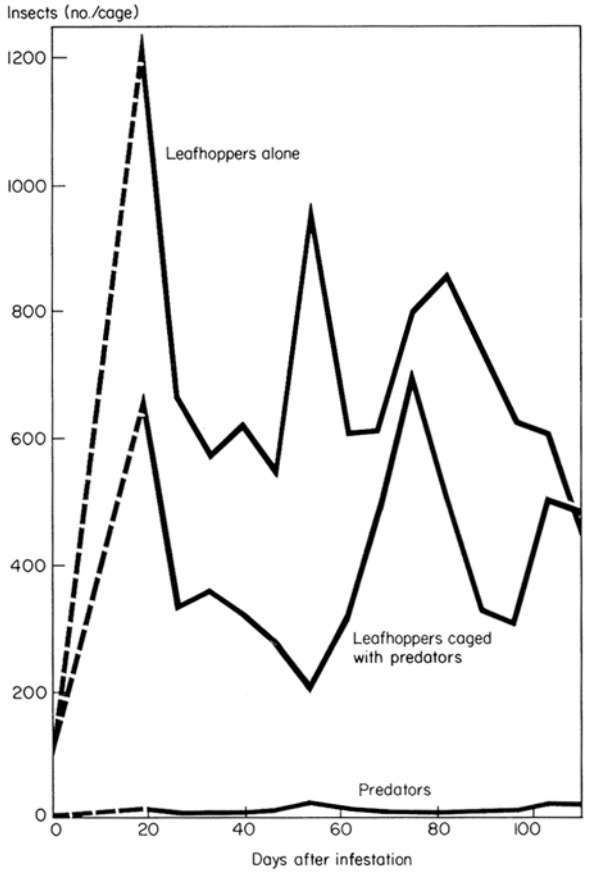
We found that 8,912 brown planthoppers per day were captured in 1973 vs. 1,195 in 1974. Further, 3.4 percent were infective in 1973 vs. 2.2 percent in 1974. We concluded that the population of the insect contributed more than the percentage of infective insects to outbreaks of grassy stunt.

Insect control. We continued to seek biological methods of controlling rice insects. We tested two commercial insect pathogen preparations of the bacterium *Bacillus thuringiensis* against larvae of the leaf folder and stem borer. Mortality against leaf folders was high for both preparations but only moderate against stem borer.

We found that the predator *Cyrtorhinus lividipennis,* when caged with green leafhoppers, significantly reduced the prey (fig. 20). A second predator, the spider *Lycosa pseudoannulata,* is even more effective against brown planthoppers, killing up to 25 nymphs, or 15 adults, per day.

We recorded that a foliar spray of Perthane was less toxic than other insecticides to predators of rice pests. A combination of plant resistance and predation better controlled brown planthoppers and green leafhoppers than either control method used alone.

Insecticides remain important tools even when new varieties with broad pest



20. Caging the predator *Cyrtorhinus lividipennis* with green leafhoppers significantly reduced the population density of the pests.

resistance are grown. The new varieties are not resistant to the whorl maggot and several minor pests.

In 1974, we screened 65 chemicals for their insecticidal properties against the brown planthopper and the green leafhopper. Carbofuran, MTMC, MIPC, and BPMC were effective against both insects.

We continued to find that applying insecticides in the root zone of the plants provides highly effective and long-lasting control of common insects such as stem borers, leafhoppers, planthoppers, and whorl maggots. We investigated several approaches to develop practical methods of application.

Weed control. The perennial sedge *Scirpus maritimus* is becoming one of the most serious weed problems in South and Southeast Asia. Ironically, water management and the control of other weeds have helped spread this fast-growing weed in lowland rice fields. When the farmer applies herbicides that control annual weeds, he creates conditions ideal for *Scirpus* or other perennial weeds to move in. Once established, *Scirpus* multiplies rapidly.

We experimented with the control of *Scirpus* by crop management. We planted alternative crops and tested cultural systems designed to discourage *Scirpus* and shift the weed population to weeds that are more easily controlled. Three cropping patterns

were used: continuous rice (lowland culture); corn-peanut intercrop combination followed by lowland rice (upland-lowland culture); and corn followed by two crops of direct-seeded bunded rice (rainfed rice culture).

In the continuous lowland plots, without weed control, the first crop of rice produced 3.2 t/ha and the second crop, which was heavily damaged by *Scirpus*, 1.6 t/ha. In the upland followed by lowland experiment, corn without weed control yielded 9,500 ears/ha and peanut, 146 kg/ha. The lowland rice sown immediately after corn harvest yielded 2.6 t/ha. Without weed control, yields were higher than in the continuous rice, primarily because the weeds had shifted away from difficult-to-control *Scirpus*.

In the plots where an upland crop, corn, was planted in the dry season, followed by two crops of rainfed bunded rice, without weed control, the rice crops produced nothing, primarily because of heavy competition with upland weeds. With this system of rice culture, however, weed population shifted from *Scirpus maritimus* to annual weeds that are easily controlled by herbicides.

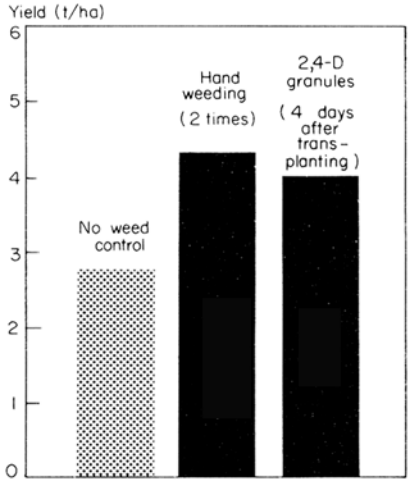
Such integrated weed management systems are possible and practical for small farmers, but they will require rice varieties that can compete with weeds. Such varieties will probably be intermediate in height, high in tillering capacity, high in total leaf area, and able to rapidly establish stands.

Interaction of weed control and fertilizer nitrogen applications. The response of rice to nitrogen fertilizers is markedly influenced by the adequacy of weed control.

In experiments conducted in farmers' fields in the Philippines, without weed control, the applied nitrogen increased grain yield by a maximum of 0.5 t/ha. However, without fertilizer nitrogen and with weed control, the grain yield increase was 1.5 t/ha, indicating the importance of weed control to increase fertilizer efficiency.

Herbicide screening. In 1974, we found that weed control, either by hand or by herbicides, increased yields on farmers' fields by about 1½ t/ha (fig. 21).

Agronomists put together herbicide trials and distributed them to cooperating scientists in 24 nations during 1974. The experiments were conducted under transplanted, direct-seeded, flooded, and upland conditions (Table 19).



21. Yield response to weed control by hand weeding or by herbicide in IR26 rice in farmers' fields in the Philippines.

Table 19. Cooperative weed control experiments. IRRI herbicide shipment for 1974.

Country	Sets (no.)			
	Transplanted	Broadcast	Upland	Total
Asia				
Bangladesh	1	–	1	2
Fiji	2	–	2	4
India	20	27	8	55
Indonesia	–	–	2	2
Iran	2	2	–	4
Korea	3	1	1	5
Malaysia	3	1	1	5
Nepal	3	2	4	9
Pakistan	1	1	–	2
Sri Lanka	4	4	3	11
Taiwan	1	1	1	3
Vietnam	4	5	1	10
Total	44	44	24	112
Africa				
Egypt	1	2	2	5
Liberia	15	–	15	30
Sudan	–	–	1	1
Tanzania	–	–	1	1
Uganda	–	–	1	1
Total	16	2	20	38
Grand total	60	46	44	150

Herbicides for more trials were sent to the West Africa Rice Development Association (WARDA), which used them in their weed programs. Several new herbicides looked promising in 1974.

MON 0358 controlled weeds most effectively in transplanted rainfed IR26 applied 4 days after transplanting (Table 20). Each of the new herbicides increased yields by at least 1 t/ha over the untreated control and gave yields similar to those of those of the handweeded plots.

MON 0358 also controlled weeds effectively while causing little crop injury in both direct-seeded flooded rice and in upland rice. The herbicide will be extensively evaluated in rainfed rice during the 1975 wet season.

WATER MANAGEMENT

The water management program focuses on improving the performance of canal irrigation systems. Most systems cannot provide adequate water to all farms within their service areas all of the time.

The most important reason is that most systems divert flowing river water into the canal laterals and onto farmers' fields, with essentially no water storage. But the river flow often drops off during the dry season, or during temporary dry periods in the wet season, and the systems do not receive enough water to supply all farms. Inadequate water results in yield losses. Those farms that are farthest away from the river generally receive the least water during periods of shortage.

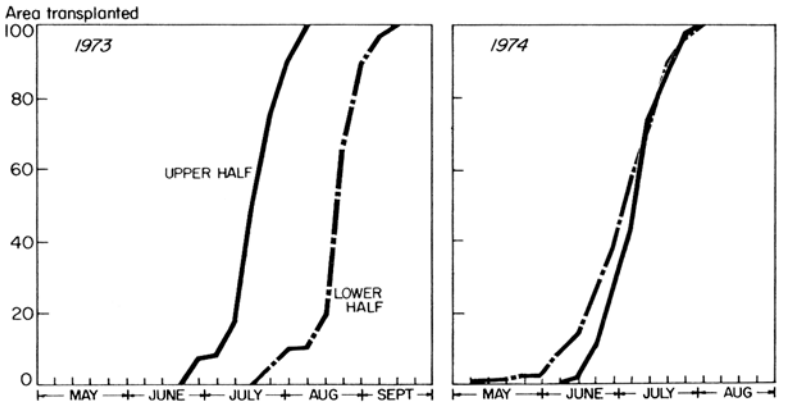
Table 20. Several new herbicides almost doubled yields of transplanted rainfed IR26 over the untreated control and gave yields about equal to those of hand weeding. Herbicides were applied at 4 days after transplanting (before weeds emerge) and at 10 days after transplanting (after weeds emerge). IRRI, 1974 wet season.

Treatment[a]	Rate (kg a.i./ha)	Grain yield (t/ha)
K–223/2, 4-D IPE (G)	1.5/0.75	4.6
MON 0358 (L)	0.5	4.2
MON 0358 (L)	1.0	4.4
MON 9358 (G)	0.5	4.0
MON 0358 (G)	1.0	4.7
MON 0358 (G) + 2, 4-D IPE (G)	0.5 + 0.5	4.0
MON 0358 (G) + 2, 4-D IPE (G)	1.0 + 0.5	4.0
RH 2915 (G)	0.5	4.0
RH 2915/2, 4-D IPE (G)	0.5 + 0.5	4.4
Benthiocarb/2, 4-D IPE (G)	1.0/0.5	3.3
2, 4-D IPE (G)	0.8	3.4
Hand weeding	twice	5.0
Untreated control		2.7

[a]G = granulated; WP = wettable powder; L = liquid.

In 1973, we undertook a 2-year cooperative project with the Philippine National Irrigation Administration to attempt to improve water management and distribution in Lateral C of the Peñaranda River Irrigation System, which serves 5,700 ha. During 1973–74, the system was operated in the traditional manner; as a result, farmers in the lower half of the system planted a month later than those closer to the source of water (fig. 22).

During the 1974–75 dry season, we tested a water distribution system to allow farmers in the lower canal reaches of the canal system to plant as early as those in the upper portion. Water was delivered to the lower half of the lateral for the first 2



22. During 1974, a water distribution system was tested that allowed farmers in the lower reaches of a Philippine canal system to plant as early as those in the upper regions by delivering water to the lower portion first. This permitted farmers in the lower regions to finish transplanting at about the same time as those in the upper region.

weeks, followed by alternating 4 days of delivery to the lower half and 3 days to the upper half. This permitted farmers in the lower half of the system to start preparing land and transplanting 2 weeks ahead of farmers in the upper half. This lead was steadily reduced once the farmers in the upper half started transplanting; the two groups finished together (fig. 22).

Because of additional water supplied from new irrigation development, the total area planted increased throughout the system. But the improved distribution of water reduced the difference in yields and total production among the four sections of the canal system.

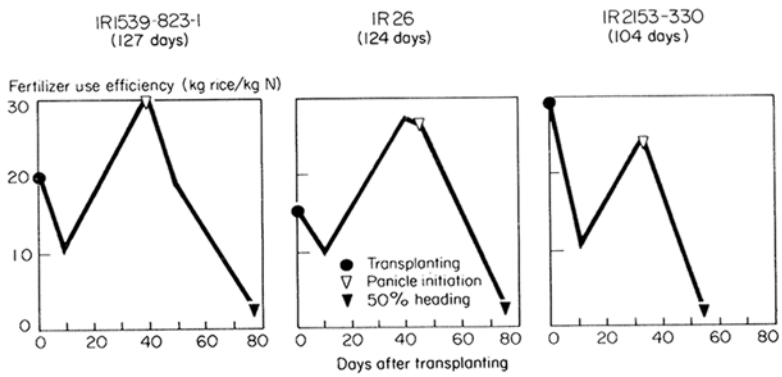
Rotational vs. continuous irrigation. Rotational and continuous irrigation were compared in the Upper Pampanga River Project. The rotational area following the UPRP design is a 50-ha block composed of five rotational units of 10 ha each. We chose three sites and compared yields on two 50-ha blocks at each site, one with and one without rotational irrigation. No yield benefits were obtained through the rotational scheme at any of the three sites.

Power sources. We also examined the effect of different power sources on the speed of land preparation when sufficient water was available. Four-wheel tractors with rotovators, two-wheel hand tillers, and carabaos were the most common power sources. Farmers who hired four-wheel tractors and rotovators averaged several more days to prepare their land than farmers who used carabao or two-wheel tillers, but the difference was not significant. Apparently, the ready availability of a power source under the direct control of the farmer helps speed up land preparation.

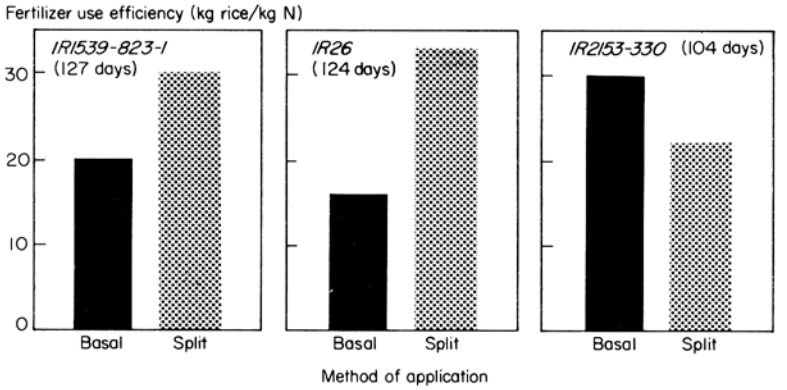
SOIL AND CROP MANAGEMENT

Because of high fertilizer prices, we focused our attention on means of maximizing yields with limited fertilizer. We learned that timing of nitrogen applications greatly influences the efficiency of this element. The yield of rice per kilogram of nitrogen applied was highest when the fertilizer was applied at panicle initiation or at transplanting time (fig. 23). We also found that split applications, part of the nitrogen applied at transplanting and part at panicle initiation, are more effective than single applications (fig. 24).

Nitrogen fixation. We expanded our studies on nitrogen fixation in the rice paddy. We measured the rhizosphere fixation of nitrogen in about 40 varieties and found considerable variation. We are determining the practical significance of rhizosphere fixation.



23. Time of N application. The efficiency of nitrogen fertilizer use was highest in terms of kilograms rice per kilogram nitrogen when 60 kg N/ha was applied at panicle initiation or at transplanting.



24. Method of N application. The efficiency of fertilizer use was higher when 60 kg N/ha (ammonium sulfate) was applied by split application (two doses) than when applied as a single basal application (broadcast and incorporated). Split applications for IR26 and IR1239-823-1 were applied half at 40 days after transplanting and half at panicle initiation; for IR2153-330, half was applied as basal and half at panicle initiation.

We used the N^{15} isotope to prove that atmospheric nitrogen moves down the stem of the rice plant to the roots, especially when the plants are at the heading stage (Table 21). This suggests the ready availability of nitrogen gas for fixation in the root zone of paddy rice.

We measured nitrogen fixation in a paddy field that had long been known to yield well without fertilizer nitrogen. We found the rate of nitrogen fixation to be about 30 kg/ha per crop. We suspect that most of the fixation was by blue-green algae.

Water management and nitrogen supply. We learned that drying a paddy field for a few days at mid-season increased rice yields on three different soils. This yield increase is thought to be due to the release of soil nitrogen which, when the soil is rewetted, is quickly absorbed by the plants.

Table 21. Movement of ^{15}N-enriched N_2 through rice plants into the rhizosphere. IRRI, 1974.

Rice plant	^{15}N in atm (%) at		
	0 h	3 h	6 h
		Shoot compartment	
Bonnet-73, tillering stage	21.6	21.7	21.3
Colusa, heading stage	13.2	10.7	
		Root compartment	
Bonnet-73, tillering stage	0.38	0.47	0.53
Colusa, heading stage	0.61	4.78	

Table 22. The nitrogen content of three soils after 16 seasons of dry or flood fallow. IRRI, 1974.

Soil	Soil nitrogen content (%)		Increased N[a] under flood fallow[b] (kg/ha)	Yield increase under flood fallow[b] (%)
	Dry fallow	Flood fallow		
Luisiana clay	0.131	0.199	85	69
Maahas clay	0.127	0.179	65	129
Clay loam	0.118	0.154	45	137

[a]Represents both savings of nitrogen through lower denitrification and increase through nitrogen fixation. [b]Over dry fallow.

We measured the soil nitrogen content after 16 seasons of differential water management treatment. Where the soil had been kept flooded during the normal fallow period, soil nitrogen content was about 30 percent higher than where dry fallow was practiced (Table 22). Long fallow periods probably result in more rapid mineralization and loss of nitrogen.

ENVIRONMENT AND ITS INFLUENCE

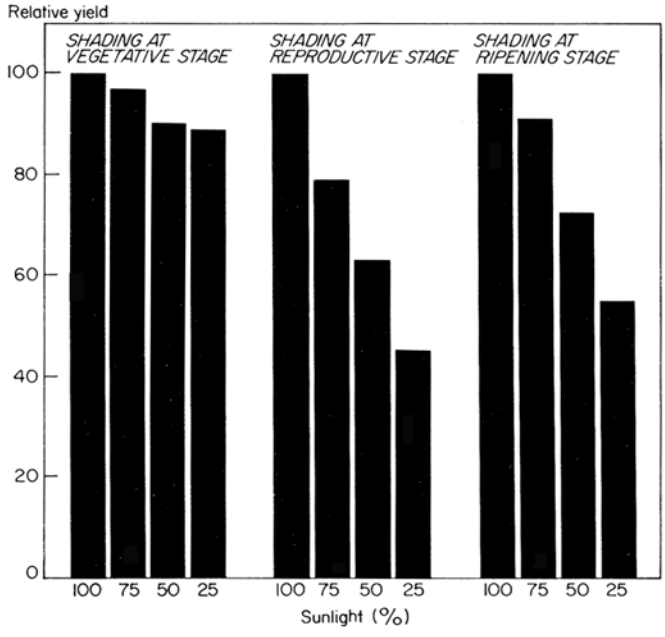
Our environmental studies focus on the responses of the rice plant to temperature, solar radiation, daylength, water supply, and soil density.

Shading experiments at different growth stages demonstrate that the amount of solar radiation is not too important during the vegetative stage (fig. 25). But at the reproductive stage, shading had a pronounced effect on spikelet number and, hence, on yield. Shading during the ripening stage also reduced yields by reducing the percentage of filled grains.

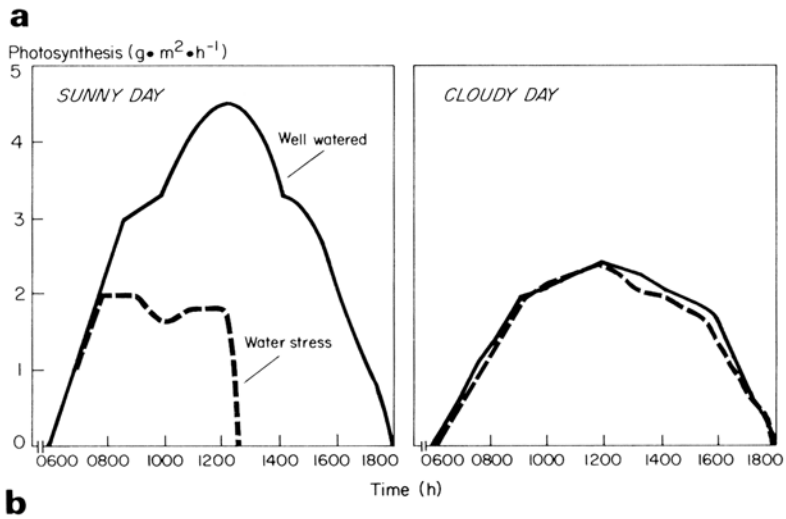
About 5 t/ha yield can be obtained with 300 $cal \cdot m^{-2} \cdot day^{-1}$, which is about average during the rainy season in many tropical Asian countries. Thus, the amount of solar radiation may not be the first limiting factor in farmers' fields in most tropical countries.

When water is limiting on cloudy days, the stomata (tiny pores on the leaf surface) remain open. On sunny days, however, they remain open only in the morning and close in the afternoon – perhaps to conserve plant moisture. A simulation model of crop photosynthesis indicates that a large portion of solar energy is wasted when the crop is under water stress on sunny days (fig. 26).

We found that crop photosynthesis on a cloudy day is 70 percent greater than on a sunny day under the same degree of water stress. Thus, when water supply is limited, not only is much solar energy wasted, but high solar radiation may also reduce



25. In shading experiments, scientists found that reducing the amount of solar radiation by shading did not affect yields much at early growth (vegetative) stage. Shading significantly reduced yields, however, at reproductive and ripening stages.



26 a. Scientists found that a large portion of solar energy is wasted and that crop photosynthesis is lower when the crop is under water stress on sunny days. Under equal water stress on cloudy days, crop photosynthesis continued throughout the day. **b.** This indicates that in areas where drought is common, growing rice under shade, such as under coconut trees, may have some advantage, Batangas province, Philippines.

crop growth. This indicates that in areas where drought is common, growing upland rice in a partial shade, such as under coconut trees, may have some advantages.

Temperature affects both growth duration and grain yield. We found that different varieties respond in different ways to temperature. Phytotron experiments indicate that temperature has little effect on growth duration within the day/night range of from 29°/21°C to 35°/27°C.

Temperature markedly affects growth duration, however, between 29°/21°C and 26°/18°C. A difference in temperature of only 3°C extended the growth duration of IR26 from 130 days (at 29°/21°C) to 165 days (at 26°/18°C).

Yield response to temperature varied greatly among varieties. Improved varieties appear to have greater yield stability over a moderately wide range of temperatures than traditional varieties.

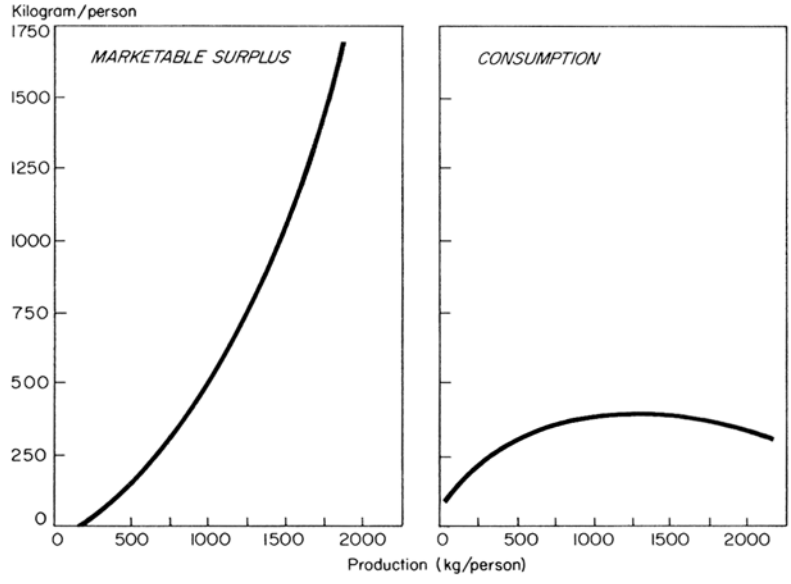
Most upland varieties tested were insensitive to daylength; only eight of 30 varieties tested were strongly sensitive. Photoperiod sensitivity may be one way that these upland varieties adapt to areas of bimodal rainfall pattern.

Marketable surplus. During 1973–74, we studied how farmers allocate their paddy after harvest – how much is saved for home consumption and how much is sold in the market. As anticipated, the farmer's first consideration was to save enough good paddy to feed his family through the next year. In an economy characterized by an underdeveloped rural marketing system, the paddy that enters the market is residual, and sold after household needs have been assured.

We analyzed several factors that affect home consumption and the marketable surplus – family size, quantity produced, price of consumer goods, and price of rice. Not surprisingly, we found consumption needs to be relatively insensitive to changes in the price of rice. The quantity available for the market, however, was affected markedly by the level of production. As output increases, the marketable surplus increases at a rate higher than output (fig. 27).

There is an obvious inverse relationship between family size and the amount sold. We found that most of the rice produced is consumed up to an annual per capita level of about 264 kg of paddy (or, roughly, 150 kg of milled rice), following which it levels off. The amount of rice sold in the market is a relatively low proportion of total output until household consumption requirements are satisfied.

This simple analysis implies that price subsidies to induce movement of more grain into the market may be less successful and more costly than programs designed to increase production, such as improved varieties and cultural practices. This would be particularly true when farm households are large and production is low.



27. Annual per capita consumption of rice in the Philippines was found to rise proportionately with total production up to 264 kg of paddy/person (about 150 kg of milled rice/person), after which market sales increased and rice consumption leveled off.

Quality of paddy rice. To determine the quality of paddy rice entering the pre-processing system, we gathered samples from 111 rice mills in three regions of the Philippines. We found significant quantities of immature, fermented, and cracked grains and red kernels in these samples – indications of improper drying and poor post-harvest management. We graded these samples and found that two-thirds were classified as substandard and only one-third were considered of high quality standard.

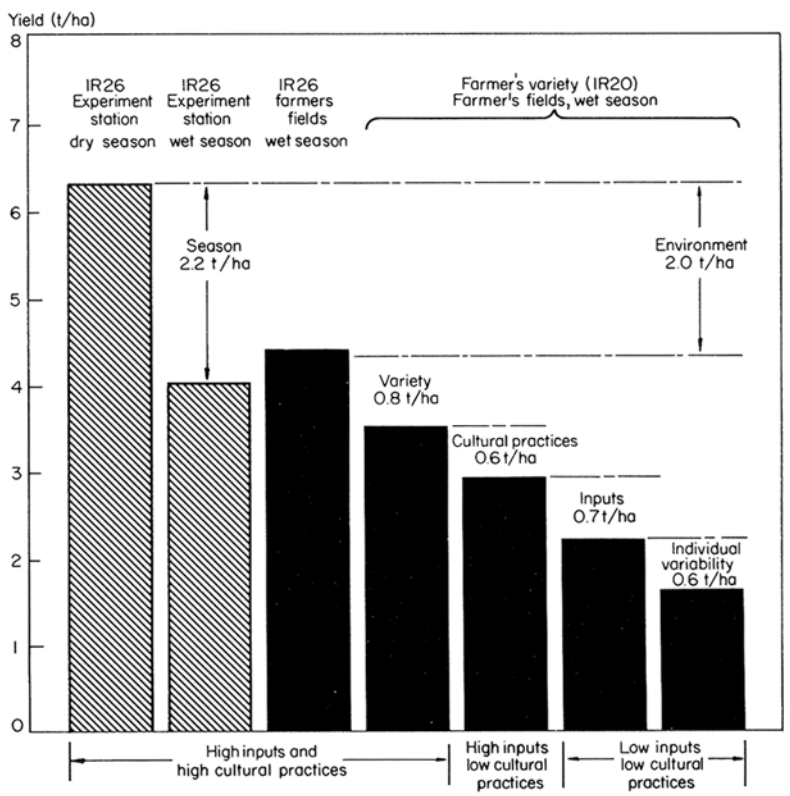
One conclusion is that Philippine farmers are delivering poor quality paddy to the processors, and saving the better paddy for home consumption.

This has serious implications for both the quantity and quality of milled rice entering the market. Even modern rice processing techniques can do little to alleviate defects resulting from a lack of suitable technology, management, and farm-level incentives.

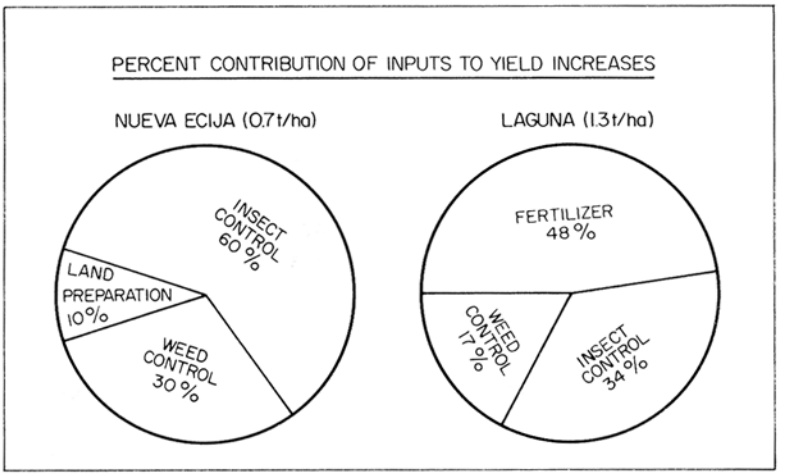
CONSTRAINTS TO INCREASED RICE PRODUCTION

We expanded our efforts in 1974 to understand why yields are not increasing faster on Asian rice farms. We focused our attention on the "gap" between farmers' actual yield and those that we know are possible with the new technology.

The methodology being developed consists of two parts. Agronomic experiments are conducted in farmers' fields to indicate *what* needed inputs are missing. At the same time and in the same area, socioeconomic surveys are being conducted to find out *why* the farmers may not be using the best inputs or cultural practices.



28. Using IR26 and an optimum level of chemical inputs and improved cultural practices, farmers in Nueva Ecija province, Philippines, produced yields comparable to those on experiment farms. But using IR20 (which has less pest resistance) and the same inputs and cultural practices, yields averaged 0.8 t/ha lower.



29. The contribution of selected inputs to gains in yield above the farmers' level at two locations. Insect control was a major factor in both provinces. Fertilizer did not increase yields in Nueva Ecija because of typhoon damage to the crops. Philippines, 1974 wet season.

Using this methodology, we were able to identify more clearly the nature of the yield gap in Nueva Ecija and Laguna provinces, Philippines.

We found that a major constraint on yields in farmers' fields in Nueva Ecija province was the variety used. IR26 produced an average of 1 t/ha more than the IR20 grown by the farmers, probably because of IR26's superior resistance to insects and diseases (fig. 28).

Insects and weeds were major constraints in both provinces. It should be emphasized, however, that the contributions of various inputs to yield gains differ from year to year. For example, fertilizer had no effect on yield in Nueva Ecija, probably because of heavy typhoon damage. Insecticides were quite important in Nueva Ecija and Laguna during the wet-season outbreak of brown planthoppers (fig. 29).

Our analysis points out that applying higher levels of inputs such as fertilizer, insecticides, and herbicides without giving attention to improved cultural practices and to the right choice of variety increased yields only modestly. In fact, yield increases due to higher levels of chemical inputs alone were generally not adequate to pay for these inputs.

In surveys conducted in 32 Asian villages, we found a close association between the adoption of labor-saving technology and farm size. Hand weeding was commonly practiced on all farms, while herbicides were mostly used on farms larger than 1 ha (Table 23). Tractors and threshers were common on larger farms. By contrast, other

Table 23. Percentage of farms of different sizes on which selected practices have been adopted in 32 selected Asian villages during 1971–72.

Farm size (ha)	Farms (%) that reported adoption of				
	Modern varieties	Weeding		Tractors	Threshers
		Hand	Herbicide		
Less than 1	87	82	6	13	36
1 to 3	89	83	20	41	43
More than 3	94	89	29	57	63

yield-increasing technologies – fertilizers, insecticides, and modern varieties – were widely used on all farms regardless of size.

We examined the adoption of new technology with respect to *relative* as well as *absolute* farm size, since relative size within the village may reflect the farmers' socio-economic position and, hence, his access to modern inputs. Except for one village in this study, the rate of adoption of new varieties was not affected much by farm size. Only in a limited number of villages in South Asia did farm size appear to significantly affect the sharing of the benefits of the new technology.

CROPPING SYSTEMS

We worked with cooperators in national programs to identify five macro agroclimatic zones in South and Southeast Asia suitable for multiple cropping. Within these zones, a network of six test sites was selected – three in the Philippines, two in Indonesia, and one in Bangladesh. More test sites will be identified in other nations.

A representative upland rice area with gently sloping, well-drained land represents one zone in Batangas province, Philippines. Research has been underway at this location for several years and was intensified in 1974.

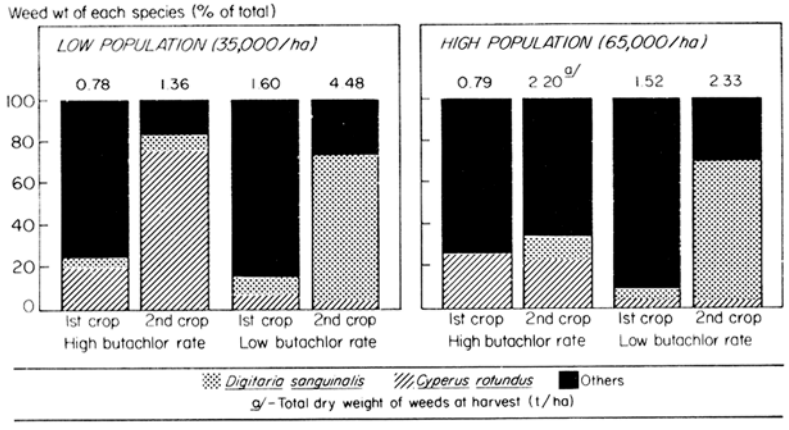
We conducted all of the cropping systems research in Batangas on small rice farmers' fields. Large research plots (1/10 ha each) are superimposed on the farmers' regular management and cultural systems. The farmers helped select the systems to be evaluated. Table 24 shows the number of farmer-participants in the various field investigations. The studies included surveys for basic economic as well as social information. We will analyze the data in 1975 and use it to help develop models for improved cropping systems.

Upland rice followed by corn or other field crops is a typical cropping sequence used in this area. Corn and rice intercropped produced a total yield of 5.3 t/ha. Corn alone produces 4.2 t/ha and rice alone, 3.8 t/ha.

Table 24. The number of farmer-participants in cropping systems research in Batangas, Philippines, during 1974.

		Farmer participants (no.)
Cropping pattern studies		40
Daily records of entire farm operations		50
Baseline economic surveys		50 (+ above – 90)
Social survey		237
Entomology studies (insect monitoring)		14
Agronomic experiments[a]		18
Intercropping	(9)	
Weed management	(6)	
Insect management	(5)	
Nitrogen response	(5)	
Nitrogen residual on following crop	(8)	
Sorghum patterns	(1)	
Mungbean residual effect	(1)	
Mungbean variety × nitrogen	(2)	
Rice variety trial	(3)	
Totals:		
Daily record keeping		90
Survey		427
Field experiments		76

[a] 15 were overlapped with studies of economic record-keeping.



30. High density planting and low rates of herbicide application prevented the build-up of the troublesome sedge *Cyperus rotundus* in a corn-rice rotation.

Weed management. Supporting research indicates that yields in upland rice areas can be improved considerably through weed management. Combinations of dense stands or leafy varieties, low rates of herbicide, and limited mechanical tillage gave good control from season to season and greatly reduced troublesome weeds such as *Cyperus rotundus* (fig. 30).

At low chemical rates, the predominant weed was *Digitaria sanguinalis* in the second crop season. This is an easy-to-control weed that affects crop yield comparatively less than *Cyperus.*

Herbicide screening showed that chemicals such as MON 0358 are promising.

Intercropping. Within the socioeconomic framework of small farms with limited power for tillage and little cash for inputs, we have found that intercropping (growing two or more compatible crops simultaneously in alternate rows) is often profitable.

Corn and upland rice combinations are consistent in their higher yields, giving a 50-percent advantage at optimum row spacings and plant populations. Corn and peanut are similarly productive over a range of planting arrangements on small, labor-intensive farms.

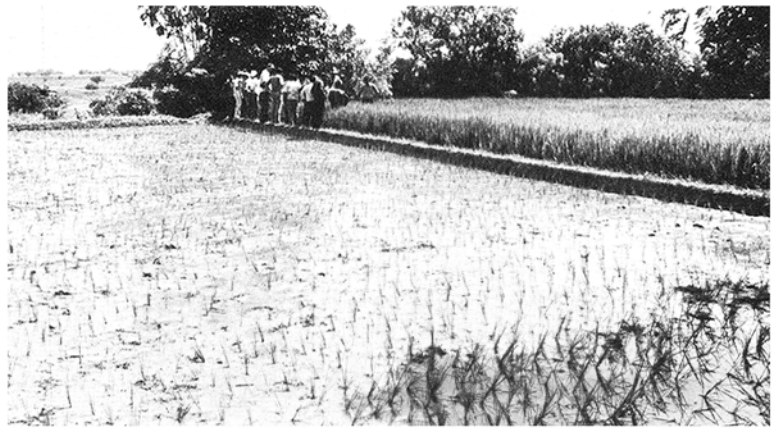
Productivity for corn and soybeans increased at 60 kg N/ha, 120 kg N/ha, and 180 kg N/ha, but not above or below those N levels.

Two-crop rice systems on rainfed land. Millions of hectares in rainfed areas of Asia produce only one crop of rice per year. Farmers transplant their single rice crops in the middle of the monsoon season on most of this land because they must wait until their paddies are waterlogged to plow and puddle the soil. After transplanting, most depend on paddy water to help control weeds.

This delay, coupled with the farmers' use of late-maturing traditional varieties, makes it impossible to grow more than one rice crop during a monsoon season.

We are taking advantage of four developments to try to change this situation and help farmers grow two crops where they have been growing only one: a) direct seeding of rice at the onset of the monsoon rains; b) early maturing improved rices; c) better technology for weed control; and d) timeliness and method of land preparation.

In cooperation with Philippine agencies, we have conducted extensive field trials and a 3-year pilot project to demonstrate the feasibility of two-crop systems in rainfed areas. In early May, we direct seeded short-seasoned varieties, using herbicides to control weeds. The first crop was taken off in mid-August and a second crop planted –



31. A direct-seeded rainfed rice crop (right) is almost ready for harvest by the time that surrounding crops (left) have just been transplanted. Bulacan, Central Luzon, Philippines.

either of rice or an upland crop (fig. 31). These second crops were ready for harvest about the same time – or even before – the traditional farmer could harvest his first, and only, crop.

The Philippine government has developed a national program to encourage the two-crop system by direct seeding the first crop. Some 25,000 ha were included in the 1974 phase. The farmers' experiences have helped in our applied research to improve the system.

Direct seeding technology. In 1974, we learned that the success of the direct-seeding technology depends on a number of management factors. Land must be initially prepared after harvesting the wet-season crop so that farmers can mechanically control weeds through the dry season. They can then seed early enough to use the first monsoon rains at the start of the following wet season.

Farmers who sowed their rice before May 20 harvested bumper crops, averaging 3.4 t/ha, compared with 1.9 t/ha for transplanted crops. But farmers that direct seeded after May 20 generally had lower yields than those who transplanted.

We also learned that the herbicides must be applied early to direct-seeded rice. If the early rains are sufficient to germinate the rice seeds, they will also germinate the buried weed seeds; the herbicide must be on the soil to kill emerging weeds.

Butachlor was found to be the most effective herbicide but *only if applied at the time of seeding, with the early monsoon rains.*

Butachlor controlled weeds effectively on the land that was properly prepared and direct seeded in wet soil before weed emergence.

Direct seeding has great potential in irrigated areas, even where irrigation water is only available to supplement rainfall. The new technology also has potential for other Asian countries, Africa, and South America. We hope to cooperate with scientists in national programs to further evaluate that potential through applied research.

MACHINERY DEVELOPMENT AND ECONOMICS

Production of the 5- to 7-hp power tiller continued to steadily increase in the Philippines; six companies produced 5,000 tillers during 1974. Prototype power tillers have been fabricated by companies in Vietnam, Thailand, and Sri Lanka, and have been evaluated through IRRI's cooperative machinery testing programs. Manufacturers in Vietnam, Sri Lanka, and Thailand have begun regular commercial production of IRRI tillers.

A larger power tiller with an 8.5-hp diesel engine has been developed and released for test production to five companies in the Philippines. This machine was designed for farmers who need features not found on the smaller 5- to 7-hp tiller. It has steering clutches and three forward gears and one reverse.

The axial flow thresher, which was introduced in 1973, has rapidly gone into commercial production. Ten Philippine companies now manufacture the machine; most are selling as many machines as they can produce. It has been well received for custom threshing operations across the Philippines. Prototype axial flow threshers have been fabricated by companies in Vietnam, Thailand, Sri Lanka, Indonesia, India, Pakistan, Ghana, and Ecuador; the machines are being evaluated by cooperating engineers and commercial production has started in some of these countries. An Indian company is testing 15 axial flow threshers before starting regular production. This company is also modifying the machine for wheat threshing, because demand is high for wheat threshers.

IRRI agronomy and entomology experiments indicate that the efficiency of fertilizer and insecticide use can be substantially improved by placing the chemicals below the surface of the puddled soil. We evaluated several concepts for deep-placement applicators and developed a liquid applicator that injects the chemical into the mud and an inexpensive push-type granular applicator that places fertilizer at 10-12 cm depth in wet fields.

The power weeder continues to sell strongly in Japan. The manufacturer has developed 14 attachments that equip this machine to prepare both paddy and upland fields. Two more Japanese companies will soon begin production.

About 7,000 IRRI-designed machines were produced in 1974 by Philippine firms. The companies report that 700 additional workers have been employed to manufacture IRRI-designed farm equipment, with an additional average capital investment of US$200 per job.

Since the first IRRI machine was released in 1970, more than 22,000 IRRI-designed machines have been produced by cooperating machinery manufacturers in Asia.

Markets are increasing across Asia, and opening in Latin America and Africa, for the 5- to 7-hp tiller, axial flow thresher, batch dryer, power weeder, and paddy seeder.

INTERNATIONAL PROGRAMS

The ultimate measure of IRRI's contribution to increased worldwide rice production and quality is the extent that we are able to influence and assist national rice research and production programs to attain their goals. Through our cooperative and collaborative programs with rice-growing countries, IRRI is helping to strengthen national rice improvement capabilities.

IRRI continues to coordinate several international testing programs, such as the International Rice Observational Nursery; the International Rice Yield Nursery; and the International Bacterial Blight Nursery. These are being expanded and intensified with an anticipated grant from the United Nations Development Programme for the International Rice Testing Program.

Eleven countries cooperated in evaluating IRRI-designed machinery in 1974. They are India, Indonesia, Vietnam, Korea, Pakistan, Malaysia, Philippines, Ecuador, Guatemala, Ghana, and Thailand.

The groundwork was laid in 1974 for a regional cooperative program on deep water rice research. Plans are for the project to be based in Thailand, and for scientists to cooperate in Bangladesh, Vietnam, India, Burma, and Indonesia.

During 1974, IRRI scientists participated as members of collaborative research teams in Bangladesh, India, Sri Lanka, Indonesia, Thailand, Egypt, Vietnam, and the Philippines.

ASSOCIATED FORMAL TRAINING

IRRI's training programs provide trained people for all four categories of our international cooperative activities: 1) collaborative research; 2) international research networks; 3) strengthening of national capabilities; and 4) coupling of research and action programs. Opportunities are available for degree and non-degree research and production programs.

During 1974, 157 research scholars and fellows and production trainees from 24 countries studied at IRRI. The participants were staff members of government agencies and institutions concerned with rice research and extension, particularly in countries where IRRI has cooperative or collaborative projects. The institute provided 80 man-years of training during the year.

INFORMATION DISSEMINATION

During 1974, the IRRI Office of Information Services (OIS) published the following: *An Agro-Climatic Classification for Evaluating Cropping Systems Potentials in Southeast Asian Rice-Growing Regions; Planting Rice; Research Highlights for 1973; the 1973 Annual Report;* and four issues of the *IRRI Reporter.*

We reprinted five publications, including 40,000 additional copies of *Field Problems of Tropical Rice.*

All back issues of the *IRRI Annual Report* were duplicated on microfiche and made available.

To familiarize our thousands of visitors with IRRI's purpose and programs, we prepared and taped a short audio-visual presentation with synchronized slides.

EXPERIMENTAL FARM

The current experimental area of about 65 ha was increased about three times with the addition of 192 ha made available by the Philippine government through the University of the Philippines at Los Baños. The new area is composed of 114 ha of upland fields and 78 ha of lowland rice paddies.

During the 1974 dry season, we multiplied seed of IR26, the Korean varieties Milyang and Suwon 242, and the experimental line IR1514A-E597. In the wet season, we planted almost 25 ha to IR26, IR28, IR29, IR30, and the lines IR2071-88-3, IR2035-290-2-1-2, IR2061-213-17, and IR2061-255-3-6-3.

Genetic evaluation and utilization (GEU) program

Introduction

52 NEW VARIETIES
52 FARMER ACCEPTANCE OF IR26
53 EXCHANGE OF GERM PLASM
53 IRRI LINES NAMED IN OTHER COUNTRIES
53 BREEDING PROGRAM
54 PROGRESS IN DEVELOPING LINES WITH MULTIPLE RESISTANCE

NEW VARIETIES *(Plant Breeding Department)*

IRRI named three early maturing varieties – IR28, IR29, and IR30 – in 1974. These varieties have resistance to major diseases and insects, good grain quality, and high yield potential. IR28 and IR30 mature in 105 days and IR29 matures in 115 days. These short-season varieties should enable farmers in some areas to adopt multiple cropping systems – growing successive crops of rice, or upland cash crops, after the rice harvests. All three varieties are insensitive to changes in photoperiod.

IR28, IR29, and IR30 are the only known rice varieties that are highly resistant to grassy stunt virus, which is becoming a serious disease in many countries. They inherit this resistance from *Oryza nivara*, a wild species of rice from central India. The varieties are also resistant to bacterial blight and tungro diseases, as well as to brown planthoppers (the vector of grassy stunt), and to green leafhoppers, and are moderately resistant to stem borers. IR28 and IR29 are resistant to blast, but IR30 is moderately susceptible (Table 1).

In the 1974 dry season at IRRI, IR28 yielded 5.4 tons per hectare; IR29, 5.2 t/ha; and IR30, 6.7 t/ha. In the 1974 wet season, IR28 yielded 4.7 t/ha; IR29, 4.9 t/ha; and IR30, 4.8 t/ha.

IR28 has long, slender, and translucent grains of high amylose content, that cook light and fluffy. Its eating quality is comparable to that of IR22. IR30 has medium-long, slender, and translucent grains of high amylose content and low gel consistency. It cooks soft and moist, and its eating quality is similar to that of IR26.

IR29 is the first IRRI variety with glutinous or waxy endosperm. Glutinous rice cooks soft and sticky. It is the staple food in Laos and northeast Thailand and is used across Asia in special preparations, such as cakes and pastries. Beginning with IR29, IRRI will name its future glutinous varieties with odd numbers.

The new varieties have fairly broad spectrums of tolerance to adverse soil conditions. IR28 is moderately tolerant of salinity and alkalinity, and tolerant of zinc deficiency and phosphorus deficiency. IR29 is moderately susceptible to salinity and alkalinity, but tolerant of zinc deficiency and phosphorus deficiency. IR30 is moderately tolerant of salinity, alkalinity, and phosphorus deficiency, and is tolerant of zinc deficiency (Table 1).

IR28 and IR29 resulted from a complex cross, Peta[3]/TN1/ /Gam Pai 15/4/TKM 6[2]/TN1/ /IR8/Tadukan///IR24[2]/*O. nivara*. IR28 was previously known by its experimental number, IR2061-214-3-8-2, and IR29 as IR2061-464-4-14-1. IR30 resulted from the cross IR26//IR20[3]/*O. nivara*. Its experimental line number was IR2153-159-1-4.

FARMER ACCEPTANCE OF IR26

Philippine farmers generally seem to be satisfied with the yielding ability of IR26 under field conditions, and are enthusiastically adopting it. About 250,000 ha were planted in the Philippines during the 1974 wet season. Both brown planthopper

Table 1. Resistance ratings of IRRI varieties.

Variety	Diseases				Insects			Soil problems			
	Blast	Bacterial blight	Grassy stunt	Tungro	Green leafhopper	Brown planthopper	Stem borer	Alkali injury	Salt injury	Zinc deficiency	Phosphorus deficiency
IR8	MR	S	S	S	R	S	MS	S	MR	S	MR
IR5	S	S	S	S	R	S	S	S	MR	R	MR
IR20	MR	R	S	R	R	S	MR	S	MR	R	R
IR22	S	R	S	S	S	S	S	S	S	S	MR
IR24	S	S	S	MR	R	S	S	MR	MR	S	MR
IR26	MR	R	MS	R	R	R	MR	MR	MR	S	R
IR28	R	R	R	R	R	R	MR	MR	MR	R	R
IR29	R	R	R	R	R	R	MR	S	MS	R	R
IR30	MS	R	R	R	R	R	MR	MR	MR	R	MR

R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible.

Table 2. IRRI lines named as varieties in other countries during 1974.

IRRI line	Cross	Name	Country where named
IR5-198-1-1	Peta/Tangkai Rotan	ROK-6	Sierra Leone
IR5-250	Peta/Tangkai Rotan	SM 1	Malaysia
IR532E-208	IR262-24/ TKM 6	N.G. 6637	Papua New Guinea
IR665-4-5-5	IR8//Peta[5]/ Belle Patna	–	Brazil
IR747B2-6-3	TKM 6[2]/TN1	GPL 1	Solomon Islands
IR837-20-3-6	IR262-43/N.S. Pah Tawng	Piedras Negras A74	Mexico
IR837-46-2	IR262-43/N.S. Pah Tawng	Bomoa A74	Mexico
IR841-36-2	IR262-43/ Khao Dawk Mali	Abbasi 72	Pakistan
IR841-63-5	IR262-43/ Khao Dawk Mali	–	Brazil
IR822-81-2	IR8[2]/Pankhari 203	CR 1113	Costa Rica
IR1614-138-3-1	IR22//Mudgo/ IR8	GPL 2	Solomon Islands

populations and insecticide use are declining as IR26 and the experimental line IR1561-228-3-3 (also resistant to brown planthoppers) are widely planted.

At the time that IR26 was approved for cultivation in Vietnam, in November, 1974, about 30,000 ha had already been planted to it. IR26 is being multiplied in Indonesia, Sri Lanka, and Kerala state, India, and is being extensively tested in Burma, Bangladesh, India, Sri Lanka, and Indonesia.

EXCHANGE OF GERM PLASM

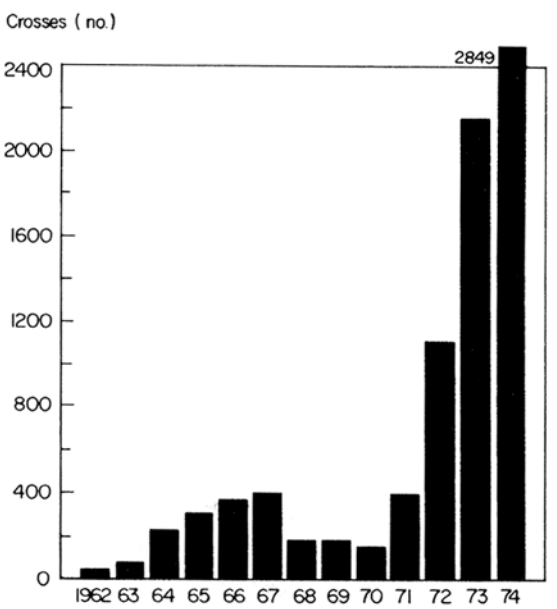
We continued to supply improved breeding lines to scientists across the rice-growing world. We sent 11,492 seed packages of breeding lines to 57 countries in 1974.

IRRI LINES NAMED IN OTHER COUNTRIES.

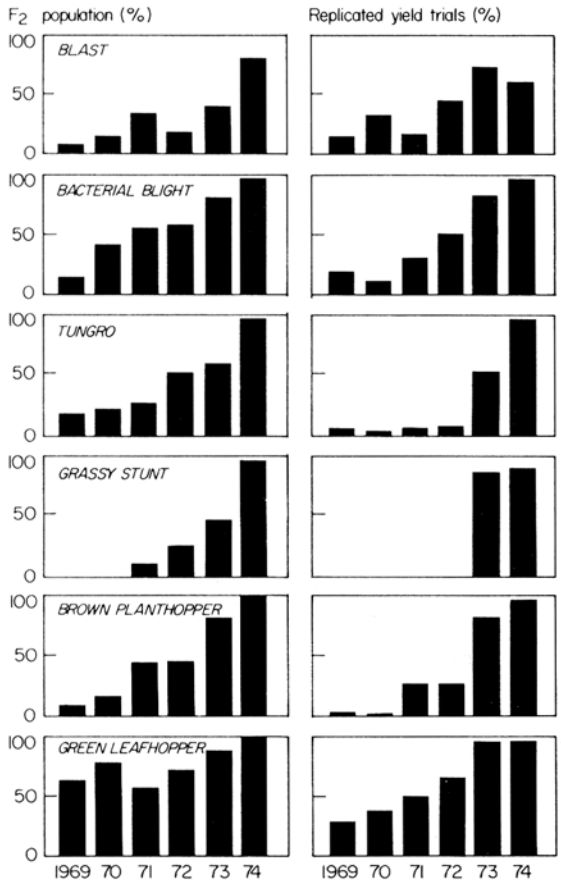
Eleven IRRI lines were named as varieties in other countries during 1974 (Table 2). This brings to 36 the number of IRRI lines named in other countries. IR5-198-1-1 was named as a variety in Sierra Leone, where it is adapted to growing under lowland swampy conditions. IR665-4-5-5 and IR841-63-5, which have long and slender grains of excellent quality, were released for cultivation in Brazil. IR747B2-6-3 and IR1614-138-3-1 were named in the British Solomon Islands. These two lines are resistant to brown planthoppers, a serious pest in that country. IR837-20-3-6 and IR837-46-2, two lines with excellent long and slender grains and high yield potential, were named in Mexico. IR841-36.2, an early maturing line, was named in Pakistan. IR822-81-2 was released in Costa Rica, where it is highly resistant to blast. IR532E-208 was released for cultivation in Papua, New Guinea. Malaysia approved IR5-250, a sister line of IR5 and Bahagia, for general cultivation.

BREEDING PROGRAM

The crossing program was further expanded during 1974 (fig. 1). Of the 2,849 crosses made, 1,762 were single crosses, 741 were topcrosses, and 346



1. Crosses accomplished in the IRRI breeding program.



2. Changes in proportion of F_2 populations and entries in the replicated yield trials with resistance to important insects and diseases.

were doublecrosses. Several new sources of resistance to diseases and insects were used in the crossing program. Similarly, we crossed improved disease- and insect-resistant breeding lines with several tall varieties that have high protein content or tolerance to drought, adverse soils, cold temperatures, or floods.

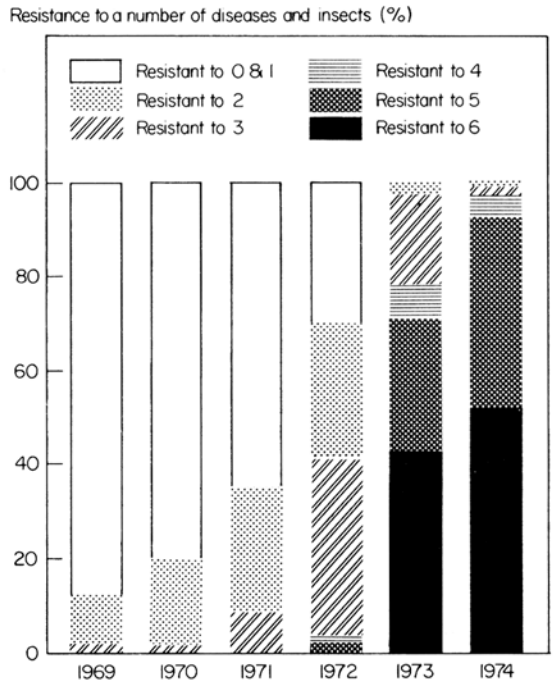
We grew F_2 populations from 316 cross combinations, most without pesticide protection. During the 1974 dry season, severe natural pressures of brown planthoppers and grassy stunt virus disease helped eliminate susceptible genotypes. But during the wet season, farmers in neighboring Laguna province had planted the resistant variety IR26 so widely that the brown planthopper population declined to negligible numbers in farmers' fields, as well as at IRRI. Consequently, we could not screen for resistance to brown planthoppers and grassy stunt under field conditions at the IRRI farm.

We grew 45,302 pedigree rows, most without chemical protection. In the dry season, we screened the pedigree rows in the field for bacterial blight, brown planthopper, and grassy stunt resistance. During the wet season, we screened for bacterial blight and *Cercospora* resistance.

We evaluated the yield and protein content of 414 dry-season and 368 wet-season entries in the replicated yield trials, and of more than 1,000 breeding lines in the wet- and dry-season observational nurseries.

PROGRESS IN DEVELOPING LINES WITH MULTIPLE RESISTANCE

Numerous lines have been developed with combined resistance to several diseases and insects. These lines were extensively used in the crossing program. Eighty percent of the F_2 populations grown during the 1974 wet season were either



3. Changes in proportion of entries in IRRI's annual replicated yield trials with multiple resistance to important diseases and insects (blast, bacterial blight, tungro, grassy stunt, brown planthopper, and green leafhopper). Each year's trial consisted of about 185 entries.

Table 3. Data on agronomic characteristics, grain quality, and disease and insect resistance of promising breeding lines.

Selection	Cross	Growth duration (days)	Amylose content (%)	Gel. temp.	Protein content (%)	Reaction[a] to							
						Blast	Bacterial blight	Tungro	Grassy stunt	Green leaf hopper	Brown plant hopper	Gall midge	Stem borer
IR1632-93-2-2	IR24/Co 13	112	28	L	8.0	S	R	R	S	R	R	–	M
IR1702-74-3-2[b]	IR24/PTB 18	125	26	L	8.6	MR	S	R	S	R	R	R	MR
IR2031-724-2-3	IR24[3]/*O. nivara*//IR400-28-4-5/Tetep///IR1330-3-3-2	120	27	L	8.5	S	R	S	R	R	R	S	MR
IR2035-290-2-1	IR400-28/Tetep//IR1364-37///IR1539-260//IR24[3]/*O. nivara*	130	26	L	8.0	R	S	R	R	R	R	S	MS
IR2058-78-1-3	IR400-28/Tetep//IR1364-37///IR1366-120/IR1539-111	120	27	L	8.3	R	R	R	S	R	R	S	MR
IR2061-213-2-17	IR833-6-2///IR1561-149//IR24[4]/*O. nivara*	125	27	L	8.0	R	R	R	R	R	R	S	MS
IR2070-423-2-5	IR20[2]/*O. nivara*//CR94-13	125	27	L	8.4	MR	R	R	R	R	R	–	MR
IR2070-414-3-6	IR20[2]/*O. nivara*//CR94-13	115	28	L	9.2	MR	R	R	R	R	R	R	MR
IR2070-747-6-6[b]	IR20[2]/*O. nivara*//CR94-13	140	28	L	8.8	MR	R	R	R	R	R	R	MR
IR2071-77-9-3	IR1561-228//IR24[4]/*O. nivara*///CR94-13	125	28	L	8.6	MR	R	R	R	R	R	R	MR
IR2071-588-5-6	IR1561-228//IR24[4]/*O. nivara*///CR94-13	130	26	L	9.5	MR	R	R	R	R	R	–	MR
IR2071-625-1	IR1561-228//IR24[4]/*O. nivara*///CR94-13	105	25	L	8.2	MR	R	R	R	R	R	–	MS
IR2071-669-3-4	IR1561-228//IR24[4]/*O. nivara*///CR94-13	160	27	L	8.8	R	R	R	R	R	R	—	MR
IR2151-957-5-3	IR26//IR20[3]/*O. nivara*	120	27	L	7.9	S	R	R	R	R	R	S	MR
IR2153-26-3-5[c]	IR26//IR20[4]/*O. nivara*	120	27	L	8.4	S	R	R	R	R	R	–	MR
IR2153-43-2-5[c]	IR26//IR20[4]/*O. nivara*	120	27	L	7.4	S	R	R	R	R	R	–	MR
IR2153-338-3	IR26//IR20[4]/*O. nivara*	110	26	L	8.2	S	R	R	R	R	R	–	MR

[a]R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible. [b]Resistant to iron toxicity. [c]Resistant to salinity.

homozygous resistant to blast or were segregating for resistance (fig. 2). The proportion of F_2 populations that were either segregating or homozygous for resistance to bacterial blight was 95.6 percent; for tungro resistance, 94.5 percent; for grassy stunt resistance, 86.4 percent; for brown planthopper

resistance, 100 percent; and for green leafhopper resistance, 100 percent. A large majority of the F_2 populations grown during the year were produced to combine resistance to all the major diseases and insects, along with other traits.

The proportion of entries with multiple resistance in the replicated yield trials planted during the 1974 wet season was also higher than that in the 1973 wet season. A great majority of the entries were resistant to four, five, or six diseases and insects (fig. 3).

Outstanding selections with multiple resistance are listed in Table 3. These selections are being tested in various coordinated trials in the Philippines, and many are being tested in other countries through the International Rice Yield Nursery. Numerous sister selections of these lines have similar levels of disease and insect resistance. At least four of these lines are resistant to gall midge. Two of them, IR2153-26-3-5 and IR2153-43-2-5, are tolerant of salinity and another two, IR1702-74-3-2 and IR2070-747-6, are tolerant of iron toxicity. Some of these lines have protein contents significantly higher than that of the IR20 check. They vary in growth duration from 105 to 160 days. Plant statures also differ; some lines are taller than others. IR2061-213-2-17, like IR5, is of intermediate height and should be particularly adaptable to areas where farmers prefer intermediate-statured varieties.

Genetic evaluation and utilization (GEU) program

Germ plasm collection and preservation

Plant Breeding Department

During 1974 different rice experiment stations furnished 3,057 rice seed samples to the International Rice Research Institute (IRRI). The National Institute of Genetics of Japan made available to IRRI a collection of 1,135 varieties of rice previously gathered from the Indochina region by H. Hamada of Japan in the late 1950's. The Bangladesh Rice Research Institute (BRRI) provided seed stocks of 1,710 pure lines of aus, boro, transplanted aman, and broadcasted aman or floating types of rice. IRRI Director N. C. Brady, as a member of a U.S. plant science group visiting the People's Republic of China, brought back 38 cultivars from that country. However, many of the samples received in 1974 by the Institute were either duplicate accessions or replacements for non-viable samples received earlier. Only 1,280 samples and an undetermined number of the pure lines were actually new accessions – the original names of the pure lines were no longer available.

The IRRI staff maintained its contact with rice researchers, botanists, missionaries, and U.S. Peace Corps members in various countries and provided technical assistance to field collection operations. Of the 1,603 recently collected *Oryza sativa* samples received in 1974, 225 came from Liberia, 288 from East Malaysia, 735 from Pakistan, 47 from the Philippines, 127 from Thailand, and 181 from South Vietnam (Table 1). About 150 of these samples were found to be duplicate accessions. Additionally, UNDP/FAO officers in Liberia collected and forwarded to IRRI 564 samples of African rice (*O. glaberrima*).

IRRI's field advisor on rice collection participated in the collection operations in Bangladesh (April to May for aus varieties, July to August for aus and aman varieties, mid-November for the rayadas in deep-water areas), Burma (November to December), and Indonesia (February to March in Sumatra, and September to October in Sulawesi), and gathered 1,271 samples. An additional 1,131 samples were collected by research and extension workers in Bangladesh and Indonesia (Table 1). About 840 samples were special types – tolerant to cool temperatures at high elevations, resistant to drought in upland culture, or adapted to deep water. Indonesian collectors submitted 1,794 samples of cultivars and two samples of wild species and an additional 128 samples were received from Bangladesh.

Table 1. Field collection of *O. sativa* in five collaborating Asian countries during 1974.

Country	Samples collected (no.)	
	Directly participated	Indirectly participated
Bangladesh	234	548
Burma	110	
Indonesia	927	583
Malaysia, E.		288
Philippines		59
Total	1271	1478

Since the field collections began in 1971, 5,089 samples were collected in five Asian countries with direct participation of the IRRI, while another 7,748 samples were secured from local workers in nine Asian countries with technical assistance from IRRI. Twelve countries in Asia collaborated with IRRI on the genetic conservation program. Among the samples collected from farmers' fields or acquired by correspondence, 3,931 were special types (Table 2). Eighty-two wild taxa were collected during the same period.

By the end of 1974, IRRI's germ plasm bank contained approximately 35,000 cultivars and a second collection of 3,000 entries, consisting of African rices, genetic testers, and wild taxa.

Seeds were grown for increase and characterization in both the dry season (4,508 plots) and wet season (3,168 plots). The dry-season plantings were damaged by heavy infestations of brown planthopper and grassy stunt virus. Very little seed was harvested from the 275 highly susceptible accessions. The 628 strongly photoperiod-sensitive cultivars from Khmer, Malaysia, and Vietnam did not flower during the dry season. Remnant plants were potted and treated under 10-hour daylength to induce flowering. Subsequently, an extra 909 photoperiod-sensitive accessions were planted in November 1974, primarily for seed increase.

Seeds of depleted stocks were grown in 1,047 plots to replenish the supply. Duplicate seed samples of 6,912 accessions were shipped to the U.S. National Seed Storage Laboratory in Ft. Collins, Colorado, for safe keeping.

Recording the various morpho-agronomic characteristics of 3,912 accessions brought the total

number of accessions that have been systematically described to 22,426.

As a service to overseas rice breeders and geneticists, 2,603 seed samples of various cultivars were sent to 43 countries in response to 142 requests. Additionally, 167 seed packages of wild taxa were furnished to 11 foreign researchers. Seeds of 140 wild taxa were rejuvenated to replenish depleted seed stocks.

IRRI research departments received 20,498 seed samples in 108 batches for the Genetic Evaluation and Utilization (GEU) program. When sufficient quantities of newly collected seeds became available, the special types were channeled into the screening tests for tolerance to deep water, field resistance to drought, or tolerance to adverse soil factors. The lists of new accessions reputed to have tolerance or resistance to ecological stresses or edaphic factors were updated to expedite the introduction of seeds into different testing and screening programs.

Thousands of newly acquired samples were stored temporarily because the physical facilities and technical manpower were insufficient to handle the seed increase, characterization, and storage of the new accessions coming from the expanded field collection program. Hundreds of potentially duplicate accessions must be planted adjacent to earlier acquisitions that have the same or a similar name for comparison and possible removal where appropriate. The cold storage facilities were filled to capacity, and 6,712 accessions could not be properly stored, reflecting the serious need for additional seed storage space. The viability of 11-year-old seed samples in cold seed storage is declining and rejuvenation will be necessary within the next 1-2 years.

Table 2. Special types of rice varieties and wild taxa acquired between July 1972 and December 1974.

Reported feature	Samples (no.)
Tolerance to salinity	124
Tolerance to acid soils (flooded)	150
Tolerance to alkaline soils	11
Upland types	2425
Floating types	518
High-elevation types	600
Resistance to nematodes	5
Escape from rodent damage	9
Aromatic types	89
(Total for special types)	(3931)
Wild taxa	82

Genetic evaluation and utilization (GEU) program

Agronomic characteristics

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68 INHERITANCE OF PHOTOPERIOD RESPONSES

The agronomic characteristics, nitrogen responses, and field reactions to disease of varieties or lines developed by IRRI and other breeders were studied in experiments conducted in the Philippines at the IRRI farm, in experiment stations in cooperation with the Philippine Bureau of Plant Industry (BPI), and in farmers' fields.

YIELD PERFORMANCE UNDER IRRIGATED CONDITIONS

Agronomy Department

Several promising lines from the IRRI breeding program were compared with IR8, IR20, and Peta during the 1974 dry and wet seasons.

At the IRRI farm, IR26 and the experimental line IR2035-290-3 produced the highest yield of 8.5 t/ha in the dry season (Table 1), both with 120 kg N/ha applied. An early maturing line, IR2061-214-3, which matured in 111 days, produced similar high yields of 8.4 t/ha with 150 kg N/ha applied.

Increasing attention is being given to those experimental lines which produce high yields without applied fertilizer nitrogen or moderate levels of nitrogen fertilizer. In the dry season, IR2035-290-3 gave the highest grain yields both without applied fertilizer nitrogen and with 60 kg N/ha applied.

Due to heavy brown planthopper infestation and the incidence of grassy stunt virus, the highest yield of IR8 was 4.9 t/ha, which was no greater than the maximum yield of Peta.

Although there were no serious pest and disease

Table 1. Effects of levels of nitrogen[a] on the grain yield of rice varieties and promising lines.[b] IRRI, 1974.

Designation	Dry season						Wet season					
	Maturity (days)	Yield[c] (t/ha)					Maturity (days)	Yield[d] (t/ha)				
		0 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha		0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha
IR8	133	2.8	3.9	4.9	4.2	4.4	126	2.9	3.3	3.6	3.3	3.7
IR20	117	3.8	5.5	6.4	6.2	6.9	123	3.4	3.4	3.4	3.4	2.6
IR26	137	5.1	7.0	8.2	8.5	8.2	126	3.0	3.5	3.7	3.6	3.3
IR1514A-E597-2	113	3.7	5.8	6.9	6.8	6.8	123	3.7	3.3	3.8	3.6	2.7
IR2031-354-2	137	5.4	7.1	8.0	7.7	7.9	–	–	–	–	–	–
IR2035-290-3-3	137	6.2	7.3	8.1	8.5	7.7	132	3.0	2.7	3.0	2.4	2.2
IR2061-214-3-8	111	5.2	6.3	7.5	7.8	8.4	105	3.7	3.7	3.7	4.6	4.4
IR2061-464-2	113	4.4	6.5	7.6	7.2	7.7	–	–	–	–	–	–
IR2061-465-2-1-5	111	4.7	6.1	7.3	6.6	7.4	–	–	–	–	–	–
IR2070-24	133	5.2	6.5	6.3	7.5	7.3	–	–	–	–	–	–
IR2071-88	133	4.4	5.9	6.9	7.0	7.6	–	–	–	–	–	–
IR2071-887	124	5.1	6.8	7.4	7.5	7.5	–	–	–	–	–	–
IR2151-957-5	113	4.9	6.2	7.0	7.1	7.1	123	3.5	3.0	3.3	3.5	3.3
Peta	139	4.6	4.5	5.2	5.1	4.5	135	1.8	1.5	1.5	1.2	0.7
IR2061-213-2-16	–	–	–	–	–	–	128	2.9	2.5	2.2	1.6	1.8
IR2070-747-6-2	–	–	–	–	–	–	132	3.5	3.3	2.9	3.2	2.7
IR2071-588-6	–	–	–	–	–	–	132	3.0	3.4	3.2	3.3	3.0
IR2071-625-1	–	–	–	–	–	–	116	3.8	4.2	4.0	4.3	4.1
IR2153-159-1-4	–	–	–	–	–	–	116	3.3	3.2	3.7	3.9	4.0
IR2153-189-2-6	–	–	–	–	–	–	123	3.6	3.5	4.0	4.1	3.9

[a]Includes 30 kg N/ha topdressed at panicle initiation in the dry season and 20 kg N/ha topdressed at panicle initiation in the wet season except in the 0 kg N/ha treatment. [b]Av. of three replications. [c]LSD (5%) between two treatment means: 1.3 t/ha. [d]LSD (5%) between two treatment means: 0.7 t/ha.

Table 2. Effects of levels of nitrogen[a] on the grain yield of rice varieties and promising lines at three locations[b]. Maligaya Rice Research and Training Center, Bicol Rice and Corn Experiment Station, and Visayas Rice Experiment Station, Philippines, 1974 dry season.

Designation	Maturity[b] (days)	Grain yield[c] (t/ha)					
		0 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha	180 kg N/ha
IR8	145	3.5	5.0	5.4	5.2	5.2	5.4
IR20	129	3.2	4.9	5.3	5.5	5.7	5.8
IR26	138	3.8	5.5	5.7	5.6	6.2	5.8
IR1514A-E597-2	129	3.6	5.5	6.2	6.2	6.4	6.2
IR2035-290-3-3	143	4.4	5.8	6.1	5.9	6.1	5.5
IR2061-214-3-8	121	2.9	4.6	5.4	5.2	5.9	5.9
IR2061-464-2	123	3.5	5.7	5.8	6.0	6.3	6.6
IR2061-465-1-5	121	3.4	4.9	5.6	5.4	5.9	6.0
IR2070-24	143	3.7	5.0	5.0	4.7	5.3	4.8
IR2071-88	140	3.6	5.0	5.3	5.1	5.9	5.8
IR2151-957-5	125	3.6	5.4	5.6	5.4	5.7	5.5
Peta	155	2.7	2.9	2.6	2.1	2.4	2.3

[a]Includes 30 kg N/ha topdressed at panicle initiation except in the 0 kg N/ha treatment. [b]Av. of three locations. [c]Av. of three replications. LSD (5%) = 0.5 t/ha.

problems in the wet season, the grain yields were generally low because of a series of tropical storms that occurred during the reproductive and ripening stages of the rice crop, which caused severe lodging in most varieties and lines.

The highest yield, 4.6 t/ha, was obtained with IR28; however, yields of IR2071-625-1, IR2153-159-1, and IR2153-189-2 were statistically similar to that of IR2061-214-3.

BPI stations. As was done at the IRRI farm, nine promising lines were compared with IR8, IR20, and Peta during the dry and wet seasons at the BPI Maligaya, Bicol, and Visayas experiment stations.

In the dry season trials using six nitrogen levels – 0, 60, 90, 120, 150, and 180 kg/ha – on the twelve rice varieties and lines, IR2035-290-3-3 produced the highest average grain yield (Table 2) at the three BPI stations. These results were similar to those obtained at the IRRI farm (Table 1) where 14 varieties and lines were used. Three early maturing IR2061 lines and IR1514A-E597 produced high grain yields. The IR2061 lines, being resistant to grassy stunt virus, are expected to have an added advantage over IR1514A-E597 which is susceptible to that virus.

In the wet season trials using six nitrogen levels – 0, 30, 60, 90, 120, and 150 kg/ha – the highest average grain yields ($\geq$ 5 t/ha) at the three BPI stations was obtained with two early maturing experimental lines – IR2061-214-3 and IR2153-159-1 (Table 3).

Farmers' fields. As in previous years, the reactions of rice varieties and experimental lines to applied nitrogen levels were studied in farmers' fields under management conditions that are within the reach of the majority of Asian farmers.

In the dry season, IR26 produced the highest grain yield (8.9 t/ha) followed by an early maturing experimental line – IR2061-214-3 (8.0 t/ha) (Table 4) – primarily because they are resistant to brown planthopper which heavily infested the experimental area. The maximum yield of IR8, which was highly susceptible to the severe brown planthopper infestation that occurred 2 weeks before harvest, was 6.5 t/ha, demonstrating the high risk of growing an insect-susceptible variety in areas where the insecticide application is minimal.

At the IRRI farm, at the three BPI stations, and in farmers' fields the two experimental lines IR2061-214-3 and IR2153-159-1 matured in 111–121 days while IR26 matured in 125–138 days. These two lines are resistant to six insects and diseases. Considering their agronomic charac-

Table 3. Effects of levels of nitrogen[a] on the grain yield of rice varieties and promising lines at three locations[b]. Maligaya Rice Research and Training Center, Bicol Rice and Corn Experiment Station, and Visayas Rice Experiment Station, Philippines, 1974 wet season.

Designation	Maturity[b] (days)	Grain yield[c] (t/ha)					
		0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha
IR8	130	2.6	3.1	3.4	3.6	3.5	3.4
IR20	126	2.5	3.3	4.0	4.1	3.7	3.0
IR26	129	3.0	3.6	3.8	4.2	4.1	3.2
IR1514A-E597-2	126	2.9	3.9	4.0	4.0	4.1	3.4
IR2035-290-2-1	136	2.6	3.2	3.5	3.4	3.3	2.9
IR2061-213-2-16	134	3.0	3.4	3.3	2.7	2.3	2.5
IR2061-214-3-8-2	108	3.1	4.2	4.6	5.0	5.2	4.8
IR2070-747-4	138	2.9	3.2	3.5	3.2	3.0	2.5
IR2071-588-6	138	3.2	4.0	4.3	4.4	4.5	3.5
IR2153-159-1-4	110	3.2	3.9	4.3	5.0	4.9	4.8
IR2153-189-2-6	124	3.0	4.1	4.3	4.8	4.5	4.3
Peta	138	2.2	2.1	2.2	1.9	1.7	1.8

[a]Includes 20 kg N/ha topdressed at panicle initiation except in the 0 kg N/ha treatment. [b]Av. of three locations [c]Av. of three replications. LSD (5%): Difference between two variety means at same nitrogen level – 0.7 t/ha; difference between two nitrogen means of same or different variety – 0.8 t/ha.

teristics, early maturity, insect and disease resistance, and yielding ability in various experiments at IRRI and elsewhere, IRRI subsequently named IR2061-214-3 as IR28 and IR2153-159-1 as IR30.

International variety trial. The yield potential under different levels of nitrogen of several rice varieties from different countries and three IRRI varieties were evaluated in trials at the IRRI farm. In the dry season, when the incidence of grassy stunt virus was high, the varietal reactions to the virus were evaluated at harvest. Chianung sen-yu 6 from Taiwan, RD 1 from Thailand, CICA 4 from Colombia, and IR8 had over 50 percent virus infection; Pelita I/1 from Indonesia and BG 66-1 from Sri Lanka had about 30 percent infection, while Jayanti (IET 1039) from India, Azral (IR480-5), a variety named in Fiji, and the Philippine variety C4-63 G each exhibited 20 percent infection, IR26, which had less than 5 percent virus, appeared to be the most resistant among the varieties tested. The highest grain yield, 8.7 t/ha, was produced by IR26 at 150 kg N/ha (Table 5). Although Pelita I/1 had more virus infection than IR20, both produced 6.1 t/ha.

While there was no virus incidence during the wet season, bacterial leaf blight, *Cercospora* leaf spot, and sheath blight caused some minor leaf discoloration. The Thai variety RD 1, which yielded very low in the dry season, and BG 90-2 produced the highest yield, 5.2 t/ha (Table 5).

YIELD PERFORMANCE AND NITROGEN RESPONSE IN RAINFED LOWLAND RICE

Agronomy Department

Promising lines. Twelve promising lines and four varieties were evaluated under rainfed lowland conditions during the wet season. A dry spell which occurred during the reproductive stage of the crop caused the soil to crack, but there was no apparent sign of crop stress. Low grain yields were attributed to lodging caused by a series of tropical storms at flowering and grain ripening. The experimental line, IR2061-214-3-8 produced the highest grain yield of 5.0 t/ha; however, three other lines – IR2071-625-1, IR2153-214-1-4, IR2153-189-2-6 – and IR26 gave yields statistically similar to the yield of IR2061-214-3-8 (Table 6).

Farmers' fields. Experiments conducted in farmers' fields in previous years were repeated during the 1974 wet season, but under rainfed

conditions to evaluate the performance of promising lines under minimal insecticide applications.

Experimental line IR2061-214-3 matured the earliest and was severely damaged by rats. The performance of IR26 under rainfed conditions in the wet season was similar to that in the irrigated experiment in the dry season. IR26 again produced the highest yield of 5.8 t/ha when grown on a fertile soil in Laguna, Philippines, at 40 kg N/ha (Table 7). Severe lodging in IR20 and IR2061-213-2 at 120 kg N/ha markedly reduced the grain yield.

Table 4. Effects of levels of nitrogen[a] on the grain yield of rice varieties and promising lines in a farmer's field[b]. Laguna, Philippines, 1974 dry season.

Designation	Maturity (days)	Yield[c] (t/ha)			
		0 kg N/ha	50 kg N/ha	100 kg N/ha	150 kg N/ha
IR8	129	3.9	6.5	3.4[d]	4.2[d]
IR20	122	5.6	6.8	5.3	4.5[d]
IR26	132	7.7	8.7	8.9	7.2
IR2061-214-3	108–114	6.6	7.8	8.0	6.4
IR2071-88	129	7.0	7.2	7.5	5.2
IR2151-957-5	114–118	6.3	7.3	7.0	4.6

Insecticide application: 3 days after transplanting, furadan; 48 days after transplanting, mipcin. [a]Includes 20 kg N/ha topdressed at panicle initiation. [b]Av. of two replications. [c]LSD (5%): Difference between two variety means at same nitrogen level – 0.8 t/ha; difference between two nitrogen means of the same or different variety: 1.8 t/ha. (Data on IR8 were not included.) [d]Hopper burn 10 days before harvest.

GROWTH DURATION

Plant Breeding Department

This year emphasis was placed on the development of lines differing in growth duration. Varieties with an early growth duration of 100–105 days are in particular demand in all rice-growing areas because they are suited to multiple cropping systems in which one or two rice crops are grown in rotation with other crops. The success of IR1561-228-3-3, an early maturing line, in the Philippines where it is widely grown and in Vietnam where it was introduced under the name of TN 73-2 in 1973, provide ample evidence that during the next 5–7 years, early maturing rice varieties will replace medium duration improved varieties in areas with good water control. Farmers using IR1561-228-3-3

Table 5. Effects of levels of nitrogen[a] on the grain yield of rice varieties from several countries[b]. IRRI, 1974.

Designation	Dry season						Wet season					
	Maturity (days)	Yield[c] (t/ha)					Maturity (days)	Yield[d] (t/ha)				
		0 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha		0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha
IR8	132	1.8	3.0	4.1	4.1	4.7	125	3.1	4.3	4.5	4.6	5.0
IR20	116	2.6	5.0	4.3	5.8	6.1	122	3.8	4.6	4.5	4.8	4.2
IR26	139	4.5	6.6	6.8	8.1	8.7	122	3.8	4.0	3.9	4.4	5.0
Azral (IR480-5)	117	3.2	4.0	5.3	4.9	5.5	116	3.4	3.3	3.2	3.1	3.6
BG 66-1	132	2.5	4.4	4.2	4.1	5.6	–	–	–	–	–	–
C4-63 G	135	2.7	4.1	5.3	5.1	6.0	129	4.0	4.6	4.4	4.1	3.7
Chianung sen-yu 6	114	1.5	2.9	3.2	3.4	4.4	116	3.7	4.5	3.9	4.7	4.8
Cica 4	117	2.2	3.0	2.8	3.5	3.8	116	2.9	2.1	3.4	3.1	3.2
Jayanti (IET 1039)	117	3.8	3.8	5.5	5.1	6.1	122	3.6	3.8	3.5	3.6	4.6
Pelita I/1	132	2.7	4.9	5.2	5.4	6.1	134	3.5	4.8	4.2	3.5	3.4
RD1	132	1.6	2.1	2.4	2.4	3.6	134	3.1	4.1	5.2	4.6	4.6
Peta	142	4.2	3.7	3.8	2.7	2.4	142	2.2	1.5	1.2	0.9	1.0
BG 90-2	–	–	–	–	–	–	122	4.2	4.6	5.2	4.7	4.7

[a]Includes 30 kg N/ha topdressed at panicle initiation in the dry season and 20 kg N/ha topdressed at panicle initiation in the wet season except in the 0 kg N/ha treatment. [b]Av. of three replications. [c]LSD (5%) between two treatment means: 1.6 t/ha. [d]LSD (5%) between two treatment means: 0.8 t/ha.

Table 6. Effects of levels of nitrogen[a] on the grain yield of rice varieties and promising lines under rainfed conditions[b]. IRRI, 1974 wet season.

Designation	Maturity (days)	Yield[c] (t/ha)				
		0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha
IR5	136	3.2	3.1	2.9	2.6	2.8
IR20	129	3.1	3.0	2.7	2.7	2.4
IR26	128	3.9	4.0	3.9	4.3	4.2
IR442-2-58	129	2.9	3.2	3.2	3.2	2.9
IR1539-823-1-4	135	3.2	3.7	3.2	3.6	3.5
IR2035-290-2-1	135	2.9	3.5	2.8	2.9	3.0
IR2061-213-2	135	3.3	3.4	2.8	2.0	1.6
IR2061-214-3-8	115	4.4	4.6	4.4	4.6	5.0
IR2070-747-6	136	3.4	3.8	3.0	2.7	3.1
IR2071-88-8	128	2.8	3.4	3.4	3.6	3.6
IR2071-588	136	3.6	4.1	3.7	3.6	3.0
IR2071-625-1	115	4.1	3.7	3.8	3.5	4.7
IR2151-957-5-3	122	2.9	3.8	3.8	3.9	3.7
IR2153-159-1-4	115	4.2	4.1	4.1	4.2	4.7
IR2153-189-2-6	128	3.4	3.8	4.0	4.2	3.9
C4-63 G	135	2.5	3.1	2.7	2.5	2.7

[a]Includes 20 kg N/ha topdressed at panicle initiation except in the 0 kg N/ha treatment. [b]Av. of three replications. [c]LSD (5%) between two nitrogen means of same or different variety: 0.8 t/ha, two variety means of the same nitrogen level: 0.7 t/ha.

now grow two or three crops of rice where they used to grow only one or two crops before. Cognizant of the growing demand for early maturing rices, IRRI named IR28 and IR30; both mature in 105–107 days. Important features of the early maturing rices is the early vegetative vigor and rapid tillering ability. IR2071-625-1 is another high-yielding line which has been widely tested; like IR28 and IR30 it is resistant to the major diseases and insects.

Table 7. Effects of levels of nitrogen[a] on the grain yield of rice varieties and promising lines[b] in a farmer's field under rainfed lowland conditions[c]. Laguna, Philippines, 1974 wet season.

Designation	Maturity (days)	Yield[d] (t/ha)			
		0 kg N/ha	40 kg N/ha	80 kg N/ha	120 kg N/ha
IR8	124	4.2	4.1	4.9	4.4
IR20	124	3.7	4.1	4.0	2.6
IR26	128	4.7	5.8	3.8	3.0
IR2061-213-2	135	4.2	4.3	3.4	1.5
IR2071-588	135	4.1	4.6	4.0	3.5

[a]Includes 20 kg N/ha topdressed at panicle initiation except in the 0 kg N/ha. [b]IR2061-214-3-8 was completely damaged by rats. [c]Av. of two replications. [d]LSD (5%): Difference between two variety means at same nitrogen level: 1.1 t/ha; difference between two nitrogen means of same or different variety: 1.6 t/ha.

Varieties with a longer growth duration (more than 145 days) are needed for river delta areas during the rainy season. The several experimental lines with long growth duration, which were selected from IR2070 and IR2071 crosses (Table 8), have excellent grain quality and are resistant to major diseases and insects. They are being evaluated in areas with a long rainy season where varieties with medium growth duration cannot be grown successfully because they mature before the end of the rainy season and when water is still standing in the fields. Traditional varieties grown in these areas mature in 150–170 days and are generally photoperiod sensitive. A large number of crosses were made with photoperiod-sensitive rice varieties to combine this trait with high yield and disease and insect resistance. F_3 populations from these crosses were grown in 1974 and these lines will be tested in problem areas in 1975.

Table 8. Promising selections with long growth duration.

Selection	Cross	Growth duration (days)
IR2070-210-4-1	IR20[2]/*O. nivara*//CR94-13	145
IR2070-575-5-5	IR20[2]/*O. nivara*//CR94-13	145
IR2071-176-1-1	IR1561-228-1-2//IR24[4]/ *O. nivara*///CR94-13	155
IR2071-669-3-4	IR1561-228-1-2//IR24[4]/ *O. nivara*///CR94-13	160
IR2071-688-4-2	IR1561-228-1-2//IR24[4]/ *O. nivara*///CR94-13	165
IR2071-757-6-4	IR1561-228-1-2//IR24[4]/ *O. nivara*///CR94-13	165
IR2071-783-3-1	IR1561-228-1-2//IR24[4]/ *O. nivara*///CR94-13	170
IR2071-803-5-4	IR1561-228-1-2//IR24[4]/ *O. nivara*///CR94-13	160
IR2071-866-6-2	IR1561-228-1-2//IR24[4]/ *O. nivara*///CR94-13	170
IR2071-875-2-4	IR1561-228-1-2//IR24[4]/ *O. nivara*///CR94-13	165

PLANT TYPE

Plant Breeding Department

The development of rices with an intermediate stature has been emphasized in recent years, because such varieties are preferred in Indonesia, Burma, and Malaysia, as well as in parts of Thailand, Bangladesh, and India. A large number of crosses has been made with intermediate-statured varieties, such as C4-63 and Pelita I/1. The F_3 and F_4 lines with intermediate stature which were evaluated this year will become available for testing in the international nurseries. IR2061-213-2-17, a disease and insect resistant line, has intermediate stature and excellent grain quality. It matures in 125 days, and has excellent seedling vigor and a high yield potential. It has been included in many international testing nurseries.

GENETIC STUDY ON GRAIN CHARACTERISTICS

Plant Breeding Department

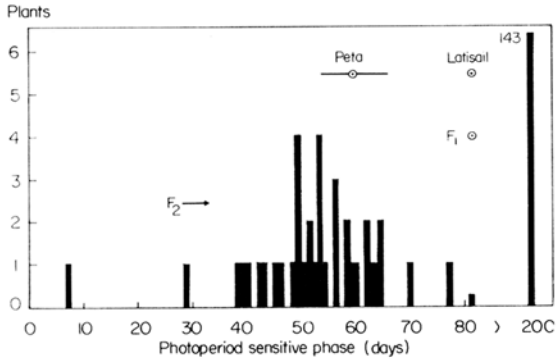
Two slender-grained and tall-statured Thai varieties, Gow Ruang 88 and Khao Pak Maw 148, were each crossed with a bold-grained and semidwarf selection, IR648-3-1-2-3, to study the genetic control of the physicochemical characteristics of the grain. The genetic materials in each cross include the parents, F_1, F_2, F_3, B_1s, and B_2s populations.

Variation in the 100-grain weight appeared to be predominantly due to the additive gene effect, as indicated by an analysis of generation means. Generally, the variations in grain length and the ratio of grain length to width could be attributed to the additive and dominance effects. Variations in chalkiness score and alkali digestion index in IR648 × KPM 148 were largely due to an additive effect, while in IR648 × GR 88 both additive and dominance effects were important. For amylose content, the dominance effect appeared to be more important for amylose content than the additive effect.

The amylose content appeared to be controlled by a single dominant gene and minor genes which have a modifying effect, as indicated by an analysis of the F_2 data. In both crosses, among the three types of epistatic gene effect, additive × additive and dominance × dominance gene effects appeared to be more important than the additive × dominance type.

Heritability estimates for grain yield per plant, tiller number, and panicle number were relatively low, indicating large environmental influences. The heritability for 100-grain weight ranged from 40 to 60 percent. Estimates of heritability for grain length, length:width ratio, alkali digestion index, chalkiness, and amylose content ranged from 70 to 95 percent.

In both crosses, phenotypic correlations indicated that the grain yield per plant was significantly and positively associated with panicle number, panicle weight, and weight of 100 grains. The expected positive association between high grain yield and semidwarf plant type was not realized. Heavy panicle weight was closely correlated with tall plant stature. The length of grains was significantly and positively associated with the degree of slenderness and high amylose content, while negatively related to the degree of chalkiness and gelatinization temperature. There was a positive correlation between the weight of 100 grains and the grain length, and a similar relationship existed between the high amylose content of the rice grain and a low gelatinization temperature.



1. Distribution of the photoperiod-sensitive phase in a strongly sensitive X weakly sensitive cross.

INHERITANCE OF PHOTOPERIOD RESPONSES

Plant Breeding Department

While the inheritance of weak photoperiodicity in tropical rice varieties such as Peta has been partly analyzed (Annual Report for 1972, IRRI), the genetic relationship between the strongly photoperiod-sensitive type of rice and the weakly photoperiod-sensitive type remains unknown. This relationship was investigated in a cross between Peta and its strongly photoperiod-sensitive parent, Latisail. The vegetative tillers were separated from each plant and the plants were exposed to two photoperiods in order to estimate the length of the basic vegetative phase (BVP) and that of the photoperiod-sensitive phase (PSP).

The two parents differed in the BVP by 6 days. The F_1 plants had the shorter BVP, exactly like that of Latisail. The F_2 population was essentially normally distributed over a wide range of transgressive segregation encompassing the parental ranges. The F_2 distribution suggested additive effects of the multiple genes.

The strongly photoperiod-sensitive reaction was completely dominant to the weakly photoperiod-sensitive type (fig. 1), as indicated by the PSP data gathered from the parents and F_1 plants. A monogenic ratio of three strong to one weak ($P = 0.5\text{-}0.2$) was suggested by the distribution of the F_2 plants, but two insensitive plants were found in the F_2 sample. The recovery of insensitive progenies in this cross, along with the finding of strongly photoperiod-sensitive plants in the weakly photoperiod sensitive x insensitive crosses in 1972 is strongly indicative of the complex nature of the photoperiod responses in tropical rice.

Genetic evaluation and utilization (GEU) program

Grain quality

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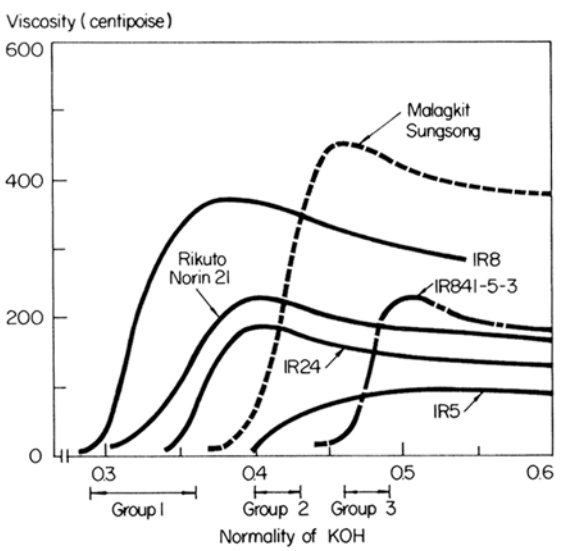
BREEDING PROGRAM

Plant Breeding Department

Over the past several years efforts have been made to develop varieties with an intermediate amylose content (20–25%). Crosses were made with BPI 121–407, an intermediate-amylose variety with an improved plant type. Several breeding lines from crosses of BPI 121–407 have an improved plant type and intermediate amylose content but lack resistance to one or two of the important rice diseases or insects. These lines were used extensively in the hybridization program during 1973 and 1974. F_3 progenies from several of these crosses were evaluated during 1974 and were found to have an intermediate amylose content as well as combined resistance to all the major diseases and insects. It is hoped that high-yielding varieties with an intermediate amylose content will become available within 2 years.

Screening breeding lines for gel consistency is under way and all the breeding lines with a low or intermediate amylose content screened were found to have a soft gel consistency. However, high-amylose lines may have either a soft, an intermediate, or a hard gel consistency. Since most of the IRRI breeding lines have a high amylose content; they were screened for gel consistency, and many were identified with a soft or an intermediate gel consistency. IR30, the most recently named IRRI variety has a soft gel consistency and will probably gain wide consumer acceptance. Several other breeding lines of IR2070, IR2151, and IR2153, now in the advanced yield trials, also have a soft gel consistency.



1. Representative alkaliviscograms of rice starch differing in gelatinization normality grouping and in peak viscosity. All are 2% dry weight basis except Malagkit Sungsong which is 1.8%.

ALKALIVISCOGRAM OF TROPICAL STARCH

Chemistry Department

Alkaliviscography is a method developed by Japanese starch chemists to characterize the pasting behavior of starch by measuring, with a Brookfield viscometer, the change in the viscosity of a starch suspension (0.2%) as a function of the KOH concentration which is adjusted by successive additions of 5 N KOH. The starch of tropical rices has not been systematically characterized for this property.

In the alkaliviscogram of starch of 26 nonwaxy rices grown in the tropics, the gelatinization normality was found to correlate positively with the final gelatinization temperature of starch ($r = 0.97^{**}$) and negatively with the alkali spreading value of milled rice ($r = -0.93^{**}$). Based on the gelatinization normality nonwaxy rice starch may be classified into three groups, corresponding to low-, intermediate-, and high-gelatinization temperature starches, group 1, group 2, and group 3, respectively (fig. 1). Peak viscosity was not related linearly to the amylose content. Among samples of rice starch having a high amylose content ($> 28\%$), a correlation was found between the peak viscosity and the gel consistency reading of starch ($r = -0.69^{**}$) and of milled rice ($r = -0.64^{**}$). These high-amylose starches exhibited the widest variation in peak viscosity. In all of the nine varieties and lines studied, the amylose content and gel consistency were inherited from the same parent whereas the peak viscosity, gelatinization normality, and the final gelatinization temperature, were inherited from either parent. Wet-milled flour gave a lower peak viscosity in the alkaliviscograph than rice starch probably because the milled rice was incompletely homogenized into discrete starch granules during wet milling by a Waring blendor.

The starch of five waxy rices had a higher gelatinization normality and a higher peak viscosity even at a concentration of 1.8% compared with

those of 2.0% nonwaxy rice starch, exemplified by Malagkit Sungsong with a low gelatinization temperature (fig. 1).

FACTORS AFFECTING GEL CONSISTENCY

Chemistry Department

Waxy and nonwaxy rices were used in a study of the factors that determine the gel consistency of milled rice and rice starch. Waxy starch, which is at least 98% amylopectin, provided a model system for the study. The final gelatinization temperature values of samples of waxy rice starch ranged between 58 and 78°C. The gel viscosity, as measured with a Wells-Brookfield viscometer, of samples with a gelatinization temperature above 70°C was higher than that of samples with a temperature below 70°C. Two indexes of molecular size of amylopectin – sedimentation coefficient and intrinsic viscosity – were positively correlated. Both showed a U-shaped relationship with the gelatinization temperature, the minima occurred at around 68°C. Differences in the viscosity properties of waxy milled rice and rice starch were due mainly to differences in the molecular weight of amylopectin, inasmuch as the mean chain lengths of the samples were similar. Gelatinization temperature, as indexed by the alkali spreading value, was a useful index of amylopectin molecular weight in the waxy rice samples.

The existence of a relationship between the gel consistency of waxy rice and the eating quality of the rice was confirmed. The quality of the new waxy Thai variety RD4 is considered inferior to that of the standard variety Niaw Sanpatong. An analysis of milled samples of both varieties showed that RD4 had a higher gelatinization temperature and harder consistency (and higher viscosity) of neutral and alkaline gels than Niaw Sanpatong. The gel consistency of milled rice and the consumer panel preference score and softness index of stored *suman* (a Philippine waxy rice cake) could be predicted from the alkali spreading value (which estimates gelatinization temperature) of the milled rice (Table 1).

The study of the gel consistency of nonwaxy milled rice and rice starch was complicated by the variability of the amylose content among varieties. The gel consistency values (in mm) of milled rice and rice starch were correlated negatively with gel viscosity. A study of the starch and starch fractions – amylose and amylopectin – of the milled rice of six IRRI varieties and C4-63G showed that amylopectin contributed more to gel viscosity than did the amylose fraction of the starch. Differences in gel viscosity were observed only at a starch concentration of 40 mg in 2 ml 0.2 N KOH or higher and were not simply related to differences in intrinsic viscosity [η] (an index of molecular size) of starch. Gel consistency of starch was negatively correlated with [η] of amylopectin ($r = -0.91^{**}$, $n = 7$). Gel viscosity was lower in potassium acetate than in KOH but the viscosity of whole starch was closer to that of amylopectin than to that of amylose (Table 2).

The amylopectin fraction of starch appears to be the major factor determining the gel viscosity of starch, both in alkaline and neutral solvents (Table 2). The amylose content and gel consistency values may serve in the rice breeding program as criteria for evaluating the eating quality of rice. Nonwaxy rices may be classified as low amylose

Table 1. Physicochemical properties of milled rice and *suman* (Philippine rice cake made from waxy rice) prepared from 16 waxy rices. 1974 dry season crop, UPLB.

Line	No.	Milled rice		Suman[a]	
		Alkali spreading value	Neutral gel consistency (mm)	Consumer panel preference[b]	Softness index[c] (mm)
Low gel. temp.	13	6.5–7.0	66–98	1.4–2.9	14.6–23.3
IR253-4 (check)	1	7.0	80	2.4	16.2
High gel temp.	2	3.0, 3.0	55, 56	3.4, 3.7	10.1, 11.7

[a]Prepared by A. M. del Mundo, Home Technol. Dep., University of the Philippines at Los Baños (UPLB) by cooking 3 cups milled rice in 5 cups of coconut milk in automatic electric cookers. [b]Mean preference score of 10 panelists 12 h after preparation, ranging from 1 (highest) to 4 (lowest). Forty panelists assessed four samples, each in an incomplete block design. [c]Depth of penetration by an improvised penetrometer after storage at 4°C for 2 days.

Table 2. Gel viscosity of starch, amylopectin, and amylose in alkaline and neutral solutions.

Starch fraction	Gel viscosity[a] (cps)			
	C4-63G		IR8	
	KOH	KOAc	KOH	KOAc
Whole starch	11.5	7.2	18.2	6.1
Amylopectin	19.6	7.5	23.4	6.8
Amylose	6.6	4.2	5.6	3.8

[a]40 mg in 2 ml 0.15 N KOH or KOAc (potassium acetate); Wells-Brookfield RVT viscometer with 1.565° cone run at 50 rpm.

(< 20%), intermediate amylose (20 – 25%), and high amylose (> 25%). The high-amylose rices may be further categorized into soft gel consistency and hard gel consistency types, and these types are easier to determine than the subgroups of moderately high-amylose rice (25 – 27%) and high-amylose rice (> 27%), formerly proposed in 1971. The gel consistency (or viscosity) is a useful index of softness of cooked rice for rice with an amylose content exceeding 25%. The peak viscosity in the alkaliviscograph (e.g., IR8 in fig. 1) of rice with a high amylose content (> 25%) and a hard gel consistency is higher than that of high-amylose rice with soft gel consistency. In the latter case the difference between peak normality and gelatinization normality was more than 0.1 N (e.g., IR5 in fig. 1). High-amylose samples with a hard gel consistency, such as IR8 and IR22, also contained lower levels of water-soluble amylose at 100°C than did samples with a soft gel consistency, such as IR5. The protein content contributed to a higher gel viscosity (harder consistency) of milled rice and starch, particularly above 8% protein in milled rice.

MECHANISM OF RICE AGING

Chemistry Department

Rice from the 1973 wet-season crop of IR29, IR24, IR480-5-9, and IR1529-680-3 was studied in order to confirm the results from similar investigations on the 1972 dry-season crop reported in 1973. Milled rice stored as rough rice, milled rice, and petroleum-ether defatted milled rice (0.01% fat) showed similar increases in consistency and viscosity of alkaline and neutral gel, amylograph peak viscosity, and the water-uptake ratio on cooking, and decreases in dissolved solids on cooking, surface whiteness, and salt-soluble protein after storage for 6 months at 29°C (28 – 30°C). The changes were less when the rice was stored at 2°C (0 – 4°C), except for the content of the salt-soluble protein. The changes due to storage of milled waxy rice (IR29) were similar to those of nonwaxy rice, but the water-uptake ratio was lower and the dissolved solids on cooking was higher with the waxy rice when compared with the nonwaxy rice.

Hardness of milled rice measured by a Wig-L-Bug amalgamator increased during storage at both 2° and 29°C except in the cases of defatted milled rice and waxy rice. Free fatty acids of milled rice increased significantly in samples stored as milled rice, particularly when stored at 29°C. The total carbonyl compounds of milled rice were also highest in samples stored as milled rice at 29°C, intermediate for samples stored as rough rice, and lowest for the samples stored as defatted milled rice.

The stickiness of cooked rice did not decrease significantly in waxy rice stored at 29°C over that of waxy rice stored at 2°C, confirming the 1973 findings. In IR24, the stickiness of cooked rice decreased with storage at 29°C and the decrease was greater for the rice stored as milled rice as compared with that of defatted milled rice or rough rice.

Purified starch of IR24 and IR1529-680-3 also exhibited an increase in the amylograph peak viscosity but the gel consistency and viscosity and gelatinization temperature did not change during storage at 29°C, indicating that changes in the amylograph viscosity of milled rice with storage could be attributed to the starch fraction. The observed increases in gel viscosity of milled rice may have been due to the reported increase in molecular weight of protein during storage as shown by its decreased solubility in water.

Apparently, starch and protein become less water soluble during storage, regardless of the form in which the rice is stored. However, fat oxidation and hydrolysis were extensive only in milled rice. Evidently during the aging of rice in storage, neither the complexing between fatty acids and amylose nor the formation of the starch- or protein-carbonyl compound complex is important for changes except probably in increasing grain hardness, as shown by defatted milled rice and waxy rice.

FERMENTED RICE CAKE QUALITY

Chemistry Department

Three aged samples of milled rice with an intermediate amylose content (20–25%), used in making fermented rice cake (*puto*), gave a greater volume of steamed cake and optimum softness of the cake as compared with five other samples of milled rice with a lower or higher amylose content of less than 20% or more than 25%. Batters of samples with an amylose content above 25% and lower than 20%, and particularly waxy rice, collapsed during steaming. Presumably, an intermediate-amylose rice provides an optimum amylose-to-amylopectin ratio with an amylopectin content high enough to allow expansion of the gelatinized starch during steaming but containing a sufficient amount of amylose to prevent the collapse of the expanded cake. All the intermediate-amylose samples had a medium to soft gel consistency. The protein content and gelatinization temperature of starch were not simply related to the quality of puto. Aging of rice decreased the gas retention during fermentation but increased it and the cake volume during steaming.

CHANGES DURING GRAIN DEVELOPMENT

Chemistry Department

The levels of reducing and nonreducing sugars, starch, and enzymes involved in the metabolism of sucrose, glucose-1-phosphate, and glucose nucleotides in the developing grain of IR1541-76-3 grown during the 1974 dry season were studied. The level of reducing sugars in the grain was highest 5–6 days after flowering whereas that of nonreducing sugars and of soluble protein was maximum 11–12 days after flowering.

The level of enzymes of sucrose metabolism was adequate to sustain starch accumulation in the developing rice grain. Bound invertase was present in higher levels than the soluble form during the second and third week after flowering. Sucrose-UDP glucosyl transferase activity was higher than the sucrose-ADP glucosyl transferase activity. UDP glucose pyrophosphorylase activity was also higher than ADP glucose pyrophosphorylase and the activity of both enzymes was maximum at 11–12 days after flowering. The activity of glucose nucleotide sucrose synthetase and pyrophosphorylase was higher than that of invertase.

Enzymes of starch biosynthesis, ADP glucose starch synthetase and phosphorylase, were present in levels adequate to account for starch accumulation in the grain. However, although the activity of soluble ADP glucose starch synthetase was lower than that of the soluble phosphorylase, it more closely paralleled the pattern of starch accumulation. The activity of ADP glucose starch synthetase was higher than that of UDP glucose starch synthetase, but there was more unprimed soluble synthetase utilizing UDP glucose, than ADP glucose throughout grain development. The activity of starch synthetase bound to the starch granule also increased progressively with the increase in starch content of the developing grain.

A refractionation was made of IR8 starch from developing rice grain to obtain purer amylose. Determination of intrinsic viscosity $[\eta]$ of these amyloses showed that $[\eta]$ of amylose in 0.15 N KOH increased progressively 1, 2, and 3 weeks after flowering (from 164 to 171 to 202 ml/g) while its blue value at 680 nm remained high (1.1–1.2). The high values reported earlier for amylose from the developing grain must have been caused by contamination with amylopectin which also has an $[\eta]$ value of 201–208 ml/g.

Disease resistance

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SUMMARY

The program for screening rice varieties and evaluating rice lines for their resistance to blast, sheath blight, bacterial blight, tungro, and grassy stunt by testing with previously developed metbods was continued. Efforts were also made to improve or modify existing methods to test the rice plant for resistance to these diseases and to standardize the scale for resistance. The study of the inheritance of resistance to bacterial blight indicated that in some varieties of rice a single dominant gene governs the resistance to this disease, while in other varieties a single recessive gene is responsible for the plant's resistance to this bacterial disease.

BLAST

Plant Pathology Department

Screening new germ plasm for blast resistance. The search for resistant sources against blast, in which the first 10,000 accessions of the germ plasm collection of IRRI were tested in the Philippines as well as in the international blast nurseries since 1962, yielded the identification of a number of resistant sources. The collection of germ plasm has been increased in recent years. A second series of tests were initiated in 1974 to search for additional sources of rice plant resistance to blast. Of the 3,705 rice varieties tested through 1974, 717 or 19.4 percent were classified as resistant on the basis of the first test and together with other resistant entries from future tests will be re-tested repeatedly in the IRRI blast nursery. Those varieties that prove resistant successfully in these sequential screening tests will be entered in the international tests. The number of resistant varieties will be reduced after further tests as many are susceptible to other races which were not present in the first test. About 1 percent of the first series of 10,000 varieties tested exhibited a broad spectrum of resistance and 0.1 percent had a very broad spectrum.

Evaluation of breeding materials for blast resistance. The blast resistance was assessed in various groups of breeding materials; 25,001 entries have been tested in the blast nursery. The percentage of resistant entries for each group of the breeding materials tested, ranging from 8 to 61 percent (Table 1), is low, suggesting the need for intensified selection of the breeding materials.

International blast nurseries. Since the international blast nurseries were started in 1963, 551 sets of seed have been distributed to 29 countries and 325 test results have been received (Table 2). The test results were published in the *International Rice Commission Newsletter* every 2 years; resistant varieties have also been reported in other publications. Tetep, Nang Chet Cuc, Tadukan, Mamoriaka, Carreon, Ram Tulasi (Sel), C46-15, Dissi Hatif, and other varieties have consistently shown a broad spectrum of resistance to blast.

New varieties and selections have been included in the tests since 1972. While resistant varieties will be tested continuously, more new varieties and selections are expected to be included in the program. The past emphasis on the search for sources of high resistance has proved successful. The program focus has now shifted to screening for the most resistant dwarf selections which are

Table 1. Assessment of blast resistance in the various groups of breeding materials.

Breeding material	Entries (no.)		
	Resistant	Intermediate	Susceptible
Pedigree nurseries	4622 (24.7%)	7599 (38.9%)	7289 (37.4%)
Observational yield trial	709 (39.2%)	645 (35.7%)	455 (25.1%)
Replicated yield trial	168 (21.7%)	228 (29.5%)	377 (48.8%)
Cold tolerance	59 (7.6%)	238 (30.4%)	485 (62.0%)
Upland variety trial	377 (22.9%)	843 (51.3%)	423 (25.8%)
Colombia breeding material	81 (61.0%)	46 (34.6%)	6 (4.4%)
International Observational Rice Nurseries	150 (42.7%)	142 (40.5%)	59 (16.8%)

being developed in many countries using international testing as its most efficient method of screening.

SHEATH BLIGHT

Plant Pathology Department

Suggested scale for assessing sheath blight resistance. Experience with screening thousands of rice varieties at IRRI between 1971 and 1974 reveals that a few simple criteria such as number or size of lesions do not provide an adequate assessment of sheath blight resistance in rice. After inoculating many thousands of rice varieties and lines and counting and measuring the disease lesions, a scale for assessing resistance was developed (Table 3). The scale may appear complicated at first perusal but is relatively easy to use once the user becomes familiar with it.

A universal system of assessment that can be used in all countries is needed and thus this system is recommended for trial in the various rice-producing nations.

Search for sources of resistance. Since 1972 several hundred rice varieties in the hybridization block, resistant varieties of the international blast nurseries, bacterial-blight resistant varieties, and varieties in the Assam Collection were tested for resistance to sheath blight. Since environment affects the development of sheath blight, the varieties which are selected are re-tested each season. No variety was found to be highly resistant or immune to the disease, but many are classified as resistant or moderately resistant (Table 4) using artificial inoculation.

Evaluation of breeding material. Several groups of IRRI's breeding materials were artificially inoculated in the field to evaluate and screen them for sheath blight resistance. The results are summarized in Table 4. Many lines in the Observational and Replicated Yield Trials have some resistance.

International sheath blight nurseries. Six cooperating countries, where the Second International Sheath Blight Nurseries were carried out, submitted seven sets of test results. There was considerable variation in reaction among the 60 varieties tested in different countries and even between the two tests in Thailand. In general, the disease was more severe in Taiwan, which may be due to a more virulent strain of the fungus used or to testing conditions that favored pathogen development. The relative degree of resistance or susceptibility of the varieties in each country generally appeared to be consistent. A few varieties, however, exhibited differential reactions to different test locations and further tests are needed to confirm this important point inasmuch as environmental factors affect the disease. A broad spectrum of resistance in these countries was observed in several rice varieties or lines, such as the talls – Laka, Ta-poo-cho-z, Kam Bau Ngan, 46 Palman, Dular, and others – and the dwarfs – IR1542-30-2-4, IR1544-340-6-1, IR883-12-2-1-3, IR1529-680-3-2, IR86/PK203, and others.

Table 2. Test results received from the International Uniform Blast Nurseries between 1964 and 1974.

Region, country	Test results (no.) 1964–1974	Region, country	Test results (no.) 1964–1974
East Asia		*Africa*	
Hong Kong	1	Egypt	4
Korea	27	Guinea	2
Taiwan	7	Ivory Coast	4
Southeast Asia		Liberia	5
Indonesia	20	Nigeria	10
Malaysia	20	Senegal	5
Philippines	77	Sierra Leone	4
Thailand	22	*South & Central America*	
Vietnam	6	Bolivia	3
South Asia		Brazil	6
Bangladesh	4	Colombia	10
India	30	Guyana	10
Iran	5	Panama	3
Nepal	7	Peru	2
Pakistan	2	Surinam	1
Sri Lanka	21	*Europe* (Italy)	4

BACTERIAL BLIGHT

Plant Pathology and Plant Breeding Departments

Screening for bacterial blight resistance *(Plant Pathology)*. The inoculation clipper has continued to be used to systematically evaluate the new Germ Plasm Bank (GPB) cultivars and all early and advanced generation breeding materials originating from crosses with one resistant parent. The bacterium was maintained at high virulent levels by isolating a new virulent culture each season and storing many samples at −4°C. Throughout the season new cultures are periodically removed for

Table 3. Suggested scale for assessing sheath blight resistance by artificial inoculation.

Scale unit	General classification[a]	Criteria						
		General disease level[b]	Lesions (no./ infected tiller)	Majority lesion length (cm)	Flagleaf sheath infection (%)	Leaf blade infection (%)		
						Flagleaf	2nd leaf	3rd leaf
0		No lesions observed						
1	Resistant (R)	Infection up to 1/3 of plants	1–2	< 2	0	0	0	0
2	Resistant (R)	1/3	2–5	< 2	< 5	0	0	< 5
3	Moderately Resistant (MR)	1/2	5–8	2–4	5–10	0	< 5	5–10
4	Moderately Resistant (MR)	1/2	5–10	2–4	10–25	< 5	5–10	10–25
5	Moderate (M)	2/3	8–15	2–4	25–40	5–10	10–20	25–40
6	Moderate (M)	3/4	10–20	2–5	40–75	10–25	20–40	40–75
7	Moderately Susceptible (MS)	3/4	15–25	3–5	75–85	25–50	40–75	75–85
8	Susceptible (S)	4/4	20–30	3–5	85–95	50–75	75–85	85–95
9	Very Susceptible (VS)	4/4	25–35	3–5	95–100	75–100	85–100	95–100

[a]Classification of the more resistant group (R-MR-M) readings should rely more on general disease level, number of lesions, lesion length; classification of a more susceptible group (MS-S-VS), on top leaves blighted. Figures within a box serve as major criteria for various levels of resistance groups. The development of the disease is markedly affected by environmental conditions (climate, plant nutrition, and others); for a comparison standard, resistant and susceptible varieties should be planted at the same time. [b]General disease level is indicated by disease development up to the 1/3, 1/2, or the entire height of the plants from point of inoculation. These criteria are not always positively correlated. Readings should be based upon weighed averages of all criteria.

use in preparing inoculum and no more than two to three transfers are made of any given culture.

A three-scale system for scoring the host reaction (R – 1, M – 5, S – 9) has been found to be simple and convenient for use in the IRRI high-volume screening program. Good success has been achieved by closely supervising those making the inoculation with the clipper, by ensuring the proper maintenance of the clippers and avoidance of inoculating in the rain. The IRRI elite breeding lines continued to be tested under natural conditions for final confirmation of their resistance to bacterial blight.

Approximately 10,000 GPB cultivars were screened during 1974, as well as 100 F_1 multiple cross populations, 292 F_2 populations, 34,000 pedigree nursery lines, and 2,500 observational and yield trial entries.

After three seasons of testing, an additional 179 cultivars which have resistance to the predominant Philippine strain of *X. oryzae* were selected from the GPB. Most of the resistant cultivars originated in either Indonesia or India (Table 5).

The proportion of breeding material with bacterial blight resistance continues to increase rapidly. During the dry season more than 95 percent of the F_2 populations had at least one parent resistant to bacterial blight. Both parents were resistant in about 50 of the F_2 populations. Most of the advanced breeding lines in the replicated yield

Table 4. Summary of rice variety groups and breeding materials tested for sheath blight resistance in 1974.

Rice variety group	Varieties, lines, entries (no.)			
	R to M/MR	M	M/MS to S	Total
		Dry season		
Varieties in 1972-W hybridization block (HB)	61	91	55	207
Varieties in 1974-D (HB)	82	61	6	149
International blast nurseries, resistant varieties	21	69	43	133
Bacterial blight, resistant varieties	67	18	0	85
Assam collection	31	13	0	44
International sheath blight nurseries	21	28	11	60
Breeding material				
Pedigree lines, 1974-D	203	763	198	1164
Observational yield trial, 1974-D	541	249	62	852
Replicated yield trial, 1974-D	201	38	8	247
IR2061 headrow lines, 1974-D	18	270	190	484
IR2035 headrow lines, 1974-D	0	14	68	82
IR2061 seed increase lines	0	12	6	18
		Wet season		
Varieties in 1972-W hybridization block (HB)	57	85	35	177
International blast nurseries, resistant varieties	59	61	14	134
Assam collection	34	26	1	61
Bacterial blight, resistant varieties	3	35	21	59
International sheath blight nurseries	13	22	13	48
Breeding material				
Replicated yield trial	6	88	106	200
International rice observational nursery	9	73	287	369
Upland breeding lines	100	74	8	182
Replicated yield trial	11	26	29	66
World collection	760	674	415	1849

R – resistant; M – moderate; MR – moderately resistant; MS – moderately susceptible; S – susceptible; VS – very susceptible; D – dry season; W – wet season.

trials were resistant to bacterial blight. The recessive gene is being used more in order to diversify the genetic source of resistance. The varieties carrying the dominant gene continued to show moderate susceptibility to the Isabela strain although no severe infection was observed when these varieties were inoculated artificially with this strain in field trials in Isabela, Philippines. At the present time the Isabela strain does not appear to have the capacity to cause a level of disease severity on varieties under natural conditions equal to that effected by isolates on susceptible rice varieties.

The third International Bacterial Blight Nursery (IBBN) was again coordinated by IRRI. Results from 19 of the 22 test locations in 10 countries confirmed that several breeding lines from India (RP633) with both the dominant and recessive gene for resistance, had the broadest level of resistance. Entries with the dominant gene for resistance (IR20, IR26 etc.) continued to show good to moderate levels of resistance in most locations.

Inheritance of resistance to bacterial blight (*Plant Breeding*). Several varieties and breeding lines were studied for their inheritance of resistance to bacterial blight as well as for the allelic relationships of their genes for resistance (Table 6). These

Table 5. Origin of new varieties with resistance to bacterial blight in the Philippines. These varieties were taken from the germ plasm bank at IRRI.

Country of origin	Varieties (no.)
Indonesia	81
India	75
Bangladesh	5
Sri Lanka	5
Korea	3
Nepal	3
Philippines	2
Vietnam	2
U.S.A.	1
Sierra Leone (West Africa)	1
Surinam	1
Total	179

Table 6. Bacterial blight-resistant rice varieties and selections employed in studying inheritance of resistance.

Variety, selection	Source of resistance
IR20	TKM6
IR22	–
IR1529-680-3	Sigadis
Pelita I/1	Syntha
IR1330-3-2	MTU15
IR1545-284	DZ192
IR1545-339	DZ192
RP291-7	BJ1
Kele	–
IR1698-241-2	Zenith
IR944-102-2	Malagkit Sungsong

varieties and lines were crossed with TN1 and F_1, F_2, and F_3, progenies of these crosses were tested for bacterial blight resistance. The reactions of the F_1 progenies and segregating populations show that a single dominant gene governs resistance in IR20, IR22, IR1529-680-3, Pelita I/1, and IR1330-3-2. On the other hand, a single recessive gene conveys resistance to bacterial blight in IR1545-284, RP281-7, Kele, IR944-102-2 and IR1698-241-2 (Table 7).

F_1, F_2, and F_3 populations of crosses between resistant varieties were used to study the allelic relationships of genes for resistance. All F_1 and F_2 progenies of intercrosses between IR20, IR22, IR1529-680-3, Pelita I/1, and IR1330-3-2 were resistant to bacterial blight, suggesting these varieties have the same dominant gene for resistance (Table 8). The F_1 and F_2 progenies of IR1545-284 × RP291-7 and Kele × IR1545-339-2 were also resistant to the blight, indicating that these three entries have the same recessive gene for resistance. The fact that the F_1 progenies of the IR1698-241-2 × IR944-102-2 cross were also resistant suggests that these two selections have the same recessive gene for resistance. A study of F_2 population of this cross may help to confirm this postulate. On the other hand, F_1 hybrids of IR1698-241-2 × IR1545-339-2 and IR944-102-2 × IR1545-339-2 were susceptible to the blight indicating that non-allelic recessive genes convey resistance in IR1545-339 and IR1698-241-2. The F_2 progenies of IR22 × IR1545-284, IR22 × RP291-7, IR1529-680-3 × IR1545-284, IR1529-680-3 × RP291-7, and Kele × IR22 segregated into a ratio of 13 resistant to 3 susceptible, thereby showing that the dominant gene for resistance present in IR20, IR22, IR1529-680-3, Pelita I/1, and IR1330-3-2 is independent of the recessive gene for resistance present in IR1545-284 and RP291-7. F_2 progenies of crosses IR1698-241-2 × IR20, IR1698-241-2 × IR22 and IR1698-241-2 × IR1529-680-3 yielded only a few susceptible plants. Apparently, the dominant gene of IR20 and other varieties and the recessive gene of IR1698-241-2 are closely linked.

The reaction of F_3 families of some of the crosses (Table 9) supported the above conclusions. As expected, all of the F_3 families from the crosses of IR20 × IR22, Pelita I/1 × IR20, and IR1330-3-2 × IR20 were homozygous resistant. On the other hand, the proportions of homozygous resistant, segregating, and homozygous susceptible families from the crosses of IR22 × IR1545-284 and IR22 × RP291-7 agreed with the calculated ratio of 7:8:1 for two independently segregating genes. Only four of 95 families were segregating in the cross of IR1698-241 × IR1529-680-3 and none were homozygous susceptible, confirming a close linkage between the dominant gene for resistance of IR22 and the recessive gene for resistance in IR1698-241.

Table 7. Reactions of F_1, F_2, and F_3 progenies of crosses between resistant rice varieties and TN1 to bacterial blight.

Cross	F_1	Reaction to bacterial blight						
		F_2 plants (no.)			F_3 families (no.)			
		Resistant	Susceptible	X^2 3:1/1:3	Resistant	Segregating	Susceptible	X^2 1:2:1
IR20 × TN1	R	1038	382	2.72	32	69	22	2.44
IR22 × TN1	R	1021	388	3.33	28	59	29	0.06
IR1529-680-3 × TN1	R	1016	374	2.85	–	–	–	–
Pelita I/1 × TN1	R	589	223	2.62	35	63	29	0.57
IR1330-3-2 × TN1	R	911	310	0.04	31	67	28	0.65
IR1545-284 × TN1	S	318	1062	2.81	34	60	26	1.35
RP291-7 × TN1	S	295	992	3.54	21	66	26	3.23
Kele × TN1	S	553	1772	1.81	–	–	–	–
IR944-102-2 × TN1	S	344	914	3.68	29	58	31	0.10
IR1698-241-2 × TN1	S	202	558	1.01	28	66	29	0.65

Table 8. Reactions of F_1 and F_2 progenies of crosses between rice varieties resistant to bacterial blight.

Cross	F_1	Reaction to bacterial blight			
		F_2			
		Resistant (no.)	Susceptible (no.)	Susceptible (%)	X^2 for 13:3
IR20 × IR22	R	1601	–	–	–
IR20 × IR1529-680-3	R	1560	–	–	–
IR22 × IR1529-6803	R	1522	–	–	–
IR1330-3-2 × IR20	R	1431	–	–	–
IR1330-3-2 × IR22	R	1372	–	–	–
IR1330-3-2 × IR1529-680-3	R	1423	–	–	–
Pelita I/1 × IR20	R	1475	–	–	–
Pelita I/1 × IR22	R	1044	–	–	–
Pelita I/1 × IR1529-680-3	R	1201	–	–	–
IR22 × IR1545-284	R	803	191	19.21	0.141
IR22 × RP291-7	R	1010	248	19.71	0.767
IR1529-680-3 × IR1545-284	R	977	251	20.43	2.30
IR1529-680-3 × RP291-7	R	517	139	21.18	2.56
Kele × IR22	R	897	222	19.84	0.87
IR1545-284- × RP291-7	R	497	–	–	–
Kele × IR1545-339-2	R	750	–	–	–
IR1698-241-2 × IR20	R	735	10	1.34	–
IR1698-241-2 × IR22	R	811	15	1.81	–
IR1698-241-2 × IR1529-680-3	R	874	21	2.35	–
IR1698-241-2 × IR944-102-2	R	–	–	–	–
IR1698-241-2 × IR1545-339-2	S	—	–	–	–
IR944-102-2 × IR1545-339-2	S	–	–	–	–

Table 9. Classification of F_3 families from crosses between resistant parents according to their reaction to bacterial blight.

Cross	Families (no.)				
	Total	Homozygous resistant	Segregating	Homozygous susceptible	X^2 for 7:8:1
IR20 × IR22	95	95	–	–	–
Pelita I/1 × IR20	95	95	–	–	–
IR1330-3 × IR20	95	95	–	–	–
IR22 × IR1545-284	94	41	46	7	0.25
IR22 × RP291-7	82	33	44	5	0.44
IR1698-241-2 × IR1529-680	95	91	4	–	–

VIRUS DISEASES

Plant Pathology Department

Screening for tungro resistance. Testing varietal resistance to tungro by the improved mass screening method (1972 Annual Report) was continued in 1974. A total of 15,460 entries involving 379,400 seedlings (60% for the IRRI Plant Breeding Department, 14% for the IRRI Plant Pathology Department, 6% for University of the Philippines at Los Baños, 3% for Philippine Atomic Research Center, and 17% for experimental purposes) were inoculated in 1974. About 40 percent of the inoculated seedlings (20% for Plant Breeding Department, 5% for Plant Pathology Department, and 15% for experimental purposes) were used mostly as a virus source. The entries included 1,048 IR selections of 165 crosses and 2,205 varieties and other selections. About 27 percent of IR selections tested exhibited less than 30 percent infection (Table 10). Of the varieties and other selections tested, 347 had less than 30 percent of the seedlings infected with tungro, but none showed resistance greater than that of Habigonj Deep Water 8 and Pankhari 203. While 1,041 of the varieties and other selections tested had more than 61 percent of the seedlings infected with tungro, the remaining 815 varietal and selection entries had 31–60 percent infected seedlings.

Table 10. Reaction to tungro disease of IRRI rice crosses tested by the improved mass screening method.

Cross no.	Selections (no.) with different percentages of seedlings infected with tungro		
	0–30%	31–60%	61–100%
IR1487	5	0	0
IR2031	5	13	0
IR2034	13	3	0
IR2035	9	11	3
IR2039	7	4	0
IR2061	31	25	10
IR2151	8	3	0
IR2732	20	1	3
IR2733	29	8	0
IR3154	6	15	4
IR3179	25	3	0
IR3265	12	44	28
IR3295	9	5	0
IR5489	8	4	1
IR5490	18	1	0
Other 150 crosses	73	247	334
Total (165 crosses, 1,048 selections, 3,346 entries)	278	387	383

Rearing insect vectors. Since both tungro and grassy stunt are transmitted only by insect vectors, testing varietal resistance to the diseases by mass screening methods depends greatly upon the success of rearing and multiplication of the insect vectors. Experience over the past several years showed that the multiplication rate of the insects was generally low under natural conditions at Los Baños, Philippines between November and February. To increase the multiplication rate and maintain a constant supply of the insects for screening purposes, both *Nephotettix virescens* and *Nilaparvata lugens* were reared and multiplied in a glassroom of the IRRI phytotron. The temperature of the glassroom was regulated at 32°C for a 12-h day and at 24°C for

a 12-h night, with a constant 60-percent relative humidity. The supply of the insects from the glasshouse was much more dependable using this technique.

Field cage method. Inasmuch as the mass screening method for tungro resistance in the greenhouse (1972 Annual Report) has its limitations, efforts were made to develop a field cage method that would facilitate: 1) the simultaneous testing of a large number of rice varieties or lines for their resistance to tungro, 2) the multiple inoculation of test plants under natural conditions, and 3) the observation of the reaction of infected plants up to maturity.

The field cage method was considered successful when: 1) the insect vectors multiplied to a sufficient number for adequate inoculation of the plants, 2) the insects became viruliferous, 3) the number of viruliferous insects was regulated to ensure an adequate number of insects per plant to achieve maximum infection and minimum insect damage to the plant, and 4) the even distribution of the viruliferous insects among the plants was achieved.

A field cage, a portion of the IRRI Entomology Department's insect screen house, which contains two concrete beds, each with a planting area of 22.9 x 2.5 m, was used for developing the field cage method. One-month-old healthy TN1 plants were transplanted in 1,440 hills at four corners of the concrete beds on April 13, 1974. About a month later, 11,800 virus-free adults of *N. virescens* were released onto the plants for multiplication. On June 15th, 816 hills of diseased TN1, serving as the virus source, were transplanted in the concrete beds beside the healthy TN1 rice plants and two rows at the center of the concrete beds. Two weeks later, 20-day-old rice seedlings of 25 test varieties and lines were transplanted in the concrete beds at one seedling per hill, 48 seedlings of each variety per row, arranged at random and replicated four times. Hence, a total of 4,800 seedlings of 25 rice varieties were tested simultaneously.

About a week after transplanting, some seedlings of the susceptible varieties began to show symptoms of tungro infection. The first reading, taken about a month after transplanting, indicated reactions similar to those obtained from the mass screening method in greenhouse. However, the second reading, taken about 2 months after transplanting, indicated that the reactions of six varieties and lines were milder than those noted during the first reading while the reactions of the rest of the varieties remained unchanged. The apparent increase in resistance might be related to the difference in degree of plant tolerance of the varieties to the tungro disease.

Table 11. Resistance of some IRRI rice selections to grassy stunt tested by the mass screening method.

IR selection	Tests (no.)	Seedlings inoculated (no.)	Infected seedlings (%)
IR1704-3-2-3	18	348	2
IR1737-19-7-8-3	18	321	4
IR1917-3-19-2	18	263	5
IR2031-354-1-3-3	4	61	2
IR2031-724-2-3-2	4	60	3
IR2035-708-3	18	275	1
IR2037-1-3	6	89	2
IR2042-175-3-2-2	4	76	5
IR2061-213-2-16	6	89	3
IR2061-P900-2	6	69	0

Despite the fact that several methods of inducing an even distribution of the insects in the cage were tried, more dead plants and severe tungro infection occurred near the virus source, apparently due to the proximity of the plants to the source of the insects. Nevertheless, regardless of the distance from the virus source, a susceptible rice variety showed a consistently high percentage of infection. Although the resistance of rice varieties to tungro disease can be tested by the field cage method, the method needs improvement.

Screening for grassy stunt resistance. Varietal resistance to grassy stunt has continued to be tested by the improved method (1968 Annual Report). A total of 8,029 entries involving 156,000 seedlings (69% for the IRRI Plant Breeding Department, 26% for the IRRI Plant Pathology Department, and 5% for others) were inoculated in 1974. About 56 percent of the inoculated seedlings were kept in greenhouse for symptom development. The remaining seedlings, mostly F_1 seedlings, were transplanted in fields by the Plant Breeding Department. Some of the IR selections (Table 11) showed a resistant reaction consistently even when tested 18 times.

Genetic evaluation and utilization (GEU) program

Insect resistance

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GENERAL SCREENING
Entomology Department

Studies begun in previous years on the resistance of rice varieties to insect pests were continued during 1974 in order to identify newer sources of plant resistance, to determine the insect-host plant interrelationships that affect resistance, to examine the development of insect biotypes capable of surviving on resistant plants, and to breed insect-resistant varieties. The resistance of rice varieties/lines to one or more of six insect pests – striped borer, yellow borer, brown planthopper, green leafhopper, white-backed planthopper, and the whorl maggot – was examined (Table 1). The techniques for screening rices for resistance to these insects in the field and greenhouse/screenhouse experiments were described in previous annual reports. The lines that exhibited resistance in mass screening tests were retested for consistency in their resistance and selected lines were used in the screening studies.

Table 1. Number[a] of accessions in the IRRI germ plasm collection and selected breeding lines screened for their resistance to various insect pests of rice. IRRI, 1974.

Insect	Varieties or lines (no.)	
	Tested	Selected as resistant or as moderately resistant
Striped borer *(Chilo suppressalis)*	664	10
Yellow borer *(Tryporyza incertulas)*	2504	56
Brown planthopper *(Nilaparvata lugens)*	5499	202[b]
Green leafhopper *(Nephotettix virescens)*	2876	306[b]
White-backed planthopper *(Sogatella furcifera)*	2259	164
Whorl maggot *(Hydrellia philippina)*	4898	155

[a]Excludes screening of early generation breeding lines of which 32,075 were tested against brown planthoppers (bph) and 14,848 against green leafhoppers (glh). [b]On further retesting, 17 varieties were highly resistant to bph and 6 highly resistant to glh.

FIELD EXPERIMENTS
Entomology Department

A total of 2,864 varieties/lines were tested in field experiments during the dry season and 1,982 during the wet season in 1974. Although these rices were exposed to the natural infestation of various insects, the major problems during these experiments were the rice whorl maggot, stem borers, brown planthopper, and virus diseases. During the dry season, the brown planthopper caused hopperburn to most of the test lines. Those that survived this infestation are being reevaluated for their resistance in greenhouse experiments.

In a study of the differences in the incidence of whorl maggot, dead heart, and virus among some selected test lines in a field experiment, many lines exhibited a moderately low incidence of whorl maggot (Table 2). Higher levels of resistance to the whorl maggot have not been recorded thus far among the approximately 10,000 varieties that have been screened. Efforts are under way to see if intercrossing the moderately resistant lines can increase the level of resistance.

Many of the test lines showed low dead heart damage, while several others had 15 percent or more dead heart tillers. Some of the test lines also, showed good field resistance to the grassy stunt virus that was prevalent during this experiment.

GREENHOUSE/SCREENHOUSE EXPERIMENTS ON YELLOW BORER
Entomology Department

Difficulty in mass rearing of the yellow borer – the most widely distributed stem borer pest of rice in tropical Asia – has precluded continuous studies on varietal resistance to this pest. In an earlier study in the greenhouse, 57 selected varieties of rice were artificially infested with the yellow borer to test their resistance to this insect (1972 Annual Report). During 1974, using a procedure similar to that developed for the striped borer, a technique of mass screening rice varieties for resistance to the yellow borer was standardized. Of the 1,000 varieties/lines evaluated with this technique, 56 were identified as moderately resistant.

When these varieties/lines were tested more intensively for the nature and consistency of their resistance, IR1820-52-2, WC1253, and IR1514A-E666 exhibited marked resistance while the sus-

ceptible lines were severely damaged (Table 3). These results concur with the earlier findings with the exception of a high incidence of dead heart in the Kipusa variety, which in previous experiments exhibited moderate resistance. This reaction of Kipusa was confirmed in a follow-up experiment in which a uniform number of yellow borer larvae were caged with each variety (Table 4). However, the larval survival on Kipusa was similar to that on other moderately resistant varieties. Furthermore, Kipusa had significantly more dead hearts than most of the other test varieties, although the yellow borer moths did not exhibit any significant preference for oviposition on this rice variety (Table 5). This indicates that Kipusa is less tolerant of the damage caused by the yellow borer than most of the other varieties tested. The differences in the number of eggs laid on different rice varieties were significant, but did not correlate with differences in plant height, number of tillers per hill, or number of leaves per tiller (Table 5).

Larvae exhibited low survival on IR1721-11, IR1917-3, and IR1820-52-2. All of these are of improved plant type and thus could be very valuable breeding materials. IR1820-52-2 was rated as the most resistant line in all three experiments. Antibiosis appears to be a major factor of resistance of these lines.

BASIC STUDIES ON INSECT-HOST PLANT INTERRELATIONSHIPS

Entomology Department

In studying selected varieties for the effect of the host plant on insects caged on them and vice versa, the resistant plants were comparatively less damaged than the susceptible hosts. Also, the larvae of the stem borers (both striped and yellow) when caged on resistant plants had a comparatively lower survival, grew at a slower rate, had a small body size, and developed fewer and light-weight pupae than those caged on susceptible plants. Similar reactions were observed with leafhoppers and planthoppers, but because the rice plants were more resistant to these insects than they were to the stem borers, the survival of the leafhopper and planthopper caged on resistant plants was generally very low.

When the reaction to the brown planthopper of 11 selected rice varieties was investigated, the survival of the insects was significantly lower on all varieties tested than on the susceptible check variety Taichung Native 1. The varieties XB-5, Ptb 20, and Ptb 21 were almost as resistant as

Table 2. Results of a general screening of the world collection of rice varieties at IRRI for insect pests resistance.[a] IRRI, 1974 dry season.[b]

Variety	Origin	Whorl maggot damage[c] 25 DT[e]	Dead hearts (%) 50 DT	Virus[d] (%) 70 DT
Cinto Kayo	Indonesia	2	2.5	28.2
Comal	Indonesia	2	1.5	28.6
Gondang	Indonesia	2	1.2	14.6
Ptb 21	India	2	2.6	2.4
Tjenta Mudja	Indonesia	2	1.5	10.3
Satrijo	Indonesia	2	21.3	61.5
Angkor	Indonesia	3	2.6	28.6
Ba Con	Vietnam	3	1.5	30.0
Brondal	Indonesia	3	2.2	22.2
Brondol	Indonesia	3	2.1	7.1
Bulu Baselijan	Indonesia	3	10.7	65.8
Bulu Menggali	Indonesia	3	2.4	30.0
Cempa	Indonesia	3	0.0	4.8
Cempo	Indonesia	3	0.6	23.8
Cempo Dirhan	Indonesia	3	0.0	10.3
Cempo Sebrang	Indonesia	3	0.5	21.4
Cempo Selak	Indonesia	3	0.8	28.6
Daringan	Indonesia	3	18.5	35.7
Djawa Bidri	Indonesia	3	2.8	30.0
Djawa Gendjah	Indonesia	3	1.4	26.5
Gidjambi	Indonesia	3	1.6	29.3
Ketan Kelapa	Indonesia	3	0.0	78.8
Ptb 20	India	3	2.9	2.4
Tjempo Rante	Indonesia	3	0.0	14.3
Umpong Kanja	Indonesia	3	1.9	26.2
Siponu	Indonesia	5	0.8	0.0
IR20 (Resistant check)		4	2.6	49.0
Rexoro (Susceptible check)		5	11.2	54.3

[a]2,483 varieties tested from accession number 16,776–20,000 of the rice collection. Many of the test varieties exhibited hopperburn. [b]No white head count was made since most of the varieties were photoperiod sensitive. [c]The larger number indicates greater damage. [d]Mostly grassy stunt. [e]DT = days after transplanting.

Table 3. Reevaluation[a] of the resistance to the yellow borer, *Tryporyza incertulas*, of rices selected from mass screening experiments. IRRI, 1974.

Variety	Dead hearts[b] (%)
IR1820-52-2	27.1 a
WC1263	28.0 a
WC1253	29.4 a
IR1514A-E666	31.4 abc
IR20	34.7 abcd
IR1704-3-2-3	37.0 bcde
IR1917-3-19-2	39.0 cdef
IR2049-120-2	39.8 def
IR1721-11-68-32	40.4 def
IR1539-823-1-4	41.1 def
C4-63	41.9 def
K8 (mutant) Sel	54.8 gh
Kipusa	62.0 h
RD5	72.1 i
Rexoro	91.3 j

[a]Av. of four replications. [b]Any two means followed by the same letter are not significantly different at the 5% level.

Mudgo (the resistant check variety), but the resistance of the remaining test varieties – Ptb 18, BKN 6809-74-40, HR 12, ARC 5785, MCM 2, MCM 1, Kentjana, and Bathurst – was lower than that of Mudgo. Although the survival of the insects caged on Kentjana and Bathurst was higher than on other resistant varieties, these two varieties sustained little damage in the mass screening tests as well as in an experiment in which 100 first-instar nymphs were caged on 30-day-old individual potted plants. This indicates that Kentjana and Bathurst can tolerate damage caused by brown planthopper nymps. However, in a separate experiment, adult brown planthoppers preferred these two varieties and caused some damage. Thus, it is likely that Kentjana and Bathurst are subject to severe damage under heavy infestation.

In further studies, the feeding behavior of the brown planthopper on varieties Kentjana and Bathurst was found to be similar to that on Taichung Native 1. The insects made fewer punctures per unit time of feeding on Bathurst than on resistant varieties. Previous studies revealed that the insects repeatedly punctured resistant rice varieties but did little feeding. However, on susceptible rice varieties the insects made fewer punctures but the feedings of the insects on the plant was sustained (1970 Annual Report). This may indicate that either the rice varieties that are resistant to brown planthoppers lack phagostimulus or contain a strong taste repellent. Inasmuch as the feeding of the insects on Kentjana and Bathurst was similar to that on susceptible varieties (fewer punctures), these two rice varieties may possess a type of resistance that is different from that observed on rices tested

Table 4. Resistance[a] of selected rice lines and varieties to the yellow borer, *Tryporyza incertulas*. IRRI, 1974.

Variety	Dead hearts[a]		Survival[a] (%)		
	20[b]	30[b]	10[b]	20[b]	30[b]
IR1820-52-2	12 a	20 ab	15 a	13 a	5 a
IR1917-3-19-2	15 ab	25 b	15 a	14 a	11 b
IR1721-11-6-8-3-2	15 ab	23 ab	21 ab	15 a	11 b
IR8	20 bc	17 a	26 abc	16 a	25 d
IR20	25 cd	37 c	15 a	13 a	18 c
WC1251	38 e	51 d	29 bc	30 b	26 d
Kipusa	34 e	42 cd	28 abc	15 a	29 cd
TKM 6	54 f	48 d	38 cd	41 c	24 d
IR1539-823-1-1-4	30 de	47 d	44 de	26 b	26 d
Rexoro	48 f	65 e	54 e	28 b	34 e

[a]Av. of four replications. Each replication consisted of infesting the primary tillers of eight potted plants individually with a first instar larva. A total of 100 larvae were used for infesting the rice plants for each observation on a variety. Means followed by a common letter are not significantly different at the 5% level. [b]At indicated days after infestation.

Table 5. Preference[a] of *Tryporyza incertulas* moths for oviposition on selected rice varieties and association[b] with some plant characteristics. IRRI, 1974.

Variety	Egg masses (no.)	Leaves (no./tiller)	Tillers (no./pot)	Plant ht (cm)
IR1820-52-2	2.5 a	7.6 cd	13 de	77 de
IR1917-3-19-2	2.6 a	9.0 a	22 a	64 f
IR1721-11-6-8-3-2	3.6 cd	7.2 d	12 ef	86 b
IR8	3.0 abc	7.9 bc	16 cd	79 cd
IR20	2.8 ab	8.7 a	21 ab	72 e
WC1251	4.0 d	8.4 ab	18 bc	102 a
Kipusa	3.0 abc	6.6 e	11 cdef	86 b
TKM 6	3.4 c	8.8 a	20 ab	98 a
IR1539-823-1-4	3.6 cd	7.6 cd	15 d	84 bc
Rexoro	3.2 bc	6.2 bc	9 f	101 a

[a]Correlations between number of egg masses and plant characters: no. of leaves – 0.0361 n.s.; no. of tillers – 0.1945 n.s.; plant height – 0.389 n.s. [b]Av. of 32 potted plants of each variety. The experiment was conducted inside a large screen cage and the observations were made 50 days after sowing. Data on plant characteristics were recorded on 10 plants of each variety. Means followed by a common letter are not significantly different at the 5% level.

in earlier trials.

In a similar experiment, but using a different set of rice varieties the survival of brown planthopper nymphs caged on resistant varieties was lower and the time required for the nymph to reach the adult stage was longer. The differences in the survival of the nymphs at 2 days after caging were not significant, but they became wider and significant in subsequent observations. At 8 days after infestation, although insect survival on some of the moderately resistant varieties was not significantly lower than that on the susceptible check, Taichung Native 1, the number of adults that eventually developed on them was significantly lower. Also, the insect took longer to reach the adult stage on the moderately resistant varieties. These rice varieties were confirmed as being resistant in another experiment in which the adult insects caged on them produced few progenies while on most of the resistant varieties, the insects died without producing any progenies (Table 6).

Current experiments emphasize the moderate level of resistance that is expected to be multigenic, and that will probably be less suitable to the development of insect biotypes capable of surviving on these moderately resistant rices as compared with monogenic resistance which occurs in rices such as Mudgo and ASD 7.

INSECT BIOTYPES CAPABLE OF SURVIVING ON RESISTANT PLANTS

Entomology Department

As the area in which insect-resistant rice varieties are intensively cultivated expands, the possibility increases that the insects will develop biotypes that can survive on resistant plants. The likelihood of the development of such insect biotypes is greater when the high level of resistance of a rice variety is governed by a single pair of genes, i.e., to brown planthopper or green leafhopper. On the other hand, the possibility of the development of biotypes on moderately resistant varieties is less when the resistance is polygenic.

Two new biotypes of the brown planthopper were identified in a 1974 project in which green leafhoppers and brown planthoppers were collected from areas in Victoria, Laguna, Philippines (about 20 km from the IRRI farm) where rice varieties resistant to these insects were intensively grown. They were reared continuously, when possible, on resistant plants in an IRRI greenhouse. This led to the development of two biotypes which were named biotypes 3 and 4. ASD 7 is susceptible to biotype 3 and both ASD 7 and Mudgo are susceptible to biotype 4. Biotype 1 is the general brown planthopper population at IRRI to which both ASD 7 and Mudgo are resistant. Mudgo is susceptible to biotype 2, while

Table 6. Longevity and fecundity of the brown planthopper adults on selected rice varieties.[a] IRRI, 1974.

Variety	Longevity (days)		Progenies produced (no./female)	
	Male	Female		
	Mean		Mean	Range
Ptb 21	2.0	2.0	0	0
Murungakayan 308	2.0	2.0	0	0
Murungakayan 307	2.0	2.0	0	0
Suduwi 306	2.0	2.0	0	0
Pai-shein	2.0	2.0	0	0
Warangal Culture 1257	2.0	2.0	0	0
Warangal Culture 1253	2.0	2.0	0	0
Murungakayan 302	2.0	2.0	0	0
Murungakayan 1263	3.2	3.8	4.5	0 – 40
Monoharsail	3.8	3.8	7.0	0 – 50
Bajang	6.8	7.4	13.2	0 – 50
Trang Duong Tam	6.0	7.3	26.0	0 – 140
Tien Nhum	7.2	8.0	61.5	0 – 225
Taichung Native 1	11.2	12.0	98.3	0 – 218
Mudgo	2.0	2.0	0	0

[a]Av. of 10 replications, each consisted of caging one pair of newly emerged adults on a 30-day-old potted plant.

Taichung Native 1 was susceptible to all biotypes. Similar studies with the green leafhopper, *Nephotettix virescens*, revealed no new biotypes.

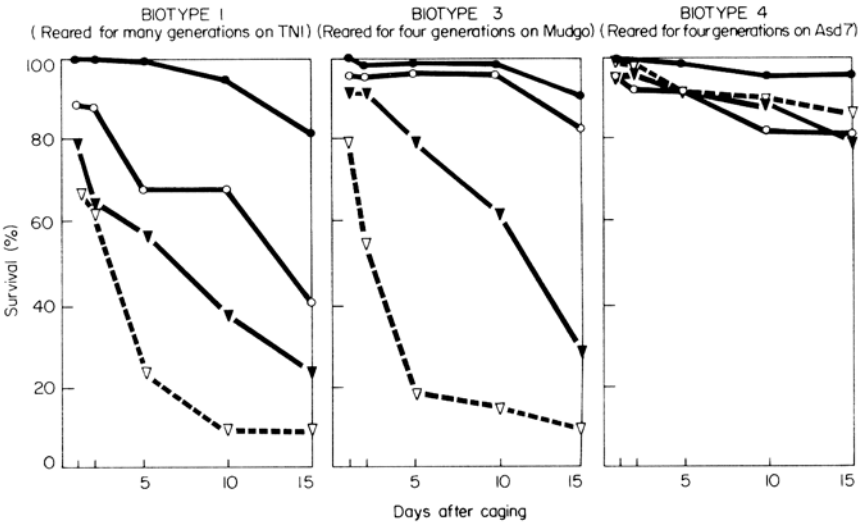
The survival of biotypes 1, 3, and 4 on varieties possessing monogenic dominant resistance (Mudgo, IR26, IR1561) and monogenic recessive resistance was studied (fig. 1). Even though biotype 4 insects survived on all three varieties, the insects surviving were smaller in size than those on the susceptible check variety Taichung Native 1. However, the size of biotype 3 adults reared on the recessive gene resistant variety ASD 7 was similar to that of those reared on Taichung Native 1.

ROLE OF RESISTANT VARIETIES IN INSECT CONTROL

Entomology Department

Varietal resistance and insecticidal treatments usually complement each other, providing better insect control and higher grain yields than when either of them is used singly. This is particularly true for rice varieties with a moderate level of resistance or when a wide variety of insect pests is involved. However, varietal resistance itself may provide satisfactory insect control when the variety is highly resistant to a predominant species. Field trials showed that while rice varieties/selections that were resistant to the brown planthopper sustained little damage, the susceptible or moderately susceptible varieties experienced hopperburn damage.

When the resistance of IR26, the first brown



1. Survival of first instar nymphs of three different biotypes of brown planthopper on selected rice varieties in a greenhouse experiment. IRRI, 1974.

planthopper-resistant variety released by IRRI, was evaluated in field trials under an infestation on the IRRI, it showed no visible damage from the insect. Additionally, the yields were similar whether or not it received insecticidal protection, while other rice varieties (IR8, IR20, IR22, IR24, Rexoro, and Taichung Native 1) showed hopperburn and produced virtually no rice, both in the plots treated with diazinon and in those plots to which no insecticide was applied. The brown planthopper population was so heavy during this experiment that even the carbofuran-treated plots of susceptible varieties yielded poorly. The 7.20 t/ha yield of IR26 even without any insecticidal protection illustrates the potential of varietal resistance of rices to the brown planthopper.

Genetic evaluation and utilization (GEU) program

Protein content

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The objective of the protein program is to raise the protein content of improved rice varieties by at least 2 percentage points (from about 7% to about 9%) through both routine and theoretical breeding procedures. A preliminary objective of our program is to better understand the genetic and environmental factors that affect protein content so that we can identify more efficient and effective selection criteria. Studies also emphasize the determination of nutritional utility and other ramifications of improved protein content.

EVALUATION TRIALS

Plant Breeding and Agronomy Departments

Plant breeders evaluated 437 varieties and lines for protein content in replicated yield trials during the 1974 dry season, and 368 during the 1974 wet season. Several lines from 23 crosses performed well during both seasons and several more were considered promising based only on wet-season data (Table 1). Five of the crosses involved the variety PTB 18 and six involved the wild rice *O. nivara*. Because these are common parents in several crosses which have produced high protein progeny, we believe they may carry genes for high protein content.

Most of the other crosses involve either the line IR480-5-9 or an IR1103 derivative, or both. We have previously identified these breeding lines as having high protein content although IR1103 yields poorly and has never been demonstrated conclusively to carry genes for higher protein content. IR480 was derived from the cross Nahng Mon $S4^2$/TN1, while IR1103 is a cross of IR8 and Chowsung.

Two lines developed at the Bangladesh Rice Research Institute (BRRI), BRJ1-5-B-7 and BRJ1-13-B-55, were identified as having higher protein content through routine screening at IRRI. The lines performed well in both seasons.

Most of our advanced materials are resistant to some of the major diseases and insects and would be suitable for cultivation in certain countries. In fact, IR480-5-9 has already been released as the variety Ajral in Fiji and is reported to be widely grown in Cuba. A few of our lines are resistant or moderately resistant to most major diseases and insects. (For a complete discussion of these problems see the insect and disease resistance sections of this report.) We plan to distribute all of these materials through the International Rice Testing Program during 1975.

Agronomists evaluated the yield potentials of 17 promising high-protein lines and three IRRI varieties, IR8, IR20, and IR26, in both seasons with IR8 and IR480-5-9 as standard controls. In the dry season, IR26 produced the highest yields, but these yields were not significantly higher than those of the two IR2153 lines and IR2145-20-4 (Table 2). With no fertilizer nitrogen the differences were not significant in the protein contents of IR480-5-9, IR1917-3-19, IR2031-724-2, and IR2153-338-3. At 150 kg N/ha, the protein contents of IR2031-724-2 and IR2153-338-3 were as high as that of the high-protein control, IR480-5-9 (Table 2). IR8 yielded poorly due to severe infection of grassy stunt virus.

In the wet season, IR26 again produced the highest grain yield (Table 3), and IR2031-724-2 and IR2153-338-3 had protein contents similar to that of the IR480 check at zero fertilizer nitrogen.

Based on data from two seasons in these yield trials, IR2031-724-2 and IR2153-338-3 look promising for high yields and high protein. The major weakness of IR2031-724-2 is its susceptibility to tungro virus disease. It has consistently performed well for protein content and yield compared with IR20 in several trials at varying nitrogen levels (Tables 1, 2, 3). IR2153-338-3 is at least moderately resistant to all major pests in the Philippines and has also performed well for protein content and yield. Both lines may be suitable for cultivation in many countries. The lysine content of their grain protein is normal.

CROSSING PROGRAM

Plant Breeding Department

Crosses were made between all outstanding high-protein lines and the best breeding materials of other problem areas. Crosses were also made during the dry season using our best improved lines and about 50 high-protein cultivars from the world collection. During the wet season we grew the F_1 plants and made numerous top crosses and double crosses with other improved lines. Lack of a suitable selection criterion, how-

Table 1. Brown rice protein and grain yield[a] of promising high-protein breeding materials in plant breeding replicated yield trials, IRRI, 1974.

Designation	Cross	Dry season				Wet season			
		Protein		Yield		Protein		Yield	
		%	Index[a]	t/ha	Index[a]	%	Index[a]	t/ha	Index[a]
BRJ1-5-B-7	IR8/DA 31	9.0*	118	5.8	95	10.3*	124	4.6	112
BRJ1-13-B-55	IR8/DA 31	8.7*	114	6.2	102	9.4*	113	4.6	112
CR94-13	PTB 21/PTB 18//IR8	8.2*	108	6.4	105	9.7*	117	4.2	103
IR480-5-7	Nahng Mon S4[2]/TN1	9.3*	122	6.5*	107	10.0*	120	4.5	110
IR1702-74-3	IR24/PTB 18	8.9*	117	6.9*	113	9.4*	113	4.0	98
IR1704-13-3	IR24[2]/ *O. nivara*	8.8*	116	5.7	93	9.4*	113	4.4	108
IR1823-111-1	IR24//Mudgo/IR8///IR8/PK 203//IR262	8.6*	113	6.3	103	9.2*	111	3.9	96
IR1825-2-31	IR22//IR24[3]/*O. nivara*	–	–	–	–	9.2*	111	4.3	104
IR1857-103-2	IR8[3]/*O. nivara*///IR841//Mudgo/IR8	8.0	105	7.4*	121	9.1*	110	4.2	102
IR2003-P3-3	IR1103-15/IR480///IR22//Mudgo/IR8	9.1*	120	5.8	95	10.6*	128	4.2	104
IR2003-P5-3-2	IR1103-15/IR480///IR22//Mudgo/IR8	9.0*	118	7.7*	126	9.0*	108	4.8*	118
IR2003-P5-3-3	IR1103-15/IR480///IR22//Mudgo/IR8	8.6*	113	7.2*	118	9.2*	111	4.8*	116
IR2003-P7-7	IR1103-15/IR480///IR22//Mudgo/IR8	9.3*	122	6.7*	110	9.0*	108	4.7*	116
IR2003-P16-7	IR1103-15/IR480///IR22//Mudgo/IR8	9.1*	120	6.5	107	9.7*	117	4.1	101
IR2003-P18-1	IR1103-15/IR480///IR22//Mudgo/IR8	10.2*	134	5.7	93	11.3*	136	3.4-	83
IR2003-P21-17	IR1103-15/IR480///IR22//Mudgo/IR8	8.7*	114	6.2	102	9.5*	114	4.3	104
IR2006-P12-12	IR1103-15/IR1163-124///IR22//Mudgo/IR8	9.1*	120	7.1*	116	9.9*	119	4.3	105
IR2006-P12-15	IR1103-15/IR1163-124///IR22//Mudgo/IR8	8.7*	114	6.4	105	9.2*	111	4.5	109
IR2006-P12-19	IR1103-15/IR1163-124///IR22//Mudgo/IR8	8.6*	113	5.7	93	9.5*	114	4.1	101
IR2016-P4-5	IR1103-49/IR480///IR22//Mudgo/IR8	10.0*	132	6.3	103	9.5*	114	3.8	91
IR2016-P7-4	IR1103-49/IR480///IR22//Mudgo/IR8	9.4*	124	6.1	100	10.0*	120	4.2	102
IR2019-P74-5	IR1103-49/IR1163-96//IR480	8.8*	116	5.9	97	9.4*	113	4.3	105
IR2031-130-6	IR24[3]/*O. nivara*//IR1416-131///IR1330-3	–	–	–	–	9.5*	114	4.1	99
IR2031-220-3	IR24[3]/*O. nivara*//IR1416-131///IR1330-3	–	–	–	–	9.7*	117	3.8	91
IR2031-724-2	IR24[4]/*O. nivara*//IR1416-131///IR1330-3	8.8*	116	6.2	102	9.5*	114	4.5	111
IR2068-65-3	IR480/L4(40-1915)-12//IR1103-15/IR1103-1	9.6*	126	6.2	102	9.1*	110	4.1	100
IR2070-189-3	IR20[2]/*O. nivara*//CR94-13	–	–	–	–	9.0*	108	4.8	117
IR2070-401-3	IR20[2]/*O. nivara*//CR94-13	–	–	–	–	9.1*	110	4.3	105
IR2070-464-1	IR20[2]/*O. nivara*//CR94-13	–	–	–	–	9.2*	111	4.2	102
IR2070-487-2	IR20[2]/*O. nivara*//CR94-13	–	–	–	–	9.2*	111	4.2	102
IR2070-834-1	IR20[2]/*O. nivara*//CR94-13	–	–	–	–	10.3*	124	4.3	104
IR2071-77-9	IR1561//IR24[4]/*O. nivara*///CR94-13	–	–	–	–	9.0*	108	4.4	106
IR2071-137-5	IR1561//IR24[4]/*O. nivara*///CR94-13	–	–	–	–	9.3*	112	4.7*	114
IR2071-486-9	IR1561//IR24[4]/*O. nivara*///CR94-13	–	–	–	–	9.1*	110	4.0	98

more of table 1

(table 1 continued)

Designation	Cross	Dry season				Wet season			
		Protein		Yield		Protein		Yield	
		%	Index[a]	t/ha	Index[a]	%	Index[a]	t/ha	Index[a]
IR2071-502-4	IR1561//IR24[4]/*O. nivara*///CR94-13	–	–	–	–	9.1*	110	3.9	95
IR2071-527-6	IR1561//IR24[4]/*O. nivara*///CR94-13	–	–	–	–	9.0*	108	4.3	105
IR2071-559-2	IR1561//IR24[4]/*O. nivara*///CR94-13	–	–	–	–	9.4*	113	4.2	104
IR2071-588-2	IR1561//IR24[4]/*O. nivara*///CR94-13	–	–	–	–	9.1*	110	4.3	105
IR2071-757-6	IR1561//IR24[4]/*O. nivara*///CR94-13	–	–	–	–	9.1*	110	4.5	110
IR2153-338-3	IR26//IR20[4]/*O. nivara*	–	–	–	–	8.7	105	5.2*	126
IR2153-479-2	IR26//IR20[4]/*O. nivara*	8.5*	112	7.0	115	9.1*	110	4.1	100
IR2172-61-2	CR94-13//IR1103-15/IR480	–	–	–	–	9.4*	113	4.1	99
IR2172-64	CR94-13//IR1103-15/IR480	8.4*	111	7.3*	120	9.3*	112	4.1	100
IR2699-2-1	IR1103-15/IR480[2]	–	–	–	–	9.0*	108	4.1	100
IR2699-18-2	IR1103-15/IR480[2]	–	–	–	–	9.5*	114	3.9	94
IR2851-42	IR480[2]///IR1103-49/IR1163-124// Pelita 1	–	–	–	–	9.4*	113	4.5	111
IR2851-83	IR480[2]///IR1103-49/IR1163-124// Pelita 1	–	–	–	–	9.2*	111	4.9*	119
IR2852-6	IR480//IR1103-15/IR480[2]	–	–	–	–	9.8*	118	4.2	102
IR2852-8	IR480//IR1103-15/IR480[2]	–	–	–	–	9.6*	116	4.3	104
IR2854-20	IR480/4/IR1103-49/IR480// Pelita I///IR480	–	–	–	–	9.4*	113	4.2	102
IR480-5-9 (ck)		9.1*	120	5.5-	90	9.5*	114	4.1	100
IR20 (ck)		7.6	100	6.1	100	8.3	100	4.1	100
cv (%)		4.9	–	7.7	–	5.9	–	11.2	–
LSD (.05)		0.5	–	0.6	–	0.6	–	0.6	–

[a]Percent of IR20 check. Significantly greater (0.05) than IR20 check – Significantly less (0.05) than IR20 check.

Table 2. Grain yield and brown rice protein content of rices at three nitrogen treatments.[a] IRRI, 1974 dry season.

Designation	Yield[b] (t/ha)			Brown rice protein[c] (%)		
	0 kg N/ha	150 kg N/ha[d]	70+40+40 kg N/ha[e]	0 kg N/ha	150 kg N/ha[d]	70+40+40 kg N/ha[e]
IR8	2.7	5.8	5.4	7.8	8.0	8.4
IR20	3.7	7.0	7.1	7.6	8.4	9.0
IR26	4.3	8.7	8.9	7.0	7.6	8.6
IR2031-724-2	4.5	7.4	8.0	8.0	9.2	10.1
IR2153-338-3	4.2	7.8	8.5	7.9	9.4	10.0
IR1857-1	4.2	7.9	8.0	7.8	8.9	9.4
IR1917-3-19	4.4	7.2	7.5	7.9	8.8	10.0
IR2145-20-4	5.1	8.2	8.6	7.7	8.4	8.8
IR2153-189-2	3.7	7.9	8.3	7.2	8.7	9.4
IR480-5-9 (check)	2.9	6.2	6.6	8.5	9.4	9.9

[a]Average of four replications. [b]LSD (5%): 0.8 t/ha for comparing variety means and 0.9 t/ha for comparing nitrogen means. [c]LSD (5%): 0.7% for comparing variety means and 0.8% for comparing nitrogen means. [d]Basal application of ammonium sulfate. [e]Split applications: basal, 30 days after transplanting, and at panicle initiation.

Table 3. Grain yield and brown rice protein content of rices at three nitrogen treatments.[a] IRRI, 1974 wet season.

Designation	Yield[b] (t/ha)			Brown rice protein[c] (%)		
	0 kg N/ha	90 kg N/ha[d]	60+30 kg N/ha[e]	0 kg N/ha	90 kg N/ha[d]	60+30 kg N/ha[e]
IR8	4.1	5.0	5.4	6.4	8.2	8.9
IR26	4.2	5.4	5.9	6.8	8.4	8.8
IR2031-724-2	4.0	4.8	5.3	7.4	9.0	9.2
IR2153-338-3	3.8	5.2	5.4	7.4	9.0	9.6
IR2003-P5-3	3.6	5.4	5.2	6.9	8.7	9.0
IR2006-P3-33	3.8	4.2	4.7	6.9	9.6	9.7
IR2153-96-1	4.2	4.7	4.6	6.6	8.1	9.5
IR2172-64	3.7	4.3	5.0	6.9	8.8	9.6
IR480-5-9 (check)	3.4	3.9	4.5	7.5	8.6	10.0

[a]Average of four replications. [b]LSD (5%): 0.6 t/ha for comparing variety means and 0.7 for comparing nitrogen means. [c]LSD (5%): 0.6% for comparing variety means and 0.6% for comparing nitrogen means. [d]Basal application of ammonium sulfate. [e]Split application: basal and at panicle initiation.

ever, continued to impede the dependable evaluation of early generation selections from the many crosses involving high-protein parents.

Work was continued on the modified diallel selective mating scheme (1973 Annual Report, p. 154) to concentrate genetic factors for protein content along with resistance to major diseases and insects. The gene pool now includes all probable sources of genes for higher protein content and carries a complete spectrum of resistance to major diseases and insects.

COMPARISONS OF PROTEIN SELECTION CRITERIA

Statistics, Plant Breeding, and Chemistry Departments

In 1974, we investigated the genetic correlation between protein content and grain yield. We studied the effect of different planting schemes on the estimates of genetic and phenotypic parameters involving grain yield and protein content of the F_2 progeny of a cross between the high-protein line IR480-5-9 and the disease resistant line IR1514A-E588. We also analyzed data from replicated yield trials, as well as data from the F_2 progeny, to evaluate the use of protein per seed as a selection criterion.

Evaluation of planting schemes. In the 1974 dry season, F_2 progeny of the cross IR480-5-9 x IR1514A-E588 were planted using three different plans:

Plan A. Each F_2 plant was surrounded by the P_1 (IR1514A-E588) parent;

Plan B. F_2 progeny and P_1 parents were planted in alternate rows;

Plan C. F_2 progeny were bulk planted in 7 x 14 hill plots.

For each plan, two different spacings were used, 25 x 25 cm and 50 x 50 cm. Nitrogen was applied basally at 100 kg N/ha.

We estimated the genetic variance for three traits – grain yield, percent brown rice protein, and protein per seed – as proportions of the phenotypic variance (referred to here as heritability). Percent brown rice protein is the protein percentage of the total brown rice weight, and protein per seed is the average weight of protein on a per-seed basis. We also estimated the genetic and phenotypic correlation between traits. The estimation procedure was based on the assumptions that the non-genetic components of variance and covariance are independent of genotype, are constant for all genotypes, and are equal to the respective variances and covariances of the P_1 parents. These assumptions, especially the latter, are weak and the estimates are expected to be biased. For each planting scheme, differences between the appropriate F_2 and P_1 variances and covariances were considered to be estimates of the genetic variances and covariances. Unfortunately, although there were P_1 (and also P_2) plots associated with Plan C, they were bulk harvested, and non-genetic variance estimates

were not available. Therefore, the estimates used for Plan C were based on P_1 variances pooled over Plans A and B for each spacing.

Comparisons of estimates among the various planting schemes (Table 4) do not clearly indicate the relative merits of the different plans. Estimates associated with yields and with percent brown rice protein were extremely variable; heritability estimates ranged from −0.22 to 0.49 for grain yield and 0.39 to 0.84 for percent brown rice protein. No apparent relation was found between the variability associated with these estimates and the differences in the planting scheme.

Even so, certain findings were consistent over all plans. In all schemes for which estimates were possible, correlations were consistently negative between protein content and grain yield. The correlations between percent protein and protein per seed were unfiormly positive and high. The estimates of the heritability of protein per seed were high with little variation over plans and spacings.

Evaluation of protein content measures. Since the heritability estimates of protein per seed were consistently high, the measure may have merit as an index for selecting high-protein lines. The magnitudes of the estimates for percent brown rice protein and protein per seed suggest that the increase in percent brown rice protein realized by selecting lines based on protein per seed could be from 76 to more than 100 percent of the increase realized by selecting on percent brown rice protein by itself. This can be attributed to the high genetic correlation between the two traits and the high heritability of protein per seed relative to that of percent brown rice protein.

Due to negative genetic correlations between grain yield and both protein measures, selection on either protein measure by itself is expected to result in an average yield reduction. However, because the genetic correlation between yield and protein per seed is much smaller in magnitude than that between yield and protein percent, selection on protein per seed is expected to result in smaller yield reductions than is selection on protein percent. Available estimates indicate that the reduction in yield that would be realized by selecting on protein per seed would be from 45 to 66 percent of that realized by selecting on protein percent. This is important because if

Table 4. Estimates of genetic and phenotypic measures for grain yield, percent brown rice protein, and protein per seed from F_2 progeny of the experimental line cross IR480-5-9 × IR1514A-E588.[a] IRRI, 1974.

	25- × 25-cm spacing			50- × 50-cm spacing		
	Yield	Protein (%)	Protein/ seed	Yield	Protein (%)	Protein/ seed
			Plan A[b]			
Yield	0.13	−0.84	−0.38	0.49	−0.58	−0.38
Protein (%)	−0.10	0.39	0.71	−0.33	0.84	0.76
Protein/seed	−0.11	0.68	0.86	−0.16	0.73	0.85
			Plan B[c]			
Yield[d]	(−0.20)	–	–	(−0.06)	–	–
Protein (%)	−0.01	0.84	0.86	−0.38	0.63	0.77
Protein/seed	0.05	0.85	0.92	−0.16	0.76	0.86
			Plan C[e]			
Yield[d]	(−0.22)	–	–	0.12	−1.51	−0.78
Protein (%)	−0.12	0.58	0.79	−0.39	0.82	0.79
Protein/seed	−0.14	0.74	0.93	−0.22	0.77	0.85

[a]For each plan and spacing, estimates of heritabilities occur on diagonals, genetic correlations on upper right-off diagonals, and phenotypic correlations on lower left-off diagonals. [b]Each F_2 plant surrounded by P_1 parent. [c]F_2 progeny and P_1 parents planted in alternate rows. [d]Negative heritability values, given in parentheses, due to negative estimates of genetic variance, so associated genetic correlations cannot be estimated. [e]F_2 progeny bulk planted in 7- × 14-hill plots.

Table 5. Estimates of genetic and phenotypic measures for grain yield, percentage of brown rice protein, and protein per seed from line means of the replicated yield trials, 1973 wet season and 1974 dry season.[a] IRRI.

	Yield		Protein (%)		Protein/seed	
			1973 wet season			
Yield	0.89	(0.75 to 0.97)	−0.15	(−0.92 to 0.49)	−0.03	(−0.55 to 0.64)
Protein (%)	−0.15	(−0.82 to 0.36)	0.71	(0.50 to 0.90)	0.51	(0.06 to 0.81)
Protein/seed	−0.03	(−0.47 to 0.60)	0.53	(0.17 to 0.77)	0.90	(0.82 to 0.97)
			1974 dry season			
Yield	0.88	(0.67 to 0.97)	−0.31	(−0.83 to 0.24)	−0.06	(−0.63 to 0.55)
Protein (%)	−0.24	(−0.78 to 0.23)	0.83	(0.50 to 0.95)	0.43	(−0.02 to 0.79)
Protein/seed	−0.03	(−0.58 to 0.52)	0.47	(0.06 to 0.80)	0.93	(0.86 to 0.98)

[a]For each trial, estimates of heritabilities occur on diagonals, genetic correlations on upper right-off diagonals, and phenotypic correlations on lower left-off diagonals. Values outside parentheses represent averages, and those inside parentheses, ranges over groups.

selection on protein content were to be based on F_2 performance, the index chosen should result in as little yield reduction as possible.

Because assumptions associated with the estimation of the F_2 genetic parameters were rather weak, and because any conclusions drawn from this study would necessarily be confined to this one cross, we analyzed the 1973 wet season and the 1974 dry season replicated yield trials to obtain a broader base of genetic information.

For both trials, the test lines were laid out in groups of 25, each group replicated four times. Selected lines from common crosses were generally entered into the same group (although there was often more than one cross within a group, and lines from a common cross sometimes occurred in several groups). The 1973 wet-season trial consisted of 13 groups with three check lines common to all groups, and the 1974 dry season trial consisted of 18 groups with two common checks.

After eliminating the check lines, the genetic and phenotypic parameters were estimated separately for each group. Table 5 contains the averages and ranges over groups of the genetic variance as a proportion of the phenotypic variance (heritability) and the averages and ranges of the between-line genetic and phenotypic correlations. These values differ from those in Table 4, both in the method of estimation and in their genetic meanings. The values in Table 5 were obtained from variance component estimates derived from analyses of variance and covariance. They represent genetic measures among the inbred line means from various crosses, while those in Table 4 represent genetic measures among individual F_2 plants of a single cross (implying no inbreeding).

Despite these differences, essentially the same picture emerges from these trials. Heritability estimates of protein per seed are consistently high with little variation, while heritability of brown rice protein percentage is lower with greater variation. The average correlation between protein per seed and percent brown rice protein is only moderate, but the range includes high values and does not go appreciably below zero.

The magnitude of the average correlation between protein per seed and grain yield is small, and the range includes moderate positive correlations. If these positive values reflect actual genetic relations in certain crosses, then, possibly, breeding programs can be set up in which selection on protein per seed could result in an increase in grain yield as well as in protein content.

In any case, the results discussed suggest that protein per seed should be seriously considered as a selection index. This index would be less likely to cause a decrease in grain yield than would percent brown rice protein. Further, given the high heritabilities associated with protein per seed, genetic advance in this trait is assured.

Table 6. Effect of chemicals on the protein content and yields of the experimental line IR2061-464-2. IRRI, 1974 dry season.

Treatment	Formulation	Rate (kg/ha)	Time of application[a]	Yield[b] (t/ha)	Brown rice protein	
					Content[b] (%)	Yield (kg/ha)
Picloram/2,4-D	granule	5.0	CH	7.8	9.6*	588
Picloram/2,4-D	liquid	5.0	PI	3.2*	10.7*	264
Picloram/2,4-D	liquid	2.0	CH	3.0*	12.6*	290
Picloram (K-salt)	liquid	2.0	CH	5.8*	10.2*	463
Simetryne	liquid	0.5	CH	6.2*	10.2*	497
Fertilized control[c]				8.5	8.8	586
Unfertilized control				4.2	7.5	237

[a]CH = complete heading; PI = panicle initiation. [b]Means are significantly different from the fertilized control at 5% level. [c]Blanket application of 100 kg N/ha during land preparation and 40 kg N/ha at panicle initiation.

EFFECT OF DEFOLIANTS ON PROTEIN CONTENT

Agronomy Department

We conducted field experiments to determine if accelerating leaf senescence by applying defoliants could help nitrogen transport from leaves to the grains, thereby increasing protein content.

We screened simetryne [4,6-bis (ethylamino)-2-methylthio-S-triazine], picloram (K-salt) [4-amino-3,5,6-trichloropicolinic acid, potassium salt], and picloram/2,4-D mixture [4-amino-3,5,6-trichloropicolinic acid, triisopropylamine salt in mixture with 2,4-D]. In the 1974 dry season, IR2061-464-2 rice was grown using four replications of the randomized complete block design. The potassium salt of picloram was applied at eight different rates ranging from 0.5 to 15.0 kg a.i./ha; picloram/2,4-D mixture rates ranged from 0.5 to 5.0 kg a.i./ha; and simetryne rates from 0.1 to 2.0 kg a.i./ha. Each defoliant was applied at panicle initiation and at complete heading. The only effective treatment observed in the dry season was picloram/2,4-D at 5 kg a.i./ha applied at complete heading in granular form (Table 6). The grain yield of IR2061-464-2 given such treatment was 7.8 t/ha, which was similar to the yield of the fertilized control mean, 8.5 t/ha. Brown rice protein was 9.6 percent which was significantly higher than the fertilized control mean of 8.8 percent. In general, liquid chemicals that caused protein content to increase significantly, however, also caused grain yield to decrease significantly (Table 6).

Table 7. Effect of liquid picloram/2,4-D mixture on the protein content and yields of rice grain of the experimental line IR1561-228-3. IRRI, 1974 wet season.

Treatment	Rate (kg/ha)	Time of application[a]	Yield (t/ha)	Brown rice protein	
				Content[b] (%)	Yield (kg/ha)
Picloram/2,4-D	0.1	7 DAPI	4.4	10.2	359
Picloram/2,4-D	0.5	7 DBPI	4.5	10.3	363
Picloram/2,4-D	0.5	14 DACH	4.3	10.2	347
Fertilized control[c]			4.5	9.4	338
Unfertilized control			3.8	8.0	236

[a]DAPI = days after panicle initiation; DBPI = days before panicle initiation; DACH = days after complete heading. [b]Means are not significantly different from the fertilized control at 5% level. [c]60 kg N/ha during land land preparation and 20 kg N/ha at panicle initiation.

The line IR1561-228-3 was tested in the wet season using a split-plot design with varieties as the main plots and chemical treatments as the subplots. The chemicals were applied 7 days before and after panicle initiation, at complete heading, and at 14 days after complete heading. Picloram/2,4-D and simetryne were applied at 0.1 and 0.5 kg a.i./ha. Because picloram (K-salt) was found to be less effective than the other two chemicals in the dry season, it was applied at higher rates – 0.5 and 1.0 kg a.i./ha.

In the wet season, typhoons caused the crop to lodge at the heading stage, increasing the variability of the results. Picloram/2,4-D liquid mixture at 0.1 kg a.i./ha applied 7 days after panicle initiation, and at 0.5 kg a.i./ha applied 7 days before panicle initiation and 14 days after complete heading, increased the brown rice protein content of IR1561-228-3 by 1 percentage point without decreasing the yield (Table 7). The granular formulation did not cause protein to significantly increase.

The two seasons' results indicate that defoliants have limited potential for increasing protein content in rice grain without significantly decreasing grain yield.

PRIMARY NITROGEN METABOLISM IN GERMINATING RICE

Chemistry Department

The rice plant grows in both flooded and upland conditions, Japanese scientists claim, because its roots have a metabolic pathway, called the "glycolate pathway," which is absent in other cereals. To better understand the primary nitrogen metabolism of the rice plant, chemists studied the levels of enzymes and substrates related to primary nitrogen metabolism and glycolate metabolism in IR22 seedlings during the first 2 weeks of germination in Hoagland solution containing 40 ppm N from ammonium, nitrate, or ammonium nitrate. Roots and shoots were sampled at 5, 7, 10, and 14 days after germination.

The peak activities per gram of tissue of most of the enzymes were observed on either the 7th or the 10th day of germination. In nitrate-grown seedlings, the high activities of nitrate reductase, nitrite reductase, and glutamate dehydrogenase in the roots 5 days after germination showed that primary nitrogen metabolism was initially active in the roots. However, nitrate reductase was absent in roots *in vitro* and was present mainly in the shoots of seedlings 7 days old, and older. Activities of glutamate dehydrogenase and of glutamine synthetase were high in both roots and shoots. The higher activities of these enzymes in ammonium-grown seedlings than in nitrate-grown ones indicate that the root is the main site of ammonium assimilation.

Glycolate oxidase was mainly present in the shoots. In contrast, Japanese workers reported its presence in roots. Catalase, the marker enzyme for peroxisomes (microbodies in leaves with glycolate oxidase) was present in both shoots and roots, but its activity was higher in shoots, particularly in seedlings grown in ammonium.

Levels of total and reducing sugars, free amino acids, and total and soluble protein were higher in shoots than in roots. Soluble protein was higher in shoots of plants grown in ammonium than in nitrate. Protein depletion from the seed reserve was also fastest in ammonium-grown plants. Ammonium-grown plants had greater shoot weight but less root weight than nitrate-grown plants. Plants grown in ammonium nitrate had values intermediate between those of nitrate- and ammonium-grown plants. Their nitrate and nitrite reductase activities, however, were similar to those of nitrate-grown plants. In weight and in glutamate dehydrogenase activity of shoots and roots, the plants grown in ammonium nitrate were similar to plants grown in ammonium.

Levels of metabolites and enzymes in nitrogen metabolism were compared in 10-day-old seedlings of IR8, IR22, and IR480-5-9 grown in Hoagland solution with 40 ppm ammonium or nitrate N. Levels of glutamate dehydrogenase, glutamine synthetase, and nitrate and nitrite reductases were similar for the three rices. Glutamate synthetase was found mainly in the shoots in the same order of magnitude as glutamate dehydrogenase. English workers have shown that glutamate synthetase rather than glutamate dehydrogenase is the major enzyme together with glutamine synthetase for reductive amination of α-ketoglutarate. The reactants are α-ketoglutarate, NADH, and glutamine resulting in two molecules of glutamate. No difference was found in the levels of total and soluble protein, or in free amino acids in rice shoots, but soluble protein and free amino acid levels were higher in ammonium-grown seedlings. The effect of N source on relative weight of shoot and root was not consistent for the three rices. Nitrogen metabolism of IR480-5-9, a higher protein experimental line, was not superior to that of IR8. Therefore, we cannot use any of these factors for screening for grain protein in plants at the seedling stage.

Table 8. Effect of higher protein content from application of N fertilizer on amino acid score and nitrogen retention in growing rats using IR8 and IR480-5-9 milled rice.[a] IRRI, 1974.

Property	IR8		IR480-5-9			LSD (5%)
	0 kg N/ha	120 kg N/ha	0 kg N/ha	60 kg N/ha	90 kg N/ha	
Protein (% N × 6.25)	8.0	9.7	9.7	11.1	12.7	–
Lysine (g/16g N)	3.57	3.41	3.50	3.38	3.33	NS
Amino acid score (%)	64.9	62.0	63.6	61.5	60.5	NS
True digestibility[a] (%)	99.2	98.0	99.0	100.6	100.1	1.3
Biological value[a] (%)	69.5	69.2	71.0	68.4	67.7	1.5
Net protein utilization[a] (%)	68.9	67.8	71.0	68.8	67.8	2.1
Utilizable protein (%)	5.5	6.6	6.9	7.6	8.6	0.2

[a]Analysis of nitrogen retention was conducted by Dr. B. O. Eggum in Copenhagen.

NUTRITIONAL VALUE OF RICE PROTEIN

Chemistry Department

Biological testing. Chemists showed that an increase in protein content of milled rice (N × 6.25), from 8.14 to 9.90 percent in IR8 and from 9.9 to 13.0 percent in IR480-5-9, due to N fertilizer application from the 1973 wet-season trials by agronomists did not significantly affect the lysine content of the protein (Table 8). Nitrogen balance assays showed that the increase in protein content had little effect on the true digestibility, the biological value, and the net protein utilization of the protein in growing rats. Utilizable protein of milled rice was mainly determined by total protein content.

Preliminary protein efficiency index (PEI) of two sets of milled rice samples, both of which included IR480-5-9 and IR8, was assessed with weaned meadow vole (*Microtus pennsylvanicus*) at Michigan State University by the group of Dr. F. C. Elliott. IR480-5-9 was found to be superior to IR8 in PEI. Standard errors could not be calculated in the second set of samples since a number of voles did not gain weight, reflecting variability within the present vole colony. Protein efficiency index did not correlate well with amino acid score (lysine) of milled rice protein. This contrasts with our earlier tests on these same samples with growing rats in which the amino acid score satisfactorily predicted the protein quality of milled rice.

Aminogram of grain parts. In a study of the changes in protein fractions in developing grain, the milling fractions of IR8 were obtained with a Satake abrasive mill. Bran was fractionated by air flotation and sieving into pericarp, aleurone, and embryo. The fractions were hydrolyzed and

Table 9. Levels of essential amino acids in defatted grain parts of IR8 rice (g/16.8 g N). IRRI, 1974.

Amino acid	Hull	Brown rice	Milled rice	Pericarp	Aleurone	Embryo	LSD (5%)
Isoleucine	4.2	4.5	4.7	4.5	4.3	3.8	0.2
Leucine	8.6	8.3	8.5	8.2	7.8	6.8	0.2
Lysine	5.7	4.4	4.0	5.7	5.1	6.8	0.5
Methionine + cystine	0.9	3.6	3.5	3.0	3.2	2.9	0.6
Phenylalanine + tyrosine	6.9	9.6	9.8	8.4	8.6	7.4	0.7
Threonine	5.3	3.9	3.9	4.6	4.0	4.5	0.2
Tryptophan	0.8	1.2	1.3	1.0	1.3	1.4	0.09
Valine	7.8	6.6	6.8	6.9	6.3	6.3	0.4
Amino acid score (%)	24[a]	76[b]	69[b]	76[a]	87[a]	79[a]	–
Protein (N × 5.95) (%)	1.5	7.8	7.2	16.0	15.8	25.3	–
Relative distribution of wt	(26.2)	100	92.2	2.2	3.4	2.3	–
Relative distribution of protein	(4.9)	100	82.0	4.3	6.5	7.2	–

[a]100% = 3.67 g met + cys/16.8 g N. [b]100% = 5.78 g lysine/16.8 g N.

their aminograms were determined. Large differences were found in the levels of the essential amino acids, lysine and methionine plus cystine (table 9). Lysine was the first limiting essential amino acid in brown rice and milled rice protein. In the other fractions, particularly hull, sulfur amino acids were limiting. The aminogram of the milling fractions is consistent with the lower lysine content of milled rice protein compared with brown rice protein since the protein of the bran fraction (pericarp, aleurone, and embryo) is richer in lysine. Glutamic acid of protein tended to be higher in milling fractions, the protein of which is low in lysine.

PROTEIN CONTENT AND OTHER GRAIN PROPERTIES

Chemistry Department

Some consumers have claimed that the Korean variety Tongil is of poorer eating quality (less sticky) than local varieties such as Jinheung. Since Tongil tends to be higher in protein, chemists investigated whether or not the flaky nature of Tongil was due to the higher protein content. In two sets of Korean-grown samples, Tongil and the Korean local variety Jinheung had similar amylose contents and alkali spreading values. Tongil, however, had higher amylograph peak viscosity and lower stickiness score of milled rice than did Jinheung. Tongil samples had 6.3 and 7.2 percent protein, while Jinheung had 7.0 and 5.6 percent protein. Thus, the more flaky nature of Tongil does not seem to be due to protein content, since the flakiness was evident in the first set, in which Tongil had lower protein content than Jinheung. Earlier research at IRRI also indicates that differences in protein content of less than 2 percentage points have a minor effect on the texture of cooked rice.

Chemists also studied the effect of protein content of the levels of fat and free amino acids in the grain. In 41 brown rice samples from the 1973 wet season crop, ranging in protein content from 6.6 to 10.7 percent, fat content ranged from 1.9 to 2.9 percent and was not correlated with protein content ($r = 0.05^{ns}$). Free amino acid fractions of milled rice protein tended to be higher in low protein samples than in higher protein samples.

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HYBRIDIZATION

Plant Breeding Department

To combine drought resistance with desired agronomic traits such as high tillering ability and stiff culms, resistance to diseases and insects, and quick recovery from drought, we made 493 single crosses, 274 three-way crosses, and 36 double- or multiple-crosses in 1974. A large proportion of the crosses included as parents one or two drought-resistant varieties, but many others involved no traditional upland varieties. Many of the crosses were designed to transfer disease and insect resistance into drought-resistant backgrounds.

We also made crosses for Indonesian breeders to combine the drought resistance of several traditional varieties with the high-yielding features of improved types. In distributing breeding lines to foreign cooperators, we attempted to include progenies that were less advanced in selfing and selection but that were reasonably homogeneous within lines. This would give other breeders more opportunities to further select within lines under local conditions.

The F_2 populations were grown under a simulated upland culture in the dry season, and a rainfed upland culture in the wet season. From 582 populations grown in the dry seasons, only 623 F_2 plants were selected. From 111 crosses grown in the wet season, only 163 F_2 plants were saved. On the fertile soils on and near the IRRI farm, the F_2 progenies were predominantly tall, leafy, and susceptible to lodging. From tall x semi-dwarf crosses, few plants of intermediate stature were recovered. We observed a tendency in wide crosses for the progenies to resemble one of the parents. We found no progeny of crosses with adequate resistance under upland conditions that did not involve one drought-resistant parent.

Similarly in the F_4 through F_6 generations, all progeny lines from crosses that lacked drought-resistant parents were susceptible to drought during the wet season. But such crosses tended to yield a larger proportion of plants that can quickly and more fully recover from drought. Obviously, drought resistance and recovery ability should be combined from diverse parental sources.

VARIETAL SCREENING FOR DROUGHT TOLERANCE

Plant Breeding, Agronomy, and Plant Physiology Departments

Drought tolerance using constant soil moisture tension *(Agronomy).* In 1973, we developed a greenhouse technique for watering pots that we can use to maintain relatively constant levels of soil moisture tension. During the 1974 dry season, we used this system to determine varietal response to soil moisture stress at different growth stages.

Table 1. Plant characters, grain yields, and some yield components of IRRI experimental lines at two levels of soil moisture tension[a] during the vegetative stages. Greenhouse studies, IRRI, 1974 dry season.

Experimental line	Growth duration (days)		Plant ht (cm)		Tillers (no./pot)		Panicles (no./pot)		Grain yield (g/pot)		Unfilled grains (%)	
	CS	VS	CS	VS	CS	VS	CS	VS	CS	VS	CS	VS
IR1721-11-6	108	153	122	118	17	25	15	24	40	43	22	34
IR2035-250-3[a]	111	141	116	112	22	23	22	23	45	41	25	22
IR2031-352-3	116	146	135	117	14	26	13	26	19	36	17	16
IR1529-680-3[b]	111	157	109	110	19	21	16	21	26	35	13	24
IR2035-157-1[b]	108	141	108	103	12	28	11	28	24	35	7	8
IR3260-91-100[b]	121	149	117	119	18	28	17	27	40	35	15	16
IR879-183-2	113	141	108	102	19	23	14	23	23	35	14	16
IR2034-326-1	108	137	101	94	17	41	16	14	17	34	18	12
IR879-314-2	113	146	117	114	15	15	14	15	42	33	7	20
IR2035-269-2	113	141	97	96	23	32	22	32	28	33	13	16

[a]CS = continuous saturation; VS = vegetative stress at 75 centibars soil moisture tension (from 5 days after seedling emergence until panicle initiation). [b]Also looked promising for drought tolerance under field conditions.

Seventy-five varieties and lines were subjected to 75 centibars (cb) soil moisture tension from 5 days after seedling emergence to panicle initiation, after which the soil was continuously saturated. In another treatment, these varieties were grown under continuous saturation from seedling emergence to panicle initiation, and then were subjected to 75 cb soil moisture tension until crop maturity. A third set of varieties was continuously saturated throughout crop growth as a check.

Most varieties matured a month later when moisture stress was at the vegetative stage than when continuously saturated. Moisture stress at the vegetative stage also reduced plant height (Table 1). When relieved of vegetative stress, the plants produced additional tillers that produced panicles and contributed to final grain yield. Under field conditions, however, a 1-month delay in maturity may significantly reduce grain yields because of inadequate rainfall during the grain-filling stage. Vegetative stress affected the percentage of unfilled grains in only a few varieties. The experimental line IR1721-11-6 yielded highest and was highly tolerant of vegetative stress, confirming earlier field results. Among the new lines, IR2035-250-3 looked promising for drought tolerance in the greenhouse (Table 1) and under upland conditions in the field. Reproductive stress did not generally affect growth duration. Although reproductive stress decreased the panicle number and increased the percentage of unfilled grains of the line IR2043-104-3, it did not affect its grain yield (Table 2).

Under the test conditions, none of these lines looked promising under both vegetative and reproductive stress. However, we will further evaluate the experimental lines that looked most promising under field conditions.

Table 2. Grain yields, panicle numbers, and percent unfilled grains of experimental lines at two levels of soil moisture tension[a] during the reproductive stages. Greenhouse studies, IRRI, 1974 dry season.

Experimental line	Grain yield[a] (g/pot)		Panicles (no./pot)		Unfilled grains (%)	
	CS	RS	CS	RS	CS	RS
IR2043-104-3[b]	16	16	25	15	15	60
IR2034-326-1	17	12	16	14	18	42
IR2035-197-3	20	12	17	13	19	38
IR2031-254-3	20	12	17	21	8	87
IR1750-F_5B-3[b]	24	11	14	13	11	51
IR2031-729-3[b]	23	11	18	12	6	59
IR2035-232-3	29	9	22	19	18	61
IR1746-226-1	27	9	12	5	11	33
IR2035-349-2	17	8	11	15	15	66
IR2035-227-1[b]	17	8	18	22	27	86

[a]CS = continuous saturation; RS = reproductive stress at 75 centibars soil moisture tension (from panicle initiation to crop maturity). [b]Also looked promising for drought tolerance under field conditions.

Drought resistance of 10 varieties at a constant water table depth *(Plant Physiology).* During droughts, soil begins to dry at the surface and drying extends to lower soil horizons. Under such conditions, the growth and yield of rice depend on deep and proliferated roots that can effectively make use of water stored in the subsoil. Thus, deep root growth can be a major characteristic contributing to drought resistance under field conditions.

To simulate drought field conditions, we constructed a constant water table depth box, 1.6 × 1.6 × 1.2 m. The water table in the box was kept at a constant depth of 45 cm below the soil surface by means of an open siphon. To minimize mechanical resistance to water flow at the water table, a layer of quartz sand about 5 cm thick was placed beneath the soil and toward the water-inlet holes. The box was placed in a glasshouse and seeds of 10 varieties were sown at spacings of 30 cm. At early growth stages, sufficient water was supplied to support normal growth (Table 3).

Figure 1 shows that the soil water potential at a depth of 15 cm was about −0.25 bar until 40 days after seeding, after which soil water potential began to gradually decrease and reached about −0.35 bar at flowering. At a depth of 30 cm, the soil water potential was kept at −0.25 bar until harvest. At 45 cm below the surface, the soil water potential was assumed to be zero. Since the soil surface was dry at around flowering time, we can assume that the soil water potential at the surface was around the permanent wilting point (about −15 bar), or lower.

Figure 2 shows the vertical distributions both of the soil water potential and of the root weight of IR20 at flowering. The root weight data were collected from a root box experiment. The roots were subjected to different degrees of water stress according to their distances from the soil surface.

Table 3. Growth and yields of 10 rice varieties grown with a constant water table 45 cm below the soil surface. IRRI, 1974.

	Plant ht (cm)	Tillers (no./row)	Panicles (no./row)	Productive tillers (%)	Dry wt (g/row)	Grain wt (g/row)	Sterility (%)	Drought resistance rating[a]
M1-48	153	56	53	95	550	89.6	45	R
Miltex	146	65	51	78	401	69.5	48	R
E 425	152	91	50	55	522	42.5	61	MR
OS 4	149	69	41	59	416	26.1	68	MR
IR5	128	104	47	45	463	29.9	77	MR
Azucena	166	76	49	64	617	27.0	81	MR
Palawan	155	63	11	8	329	2.2	91	I
IR442-2-58	109	155	6	4	442	0	100	MS
IR1529-680-3	111	96	0	0	252	0	-	S
IR20	75	152	0	0	164	0	-	S

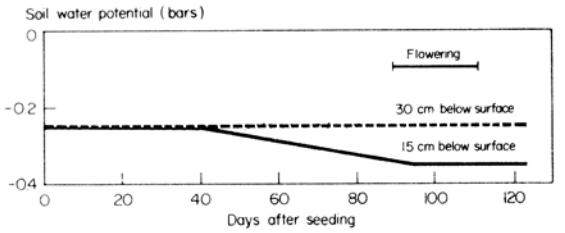
[a]R = resistant; MR = moderately resistant; I = intermediate; MS = moderately susceptible; S = susceptible.

More than 70 percent of the roots were under severe water stress.

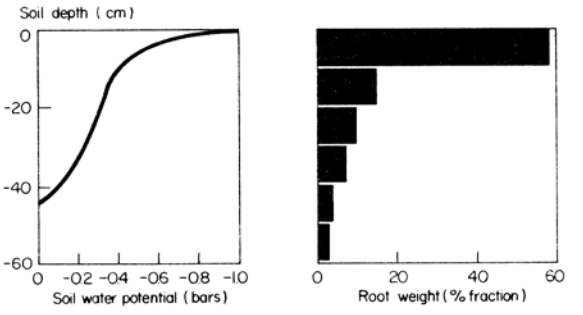
The drought resistance of 10 varieties was rated by three criteria: sterility percentage, grain weight, and panicle number (Table 3). M1-48 and Miltex are rated as resistant; E425, OS4, IR5, and Azucena as moderately resistant; Palawan as intermediate; IR442-2-58 as moderately susceptible; and IR1529-680-3 and IR20 as susceptible. Under these experimental conditions, M1-48 performed best. A high percentage of productive tillers, as well as a low percentage of sterility and high grain yields, indicates high drought resistance. Azucena produced the highest amount of dry matter but suffered from severe water stress at around flowering time. Before flowering, Azucena showed severe "leaf collapse," indicating internal water stress. No panicle exsertion was observed in IR1529-680-3 and IR20.

This experiment demonstrates clear varietal differences in drought resistance under a constant water table depth. These differences are shown in the section on root studies to be largely related to root growth at different depths.

Screening technique for drought tolerance at seedling stage *(Plant Physiology).* As a physiological term, "drought resistance" is composed of both "drought avoidance" and "drought tolerance." A deep and proliferated root system is an effective means of avoiding drought because it permits the plant to exploit water stored in the subsoil. Under certain field conditions, however, deep root penetration may be physically impaired, such as by the presence of a hard pan. Thus, drought tolerance, or the ability of plants to grow and yield



1. Changes in the soil water potential at 15 cm and at 30 cm below the soil surface.



2. Soil water potential at flowering (left) and vertical distribution of root weight (right) of IR20.

Table 4. Shoot and root elongation in a vermiculite system. IRRI, 1974.

Designation	At saturation		Under water stress		Stress: saturation ratio	
	Shoot length (cm)	Root length (cm)	Shoot length (cm)	Root length (cm)	Shoot	Root
IR1529-680-3	11.1	9.8	6.0	7.8	0.54	0.80
IR20	11.8	10.8	5.5	6.6	0.47	0.61
M1-48	9.9	12.3	4.5	7.6	0.45	0.62
81B25	10.5	10.2	4.3	7.1	0.41	0.70
NARB	13.9	13.2	5.6	6.9	0.40	0.52
IR841-67-2	10.6	9.0	4.1	7.0	0.39	0.78
Palawan	11.6	13.5	4.3	9.0	0.37	0.67
IR442-2-58	11.5	13.6	4.1	7.0	0.36	0.51
Azucena	11.0	11.9	3.8	6.6	0.35	0.55
IR127-80-1	12.5	9.4	4.2	7.2	0.34	0.77
IR8	13.7	14.5	4.7	8.2	0.34	0.57
Jappeni Tunkungo	13.8	10.9	4.7	6.5	0.34	0.60
PI-215936	11.1	14.6	3.6	7.4	0.32	0.51
Miltex	11.6	11.6	3.7	7.0	0.32	0.60
OS4	11.2	15.0	3.5	8.3	0.31	0.55
IR5	14.3	13.7	4.3	8.3	0.30	0.61
E425	11.5	16.1	3.4	8.5	0.30	0.53
Dular	15.5	12.0	4.7	7.7	0.30	0.64
Azmil	13.0	13.3	2.3	7.8	0.18	0.59
Corn (Early Thai Composite)	18.7	24.6	3.7	14.8	0.20	0.59
Sorghum (Cosor 3)	15.0	12.2	5.6	8.6	0.37	0.71

even under internal water stress, is potentially more desirable.

To test the drought tolerance of rice varieties, we used a vermiculite system similar to that described by Meyer and Boyer in 1972.

Pregerminated seeds were sown in vermiculite at two water levels: saturated with 10^{-4} M $CaCl_2$ and supplied with 1/10th of the volume of the $CaCl_2$ solution for saturation (to induce water stress). The vermiculite-$CaCl_2$ system was placed in a darkroom at 30°C and 96 percent relative humidity. After 5 days of growth, the shoot and root lengths were measured. The ratio of shoot or root length under water stress to that at saturation was considered a measure of drought tolerance: the higher the ratio, the higher the drought tolerance. This procedure selects for increased rates of cell enlargement during desiccation. Plants with the ability to compensate osmotically for drought should give superior performance.

Table 4 shows that water stress impaired shoot growth more than root growth. The ratio of shoot length under water stress to that at saturation for 19 rice varieties ranged from 0.18 for Azmil to 0.54 for the line IR1529-680-3. Among drought-resistant varieties, only M1-48 had a high ratio, 0.45. But drought-susceptible varieties, such as IR20 and IR1529-680-3, showed high values of drought tolerance. Sorghum and corn are generally considered more drought resistant than rice, yet they had low to moderate drought-tolerance values. Thus, the test for cell elongation under water stress failed to explain differences in drought resistance among rice, sorghum, and corn. Because high drought tolerance values relate to the plant's ability to grow under water stress, the results of this experiment could imply that: 1) drought tolerance as measured by the vermiculite system is not the major characteristic of drought resistance in the present drought-resistant varieties; and 2)

Table 5. Comparison of different screening techniques for drought res' ance. IRRI, 1974.

Constant water table box[a]		Relative plant ht (cm) in field under stress[b]		Visual rating in field[c]	
Designation	Rating	Designation	Relative ht	Designation	Rating
M1-48	R	E425	(78)	M1-48	R
Miltex	R	Miltex	(73)	OS4	R
E 425	MR	M1-48	(71)	E 425	MR
OS4	MR	OS4	(68)	Palawan	MR
IR5	MR	Palawan	(68)	IR5	MR
Azucena	MR	Azucena	(64)	Azucena	MR
Palawan	I	IR5	(63)	Miltex	I
IR442-2-58	MS	IR442-2-58	(59)	IR442-2-58	I
IR1529-680-3	S	IR1529-680-3	(54)	IR1529-680-3	I
IR20	S	IR20	(51)	IR20	S

[a]Constant water table at 45 cm below surface. [b]Plant height under water stress relative to that under well-watered conditions. [c]Done by Plant Breeding Department.

drought-resistant varieties could be further improved by combining drought tolerance with other desirable characteristics, such as deep and proliferated roots.

A comparison of screening techniques for drought resistance *(Plant Physiology).* Table 5 compares three screening techniques for drought resistance: growth performance in a constant water table box; measurements of plant height in the field; and visual ratings in the field. Results obtained using these three techniques generally agree.

It appears that drought-resistant varieties identified by these three techniques have deep and proliferated root systems (see section on root studies) and, hence, a greater capacity to exploit water stored in the subsoils. In this sense, all three techniques appear to measure the degree of "avoidance." Measurement of plant height in the field appears to be the simplest of the techniques.

Mass screening for drought resistance *(Plant Breeding).* During the dry season, plant breeders screened 2,288 varieties and lines for field resistance to drought under simulated upland conditions. The test materials consisted of 713 traditional upland varieties from Asia, Africa, and Latin America; 567 breeding lines from upland nurseries; 288 breeding lines from lowland nurseries; 387 *aus* purelines from Bangladesh; 7 floating varieties; 128 TOX lines from the International Institute of Tropical Agriculture (IITA), Nigeria; 30 traditional rainfed lowland varieties; 56 dual-purpose varieties and lines; and 112 strains of the African species *Oryza glaberrima.* We rated these for field resistance to drought based on plasticity of leaf rolling and unfolding, death of leaves, degree of stunted growth, and effects on reproductive processes. Five classes were used in scoring: resistant (R), moderately resistant (MR), intermediate (I), moderately susceptible (MS), and susceptible (S).

The largest proportion of drought-resistant varieties was found among the traditional upland varieties from Africa, followed by those from South America, and by hill rices from Laos. About 93 percent of the Indonesian upland varieties were rated as moderately resistant and resistant. The widest range in field resistance was found among 51 upland varieties from Japan; surprisingly, half of the entries were susceptible. The pure *aus* lines of Bangladesh also included a high proportion of entries that were found to be moderately resistant to resistant, but many of the early maturing lines may have escaped the full impact of the water-stress cycles. The floating varieties of Southeast Asia were rated from moderately resistant to moderately susceptible. Most African rices *(O. glaberrima)* were rated as intermediate.

Nearly two-thirds of the traditional rainfed-lowland varieties were rated as I; one-third as MS; and 3 percent as MR. Among semidwarf breeding lines from the lowland nurseries, 4 percent were rated MR; 60 percent, I; 32 percent, MS; and 1 percent, S. Most TOX lines were rated I and MS.

Table 6. The distribution of $F_3 - F_7$ breeding lines by their scores in field tests for drought resistance. IRRI, 1974 dry season.

Parentage	Lines (no.)	Frequency in					
		R	MR	I	MS	S	Segregating
Upland/lowland	242	1	63	146	15		17
Upland/lowland/ /upland	4		2	2			
Upland/lowland/ /lowland	22	1	4	15	1		1
Dual-purpose/lowland	7	4	3				
Lowland/lowland	292		23	190	72	1	6

Some early maturing and drought-resistant varieties that produced well-filled grains during the protracted dry period were N 22, Seratus Malam, Cartuna, Kap Nhay, Padi Tatakin, Rikuto Norin 21, Susono-mochi, Maligaya 5, Kinandang Patong, and Ba Djang Nhu.

Only a small portion of our upland breeding lines that came from crosses of upland and lowland parents is as drought resistant as the African upland parents (such as OS4). After repeated selection under upland culture for years, however, more than 20 percent of the lines were rated from MR to R, while 60 percent of the lines were rated I. About 5 percent of the lines were still segregating for R, MR, I, and MS reactions.

The mass screening test in the dry season does not indicate drought resistance as well during the reproductive stage as during the vegetative phase. During a prolonged dry spell in the wet season, however, most of the lines that had an upland parent had good grain filling, moderately good panicle exsertion, high panicle fertility, and few dead leaves. On the other hand, almost all lines from the lowland x lowland crosses showed stunted growth, dead leaves, delayed heading, poor panicle exsertion, and 80 to 95 percent panicle sterility

Among the 567 breeding lines from upland nurseries, the largest number of resistant entries came from 1970 crosses of African upland x semidwarf lowland rices. These crosses also produced more MR and I lines than did the other series. Crosses involving one or more upland varieties produced higher proportions of MR and I lines than did crosses having no upland parents (Table 6). A cross involving the dual-purpose variety Hashikalmi produced a few resistant lines but they were later discarded because of undesirable agronomic features.

Recovery from drought was also recorded shortly after watering in the dry season. Most of the lowland varieties and lines recovered faster and to greater degrees than did the upland varieties and lines. During the wet season there was a protracted dry spell, followed by light showers in mid-September. The water-stressed semidwarfs differed markedly in recovery after the showers. While drought resistance and recovery ability appeared to be independent of each other, a combination of the two features is necessary to insure stable and good performance under upland culture.

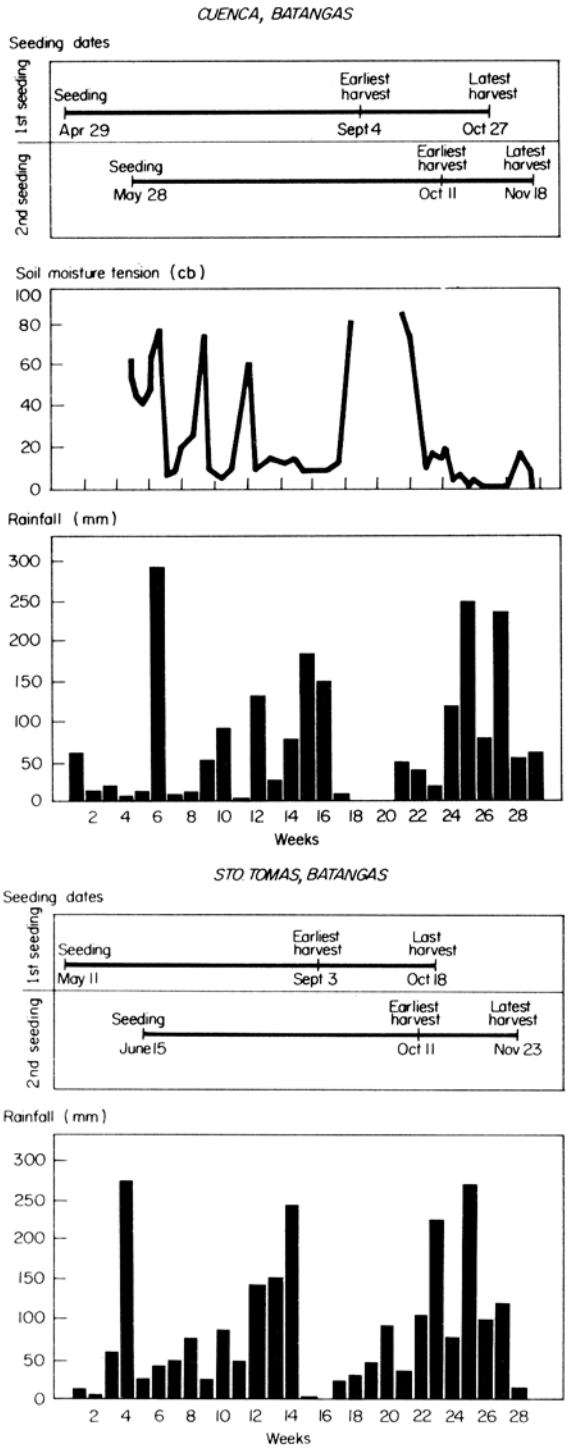
PERFORMANCE OF RICES UNDER UPLAND RICE CULTURE

Agronomy and Plant Breeding Departments

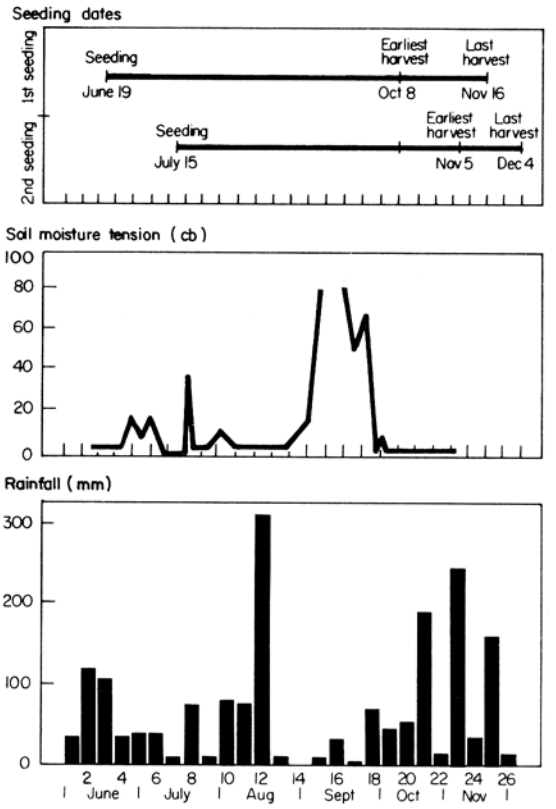
Field studies *(Agronomy Department).* During the 1974 wet season, agronomists conducted experiments in the Philippines and in several other countries in Asia, Africa, and Latin America to evaluate experimental lines under upland conditions for drought tolerance, agronomic characteristics, field resistance to diseases and insects, and yield potential.

These experiments were installed at six sites in the Philippines: at IRRI; at the Bureau of Plant Industry stations at La Granja, Negros Occidental, and Tupi, South Cotabato; at Central Mindanao State University, Bukidnon; and in two farmers' fields in Batangas.

The 81 entries consisted of high-yielding experimental lines selected from earlier yield trials, lines selected from the 1973 observation trials, and standard checks. At most locations, two dates of seeding were used with a 1-month interval between the two plantings. Eighty kilograms N/ha was applied in split doses. Phosphorus was applied as basal at 40 kg P_2O_5/ha.



3. Rainfall at one experimental site and rainfall and soil mositure tension at another site in relation to growth stages of rice grown under upland conditions in farmers' fields, Batangas, Philippines. Agronomy Department, IRRI, 1974 wet season.



4. Rainfall and soil moisture tension in relation to growth stages of rice grown under upland conditions. Agronomy Department, IRRI, 1974 wet season.

Rainfall, soil moisture tension, and solar energy data were collected at the experimental sites at IRRI and Cuenca, Batangas. For Santo Tomas, only rainfall data were collected.

Drought tolerance. The 1974 tests provided an excellent opportunity to evaluate experimental lines for drought tolerance. Data are available for only the IRRI farm and two farmers' fields in Batangas (at Cuenca and Santo Tomas).

The longest dry spell (30 days) was at Cuenca; the crop suffered from moisture stress for 20 to 25 days with soil moisture tension rising to 85 centibars (cb) and higher. Although soil moisture tensions rose considerably higher than 85 cb, the tensiometers were not capable of measuring beyond that tension (fig. 3).

At the IRRI farm, the soil moisture tension varied from 50 to 85 cb and higher for almost 2 weeks (fig. 4). The high soil moisture tension damaged rices differentially at various growth

stages. Some early maturing lines at both Batangas locations escaped most drought damage because they were about 1 week away from harvest when the drought became severe (fig. 3).

In Batangas, the late-maturing lines were at the panicle initiation stage when drought started to cause severe leaf drying. At the IRRI farm only the early maturing lines were at the reproductive stage during the dry spell (fig. 4).

For comparing drought tolerance, the experimental lines and varieties were divided into three maturity groups: 1) early maturing lines, 2) intermediate-maturing lines, and 3) late-maturing lines.

In these experiments, the degree of leaf drying was used as the basis for determining drought tolerance. A rating of 1 was given to lines and varieties which did not show any leaf desiccation during the 20-day drought spell; a rating of 3 was

Table 7. Growth duration, relative drought tolerance, resistance to important diseases, and grain yields of early maturing rices exposed to drought conditions in the upland rice variety trials at IRRI and Batangas, Philippines. IRRI, 1974 wet season.

Designation	Growth duration at Santo Tomas (days)		Drought tolerance[a] at		Affected by[b]	Grain yield (t/ha)						Av.
						IRRI		Santo Tomas		Cuenca		
	May 11 seeding	Jun 15 seeding	IRRI	Cuenca		Jun 19[c] seeding	Jul 22[d] seeding	May 11[e] seeding	Jun 15[c] seeding	Apr. 29[d] seeding	May 28[c] seeding	
IR661-1-170-1	121	137	1	2	ShB ShR	3.3	2.4	3.6	2.5	4.0	1.6	2.9
IR1154-243-1	121	146	2	3	ShB	1.7	2.3	3.8	1.4	3.8	0.7	2.3
IR1480-147-3	121	130	3	2	ShB CLS HLS	3.3	2.5	3.9	1.0	3.6	0.9	2.5
IR1487-141-6	121	137	1	2	ShB ShR	3.0	2.1	2.9	2.8	3.1	1.6	2.6
IR1545-339	121	140	1	3	ShB HLS	3.0	2.3	3.4	0.9	3.5	1.1	2.4
IR1746-226-1	121	129	3	2	ShB	2.7	2.0	2.8	1.4	3.1	0.7	2.1
IR1750-F_5B-3	111	120	1	–	ShB	1.3	2.4	3.8	0.4	3.5	0.2	1.9
IR1750-F_5B-5	111	113	3	–	ShB	1.6	2.1	3.7	0.3	3.6	0.4	2.0
IR2031-729-3[f]	120	120	2	3	ShB	2.6	2.4	3.9	2.0	3.9	1.8	2.8
IR2035-157-1[f]	121	137	2	3	ShB	3.1	1.9	2.8	2.9[g]	3.1	1.6	2.6
IR2035-227-1[f]	121	135	1	3	ShB ShR	3.1	2.6	3.9	1.4	3.8	1.2	2.7
IR2043-104-3[f]	117	128	1	2	ShB	3.0	2.6	3.9	0.8	3.5	1.4	2.5
IR2053-76-2	121	137	5	4	ShB CLS	2.2	2.6	2.5	2.3	1.7	1.8	2.2
IR2053-87-3	121	128	5	4	ShB	1.4	1.5	2.1	0.9	2.2	1.6	1.6
IR2053-419-3	121	137	4	3	ShB	2.6	2.0	2.5	2.1	3.7	1.5	2.4
IR2053-521-1	111	133	5	–	ShB	1.3	1.6	2.4	1.0	3.0	0.7	1.7
IR2053-522-5	111	130	4	–	CLS	0.9	2.0	3.1	1.4	2.7	1.0	1.8
IR2061-213-2	121	146	5	3	ShB	2.4	2.2	2.9	1.9	3.2	1.6	2.4
BPI 76/9 × Dawn	121	128	3	3	ShB CLS	3.3	2.4	3.2	1.8	3.2	1.1	2.5
BPI 76 (ns)	121	128	3	3	ShB Bn	3.3	2.0	3.1	1.3	3.3	1.9	2.5
M1-48 (early check)	120	128	1	3	ShB	3.3	1.7	1.8	1.4	3.3	0.6	2.0

[a]Degree of desiccation: 1 = no desiccation; 3 = leaves desiccated; 5 = leaves died. [b]ShB = sheath blight; ShR = sheath rot; HLS = *Helminthosporium leaf spot; CLS* = *Cercospora* leaf spot; Bn = neck blast. [c]Headed 20 to 30 days before onset of dry period. [d]Headed 10 days from resumption of fairly adequate rainfall. [e]Headed 7 to 15 days before onset of dry period. [f]Also looked promising for drought tolerance in greenhouse studies. [g]Av. of 2 replications.

given if leaf tissue was dry; and 5 was given to rices with leaves completely dry and almost dead. Cultivars with ratings of 1 were considered tolerant of drought, and those with ratings of 5, susceptible.

At Cuenca, several early maturing lines, including IR1750-F_5B-3, IR1750-F_5B-5, IR2053-521-1, and IR2053-522-5, were harvested before moisture stress caused severe leaf desiccation, so they were not rated for drought tolerance at that site (Table 7). At the IRRI farm, however, IR1750-F_5B-3 was tolerant of drought while the two IR2053 lines were susceptible. Three experimental lines, IR661-1-170, IR1487-141-6, and IR2043-104-3, were least affected by drought in farmers' fields in Batangas and at IRRI (Table 7). The Philippine upland variety M1-48 was moderately tolerant of

Table 8. Growth duration, relative drought tolerance, resistance to important diseases, and grain yields of medium-maturing rices exposed to drought conditions in the upland rice variety trials at IRRI and Batangas, Philippines. IRRI, 1974 wet season.

Designation	Growth duration at Santo Tomas (days)		Drought tolerance[a] at		Affected by[b]	Grain yield (t/ha)						
						IRRI		Santo Tomas		Cuenca		Av.
	May 11 seeding	Jun 15 seeding	IRRI	Cuenca		Jun 19[c] seeding	Jul 22[d] seeding	May 11[e] seeding	Jun 15[c] seeding	Apr 29[e] seeding	May 28[c] seeding	
IR480-5-9	138	137	4	3	ShB ShR	2.7	1.8	0.7	2.8	1.4	2.5	2.0
IR577-24-1	129	137	2	3	ShB ShR	3.6	2.8	3.2	3.2	2.8	2.4	3.0
IR937-76-2	136	146	2	3	ShB ShR	3.7	2.3	2.3	3.2	2.5	2.2	2.7
IR1163-135-2	132	137	3	3	ShB ShR	3.7	2.6	2.7	3.2	1.4	2.4	2.7
IR1529-430-3	129	137	2	2	ShB	4.1	3.2	4.0	3.6	3.6	2.9	3.6
IR1529-677-2	129	137	2	2	ShB	3.2	2.7	3.5	3.0	2.9	2.5	3.0
IR1529-680-3[f]	129	137	2	3	ShB Bl	3.6	2.8	3.3	3.4	2.9	2.6	3.1
IR26	130	137	3	3	ShB	3.1	2.7	2.4	2.6	2.4	2.4	2.6
IR1614-332-1	129	137	4	3	ShB CLS	3.3	2.3	2.6	2.2	2.2	1.3	2.3
IR1721-8	136	137	5	3	ShB Bn	1.6	–	3.1	2.4	2.2	–	2.3
IR2031-379-3	129	137	4	4	ShB	2.6	2.5	3.2	2.8	1.9	2.2	2.5
IR2035-108-2	134	135	3	2	ShB ShR	3.3	1.7	2.3	3.6	2.3	2.2	2.6
IR2035-242-1	135	137	1	3	ShB ShR	4.1	3.4	2.6	3.4[g]	2.0	2.7	3.0
IR2035-353-2	138	137	1	2	ShB ShR	4.0	3.0	1.8	2.8	2.6	2.2	2.7
IR2035-730-3	129	137	3	2	ShB	3.1	2.9	2.5	2.6	1.6	2.1	2.5
IR2042-178-1	134	137	1	3	ShB ShR	3.8	3.1	2.3	3.2	2.2	1.7	2.7
IR2053-205-2	134	137	4	4	ShB	2.8	2.2	2.3	3.6	2.1	1.9	2.5
IR2053-206-1	129	137	4	5	ShB CLS	2.7	2.5	2.4	3.2	1.8	1.8	2.4
IR2053-362-1	129	137	5	4	ShB CLS	2.6	2.2	2.5	2.8	2.4	1.9	2.4
MRC 172-9	129	137	4	3	ShB	3.0	2.6	3.2	3.1	3.1	2.2	2.9
IR442-2-58 (check)	129	128	2	2	ShB Bl Bn	2.7	1.8	2.9	0.9	2.8[h]	0.6	1.8
C 22 (check)	129	137	4	3	ShB	2.7	2.1	2.3	2.6	3.1	2.0	2.4

[a]Degree of desiccation: 1 = no desiccation; 3 = leaves desiccated; 5 = leaves died. [b]ShB = sheath blight; ShR = sheath rot; CLS = *Cercospora* leaf spot; Bl = leaf blast; Bn = neck blast. [c]Headed 10 to 15 days from resumption of fairly adequate rainfall. [d]Headed 20 to 25 days from resumption of fairly adequate rainfall. [e]Headed 10 days from start of dry period. [f]Also looked promising for drought tolerance in greenhouse studies. [g]Av. of 2 replications. [h]One replicate only.

drought at the IRRI farm but appeared susceptible when exposed to high moisture stress at Cuenca, Batangas.

At Santo Tomas, Batangas, the growth durations of all lines were prolonged by at least 1 week (Table 7).

Among the medium-maturing lines, IR2035-353-2 was the most drought tolerant at IRRI and in Cuenca. Other lines which looked promising were IR442-2-58, IR1529-430-3, IR1529-677-2, IR2035-242-1, and IR2042-178-1.

Seven lines, including the check variety IR5, matured in 5 months primarily because of prolonged drought (Table 8).

Three lines in the late-maturing group, IR2035-169-2, IR2035-712-2, and IR4520-76-90, showed practically no visible injury due to moisture stress at the IRRI farm and in Cuenca (Table 9).

Field reactions to diseases. All experimental lines and varieties except IR2053-522-5 (Table 7) and IR2035-712-2 (Table 9) were infested with sheath blight. The other diseases observed were blast, *Cercospora* leaf spot, *Helminthosporium* leaf spot, and sheath rot.

IR442-2-58 was moderately susceptible to sheath blight and susceptible to blast disease.

Grain yield. Among the early maturing lines, IR661-1-170 produced the highest average yields, about 2.9 t/ha, followed by IR2031-729-3, 2.8 t/ha, and IR2035-227-1, 2.7 t/ha (Table 7).

Two IR1750 lines (IR1750-F_5B-3 and IR1750-F_5B-5) and two IR2053 lines (IR2053-521-1 and IR2053-522-5) were subjected to moisture stress at panicle initiation during the first seeding at IRRI and during the second seeding at the two Batangas sites. All four were among those that produced the lowest grain yields in the early maturing group (Table 7).

In the medium-maturing group, IR1529-430-3 produced the highest average yields, 3.6 t/ha (Table 8). IR1529-430-3 had been the highest yielding line among the 1973 entries, when the rainfall distribution was normal. These results show that IR1529-430-3 yields consistently high under both drought-free and droughty upland conditions. The other high-yielding lines, which averaged about 3 t/ha, were IR1529-680-3, IR1529-677-2, IR577-24-1, and IR2035-242-1.

The check variety C 22 was moderately susceptible to drought and produced 2.4 t/ha; the other

Table 9. Growth duration, relative drought tolerance, infection by important diseases, and grain yield of late-maturing rices exposed to drought conditions in the upland rice variety trials at IRRI and Batangas, Philippines. IRRI, 1974 wet season.

Designation	Growth duration at Santo Tomas (days)		Drought tolerance[a] at		Affected by[b]	Grain yield (t/ha)						
						IRRI		Santo Tomas		Cuenca		
	May 11 seeding	Jun 15 seeding	IRRI	Cuenca		Jun 19[c] seeding	Jul 22[d] seeding	May 11[e] seeding	Jun 15[c] seeding	Apr 29[e] seeding	May 28[c] seeding	Av
IR2035-169-2	155	146	1	1	ShB	3.1	2.6	0.3	2.9	0.3	2.8	2.0
IR2035-250-3[f]	149	146	1	3	ShB	3.3	2.2	0.3	2.4	0.8	2.0	1.8
IR2035-438-1	156	146	4	4	ShB	2.9	2.7	0.1	3.2	0.1	2.0	1.8
IR2035-712-2	156	153	1	1	ShR	3.0	2.2	0.0	2.3	0.3	2.2	1.7
IR3260-91-100[f]	149	146	2	3	ShB CLS	3.6	2.7	0.7	3.7	1.3	2.2	2.4
IR4520-76-90	156	146	1	2	ShB ShR CLS	3.3	2.7	0.1	3.2	0.9	2.4	2.1
IR5	155	146	3	3	ShB	2.8	2.9	0.4	3.7	0.5	3.3	2.3

[a]Degree of desiccation: 1 = no desiccation; 3 = leaves desiccated; 5 = leaves died. [b]ShB = sheath blight; ShR = sheath rot; CLS = *Cercospora* leaf spot. [c]Headed 15 to 20 days from resumption of adequate rainfall. [d]Headed around 30 days from resumption of fairly adequate rainfall. [e]Headed 15 to 20 days from start of dry period. [f]Also looked promising for drought tolerance in greenhouse studies.

Table 10. Growth duration, relative drought tolerance, field reactions to diseases, and grain yields of promising rices under upland conditions in three locations in the Philippines. IRRI, 1974 wet season.

Designation	Growth duration at Santo Tomas (days)		Drought tolerance[a] at		Field reactions to diseases[b]			Grain yield (t/ha)						
								IRRI		Santo Tomas		Cuenca		
	May 11 seeding	Jun 15 seeding	IRRI	Cuenca	B	ShB	ShR	Jun 19 seeding	Jul 22 seeding	May 11 seeding	Jun 15 seeding	Apr 29 seeding	May 28 seeding	Av.
IR1529-430-3	129	137	2	2	–	S	–	4.1*	3.2*	4.0*	3.6*	3.6	2.9*	3.6
IR2035-242-1	135	137	1	3	–	S	MS	4.1*	3.4*	2.6	3.4*	2.0	2.7*	3.0
IR1529-677-2	129	137	2	2	–	S	–	3.2	2.7	3.5*	3.0	2.9	2.5	3.0
IR661-1-170-1	121	137	1	2	–	MS	MS	3.3	2.4	3.6*	2.5	4.0	1.6	2.9
MRC 172-9	129	137	4	3	–	MS	–	3.0	2.6	3.2*	3.1	3.1	2.2	2.9
IR2035-353-2	138	137	1	2	–	MS	MS	4.0*	3.0*	1.8	2.8	2.6	2.2	2.7
IR2042-178-1	134	137	1	3	–		MS	3.8*	3.1*	2.3	3.2	2.2	1.7	2.7
IR1487-141-6	121	137	1	2	–	MS	MS	3.0	2.1	2.9	2.8	3.1	1.6	2.6
IR2035-197-3	129	146	2	2	–	S	–	3.7*	2.6	2.0	3.3	1.4	2.7	2.6
IR5 (check)	155	146	3	2	–	S	–	2.8	2.9*	0.4	3.7*	0.5	3.3*	2.3
IR442-2-58 (check)	129	128	2	2	S	M	–	2.7	1.8	2.9	0.9	2.0[d]	0.6	1.8
C 22 (check)	129	137	4	3	–	MS	–	2.7	2.1	2.3	2.6	3.1	2.0	2.5
M1-48 (check)	120	128	1	3	–	S	–	3.3	1.7	1.8	1.4	3.3	0.6	2.0
CV (%)								16	14	17	15	19	19	

[a]Degree of desiccation :1 = no desiccation; 3 = leaves desiccated; 5 = leaves died. [b]B = blast; ShB = sheath blight; ShR = sheath rot. [c]Asterisk indicates significant difference from C 22 at the 5% probability level. [d]One replication only.

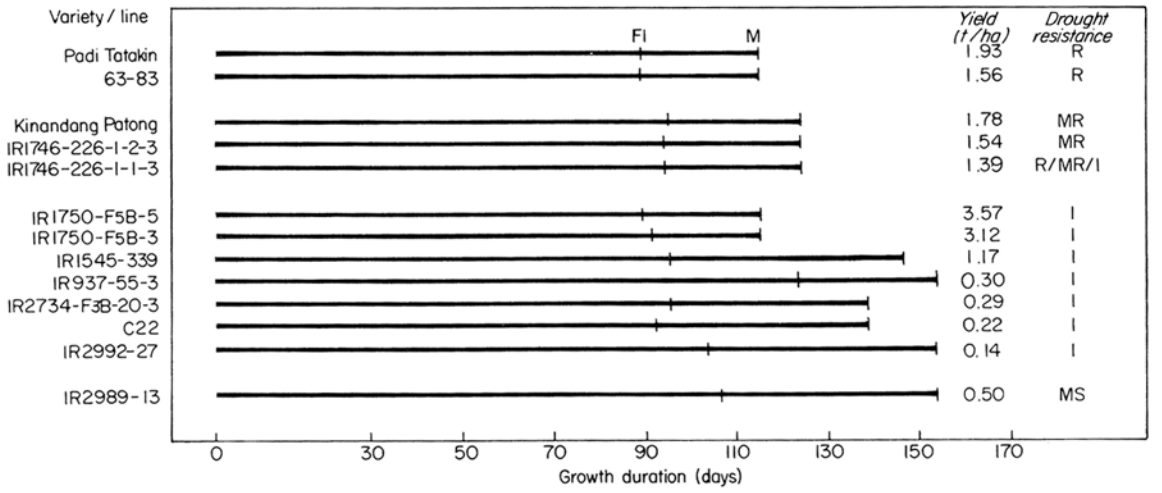
check, IR442-2-58, was infected with blast and produced 1.8 t/ha (Table 8).

In the late maturing group, at least seven varieties or lines only yielded from 0 to 1.3 t/ha, primarily because of drought damage (Table 9). No variety or line at any location or seeding date yielded better than the check variety IR5.

Based on drought tolerance, disease resistance, and yielding ability under high soil moisture stress, the following lines looked promising: IR1529-430-3, IR2035-242-1, IR1529-677-2, IR661-1-170, IR2042-178-1, IR2035-197-3, IR1487-141-6, and IR2035-353-2 (Table 10).

Performance of breeding lines *(Plant Breeding).* Two replicated yield trials were planted during the 1974 wet season to assess the yield performance and drought resistance of breeding lines selected from upland nurseries, and to compare them with traditional upland varieties and drought-tolerant semidwarf lines. One trial was planted on a well-drained field at the institute, and the other on a rented field at Santo Tomas, Batangas. Precipitation at both sites from mid-June through mid-August was substantially lower than the 1966–73 average. The drought spell lasted through the active-tillering phases and panicle-initiation phases of most of the test materials. During the period from seedling emergence until August 16, 33 percent more rain fell at Santo Tomas than at Los Baños, which received 700 mm. After the August 17–18 typhoon, no appreciable rain fell for 25 days at two sites. The prolonged drought provided an excellent opportunity to rate the reactions of different strains to water stress and to interpret yield performance partly on the basis of relative drought resistance. Table 11 shows data on maturity, 100-grain yield, and grain yield of selected entries.

The yields at IRRI were generally low – from negligible to 1.4 t/ha – because most of the strains received only 1,003 mm of precipitation during the



5. Yield performance of three traditional upland varieties, an improved upland variety (C22), two drought-tolerant semidwarfs (IR937-55 and IR1545-339), and seven breeding lines from upland nurseries in relation to field resistance to drought (1974 dry-season score) and growth duration. (Rainfall data are shown in fig. 3.) Santo Tomas, Batangas, Philippines, 1974 wet season.

growth period. At Santo Tomas, the early maturing strains received 1,232 mm of rain while the late strains received 1,355 mm. Yield levels of up to 3.6 t/ha were obtained on the rented field.

At IRRI, N 22, an early maturing and lodging-susceptible variety from India, escaped the drought which followed the August 17–18 typhoon and produced a top yield of 1.4 t/ha. The strong winds following the typhoon adversely affected seedset on those drought-resistant lines that had headed. Because of high spikelet sterility, yields of two drought-resistant IR1746 lines were low (about 0.35 t/ha) but the grains that developed were heavy (2.2 to 2.5 g/100 g). IR1750-F5B-3 and IR1750-F5B-5, two relatively short lines from E425/IR22, had intermediate drought resistance at the vegetative phase, and produced nearly 1 t/ha. The lines yielded well partly because they were early maturing (90 days from seeding to heading) and partly because the grains filled well during the stress period. For many of the strains that had drought resistance ratings of intermediate or below, yields ranged from 0 to 0.5 t/ha. Two drought-tolerant semidwarf lines, IR1545-339 and IR937-55, yielded 0.4 t/ha and no grain, respectively. The improved Philippine upland variety C 22 lacked drought resistance – it produced short, highly sterile panicles over a period of 40 days. Because heading was delayed, rats damaged the plot before it was ready for harvest

At Santo Tomas, the IR1750-F5B-5 and IR1750-F5B-3 lines produced more than 3 t/ha while two popular local varieties, Kinandang Patong and Kinandang Putih, yielded 1.8 and 1.5 t/ha, respectively. Two other upland lines, IR1746-88-1 and IR1750-F5B-2, yielded more than 2 t/ha. A drought resistant variety from Malaysia, Padi Tatakin, yielded 1.9 t/ha. Two other drought-resistant varieties, IAC 25 (from Brazil) and 63-83 (from Africa), also yielded more than 1.5 t/ha. But the improved Philippine upland variety C 22 yielded 0.2 t/ha and a dual-purpose Philippine variety, BPI-76(n.s.), produced 0.5 t/ha, because of their relatively low levels of drought resistance. Two drought-tolerant semidwarf lines, IR1545-339 and IR937-55, yielded 1.17 and 0.30 t/ha, respectively, under prolonged drought during grain development (fig. 5). These lines have rather poor root systems.

Lines having intermediate or moderately susceptible levels of drought resistance, such as IR2734-F3B-20-1 (from E425/IR8//IR5), IR2992-27 (from IR5/IR1561-228-3), and IR2989-13 (from IR5/IR1514A-E666) were able to produce only between 0 and 0.4 t/ha at maturity about 160 days after seeding at IRRI (Table 11). The grains of such lines were so shrivelled and light that they were not fit for consumption.

Table 11. Grain yield and other agronomic data of upland varieties, upland breeding lines, and drought-tolerant semi-dwarfs at two test sites. IRRI, 1974 wet season.

Designation	Field reaction to drought[a]	Plant ht[b] (cm)	Maturity[b] (days)	Grain yield (t/ha)		100-grain wt[c]
				Santo Tomas	IRRI	
BPI-76 (n.s)	MS	101	139	0.5	0.1	1.6
C 22	I	101	139	0.2	–[d]	–
IAC 25	MR	136	96	1.7	0.8	2.8
N 22	R	114	96	2.2[e]	1.4	1.3
Kinandang Patong	MR	130	125	1.8	–[f]	–
Kinandang Puti	MR	143	125	1.5	0.2	2.2
Padi Tatakin	R	137	116	1.9	0.3	1.7
63-83	R	132	116	1.6	0.0	2.2
IR937-55-3	I	66	154	0.3	–[f]	–
IR1545-339	I	72	147	1.2	0.4	2.0
IR1746-88-1	MR	125	116	2.2	0.6	1.8
IR1746-226-1-2	MR	140	125	1.5	0.3	2.2
IR1746-226-1-1	R/MR/I[g]	145	125	1.4	0.4	2.6
IR1750-F5B-2	MR	103	125	2.1	0.5	1.8
IR1750-F5B-3	I	88	116	3.1	0.9	2.0
IR1750-F5B-5	I	98	116	3.6	0.7	1.8
IR2734-F3B-20-3	I	112	139	0.3	0.2	1.6
IR2989-13	MS	86	154	0.4	–[f]	1.7
IR2992-27	I	92	154	0.1	0.4	1.9
IR3179-7	I	99	139	0.5	0.1	1.9

[a]Obtained in 1974 dry season field test. [b]At Santo Tomas. [c]At IRRI. [d]Damaged by rats. [e]One replication only. [f]Highly sterile panicles. [g]Segregating within the line.

The rainfall patterns at both sites are shown in fig. 3 and 4. At Los Baños, almost all entries that headed between the last week of August and mid-September had high panicle sterility. Drought resistance at the reproductive stage appeared essential to good grain filling under water stress (fig. 5).

The ability to recover following drought is also important to total drought resistance under field conditions. Varieties with good recovering ability, such as IAC 1246 and Gour Lao, produced a ratoon crop following frequent rains in late September. Good recovering ability alone cannot insure stable yields, however, because the rainy season at many upland rice areas is shorter than 160 days. A combination of moderately high drought resistance and relatively good ability to recover appears to be an appropriate goal in breeding for total drought resistance.

ROOT STUDIES

Plant Physiology and Plant Breeding Departments

Root-to-shoot ratio and vertical distribution *(Plant Physiology).* We investigated the rooting depths and the root-to-shoot ratios of 25 rice varieties, one sorghum variety, and one corn variety. Root boxes were used for the studies because rooting depth and penetration under field conditions may be restricted by different degrees of mechanical resistance. Although the root box environment may differ from field conditions, it allows us to properly evaluate the genetic potential of developing root systems.

The plywood root boxes were 10 x 30 x 92 cm in size, with two drainage holes and plastic glass surfaces on one side. The root box does not allow determination of maximum depth of root development because rice, sorghum, and corn may develop

Table 12. The root-to-shoot ratios of 25 rice varieties, one sorghum variety, and one corn variety. IRRI, 1974.

Root: shoot ratio (mg/g)	Designation
209	Sorghum (Cosor)
146	Corn (Early Thai Composite)
101–120	Rikuto Norin 21, Azucena, OS4, E425, Palawan, Dular, Azmil, M1-48
81–100	C22-51, IR442-2-58, 81B25, Miltex, IR5, IR8, Jappeni Tungkungo, PI 215936
60–80	TN1, NARB, Bluebonnet, Peta, IR841-67-2, IR127-80-1, IR1529-680-3, H4
49	IR20

roots longer than 90 cm. The major portion of roots, however, is found within the 90 cm soil depth. We grew one plant per box, adequately fertilized and watered. The roots were sampled at flowering by cutting the soil horizons into 10-cm portions.

The root-to-shoot ratio (mg/g) of 25 varieties ranged from 49 for IR20 to 117 for Rikuto Norin 21 (Table 12). Traditional upland varieties have high root-to-shoot ratios, suggesting that a high proportion of roots to shoots is desirable for upland varieties. Because the surface area of rice roots is proportional to the root weight to two-thirds power, higher root-to-shoot ratios should relate to higher capacity to absorb water. Sorghum and corn, which are more resistant to drought than is rice, have much higher root-to-shoot ratios, which also supports the theory that plants with high root-to-shoot ratios have increased drought resistance.

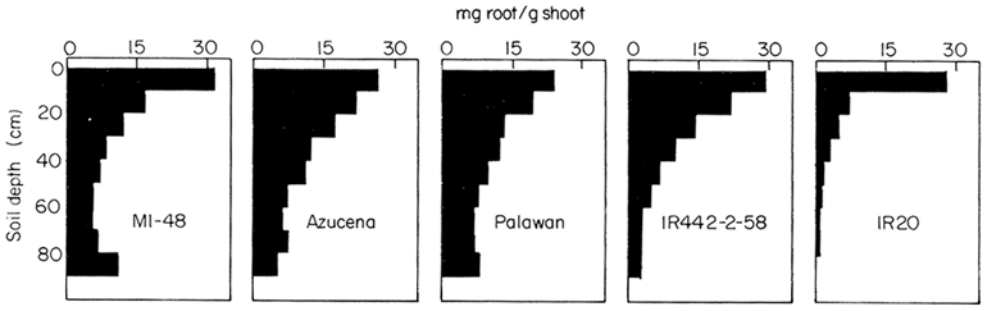
The vertical distribution of roots should relate to the plant's ability to use water stored deeper in the soil, and, hence, to drought resistance. Drought-resistant varieties have higher root weights per gram of shoot in deeper soil horizons than have drought-susceptible varieties (fig. 6). Sorghum and corn have even higher root weights in deeper soil horizons than have drought-resistant rice varieties (fig. 7). The vertical distribution of wheat roots is similar to, or poorer than, that of rice. Thus, deep and proliferated rooting habits appear to correlate with higher degrees of drought resistance.

Because the vertical distribution of roots is not easy to present graphically for a large number of varieties, and because deeper portions of roots may be an important character in drought resistance, we computed the deep-root-to-shoot ratio (dR:S ratio). The deep-root-to-shoot ratio is the ratio of the weight of roots that are deeper than 30 cm per gram of shoot; it approximately represents the amount of roots that have penetrated deeply.

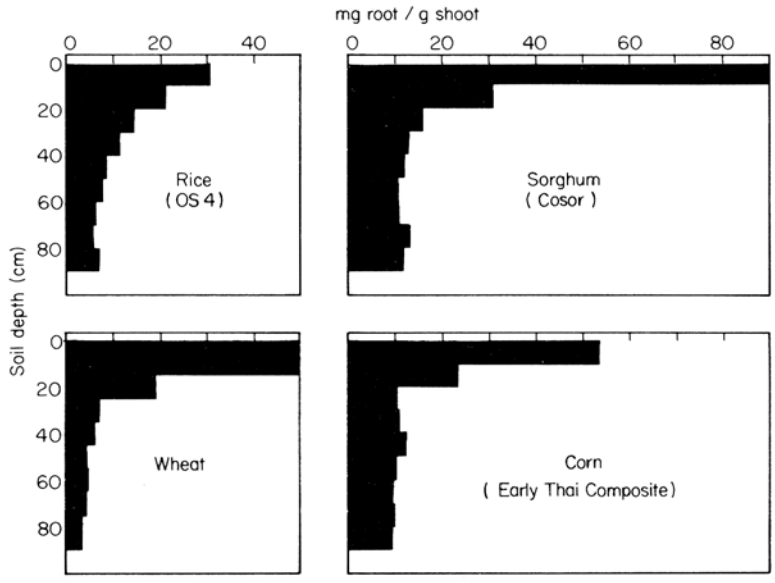
Most upland varieties have higher dR:S ratios than do most lowland varieties, indicating that the lowland varieties have shallow root systems (Table 13).

Thick vs. thin roots *(Plant Physiology).* A high proportion of thick roots is often claimed to be associated with deep penetration of root systems. Plants with a high proportion of thin roots should have large root surfaces or high frequencies of branching, and, hence, good ability to exploit soil water.

For our study, we defined "thick roots" as the



6. Distribution of depth of root dry weight per gram of shoot dry weight (mg root/g shoot) of varieties rated at flowering as resistant (M1-48), moderately resistant (Azucena), intermediate (Palawan), moderately susceptible (IR442-2-58), and susceptible (IR20).



7. Distribution and depths of the ratios of dry weight of roots per gram of shoot dry weight (mg root/g shoot) of rice, sorghum, wheat, and corn.

roots that can easily be separated by hand from fibrous roots. Botanically, these are primary roots developed from nodes while fibrous roots are secondary and tertiary roots branched from primary roots. Hence, the percentage of total weight of thick roots is roughly inversely proportional to the degree of branching. The diameter of these thick roots ranged from 0.7 to 1.5 mm. The thick roots of some upland varieties were found to be thicker than those of lowland varieties.

Table 13. The deep root-to-shoot ratios of 25 rice varieties, one sorghum variety, and one corn variety. IRRI, 1974.

Deep root: shoot ratio (mg/g)	Designation
> 60	Sorghum (Cosor), corn (Early Thai Composite)
51–60	Rikuto Norin 21, Palawan
41–50	Azucena, OS4, E425, M1-48, 81B25
31–40	Dular, Azmil, PI 215936
20–30	C22-51, IR442-2-58, Miltex, IR8, IR5, Jappeni Tungkungo, NARB, Bluebonnet, Peta
< 20	TN1, IR841-67-2, IR127-80-1, IR1529-680-3, H4, IR20

The percentages of total weight of thick roots ranged from 44 percent for IR8 to 69 percent for Bluebonnet (Table 14). This variation is rather small compared with variations in root-to-shoot ratios. As a result, thick root weight per gram of shoot is largely correlated with the root-to-shoot ratio. At higher root-to-shoot ratios, more thick roots are found per gram of shoot. The rate percentages of thick roots are not necessarily higher in upland than in lowland varieties. The physiological functions of thick and thin roots are now being studied.

Root growth and plant type *(Plant Physiology).* Rice scientists speculate widely that root growth is linked with plant height and tillering habit. Deep and proliferated root growth is often thought to be associated with tall stature and with fewer tillers.

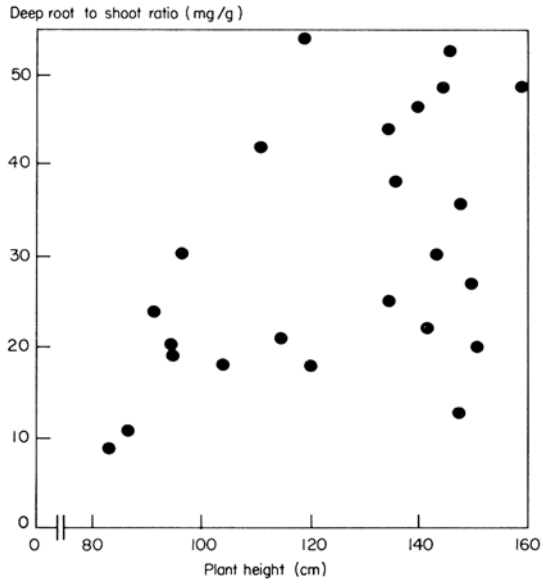
To test this theory, we examined relationships among dR:S ratio, plant height, and tiller number.

Figure 8 shows that no relationship was found between dR:S ratio and plant height.

To further study linkages between plant height and root growth, we grew in root boxes two isogenic lines of Peta that differ in height, early short Peta and early tall Peta, and three sorghum varieties of different heights. At flowering, early short Peta was 78 cm tall, and early tall Peta was 145 cm tall; the root-to-shoot ratio of early short Peta was

Table 14. The ratios of roots to shoots, percentages of total weight in thick roots, and ratios of thick roots to shoots of upland and lowland rice varieties. IRRI, 1974.

Variety	Root: shoot ratio (mg/g)	Thick roots (% of total wt)	Thick roots (mg/g shoot)
Rikuto Norin 21	117	63	74
OS4	113	61	69
Palawan	112	54	60
M1-48	104	62	64
Miltex	88	60	53
IR5	83	57	47
IR8	82	44	36
PI 215936	81	67	54
Bluebonnet	75	69	52
Peta	71	51	36
H4	61	54	33
IR20	49	64	31



8. Relationship between plant height and deep-root-to-shoot ratio of 25 rice varieties.

slightly higher than that of early tall Peta. Yet the vertical distributions of the roots of both lines were almost identical (fig. 9).

The shortest sorghum variety tested, Mini Milo 54 Br., had the deepest and most proliferated root system (fig. 10).

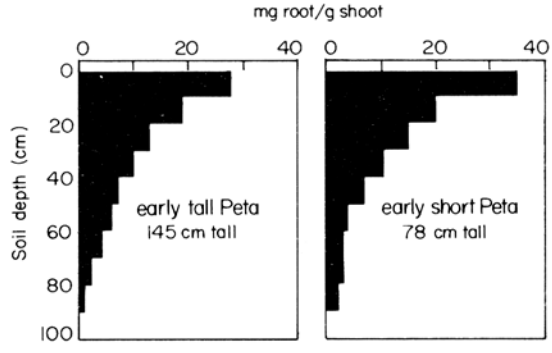
This experiment indicates that there is no genetic linkage between plant height and root growth in rice and sorghum. Consequently, it may be possible to screen for rice varieties of short stature with deep roots.

We found tiller number to be closely correlated with dR:S ratio; the fewer the tillers, the higher the dR:S ratio (fig. 11). This correlation was expected because tillers and roots develop from nodes. If a plant continues to tiller, the new roots remain short because they do not have sufficient time for growth. This, along with fewer roots per tiller, explains why late tillers usually die during droughts, while the main culms and early tillers survive.

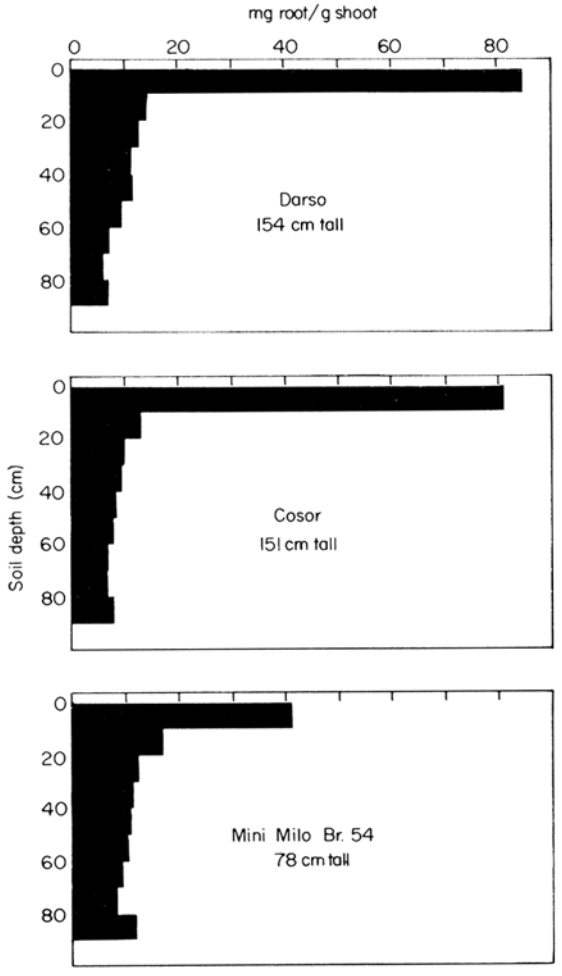
This does not account for differences in the root lengths of the main culms of low- and high-tillering varieties. Maximum root length of a main culm is a varietal character independent of plant height and tillering. Some low-tillering rices, such as the line IR127-80-1, have shallow root systems. The observed correlation between low tillering and deep root systems, therefore, should be considered to be "more frequent association" on tillered plants.

Thus, high tillering may be an undesirable character for drought resistance. On the other hand, low tillering may reduce the plant's ability to recover from drought, or to compensate for missing hills. Medium tillering might be a desirable compromise under most conditions.

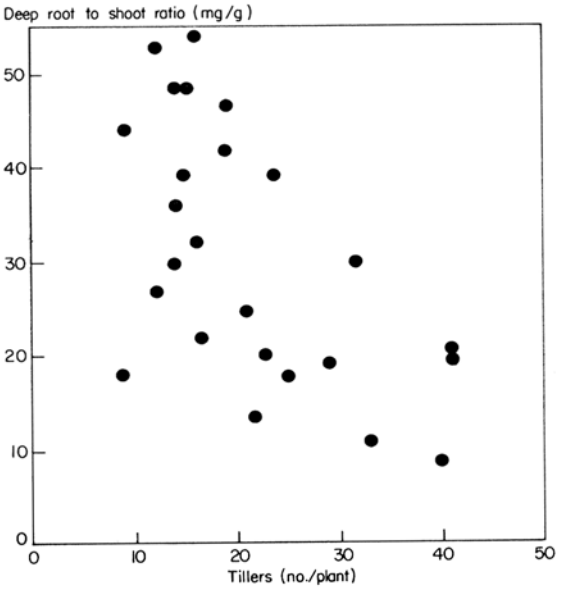
Thus, a desirable plant type for upland rice varieties may be of short to intermediate stature, with medium tillering ability, and a deep root system.



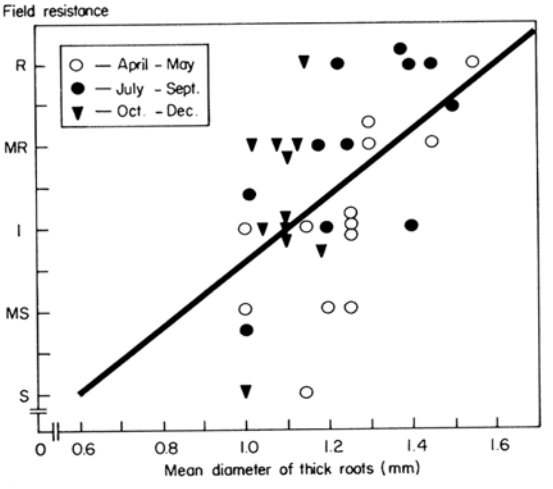
9. Distribution of depth of root dry weight per gram vs. shoot dry weight (mg root/g shoot) of early tall Peta and early short Peta at flowering.



10. Distribution of depth of root dry weight per gram of shoot dry weight (mg root/g shoot) of three sorghum varieties differing in plant height.



11. Relationship between tiller number and deep-root-to-shoot ratio of 25 rice varieties.



12. Relationship between field resistance to drought (Y) and the mean diameter of thick roots (X) obtained from 35 varieties and lines in three plantings. Estimated regression line $Y = -1.39 + 4.01X$. $r = 0.5397^{**}$.

Root system *(Plant Breeding).* Our earlier studies (1970 and 1971 annual reports) have shown that drought-tolerant upland varieties such as OS4 and M1-48 have more extensively developed systems of thick and long roots which enable them to use subsoil moisture, while semidwarfs generally have predominantly thin and rather shallow roots. During 1974, we studied in three plantings the root systems of a wide array of genetic materials, including traditional and newly improved upland varieties and lines, and drought-tolerant and drought-susceptible semidwarfs. Thirty-three varieties and lines were grown in cylinders of light-textured soil 10 cm in diameter and 60 cm deep. Water was supplied from the bottom of the cylinder. Roots were sampled at 60 days after seeding, when varietal differences were obvious.

We measured the predominant types of roots (fine or thick), total number of roots, number of

Table 15. Measurements of the roots of 60-day-old rice plants grown in mylar tubes, April and July plantings. IRRI, 1974.

Designation	Predominant types[a]	Rootlets[b]	Roots (no.)		Length (cm)		Diameter (mm)	
			Total	Thick	Mode	Max.	Av.	Thickest
April planting				*Upland types*				
OS4	6	4	38	25	67	79	1.3	1.6
IR1746-F5B-13	6	4	35	26	62	80	1.0	1.3
IR1746-226-1-1-3	5	4	23	16	69	76	1.1	1.3
IR1750-F5B-5	4	4	22	12	49	59	1.0	1.3
IR1754-F5B-16	5	4	52	41	66	81	1.1	1.3
July planting								
Cartuna	6	4	86	46	31	70	1.4	1.7
Moroberekan	6	2	73	48	30	73	1.5	1.9
Padi Tatakin	6	3	67	40	24	77	1.4	1.8
63–83	6	3	78	51	24	80	1.5	1.9
April planting				*Lowland types*				
IR20	4	4	66	29	35	38	0.7	1.0
TN1	3	4	67	25	55	69	0.9	1.2
IR937-55-3	3	4	39	14	30	38	0.8	1.0
July planting								
IR26	4	4	84	22	6	23	1.0	1.3
IR1529-430	3	4	65	34	64	85	0.9	1.2
IR1545-339	4	4	108	42	8	75	1.2	1.5

[a]1 = very fine; 6 = very thick. [b]1 = very few; 2 = from lower portion of root only; 3 = from midportion to root tip; 4 = uniformly branched from base to tip.

thick roots, mode and maximum length of roots, and mean and the maximum diameter of the thick roots. Mean diameter of thick roots differed significantly among varieties planted in April and July, but not in the October planting. Varietal differences in the July planting were highly significant for maximum root length and diameter of the thickest roots, and significant for root weight. In the April planting, the varieties differed significantly in the predominant type of roots (fine or thick).

In these plantings, traditional upland varieties such as Moroberekan, 63-83, OS4, Cartuna, and Padi Tatakin have a combination of long and thick roots. Among breeding lines selected from upland nurseries, two IR1746 lines (from a cross of OS4/IR8) have thicker roots than do the IR1750 lines (from E425/IR22) or the IR1754 lines (from E425/IR8). Lowland semidwarf varieties, such as TN1, IR20, and IR26, have many fine roots clinging to the soil surface, but rather few long and and thick roots (Table 15).

When we compare the root characteristics with the drought-resistance ratings obtained in the mass screening tests during the dry season, drought resistance appears to be associated with the mean diameter of the thick roots ($r = 0.5397^{**}$) and, to a lesser extent, with the number of thick roots (fig. 12). We also found this association among the semidwarf lines selected from lowland nurseries. Moreover, the thick-and-deep roots appeared to be a heritable trait present only in those hybrid lines that have a thick-rooted variety as a parent.

Genetic evaluation and utilization (GEU) program

Tolerance to injurious soils

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Soil problems are serious obstacles to increasing the yield per hectare of much of the current rice land and to bringing more land under rice. Among these problems are salinity, salinity-alkalinity, alkalinity, iron toxicity, toxicity of acid-sulfate soils, zinc deficiency, phosphorus deficiency, and the low productivity of peat soils. About a third of the current rice area is estimated to be affected by one or more of these problems; about 40 million ha of land in the tropics, climatically and physiographically suited to rice, lies uncultivated largely because of soil problems. In the Philippines alone, there are 280,000 ha of coastal saline soils, and about 500,000 ha of zinc-deficient soils. Because improving these lands by chemical amendments or by water management is beyond the means of most developing countries, we are selecting and breeding for tolerance to these adverse soil conditions as a component of the GEU program.

We refined our techniques for screening large numbers of plants for salt tolerance, and screened 343 varieties and selections for tolerance to salinity, alkalinity, iron toxicity, zinc deficiency, and phosphorus deficiency. Because of the current nitrogen fertilizer shortage, we explored the possibility of using genetic variability in the capacity of the rice plants to extract nitrogen from the soils.

We found: 1) that the salt tolerance of rice depends on the salt content, soil, method of planting, seedling age, temperature, and duration of exposure to salt; 2) that the performance of varieties grown in culture solution and transplanted at 2 weeks in submerged Maahas clay containing 0.4 percent salt was a good index of salt tolerance; 3) that of 48 reportedly salt-tolerant varieties, only seven actually tolerated salinity; 4) that of the improved varieties or selections, IR2153-26-3-5, IR2153-43-2-5, and IR2035-290-2 tolerated salinity; IR2151-190-3 tolerated iron toxicity; and IR28 and IR29 tolerated P and Zn deficiencies; and 5) that in pot experiments, Peta and H4 (both tall indicas) apparently extracted and used both soil and fertilizer nitrogen more efficiently than did IR5, IR20, or IR26.

Table 1. Influence of salt concentration on injury to rice plants at 24 days after transplanting. IRRI, 1974.

Salt concn (%)	EC[a] (mmho/cm)	Salt injury rating[b]			
		Pokkali	T26	Kangni Torh	IR2153-26-3
0.1	1.9	0	3	2	1
0.2	3.5	1	6	3	2
0.3	5.5	3	6	4	2
0.4	6.9	5	7	7	3
0.5	8.2	6	9	9	6

[a]Electrical conductivity of the saturation extract of the air-dried soils. [b]0 = no symptoms; 9 = plants dead.

The salt-tolerant selections are resistant to most of the major diseases and insects, and are thus potential varieties. They are all of the semidwarf plant type, however, and will not be suitable for most coastal saline areas because the water is too deep. They may be suitable for irrigated saline areas, but have not yet been thoroughly tested. Salinity causes a reduction in plant height even in the most tolerant genotypes, and this may preclude the cultivation of salt-resistant dwarfs, even in irrigated areas.

Other characteristics of the selections and varieties mentioned above are discussed in another section of this report.

SALT TOLERANCE

Soil Chemistry Department

To refine and simplify the technique for screening varieties for salt tolerance, we studied some of the factors that influence salt injury, including: the content and nature of salts, soil pH, duration of soil presubmergence, temperature, growth stage of the plant, and duration of exposure to salts.

Salt concentration. We grew four varieties on submerged Maahas clay (pH 7.0, O.M. 2.0%) treated with 0.1, 0.2, 0.3, 0.4, and 0.5 percent common salt in shallow plastic trays measuring 35 x 27 x 11 cm.

None of the varieties showed any signs of injury at 0.1 percent salt (Table 1). At 0.2 percent salt, T26 (a susceptible variety) was injured. In the 0.3 percent salt treatment, T26 and Kangni Torh showed severe symptoms of salt injury while Pokkali (a tolerant variety) and IR2153-26-3 appeared to be only slightly injured. At the 0.4-percent level, T26 died within 3 weeks, and Kangni Torh within 5 weeks, while Pokkali and IR2153-26-3 were only moderately injured. The highest level of salt (0.5 percent) was lethal to all varieties except Pokkali and IR2153-26-3, which survived in spite of severe injury.

The experiment confirmed our previous observation (1973 Annual Report) that the performance of rice varieties in Maahas clay treated with 0.4 percent salt is a good index of their salt tolerance in nearly neutral soils.

Common salt vs. seawater. Most of the saline soils of the tropics are coastal or estuarine soils subject to inundation by seawater. Because seawater contains a variety of salts and an appreciable amount of boron in addition to sodium chloride, we compared the behavior of five rice varieties on three soils treated with common salt with their behavior on the same soils treated with sufficient seawater to give comparable salt concentrations in the soil solutions after submergence. Table 2 shows the mean values for the electrical conductivity and the peak values for some cations.

At comparable electrical conductivities, seawater was slightly less injurious than a common salt solution. This may be due to the slightly lower concentration of sodium in the seawater-treated soils than in the common salt-treated soils (Table 2).

Soil pH. Soil pH markedly influenced the degree of salt injury. Salt injury was least on the Pila clay loam (pH 7.5, O.M. 3.8%), moderate on Maahas clay (pH 6.4, O.M. 2.2%), and most severe on Luisiana clay (pH 4.9, O.M. 3.2%) (Table 3). The plants in Luisiana clay showed symptoms of iron toxicity. Table 2 reveals much higher concentrations of iron in the solutions of Luisiana clay than in the solutions of the other soils.

These findings suggest that when screening for salt resistance in acid soils the level of salt may have to be lowered.

Duration of soil presubmergence. When a soil is submerged, the electrical conductivity of the soil solution increases, reaches a peak, and declines. This factor has to be considered when fixing the salt level for screening tests.

Duration of submergence up to 2 weeks had no appreciable effect on Maahas clay treated with 0.4 percent common salt (Table 4).

Temperature. To ascertain the influence of temperature on salt injury, we direct seeded or transplanted 2-week-old seedlings of four rice varieties in submerged Maahas clay treated with 0.4 percent common salt in phytotron chambers with day/night temperature regimes of 20°/20°C and 35°/27°C. Regardless of method of planting, salt injury was less at the low temperature regime than at the high temperature regime. Table 5 shows the ratings for the transplanted seedlings.

Table 2. Influence of common salt and sea water at comparable electrical conductivities on the peak concentration of cations in the solutions of three submerged soils. IRRI, 1974.

Salt source	EC (mmho/cm)	Peak concn (ppm) Na	K	Fe	Mn	Ca	Mg
		Luisiana clay (pH 4.6; O.M.3.2%)					
Common salt	6.9	1156	48	503	124	182	150
Sea water	6.8	909	43	467	112	229	164
		Maahas clay (pH 6.6; O.M. 2.0%)					
Common salt	8.3	1045	55	82	32	575	417
Sea water	8.3	929	60	75	31	566	406
		Pila clay loam (pH 7.5; O.M. 3.6%)					
Common salt	8.7	1100	42	19	23	1143	312
Sea water	8.3	856	48	23	29	1042	298

Table 3. Influence of soil properties on ratings of salt injury 23 days after transplanting. IRRI, 1974.

Soil	Salt injury rating Pokkali	IR2153-26-3	IR26	T26	M1-48
Luisiana clay	3.5	8.9	9.0	9.0	9.0
Maahas clay	1.3	6.1	7.5	7.6	8.7
Pila clay loam	0.8	6.2	7.2	6.3	7.7

Table 4. Influence of duration of soil submergence on the severity of salt injury in Maahas clay treated with 0.4 percent common salt at 2 weeks after transplanting. IRRI, 1974.

Weeks presubmerged	Salt injury rating Pokkali	IR24	T26
0	2.1	7.1	7.5
1	2.0	7.1	7.2
2	2.3	6.3	7.0

Age of seedling. The growth stage of the seedling at the time of transplanting from the culture solution to the saline soil culture markedly influenced the degree of salt injury (Table 6). In all five varieties, injury was less in the 2-week-old seedlings than in the 1-week-old seedlings. But what is more remarkable is that IR2153-26-3, which at 1 week was so markedly inferior to Pokkali, became as good as Pokkali at the 2-week stage.

Table 5. Salt injury 2 weeks after transplanting of four varieties under two temperature regimes in phytotron growth rooms. IRRI, 1974.

Temperature regime[a]	Salt injury rating			
	Pokkali	IR20	M1-48	T26
20°/20°C	2.7	4.1	7.3	6.7
35°/27°C	4.2	5.7	9.0	8.4

[a]Day/night temperature.

Table 6. Influence of the age of seedling on salt injury. IRRI, 1974.

Age of seedling (wk)	Salt injury rating				
	Pokkali	IR2153-26-3	IR26	T26	M1-48
1	1.9	6.3	6.8	6.8	7.9
2	1.0	1.0	2.9	2.7	4.1

Table 7. Influence of duration of exposure to salt and resulting injury. IRRI, 1974.

Variety	Rank[a]			Rating[b]		
	14 DT[c]	21 DT	28 DT	14 DT	21 DT	28 DT
ADT	21	22	22	S	S	S
Annapurna	9	8	8	R	MR	MR
BR 4-10	1	1	2	R	R	R
Dasal	15	13	15	MR	MS	S
IR4-11	4	10	12	R	MR	MS
Jaganath	6	12	10	R	MS	MS
Pokkali	2	3	2	R	R	R

[a]Among varieties screened. [b]R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible. [c]DT = days after transplanting.

Duration of exposure to salt. Sixty varieties transplanted on Maahas clay with 0.4 percent salt were rated at 2, 3, and 4 weeks. Table 7 shows that duration of exposure to salt did not alter the relative ranking and evaluation of the most resistant and susceptible varieties, but prolonging the period made possible a more rigorous rating for salt tolerance. Rating at 2 weeks may lead to evaluation of some susceptible varieties as moderately resistant. For example, Dasal and H4, which appeared to be moderately resistant at 2 weeks, turned out to be highly susceptible at 4 weeks.

Screening technique. We are now in a position to recommend the following procedure for screening rice plants for salinity in submerged and almost neutral clay soils:

Mix 5 kg of crushed soil which has been air dried with a mixture of 0.6 g of ammonium sulfate, 0.75 g of concentrated superphosphate, 0.25 g of muriate of potash, 3.8 g ground straw, and 0.75 g ground dried *Glyricidia sepium.* Place the soil in shallow plastic trays that measure 35 x 27 x 11 cm. Add 4 liters of a 0.5 percent solution of common salt, mix thoroughly, and level the soil slurry. Two days later, transplant three seedlings in a row in the middle of the tray. With every 20 trays, use one tray of Pokkali (resistant check) and one tray of T26 (susceptible check). Keep the soils submerged to a depth of 1 cm by daily watering.

Two weeks before transplanting, soak in tap water 20 selected, disinfected seeds of each variety. Two days later, place the seeds in rows on nylon-net floats in one-tenth strength culture solution. (The full strength solution contains 40 ppm each of N, K, Ca, and Mg; 10 ppm P; 0.5 ppm Mn; 0.05 ppm Mo; 0.2 ppm B; 0.01 ppm each of Zn and Cu; and 5 ppm Fe as FeEDTA, and is adjusted to pH 6.0.) After 3 days replace the solution with one-fourth-strength solution. Six days later, replace the solution with full-strength solution. Fourteen days after soaking, select three healthy, uniform seedlings for transplanting in the salinized soils.

Four weeks after transplanting, score the plants according to Table 8 and rate them according to Table 9.

Varietal resistance. We began our search for salt tolerance in germ plasm with varieties that were either collected from salt-affected areas or that were reported to be salt tolerant. Forty-eight such

Table 8. Scoring salt injury. IRRI, 1974.

Dead leaves (%)	Score
0	0
1 – 20	1
21 – 35	2
36 – 50	3
51 – 60	4
61 – 70	5
71 – 80	6
81 – 90	7
91 – 99	8
100	9

varieties (some from more than one source) were screened by the above method.

Only six of the 48 reportedly salt-tolerant varieties were really shown to be tolerant of salt in our test (Table 10). Of the six only Nona Bokra appeared to be more resistant to salt than Pokkali. Ten were moderately resistant. Eighteen of the so-called salt-tolerant varieties were highly susceptible; 16 were moderately susceptible. The high variability in the reactions of the same varieties from different sources, such as Pokkali, was a surprising and disturbing finding (Table 11).

Reactions of breeding lines. We screened 24 promising breeding lines with Pokkali (resistant) and T26 (susceptible) as checks. We found the selections IR2153-26-3 and IR2153-43-2 to be resistant to salt. In an outdoor test of 32 selections, the following were found to be moderately resistant: IR2035-290-2, IR2071-88, IR2153-26-3, IR2070-747-4, and IR2071-625-252. IR1529-680-2 was susceptible.

In a replicated experiment in a block of salinized Maahas clay with an electrical conductivity

Table 9. Rating resistance to salt injury. IRRI, 1974.

Rating	Score
Resistant (R)	0.0 to 3.0
Moderately resistant (MR)	3.1 to 5.0
Moderately susceptible (MS)	5.1 to 7.0
Susceptible (S)	7.1 to 9.0

Table 10. Varietal reactions to salinity. IRRI, 1974.

Resistant	Moderately resistant	Moderately susceptible	Susceptible
BR 4-10	Annapurna	Basmati (3647)	ADT 27
Gottelu	BG 79	Getu (22709)	Basmati (16130)
Kalarata 1-24 (26906)[a]	Damodar	HR 35	CAS 209
Muskkan 7	Getu (17041)	IR4-11	Dasal
Nona Bokra	RPA 5929	Jaganath	H4
SR 26 B (5908)	SR 26 B (10803)	Jhona (3654)	HR 19
Pokkali (26869) (check)	TNI / T 65	Jhona 349	Jhona (10829)
	IR2153-26 (check)	Karuna	Kalarata 1-24 (19929)
	IR2153-43 (check)	Khao-nam-king	MCM 1
	Benzer DMR 696	MCM 2	Muskkan 41
		Nang Mol	Nagpili
		Peta	Palman 46
		Pokkali (15388)	Palman 246
		Pokkali (15661)	Pokkali (8948)
		Sathra (3552)	Pokkali (15238)
		A52-20-2-2	Pokkali (15602)
			Patnai 23
			PTB 28
			Rupsal
			Sathra (6417)
			SR 3-9
			TKM 6
			M1-48 (check)
			T26 (check)
			Quinawayan DMR 697
			Kangni/Torh

[a] Accession no., IRRI germ plasm collection.

Table 11. Reactions to salinity of seeds from different sources. IRRI, 1974.

Variety	Source	Reaction
Kalarata 1-24	Acc. 26906	R
	Acc. 19929	S
SR 26 B	Acc. 5908	R
	Acc. 10803	MR
Pokkali	Acc. 26869	R
	Acc. 8948	S
	Acc. 15238	S
	Acc. 15388	MS
	Acc. 15602	S
	Acc. 15661	MS

value of 7.5 mmho/cm at the start of the experiment, Pokkali and IR26 showed the least signs of injury; M1-48 and T26 were most severely affected; SR 26 B and Nagpili (both reportedly salt-tolerant varieties) were moderately affected.

ALKALI TOLERANCE

Soil Chemistry Department

Factors. Alkali injury increased as the level of sodium carbonate used to alkalize Maahas clay rose from 1.3 to 1.5 percent. Duration of presubmergence of the soil had no effect. Whether the seedlings were 1 or 2 weeks old at transplanting in the alkalized soil made no difference. The longer the period of exposure to alkali, the more severe was the injury.

Screening technique. The soil is prepared exactly as for salinity screening, except that 1.4 percent Na_2CO_3 is used instead of 0.4 percent common salt. One-week-old seedlings raised in culture solution (as described earlier) are transplanted in the alkalized soil. Three weeks later, alkali injury is rated according to the severity of the symptoms.

Varietal resistance. Twenty-four selections or varieties were tested for alkali tolerance by observing the growth of the plants in submerged Maahas clay treated with 1.4 percent Na_2CO_3 in the greenhouse. Pokkali and Benzer DMR 696 were resistant; IR2151-918-2, IR2153-96-1, IR2153-159-1, IR2153-247-1, IR2153-276-1, and Kangni Torh were moderately resistant; and Quinawayan DMR 697, CAS 209, IR2151-105-2, IR2151-529-1, and IR2151-598-3 were susceptible. The others were moderately susceptible.

In an outdoor replicated test in concrete tanks, Pokkali, IR2031-114-2, and MI 273 showed the least injury. IR26, IR1008-14-1, IR2035-290-2, IR2061-214-3, IR2061-464-2, IR2061-465-1, and IR2071-88 were moderately injured. Severely affected were T26, M1-48, IR1529-3-2, and IR2151-957-5.

In a replicated field test on alkalized Maahas clay (pH 8.7), Pokkali and IR26 performed best, IR1008-14-1 and MI 273 performed moderately well, and Pelita I/1, M1-48, and T26 were severely affected.

IRON TOXICITY

Soil Chemistry Department

Excess water-soluble iron limits rice yields on millions of hectares of strongly acid oxisols and and acid-sulfate soils. Built-in tolerance of iron toxicity would be a boon to the poor people who grow rice on these soils.

We planted 2-week-old seedlings of 22 varieties or selections on a strongly acid oxisol that builds up more than 400 ppm iron in the soil solution a few weeks after submergence. Four weeks later, we scored the plants according to the severity of symptoms and rated them as follows: resistant – Pokkali, IR30, IR2151-190-3, and IR2153-96-1; moderately resistant – IR2151-105-2, IR2153-14-1, IR2153-15-1, IR2153-26-3, IR2153-247-1, IR2153-276-1, and IR2153-479-2; susceptible – CAS 209 and IR424-21-PK2.

ZINC DEFICIENCY

Soil Chemistry Department

Zinc deficiency occurs on alkali and calcareous soils and on continuously wet soils. In the Philippines alone, about 500,000 ha of soils have this nutritional disorder. About a third of the rice area of India and Pakistan are believed to be deficient in zinc. Varietal resistance may be a simpler remedy than applying zinc to the soil or plant.

Using plant symptoms and yields relative to those of zinc-treated plants, we screened 100 varieties and selections in pots in a screenhouse. The following were resistant to zinc deficiency: IR28, IR29, IR30, IR2071-580-6, IR2151-190-3, IR2151-598-3, IR2151-918-2, IR2153-14-1, IR-2153-15-1, IR2153-43-2, IR2153-276-1, IR2153-

479-2, and IR2153-550-2. The following were susceptible: IR2061-214-2, IR2070-747-4-3, IR2070-747-4-5, IR2070-747-4-6, IR2070-747-6-1, IR2070-747-6-4, IR2070-747-6-6, IR2153-957-5, and E425.

Zinc deficiency did not appreciably affect yield or maturity among the tolerant varieties but among the susceptible lines it delayed maturity up to 36 days and reduced yields by 22 to 52 percent. The highly susceptible E425 was completely killed.

In an outdoor replicated test of 16 varieties on a zinc-deficient soil in concrete tanks, IR26, IR2061-214-3, IR2070-747-4-3, IR2070-747-4-5, IR2151-957-2, and IR2153-189-2 were susceptible; IR1514A-E666 was resistant; and the others were moderately resistant or moderately susceptible.

Field tests of 20 entries at three locations in Laguna province, Philippines, indicated that IR20, IR1514A-E666, and IR2031-238-4 were resistant while IR442-2-58, T442, and IR2061-213-2 were susceptible.

PHOSPHORUS DEFICIENCY

Soil Chemistry Department

Phosphorus deficiency limits the rice yields on millions of hectares of ultisols, oxisols, and vertisols. Not only are these soils low in available phosphorus, but they also fix large amounts of applied phosphate. Because most of these soils occur in poor countries where farmers cannot afford to use large amounts of fertilizer, we are searching for varieties that can exploit and utilize soil phosphorus more efficiently than others.

We grew 15 varieties or lines in a phosphorus-deficient ultisol (pH: 4.9; Olsen P: 1.2 ppm) in an outdoor trial. IR20, IR26, IR28, IR1514A-E666, IR1529-680-3, IR2061-214-3, and IR2061-464-2 were resistant; M1-48, Nagpili, T26, IR442-2-58, IR1721-11-6, and IR2061-405-1-2 were susceptible.

In a replicated yield trial, we grew 30 varieties and experimental lines with and without 25 kg/ha P, over a basal dressing of N and K, on a phosphorus-deficient soil at Pangil, Laguna province, Philippines. Some varieties yielded more than 4 t/ha with no phosphate fertilizer, and yielded from 33 to 50 percent more when phosphate was applied (Table 12). These rices, IR26, IR2061-214-2, IR1529-680-3, IR944-102-2, and RD1, were classified as resistant. The susceptible varieties yielded from 2 to 3 t/ha without P; with P, yields increased from 60 to 115 percent. These rice were M1-48, IR1787-19-6, IR788-21-3, and IR2153-184-1.

SOURCES OF VARIETAL RESISTANCE TO SOIL PROBLEMS

Soil Chemistry and Plant Breeding Departments

Table 13 lists varieties that we found resistant or tolerant to various soil problems in 1974.

VARIETAL DIFFERENCES IN NITROGEN UTILIZATION

Soil Chemistry Department

Because of the current high cost and scarcity of nitrogen fertilizer, we began exploratory tests to ascertain whether rice plants vary in their innate capacities to extract and utilize soil and fertilizer nitrogen.

We grew eight varieties in pots in a screenhouse in submerged Maahas clay treated with 0, 50, 100, and 150 ppm N as ammonium sulfate over a basal

Table 12. Varietal reactions to phosphorus deficiency. IRRI, 1974.

Designation	Grain yield (t/ha)		Increase (%)
	0 kg P/ha	25 kg P/ha	
IR26	4.4	6.3	43
IR944-102	4.3	5.7	33
IR1529-680	4.0	5.5	38
IR2061-214	4.0	5.9	48
IR788-21	3.0	5.1	70
IR1787-19	3.0	4.8	60
IR2153-184	3.0	5.0	67
M1-48	2.0	4.3	115

Table 13. Sources of resistance to soil problems, 1974.

Salinity	BR4-10, Gottelu, Kalarata 1-24 (Karjat Research Station), Muskkan 7, Nona Bokra, SR 26 B (Acc. 5908), Pokkali (Acc. 26869).
Alkalinity	Pokkali (Acc. 26869), Benzer DMR 696.
Zinc deficiency	IR30, IR2153-14-1, IR2153-15-1, Pokkali.
Phosphorus deficiency	IR20, IR26, IR28, RD1, IR2061-214-2.

Table 14. Grain yields of six varieties at four levels of nitrogen in submerged Maahas clay in pots. IRRI, 1974.

Variety	Grain yield[a] (g/pot)			
	0 ppm N	50 ppm N	100 ppm N	150 ppm N
Peta	112 a	138 a	149 a	152 a
Pokkali	40 e	45 d	39 d	21 e
H4	100 ab	129 ab	159 a	151 a
Pelita I/1	95 b	115 b	110 c	133 bc
IR5	92 bc	115 b	125 b	145 a
IR20	74 d	93 c	96 c	115 d
IR26	80 cd	92 c	125 b	130 c

[a]LSD (5%): 14.7 g. Within an N level, means followed by the same letter are not significantly different at the 5% level.

Table 15. Nitrogen uptake by five rice varieties from unfertilized Maahas clay. IRRI, 1974.

Variety	Yield (g/pot)		N content (%)		N uptake (g/pot)
	Straw	Grain	Straw	Grain	
Engkatek	242	–	0.638	–	1.55
Peta	198	107	0.188	0.764	1.19
Pokkali	312	43	0.278	1.069	1.31
IR5	133	95	0.324	0.947	1.33
IR26	100	84	0.499	1.160	1.46

Table 16. Influence of phosphate on the efficiency of nitrogen utilization. IRRI, 1974.

Variety	Grain yield[a] (t/ha)							
	P_0[b] N (kg/ha)				P_1 N (kg/ha)			
	0	50	100	150	0	50	100	150
IR26	1.9	3.4	4.5	4.4	4.0	4.8	5.9	6.0
IR5	2.2	3.1	3.8	4.2	4.2	4.6	4.7	4.9
H4	2.8	3.1	3.4	3.4	3.6	4.0	4.2	3.7
Mean	2.3	3.2	3.9	4.0	4.0	4.5	5.0	4.9

[a]LSD (5%) for two N means: 0.63 t/ha; LSD (5%) for two varietal means at same N level: 0.59 t/ha. [b]P_0 = 0 kg P/ha; P_1 = 25 kg P/ha.

dressing of 0.15 percent of a 1:1 mixture of chopped straw and *Glyricidia sepium* leaves. The tall plants were supported to prevent lodging.

Peta and H4 yielded highest at all levels of N; Pokkali yielded lowest (Table 14). Peta and H4 apparently extract and utilize soil and fertilizer nitrogen more efficiently than do the others, although they do not respond positively to nitrogen under field conditions (chiefly because of lodging). The tall plants (except Pokkali) and the plants of intermediate height yielded more both at 0 and at 50 ppm N than did IR20 and IR26. Of the plants that flowered, IR26 absorbed the largest amount of N; Peta absorbed the lowest (Table 15).

In a field experiment on Luisiana clay, H4 outyielded IR5 and IR26 when no nitrogen or phosphate was applied (Table 16).

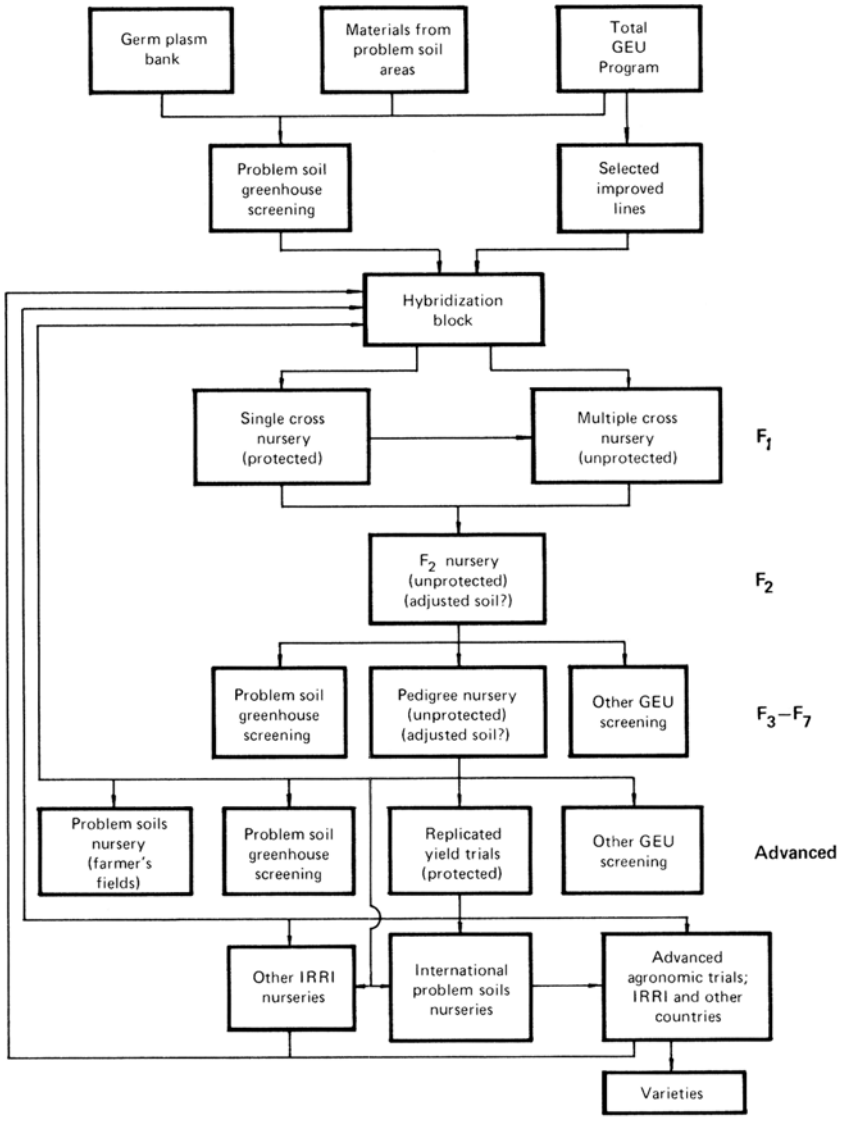
BREEDING

Plant Breeding and Soil Chemistry Departments

An extensive number of crosses were made in 1974 to combine tolerance of the various adverse soils with the many characteristics essential to improved varieties. Although high-volume screening techniques are not yet available for many of these traits, we are making the proper crosses in anticipation of their development. Much of the GEU breeding material now carries tolerance to many of the adverse soils, but we cannot presently exploit this potential.

We have systematized our approach toward the development of improved materials tolerant of the adverse soils (fig. 1). We have emphasized salt tolerance in the breeding work. During 1973, numerous crosses were made with Pokkali because it appeared to be the most tolerant cultivar to salinity and carried tolerance or moderate tolerance to several other adverse soils. During the 1974 dry season, several single-cross F_2 populations were grown. Four of the most promising populations were grown in salt-amended fields under the supervision of soil chemists, and three other populations were routinely grown in our F_2 nursery. Pokkali proved to be a very poor combiner and we were unable to select any materials of satisfactory agronomic type from these populations.

Anticipating this situation, we made numerous top crosses and double crosses involving F_1 hybrids of Pokkali and other cultivars of desirable agronomic types. The F_1 populations of these crosses were also grown and promising plants selected during the 1974 dry season. The F_2 populations of these crosses were grown in the 1974 wet season



1. Flow of genetic materials through IRRI's GEU program to develop varieties adapted to adverse soils.

and about 1,500 plants were selected. The F_3 lines will be grown in salt-amended fields during the 1975 dry season for further evaluation and selection.

Genetic evaluation and utilization (GEU) program

Deep water and flood tolerance

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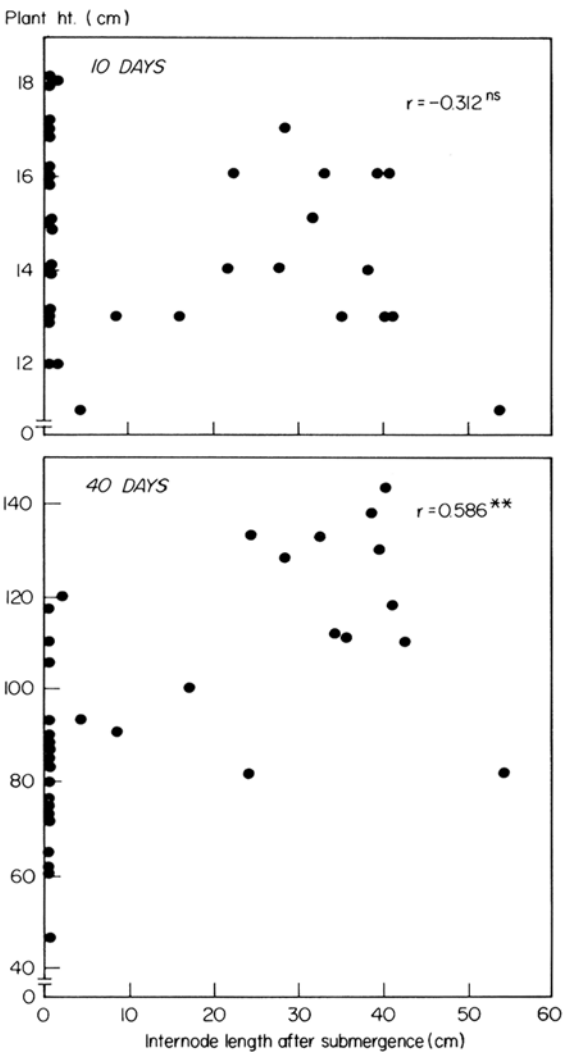
144 A CONCEPT FOR DEVELOPING RAINFED RICES WITH DROUGHT AND FLOOD TOLERANCE

At least 5 million hectares of floating rice grow in areas that are annually flooded to depths of more than 2 meters for 3 to 4 months. The prevailing attitude has been that yields of floating rice can not be significantly increased, so many scientists have ignored the crop. Breeding work has been limited to some selection among the existing varieties.

Grain yields of floating rices are comparable to average yields of traditional lowland rices. Breeding is limited by the lack of information on how to improve yields.



1. Plant height of floating rice varieties at 10 and 40 days, and total internode length after 7 days of submergence at 40 days.

The extensive tidal swamps, areas around lakes, and edges of the floating rice areas often have water levels of less than 2 meters, but the water remains on the land for 4 to 8 months. Improved varieties that are sensitive to photoperiod and that can elongate when necessary are needed in these areas.

In other vast areas, where control is poor and the crops are periodically flooded, high-yielding flood-tolerant varieties would be ideal. Such varieties can probably be developed by breeding the ability to escape or to withstand submergence into high-yielding varieties of semidwarf and intermediate stature.

To accomplish our main objective – to increase and stabilize grain yields in the deep-water rice areas – we began to screen germ plasm for the needed characters and to identify the factors that limit yields.

We are screening breeding lines for rapid ability to elongate, flood tolerance, drought tolerance, and other desirable plant characteristics. Composite crosses have been made at IRRI that involve high-yielding rice varieties of intermediate plant height and floating varieties.

FLOATING RICE PLANT CHARACTERS AND THEIR POSSIBLE IMPROVEMENT

Plant Physiology Department

Floating rice varieties are able to elongate, primarily by internode elongation, as the water levels rise. In shallow water, the floating rices are relatively tall and leafy, with spreading tillers. Some speculate that these plant characters may have to be changed to give the plants greater yield potentials. But it might be difficult to decrease plant height, increase tiller number, and have upright tillers at early growth stages, because these characters seem to be associated with elongation ability. The plant characters of floating rices, however, have not yet been fully studied.

Plant height. As seedlings, floating rices vary considerably in height, but are generally shorter than non-floating varieties (fig. 1). After 40 days of growth, however, the same floating varieties are generally taller than the non-floating varieties. We have found a correlation between plant height and total length of internode elongation. At 40 days, however, the differences in plant height were

Table 1. Number of varieties that tolerate submergence better than Nam Sagui 19. IRRI, 1974.

Type	Varieties used (no.)	Varieties better than N.S. 19 (no.)
Floating	27	3
Non-floating	24	10
Total	51	13

not sufficiently great to distinguish floating from non-floating varieties. Because many non-floating varieties are tall, plant height is not a reliable criterion to distinguish floating from non-floating rices.

Plant height before the water rises may be important in determining the dry matter production and fertilizer response of rice in deep-water areas (more than 150 cm). The short plant type tends to respond better to nitrogen. Plants need not be tall at the tillering stage to withstand a gradual increase in water depth if they can elongate. But when the initial water level increases rapidly, tall varieties have a decided advantage. We hope to develop rices of semidwarf or intermediate plant height that have the capacity to rapidly elongate when flooded.

Tolerance of submergence. The tillers of many floating rices die because they cannot elongate fast enough to keep up with the rapid rise of flood waters (as much as 90 cm/day). Further increasing their elongation rates may not necessarily increase their grain yields, but may improve their adaptability for areas where water levels rapidly increase. In such areas the varieties also need some tolerance of submergence, which may not involve internode elongation.

Floating rice varieties were found to tolerate submergence poorly at the seedling stage, when more than 70 percent of the plants were killed (Table 1). Of the 27 floating rice varieties tested, only Nang Dum To (from Vietnam) had a survival rate of more than 30 percent. Incorporation of the capacity to withstand submergence into floating rice varieties would increase their adapatability and flood tolerance, but not necessarily their potential yields.

Tiller number and angle. Most rice varieties that elongated when submerged also had fewer tillers than non-floating varieties had (Table 2). In the first test, only one floating variety, Kalar Harsall from Thailand, had 10 tillers; the remainder had from five to eight tillers.

In a preliminary survey of the floating rice fields of Thailand, we found low numbers of tillers and panicles per unit area, but the low tillering ability does not seem closely associated with elongation ability. The present data indicate that the number of tillers per plant can be increased through breeding.

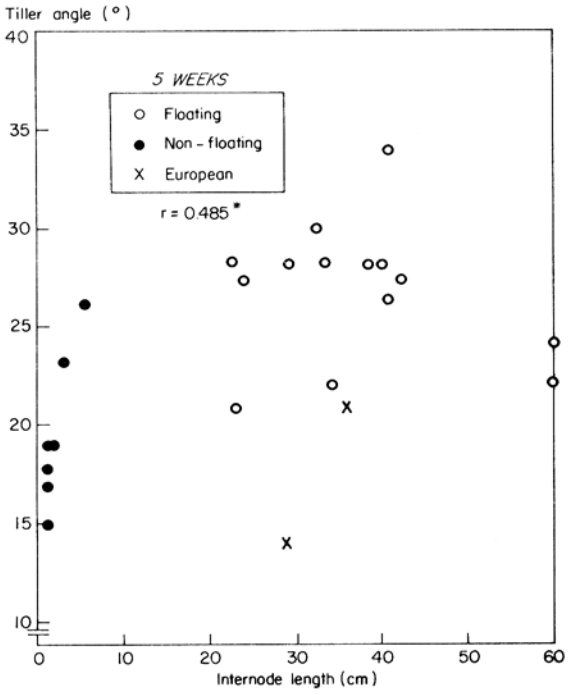
Increasing the seeding rate might also increase the number of tillers per unit area, although field experiments in the floating rice areas seem to contradict this. The spreading habit of the tillers is pronounced under field conditions. Because the spreading habit increases mutual shading, it may also limit the number of tillers per unit area.

Measurements of the tiller angle showed that the tillers of floating varieties are more open than are those of non-floating varieties (Table 2). Floating varieties might be selected that have upright tillers, reducing mutual shading and allowing more tillers per unit area (fig. 2). On the other hand, the spreading habit of floating rice varieties may lessen weed competition because floating rice areas are seldom weeded even during the early growth stages.

Improving grain yields by increasing the number of tillers per plant would necessitate a plant type much like the present high-yielding varieties with

Table 2. Tiller angle before submergence and internode length and tiller number after submergence of selected varieties. IRRI, 1974.

Type	Varieties (no.)	Internode length (cm)		Tillers (no./hill)		Tiller angle	
		Mean	Range	Mean	Range	Mean	Range
Floating	16	33	9–63	6.4	5–10	32°	25°–40°
Non-floating	31	1	1–5	8.7	5–13	27°	16°–35°



2. Tiller angles and total internode lengths of floating and non-floating varieties.

short upright tillers and erect leaves to prevent mutual shading, but with the ability to elongate with rising water.

Leaf angle and leaf length. The vegetative growth of rice plants, including floating varieties, tends to be excessive in the tropics. This causes mutual shading and, often, low grain yields. Mutual shading makes it difficult to increase the tiller numbers of floating rices per unit area through closer spacing.

In the tropics, leaf erectness affects the penetration of sunlight and may affect dry matter production and grain yields. Floating rice varieties have long and open leaves. We compared the leaf measurements of several varieties with those of Peta, a tall variety with medium-open leaves and medium to long leaf blades. The floating and non-floating varieties had higher values for leaf openness than Peta had (Table 3). The leaves of floating varieties are more droopy than are those of semi-dwarf varieties, partly because they are longer.

Floating rice varieties generally respond negatively to nitrogen fertilizer. Unless the plant type during the pre-flooding period is improved, they will continue to do so, since mutual shading precludes the maximum use of sunlight by the plant. Rice breeders have often used leaf erectness as a selection criterion for responsiveness to nitrogen. Developing floating varieties with more erect leaves is a possible way to improve the plant type, nitrogen response, and plant density.

Possible ways to increase yields. Breeding programs have been stifled because scientists have not yet found ways to increase the yield potential of floating rice.

Although the floating varieties generally have large panicles, the tillers or number of panicles per unit area is generally low. Increasing the panicle size or the number of spikelets per panicle does not seem practical because the stalks tend to bend and fall into the water when panicle weight increases. Perhaps the yield can be improved by increasing the number of panicles per unit area.

Neither grain yield nor panicle number per unit area increases with higher planting density, indicating that the spreading tillers and the long, droopy leaves of the floating varieties probably cause heavy mutual shading, which inhibits an increase in tillers (this is also true for traditional lowland varieties). Poor land preparation and the broadcast

Table 3. Angles and lengths of the leaves of 11 floating rice varieties, 7 non-floating rice varieties, and Peta[a]. IRRI, 1974.

Type	Leaf angle				Leaf length (cm)			
	2nd leaf		3rd leaf		2nd leaf		3rd leaf	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Floating	67°	50°–103°	81°	60°–107°	78	63–87	64	51–74
Non-floating	73°	62°–80°	92°	72°–107°	66	55–79	56	50–67
Peta	62°	–	44°	–	51	–	45	–

[a]The second and third leaves from the top of the main tiller were measured.

Table 4. Plant height and total length of internodes before and after submergence of floating rice plants of different ages. IRRI, 1974.

Plant age (wk)	Before submergence[a]			After submergence[a]		
	HBJ DW 8	DW 6255	LMN 111	HBJ DW 8	DW 6255	LMN 111
			Plant ht (cm)			
2	30 fg	25 g	34 f	43 f	40 f	44 f
4	70 e	83 cd	81 d	109 e	123 d	97 e
6	90 c	106 b	106 b	141 c	157 ab	155 bc
8	107 b	129 a	136 a	143 c	162 ab	170 a
			Length of internodes (cm)			
2	0 e	0 e	0 e	0 e	0 e	0 e
4	0 e	0 e	0 e	29 d	38 c	1 e
6	6 d	9 c	3 e	60 a	60 a	32 d
8	21 b	30 a	12 c	59 a	64 a	47 b

[a]Means followed by a common letter are not significantly different at the 5% level; HBJ DW 8 = Habijanj DW 8; LMN = Leb Mue Nahng 111.

seeding method result in sparse seedling populations in many areas. Medium-tillering varieties might compensate for such practices. Current screening tests show that rice plants can be selected with medium tiller number and non-spreading tillers.

Under lowland conditions, the long and droopy leaves of floating varieties are inefficient for dry matter production. Plant types with short, erect leaves might ultimately increase the grain yield potential.

Because the floating rice varieties tested were generally susceptible to submergence (a high percentage were killed or set back) better submergence tolerance should increase the number of tillers per unit area that survive rising water. This would widen the adaptability of the plants, although it might not increase its yield potential. Breeding or selecting for floating rice varieties that rapidly elongate would increase yield by insuring that more plants survive flooding.

PLANT AGE AND INTERNODE ELONGATION

Plant Physiology and Agronomy Departments

If floating rice plants are younger than 4 to 6 weeks old when the fields are flooded, their internodes will not elongate, or will elongate insufficiently for survival.

We conducted an experiment to determine the earliest growth stage at which internodes of submerged rice plants can elongate, and to study factors associated with early internode elongation.

We found that internodes of floating rices can elongate as early as 4 weeks after sowing, but not at 2 weeks (Table 4). The three floating rice varieties differed in the ages at which seedlings elongate and in the extent to which they elongate.

The capacity for internode elongation at an early growth stage, as in Habiganj DW 8 and DW 6255, might be important. Rapid internode elongation, as in DW 6255, might be useful in areas of sudden flooding.

The degree of elongation of the floating varieties seems critical because the non-floating varieties such as IR8 also elongate, but to a lesser degree (Table 5).

The floating varieties, like the tall indicas, elongate before panicle initiation, even under non-submerged conditions. By 6 weeks of age, the floating varieties are tall enough to easily stand 1 meter of water, even if rapidly flooded. Semidwarf varieties would have to elongate to stay above the water level, even at 1-m depth. A plant type taller than that of IR8 would have an advantage in areas of rapidly rising water.

Because the accumulated plant carbohydrates are among the main energy sources for rapid internode elongation, the carbohydrate content may limit elongation. The floating rices differed in the total amounts of carbohydrates in the main culm and leaf sheaths. Within a variety, plant elongation was greater with greater carbohydrate content, but

Table 5. Response of three rice varieties to deep water stress (90 cm depth) at different plant ages. IRRI, 1974.

Age of plants (wk)	Leb Mue Nahng 111	IR442-2-58	IR8
	Internode length [a] *(cm)*		
2	0 e	0 e	0 e
4	0.4 e	0 e	0.2 e
6	19.6 c	17.2 c	2.2 e
8	38.2 a	31.6 b	12.4 d
	Plant ht [a,b] *(cm)*		
2	74 (114) f	45 (81) g	54 (99) g
4	124 (65) c	79 (51) f	76 (38) f
6	142 (29) b	106 (36) d	83 (21) ef
8	162 (11) a	114 (25) d	90 (11) e
	Leaf sheath [a,c] *(cm)*		
2	29 bc	21 c	25 bc
4	45 a	30 bc	22 c
6	47 a	26 bc	28 bc
8	36 b	25 bc	24 c
	Leaf blade [a,c] *(cm)*		
2	40 d	24 e	26 e
4	51 bc	47 cd	39 d
6	75 a	59 b	46 cd
8	86 a	63 b	54 bc

[a]Means followed by a common letter are not significantly different at the 5% level. Figures enclosed in parentheses represent percentage increases based on height before submergence. [b]First matured leaf from the top of the plant measured.

the carbohydrate contents among different varieties did not correlate with the total internode lengths or plant height (Table 6).

We do not know the basic carbohydrate content required before internodes can elongate. For example, at 4 weeks of growth, we found no significant differences in the carbohydrate contents

Table 7. Varieties with rapid rates of internode elongation (selected from 20 varieties tested). IRRI, 1974.

Variety	Increase in internode length (cm)			
	24 h[a]	48 h	72 h	120 h
Boon Nahk	13	27	34	43
DW 6255	17	40	35	45
HBJ DW 8	27	35	46	44
Leb Mue Nahng 111	23	32	38	51
Nang Dum To	20	34	32	47
Khao Hawn	31	36	40	48
Nak Neva	24	39	36	46

[a]After submergence.

of the three floating varieties, yet the internodes of two of the three varieties elongated when submerged. Other factors, such as endogenous plant growth regulators, may not be present in sufficient quantities to initiate internode elongation at early stages. Because the leaf sheaths and blades elongate even in 2-week-old seedlings, the requirements must differ for elongation of internodes and of leaf sheaths and blades.

Internode elongation alone cannot account for the rapid initial increase in plant height of floating rices; the leaf sheath and blade contribute considerably. At greater water depths, several internodes must elongate since the length is limited for each internode, leaf sheath, or leaf blade.

RATE OF INTERNODE ELONGATION

Plant Physiology and Agronomy Departments

Varieties must elongate rapidly to keep up with the water level in areas where it rises rapidly (60–90 cm/day at the beginning of the monsoon).

Twenty floating varieties were tested for elongation rates by growing them under upland conditions in porcelain pots for 40 days and then completely

Table 6. Tiller number and total carbohydrate content before submergence of Habiganj DW 8, DW 6255, and Leb Mue Nahng 111. IRRI, 1974.

Age of plants (wk)	Tillers[a] (no.)			Total carbohydrate[a] (mg/tiller)		
	HBJ DW 8	DW 6255	LMN 111	HBJ DW 8	DW 6255	LMN 111
2	1 g	1 g	1 g	0.9 f	0.9 f	1.2 f
4	4 f	3 f	4 f	14.0 ef	15.7 ef	18.5 e
6	12 b	6 e	8 d	53.6 d	90.3 c	88.6 c
8	14 a	9 cd	10 c	51.1 d	146.3 b	181.6 a

[a]Means followed by a common letter are not significantly different at the 5% level; HBJDW8 = Habiganj DW8; LMN III = Leb Mue Nahng III.

submerging them for 5 days. Total length of the internodes before submergence was measured and subtracted from the subsequent measurements.

The seven best varieties are listed in Table 7.

Elongation was rapid during the 5 days of submergence for Leb Mue Nahng 111, Khao Hawn, and Nang Dum To. Khao Hawn elongated most during the first 24 hours. The internode length of Khao Hawn increased by 31 cm within the next 24 hours – a higher rate than the maximum reported in Bangladesh for total increase in plant height (25 cm/day).

SCREENING FOR RAPID INTERNODE ELONGATION

Plant Physiology Department

We screened 144 varieties for the ability to elongate rapidly when submerged in water (Table 8). The varieties were grown in pots and the soil was kept at field capacity until 6 weeks after sowing. The plants were then submerged in 30 cm of water, which was increased to 60 cm the second day, and to 90 cm the third day. After 7 days, we measured the total length of the internodes.

Most of the 13 varieties which rapidly elongated came from Bangladesh, Thailand, and India. The tiller angle and tillering capacity of these varieties were also measured for future use. Of the 13 floating varieties, only Nang Dum To was tolerant of submergence at seedling stage.

These selections are being screened for disease and insect resistance; plant pathologists have found that only DM 53 is resistant to bacterial blight.

Table 8. Varieties with rapid rates of internode elongation when submerged in deep water. Screened from 144 varieties. IRRI, 1974.

Variety	Origin	Internode length (cm)
	Screened in August 1974	
DW 6255	India	63
TD 72	Thailand	46
Habiganj DW 8	Bangladesh	45
Boon Nahk	Thailand	41
Khao Hawn	Thailand	41
Nak Neva	Thailand	40
Hawn Chahng	Thailand	38
Cheng Chang	China	37
Sai Bur	Thailand	34
DM 53	Bangladesh	32
Srau Kraham (F10)	Khmer Republic	28
Nang Dum To	Vietnam	27
Kekowa Bao	India	23
	Screened in November 1974	
Habiganj Deep Water 1	Bangladesh	70
Bhoro Diga	Bangladesh	65
Bhoro Nepa	Bangladesh	64
Maliabhangar	Bangladesh	64
Bhawalia Diga	Bangladesh	62
Banor Jhota	Bangladesh	59
Kala Digha	Bangladesh	59
Jhota	Bangladesh	58
Dol Kochu	Bangladesh	57
Raja Moral	Bangladesh	56
Manik Digha	Bangladesh	54
HBJ Amon II	Bangladesh	53
Katia Bagdar	Bangladesh	53
Baisbish	Bangladesh	52
Habiganj Deep Water 2	Bangladesh	51
Digha	Bangladesh	49
Gour Kajol	Bangladesh	49
Hijli Digha	Bangladesh	49
Nam Sagui 19	Thailand	17

SCREENING FOR TOLERANCE TO SUBMERGENCE IN THE GREENHOUSE

Plant Physiology Department

Submergence tolerance is important in both floating and ordinary lowland rice. Floating rice needs the ability to survive complete submergence in situations where the internodes cannot elongate fast enough to keep pace with the water depth. Ordinary lowland rice needs the ability to survive complete submergence in areas that may be periodically inundated by flood.

In many monsoon areas, rice plants are often inundated from 1 to 7 or more days. In 1972, for example, a 4-week flood damaged about 230,000 ha of rice lands on the island of Luzon, Philippines, causing a crop loss of several million dollars. Rice varieties which could tolerate such submergence would greatly reduce annual flood losses.

The principal environmental factors that affect

submergence tolerance have been identified. Seedling survival after complete submergence decreased as duration of submergence, depth, temperature, and turbidity of water increased; as nitrogen fertilization increased; and as light intensity decreased.

We tested several cultural practices to improve submergence tolerance, such as the use of older seedlings, lower nitrogen levels in the seedbed, and lower basal application of nitrogen in the field. Because these cultural practices resulted in slow recovery after submergence, the final grain yields did not improve. The data indicate that submergence tolerance might best be increased through plant breeding. Preliminary tests show that varieties differ in their abilities to survive submergence. The initial step in breeding for high-yielding, flood-tolerant varieties is to identify the sources of genetic tolerance.

The varieties from the IRRI germ plasm collection were used in this project. Because screening the 35,000 entries in the world collection will take considerable time, priority was given to varieties from areas frequently inundated.

The plants were grown in 40- x 25-cm porcelain trays, each of which contained 3.5 kg Maahas clay soil, 4 g ammonium sulfate, 2 g muriate of potash, and 2 g solophos. Each tray had 10 rows, and 12 pregerminated seeds of one variety were planted in each. Each set of varieties was replicated twice.

The plants were grown in the greenhouse for 10 days, and then the seedlings were thinned to 10/row. The trays were then submerged to a depth of 30 cm above the soil level in a 150- x 150-cm water tank. The water temperature was kept constant at 30°C and the light intensity was maintained at 400 lux at the tray level. Continuous light was provided with incandescent and fluorescent light bulbs.

After 7 days of submergence, the trays were transferred to the greenhouse, and 5 days later the percent survival was calculated as follows:

$$\frac{\text{Av. number of living seedlings}}{10} \times 100.$$

Nam Sagui 19, identified in Thailand as one of the more submergence-tolerant varieties, was included as a common check for all sets of varieties. The percent comparative survival of a variety was calculated by dividing its percent survival by the percent survival of Nam Sagui 19 and multiplying it by 100. About 80 varieties were tested at a time.

Table 9. Survival of 479 varieties submerged in water for 7 days at the seedling stage. Nam Sagui 19 was used as the basis for comparison. IRRI, 1974.

Comparative survival[a] (%)	Varieties (no.)
0–25	414
26–50	39
51–100	18
100 +	8

[a]Comparative survival (%) = $\frac{\text{Survival (\%) of a variety}}{\text{Survival (\%) of Nam Sagui 19}} \times 100.$

Of the varieties screened, those that were 50 percent more tolerant of submergence than Nam Sagui 19 were selected and retested.

Most of the rice varieties being used were found susceptible to submergence at the seedling stage (Table 9).

When retested, 25 of the 26 selected varieties that were 50 percent more tolerant of submergence than Nam Sagui 19 in the preliminary tests had a high percentage of survival (Table 10). However, the 25 varieties were not significantly better in terms of survival than Nam Sagui 19.

Ninety-five percent of the varieties susceptible to submergence can be eliminated by this method. Only varieties that are more submergence tolerant than Nam Sagui 19 should be selected and these should be retested to further select the more tolerant varieties.

Most of the submergence-tolerant varieties were collected from areas of Sri Lanka where flooding during the growing season is a constant problem.

Padi Ewang Janggut is a variety from the tidal swamps of Indonesia. Several rice varieties from this area were tested because the water level periodically increases and the plants must have certain flood tolerance.

SML Temerin, from Surinam, has shown a consistently high percentage of survival in three tests. It elongates well when submerged, resulting in a taller plant. The other selections elongated very little (Table 10).

T442–57, a semi-floating line selected in

Table 10. Changes in plant height of rice varieties found to be tolerant of submergence. Screened from 479 varieties. IRRI, July 1974.

Variety	Country	Survival[a] (%)	Plant ht (cm)		Increase in plant ht (%)
			Before submergence	After submergence	
Jamis Wee	Sri Lanka	100 a	22	24	9
Thavalu (15314)[b]	Sri Lanka	100 a	24	26	8
Thavalu (15325)[b]	Sri Lanka	100 a	18	20	11
Kaharamana	Sri Lanka	100 a	23	25	9
Goda Heenati	Sri Lanka	100 a	23	25	9
Madael	Sri Lanka	100 a	20	25	25
Weli Handiran	Sri Lanka	100 a	25	28	12
Kurkaruppan	Sri Lanka	100 a	21	23	10
Padi Ewang Janggut	Indonesia	98 ab	22	25	14
SML Temerin	Surinam	95 abc	20	31	55
Lumbini	Sri Lanka	95 abc	21	24	14
Kalukanda	Sri Lanka	95 abc	20	23	15
Kanni Murunga	Sri Lanka	95 abc	22	25	14
Nang Dum To	Vietnam	90 abcd	17	20	18
T442-57	Thailand	90 abcd	16	21	31
Vanam Vellai	Sri Lanka	90 abcd	17	21	24
Kaluwee	Sri Lanka	88 abcd	19	23	21
Kottamalli	Sri Lanka	88 abcd	18	24	33
Ratawee	Sri Lanka	88 abcd	16	18	13
Nam Sagui 19	Thailand	85 abcd	22	25	14
Peria Karuppan	Sri Lanka	82 bcd	21	23	10
Kalu Gires	Sri Lanka	82 bcd	23	25	9
Buruma Thavalu	Sri Lanka	82 bcd	22	24	9
Madabaru	Sri Lanka	78 cd	21	23	10
Sudu Gires	Sri Lanka	75 d	21	24	14
Pokuru Samba (15337)[a]	Sri Lanka	75 d	21	24	14
Maduru Samba	Sri Lanka	5 e	14	16	14

[a]Means followed by a common letter are not significantly different at the 5% level. [b]Accession no. in IRRI germplasm bank.

Thailand, is tolerant of submergence and increases considerably in plant height in response to submergence. Upland varieties were also tested and found to be susceptible.

In areas where the rice plants are inundated for only a few days, plants that do not elongate or increase in plant height are preferred because they are not likely to lodge when the water recedes. But in areas where rice plants are inundated for long periods, as in the deep water areas, the ability to elongate, when submerged, will be advantageous.

This submergence screening method can also be used to identify tolerant breeding lines at the seedling stage. Plants that survive submergence can be transplanted to field plots. Although inundation usually occurs during transplanting and the vegetative stage, it may also occur at later growth stages. Even though the rice plant is known to become more tolerant of submergence with age, survival differs from grain production. Complete survival is possible at later growth stages but grain yield may be reduced by more than 50 percent.

The germ plasm is being screened for submergence tolerance under field conditions in Thailand. The method is a slightly different because the Thai screening program has a more

Table 11. Elongation characteristics of rice varieties tolerant of submergence, screened from 355 varieties. IRRI, December 1974.

Variety	Country	Survival (%)	Plant ht (cm)		Increase in ht (%)
			Before submergence	After submergence	
Anlong Phnom	Khmer Republic	100	16	19	19
ARC 5938	India	100	21	24	14
ARC 5955	India	100	22	25	14
ARC 6205	India	100	21	23	10
ARC 6239	India	100	22	26	18
ARC 6605	India	100	19	22	16
ARC 6626	India	100	19	21	11
Bong Tranh	Vietnam	100	24	28	17
ARC 5939	India	98	19	23	21
ARC 6066	India	98	19	21	11
ARC 6077	India	98	19	21	11
Baguamon 288	Bangladesh	98	18	22	17
Moddai Karuppan	Sri Lanka	98	19	25	32
Naalumoli Karuppan	Sri Lanka	98	19	25	32
ARC 5756	India	95	21	22	5
ARC 5764	India	95	22	25	14
ARC 5984	India	95	20	22	10
ARC 6133	India	95	19	22	16
ARC 6572	India	95	20	23	15
ARC 6629	India	95	18	23	28
Kalamon 243	Bangladesh	95	18	22	22
Leb Mue Nahng 111	Thailand	95	18	24	33
Nam Sagui 19	Thailand	95	21	25	19
Nang Cho	Vietnam	95	22	26	18
Tep Trang 176T-1	Vietnam	95	18	22	22

specific purpose: to identify material that is tolerant of submergence in water that does not recede for 2 to 4 months.

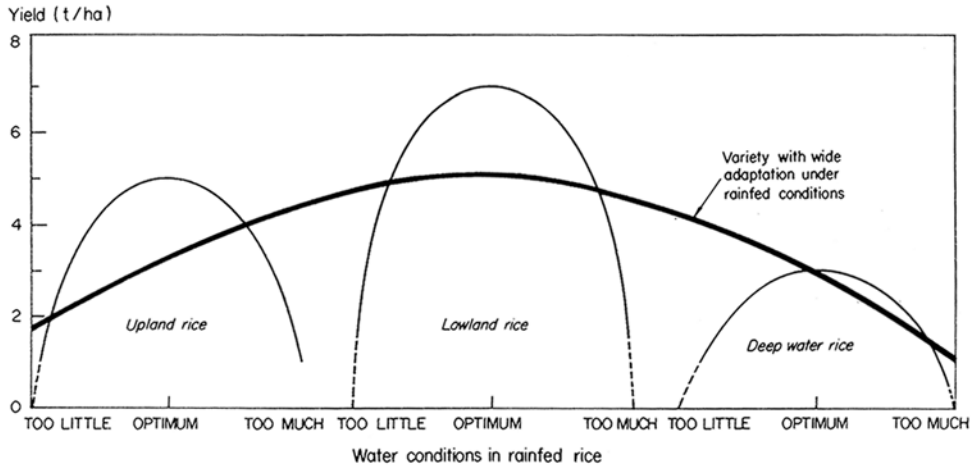
IRRI's simple screening method requires at least 25 days per set of varieties, although plantings can be staggered to increase the turnover in the use of the water tanks. By December 1974, 1,126 varieties had been screened (Table 11).

A CONCEPT FOR DEVELOPING RAINFED RICES WITH DROUGHT AND FLOOD TOLERANCE

Agronomy Department

Most of Asia's rice is rainfed, including upland, lowland, and deep-water rice. Because the water supply is not controlled, drought or floods, or, occasionally, both, may destroy the crop or reduce the grain yields. It is difficult to predict whether rainfed rice will suffer from too little or from too much water.

We studied varietal adaptation to various water conditions in IRRI experiments for three cropping seasons. The tests demonstrate that varieties can be developed that have both semidwarf and floating traits, such as the IR442 plant type. Such varieties would adjust their growth characteristics to fit the moisture supply, whether too little or too much (fig. 3). This would provide insurance against total crop failure if the rainfall in a given year is not typical for the specific water and land management system. We recognize, however, that varieties with



3. A concept for developing varieties for rainfed rice with drought tolerance and elongating capacity.

both drought tolerance and elongating capacity may have somewhat lower yield potential than do varieties bred for specific water and land management systems. Nevertheless, this type of hybrid, derived from floating and semidwarf parents, might stabilize yields during the atypical years.

This concept is further substantiated from the fact that one IR442 line is being grown as the upland variety Hullaga in Peru, while two other lines from the same cross were selected and named as the lowland rice varieties Panidhan 1 and Panidhan 2 in Bihar, India, where water depths are highly variable. Two lines from the same cross, IR442-2-58 and IR442-2-50, are being grown extensively under medium-deep water conditions (75 to 90 cm) in West Bengal, India.

If submergence tolerance and photoperiod sensitivity are incorporated into such varietal types, they could further stabilize yields under certain deep water conditions.

Genetic evaluation and utilization (GEU) program

Temperature tolerance

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Both low and high temperatures limit the adoption of high-yielding varieties (HYV's) in some rice areas.

HYV's cannot be grown on at least 7 million hectares in Southeast Asia because of low temperatures. The main objective of our cold tolerance program is to incorporate tolerance of low temperatures into modern rice varieties. To do this, we identify germ plasm that is tolerant of low temperatures, and breed this tolerance into improved varieties that will grow with greener leaves, shorter growth durations, and lower sterility.

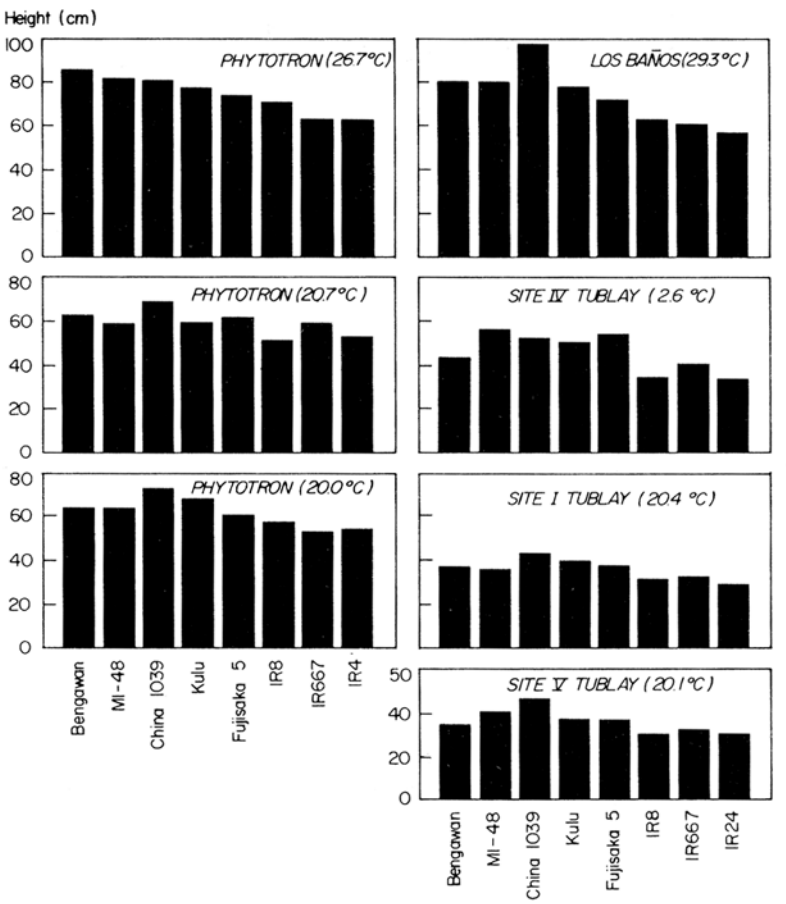
Screening techniques must also be developed to identify cold-tolerant materials. Basic studies must be conducted to understand the physiological effects of low temperature on the rice plant.

High temperature problems have been reported for lowland rice in areas where air temperature exceeds 35°C at flowering. High temperatures are likely to be a problem in upland rice, where leaf temperatures rise under moisture stress. The main objective of the high temperature program is to incorporate tolerance to heat stress into both lowland and upland rice varieties. Because few studies have been conducted on this subject, our immediate emphasis is on understanding heat stress.

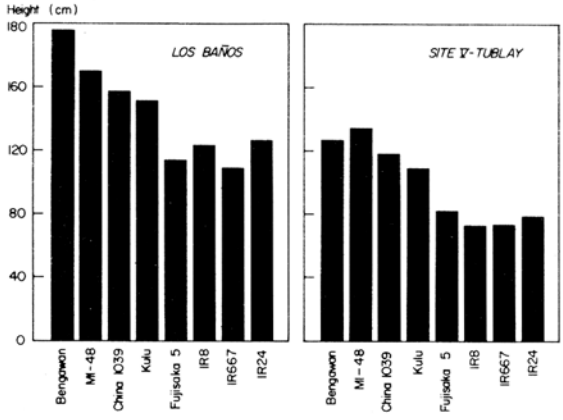
COLD TOLERANCE

Plant Physiology and Plant Breeding Departments

Varietal response in plant height to temperature (*Plant Physiology*). We selected a steep area in Benguet province, Philippines, to study varietal response to low temperatures because we felt that the temperatures would be comparable to



1. Heights of eight test varieties at 36 days after transplanting under different average temperatures during the growing period.



2. Heights at harvest of eight test varieties planted at Los Baños and Tublay, Benguet, Philippines.

those of other high-altitude rice-growing areas. We hoped to identify the best criteria to use in determining cold tolerance during the vegetative and reproductive stages of growth.

A "differential" set of eight varieties was planted at three sites at different altitudes: 1,210 m, 1,070 m, and 1,015 m. This set was also planted at the IRRI farm and in the IRRI phytotron. Determining the criteria to use in selecting cold-tolerant plants under field conditions at Los Baños or under phytotron conditions would also help since several generations of breeding lines are grown at IRRI for disease and insect screening. We measured the reactions of these rices in terms of tiller number, height, panicle exsertion, sterility, grain yield, and growth duration.

Plant height seems to be the easiest and most consistent character by which to determine cold tolerance.

Plant height was reduced in all plants as temperature was decreased (fig. 1). IR8, IR24, Fujisaka 5, and the experimental line IR667 were too short for Benguet, Philippines (1,070 m elevation), even at harvest time. Bengawan, M1-48, China 1039, and Kulu all grow very tall (more than 140 cm) at Los Baños, where they would probably be discarded because of lodging (fig. 2). These varieties were all over 100 cm tall at Benguet. Lines selected in Los Baños for cold tolerance should be at least 140 cm tall during the wet season.

At 36 days after transplanting, China 1039 was the tallest variety in Los Baños, at the three sites in Benguet, and at day/night temperatures of 20°/20°C and 26°/18°C in the phytotron. China 1039 was not tallest in Los Baños and Benguet at harvest time, however, because it matures earlier than does Bengawan and M1-48.

Plant height can be used as a selection criterion for cold tolerance, either at high or low temperatures.

Effect of temperature on growth duration (*Plant Physiology*). Temperature affects the growth duration of rice varieties; as temperature declines, growth duration lengthens. HYV's generally have extended growth durations when planted in cool areas. For example, IR8 matures in 130 days in Los Baños, but matures in from 170 to 200 days in Australia and Nepal.

To study how temperature affects growth duration, the differential set of eight varieties was tested for growth duration at different temperature regimes in the glasshouse of the phytotron, in IRRI fields, and in Benguet.

Of the eight varieties used, Bengawan and Fujisaka 5 changed least in growth duration as a result of temperature differences while IR8 and IR24 changed most (Table 1). Varieties can be screened for temperature reaction in the glasshouse of the phytotron using day/night temperatures of 32°/24°C and 26°/18°C. Varieties with long growth durations, and those which vary widely in growth duration, can be discarded.

Varieties grown at 32°/24°C had similar growth durations when grown at the IRRI farm during the wet season. Only varieties with growth durations of less than 110 days at IRRI or at 32°/24°C temperature regimes should be selected.

At IRRI, the number of days from sowing to

Table 1. Growth durations and temperature summation of eight test varieties grown under different temperature regimes at Los Baños, IRRI phytotron, and Benguet. IRRI, 1974.

Designation	Days from seeding to harvest					Temperature summation[b] (× 10²)		
	Benguet	At Los Baños	32°/24°C[a]	26°/18°C	20°/20°C	32°/24°C	26°/18°C	20°/20°C
Bengawan	181	142	152	156	154	40.6	32.3	30.8
IR8	181	126	130	160	141	34.7	33.1	28.2
M1-48	158	123	122	143	128	32.6	29.6	25.6
IR24	158	119	119	147	130	31.8	30.4	26.0
IR667	158	107	111	130	124	29.6	26.9	24.8
Kulu	158	106	120	149	125	32.0	30.8	25.0
China 1039	137	96	100	118	102	26.7	24.4	20.4
Fujisaka 5	137	98	97	108	103	25.9	22.4	20.6

[a]Day/night temperature regimes in glasshouse of the IRRI phytotron. [b]The average temperature multiplied by the corresponding growth duration.

harvest is still the simplest criterion for screening varieties for suitable growth duration for cooler areas. Varieties or lines with growth durations of less than 110 days have more stable growth durations under various temperatures, and do not have long growth durations even when delayed by low temperatures.

Because rice varieties in temperate countries have a definite temperature summation (they need a certain number of heat units to complete their life cycles) higher temperatures mean faster development and shorter growth duration. This experiment clearly showed that temperature summation is an ineffective selection criterion because it differs greatly even within varieties.

Table 2. Percent sterility of rice varieties grown under different temperature regimes and subjected to a 5-day cold treatment in a 15°C darkroom during the booting stage. IRRI, 1974.

Designation	32°/24°C	26°/18°C	20°/20°C	Av.
Kulu	32	20	48	33
China 1039	10	49	25	28
IR8	36	36	36	36
Fujisaka 5	4	47	64	38
M1-48	34	49	49	44
Bengawan	40	10	20	23
IR24	35	24	36	32
IR667	22	25	36	28
Av.	27	32	39	

Effect of temperature during early growth on cold-induced spikelet sterility (*Plant Physiology*). The eight test varieties of the differential set were grown from sowing up to the time when the collar of the flag leaf was no more than 3 cm above the collar of the penultimate leaf under three day/night temperature regimes, 32°/24°C, 26°/18°C, and 20°/20°C. For 5 days afterwards, the plants were placed in a 15°C darkroom from 1700 hours to 0900 hours. After the low temperature treatment, the plants were grown until harvest in the 29°/21°C glasshouse.

The plants grown under higher temperature regimes prior to the low temperature treatments generally had lower sterility than did those grown at lower temperatures (Table 2). This challenges the common belief that low temperature preconditions plants for subsequent low temperatures. At 32°/24°C, Bengawan had the highest percent sterility while Fujisaka 5, China 1039, and IR667 had the lowest. At low temperatures (26°/18°C and 20°/20°C), the percent sterility of Bengawan was consistently low while that of M1-48 and Fujisaka was higher.

While no explanation can be made at this point, the data clearly show varietal differences in percent sterility as a response to low temperature treatments. The temperature under which the plants are grown also influences the reaction of rice varieties to low temperature at later growth stages.

Plant breeding for cold tolerance *(Plant Breeding, Plant Physiology).* During the 1974 dry

season, we evaluated 826 varieties and breeding lines and grew 23 F_2 populations in Benguet province, Philippines (elevation 1,070 m). Temperatures averaged 23°C, ranging from 16° to 29°C. During the wet season we evaluated 841 varieties and lines and grew 16 F_2 populations. Temperatures averaged 23°C, ranging from 17° to 29°C. Several typhoons severely damaged the nursery, making evaluation and selection difficult.

The materials were evaluated for maturity, fertility, and agronomic desirability during both seasons at Benguet. They were concurrently evaluated at IRRI for resistance to blast and bacterial blight diseases, tolerance of cold water, and various grain quality characteristics. About 450 of the more desirable lines and varieties were chosen for the First International Rice Cold Tolerance Nursery (IRCTN), which will be distributed in 1975 to all requesting cooperators in cool-temperature rice areas throughout the world.

Several varieties and lines performed well under Philippine conditions. During the dry season at Tublay, we selected 56 to be further evaluated by the Philippine Bureau of Plant Industry (BPI) during the wet season at Banaue, Ifugao province, Philippines (elevation 1,200 m). Banaue is a relatively remote location where indigenous, cold-tolerant varieties have been cultivated for centuries. The growth duration of these varieties is long, allowing only one crop per year. The BPI identified several lines of suitable growth duration and agronomic type to permit the cultivation of two crops per year (Table 3).

We continued to collect the better varieties and breeding lines from areas of cool temperature for crossing with improved material at IRRI. Seed of 81 F_2 populations was available for distribution to requesting cooperators at the end of 1974.

Table 3. List of promising selections (from 56 entries) grown at Banaue, Ifugao province, Philippines. Cooperative experiment, Philippine Bureau of Plant Industry (BPI) and IRRI, 1974.

Designation	Tillers (no.)	Plant ht (cm)	Days to heading	Panicle exsertion (cm)
China 1039	11	85	84	3.0
Claket 520	9	67	87	2.5
JP 5	12	78	76	5.8
Kn-1h-214-1	7	83	90	1.5
Kn-1h-361-1-8	10	87	90	0.6
Sug	10	82	56	5.0
Swat Valley 314	13	86	82	0.6
Kn-1b-361-1	10	78	87	1.3
Kn-1b-361-18	9	78	87	2.0
Kn-1b-361-B1K-2	8	76	87	2.8
Kn-1b-361-B1K-13	11	84	87	2.0
Kn-1b-361-B1K-22	11	83	92	1.1
Kn-1b-361-B1K-27	9	85	89	2.0
IR1846-300-1	13	81	87	1.8
Fujisaka 5	12	56	86	3.0

HEAT TOLERANCE

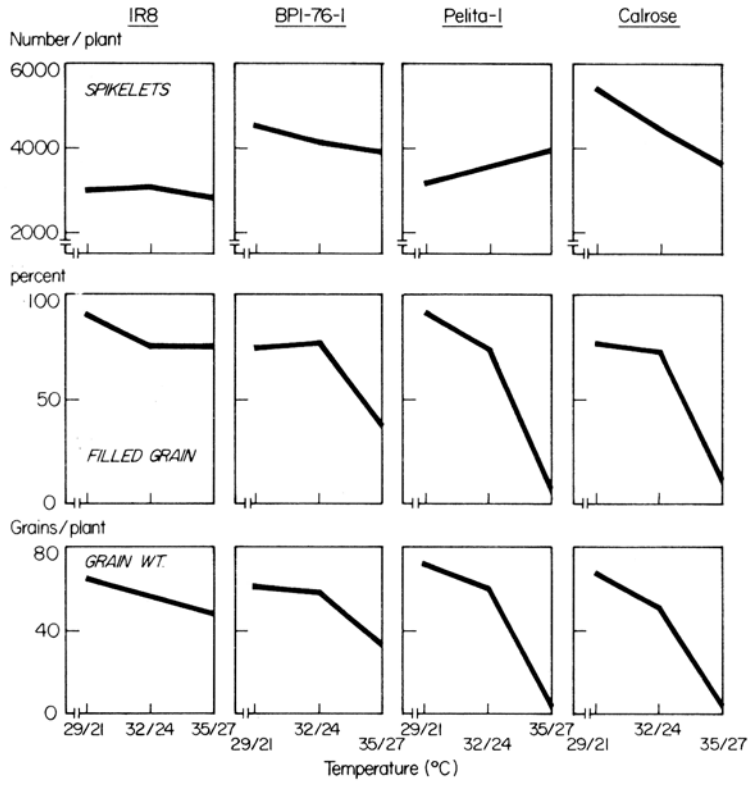
Plant Physiology Department

High sterility has been reported in dry season lowland crops in Cambodia, Thailand, and India. The same problem may occur in other countries where high temperature and low relative humidity prevails during the dry season, such as Pakistan, Iran, and West African countries.

High temperature seems more responsible for sterility than does low relative humidity. Varieties

Table 4. Symptoms of heat stress and varietal differences. IRRI, 1974.

Growth stage	Symptoms	Susceptible varieties
Vegetative	White leaf tip Chlorotic bands and blotches White bands and specks Reduced tillering Reduced height	IR26, Calrose, BKN6624-46-2
Reproductive	White spikelets, white panicles Reduced spikelet numbers	IR24, Calrose
Anthesis	Sterility	C4-63G, H4, Calrose, Pelita I/1 Basmati-370, BKN6624-46-2
Ripening	Reduced grain filling	TN1, IR24, IR26, H4, Fujisaka 5, C4-63C, Pelita I/1



3. Effects of temperature on yield and yield components of four varieties.

have been shown to differ in sterility percentages at high temperature. In upland rice, the air temperature is usually high during drought. Leaf temperature becomes even higher because transpiration is restricted (1972 Annual Report). Thus, tolerance of heat stress is a desirable character for drought-resistant varieties.

This consideration led to the idea that heat stress may limit grain yields in dry-season lowland and in upland rice crops.

We grew 19 varieties at three temperature regimes in the glasshouse rooms of the IRRI phytotron. These varieties cover a wide geographic distribution from 43°N (northern Japan) to the Equator (Indonesia). The three day/night temperature regimes used were 29°/21°C, 32°/24°C, and 35°/27°C. Daytime temperature was maintained for 8 hours, from 0900 to 1700, while day length was under natural Los Baños conditions.

Symptoms of heat stress. Various types of visual symptoms were observed at different growth stages; varietal differences in heat tolerance were dramatic (Table 4).

Only one variety, Calrose, from the U.S., suffered from severe heat stress at 35°/27°C throughout all growth stages. Other varieties suffered from heat stress at certain stages but grew well at others. For instance, IR26 suffered from heat stress at the seedling stage, but recovered at later stages. Growth of Pelita I/1 and C4-63G was excellent at 35°/27°C until anthesis. Sterility of these varieties, however, was more than 90 percent – an abrupt and dramatic change in response to heat stress.

Japanese scientists frequently mention that high temperature impairs grain filling. In our experiment, the 1,000-grain weight at 35°/27°C was reduced by from 5 to 15 percent in some varieties, but was not reduced at all in others. Geographic origin of varieties did not appear related to susceptibility to heat stress.

Spikelet number, sterility, and grain yield. The largest variation among the yield components was found in percentage of filled grain. Figure 3 shows little difference in spikelet number per plant among IR8, BPI-76, and Pelita I/1 at three temperature regimes. Only in Calrose did spikelet number

decrease with increasing temperature. The filled grain percentage of IR8 decreased slightly at high temperatures, and that of BPI-76 decreased considerably at 35°/27°C. Pelita I/1 and Calrose had only 10 percent or less filled grain at 35°/27°C. As a result, the grain yields of these varieties were largely determined by filled grain percentage.

Available climatic data for tropical countries indicate that day temperatures can be from 35 to 40°C, or even higher, during the hottest months of the dry season. The high temperatures, however, do not last long because diurnal temperature changes follow a sine curve. But daytime temperatures were maintained for 8 hours in the IRRI phytotron, so our experimental results may not be directly applicable to natural conditions. The results strongly suggest, however, that varietal susceptibility to heat stress could limit grain yields during the dry season. Thus, varieties for the dry-season and upland varieties may need higher tolerance of heat stress.

Soil and crop management

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SUMMARY

Studies of the effect of puddling on the performance of IR26 rice when subjected to water stress revealed that puddling decreased the duration of water stress and produced a favorable chemical environment, i.e., more plant nutrients were available to the plants. Under water-stress conditions, the yield of rice grown on puddled soils was greater than that of rice grown on nonpuddled soil.

Assessment of nitrogen fixation by algae in rice fields showed that, depending on soil type, blue-green algae fixed as little as 2.3 kg N/ha per cropping season to as much as 33.3 kg N/ha.

Losses of ammonia via volatilization in paddy soils were less in soils subjected to alternate submergence and drying than those in soils continuously flooded. The drying and rewetting cycles shortened the duration of ammonia volatilization.

A study of the effect of water management on the nitrogen fertility of paddy soils indicated that flood fallowing between crops (compared with dry fallowing) conserves and adds nitrogen to the soil. Also, midseason soil drying followed by flooding appeared to increase the availability of the soil nitrogen to rice plants.

The use of phosphorus appeared to improve the efficiency with which rice plants used nitrogen in the soil. The highest efficiency of nitrogen utilization by medium-maturing rice lines occurred when the nitrogen fertilizer was applied just before panicle initiation. Shorter season lines also responded well when the nitrogen fertilizer was supplied before panicle initiation, but showed the greatest efficiency of fertilizer use when the nitrogen was applied basally. Urea at 60 kg N/ha, when applied as mudball at a soil depth of about 12 cm, gave yields comparable to those achieved when 100 kg N/ha was applied by other methods. Nitrogen at 60 kg/ha, applied as mudball gave the greatest efficiency of nitrogen fertilizer, 53 kg rice/kg N.

Sulfur-coated urea (SCU) and ordinary urea, when applied in split doses, gave similar results. However, when applied basally SCU frequently yielded superior results.

Weed control improved the response of paddy rice to nitrogen fertilizers. It may be possible to combine fertilizer and insecticide in one application using the placement concept.

A greenhouse technique was developed using natural drying of the soil to a predetermined level of soil moisture tension (18 bars) to screen rice varieties for drought tolerance. With this method, an upland variety of rice from Africa, Moroberekan, was identified as a susceptible check. IR1750-(F_5B)-5, IR1529-430-3, IR1480-147-3-1, IR442-2-58, and other rices were found to exhibit considerable tolerance to soil moisture stress.

EFFECTS OF SOIL PUDDLING AND TEMPERATURE ON RICE GROWTH

Soil Chemistry Department

Effects of puddling. Sixty percent of the world's rice is grown on puddled soils that have no assured water supply. The dearth of information on how the rice plant reacts to water or chemical stress when puddled soils dry prompted a study in which the performance of IR26 rice on three soils (Luisiana clay, Maahas clay, and Agoncillo sandy loam) under puddled and unpuddled conditions subjected to water stress was compared with that of IR26 on a soil treated in the usual manner – puddled and kept continuously submerged. Efforts were made to relate the response of rice to soil moisture tension, redox potential, and chemical analyses of the plants and soils.

Each soil was placed in a 200-liter drum. The drum was filled to the top; then, the soil was compacted until the surface was 25 cm below the rim of the drum. An additional 50 kg of each soil was mixed with 0.15 percent of a 1:1 mixture of straw and *Glyricidia sepium*, 100 ppm N, 25 P, and 50 ppm K, and then used to fill the remaining space in the drum. Each of the three soils was subjected to the following treatments:

- puddled and submerged throughout;
- puddled, kept wet for 6 weeks, then allowed to dry for 10 days, rewetted, and kept waterlogged until harvest;
- granulated, field capacity for 6 weeks, followed by no watering for 10 days, and then field capacity until harvest.

The yield of grain and straw in the puddled, water-stress treatment was markedly superior to that in the nonpuddled water-stress treatment and was only slightly less than that achieved with the puddled, continuously submerged treatment (Table 1).

Table 1. Effect of puddling and water stress on the yield of IR26 rice.

Puddling	MSD[a]	Yield (g/drum)					
		Luisiana clay		Maahas clay		Agoncillo loam	
		Straw	Grain	Straw	Grain	Straw	Grain
Yes	No	366	253	371	286	351	257
Yes	Yes	316	213	365	226	353	239
No	Yes	277	66	183	29	187	16

[a]Midseason soil drying. LSD straw (5%): 34 g LSD grain (5%): 27 g.

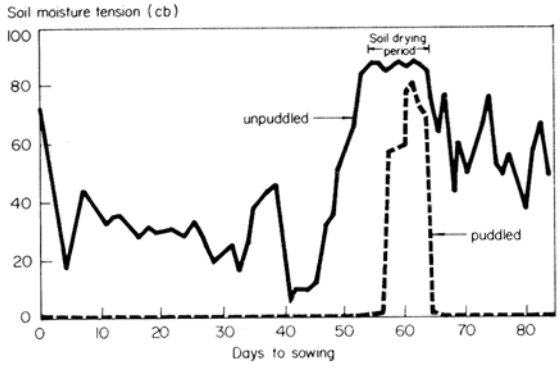
The water stress of the puddled soil exceeded 50 cb for only 8 days as compared with about 40 days for the unpuddled soil (fig. 1). The redox potential of the puddled soil was below 0.2 V (the threshold for soil reduction) throughout the entire season while that of the unpuddled soil was above 0.2 V. The contents of extractable iron and manganese in the unpuddled soil were much lower than those in the puddled soils, whether subjected to water stress or not. These differences were reflected in the results of plant analysis with respect to the iron content among the three soils and with respect to the manganese content of the Maahas clay and the Agoncillo sandy loam. The straw of the nonpuddled soil had a much lower silica content than did the straw of the puddled soils.

Puddling decreased the duration of water stress, produced a favorable chemical environment (more plant nutrients available to the plants), and increased the yield of rice over that of rice grown on unpuddled soil under water-stress conditions.

Soil temperature and the growth of rice on flooded and nonflooded soils. Low soil temperature causes a lack of sufficient available nitrogen and phosphorus and the accumulation of the products of soil microorganisms under anaerobic soil conditions which adversely affect the growth of rice (1968, 1969 annual reports). To ascertain whether microbial metabolism under aerobic soil conditions would eliminate low-temperature injury and whether high temperature would increase the supply of nutrients available to the plants, IR26 rice was grown on two flooded and nonflooded soils at 20°C (day) – 20°C (night), 29 (day) – 21°C (night), and 35° (day) – 27°C (night) in the phytotron.

Regardless of temperature, aerobic conditions eliminated the possible plant toxicities of iron, carbon dioxide, organic acids, and reduction products and increased the concentration of water-soluble zinc in each soil, but depressed the concentrations of water-soluble iron, manganese, and phosphorus, as compared with the flooded (anaerobic) soils. In the flooded soils, a low temperature slowed the rate of decrease of the redox potential, the rate of increase of pH, and the release of water-soluble iron, manganese, phosphorus, and silica. The peak concentrations of iron, organic acids, and carbon dioxide were higher with the 20–20°C treatment. They persisted longer under these soil temperature conditions than at soil temperatures of 29–21°C and 35–27°C; they did not reach toxic levels.

Vegetative growth was best at 20–20°C on aerobic Luisiana clay (pH: 4.6; O.M.: 3.2%); but it was poorest with this temperature regime on aerobic Maahas clay (pH: 6.6; O.M.: 2.0%) (Table 2). Foliar symptoms indicated deficiencies of available nitrogen and iron in the aerobic Maahas clay at 20–20°C. In the flooded soils, the grain yield decreased as the soil temperature increased,



1. Changes in soil moisture tension in Maahas clay.

Table 2. Influence of phosphate of the efficiency of nitrogen utilization by three rice varieties.

Variety	Grain yield (t/ha)							
	P_0				P_1			
	0 kg N/ha	50 kg N/ha	100 kg N/ha	150 kg N/ha	0 kg N/ha	50 kg N/ha	100 kg N/ha	150 kg N/ha
IR26	19	3.4	4.5	4.4	4.0	4.8	5.9	6.0
IR5	2.2	3.1	3.8	4.2	4.2	4.6	4.7	4.9
H4	2.8	3.1	3.4	3.4	3.6	4.0	4.2	3.7
Mean	2.3	3.2	3.9	4.4	4.0	4.5	5.0	4.9

LSD (5%) for two N means: 0.63 t/ha; LSD (5%) for two varietal means at same N level: 0.59 t/ha.

while in the nonflooded soils the grain yield was highest at 29–21°C and lowest at 35–27°C. White tips and scorched leaves indicated high-temperature injury to the rice foliage at 35–27°C. and such injury was more severe in the nonflooded soils than in the flooded soils.

Nitrogen and iron deficiencies were two yield-limiting factors at 20–20°C on aerobic Maahas clay. At 35–27°C, high-temperature injury to the shoot system and high sterility depressed the yield.

ATMOSPHERIC NITROGEN FIXATION

Soil Microbiology Department

Algal nitrogen fixation in rice fields. A previously developed technique for assaying acetylene-ethylene in rice fields under *in situ* conditions was tested in an unplanted experimental field at the IRRI farm. One plot received no nitrogen while another received 90 kg N/ha, and each treatment was replicated three times. Ten plastic assay bottles were installed in each replicated plot and then assayed between 0830 and 1130 hours for ethylene formed from acetylene reduction. About a month after submergence, the average fixation of nitrogen was estimated to be 38.7 g $N_2 \cdot ha^{-1} \cdot h^{-1}$ (46.4 kg N/ha each cropping season) for the unfertilized plot and 25.7 g $N_2 \cdot ha^{-1} \cdot h^{-1}$ (30.8 kg N/ha each cropping season) for the fertilized plot.

The assay was also conducted in rice fields in two locations in Albay province, Philippines, which represent two distinct soil types, i.e., Puro clay loam (pH 5.2, O.M., 3.08%, total N, 0.19%; available P, 11.5 ppm) and Santo Domingo loamy sand (pH, 6.7, O.M., 2.6%, total N, 0.14%; available P, 11.7 ppm). Nitrogen fertilizers were applied to the Santo Domingo soils but none to the Puro soils.

Sixty rigid plastic assay bottles were installed at random between hills at each site, covering about 10 sq m. Additionally, five bottles served as checks for endogenous ethylene formation. Ten percent of the gas phase inside the treatment bottle was replaced with acetylene and after 2 hours of incubation, gas samples were withdrawn with pre-evacuated B-D Vacutainer tubes and analyzed for ethylene formation via gas chromatography. The pH of the paddy water was also measured at each assay time, performed between 0830 and 1330 hours at 3-week intervals until harvest. Samples used as controls were covered with black cloth and then assayed for nitrogenase activity.

The rate of nitrogen fixation in the paddy soils of Puro fields was higher than that of the Santo Domingo paddy soils. Peak nitrogenase activities equivalent to 48 g $N_2 \cdot ha^{-1} \cdot h^{-1}$ for the Puro soils and 6.4 g $N_2 \cdot h^{-1} \cdot h^{-1}$ for the Santo Domingo soils were obtained at 44 and 41 days, respectively, after transplanting; thereafter the activity decreased steadily until harvest.

The nitrogen fertilizer applied to Santo Domingo fields may have raised the nitrogen content of the soil to a level that inhibited nitrogen fixation.

The absence of nitrogenase activity in samples covered with a black cloth suggests that the blue-green algae are the principal agents of nitrogen fixation in these fields. Additionally, algae grew abundantly in both Puro and Santo Domingo soils. The heterogenous distribution of the algal flora in the field caused a wide variation in the nitrogenase activity obtained in individual assay bottles.

The estimated amount of nitrogen fixation by

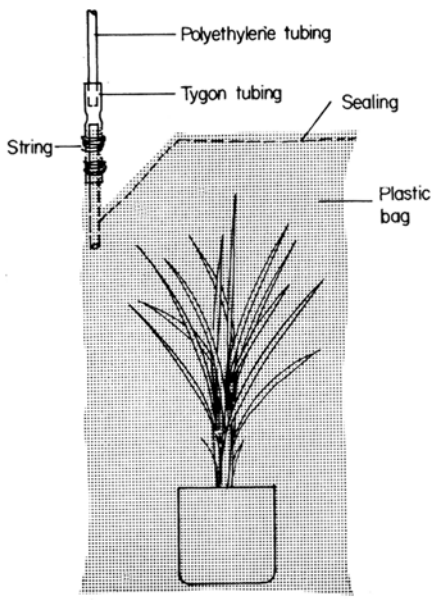
nitrogen-fixing blue-green algae ranged from 18.5 to 33.3 kg N/ha per cropping season for Puro soils and from 2.3 to 5.7 kg N per cropping season for Santo Domingo soils.

Varietal screening of nitrogenase activity in the rice rhizosphere. In screening rice varieties for nitrogen-fixing activity in the rice rhizosphere, a polyethylene (plastic) bag, 20 cm x 37 cm in size and 0.012 mm thick, was used with the acetylene reduction method (fig. 2). The volume of a plastic bag was measured on the basis of dilution of the tracer gas. The bag was slightly permeable to gas; only about 11 percent of the initial amount of ethylene was lost during 24 h. The feasibility of using the plastic bag was studied in a time-course experiment.

The rhizosphere, separated from the top, and the whole plant, when incubated in the dark or in the laboratory, did not greatly differ in nitrogen-fixing activity. Time-course studies were then made with the rhizospheres detached from the tops. The root with soil of a rice plant grown in a pot containing 500 g Maahas clay loam soil until the heading stage was assayed and incubated in the dark at 25°C for 24 h under aerobic (C_2H_2 20%, air 80%) and under anaerobic (C_2H_2 20%, Ar 80%) conditions. One ml of gas was sampled at 4, 7, 10, and 24 h after the introduction of gas and analyzed for ethylene gas by chromatography. Simultaneously the gas phases without acetylene under aerobic and anaerobic conditions were prepared and the ethylene that evolved naturally from the rhizosphere was also measured.

After the lag phase of 0 to 10 hours of incubation, the acetylene reduction activity became greatly higher under the anaerobic conditions than under the aerobic conditions (fig. 3). But it was not certain whether a strictly anaerobic condition was maintained during incubation because the plastic bag was semi-permeable. Ethylene that evolved naturally from the rhizosphere was negligible.

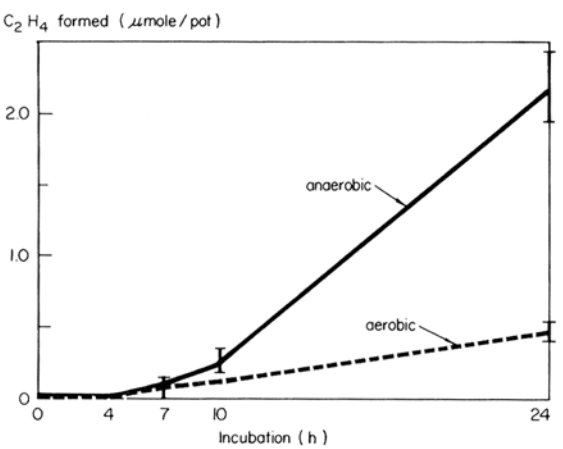
The acetylene-reduction activities in the rhizospheres of 29 rice varieties were measured using the acetylene reduction method with the plastic bag. The rices were grown without fertilizer in pots containing 500 g Maahas soil under flooded conditions. Unplanted pots served as the controls. The soil surface in each pot was covered with a black cloth to prevent algal growth. Four weeks after transplanting and at heading, the soil with root was separated from the plant top and exposed to acetylene; it was then incubated at 25°C in the dark for 24 h.



2. Diagram of ethylene-acetylene assay using a plastic bag.

Rice roots had distinct stimulatory effects on acetylene reduction. The acetylene reduction activity reached 2.7 μmol $C_2H_4 \cdot day^{-1} \cdot pot^{-1}$.

While none of the rice varieties exhibited an outstandingly high nitrogen-fixing activity, JBS236,



3. Time course of acetylene reduction in a rice rhizosphere under aerobic and anaerobic conditions. Vertical lines show standard error of means.

IR8, and Pokkali showed relatively higher activities than did the other 26 rices on both the pot and (or) root-weight bases.

Movement of atmospheric nitrogen in rice plants. Rice roots are able to function in anaerobic soils because of their oxidizing activity. The rice plant has an air-transporting system through which it supplies atmospheric molecular oxygen to the roots.

The fixation of nitrogen in the rice rhizosphere under submerged soil conditions is contingent on the presence of molecular nitrogen in the soil. If molecular oxygen from the atmosphere can diffuse into the rhizosphere through an air-transporting system of the rice plant, it is interesting to speculate on the possibility of the diffusion of nitrogen gas from the atmosphere through the rice plant into the rice rhizosphere.

Three *Oryza sativa* rice varieties, Bonnet-73, Colusa, and an experimental line (CI-9940) from the U.S. Department of Agriculture, were grown in submerged soils under greenhouse conditions. In the first experiment, an intact Bonnet-73 plant at the tillering stage and Colusa plants at the heading stage were removed from 2-liter pots and the soil was washed from the roots with running tap water. Five fresh culms of Bonnet-73 (about 45 cm tall and weighing about 15.8 g) and nine culms of Colusa (about 70 cm tall and weighing 31.9 g) were used. In the second experiment, four culms of Bonnet-73 at the early tillering stage (about 40 cm tall and 14.8 g in fresh weight) and four culms of CI-9940 at the flowering stage (about 80 cm tall and 33.5 g in fresh weight) were used. The plants were left intact.

A glass cylinder enclosed the rice tops and was attached to a 1-liter, 3-necked distilling flask in which the rice roots were placed. A paraffin seal separated the two portions. Half of the roots was immersed in 750 ml of culture solution and the remainder was exposed to the atmosphere of the flask.

In the first experiment, the atmosphere in the cylinder containing the aerial parts of the rice plant was filled with a gas mixture of 20% oxygen, 5% carbon dioxide, and 20% ^{15}N-enriched nitrogen. There was no evidence of leakage from either the aerial chamber or the root container.

With the Bonnet-73 rice (tillering) the concentration (percent) of ^{15}N-enriched nitrogen gas in the shoot cylinder remained relatively constant (21.6, 21.7, and 21.3% on days 0, 3, and 6, respectively) while that in the root compartment increased slightly (0.38, 0.47, and 0.53% on days 0, 3, and 6, respectively. With the Colusa rice (heading), the amount of ^{15}N-enriched nitrogen gas in the root compartment increased significantly – 0.61 and 4.78% at day 0 and 3, respectively. The similarity in the results of the first and second experiments indicates that ^{15}N-enriched nitrogen gas moved slowly from the shoot to the root in the rice plant during the vegetative stage of growth (tillering) and much more rapidly during the reproductive stage of growth (heading).

Apparently, the rice plant has a system through which gases move from the aerial parts through the plant tissue into the rhizosphere.

TRANSFORMATION OF FERTILIZER AND SOIL NITROGEN

Soil Microbiology Department

Ammonia volatilization from flooded soils. Previous direct field measurements of ammonia volatilization (1973 Annual Report) were continued. They were carried out after nitrogen fertilizers were applied to flooded soils. IR20 plants at panicle initiation were topdressed with urea and ammonium sulfate fertilizers at 100 kg N/ha. Glass wool was wet with H_2SO_4 and was placed inside a volatilization bottle to absorb the evolved ammonia. The upper portion of the volatilization bottle was placed in the soil between the rows of rice plants. A distance of 6 cm separated the acidified glasswool and the enclosed water surface within the bottle. The control or no-fertilizer plots were also measured. All fertilizer treatments were replicated four times.

Ammonia volatilization was measured under various soil conditions. The lowland soil conditions were essentially the same as those in the earlier field experiments. In upland soils, IR20 seeds were drilled in rows (20 cm apart) at 80 kg/ha. Ammonium sulfate, at 100 kg N/ha, was broadcast simultaneously just after transplanting or 15 days after sowing. Under continuously flooded condition, the irrigation water was maintained at a depth of 3 cm. In the alternately flooded-and-dry condition the 3-cm deep water at the time of transplanting was allowed to dry until small cracks appeared in the soil surface before the field was

irrigated again to 3 cm. The upland plots were irrigated to field capacity every 3 days. All fertilizer treatments were replicated four times.

Nitrogen losses through ammonia volatilization were negligible when urea and ammonium sulfate fertilizers were topdressed at panicle initiation when the uptake of nitrogen was rapid through the well-developed root system.

Such losses of nitrogen occurred continuously in small quantities from the unamended soils. After 26 days, 0.96 and 0.88 kg N/ha were volatilized as ammonia from upland and flooded soils, respectively.

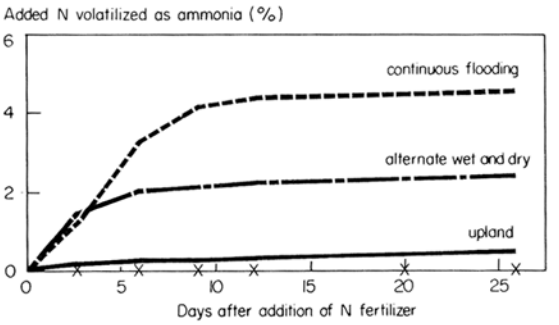
Flooding increased ammonia volatilization losses (fig. 4). Ammonia losses were 3.6 times greater under continuously flooded conditions than under upland conditions. The initial pH of the flooded soil was 7.1 compared with 6.6 of the upland soil.

Ammonia volatilization losses were lower in the alternately submerged-and-dried soil than in the soil continuously flooded (fig. 4). By promoting nitrification, drying lessened the amount of ammonium ions that were available for volatilization. The drying and rewetting cycles shortened the duration of ammonia volatilization.

Availability of soil and fertilizer nitrogen. To measure the availability of soil nitrogen to rice crops and to determine how it is affected by nitrogen fertilizer under submerged conditions, two 18-day-old seedlings were transplanted per pot into glazed porcelain pots filled with Maahas soil, 1 day after the entire soil had been puddled with the fertilizer at 30, 60, and 90 kg N/ha, as ^{15}N-labeled ammonium sulfate. The pots were placed in a lowland field during the 1973 wet season. The water level in the pots was maintained above the soil surface through harvest time, which was after 120 days.

The rate of nitrogen applied did not appreciably affect the A-value (availability index of soil nitrogen). The A-values were 206, 201, and 216 ppm at 30, 60, and 90 kg N/ha, respectively. The A-values were 14 to 15 percent of the total soil nitrogen.

Mineralization of the soil nitrogen appeared to increase with the addition of inorganic nitrogen fertilizer, as reflected in the increased uptake of soil nitrogen by the rice crop when the rate of applied nitrogen exceeded 60 kg N/ha. Generally, the uptake of fertilizer nitrogen by rice increased



4. Cumulative loss of nitrogen added to soil under different soil conditions in the field (100 kg N/ha, as ammonium sulfate; Maahas clay loam).

with increased levels of applied nitrogen. The fertilizer nitrogen uptake by rice crops was greater when calculated by the differential method than when calculated by the isotope method when the applied fertilizer level exceeded 60 kg N/ha. At 30, 60, and 90 kg N/ha (applied), the amounts of fertilizer nitrogen taken up by rice were 35.0, 39.7, and 40.3 percent, respectively, of the applied fertilizer by the isotope method, and 36.3, 65.0, and 71.8 percent by the differential method.

The recovery of fertilizer N in the plant was 5 percent lower with the 30 kg N/ha application than with the 60 and 90 kg N/ha applications. The amount of fertilizer nitrogen which remained in the soil increased as the rate of applied nitrogen increased. The percentage of the fertilizer nitrogen that was recovered from the soil decreased with an increased rate of applied nitrogen. The percentages of fertilizer nitrogen detected in the soil at harvest were 51.5, 40.4, and 28.9 when 30, 60, and 90 kg N/ha, respectively, were applied. At 30, 60, and 90 kg N/ha applications, the total recoveries of tagged nitrogen in soil and rice plants were 96.5, 80.1, and 69.2 percent, respectively; the losses of fertilizer nitrogen were 13.5, 19.9, and 30.8 percent, respectively. When the availability of ^{15}N-labeled fertilizer was studied, 7.2, 7.9, 7.5, and 8.1 percent, respectively, of the nitrogen that was immobilized into soil organic nitrogen when 0, 30, 60, and 90 kg N/ha were applied, were released and taken up by the following rice crop. Apparently, the different amounts of fertilizer nitrogen added to the soil did not significantly affect the release of the immobilized nitrogen.

To study the availability of nitrogen in rice

straw in submerged soil, two 18-day-old IR20 seedlings were transplanted per pot into glazed porcelain pots 1 day after rice straw (0.67% nitrogen) at the rate of 0.5 percent and ^{15}N-labeled ammonium sulfate (50 ppm N, equivalent to 100 kg N/ha) were incorporated into the Maahas clay soil. The soil remained submerged throughout the growing period of the rice crop during the 1970 wet season.

The tagged N in the rice straw appeared to become available gradually to the rice plants from the tillering stage to harvest: 5.1, 7.7, and 12.9 percent, at tillering (30 days after transplanting), panicle initiation, and harvest, respectively. When nitrogen was added to the soil, however, the availability of the nitrogen in the rice straw increased to 6.4 percent at tillering, 14.0 percent at panicle initiation, and 15.3 percent at harvest.

The dry matter weight at different stages of plant growth indicated that the addition of rice straw to the soil reduced the uptake of nitrogen by the rice plant until the panicle initiation stage. However, plant growth was not retarded when inorganic nitrogen was incorporated with the rice straw into the soil.

Assessment of soil nitrogen availability. The nitrogen released from soils plays an important role in lowland rice production. The pattern of nitrogen release from soil and nitrogen uptake by rice plants under tropical conditions was studied at the IRRI experimental farm in the 1973 wet season with IR20 and in the 1974 dry season with IR747 and IR26. Rice plants were transplanted at a 20- × 20- cm spacing, and the ammonium nitrogen in the whole puddled soil layer and in the upper portion of the subsoil per hill was measured. The nitrogen uptake by the rice plants was also measured at various stages of growth.

The nitrogen uptake by the rice plants increased continuously up to the heading or ripening stage and reached 70 to 80 kg N/ha in the no-nitrogen plots, while the ammonium nitrogen in the soil decreased to less than 10 kg N/ha 25 days after transplanting. The original levels of ammonium-nitrogen in the soil were about 35 and 23 kg/ha for the wet and dry season, respectively. When no nitrogen was applied, about 42 kg N/ha was taken up during panicle initiation in the wet season (IR20) and 28 kg N/ha in the dry season (IR26), although the panicle initiation stage was shorter in the wet season than in the dry season. Because of its short growing time, IR747 took up only a small amount of nitrogen. The average amount of nitrogen taken up between initiation and heading, except by IR747 rice plants, was about 30 kg N/ha for both the no-nitrogen and the nitrogen-applied plots during both the wet and dry seasons. After heading, the rice plants took up considerable nitrogen except the IR20 plants which lodged. Apparently, nitrogen from this soil was supplied to the rice plants continuously during the vegetative and reproductive stages under the prevailing tropical conditions.

The content of exchangeable ammonia in the soil during the wet season decreased rapidly 25 or 30 days after transplanting and reached stable low levels in all plots. However, the decrease was slightly slower in the dry season in those plots that received nitrogen. It reached stable levels at 40 days after transplanting. When the ammonium-nitrogen content in soils reached a stable low level, the loss of nitrogen by denitrification or immobilization must have become very small. The increase in the levels of nitrogen in the rice plants and soil 25 or 30 days after transplanting therefore indicates the tendency of mineralization of soil nitrogen.

The lower rate of recovery of the applied nitrogen, as estimated by the difference method of 47.3% (IR20) in the wet season compared with 69.7% (IR26) and 69.8% (IR747) in the dry season may have been due to typhoon damage before harvest. The amount of effective nitrogen was then estimated by multiplying the recovery rate by the total amount of exchangeable ammonium nitrogen at transplanting. This value indicates the portion of the ammonium nitrogen present at transplanting time that had been finally taken up by the rice plant or that had remained available in the soil.

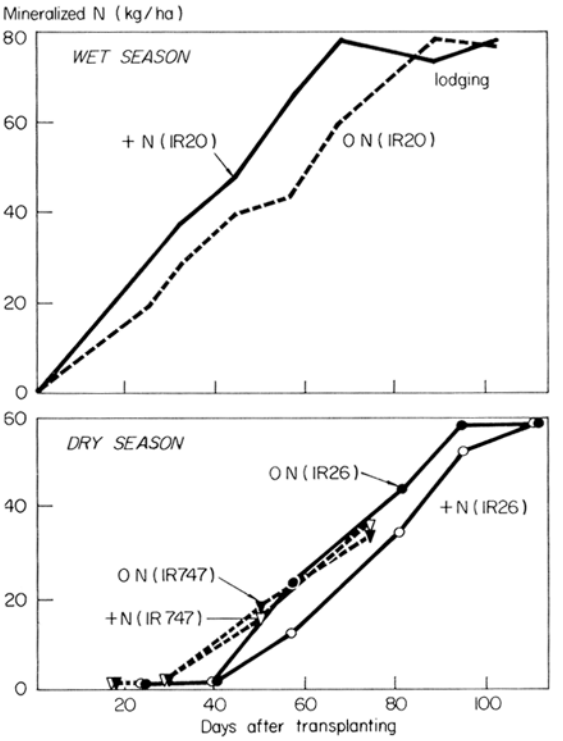
The amount of nitrogen mineralized during a cropping season was estimated by subtracting the level of effective nitrogen at the beginning of the growing season from the total amount of the plant and the soil nitrogen at each growth stage. When a considerable amount of ammonium remained in the soil at the early growth stage of the rice plant, the subtracted value was not used because some ammonia could be lost.

In the wet season the patterns of nitrogen mineralization were almost rectilinear from transplanting to ripening in the no-nitrogen plots and

up to heading in the nitrogen plots (fig. 5). In the dry season, nitrogen mineralization was slow during the early growth stages and began to increase from 30 to 40 days after transplanting. The nitrogen mineralized during a cropping season of IR26 reached 60 kg/ha. The difference in the nitrogen mineralization between wet and dry seasons was probably due to the differences of temperature during the early growth stages as well as to the difference in soil conditions, such as the long-term flooding before transplanting in the wet season and the short-term flooding in the dry season.

The amount of nitrogen mineralized in different samples of the same soils incubated under laboratory conditions was calculated by subtracting the initial ammonium nitrogen content from the accumulated value each time and expressed as kilograms of nitrogen per hectare, assuming 1,300 tons of soil/ha. The amount of nitrogen mineralized in the puddled soil was similar to that in the cropped flooded soil under field conditions in both the wet and dry seasons. The amount of nitrogen mineralized in air-dried soils was not useful for the assessment of available nitrogen because air-drying increases the mineralization of soil nitrogen and changes the pattern of the mineralization of nitrogen in the soil. A low amount of nitrogen was mineralized in the wet soil stored at room temperature. The pattern of nitrogen mineralization in puddled soil, incubated at 30°C, however, did not correspond completely with that under field conditions. But the difference could be reduced by correcting the incubation values with the effective accumulated soil temperature (T°C-15°C) x days.

The pattern of mineralization of soil nitrogen under cropped condition in pots was also determined in Maahas clay, Luisiana clay, and Pila clay loam soils taken from paddy fields and stored under wet conditions. The amounts of nitrogen mineralized in these soils during incubation was compared with those of soils in the greenhouse pot experiments. Since the wet soils used for both pot and incubation tests were stored for a while under oxidized conditions, the amount of nitrogen mineralized was low. However, the amounts of nitrogen and the patterns of mineralization in both experiments correlated closely in the three soils. The incubation method which uses soils under conditions similar to those of cropped soils was useful for estimating the amount of nitrogen mineralized and the pattern of the mineralization of soil nitrogen during a cropping season.



5. Mineralized nitrogen in rice cropped flooded Maahas clay loam soil under field conditions.

FERTILIZER-SAVING CULTURAL PRACTICES

Soil Chemistry Department

Water management and soil nitrogen. Flood fallowing between crops (compared with dry fallowing) increased the nitrogen content of the soils studied – Luisiana clay, Maahas clay, and Pila clay loam. Some of the accumulated nitrogen was used by the rice crop, confirming previous findings (1973 Annual Report) that showed that water management profoundly affects the nitrogen economy of lowland rice soils.

Flood fallowing increased the yield of grain over the dry-fallowed treatments on the three soils studied. Averaged for the three soils and the two midseason soil drying treatments, the increase was nearly 100 percent. The green color of the plants and the measured nitrogen uptake from the soil provided ample evidence that the benefits of flood fallowing were largely nitrogen effects.

A repetition of the experiment in the wet season (without applied nitrogen) revealed significantly increased grain yields with flood fallowing in Maahas clay and in Pila clay loam and with midseason soil drying in all three flood-fallowed soils. Apparently, the extra nitrogen released by midseason soil drying in these unfertilized soils was rapidly absorbed by the plants, leaving little for nitrification and subsequent denitrification on reflooding.

Flood fallowing appears to conserve and add nitrogen to the soil and midseason soil drying followed by flooding seems to increase the availability of the stored nitrogen to rice plants. To maximize the natural sources of available nitrogen in the soil, the fields should be kept flooded between the rice crops and allowed to dry in midseason and then be reflooded.

Straw as a source of nutrients. This year's studies yielded soil and plant data which confirmed the benefits of applying straw (straight or composted) as a source of plant nutrients described previously (1973 Annual Report).

The effects of straw removal were compared with those when the straw was left in the field in a long-term factorial experiment using three water treatments and five rice varieties, over a basal application of 100 kg N/ha. Leaving the straw in the field during five seasons brought some increases – averaged for the 15 factorial combinations of water and rice varieties – of 0.74 percent in organic matter, 0.030 percent in nitrogen, 3.3 ppm in phosphorus, and 0.32 meq potassium/100 g soil. The nitrogen gained by the straw-treated soils amounted to 60 kg/ha per season. When straw was added, grain yield was increased by 0.93 t/ha or 18% with IR22 rice and by 0.76 t/ha or 12% with IR773-112-2 rice as compared with no-straw treatments.

The addition of straw to the soil increased the nitrogen in the soil in two ways – the nitrogen in the straw and the additional nitrogen presumably fixed by bacterial action, as suggested previously (1973 Annual Report).

During this excessively wet season, proper water control was not possible. Thus, no significant response to the water treatments was found.

The effects of four methods of straw application – removed, burnt *in situ*, plowed in, and composted and incorporated – on the nutrient status of the soil and on the yield of rice were studied in a long-term experiment. Straw, in whatever form it was applied, increased the phosphorus and potassium contents of the soil, but the organic matter and nitrogen contents were significantly enhanced only when unburnt straw or compost was applied. In whatever form it was applied, straw benefited rice in the dry season; in the wet season, only the compost form produced a significant increase in the grain yield.

Additionally, the response of rainfed rice to 100 kg N/ha as urea and ammonium sulfate in the presence and absence of 10 t/ha compost was investigated in order to ascertain whether iron deficiency which was likely to arise when the soil dried and became aerobic would be corrected by the acidifying effect of ammonium sulfate or the chelating effect of compost.

At the end of the fifth season, ammonium sulfate had depressed the pH (from 6.8 to 6.6) while compost had increased the content of organic matter (35 to 49%), nitrogen (up to 35%), phosphorus (9- to 10-fold), and potassium (up to 20%). The much higher concentration of phosphate in the compost-treated soils can be traced to the phosphate added to the straw to hasten its decomposition during composting. Because of severe brown planthopper burn the plots were not harvested.

Increasing the efficiency of nitrogen utilization. In a field experiment on Luisiana clay (pH 4.9; O.M. 3.6%; Olsen P 1.3 ppm) in the 1974 dry season, H4 rice outyielded IR5 and IR26 when no nitrogen or phosphate was applied (Table 2). However, when phosphate was applied, IR5 and IR26 used the available soil nitrogen as efficiently as H4. Averaged for three rice varieties, the response to 25 kg P/ha without nitrogen was as good as the response to 100 kg N/ha without phosphate fertilizer. The three varieties utilized the soil nitrogen more efficiently with applied phosphorus than without it.

INCREASING EFFICIENCY OF FERTILIZER NITROGEN IN LOWLAND RICE

Agronomy, Soil Microbiology, and Entomology Departments

Time of nitrogen application (*Agronomy*). The possibility that high prices and low supplies of fertilizers might, in the next 3 to 4 years, limit the

quantity of fertilizers – especially nitrogen – needed to increase rice yields in the Asian tropics has led to a marked interest in method of maximizing yields using low rates of fertilizers.

In several earlier experiments, a single-dose application of nitrogen gave results comparable to those obtained with a split application of nitrogen in lowland rice. However, two factors should be reconsidered. One is precise water management, generally observed under experiment station conditions, but which is almost impossible to maintain under the usual farm conditions in tropical Asia. The other factor is the high rates of application, 120 kg N/ha during the dry seasons and 80 kg N/ha during the wet seasons, in the earlier experiments. Previous findings should be re-evaluated using low rates of fertilizer since the price of fertilizers is higher.

Single application. During the 1974 dry season at the IRRI farm (vertisol: pH 6.0, CEC 45 meq/100 g, total N 0.14%) the efficiency of nitrogen utilization applied at four stages of growth of three IRRI lines with two growth durations – medium maturity (124 and 127 days) and short-season (104 days) maturity – was investigated.

For the medium-maturing lines, the fertilizer nitrogen supplied just before panicle initiation gave the highest efficiency (fig. 6). The shorter seasoned line showed the highest fertilizer nitrogen efficiency with nitrogen applied basally but responded well when the fertilizer was applied just before panicle initiation.

IR26 rice gave similar average yields with nitrogen applied either as basal (5.0 t/ha), or 5 to 7 days before panicle initiation (5.2 t/ha), or at panicle initiation (5.1 t/ha) in field trials during the 1974 wet season at IRRI and at three farmers' fields under two irrigated and two rainfed conditions.

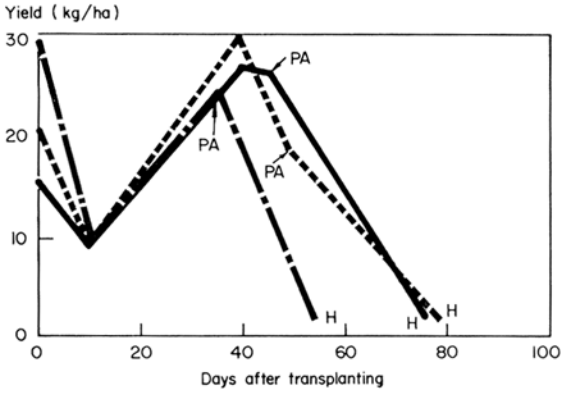
Basal vs. split application. When properly timed, split applications of nitrogen fertilizer gave higher grain yields than when all the fertilizer was broadcast and incorporated prior to planting. In an experiment conducted by the Agronomy Department at the IRRI farm during the 1973 dry season, split applications of urea yielded 1.4 t/ha more rice than did a single basal application at the same rate. A grain yield increase of 0.5 t/ha was obtained from split applications in a comparable IRRI-Philippine Bureau of Plant Industry (BPI) cooperative study at the Maligaya station in Central Luzon.

Split applications of fertilizer nitrogen gave significantly higher grain yields than did a single application at 60 kg N/ha but this was not true at 120 kg N/ha in an experiment at the IRRI farm.

Two IRRI medium-maturing lines (IR1539-823-1 and IR26) used fertilizer nitrogen more efficiently when the nitrogen was applied in split dose than when it was applied in a single dose. The reverse was found with the shorter season rice lines, IR2153-330.

With a single application of fertilizer nitrogen at 40 days after transplanting (or at panicle initiation) considered as the base, no split applications gave a significantly higher yield. These results were supported by similar findings of the Soil Microbiology Department where a split application between basal and panicle initiation was shown to be no better than a single basal application.

Two-split vs. three-split applications. At the IRRI farm during the 1974 dry season, all types of two-split applications significantly increased grain yield except when the fertilizer was applied 10 days after transplanting and at heading. When nitrogen is applied 10 days after transplanting, the plant's root system is not sufficiently developed to enable it to absorb nitrogen faster than the rate at which it is lost by various processes operating in



6. Efficiency (kg rice/kg N) of 60 kg N/ha as ammonium sulfate applied in a single dose at different times to three rice varieties. IRRI, 1974 dry season. Solid line — IR2153-330, maturity: 104 days; Broken line --- IR26, maturity: 124 days; Dotted line ... IR1539-823-1, maturity: 127 days.
PA = panicle initiation
H = 50% heading

Table 3. Grain yields and efficiency of nitrogen as urea (kg rice/kg N applied) of IR2061-464-1 and IR26 under different methods of application of urea at 60 and 100 kg N/ha. IRRI, 1974 dry season.

Method of applying nitrogen	IR2061-464-1				IR26			
	60 kg N/ha		100 kg N/ha		60 kg N/ha		100 kg N/ha	
	Yield[a] (t/ha)	Efficiency (kg rice/kg N applied)	Yield[a] (t/ha)	Efficiency (kg rice/kg N applied)	Yield[a] (t/ha)	Efficiency (kg rice/kg N applied	Yield[a] (t/ha)	Efficiency (kg rice/kg N applied)
Placement as mudball[b]	7.8 ab	53	8.2 ab	36	8.1 ab	53	8.7 a	38
Basal	6.4 d	30	7.3 bc	27	7.1 c	37	7.6 bc	28
Topdressing[c]	5.3 e	12	6.2 d	16	6.2 d	23	7.0 cd	21
Foliar spray[d]	5.0 e	7	6.5 cd	19	6.2 d	22	7.0 cd	21
Unfertilized control	4.6	–	e	–	4.9	–	e	–

[a]For each variety, means followed by a common letter are not significantly different at the 5% level. [b]Placement at 10- to 12-cm soil depth. [c]Three topdressings at 10 days after transplanting (DT), 40 DT, and at panicle initiation. [d]For 60 kg N/ha, applications were made at 15, 28, 41, 51, 58, and 65 DT. For 100 kg N/ha, applications were made at 15, 22, 29, 36, 43, 51, 56, 61, 66, and 71 DT.

the soil. When nitrogen is applied to the soil at the heading stage of the rice plant, it is too late to contribute to grain production although it increases the protein content of the grain. The best timing for a two-split application of nitrogen to rice seemed to be 40 days after transplanting and at panicle initiation, which gave the highest tiller and panicle number at harvest.

At the IRRI farm, three-split applications made in six different combinations gave a lower yield (average of 4.4 t/ha with two medium-maturing lines) than a two-split application using the same total amount of nitrogen (averages of 5.8 t/ha for the two medium-maturing lines and 4.6 t/ha for the earlier maturing lines).

Experiments in the 1974 dry season at IRRI farm and in three farmers' fields in Central Luzon and one in a farmer's field in the Bicol region of the Philippines compared two-split with three-split applications of nitrogen. There was no significant difference between the two-split versus the three-split application of nitrogen as ammonium sulfate, except on the clay soil (compared with a loam and silty clay loam) where the two-split application gave a significantly higher grain yield. The average yield difference was 0.6 t/ha.

The two-split application of urea gave a slightly higher yield than did the three-split application at IRRI and in two farmers' fields but only with 60 kg N/ha or 90 kg N/ha, and not at 30 kg N/ha rate.

Methods and time of nitrogen application (*Agronomy*). Deep-placed fertilizer is apparently less subject to volatilization and microbial oxidation. The loss of nitrogen is commonly more serious in rainfed lowland conditions than in irrigated fields.

At the IRRI farm during the 1974 dry season, urea fertilizer was applied at 60 and 100 kg N/ha by four methods (broadcast and incorporated; topdressed at 10 and 40 days after transplanting and at panicle initiation; foliar spray; and deep placement using the mudball technique). The topdressing treatment corresponded to the method of nitrogen fertilizer application commonly practiced by rice farmers in the Philippines. One early maturing line, IR2061-464-1, and one intermediate-maturing variety, IR26, both resistant to six common diseases and insects of rice, were used in the trial.

With either rice variety, urea applied at 60 kg N/ha as a mudball gave 3.2 t/ha more grain than the unfertilized control (Table 3). This increase was not only significantly higher than those obtained at the same rate (60 kg N/ha) with other methods of application, but was also comparable with the yield increase achieved with 100 kg N/ha applied as basal and was significantly greater than that obtained with either the three-topdressing or the foliar-spray treatment (Table 3).

The topdressing treatment gave a significantly lower grain yield than did the basal application (broadcast and incorporated) primarily because it was made 10 days after transplanting and caused higher losses of nitrogen than when the nitrogen was incorporated into the soil during land preparation.

Of the various methods and rates of nitrogen application tested, the application of urea at 60 kg N/ha as mudball gave the greatest efficiency of fertilizer nitrogen, 53 kg rice/kg N (Table 3).

The mudball technique was compared with other methods of fertilizer application at the IRRI farm and in three farmers' fields in Central Luzon, Philippines, during the 1974 wet season. Two nitrogen rates, 30 and 60 kg/ha, were used, and both rainfed and irrigated conditions were studied. At 30 kg N/ha under irrigated conditions, the mudball technique did not give a significantly higher yield than that of the best split application treatment, of six split-application treatments.

In rainfed rice, however, the mudball method resulted in about 0.5 to 0.7 t/ha higher grain yield than the other methods of application.

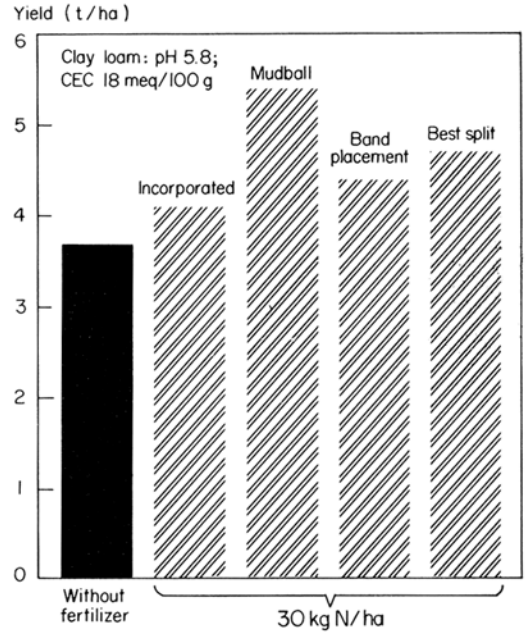
Grain yields obtained with 30 kg N/ha applied by the four methods in a rainfed farmer's field in Malayantoc, Nueva Ecija, Philippines were compared (fig. 7).

At the IRRI farm, 30 kg N/ha applied to rainfed IR26 rice in split doses, between 10 and 30 days after transplanting and at panicle initiation, gave yields similar to those obtained with 30 kg N/ha applied using the mudball technique. This is because the soil at the IRRI farm (clay, CEC 45 meq/100 g) is more fertile than the soil in the farmer's field in Malayantoc (clay loam, CEC 18 meq/100 g). The rainfall distribution was somewhat more uniform at the IRRI farm than in the farmer's field.

The effectiveness of the mudball technique appears to be best demonstrated when the differences in yield obtained from unfertilized and fertilized (nitrogen) treatments are large.

Sources of nitrogen (*Agronomy and Soil Microbiology*). For lowland rice, both urea and ammonium sulfate fertilizers have been found to be satisfactory sources of nitrogen in most flooded tropical rice. Similar results were obtained also at the IRRI farm and in four experiments conducted in farmers' fields in the Philippines during the 1974 dry season.

Experiments using slow-release fertilizer materials from Japan (isobutylidene diurea) and TVA (Tennessee Valley Authority), U.S.A. (sulfur-coated urea, SCU) were carried out for a number of seasons. Recent experiments at two locations showed SCU to be equal or superior to ordinary urea when both were applied as a basal treatment. When



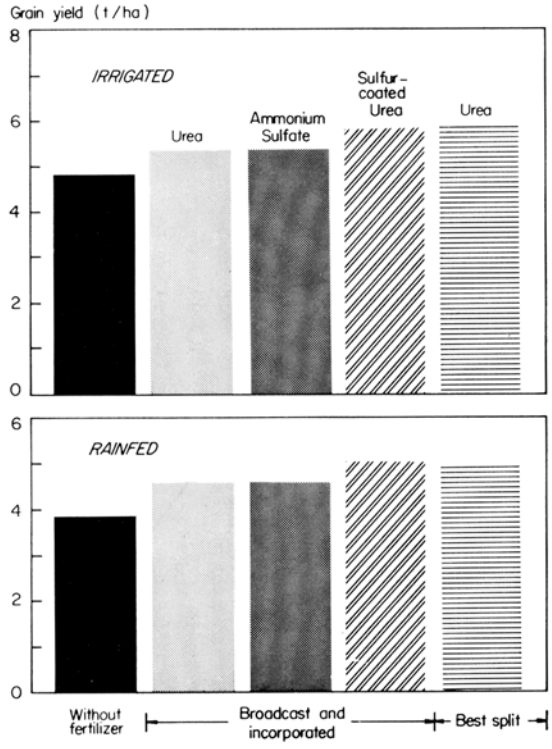
7. Relative grain yield of IR26 rice grown under rainfed conditions without fertilizer nitrogen and with 30 kg nitrogen/ha as urea under different methods of application. Farmer's field, Malayantoc, Nueva Ecija, Philippines, 1974 wet season.

applied in split doses, however, ordinary urea was as effective as SCU.

During the 1974 dry season, the effects of lower rates of nitrogen (60 and 100 kg/ha) basally applied as urea or sulfur-coated urea (6% dissolution rate in 14 days) were determined for two disease- and insect-resistant rices, IR26 and IR2061-464-1. The sulfur-coated urea was superior for both rates of fertilizer and both rices.

In experiments conducted during the 1974 wet season at the IRRI farm and in three farmers' fields in Central Luzon, Philippines, all nitrogen sources tested, urea, ammonium sulfate, and sulfur-coated urea (28% dissolution rate in 14 days), gave comparable results for both irrigated and rainfed rice (fig. 8).

Controlled-release fertilizers are receiving attention since they offer definite advantages under certain situations, but the cost per ton of nitrogen as sulfur-coated urea will be about 16 percent higher than its cost as granular urea. Therefore, the future use of controlled-release or slow-release fertilizers will largely depend on technological developments that minimize production costs suf-



8. Average (of two locations each) grain yields of IR26 rice grown under irrigated and rainfed conditions without fertilizer nitrogen and with 30 kg nitrogen/ha as urea, ammonium sulfate (AS), and sulfur-coated urea (SCU) applied as basal treatment and urea applied in split doses. IRRI and farmers' fields in Malayantoc, Maligaya, and Talavera, Nueva Ecija, Philippines. 1974 wet season.

ficiently to make the widespread use of these types of fertilizer economically feasible.

Large-sized fertilizers. One method of increasing the efficiency of applied nitrogen in flooded soils is using large-sized fertilizers. Large-sized fertilizers appear to be well suited for deep applications of nitrogen into the soil and for reducing the areas of contact with soil microorganisms.

In field experiments carried out in the 1973 wet season and in the 1974 dry season at the IRRI farm, the effects of ball fertilizer (dango) were measured at different stages of growth of lowland rice. A "dango" fertilizer (essentially ammonified peat moss and containing 5-5-5% N-P_2O_5-K_2O), large, oblong shaped, 3 cm in diameter and weighing 15 g per piece, was used in the wet season. In the dry season, two kinds of large-sized granulated fertilizers (G) were used. One was the "dango" oblong fertilizer balls, each weighing 9.5 g and containing 10.3-13.0-6.0% of N-P_2O_5-K_2O. The other mudball fertilizer contained the same amount of nitrogen and was made by mixing ammonium sulfate and Maahas clay loam soil shaped by hand into a round ball. All treatments were applied with 50 kg P_2O_5 and 50 kg K_2O/ha, and were replicated three times. Two seedlings at the fourth-leaf stage were transplanted at 20 x 20 cm spacing. Basal fertilizer, as ordinary ammonium sulfate, was incorporated into the puddled soil layer a day before transplanting and the large-sized fertilizers were applied 12 cm deep between rows of rice plants at the desired stage of growth. Rice plants from three average hills were pulled up at different growth stages and analyzed for the nitrogen content.

The incorporation into the soil of the whole amount of nitrogen at transplanting time had an advantage over a split application; it increased the number of tillers at the early stage of growth. Split application, on the other hand, kept the nitrogen content and the number of tillers of the rice crop higher at the later stages of growth. The release of nitrogen from the large-sized fertilizers appeared to be slightly slower but the effect was more lasting on all three rice varieties than that of incorporated ammonium sulfate. More nitrogen was recovered from mudball fertilizer than from the "dango" fertilizer.

For the early maturing rice variety IR747, the total grain number was highest when the large-sized fertilizer was applied at transplanting time and decreased with delayed application; the grain yield followed the same order. For the medium-maturing rice IR26, however, the total grain number was greater when the large-sized fertilizer was applied at 41 or 24 days before heading than with the basal application treatment. In all of the rice varieties the differences among grain yields in the various treatments with the same amount of nitrogen were not clear because the percentage of filled grains tended to be inversely related to the total grain number.

Large-sized fertilizers had different effects on the grain number of IR747 and IR26 rices. For the early maturing IR747, the most effective time of application was just after transplanting and for IR26, about 40 days before heading. In early maturing varieties, the basal application or top-dressing (T) of nitrogen appears better than the

application of large-sized fertilizers at relatively later stages of growth, probably because of differences in root extension at the time of fertilizer application.

In both IR747 and IR26, the grain number increased with increased nitrogen uptake and reached 48,000/sq m in the mudball fertilizer [41 days before heading (DBH)] plots of IR26. The grain yield of IR747 was high with 100 G basal and 50 N + 50 T (20 DBH); and that of IR26 was high with 100 G basal, 50 N and 50 G basal mixed, 50 N + 50 G (41 DBH), and 50 N + 50 B (41 DBH). The increase in grain number was associated to some extent with increased grain yield. The grain number, however, was not always related to the grain yield because the percentage of filled grains tended to decrease as the number of grains increased.

Interaction of weed control and fertilizer nitrogen application (*Agronomy*). The adequacy of weed control markedly affects the response of rice to nitrogen fertilizers.

During the 1974 wet season, two field experiments were conducted in farmers' fields in Laguna, Philippines, using IR26 to determine the best time to apply a limited amount of nitrogen (30 kg N/ha as urea) to obtain maximum yield when weeds are not controlled or when weeds are controlled by chemicals or by hand weeding. Granular 2,4-D was applied 4 days after transplanting and in another treatment two hand weedings were performed at 30 and 40 days after transplanting to control the weeds.

Without weed control, the applied nitrogen increased the grain yield by a maximum of 0.5 t/ha. However, without fertilizer nitrogen and with weed control, the grain yield increase was between 1.1 and 1.5 t/ha, indicating the importance of weed control in farmers' fields. When 30 kg N/ha was applied during final land preparation, the grain yield increase due to weed control by granular 2,4-D was 0.7 t/ha while that due to hand weeding was 1.3 t/ha (Table 4). The best time to apply a small amount of nitrogen appears to be from 5 to 7 days before panicle initiation. The grain yield increase due to fertilizer treatments was not significant, however, because the soils in the Laguna area of the Philippines are relatively fertile and their response to fertilizer in the wet season is generally low. The average (for six nitrogen treatments) grain yield increases due to weeding were significant and they ranged from 1.2 to 1.5 t/ha (Table 4). Under these conditions, it is advisable to control weeds before applying a small amount of fertilizer.

These data emphasize the interaction between fertilizer response and good agronomic practices. Without the control of weeds, insects, and diseases, little response from nitrogen can be expected. Likewise, factors such as the variety used, water management, and seedbed management, influence grain yield responses to fertilizer.

Table 4. Interactions of weed control methods and time of nitrogen (30 kg N/ha as ammonium sulfate) application in grain yield of IR26 rice. Data are averages for experiments in two farmers' fields (Cabuyao and Famy, Laguna, Philippines), 1974 wet season.

Nitrogen fertilizer treatment[a]	Weed control treatment			Av. (fertilizer treatment)
	No weed control	2,4-D at 4 DT	Hand weeding 30 & 40 DT	
	tons/ha of rice grain			
All basal	3.0	3.7	4.3	3.7
2/3 basal + 1/3 PI	2.5	4.7	4.1	3.8
1/3 basal + 1/3 30 DT + 1/3 PI	3.2	3.5	4.4	3.7
All 5-7 days before PI	3.1	4.1	5.0	4.1
1/3 10 DT + 1/3 40 DT + 1/3 PI	2.2	4.3	4.2	3.6
Unfertilized control	2.5	3.6	4.0	3.4
Average (weed control)	2.8	4.0	4.3	–

[a]DT = days after transplanting. PI = panicle initiation. LSD (5%) for weeding treatment (average for six fertilizer treatments) = 1.2 t/ha.

LONG-TERM FERTILITY EXPERIMENTS

Agronomy Department

The 20th and 21st crops in the long-term fertility experiments grown at the IRRI farm in 1974 showed no significant response to phosphorus or to potassium in either the dry season or wet season (Table 5). In the dry season, IR26 gave yields higher than IR8 and IR20 primarily because of the heavy incidence of brown planthopper since IR26 is resistant to brown planthopper.

Another series of long-term fertility experiments with the same objectives as the experiments at the IRRI farm were initiated in 1968 at three experiment stations of the Philippine Bureau of Plant Industry.

When the 1971 data were averaged for the three rice varieties – IR8, IR20, and IR26 – a marked response to nitrogen was found in all stations except in the wet season at the Maligaya station where five tropical depressions in Central Luzon caused serious lodging in the wet season.

The most interesting results were obtained at the Visayas station where phosphorus (NP) improved the grain yield by 1 t/ha over that of the nitrogen-only (N) treatment.

At each of the three stations, plots that received complete fertilizer (NPK) gave the highest yield. Interestingly, for the first time after 5.5 years of two-crops-a-year culture at the Visayas station, complete fertilizer caused significantly higher yield responses than did the N or NP or NK treatments (Table 6).

Thus, with adequate nitrogen supply, the response of rice to P or K, or both, is marginal in some areas under one-crop-a-year rice culture, but the response to these elements becomes marked under intensive rice cultivation (two crops or more a year) over the years.

EFFICIENCY OF FERTILIZER NITROGEN AND INSECTICIDE APPLICATION IN LOWLAND RICE

Agronomy and Entomology Departments

Experiments at IRRI have demonstrated that the efficiency of fertilizer nitrogen is considerably increased if the fertilizer is applied as mudball 10 to 12 cm deep in the soil. In earlier studies (1973, Annual Report) at IRRI, systemic insecticides were found to be more efficient when they were applied at the reduced soil layer.

During April and July, 1974, in an experiment at the IRRI farm to evaluate the performance of combined placement of fertilizer and insecticide using a mudball technique, an insect-resistant experimental line, IR2061-464-1, was used as the test variety. Nitrogen as urea was applied at 60 and 100 kg/ha using three application methods – broadcast and incorporated (basal), as mudball at 10 to 12 cm soil depth, and band placement. Superimposed on these nitrogen treatments was the application of a systemic insecticide carbofuran as a mudball once or continual topdressing of insecticides into standing water at various stages of crop growth.

While no significant differences in grain yield were found among the three methods of nitrogen application, carbofuran applied as a mudball gave a significantly higher yield than that obtained with optimum insect control through the conventional method of topdressing at various stages of growth.

These results suggest the possibility of combining fertilizer and insecticide in one application using the mudball technique.

In a follow-up experiment conducted at the IRRI farm in the 1974 wet season, three systemic insecticides were tested – carbofuran, cartap, and chlordimeform. In addition to the mudball technique, two experimental fertilizer applicators were tested; one was developed by the IRRI Agricultural Engineering Department and the other was obtained from Japan.

Carbofuran combined with urea at 30 kg N/ha in the same mudball gave a grain yield statistically similar to that obtained with urea at 30 kg N/ha as a mudball with optimum insect protection, indicating that considerable savings are possible if the insecticide can be applied as a mudball.

Under optimum insect protection, the grain yields from applying urea at 30 kg N/ha as a mudball were similar to grain yields from applying the urea with the IRRI mechanical applicator. Both techniques appear to be superior to either broadcast and incorporated, placement by a Japanese machine, or by applying nitrogen in split doses.

When the insecticide was applied as a mudball, carbofuran gave a significantly higher grain yield than chlordimeform. When the insecticides were

Table 5. Effects of NPK fertilization on the grain yield of IR8, IR20, and IR26 in the 20th (dry season) and 21st (wet season) consecutive crops. IRRI, 1974.

Fertilizer treatment[a]			Yield[b] (t/ha)			
N	P_2O_5	K_2O	IR8	IR20	IR26	Mean[c]
			Dry season			
0	0	0	2.5	3.8	3.9	3.4 c
140[a]	0	0	5.6	6.9	9.0	7.2 a
0	30	0	3.3	3.7	4.7	3.9 b
0	0	30	2.5	4.3	4.3	3.7 bc
140[a]	30	0	6.2	6.7	9.1	7.3 a
140[a]	0	30	5.6	6.8	9.3	7.2 a
140[a]	30	30	5.8	6.7	9.2	7.2 a
140[ad]	30	30	5.2	7.2	8.8	7.1 a
			Wet season			
0	0	0	4.5	4.1	3.9	4.2 d
60	0	0	4.5	4.8	5.1	4.8 a
0	30	0	4.8	4.0	4.1	4.3 bcd
0	0	30	4.6	4.3	3.9	4.3 cd
60	30	0	4.7	4.5	4.8	4.7 ab
60	0	30	4.8	4.5	4.4	4.6 abc
60	30	30	4.6	4.9	4.4	4.6 abc
60[d]	30	30	4.9	5.0	4.6[e]	4.8 a

[a]Includes 40 kg N/ha applied at panicle initiation. [b]Average of four replications. [c]Any two fertilizer means followed by the same letter are not significantly different at 5% level. [d]Compost (10 t/ha) plus inorganic (24.0 kg N/ha compost + 116 kg N/ha inorganic, dry season; 24.0 kg N/ha compost + 36 kg N/ha inorganic, wet season. [e]3 replicates only.

Table 6. Effects of NPK fertilization on the grain yield of IR8, IR20, and IR26 in the 13th (dry season) and 14th (wet season) crop in long-term fertility experiments at three locations (av. of three replications). Maliyaga Rice Research and Training Center, Bicol Rice and Corn Experiment Station, and Visayas Rice Experiment Station, Philippines. IRRI-BPI cooperative experiments, 1974.

Fertilizer (kg/ha)			Yield (t/ha)						
			Maligaya		Bicol		Visayas		Av.
N[a]	P_2O_5	K_2O	Dry	Wet	Dry	Wet	Dry	Wet	
0	0	0	3.0 c	2.3 c	3.0 c	2.3 c	3.1 c	1.9 d	2.6 d
140/70	0	0	4.5 b	2.8 bc	4.5 b	3.3 b	4.9 ab	2.7 c	3.8 c
140/70	60	0	5.0 ab	2.9 abc	4.5 b	3.7 a	5.6 a	3.7 b	4.2 b
140/70	0	60	5.0 ab	2.8 bc	5.2 b	3.0 b	4.6 b	2.7 c	3.9 c
140/70	60	60	5.7 a	3.6 a	6.9 a	4.2 a	5.6 a	4.1 a	5.0 a
140/70	60	30+30[b]	5.7 a	3.3 ab	6.6 a	4.1 a	5.7 a	3.8 ab	4.9 a

[a]140 kg N/ha in the dry season; 70 kg N/ha in the wet season, including 40 kg N/ha in the dry season and 30 kg N/ha in the wet season topdressed at panicle initiation. [b]Applied in split doses: basal + panicle initiation.

topdressed twice, carbofuran produced a grain yield significantly higher than that obtained with cartap.

Carbofuran when applied as a mudball at transplanting controlled whorl maggot although not as well as when it was topdressed at 3 days after transplanting (DT) and at 15 DT. This was probably because the early infestation of whorl maggot was controlled by the surface application of carbofuran at 3 DT while as a mudball, the insecticide was

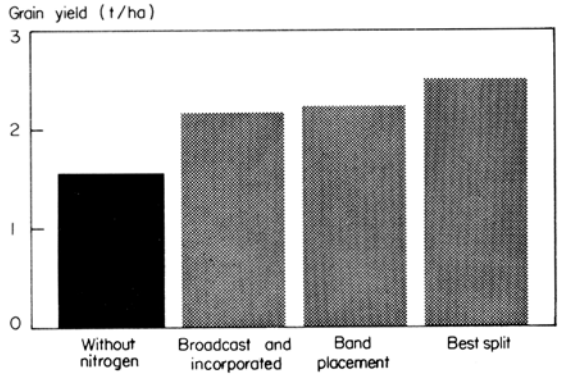
Table 7. Whorl maggot damage on IR1480-137-3 rice as affected by three sources of insecticides at two methods of application. IRRI farm, 1974 wet season.

Source of insecticde	Whorl maggot damage rating[a]			
	Insecticide combined with urea as mudball		Insecticide surface applied at 3 DT + 15 DT; urea by broadcast incorporation	
	Taken at 21 DT	Taken at 34 DT	Taken at 21 DT	Taken at 34 DT
		30 kg N/ha		
Carbofuran	2.5	2.2	1.0	1.0
Cartap	4.5	4.7	3.5	5.0
Chlordimeform	4.7	5.0	3.0	5.0
Optimum insect protection		1.0		
No insect protection		5.0		
		60 kg N/ha		
Carbofuran	3.2	1.2	1.0	1.0
Cartap	4.0	5.0	3.5	5.0
Chlordimeform	4.0	5.0	3.0	4.2
Optimum insect protection		1.0		
No insect protection		4.7		

[a]0 = no damage; 5 = badly damaged. LSD for 21 days after transplanting [DT] (5%) = 0.7 t/ha; LSD for 34 DT (5%) = 0.4 t/ha.

not as rapidly absorbed by the rice plant. Cartap and chlordimeform were both ineffective in controlling the whorl maggot. Plants treated with these chemicals were just as badly damaged by this pest as were the untreated controls (Table 7).

Since stem borer incidence was very low from tillering to the booting stage, stem borer damage (recorded as percent dead hearts) was negligible for the plots treated with carbofuran combined with urea as mudball and compared well with the control achieved on the plots receiving optimum insect protection.



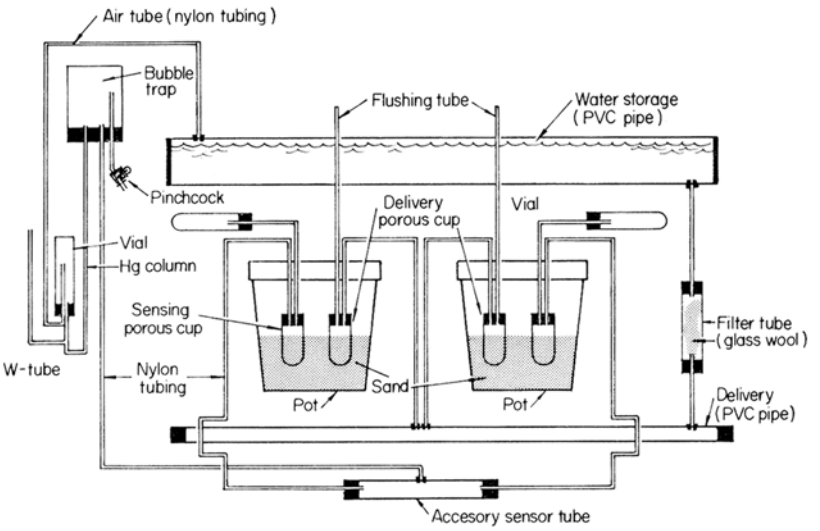
9. Average (of two locations) grain yields of three experimental lines of rice (IR442-2-58, IR937-55-3, and IR2061-213-2) grown under rainfed upland condition without fertilizer nitrogen and with 60 kg nitrogen/ha as urea applied as basal treatment and in split doses. IRRI and farmer's field, Cuenca, Batangas, Philippines, 1974 wet season.

EFFICIENCY OF FERTILIZER NITROGEN IN UPLAND RICE

Agronomy Department

Experiments were conducted during the 1974 wet season at the IRRI farm and at two dates of seeding in farmers' fields in the Philippines' province of Batangas to evaluate fertilizer efficiency in upland rice with three nitrogen sources – ammonium sulfate, urea, and sulfur-coated urea (28% release rate) – under four methods of application. Nitrogen at 60 kg/ha was applied as basal (broadcast and incorporated), band placement, basal dressing, and in split doses. Three experimental rice lines, IR442-2-58, IR937-55-3, and IR2061-213, were used.

At both locations, periods of drought lasted 20 to 30 days, but the intensity and duration of water stress were greater in Batangas where the



10. An automatic setup for maintaining a predetermined and constant soil moisture tension in a pot. IRRI, October 1974.

crop seeded on June 4 underwent more damage from moisture stress than did the crop planted July 11. Despite the severe moisture stress, the increase in grain yield due to applied nitrogen was significant. Averaging the grain yield data for three experimental rice lines, a split application of 60 kg N/ha made half at 30 days after rice emergence and half at panicle initiation gave the highest yield (fig. 9). Band placement and broadcast-and-incorporated treatments gave similar grain yields.

Grain yield differences among ammonium sulfate, urea, and sulfur-coated urea were not significant, as in most lowland rice experiments. Among the three rice lines, IR442-2-58 was the most tolerant to drought and IR2061-213 was the least tolerant.

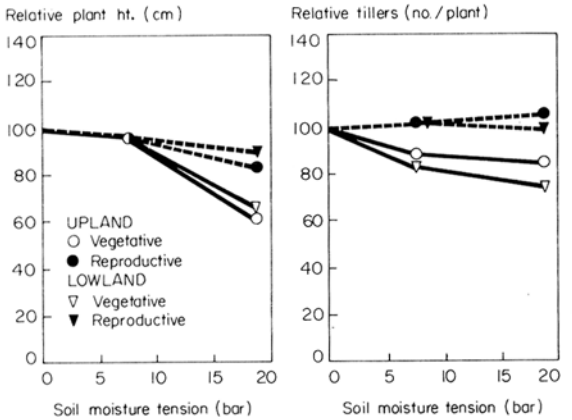
DROUGHT TOLERANCE

Agronomy Department

An automatic setup for maintaining a predetermined soil moisture tension. The technique developed earlier (1973 Annual Report) to maintain a predetermined and relatively constant soil moisture tension in pots (three pots per setup) for soil-water-plant atmosphere relationship studies was modified in an attempt to circumvent problems of cost, labor, and maintenance. Such problems limited the screening of large numbers of rice lines and varieties for drought tolerance. The modified technique is about one-third as expensive as the original setup and the maintenance requirements are considerably simplified.

Four major components of the setup are a W-tube containing a predetermined amount of mercury, sensing elements, water delivery systems, and pots containing 8 kg of soil (fig. 10). The sensing porous cups of the different pots are connected to the accessory sensor tube and when the total height of the mercury in the W-tube is equal to the soil moisture tension in the pots, the mercury is pulled up in the left side of the tube which is connected to the bubble trap of the tensiometers. The air is thus permitted to enter the water storage pipe, which is otherwise airtight, through the W-tube and air tube. Water from the storage pipe moves down to the delivery pipe through the filter tube and delivers water to the different pots through the porous cups. As the soil moisture tension is relieved, the mercury in the left side of the W-tube moves down, blocking the air entering the storage pipe. Thus, the flow of water from the storage to the delivery pipe is stopped. The process repeats itself to provide water promptly in each pot. Ten pots were connected in parallel to the delivery pipe of the distribution system.

Methodology for screening rice varieties for drought tolerance. Drought is common in rainfed rice and it occurs in irrigated rice when water



11. Plant height and tiller number per rice plant (relative values with continuous saturation taken as 100) of upland and lowland varieties, as affected by soil moisture tension at vegetative and reproductive stages. Each point is an average value for either 6 upland or 12 lowland varieties. IRRI greenhouse experiment, 1974 wet season.

control in the field is not adequate. The main impediment in accurately assessing the real potential of drought tolerance among existing rice varieties and breeding lines is the dearth of suitable techniques which can duplicate the actual conditions that occur during a drought. Greenhouse conditions cannot duplicate the soil-climate conditions prevalent in the field. On the other hand, control of environmental variables is not possible in field studies. A number of techniques for measuring drought tolerance have been developed by rice scientists, but none are completely satisfactory.

During the 1974 wet season, the effect of water stress on 21 rices was studied using a single cycle of low or high soil moisture tension in the greenhouse. The plants were grown in Maahas clay soil (vertisol) fertilized with nitrogen, phosphorus, and potassium in gasoline drums with an effective rooting depth of about 45 cm. The three moisture treatments of continuous saturation (0 bar), 7.5 bars, and 15 bars of soil moisture tension were imposed in a split-plot design and at the vegetative stage (14 days after seeding) and the reproductive stage (46 days after seeding). The soil was dried to the predetermined soil moisture tension via natural drying. Precalibrated gypsum blocks were placed at 10 and 20 cm depths in the soil. The soil moisture tension of 15 bars at the vegetative stage was relieved between 41 and 50 days, but gravimetric measurements indicated that the soil moisture tension was actually 18 to 19 bars and not the 15 bars originally planned.

Agronomic characteristics. Plant height was measured at the end of the moisture stress period. Little or no reduction in plant height occurred at 7 to 8 bars of soil moisture tension at either the vegetative or the reproductive stage (fig. 11). At 18 to 19 bars, however, plant height was considerably reduced compared with that at saturation. The reduction in plant height was greater when the moisture stress occurred at the vegetative stage than when it occurred at the reproductive stage of plant growth. As a group, upland varieties exhibited greater reduction in plant height than lowland varieties when the moisture stress occurred at the reproductive stage.

The number of tillers per plant was reduced considerably for different cultivars when the moisture stress was imposed at the vegetative stage. The reduction was greatest at 18 to 19 bars (fig. 11) and was greater for the lowland rices as compared with the upland varieties. Lowland varieties generally have high tillering capacities under normal moisture conditions and continue to tiller even when the upland varieties cease to produce new tillers. No reduction in the number of tillers per plant was noted when the moisture stress was imposed during the reporductive stage because by the time the rice plant reaches this stage of growth, tillering has essentially ceased.

Proline content in the leaf tissue. Free proline levels in the foliar tissue of the second leaf from the top were determined, using a standard method, for continuous saturation, stress treatments and during the recovery period, 48 hours and 7 days after relieving the moisture stress imposed during the vegetative stage. All varieties and lines accumulated higher amounts of proline with increasing levels of moisture stress (fig. 12); proline increased rapidly at about 7 bars. Under continuous saturation, the proline content was constant regardless of the stage of growth.

At tensions greater than 7.5 bars, the proline content of the rice leaves was higher during the reproductive stage than during the vegetative stage. For example, the proline content of the leaves of IR2035-197-3 which was subjected to 13 to 14 bars of soil moisture tension, was 79-fold and 146-fold greater than that of the saturation control treatment when the moisture stress was imposed

during the vegetative and reproductive stages, respectively. During the recovery period, the amount of proline in the leaves 7 days after the moisture stress was relieved was higher than that of plants in the continuous saturation regime.

The upland varieties accumulated less proline than did lowland varieties at higher levels of soil moisture tension. While Saovina, the upland variety from Africa, and TOX 6-14-2-B_1-B, a selection bred for upland areas by the International Institute for Tropical Agriculture (IITA) in Nigeria, accumulated 12 mg/g dry leaf, IR1646-623-2, a lowland breeding line, contained 17 mg/g dry leaf at 18 to 19 bars soil moisture tension during vegetative stage. During soil moisture stress at the reproductive stage, IR2035-197-3, a lowland breeding line, accumulated as much as 29 mg/g dry leaf at 12 to 13 bars of soil moisture tension. Generally, the lowland rices used a high percentage of the accumulated proline within 48 hours of relieving the moisture stress during the vegetative stage. This may be due to the suggested role of this imino acid as a storage compound for energy and nitrogen which are necessary to the recovery of the cells after drought.

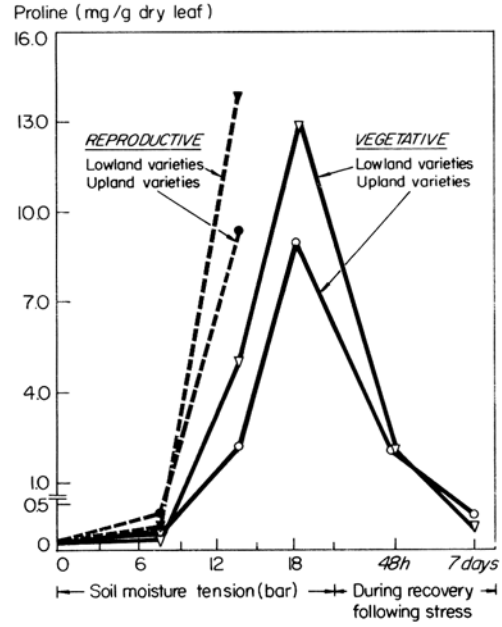
Drought-tolerant plants have been reported to accumulate more proline during water stress. Thus, the proline content of different rices were compared at high levels of moisture stress and during recovery from this stress. During the vegetative stage, Moroberekan (an upland variety from Africa) was the only variety which died at 18 to 19 bars of soil moisture tension, while IR1746-226-1-1-2, a selection bred for upland conditions, was severely damaged by the moisture stress. The proline accumulation in the leaves of these two rices was, however, in the intermediate range. Traditional upland varieties, such as M1-48 and E425, had the lowest amount of accumulated leaf proline at the highest level of soil moisture tension. During the reproductive stage when 18 to 19 bars of soil moisture tension was imposed, Saovina (an upland rice) was severely damaged, and M1-48, E425, OS6, and Moroberekan (other upland varieties), and an experimental selection, IR1746-226-1-1-2 died. Only TOX 6-14-12-B_1-B, and IR1750(F_5B)-5, a line derived from a cross with an upland rice, showed tolerance to drought.

IR1545-339 and IR5 were among the lowland varieties that survived moisture stress during the vegetative stage but died when the soil moisture tension was 18 to 19 bars during the reproductive stage. The proline content of IR5 and IR1545-339 leaves during the reproductive stage when moisture stress was imposed was generally low.

The data confirm that rice varieties are more susceptible to drought injury at the reproductive stage than at the vegetative stage, and indicate that many upland rice varieties, although possessing considerable tolerance to drought at the vegetative stage, may be susceptible to moisture stress at the reproductive stage.

Rice lines and varieties did not show a consistent trend in the level of proline accumulated in the leaves during high soil moisture stress, suggesting that further studies are needed to determine the feasibility of using the content of leaf proline as a criterion for assessing drought tolerance in rice.

Diffusive resistance. Diffusive resistance was measured on the upper surface of the second leaf from the top, near the mid-portion, with a diffusive resistance meter. The data were collected (Table 8) at continuous saturation and at high moisture tension and revealed that the upland varieties, in



12. Leaf proline content as a function of soil moisture tension at vegetative and reproductive stages. Each point is an average value for either 5 upland or 12 lowland varieties of rice. IRRI greenhouse experiment, 1974 wet season.

Table 8. Effect of soil moisture tension on the diffusive resistance and leaf desiccation of 21 rices. IRRI greenhouse experiment. 1974 wet season.

Rice lines and varieties	Diffusive resistance (s/cm)					Percentage of fully desiccated leaves
	Vegetative stage		Reproductive stage			Reproductive stage
	Continuous saturation	12-13 bars	Continuous saturation	7-8 bars	12-13 bars	18-19 bars
Upland varieties						
Saovina	2	5	3	11	16	88
M1-48	2	11	3	16	26	95
E425	2	17	2	17	33	98
OS6	2	16	3	16	30	92
Colombia I	2	14	2	10	12	98
Moroberekan	2	14	3	10	17	100
Experimental lines selected under upland condition						
IR1746-226-1	2	14	2	13	24	99
IR1750-(F_5B)-5	2	8	2	5	17	65
TOX 6-14-2	2	9	2	7	12	48
Experimental lines selected under lowland condition						
IR20	2	8	2	14	21	53
IR1529-430-3	2	14	3	8	17	58
IR1545-339	2	10	3	13	19	98
IR1480-147-3	2	9	3	13	21	46
IR442-2-58	2	10	3	7	20	70
IR5	2	11	3	9	21	84
IR1646-623-2	2	9	2	6	12	72
IR1539-823-1	2	8	3	5	17	55
IR937-55-3	2	10	2	9	11	42
IR2035-353-2	2	13	3	7	14	56
IR2035-117-3	2	14	3	5	20	57
IR2035-197-3	2	9	3	7	20	85

general, possessed a higher resistance to soil moisture tension than lowland rices at both the vegetative and the reproductive stages. The diffusive resistance generally increased when the soil moisture tension reached 4 to 5 bars. While E425, an upland variety from Africa, showed the highest diffusive resistance at 12 to 13 bars soil moisture tension at both growth stages, the lowest values were recorded with Saovina, another upland variety from Africa, when the moisture stress occurred during the vegetative stage of growth and with the IRRI experimental line, IR937-55-3 when the stress was imposed during the reproductive stage.

At both the growth stages, the increase in diffusive resistance of upland varieties was generally linear, which was not the response of lowland varieties. A greater soil moisture tension appears to be required to increase stomatal resistance in lowland rices. Because stomatal closure is a function not only of the moisture status of soil and its absorption by and translocation to various parts within the plant, but also of the evaporative demand of the crop, microclimate, its usefulness as a measure of drought tolerance, particularly at high soil moisture tensions, is questionable. Furthermore, high diffusive resistance at low levels of soil

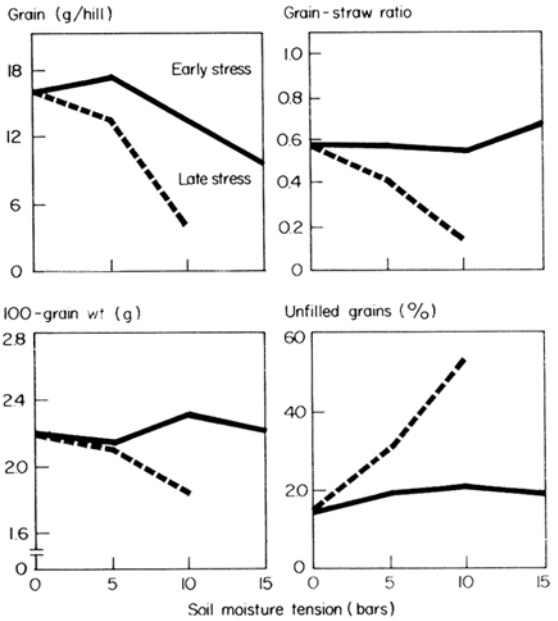
moisture tension in most upland varieties not only curtails the transpirational loss by the plants but may also limit carbon dioxide diffusion into the leaf, thereby lowering photosynthetic activity. Whether the potential savings in soil moisture by decreased transpiration is desirable at the expense of photosynthetic activity further complicates any assessment of diffusion resistance as a suitable criterion for evaluating drought tolerance in rice. This suggests the need for studies to identify and evaluate differences in the diurnal stomatal behavior of rice varieties during drought.

Leaf desiccation. Data on leaf desiccation, recorded at the reproductive stage before relieving the moisture stress (Table 8), showed that varieties with 80 percent or more desiccated leaves failed to recover and died after the moisture stress was relieved, except Saovina and IR2035-197-3 which exhibited a partial recovery. The percentage of desiccated leaves in a rice variety may serve as a useful criterion for assessing its drought tolerance at high levels of moisture stress.

Experimental lines from IRRI, IR1750(F_5 B)-5, IR1529-430-3, IR1480-147-3-1, IR442-2-58, IR1646-623-2, IR1539-823-1-4, IR937-55-3, IR2035-117-3, IR2035-353-2, and TOX 6-14-2-B_1-B from IITA, Nigeria, exhibited considerable tolerance to high soil moisture tension at both vegetative and reproductive stages. More varieties were tolerant of a high soil moisture tension during the vegetative stage than during the reproductive and ripening stages. This suggests that one criterion for selecting for drought tolerance in rice might best be based on assessing the reaction of rice plants to high soil moisture tension/stress at the reproductive stage when varieties and lines differ markedly in their tolerance or susceptibility to drought.

Plant response to soil moisture tensions at vegetative and reproductive stages – greenhouse studies. In a greenhouse, the effect of different levels of soil moisture stress (0.5, 10, and 15 bars) at two growth stages of rice – 14 days after seeding and booting stage – was studied. IR442-2-58, IR937-55-3, IR20, and Moroberekan were grown in 20 kg of soil to which 150 kg N, 100 kg P_2O_5, and 100 kg K_2O/ha were added just before seeding.

In the early stress treatments (no water beginning 14 days after seeding), the grain yield increased, slightly as the moisture tension increased from 0 to 5 bars and decreased proportionally as the soil

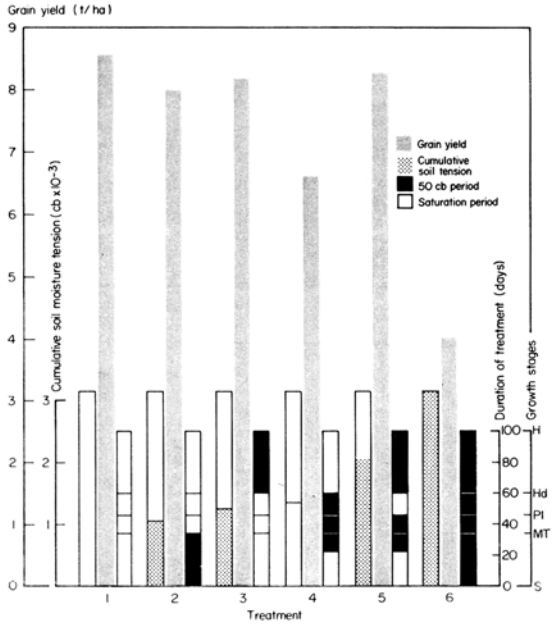


13. Effect of levels of soil moisture tension on grain yield and yield components of rice (av. of four varieties). Agronomy Department, IRRI greenhouse, 1974.

moisture tension rose above 5 bars (fig. 13). This effect appears to be due to the differences in tillering ability since the 100-grain weight, percentage of unfilled grains, and grain-to-straw ratio were similar for all the moisture stress treatments.

In the late stress treatments (initiated at the booting stage), the rate of grain yield reduction appeared to increase with increased soil moisture tension up to 10 bars. Almost no yield was obtained when the soil moisture tension was increased to 15 bars (fig. 13). The increase in the percentage of unfilled grain and the reduction in the 100-grain weight, and the grain-to-straw ratio as the soil moisture tension increased explain in part the decrease in grain yield under these moisture stress treatments.

Response of yield to soil moisture deficits at different growth stages – field studies. In usual field studies of the effect of drought on yield, the experimental conditions cannot be controlled. Thus, the variance in the degree, duration, and timing of soil moisture deficits constituting drought conditions make it difficult to derive general trends from the results. Such studies are additionally handicapped since it is known that soil water



14. Histogram illustrating yield response of rice to six selected treatment combinations of growth stage and duration of the 50 cb soil moisture tension.

deficits affect plant growth and development differently depending upon the growth stage.

During the 1974 dry season, the response of two IRRI lines (IR2061-214-3-6 and IR1545-339) to soil water deficits was studied in a field experiment where the degree, duration, and growth stage interactions were controlled to some extent. The rice was direct seeded into soil-filled steel tanks recessed to ground level, and water was delivered through a perforated pipe at a 30-cm depth when needed.

Nitrogen, phosphorus, and potassium were applied at 120 kg/ha each as a split application. Four growth stages – maximum tillering, panicle initiation, heading, and harvest – were used and the duration of the 50-cb treatment was varied according to growth stage and frequency of treatment (fig. 14). Treatments 1 and 6 were the checks – continuous saturation and continuous 50 cb soil moisture tension, respectively. Treatments 2 and 3 were moisture stress between the seedling and maximum tillering stages and between heading and harvest, respectively. Treatment 4 was subjected to soil moisture stress from before maximum tillering through panicle initiation, terminating at heading. In treatment 5, the moisture stress was imposed at maximum tillering and at heading, but a saturation period was imposed between these two stages at the panicle initiation stage.

The check treatments indicated the detrimental effect of 50 cb soil moisture tension on yield. Treatments 2, and 3 revealed that moisture stress at the early vegetative and the late reproductive growth stages had little effect on yield. However, when the water stress occurred at panicle initiation, as in treatment 4, the yield decrease was substantial. Any limitation at this stage may affect spikelet number, an effect which would be irrevocable in determining grains per panicle regardless of subsequent conditions of growth.

Treatment-4 plants had only 82 percent as many grains per panicle as the control, treatment 1. On the other hand, treatment-5 plants had 99 percent as many grains per panicle as the control. There was no difference in grain size between treatments 4 and 5.

Treatment 5 is representative of the situation where periods of soil moisture deficit alternate with saturation conditions and where the residual value of physiological water stress has been referred to as "hardening" (less succulence of the tissues, hardening of the cell walls, more concentrated cell sap and protoplasm, more bound water, and a general increase in hardiness to adverse growing conditions). It appears that such an adaptation occurred in treatment 5. This treatment also exhibited one of the highest cumulative soil moisture tension values associated with relatively high yield, and the highest water use efficiency (grain yield per millimeter of water applied).

Control and management of diseases

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SUMMARY

From the 3,225 isolates of *Pyricularia oryzae* that had been inoculated to Philippine differentials since 1963, 255 pathogenic races have been identified. Among these races P8 is the most prevalent; it has an occurrence frequency of 26.8 percent.

Tested lines that showed very few blast lesions in the field were resistant to most races present in the field by artificial inoculation. Therefore, quantitative difference in blast resistance may reflect the spectrum of qualitative resistance of the lines or varieties.

Epidemiological studies of blast disease showed that a temperature of 21–22°C and a long wet period favored infection. Favorable colonization of the blast fungus occurred at 20–25°C. The relative humidity did not considerably affect colonization of the blast fungus.

The severity of blast disease in upland areas was confirmed. The sugar and protein contents of the rice leaf are higher and the dew period longer under dry conditions than under flooded conditions.

The aggressive strain of *Xanthomonas oryzae* from Isabela Province in the Philippines, caused a lower incidence of bacterial blight on IR20 under natural field conditions than when IR20 was artificially inoculated. Rice varieties with the recessive gene for resistance to bacterial blight (BJ 1 and DZ 192) remained highly resistant to this strain of *X. oryzae*.

Controlled environmental studies in the phytotron showed that bacterial blight developed at relatively wide ranges of temperatures (20–40°C), but 25 to 35°C were most favorable. Relative humidity levels between 50 and 75 percent did not greatly affect the development of this disease. High nitrogen content in the leaf tissue did not significantly favor lesion development.

An epidemiological survey of rice tungro disease in farmers' fields in Luzon, Philippines, indicated that a decrease in the population of the insect vector during July and August could have restricted the outbreak of the disease in the wet-season crop in 1974.

Temperature affected the transmission of tungro virus by the green leafhopper, *Nephotettix virescens*, which achieved maximum infective capacity at 34°C. The insects lost their infectivity at a much lower rate at 7°C than at room temperature.

A study of the movement of viruliferous *N. virescens* in relation to the spread of the tungro disease indicated that the frequency of movement affects the duration of the insect's visit per seedling. The average duration of the insect's visit on infected seedlings is longer than that on non-infected seedlings. The field resistance of a rice variety to tungro disease may be due to the non-preference of the insect for the rice variety. This nonpreference causes the insect's frequent movement on the variety.

RICE BLAST DISEASE

Plant Pathology Department

New pathogenic races. Twenty-six new races of *Pyricularia oryzae* were identified from various isolates in the Philippines during the year, bringing to 255 the total number of known races in the Philippines. The reaction of the 12 Philippine differential rice varieties to these new races of rice blast was studied (Table 1). Most of the new races have been isolated only once or twice. It was unusual that 11 of the 26 new races did not infect Khao-teh-haeng 17, a very susceptible variety.

Based on the reactions of the international differentials, the new isolates were classified into IA-45, IA-65, IA-66, IA-70, IA-74, IA-86, IA-106, IA-109, IA-110, IA-111, IA-112, IA-113, IA-118, IA-121, IA-122, IA-125, IA-126, IA-128, IC-1, ID-5, ID-13, ID-14, ID-16, ID-20, IG-1, IG-2, and II-1 according to the standardized international race numbers.

Philippine races of *P. oryzae* and their frequency of distribution. Since 1963, 3,225 isolates of *P. oryzae* have been tested on 12 Philippine differential varieties of rice and from these isolates 256 races have been identified. The frequency of occurrence of the two most commonly found isolates – P8 and P12 – are 864 and 174, respectively. Ninety-five of the 256 races were found only once; 40 were found only twice; 23 races, three times; 17 races, 4 times; 10 races, 5 times; 16 races, 6 to 10 times; 19 races, 11 to 20 times; and 4 races, 21–30 times; 14 races, 31–50 times; 8 races, 51–103 times; and 1 race, 119 times.

Qualitative and quantitative resistance. The reaction of rice varieties to single races of the blast fungus is usually vertical or qualitative, i.e., resistant or susceptible. Rice varieties in fields, how-

ever, exhibit a wide range of quantitative susceptibility; some have a few typical leaf lesions, while others have so many lesions that entire leaves are killed. The experiment on the relation between qualitative and quantitative resistance was continued to determine why or how disease intensity varies among rice varieties in the field.

Three selected lines – IR1514A-E666, IR2031-421, and IR442-2-58 (referred to later as IR1514A, IR2031, and IR442, respectively), representing varieties with very few, moderate, and very many lesions, were selected from the 1973 wet season upland rice variety trial at IRRI. Fungus isolates were prepared from samples collected at random from the field plot. The three test lines were inoculated with 105 isolates and lesion number was recorded. The 12 Philippine differential rice varieties were also inoculated with the same fungal isolates (Table 2).

The relative resistances or susceptibilities (lesion numbers) of the three lines, as evaluated by the 105 inoculations, were similar to those observed in the field. Many pathogenic races of the fungus are present in a diseased field. Rice lines that are resistant to most races had fewer lesions. Quantitative differences in resistance in the field reflect the spectrum of qualitative resistance of the rice lines to blast. Rice varieties with many vertical genes for resistance can phenotypically appear to have horizontal resistance.

Epidemiology of blast. In 1974, several experiments were conducted on the epidemiology of the rice blast disease to gain a better understanding of how climatic factors affect the various disease processes of blast in the tropics and on the basis of such information develop a useful forecasting method. Additionally, perhaps the methods developed in assessing different disease processes, such as rate of sporulation, infection, colonization, and others, may also be used to measure certain types of horizontal resistance to blast.

Effect of temperature and length of the wet period on infection rate. Three-week-old seedlings sprayed with a spore suspension of blast fungus were held in dew chambers of various temperatures for various periods of time. They were removed, dried with a blower, and moved to a greenhouse. The lesions were counted 1 week after inoculation. The favorable temperature range for infection is between 21 and 28°C, with 21–22°C being the

Table 1. Reaction of 12 Philippine differential rice varieties to 26 new races of *Pyricularia oryzae*.

Philippine differential variety	P 230	P 231	P 232	P 233	P 234	P 235	P 236	P 237	P 238	P 239	P 240	P 241	P 242	P 243	P 244	P 245	P 246	P 247	P 248	P 249	P 250	P 251	P 252	P 253	P 254	P 255
Kataktara DA2	R[a]	R	R	R	S	R	R	R	S	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	S
CI 5309	R	R	R	R	R	S	R	S	R	S	R	R	R	R	R	R	R	S	R	S	S	R	R	R	R	R
Chokoto	R	R	R	R	S	S	S	R	R	R	R	R	R	R	R	R	R	S	R	R	S	R	R	S	R	S
Co 25	S	R	R	S	S	R	S	S	R	R	R	S	S	S	R	R	R	R	R	R	R	R	R	R	R	R
Wagwag	R	R	R	S	R	R	R	S	R	R	R	S	R	R	R	S	R	S	R	R	S	R	S	S	S	S
Pai-kan-tao	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	S	R	R	R	R	R
Peta	R	S	R	S	S	S	R	S	R	S	S	S	S	R	R	S	R	S	R	S	S	R	S	R	S	S
Raminad Str. 3	R	R	R	R	S	S	S	S	R	R	R	S	R	R	S	S	R	S	R	R	R	S	S	S	S	S
Taichung T.C.W.C.	R	R	R	S	S	R	R	S	R	R	S	R	S	R	R	R	R	x	S	R	R	R	S	S	S	S
Lacrosse	S	S	S	S	S	S	S	S	R	R	S	R	S	S	S	R	R	S	R	S	S	R	S	S	R	S
Sha-tiao-tsao(s)	R	R	R	S	R	S	R	R	R	R	R	R	S	R	R	S	S	S	R	S	S	R	S	S	R	S
Khao-teh-haeng 17	R	R	R	R	S	S	S	S	S	R	R	R	R	S	R	S	S	S	S	S	S	R	R	S	S	S

[a]R = resistant; S = susceptible.

Table 2. The relative numbers of leaf blast lesions on three selected rice lines in the field, the reaction of the lines to the races and isolates, and numbers of lesions developed by artificial inoculations with 105 isolates.

	Relative susceptibility of selected lines		
	IR442	IR2031	IR1514A
Lesions (av. no.)/tiller in the field (100 tillers)	72.8	36.4	2.9
Lesions (av. no.)/10 tillers by 105 artificial inoculations	35.3	11.0	0.5
Pathogenic races (no.) of the total 26 races	24	17	2
Pathogenic isolates (no.) of the total 105 fungal isolates	94	68	6

Table 3. Effect of temperatures and length of wet period on rice blast disease infection rate on variety KTH 17.

Wet period (h)	Av. no. of type 3 and 4 lesions on 100 leaves[a]			
	Temperature (°C)			
	21–22	26–28	32–34	36–37
4	0	0	0	0
6	29.9	22.9	15.6	0.8
8	49.4	46.4	4.4	2.5
10	94.9	58.2	8.1	5
12	285.1	115.8	12.4	3.8
24	1132.9	551.8	36.2	9.2
Control inside dew chamber (24 h)	0	0	0	0
Control outside dew chamber (24 h)	0	0	0	0

[a]Average of two experiments, each experiment consisting of two replicates with 20 plants each.

most favorable (Table 3). The period of wetness also greatly affects the rate of infection, the longer the period of wetness, up to 24 hours, the greater was the incidence of infection. Appreciable infection occurs at about 12 hours of wetness.

Effect of temperature and relative humidity on colonization. To test post-infection development of rice blast disease, 3-week-old seedlings sprayed with spore suspension and kept in 26°C dew chambers for 24 hours were subjected to limited ranges of constant and fluctuating day/night temperatures in naturally lighted growth cabinets (Koitotron 3 SA-L) in the IRRI phytotron.

Lower temperatures (20–25°C) are more favorable for colonization as well as for infection (Tables 4 and 5). These findings concur more closely with the data of Japanese reports than with those of the United States. Relative humidities between 50 percent and 85 percent did not affect colonization greatly although 85 percent was more favorable than 50 percent. More significant differences may be found in wider ranges of relative humidity.

Disease severity on upland rice. Rice grown under upland conditions is known to be more susceptible to blast damage than rice grown under flooded conditions. The reason for this difference is not well understood. However, the major possible reasons are: 1) change of chemical constituents of the plants, and 2) more meteorological factors that favor the development and growth of the pathogen under upland conditions. Some preliminary experiments were carried out.

In an experiment studying the chemical constituents of rice leaves, about 30 2-week-old seedlings of a susceptible variety, Khao-teh-haeng 17, were each transplanted in 14-inch pots. The plants were divided into two groups; 5 g ammonium sulfate was added to each pot of one group, while the other group received no nitrogen. Within each group, two pots were flooded, two were kept dry (50 centibars), and two were kept very dry (75 centibars). Leaf samples were taken for chemical analysis by the IRRI Chemistry Department 2 months after seeding; the plants were inoculated 1 day after leaf sampling.

Rice grown under dry soil conditions was more susceptible than when grown under flooded soil conditions and there seemed to be a concomitant increase in the plant's susceptibility to the rice blast disease as the soil became drier (Table 6). Both the sugar and protein contents were higher under the dry than under the flooded conditions. Higher contents of nitrogen and carbon in the plants are known to be correlated with higher susceptibility to blast.

In a preliminary study of the influence of meteorological factors, rice variety C4-63G was planted simultaneously in a lowland and in an upland plot (about 250 sq m) adjacent to each other. The same amount of fertilizer was applied to both plots. In addition to these two small field plots, to

Table 4. Effect of constant temperature and of relative humidity on the colonization of rice blast disease on rice differential line KTH 17.

Temperature (°C)	Relative humidity (%)	Lesions (av. no.) on 100 leaves				
		Experiment no.			Total	Av.
Day/night	Day/night	1[a]	2	3		
20/20	75/75	145	709	383	1237	412
25/25	75/75	123	354	382	860	287
30/30	75/75	40	421	294	754	251
35/35	75/75	0	309	59	367	122
26/26	50/50	101	480	396	977	326
26/26	70/70	118	499	407	1025	342
26/26	85/85	135	615	410	1160	387

[a]The spore concentration for experiment 1 is less than normal. Each experiment is the average of 10 replicates; each replicate consists of 100 leaves from 20 plants.

simulate upland rice in lowland environment and lowland rice in an upland environment, seedlings were planted in 10 porcelain pots (531 sq cm) of flooded soils. They were placed in the upland plot (the lower portion of each pot was buried in the soil). Additionally, 10 porcelain pots of upland soils with seedlings were placed in the flooded plot. Preliminary meteorological data on temperature, relative humidity, and dew period within the plant layer of both the upland and flooded plots were taken periodically during July to September.

The blast lesions on leaves and the incidence of neck rot on the panicles (neck blast) were counted at three different times. In both the pots and the plots, the plants grown under upland conditions exhibited more lesions (Table 7). Further studies are needed to determine whether the chemical constituents of plants or climatic factors have the greater influence on the susceptibility of rice to the rice blast disease.

In this study the climatic factors appeared to have a greater influence at the early stages of plant growth (first reading) while the chemical constituents of the rice plant were more influential during the later stages of plant growth. Only slight differences in the temperature and relative humidity between the upland and lowland plots were noted. More significant differences occurred with the dew period between the lowland (11.3 hours) and the upland plot (13 hours). Twelve hours of dew period is critical; more or less than 12 hours may cause considerable differences in disease development with rice blast.

SHEATH BLIGHT

Plant Pathology Department

Yield losses. There is a dearth of information on actual yield losses from sheath blight. Several field experiments during 1973 and 1974 were unsuccessful because other diseases and insects attacked the field plots. The effect of various intensities of the disease on the yield of a moderately susceptible line (IR3265-193-3-4) was investigated in a study in which the rice plants were grown in 14-inch pots and were inoculated at the booting stage by inserting a sclerotium inside the upper portion of leaf sheaths. One to five sheaths of each tiller were inoculated and all tillers in the four hills of each pot were similarly inoculated. The treatments were replicated eight times (eight pots). When all the leaf sheaths and leaves were infected, the yield

Table 5. Effect of fluctuating day and night temperatures on the colonization of rice blast disease on rice differential line KTH 17.

Temperature (°C)	Relative humidity (%)	Type 3 and lesions (no.) on 100 leaves				
		1	2	3	4	Av.
20/15	50/50	82	94	84	55	79
30/20	50/50	58	41	72	27	50
40/30	50/50	32	23	9	6	17
20/15	75/75	90	92	73	93	87
30/20	75/75	87	89	72	54	83
40/30	75/75	17	8	26	18	17

Table 6. Effect of soil moisture on KTH 17 susceptibility to the rice blast disease and on the leaf content of protein and sugar.[a]

Treatment	Lesions[b] (no.) on 100 leaves	H_2O(%)	Total protein (%)	Sugar (%)	
				Total	Reduced
0 N/pot					
Flooded	223.0	76	5.23	2.64	0.33
Dry	729.0	70	6.78	4.09	1.99
Very dry	1477.0	70	7.44	3.64	1.66
5 g $(NH_4)_2SO_4$/pot					
Flooded	427.0	77	6.88	2.74	0.57
Dry	967.0	72	7.73	3.37	1.17
Very dry	1098.0	71	8.23	3.33	1.34

[a]Fully expanded leaf blades (12 leaves/pot) of KTH 17 were sampled 2 months after seeding. The plants were inoculated 1 day after leaf sampling. Both fertilized and unfertilized plants were green, indicating that the soil used was rich in nitrogen.[b] The figures represent the average of two pots.

Table 7. Leaf blast lesions and neck blast in C4-63G rice grown under upland and lowland conditions.

	Leaf lesions[a] (no.) on 100 leaves		Neck blast[b]
	1st reading	2nd reading	Final reading
Upland potted plants in lowland	122.3[b]	387.0	20/92 (21.7%)
Upland plants	36.1	104.3	430/2480 (17.3%)
Lowland potted plants in upland	174.1	275.3	26/182 (14.3%)
Lowland plants	14.6	28.7	202/2366 (8.5%)

[a]Average of 10 replicates; each replicate consisted of 100 leaves from 50 plants. At the first reading the plants were 48 days old and at the second reading they were 74 days old. [b]Neck blast readings were made 2 weeks after flowering.

losses were 25 percent at the lower nitrogen level (30 kg N/ha) and 30 percent at the higher nitrogen level (60 kg N/ha) (Table 8). Whether similar yield losses occur under field conditions will have to be confirmed.

BACTERIAL BLIGHT

Plant Pathology Department

Isabela strain. *Distribution.* In 1972, a more virulent strain of *Xanthomonas oryzae* was isolated in Isabela province, Philippines, which partially broke down the resistance of IR20 and other rice varieties that carry the dominant gene for resistance. Five survey trips were made in Isabela province during 1973 and 1974 to study the distribution of this strain. Although the virulent strain was isolated from many rice areas in Isabela province,

Table 8. Yield losses of a moderately susceptible rice line (IR3265-193-34) from sheath blight in a pot experiment.

Treatment (no. leaf sheaths inoculated)	30 kg N/ha			60 kg N/ha		
	Disease index[a]	Av. grain wt/ plant (g)	Loss (%)	Disease index[a]	Av. grain wt/ plant (g)	Loss (%)
0 control	0	26.8	0	0	34.0	0
1 leaf sheath	3.7	25.9	3	3.9	31.4	8
2 leaf sheaths	3.9	25.1	6	4.9	28.2	17
3 leaf sheaths	4.9	23.5	12	4.9	28.9	15
4 leaf sheaths	5.6	22.8	15	5.8	26.4	22
5 (all) leaf sheaths	6.2	20.2	25	6.5	24.1	30

[a]Disease index is based on percentage area infected varying from 0 (no infection) to 9 (80 to 100 percent infection).

Table 9. Effect of storage conditions and host passage on aggressiveness of highly and weakly virulent isolates of *X. oryzae* from Isabela.

A. Four storage conditions for 16 weeks

Isolate	Lesion length (cm) indicating virulence on IR20 of isolate				
	Original culture	After 16-wk storage			
		−4°C	+4°C	24°C	
				Stored	Transferred weekly
Pxo 63[a]	14	10	13	9	9
Pxo 60[b]	7	5	4	4	2

B. Ten continuous passages through IR8 and IR20

Test variety	Pxo 65[a]			Pxo 66[b]		
	Original culture	Passed through		Original culture	Passed through	
		IR8	IR20		IR8	IR20
IR1545	4	1	2	3	1	1
IR1698	16	3	13	18	3	3
IR20	11	5	2	4	1	2
IR8	15	15	33	17	16	14
TN 1	16	23	38	15	21	17

[a]Highly virulent on IR20. [b]Weakly virulent on IR20.

it was not isolated from the province south of it (Nueva Vizcaya) or the province to the north of it (Cagayan). Some fields in southern Isabela had a high frequency of the Isabela strain and others had only the strain typical to other parts of the Philippines.

Aggressive isolates of *X. oryzae* were identified from specimens sent from other areas in the Philippines – San Miguel, Bulacan province (Luzon); Bukidnon in Mindanao, and near Puerto Princesa in Palawan. Although none of these were quite as aggressive as the Isabela strain, the bacterium appears to show some variation in virulence in several locations in the Philippines.

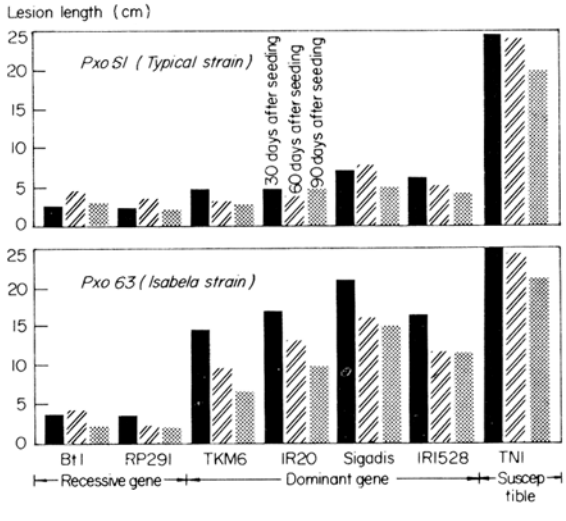
Virulence. IR20, by giving a moderately susceptible reaction, continued to clearly differentiate the Isabela strain. Breeding lines with the recessive source of resistance (IR 1545, RP 291) continued to be resistant to the strain. The Isabela strains were generally slightly less aggressive on IR8 than was the common Philippine strain.

Some virulent isolates remained stable and consistently gave the same reaction pattern after long periods of storage. Isolate Pxo 63 produced lesions with lengths of 13, 9, and 9 cm on IR20 plants after being stored for 16 weeks at 4°C, 24°C, and following weekly transfers, respectively, as compared with 14-cm lesions of the non-stored controls. The respective values for Pxo 60 were 4, 4, and 2 cm compared with 7 cm for the control.

Other isolates lost virulence when stored and when passed through the host (Table 9). All isolates that exhibited weak virulence remained weak and the virulence did not increase through transfer, storage, or passage through the host.

Varietal resistance. All accessions in the IRRI germ plasm bank that are resistant to bacterial blight were inoculated with Pxo 63 in the greenhouse. About 67 percent of the 400 entries was resistant to the Isabela strain. Most of the rice varieties originated from northeast India or Bangladesh, where BJ1, DZ 192, Hashikalmi, and other varieties with the single recessive gene originated. Since these varieties (BJ1, DZ 192, Hashikalmi) are all highly resistant to the Isabela strain, it is possible that the Isabela strain can be used to identify varieties with the recessive gene. Allelic studies are under way to verify this hypothesis.

Plant age was significantly associated with disease expression in rice varieties with the dominant gene for resistance. Such rices were susceptible to Pxo 63 strain at the young stage (30 days) but were less susceptible at the adult stage (fig. 1).



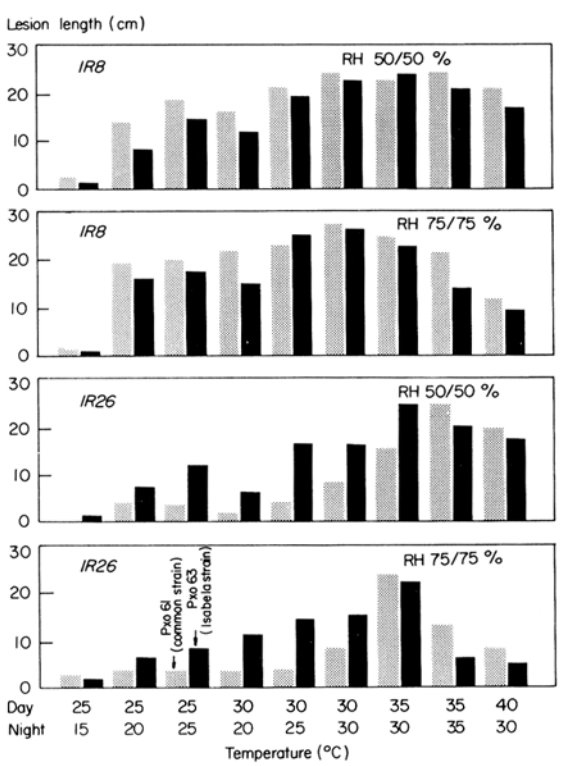
1. Effect of plant age on varieties with the dominant and the recessive gene for resistance when inoculated with the common strain (Pxo 61) and the Isabela strain (Pxo 63).

They were highly resistant to the Pxo 61 strain at all stages of growth. Rice variety TKM 6 was slightly more resistant at all stages of growth to Pxo 61 and other isolates than was Sigadis, indicating that TKM 6 may have some modifying genes which endow it with a slightly broader and stronger resistance than that of Sigadis.

Both BJ1 and RP 291 (BJ1 progeny) had strong resistance against the Isabela strain at all stages of growth.

Spread experiment. In collaboration with scientists at the Cagayan Valley Agricultural Experiment Station in San Mateo, Isabela province, Philippines, a simple field experiment was carried out to evaluate the natural spread of the Isabela strain. Plots of IR20 and IR24 rice were artificially inoculated with both a highly aggressive and a weakly aggressive isolate from Isabela and the natural spread of the disease was observed from the point of inoculation.

IR24, the susceptible variety, developed considerable natural infection after being inoculated with both the common and Isabela strain. However, with the IR20 variety, the infection failed to spread from the inoculation point, suggesting that despite the tissue susceptibility of IR20 to the Isabela isolate, the bacterium was not sufficiently aggressive to spread naturally in the field. This may be due in part to the moderate resistance to the Isabela strain of the mature IR20 plant. The threat by this type of isolate to varieties with the dominant resistant gene appears to be minimal although the situation will be continuously monitored.



2. Effect of temperature and relative humidity on lesion length of bacterial blight in a resistant and susceptible variety of rice.

Environmental influences on bacterial blight development. The effect of temperature, relative humidity, and light intensity on the development of lesions and kresek (incidence of dead seedlings) caused by bacterial blight was studied in growth cabinets in the IRRI phytotron. The temperature was divided into day and night regimes ranging from 15 to 40°C. Two levels of relative humidity were investigated – 50 and 75 percent, the lower and upper range capacity of the phytotron. The effect of light intensity was also studied in an experiment in artificially lighted cabinets. IR8 (susceptible) and IR26 (resistant) rices and two bacterial isolates (Pxo 61 – common Philippine isolate, and Pxo 63 – Isabela isolate) were used.

Relative humidity and temperature. The two levels of relative humidity, 50/50 percent and 75/75 percent (day/night), had no major effect on infection frequency and initial symptom appearance. While high rates of relative humidity (above 90 percent) were not tested, it appeared that the clip inoculation (1973 Annual Report) is effective even under conditions of low relative humidity (fig. 2). This indicates that field inoculation can successfully be made under very dry conditions.

Lesion length and kresek were not notably affected by the two humidity regimes, but were greatly influenced by temperature. In IR8, a wide range of temperature regimes, ranging from 25/20°C to 35/35°C, promoted lesion development (fig. 3). Kresek also developed at these temperature regimes except at 35/35°C with a 75/75 percent relative humidity where no kresek developed. In IR26, however, lesion development was noticeably favored at higher temperatures. The high temperatures appeared to enhance the lesion development on IR26 caused by Pxo 61 as it became more aggressive than Pxo 63.

Table 10. Effect of two light intensities on lesion development of bacterial blight on IR8 and IR26 rices.

Isolate	Light intensity (klx)			
	20	50	20	50
	High relative humidity (80%)		Low relative humidity (40%)	
		IR8		
Pxo 61	25	23	18	22
Pxo 63	20	21	19	24
		IR26		
Pxo 61	4	7	4	8
Pxo 63	9	18	16	14
Av.	14.5	17.2	14.2	17

Light intensity. Light was supplied to the plants for 12 hours daily in the growth cabinet. High light intensity (50 klx) generally favored more disease development than did low light intensity (20 klx) (Table 10). Symptoms appeared about the same time in all treatments. Lesions on diseased plants at low humidity and high light intensity dried up much more quickly than those at low light intensity and low relative humidity.

Effect of nitrogen in leaf tissue on bacterial blight. The increased intensity and area affected by bacterial blight during recent years in the Asian tropics has often been attributed to the application of high levels of nitrogen fertilizer on semidwarf rice varieties. Both genetic susceptibility of many of the new semidwarf varieties and intensive double cropping of rice have also been suggested as contributing to this increase.

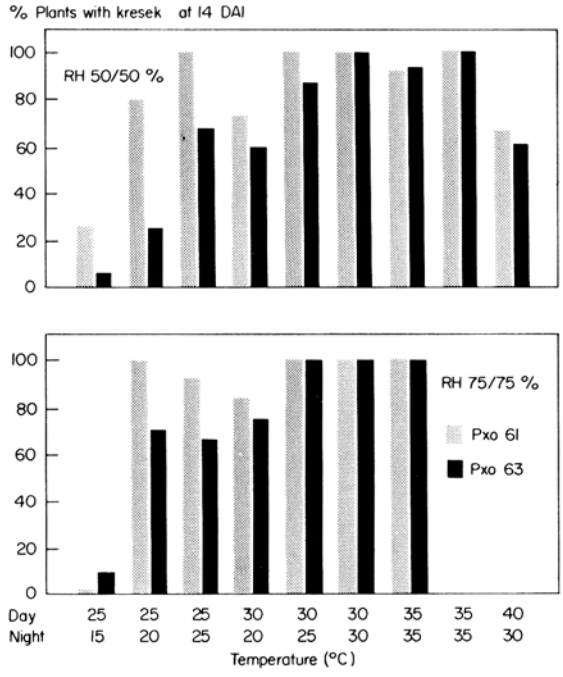
In studying the role that high levels of nitrogen play in the development of bacterial blight in the leaf tissue of susceptible (IR8) and resistant (IR20) rice varieties, two isolates – Pxo 61 (virulent only on IR8) and Pxo 63 (virulent on IR8 and moderately virulent on IR20) – were used. All plants were grown in culture solution in the phytotron glasshouse under controlled day/night temperatures of 32/24°C.

Nitrogen was applied uniformly to all plants at 40 ppm for the first 30 days. Afterwards differential rates were applied – 80 ppm to achieve luxurious growth in the high nitrogen treatment and 20 ppm to induce typical nitrogen deficiency symptoms in plants at the low nitrogen treatments. The nitrogen content of the leaves was measured by the Plant Physiology Department with the standard Kjeldahl procedure.

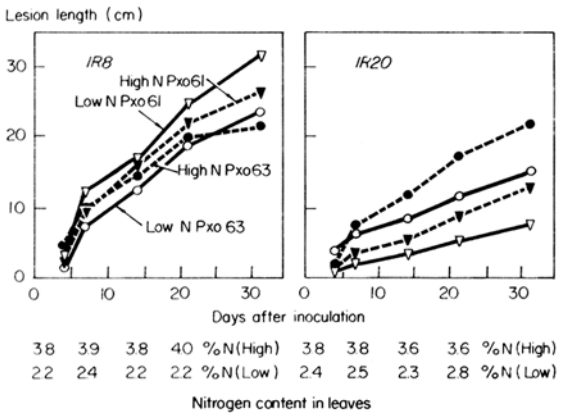
At 70 days after seeding, plants receiving 80 ppm nitrogen averaged 7–8 productive tillers while those receiving 20 ppm nitrogen averaged 2–3 tillers. The nitrogen content of the leaves of both varieties (IR8 and IR20) when receiving 80 ppm nitrogen ranged from 3.6 to 4.0 percent; the leaves of rice plants receiving 20 ppm nitrogen contained from 2.2 to 2.8 percent nitrogen.

The levels of nitrogen in the leaves of IR8 had little effect on lesion development since plants receiving either the high or the low nitrogen level exhibited similar disease development from both isolates (fig. 4).

However, high-nitrogen leaves of IR26 showed considerably more susceptibility than did the low-nitrogen leaves. This indicates that big levels of nitrogen applied to the semidwarf rices may not directly increase disease by making the tissue more susceptible but indirectly by increasing the number of leaves for the bacterium to infect and by changes in microclimate around the plants which favor the disease build-up.



3. Effect of temperature and relative humidity on the proportion of 16-day-old IR8 rice plants with kresek. *DAI = days after inoculation. Kresek = dead seedlings.



4. Effect of high and low nitrogen content in rice leaves on disease development by two isolates of *Xanthomonas oryzae.*

RICE VIRUS DISEASES

Plant Pathology Department

Tungro incidence in Luzon. The epidemiological study of rice tungro disease in farmers' fields in Luzon, Philippines, was continued. Insect vectors were collected and their infectivity was studied, and disease incidence was observed at bi-weekly intervals. The study included 37 fields in 19 municipalities in five Philippine provinces – Bulacan, Laguna, Nueva Ecija, Pampanga, and Tarlac.

The data presented in this section include over 900 field observations made between November 1973 and October 1974; 99 were on seedbeds, 315 at the vegetative stage of the rice plants, 166 at the reproductive stage, 179 on the regenerated growth of rice stubbles, 44 on idle fields, and 101 on plowed fields. Each month, the idle and plowed fields constituted between 6 and 37 percent of the total experimental area observed, with the maximum occurring in June. The rice varieties and lines included in the study were IR1561-228-3-3, IR20, C4-63G, IR26, C12, and others, accounting for 35, 30, 7, 5, 4, and 19 percent, respectively, of the planted fields observed.

Disease incidence. The incidence of tungro disease in the observed area was considerably low, the overall average being 1.2 percent in 759 observations. The disease appeared in the field every month except January, with the highest incidence of 3.1 percent occurring in September, and included both the disease in the rice crop and the disease in the regenerated growth of rice stubbles. The latter constituted a large portion of the monthly disease incidence from November 1973 to May 1974 (fig. 5).

The incidence of tungro disease varied among the provinces and changed with the stage of plant growth, being highest during the reproductive growth. The highest incidence occurred in Tarlac and the lowest in Laguna (Table 11). The incidence of tungro varied among rice varieties and lines and was highest in C12 plantings and second highest in IR1561-228-3-3 plantings (Table 11).

Number of insect vectors. During the study, of the 5,921 tungro vectors collected, 53 percent was *Nephotettix virescens,* 43 percent was *N. nigropictus,* and 4 percent was *Recilia dorsalis.* These were collected from 595 insect collections with 10 sweeps each.

The population of the insect vectors differed from that in 1973 when the number of insects was very low in April, May, and June (1973 Annual Report). The average number of insects per month increased gradually from November 1973 to June 1974, but declined in July and August, probably because of extensive chemical control in the rice fields and heavy rains in August. However, a sharp increased occurred in September 1974. Generally, the number of insects in the field did not appear to be high during the entire study period. On the average, only 3 to 24 insects were collected per 10 sweeps per month.

The population of the insect vectors differed in number and species among the five provinces. The highest average number was recorded in Laguna. The majority of the insects was *N. nigropictus* in Laguna and *N. virescens* in the other four provinces (Table 11).

The number of insects varied with the stage of growth of the rice plants, being higher in seedbeds and in the regenerated growth of rice stubbles than during the vegetative stage of growth (Table 11) and very low in idle fields. The source of insects in the seedbeds may be from rice plants either at the vegetative or reproductive stage of growth or from the regenerated growth of rice stubbles. The insects in the seedbeds probably did not migrate from idle fields since the number of insect vectors in idle fields was very low, particularly the *N. virescens* and *R. dorsalis* species. Hence, immedi-

ately after the off-crop period, the insects in the seedbeds may originate mainly from the regenerated growth of rice stubbles.

The numbers of adults and nymphs of the insect vectors varied according to the time of the year. Generally, more adults were collected by sweeps from March to October. The overall average ratio of insect adults to nymphs was 64:36 for *N. virescens* and 79:21 for *N. nigropictus.*

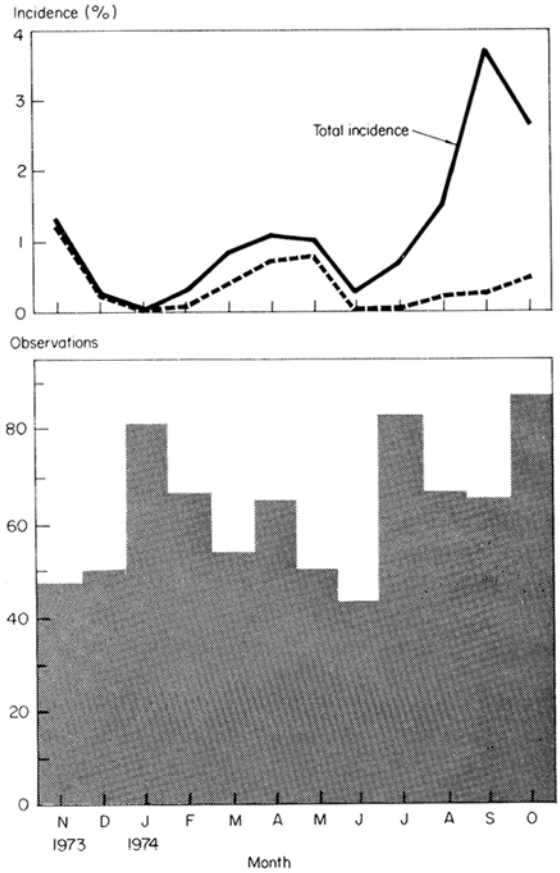
The field with diseased plants generally had more insect vectors: 32 and 6 *N. virescens* per 10 sweeps for seedbeds with and without tungro disease, respectively; 10 and 3 *N. virescens* per 10 sweeps for fields with and without disease at the vegetative stage of plant growth, respectively; and 11 and 4 *N. virescens* per 10 sweeps for fields of regenerated growth of rice stubbles with and without tungro, respectively. A similar trend was found with *N. nigropictus.*

Infective insects. The percentage of infective insects ranged from 0.3 to 5.7, varying from month to month. The highest occurred in November and December 1973. From January to October, it ranged from 0.3 to 3.0 percent. Among the five provinces, Nueva Ecija had the highest percentage of infective insects. The percentage of infective insects was higher in the field of regenerated growth of rice stubbles than in the seedbeds or in the fields of rice plants at the vegetative stage. It ranged between 0.3 and 2.0 percent among rice varieties (Table 11).

The percentage of infective insects differed among the three species of insect vectors. Of the 10,500 insects tested, only 122 were infective; 1.6 percent of which was *N. virescens,* 0.6 percent *N. nigropictus,* and 1.3 percent *R. dorsalis.* Of the 122 infective insects 70, 23, and 7 percent were *N. virescens, N. nigropictus,* and *R. dorsalis,* respectively.

Fields with tungro disease generally contained a higher percentage of infective insects, particularly those with regenerated growth of rice stubble. The ratoon field with tungro disease gave an average of 5.3 percent of infective *N. virescens* while the field without the disease had 1.9 percent.

Tungro vectors in IRRI farm fields. The program of collecting insect vectors of rice tungro disease by a light trap at the IRRI farm on every Tuesday evening from 1700 hours until 2 hours after sunset was continued. Between November 1973 and October 1974 the number of insect vectors caught in the light trap varied from month to month and among the species of insect vectors (Table 12). For *N. virescens,* the highest number of insects collected in 1 month occurred in March, for *N. nigropictus* in May, and for *R. dorsalis* in October. The highest numbers of these insects by a single light trap were 19,274 *N. virescens* on March 26th; 19,550 *N. nigropictus* on May 7th; and 3,673 *R. dorsalis* on October 29th. Of the more than 3,600 insects tested, only 53 were infective, ranging between 0 and 4.4 percent for different months.



5. Tungro incidence in Luzon (broken line shows the disease on the regenerated growth of rice stubbles).

The difference in percentage of infective insects between 1973 (November 1972 to October 1973) and 1974 (November 1973 to October 1974) was very small – 1.3 versus 1.5 percent – but the number of insects, regardless of species, trapped in 1974 was more than three times higher than

Table 11. Tungro incidence and insect vectors in Luzon, Philippines, classified by province, condition of the field or stage of growth of the rice plant, and variety between November 1973 and October 1974.

Designation	Observations (no.)	Tungro incidence (%)	Vectors			Infective vectors	
			Collections (no.)	Av. no. per 10 sweeps	Ratio[a]	No. tested	%
Bulacan	258	1.19	194	12.5	60:35:5	3311	0.94
Laguna	183	0.01	108	14.1	30:68:2	2106	0.57
Nueva Ecija	114	1.62	88	8.2	62:32:6	1620	3.15
Pampanga	152	0.21	83	5.5	70:26:4	1235	0.57
Tarlac	197	2.81	122	6.5	57:37:6	2289	0.92
Seedbed	99	0.03	91	13.9	56:33:11	1832	0.82
Vegetative	315	1.02	282	7.9	60:37:3	5538	0.72
Reproductive	166	2.01	0	–	–	0	–
Regenerated	179	1.39	178	13.2	46:51:3	3078	2.18
Idle	44	0	44	1.4	1:99:0	113	0
C4-63G	49	0.26	36	5.2	42:52:6	682	0.29
C12	32	2.94	25	12.3	81:17:2	615	1.30
IR20	228	0.14	168	5.3	51:43:6	2226	1.17
IR26	41	0.48	30	8.9	59:32:9	696	1.01
IR1561-228-3-3	267	2.24	190	17.6	49:47:4	4127	0.87
Others	142	1.07	102	8.4	61:34:5	2102	2.05

[a]Ratio: *Nephottetix virescens: N. nigropictus: Recilia dorsalis* (in %).

that in 1973. Nevertheless, the populations of insect vectors of tungro in 1973 and 1974 did not cause an outbreak of tungro disease on the IRRI farm.

Quality of tungro source. The percentage of infective *N. virescens* after an acquisition feeding on diseased plants differs among rice varieties (1973 Annual Report). The effect of the quality of the virus source on the incidence of tungro disease was, therefore, determined by the cage method (1972 Annual Report). The average percentage of TN1 seedlings that became infected when diseased plants of C4-63G, IR20, IR22, and TN1 served as the virus source, was 32, 29, 63, and 71, respectively. The differences between varieties were statistically significant except between C4-63G and IR20 and between IR22 and TN1. Consequently, the incidence of tungro disease was affected by the quality of the virus source. The diseased IR22 and TN1 plants were better virus sources than were C4-63G and IR20.

Effect of temperature on tungro virus transmission. Environment is one of the factors that affect the transmission of a virus from a diseased to a healthy plant by an insect vector. One environmental factor, temperature, may affect the ability of the insect to acquire and to transmit the virus. Therefore, the effect of temperature on the transmission of tungro virus by *N. virescens* was studied under controlled conditions in the IRRI phytotron.

Life span of viruliferous insects. The life span of tungro-viruliferous adults of *N. virescens* varied under different constant temperatures, increasing with decreasing temperatures between 34 and 13°C. Of the 1,280 viruliferous insects tested, the longest life span was 118, 76, 28, and 18 days, giving an average of 34.2, 18.5, 13.0, and 8.2 days at 13, 20, 27, and 34°C, respectively. The difference between any two temperatures was statistically significant at the 1-percent level.

Acquisition feeding. The effect of temperature on acquisition feeding of 4,649 *N. virescens* was assessed by determining the degree of infectivity of the insects after they had been confined on diseased plants under different constant temperatures for 1 to 4 days. The insects acquired the virus from diseased plants at temperatures ranging

Table 12. Average number of tungro disease vectors collected per month by light trap on the IRRI farm between 1700 hours and 2 hours after sunset.

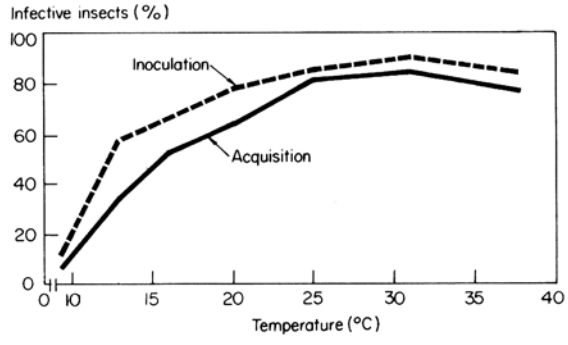
Month	Insects (av. no./collection)			Infective insects (%)
	N. virescens	*N. nigropictus*	*R. dorsalis*	
November 1973	17	16	46	0
December	15	62	3	3.1
January 1974	6	10	1	3.8
February	52	27	2	0.4
March	4888	55	17	0.6
April	78	47	39	1.2
May	857	4571	613	1.3
June	67	414	47	0.3
July	717	910	44	0.7
August	18	21	23	1.4
September	2588	355	249	4.4
October	2141	1483	889	0
Av.	954	664	164	1.5

from 10 to 38°C. However, the percentage of the insects that acquired the virus varied with the ambient temperature. The percentage increased gradually with temperature from 10 to 31°C, but decreased slightly between 31 and 38°C (fig. 6). There seemed to be no marked difference in the percentage of insects that acquired the virus between 25 and 38°C.

Inoculation feeding. The effect of temperature on inoculation feeding of tungro-viruliferous *N. virescens* was assayed by measuring the percentage of infected seedlings after the seedlings had been exposed to individual viruliferous insects at different temperatures for 24 hours. The 1,201 insects transmitted the virus to seedlings at various temperatures between 10 and 38°C. The percentage of infected seedlings increased with increasing temperature from 10 to 32°C, but decreased slightly between 31 and 38°C. The percentage of infected seedlings recorded between 20 and 38°C (fig. 6) did not differ markedly.

Seedling infection. Except for extremely low temperatures, temperature did not have a marked effect on the transmission (acquisition and inoculation) of tungro virus by the vector *N. virescens.* Apparently, temperature will not ordinarily be a major factor limiting the outbreak of tungro in rice fields under natural conditions in a tropical region where the minimum temperature is rarely lower than 20°C. For instance, the highest and the lowest temperatures recorded in Los Baños during the last 25 years were 37.8 and 15.6°C, respectively. The seedling infection under three different temperature regimes (day-night temperatures of 24–16, 27–19, and 30–22°C, 12 hours each daily) was therefore studied by the cage method (1972 Annual Report) for verification.

The percentage of seedling infection was affected by both the temperature and the amount of virus source. When four pots of diseased plants served as the virus source in a 16-pot cage, the differences in the percentage of infected seedlings among the



6. Effect of temperature on the transmission (acquisition and inoculation) of tungro virus by *Nephotettix virescens.*

three temperature regimes were not statistically significant. However, there was a trend towards an increased percentage of infected seedlings as the temperature was increased, and the difference in the percentage of infected seedlings between the lowest and the highest temperature regimes was about 11. When the virus source was reduced to one pot of diseased plants in a 16-pot cage, the difference in percentage of seedling infection was statistically significant between the temperature regimes of 30–22°C and 24–16°C. Consequently, a slight to moderate difference in temperature may not markedly affect the spread of tungro disease, particularly when the amount of the virus source in a field is adequate.

Infected seedlings per insect. Thirty is the maximum number of seedlings that an infective *N. virescens* can infect with tungro daily when the insect is transferred successively from seedling to seedling at 30-minute intervals (1973 Annual Report). A total of 320 viruliferous insects were exposed to 6,400 seedlings by transferring the insects individually and successively under four constant temperatures at 30-minute intervals from 0800 to 1800 hours. Eighty of the seedlings died before symptom development.

Both average and maximum percentages of infected seedlings increased gradually with increasing temperature from 13 to 34°C, but the minimum was the same in all the four test temperatures – 13, 20, 27, 34°C. On the basis of the obtained percentages of infected seedlings and assuming the infectivity of the insects for the first 10-hour period remains unchanged for the rest of the day, an insect infected 8.5, 15.3 15.8, and 18.5 seedlings per day at 13, 20, 27, and 34°C, respectively. The maximum number of seedlings infected by one insect daily at 34°C was 40.4 higher than at other temperatures. Apparently, the insects can infect more seedlings with tungro under favorable temperatures. Although the present figure is much higher than the figures obtained in 1973 (30.3 infected seedlings daily), it is much smaller than the theoretical maximum – 288 infected seedlings/insect daily – calculated on the basis of the shortest inoculation access time for positive transmission, obtained in a transmission test.

Retention at 7°C. The tungro virus does not persist in insect vectors; the infectivity of the insects decreases gradually with time after acquisition feeding. While the retention period varies among insects, it is affected by the initial amount of virus in the insects after acquisition feeding and the rate of loss of the virus in the insects. The longest retention period obtained in the Philippines was 5 days. To determine whether the infectivity of the insects can be retained at a low temperature, 468 viruliferous *N. virescens* adults from a same colony were transferred individually to seedlings once every day for 3 consecutive days. They were subjected to four treatments consisting of confinement of the insects at 7°C for 1 or 2 days either immediately after or 1 day after acquisition feeding. The insects serving as the checks were maintained continuously at room temperature.

The infectivity of the insects did not change much when the insects were kept at 7°C or at least had a much lower rate than the insects kept at room temperature (fig. 7). The insects were kept at 7°C for 1 day; their infectivity on the following day was much higher than that of the check insects that were held at room temperature for the same number of days after acquisition feeding. When the insects were kept at 7°C for 2 days, the infectivity of the insects on the third day was markedly higher than that of the check on the third day or than that of insects kept only 1 day at 7°C. However, once the insects moved to the room temperature, their infectivity decreased as usual. Consequently, holding the insects at 7°C could not increase their infectivity, nor could it change the nonpersistent nature of the virus in *N. virescens.*

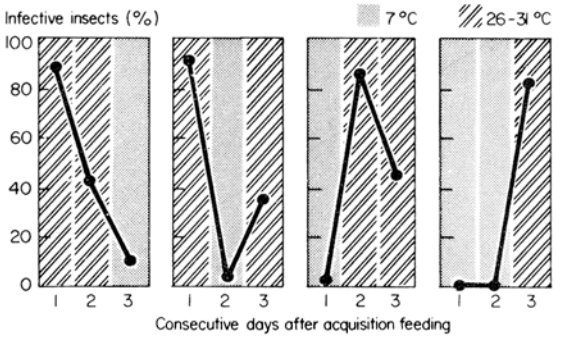
Movement of viruliferous *N. virescens.* The spread of tungro disease in a field by an infective *N. virescens* depends primarily on its movement. The movement of a tungro-viruliferous insect can be initiated by direct or indirect stimulus, conditioned by intrinsic factors, and influenced by external environmental agents. Since the stimulus received by the insect causing it to move is not clearly known and since it is difficult to trace the stimulus under almost uncontrolled conditions, the study concentrated on the occurrence of movement of the insect at hourly intervals after the insect was confined in a cage with rice seedlings.

The movement of a tungro-viruliferous *N. virescens* includes any change of place, position, or posture of the insect. The movement in relation

to a rice plant can be categorized: 1) movement from one part of a rice plant to another, 2) movement from one rice plant to another either adjacent to it or away from it – "seedling-to-seedling" movement, 3) movement from one rice plant to another plant host or non-host or a non-plant location – "off-seedling" movement, and 4) movement from a non-rice plant location to a rice plant – "back-to-seedling" movement. However, not every kind of movement spreads the disease. For instance, if a viruliferous insect moves only from one part of a plant to another for the rest of its life, the insect can infect only one rice plant. Hence, the disease would not spread. The movement of a viruliferous insect between rice plants spreads the disease and the frequency of such movement affects the rate of disease spread. If all viruliferous insects performed the "off-seedling" movement, no additional infection of rice plant would occur. Only the incoming viruliferous insects that move to rice plants from outside of a rice field (back-to-seedling movement) can introduce the virus into a non-infected rice field. Obviously only the movement of category 1 neither increases nor reduces the number of infected seedlings. Such movement was not monitored in the study.

The movement of tungro-viruliferous *N. virescens* adults were studied by observing the location of the insects at hourly intervals from 800 to 1700 hours after the insects were confined individually in cages with IR8 or TN1 rice seedlings. Twenty adults were used for each rice variety for each test made on the same date. The test was repeated 11 times. Data on 237 insects on IR8 seedlings and on 238 insects on TN1 seedlings were recorded. An additional 23 tests, with 20 to 40 viruliferous insects per test, on seedlings of TN1 seedlings, were made. The data of all tests, 1,072 viruliferous insects on TN1 seedlings, were used to check the variation of the movement of the insects on the same variety as well as to represent the movement of the insect on seedlings of the variety.

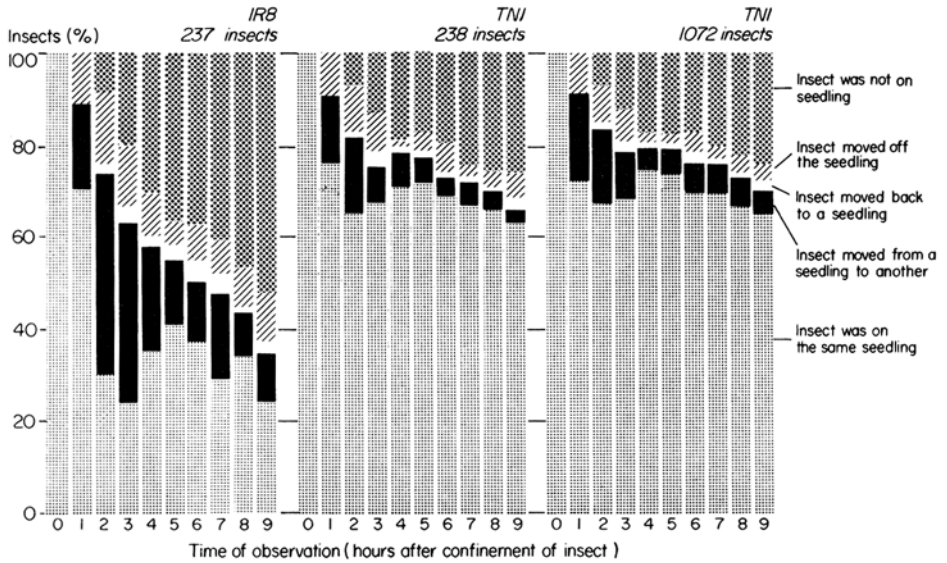
Since a single parameter may not express all necessary information concerning the movement of the viruliferous insects, the data were compiled in different ways to illustrate various aspects of movement. Because insect movement was observed only once every hour, insect movement between two observations could not be traced. Thus, while



7. Daily percentage of tungro-infective *Nephotettix virescens* adults showing the nonpersistent nature of the virus in the vector, difference in transmission between the two temperature regimes, and retention of infectivity of the insects at 7°C.

an insect may not have been observed to move at the hourly recording time, it could have moved within the hour. Similarly, although the data indicated that an insect moved from one seedling to another, the insect may, in fact, have visited other seedlings before reaching the particular seedling on which it was found at the hourly observation time. Moreover, unless the insect moved exactly at the time of observation, the duration of the insect's visit at the last visited seedling was recorded longer than the actual duration of the visit. On the contrary, the duration of the visit to a newly visited seedling was recorded as being shorter than it actually was. However, the maximum error in the duration of an insect's visit on a seedling never exceeded 1 hour.

How many insects moved. The number of viruliferous *N. virescens* adults that moved after being caged with seedlings varied according to the variety (IR8 or TN1) and the time duration (an hour or longer). On seedlings of IR8, at hourly intervals, there were 19.6 to 61.1 percent, or an average of 33.7 percent, of 237 viruliferous insects that moved. The remainder did not move; they were either on seedlings or outside of the seedlings. An average of 14.4 percent of 238 viruliferous insects caged with TN1 seedlings moved at hourly intervals, ranging between 8.8 and 27.2 percent. The difference between the two averages was statistically significant. The test of 1,072 viruliferous insects on seedlings of TN1 indicated that 8.6 to 28.6 percent, with an average of 15.2 percent, of the insects moved (fig. 8).



8. Percentage of tungro-viruliferous *Nephotettix virescens* adults in various categories of movement at hourly intervals after the insects were individually confined in cages with seedlings of IR8 or TN1.

Apparently, there were always some insects that moved at each hourly interval regardless of whether the insects were confined with IR8 or TN1 seedlings. However, the percentage of insects that moved on IR8 seedlings was higher. On an hourly average, about 65 and 85 percent of the insects on seedlings of IR8 and TN1, respectively, did not move. The insects that moved can be categorized according to type of movement: about 60 percent, from seedling-to-seedling; 30 percent, off-seedling; and 10 percent, back-to-seedling.

The longer the time given to an insect, the greater is its chance not only to move but also to make more movements. During the whole testing period of 9 hours, 97.9 percent of the viruliferous insects on seedlings of IR8 moved, while only 63.8 and 64.8 percent of 238 and 1,072 viruliferous insects on seedlings of TN1 moved, respectively. On IR8 seedlings, about 40 percent of the insects that moved made two kinds of movement, seedling-to-seedling and off-seedling. On TN1 seedlings, about 40 percent of the insects that moved made only the seedling-to-seedling movement. About 74 and 41 percent of the insects on seedlings of IR8 and TN1, respectively, made either the off-seedling or off-seedling and back-to-seedling movement, and these two movements could be considered as somewhat long-distance movements although the insects moved only about 25 cm. Insect movement was limited by the size of the cage used for the study. Consequently, more insects on IR8 seedlings made such long-distance movements.

When the insects moved. The insects could move any time. However, the percentages of the insects that moved were not the same at hourly intervals. The two highest percentages of the insects that moved on seedlings of IR8 were 61.1, and 55.8, occurring at the second and third hours after the insects were confined individually in cages, respectively. On seedlings of TN1, two highest percentages were 24.3 and 27.2 percent of 238 insects and 28.6 and 25.9 percent of 1,072 insects that moved at the first and second hours after confinement, respectively (fig. 8). Regardless of whether the insects were caged with IR8 or with TN1, the low percentages of insects that moved occurred at the fourth hour after confinement.

Frequency of insect movement. The movement of the viruliferous insects was observed only once every hour from 0800 to 1700 hours; thus, the insect could have only one movement per hour and a maximum of nine moves per day.

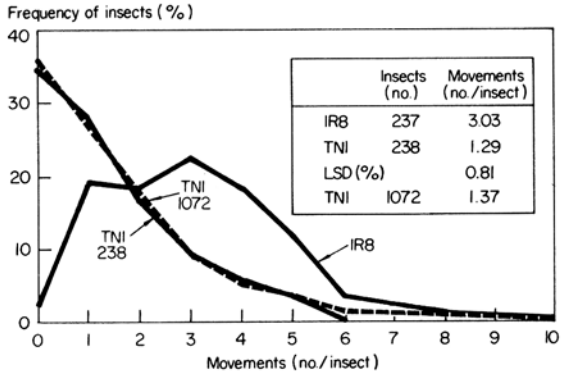
During the whole testing period of 9 hours, the number of movements varied among individual insects, ranging from 0 to 8 for the insects on IR8

seedlings. On TN1 seedlings, the number ranged from 0 to 5 for the 238 insects and between 0 and 9 for the 1,072 insects. The differences in the ranges of the insects on TN1 seedlings could be due to sample size. About 80 and 60 percent of the insects on IR8 and TN1 seedlings, respectively, made one to four moves. Consequently, the frequency of tungro-viruliferous *N. virescens* by number of movements on IR8 and TN1 seedlings was different (fig. 9). The average numbers of movements per insect in 9 hours were 3.03 and 1.29 for insects on IR8 and TN1 seedlings, respectively, and this difference was statistically significant. A higher proportion of the movements per insect on both IR8 and TN1 seedlings was the seedling-to-seedling movement.

The numbers of movements per insect that moved in 9 hours were 3.08 and 1.99 for the insects on IR8 and TN1 seedlings, respectively. Apparently, the frequency of movement of tungro-viruliferous *N. virescens* during a 9-hour period varied according to the variety of rice used. The insects moved more frequently on IR8 seedlings than on TN1 seedlings.

Manner of insect movement. More insects moved from seedling to seedling and generally the insects made more seedling-to-seedling movements than other types of movements. Because the insects were initially confined on seedlings, they could not have made a back-to-seedling movement without first making an "off-seedling" movement. The amounts of back-to-seedling movements of those insects that moved off IR8 and TN1 seedlings were similar – 67.1 and 71.9 percent, respectively.

Interval between two insect movements. The more movements an insect makes in a given time, the shorter is the interval between two movements. In the experiments conducted at IRRI in 1974, the theoretically shortest and longest intervals were 1 and 9 hours, respectively. The average interval between two movements for insects on IR8 and TN1 seedlings were different – 1.85 and 2.69 hours, respectively. The frequency distribution of the intervals by duration in hours indicated that 59.7 and 29.0 percent of the intervals for the insects on IR8 seedlings were 1 and 2 hours, respectively. For the insects on the TN1 seedlings 36.5 and 26.5 percent of the intervals between two insect movements were 1 and 2 hours, respectively.



9. Frequency of tungro-viruliferous *Nephotettix virescens* by number of movements after the insects were individually confined in cages with seedlings of IR8 or TN1, observed hourly from 800 to 1700 hours.

Distance of insect movements between seedlings. When a viruliferous *N. virescens* moved from one seedling to another it did not always start from a seedling at a definite location in a pot. Therefore, the distance and direction of movement of the insect from seedling to seedling were limited by the location of the seedling from where the insect started to move to another seedling. The insect could move from a seedling to another seedling in any direction and at any distance in a pot regardless of whether the insect was on seedlings of IR8 or TN1; usually a higher percentage of insect movements was between adjacent seedlings. About 47 and 59 percent of the between-seedlings movements of insects on IR8 and TN1 seedlings, respectively, were between adjacent seedlings. As the distance increased (number of seedlings between the insect's seedling-to-seedling movement), the frequency of these movements decreased; 33.2, 12.6, and 6.7 percent of the *N. virescens* seedling-to-seedling movements on IR8 were between seedlings separated by one (every other one), two, and three seedlings, respectively. The respective percentages for insects on TN1 seedlings were 25.3, 12.6, and 2.7.

Duration of insect's visit on seedlings. The viruliferous insects were not always on seedlings of IR8 or TN1 at hourly observations, except immediately after confinement. Thus, both the percentage of the insects on seedlings and the duration of their visit on seedlings varied. The visiting duration of the insect described the duration of the insect's visit on a rice seedling. The number of

seedlings visited per insect may not be equal to the number of movements of seedling to seedling plus back to seedling plus one seedling where the insect was initially introduced because the insect may move back to the seedling that was visited previously.

The insects were on seedlings at the beginning of the test; some remained on the seedlings and others moved off the seedlings. Some of the insects that moved off the seedlings moved back to seedlings, others did not. The percentage of insects on seedlings of both IR8 and TN1 decreased gradually with increasing time after confinement of the insects. However, more insects confined on TN1 seedlings stayed on the seedlings than the insects confined on IR8 seedlings, with the hourly average of insects on IR8 and TN1 seedlings being 63.7 and 79.4 percent, respectively. Thus, the duration of the insects' visits on TN1 seedlings was longer – 4.82 hours compared with 2.09 hours for the visiting duration of insects on IR8 seedlings.

The insects confined on IR8 seedlings moved more often from seedling to seedling, and thus, the number of seedlings visited per insect in 9 hours was significantly higher than that of the insects on TN1 seedlings (3.09 as compared with 1.78 seedlings per insect).

Seedling infection. Of the 25 seedlings exposed to each tungro-viruliferous insect in a test, only one to eight seedlings of both IR8 and TN1 were visited by an insect in a 9-hour period. Of those seedlings visited by an insect, 10.0 percent of IR8 and 46.3 percent of TN1 seedlings became infected.

The average number of infected seedlings per insect was significantly lower for IR8 seedlings than for TN1 seedlings – 0.27 compared with 0.70 – because more insects on the TN1 seedlings were infective. An infective insect actually transmits the disease.

Not every seedling visited by an infective insect becomes infected although the reason is not clear. The infective insects visited as few as one and as many as six IR8 seedlings in a 9-hour test period, with most visiting two to four seedlings, or an average of 3.13 seedlings visited per infective insect. Each infective insect on TN1 seedlings visited one to five seedlings during the 9-hour test, with the majority visiting only one or two seedlings, or an average of 1.78 seedlings. Of the IR8 seedlings visited by an insect only one to three became infected, and one to four of the TN1 seedlings visited by insects became infected (Table 13). The numbers of infected seedlings per insect on IR8 (1.17) and TN1 (1.23) seedlings were not significantly different. Thus, the infective insects transmitted the disease at almost the same level of efficiency on the seedlings of both rice varieties.

Of 511 infective insects tested, only one caused tungro infection in four TN1 seedlings in a 9-hour period. This is the largest number of infected seedlings per insect obtained, and suggests that a maximum number of seedlings infected by one insect with the tungro virus is 11. This assumes that the activity and infectivity of the insect for the first 9 hours remain unchanged throughout the day. This figure is considerably smaller than the highest number of infected seedlings per insect per day obtained by serial transfer of the insect at 30-minute intervals at 34°C, as previously discussed.

The infective insects did not visit the seedlings at the same time after their confinement. The infected IR8 and TN1 seedlings were visited by the insects for the first time between 0 and 7 and 0 and 9 hours after their confinement, respectively. At 0, 2, 3, and 5 hours after the confinement of the insects, 42, 10, 18, and 16 percent, respectively, of the IR8 infected seedlings were first visited by the infective insects. The rest of the infected seedlings were first visited by the insects at other times. On the other hand, about 60 percent of the infected TN1 seedlings were first visited by the insects immediately after their confinement; the rest, at other times, but the percentage decreased gradually with increasing time after the confinement of the insect.

Insects' visiting duration and seedling infection. The percentage of tungro-infected seedlings increases gradually as the inoculation access time lengthens from 1 to 9 hours (1972 Annual Report). The inoculation access time, previously known as inoculation feeding period, refers to the length of time a vector is allowed to spend on a test plant in transmission experiments. The duration of the insect's visit is equivalent to the inoculation access time as far as the transmission of the virus is concerned, and thus, affects seedling infection.

The duration of the insect's visit on seedlings that became infected varied because of the insect's

movements. The average duration of an insect's visit on TN1 infected seedlings was almost two-fold longer than that on IR8 seedlings – 6.18 and 3.30 hours, respectively. The difference in percentage of infected seedlings between the two rice varieties may be related to the length of the insect's visiting duration, but the difference in susceptibility to the tungro disease between these two rices cannot be discounted.

A comparison of the duration of the insect's visit on infected and non-infected seedlings of the same rice variety shows that regardless of the rice variety tested, generally the average duration of an insect's visit on a seedling that became infected with tungro was significantly longer than that on a seedling that did not become infected – 3.30 and 1.93 hours per IR8 seedling and 6.62 and 3.62 hours per TN1 seedling that became infected and did not become infected, respectively.

Significance of insect movement. IR8 seedlings are resistant to the colony of *N. virescens* reared on TN1 rice plants in cages under Los Baños, Philippines, conditions. The percentage of infected seedlings varied according to method of inoculation. When seedlings were inoculated individually in test tubes by viruliferous insects, where the insects could not move from a seedling to another, 86 and 97 percent of IR8 and TN1 seedlings became infected, respectively. On the contrary, when the seedlings were confined in cages together with the insects and diseased TN1 plants as the virus source, where the insects could move freely from a seedling to another, 22 and 68 percent of IR8 and TN1 seedlings became infected. The difference in percentage of infected seedlings of IR8 between the two methods of testing was greater than that of TN1. Similarly, IR8 often showed a resistant reaction to tungro in a field, particularly in early years when the insects had not developed the adaptability to the variety under natural conditions.

The field resistance of IR8 is definitely related to its resistance to *N. virescens.* In a large field of IR8, its field resistance to tungro could be explained by the mechanism of antibiosis of the variety on the insect, particularly when the insect population in the field was low. Antibiosis was proposed for those adverse effects on the insect's life history which result when a resistant host-plant variety or species is used as a food source. The mechanism of antibiosis may not be applicable to the field resistance of IR8 to tungro in a small field trial with different rice varieties because the viruliferous insects should have an equal chance to visit each variety. The reason for the field resistance of IR8 in this particular case remained unexplained for the last several years. The 1974 investigations have shown that since the insect moves often on seedlings of IR8, it visits more IR8 seedlings. Consequently, within a given time, the duration of the visit per seedling becomes shorter. Since shorter visits by viruliferous insects result in a low percentage of infected seedlings, a plausible reason for the field resistance to tungro of IR8 could be the shorter duration of the insect's visit per seedling in the field, as compared with that of the seedlings inoculated artificially in the greenhouse where the insect either does not have a chance to move or does not have a chance to move to the seedlings of other rice varieties. Consequently, one of the reasons for the field resistance of a rice variety to tungro disease might be related to the duration of the insect's visit per seedling visited which is shorter because of the insect's frequent movement. The frequent movement of the insect could be the result of the mechanism of non-preference of the insect for the variety.

Table 13. Frequency distribution of tungro-infective *Nephotettix virescens* by number of seedlings of IR8 or TN1 visited by an insect in 9 hours and number of seedlings infected.

Infected seedlings (no.)	Frequency distribution (%)						
	Seedlings (no.) visited						Total
	1	2	3	4	5	6	
	IR8 (52 infective insects)						
1	9.6	21.2	19.2	19.2	11.6	1.9	82.7
2		5.8	1.9	3.9	0	1.9	13.5
3			1.9	1.9	0	0	3.3
4				0	0	0	0
Total	9.6	27.0	23.0	25.0	11.6	3.8	100.0
	TN1 (459 infective insects)						
1	53.8	18.3	7.8	3.3	0.9	0	84.1
2		7.0	4.6	1.3	1.3	0	14.2
3			0.2	0.9	0.4	0	1.5
4				0.2	0	0	0.2
Total	53.8	25.3	12.6	5.7	2.6	0	100.0

Grassy stunt vectors in IRRI farm. The average number of *Nilaparvata lugens* trapped by light per

collection was 1,400 in November, 1973; 31 in December; 17 in January, 1974; 339 in February; 7,259 in March; 335 in April, 230 in May; 23 in June; 75 in July; 77 in August; 863 in September and 3,693 in October. The infective insects varied from 0.4% to 7.3% during the period.

A comparison of the 1973 data (November 1972 to October 1973) with the 1974 data (November 1973 to October 1974) indicated that the overall percentages of infective insects (3.4 percent versus 2.2 percent) did not differ markedly, but the number of insects (av. 8,912 per collection) in 1973 was about 7.5 times higher than that (1,195 per collection) in 1974. An outbreak of the disease occurred in 1973 (1973 Annual Report) but not in 1974. Although a number of factors determine an outbreak of grassy stunt disease, the difference in the number of insects between 1973 and 1974 suggests that the insect population might be a more important factor contributing to the outbreak of the grassy stunt disease than the percentage of infective insects.

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SUMMARY

Chlordimeform and Perthane insecticides effectively controlled the brown planthopper, both by contact toxicity and, although slowly, by foliar sprays. In the field these two compounds and carbophenothion controlled the planthoppers when sprayed regularly on the base of the plants.

A gas-liquid chromatographic analysis showed that the amount of carbofuran residue in the paddy water was low after an insecticide capsule was placed in the root zone of each hill. However, the concentration in the roots and shoots of the plant was high and reached a maximum about 20 days after treatment. Then, it declined to a low level 100 days after application. This suggests a low residual hazard in the harvested crop with high insect control efficiency during crop growth.

Carbofuran gave better pest control when it was applied at the root zone at each hill or when the granules were incorporated into the soil than when the granules were broadcast or when the capsules were placed at the center of four hills. Other methods of application that gave a level of pest control similar to that obtained by placement at each hill were the injection of a slurry at each hill and the injection of a slurry or liquid in a band between rows.

When either carbofuran or chlordimeform were injected, at 1 kg active ingredient (a.i.)/ha, only once into the root zone of IR26 rice along with a fertilizer slurry at 3 days after transplanting, the grain yield was significantly greater than that of the untreated control, and the same as that of the treated control (2 kg a.i./ha – carbofuran granules broadcast every 20 days).

Two commercial preparations of *Bacillus thuringiensis* sprayed on rice plants killed leaf folder larvae within 5 days. Caging two predators (*Cyrtorhinus lividipennis*) with 50 or 100 prey (*Nephotettix virescens*) at the start of three generations reduced the density of *N. virescens* over time by 34 to 42 percent. Over a 3-day period a single predatory spider, *Lycosa pseudoannulata,* killed at least 25 nymphs of caged *Nilaparvata lugens* prey daily or 15 or more adults per day when 100 planthoppers were available.

Damage by rice whorl maggots increased with wider spacings, and caused a significant yield loss at 30- × 30-cm and 40- × 40-cm spacings. The damage was reduced by broadcasting the seed or by spacing the transplanted seedlings close together.

Plant resistance in IR26 rice to brown planthoppers and grassy stunt virus reduced the need for insecticide application, but insecticidal protection from whorl maggot damage was still required for a high yield. Of the many foliar sprays tested, Perthane appeared to be the least toxic to predators in contact toxicity trials. The combination of rice plant resistance (to leafhoppers and planthoppers) and predation controlled the pests better than did either control method alone.

Insect damage caused a significant yield loss to upland rice in four of six locations. Experiments with the brown planthopper suggested that a maximum of 25 to 50 insects per hill could develop during the last half of a crop period without causing a significant yield loss.

The population density of all major rice pests at the IRRI farm sites fluctuated markedly within a crop period and over the years. Light-trap catches of green leafhoppers and brown planthoppers increased for several years, and such fluctuations appear to correlate with agronomic and cropping practices, plant age, rice variety, insect resistance, climate, and the abundance of natural enemies of the rice pests. The decreased trap catches of brown planthoppers in 1974 may be due to the large-scale planting in the IRRI environs of rice varieties and selections that are resistant to these insects. and number of insects per hill. Insects tended to distribute themselves over tillers rather than over hills. Since insects are distributed in the field in a non-random fashion, sampling procedures must be designed to locate the samples or sampling units throughout an experimental area.

The distribution of brown planthoppers in a field was not random. There was a tendency among nymphs and adults to cluster in the field, but it was less pronounced among the adult insects. Also, nymphs and adults tended to cluster together on the same hill, and this appears to be associated with the positive correlation between tiller number

INSECTICIDES

Entomology Department

Insecticides continued to be screened in the greenhouse, laboratory, and fields in 1974. The main objectives of these tests were to identify com-

pounds that are highly effective against the brown planthopper and the green leafhopper, and have fast knockdown effects that can minimize the infection of rice plants with virus diseases carried by these insect vectors, and to develop insect control practices which are less costly than the present ones.

Laboratory and greenhouse experiments. A total of 65 compounds was tested in a series of greenhouse and field experiments. When the contact toxicity of selected compounds was tested in a laboratory experiment (Table 1), carbofuran, MTMC, MIPC, BPMC, and PPDB11 were found to be effective against both the green leafhopper and the brown planthopper. However, all these compounds had faster knockdown effects on the brown planthopper than on the green leafhopper. The insecticide carbaryl was highly effective against the green leafhopper but had a low effectiveness against the brown planthopper, even when used as a 0.08 percent spray. Conversely, the compounds chlordimeform and Perthane, although highly effective against the brown planthopper, were not effective against the green leafhopper. Of the compounds tested, chlordimeform and Perthane are the only insecticides that were effective against the brown planthopper but not against the green leafhopper, while the opposite is true for a large number of compounds. Foliar sprays of chlordimeform and Perthane, as described in the 1972 and 1973 annual reports, gave long lasting control of the brown planthopper.

Table 1. Contact toxicity of 0.04% insecticidal sprays on adult insects treated in a Potter's spray tower.

Insecticide	Formulation[a]	Insect mortality[b] (%)					
		Brown planthopper			Green leafhopper		
		1 HT	2 HT	24 HT	1 HT	2 HT	24 HT
Carbofuran	75 WP	100	100	100	100	100	100
MTMC	50 WP	100	100	100	7	65	100
MIPC	50 WP	97	97	97	8	23	100
PPDB 11	40 EC	92	100	100	2	2	96
BPMC	50 EC	88	88	92	70	97	100
Carbaryl + MIPC	(25 + 25) WP	67	87	92	10	80	100
BPMC + chlorpyrifos	(15.8 + 14.2) EC	55	62	72	25	75	100
BAS 262 01 J	20 EC	53	64	80	18	100	100
Dow 4828	21 EC	38	41	78	2	8	95
CPMC	50 EC	28	55	62	40	52	100
PPDB 21	30 EC	26	28	56	5	22	98
CPMC-Imidan	(20 + 20) WP	15	25	41	0	46	100
Dow 4829	21 EC	9	13	33	0	5	93
PPDB 31	27 EC	8	16	67	0	8	95
Chlordimeform[c]	800 SP	7	15	95	2	8	20
PPDB 41	25 EC	5	16	62	0	3	98
Carbaryl[d]	85 WP	5	13	33	0	2	100
LS 63-1323	50 EC	3	8	43	0	46	100
Perthane	45 EC	0	18	88	2	2	15
Chlorpyrifos	15.8 EC	0	3	30	0	0	65
BAS 263 01 I	50 WP	0	3	18	0	30	98
Carbophenothion	30 EC	0	0	55	0	0	78
Imidan + carbophenothion	(25 + 25) WP	0	0	8	0	0	70

[a]WP = wettable powder; EC = emulsified concentrate; SP = soluble powder. [b]Adjusted using Abbott's formula. HT = hours after treatment. [c]Not effective against green leafhopper even at 0.08% concentration. [d]Not effective against brown planthopper even at 0.08% concentration.

Table 2. Knockdown effects of selected insecticides applied as 0.04% foliar sprays.[a] Rice variety Taichung Native 1. IRRI, 1974.

Insecticide	Formulation[b]	Mortality[c] (%)					
		Brown planthopper			Green leafhopper		
		1 HAC	2 HAC	24 HAC	1 HAC	2 HAC	24 HAC
BPMC	50 EC	100	100	100	100	100	100
Carbaryl	85 WP	100	100	100	100	100	100
Carbofuran	75 WP	100	100	100	100	100	100
MIPC	50 WP	100	100	100	100	100	100
PPDB 11	40 EC	100	100	100	88	92	100
CPMC	50 EC	82	83	93	80	83	100
PPDB 31	27 EC	80	100	100	72	90	100
PPDB 41	25 EC	80	98	100	75	100	100
MIPC + carbaryl	(25 + 25) WP	77	100	100	93	100	100
PPDB 21	30 EC	75	92	100	75	92	100
Monocrotophos + mevinphos	(16.8 + 3.4) EC	67	79	100	100	100	100
MTMC	50 WP	53	62	89	70	83	100
BPMC + chlorpyrifos	(15.8 + 14.2) EC	50	72	100	90	100	100
Perthane	45 EC	33	97	100	87	97	100
Dow 4829	21 EC	28	78	100	62	100	100
Dow 4828	21 EC	15	41	100	72	88	100
Chlorpyrifos	15.8 EC	8	20	100	0	8	100
Imidan + carbophenothion	(25 + 25) WP	0	18	92	67	83	100
Carbophenothion	30 EC	0	14	100	0	7	100
Chlordimeform	800 SP	0	4	92	0	3	100

[a]Replicated 4 times using 45-day-old plants. Ten insects/plant were caged 30 minutes after treatment. [b]WP = wettable powder; EC = emulsified concentrate; SP = soluble powder. [c]Adjusted using Abbott's formula. HAC = hours after caging.

The compounds from these experiments were further evaluated for their effectiveness as 0.04 percent foliar sprays in a greenhouse experiment. Several compounds caused rapid knockdown of both the green leafhopper and the brown planthopper (Table 2). Perthane and chlordimeform were slow acting, although under field conditions their foliar sprays provided highly effective control against these insects. The residual effects of the promising compounds from these experiments are being studied.

The systemic effects of these selected compounds, when applied to the paddy water to control the brown planthopper and the green leafhopper, were evaluated. Several compounds were effective against the green leafhopper, but only a few were effective against the brown planthopper. Most had only a short residual effect (Table 3). Perthane and chlordimeform, which were highly effective when used as foliar sprays and gave excellent protection against the brown planthopper in field experiments, were not effective when applied to the paddy water (Table 3). This suggested a lack of systemic effects of these insecticides in rice plants.

Field experiments. *Foliar sprays.* The trend of the build-up of the brown planthopper populations in intensively cultivated rice areas has created the need to develop an effective control for this insect. The brown planthopper population build-up generally occurs near the time of crop maturity; thus, early treatment with insecticides may not be necessary, except to control other pests. Because the insects habitually feed near the base of the plant, a method of applying an insecticide to provide pesticide coverage of the basal half of the

Table 3. Effect of granular insecticides, applied at 2 kg a.i./ha to the water of potted rice plants, on the control of brown planthoppers and green leafhoppers. Variety Taichung Native 1. IRRI, 1974.

Insecticide	Formulation[a]	Mortality[b] (%) of insects caged at indicated days after treatment (DT)					
		Brown planthopper			Green leafhopper		
		1 DT	5 DT	10 DT	1 DT	5 DT	10 DT
Carbofuran	3 G	100	82	5	100	100	100
Metalkamate	5 G	100	10	0	90	2	0
Acephate	5 G	90	12	5	100	70	25
Diazinon	30 F	50	2	0	18	2	0
MTMC	5 G	45	2	0	82	12	0
Imidan + MIPC	9 G	38	5	–	64	5	–
Endosulfan + BPMC	5 + 5 G	31	18	–	62	44	–
Monocrotophos	5 G	10	3	–	82	62	–
JF 4089	5 G	10	5	22	12	2	5
SAN 155	10 G	8	0	–	0	0	–
Chlordimeform + carbaryl	9 G	5	3	–	32	26	–
RH 812	9 G	3	3	–	0	0	–
Perthane	5 G	3	5	–	0	0	–
Imidan	5 G	2	2	0	0	0	0
Carbophenothion	5 G	0	5	0	2	2	2
Imidan + carbophenothion	10 G	0	2	0	0	0	0
Chlordimeform	20 F	0	5	2	0	0	2
SAN 201	10 G	0	0	–	8	3	–
Dupont 1410	10 G	0	5	2	2	0	0

[a]F = floating liquid formulation; G = granular formulation; a.i. = active ingredient. [b]Recorded 24 hours after caging. Values adjusted using Abbott's formula.

plants needs to be devised. Furthermore, the large population build-up of the brown planthopper, resulting in the migration of huge numbers of the pests to uninfested fields and the transmission of the grassy stunt virus, requires a fast knockdown of this pest for effective control. This can be accomplished more effectively by using insecticides as foliar sprays and applying them to the basal half of the plants to provide effective and long-lasting control (1973 Annual Report).

In another field experiment 0.04 percent foliar sprays of selected insecticides were applied to the basal half of IR20 rice plants (Table 4). The sprays were repeated every 15 days. IR20 rice is moderately resistant to stem borers and the tungro virus, but is susceptible to the whorl maggot and the brown planthopper. As expected, the incidence of stem borers and the tungro virus was low. There was a moderately heavy incidence of the whorl maggot, but in general none of the compounds provided highly effective control of the whorl maggot. In previous experiments foliar sprays also generally failed to control effectively the whorl maggot. The population of the brown planthopper was quite large, and plots treated with ineffective compounds were hopperburned. Carbophenothion, chlordimeform, and Perthane provided the most effective control; plots treated with them produced the highest yields (Table 4). Ofunack failed to control the brown planthopper, and the yields of the plots treated with Ofunack were lower than those of the untreated control plots. Such a situation, in which a plot treated with an ineffective insecticide yielded less than an untreated plot, has also been encountered in other experiments and may be due to a deleterious effect of the insecticide on the parasites and predators of the planthoppers. This experiment demonstrated that the use of effective insecticides as foliar sprays directed toward the base of the plant can effectively control

Table 4. Effect on insect[a] control of foliar sprays (0.04% every 15 days) on the basal half of rice plants. Variety IR20. IRRI, 1974 dry season.

Treatment	Formulation[b]	Whorl maggot damage[c]		Brown planthopper nymphs[d] (no./hill)			Hopperburned area (%)	Grain yield (t/ha)
		20 DT	40 DT	1 DBS	2 DAS	5 DAS		
Carbophenothion	8 E	0.8 a	2.2 a	3 a	0 a	0 a	0 a	5.86 a
Chlordimeform	800 SP	1.8 abc	2.8 a	18 b	10 c	42 c	5 a	5.28 b
Perthane	45 EC	2.2 bc	3.5 a	19 b	2 b	0 a	0 a	4.76 bc
Acephate	75 SP	1.8 abc	2.8 a	82 de	44 d	37 c	20 ab	4.51 c
Metalkamate	24 EC	2.0 abc	3.8 a	31 bc	19 c	29 b	18 ab	4.39 c
Monocrotophos	16.8 EC	0.8 a	2.5 a	132 ef	188 f	170 d	71 cd	3.59 d
MIPC	50 WP	2.8 c	3.5 a	150 ef	102 ef	46 c	44 abc	3.34 d
BPMC	50 EC	2.5 bc	3.0 a	89 e	70 de	138 d	54 bc	3.22 de
Ofunack	40 EC	1.2 ab	2.8 ab	28 ab	180 f	306 d	100 d	2.72 e
Untreated control		2.0 abc	3.5 a	43 cd	40 d	56 c	31 ab	3.81 d

[a]Brown planthoppers were the only major pest during this experiment. The incidence of dead heart and of white head was less than 1 and 2%, respectively. The infection by grassy stunt virus ranged from 2 to 6% in different plots, but the differences were not statistically significant. [b]E = emulsion; EC = emulsified concentrate; SP = soluble powder; WP = wettable powder. [c]Scale 0 to 5. Larger number indicates greater damage. DT = days after transplanting. [d]Data recorded at sixth spraying, 80 DT. DBS = days before spraying; DAS = days after spraying.

the brown planthopper and promote high rice yields.

Methods of applying carbofuran to the root zone of rice. The effects of different methods of applying carbofuran to the root zone of the rice plant were further evaluated in follow-up experiments. These methods of application included the use of an encapsulated formulation, injection of a slurry formulation into the root zone, and placement in a band below the soil surface with applicators developed by the Agricultural Engineering Department at IRRI. These applicators dispensed insecticides as granules, as a slurry formed by adding water and starch to the granules, or as liquids by adding water to the granules. Since the incidence of virus, dead hearts, and white heads was low in this experiment, most of the expressions of the insecticidal effectiveness were in terms of differences in whorl maggot damage and in plant height. The results showed that the slurry method used either before transplanting or 3 days after transplanting, or band injection of slurry along with fertilizer between two rows at 3 days after transplanting, or band injection in water solution, was almost as effective as the placement of capsules in the root zone of individual plants (Table 5). While the soil injection of insecticide in a slurry at the base of each hill was highly effective, injection between four hills was comparatively ineffective. However, the addition of urea to the slurry improved the effectiveness of the insecticide. Probably the presence of nitrogen in the insecticidal slurry stimulated root growth towards it, thus, the insecticide may have become available to the plants sooner than when no nitrogen was added.

The band injection of the insecticide in a slurry form or in water solution controlled insects effectively, provided the treatments were made along each row. However, the effectiveness of the insecticide was less when the treatments were made on alternate rows.

Although further confirmation of these results is needed, band injection of the insecticide between rows of rice to control pests effectively shows practical value in that it may save time and costs involved in preparing encapsulated formulations.

Root zone injection of insecticide plus fertilizer slurry. Selected insecticides were injected with a modified grease gun into the root zone as a slurry and were evaluated to determine whether the rates of application could be reduced to less than 2 kg a.i./ha. Each insecticide was tested at 0.25, 0.5, 1 and 2 kg a.i./ha; however the amount of urea used in preparing the slurry in each case was equivalent to 30 kg N/ha (Table 6). The insecticides

Table 5. Effect of different methods of applying carbofuran and fertilizer to the root zone of rice plants on the control of insect pests. Selection IR1737-19-7-8-3. IRRI, 1974 wet season.

Treatment			Whorl maggot damage[a] (grade)		Dead heart[b] (%)	Green leafhopper[b] (no./10 sweeps)	Plant height[b] (cm)	
Method of application	Carbofuran (kg a.i.[c]/ha)	Urea (kg N/ha)	20 DT	36 DT	48 DT	63 DT	48 DT	67 DT
Capsules at each hill	2	30	0.5	0.0	0.1 b	0.2 a	82 a	101 ab
Grease gun method at each hill[d]	2	30	0.5	0.0	0.0 a	0.2 a	80 ab	100 ab
Grease gun method at each hill	2	30	0.2	0.0	0.0 a	0.8 b	81 ab	101 ab
Grease gun method at center of 4 hills	2	30	5.0	3.8	0.0 a	0.8 b	65 c	92 c
Grease gun method at center of 4 hills	2	0	5.0	4.0	0.0 a	1.2 b	61 d	83 c
Band application – slurry every row	2	30	0.5	0.0	0.0 a	0.8 b	81 ab	99 b
Band application – slurry every row	2	0	1.2	0.2	0.1 b	0.2 a	69 c	92 c
Band application – slurry every other row	2	30	2.2	0.8	0.0 a	0.0 a	77 b	98 b
Band application – water solution every row	2	30	0.5	0.0	0.0 a	0.0 a	78 ab	102 ab
Band application – water solution every other row	2	30	2.0	1.0	0.0 a	0.2 a	78 ab	99 b
Grease gun method (fertilizer only) at each hill	8[e]	30	0.5	1.0	0.2 b	0.5	81 ab	104 a
Grease gun method (fertilizer only) at each hill	0	30	5.0	5.0	0.1 b	6.8 c	55 e	78 e

[a]On a scale of 0-5. Higher number indicates greater damage. DT = days after transplanting. [b]Values in a column followed by a common letter are not significantly different at the 5% level. [c]a.i. = active ingredient. [d]Applied just before transplanting. In other cases the treatments were made at 3 DT. [e]2 kg a.i./ha applied as granules to paddy water at 3, 23, 43, 63 DT.

were applied only once at 3 days after transplanting, except for the standard check treatment which consisted of applying carbofuran every 20 days to the paddy water at 2 kg a.i./ha. Two other checks were used in this experiment: 1) fertilizer was injected to the root zone of the plants but no insecticide was added, and 2) neither insecticide nor fertilizer was added.

With the exception of diazinon, which was effective only against the whorl maggot at 2 kg a.i./ha, all insecticides provided control of the various pests (Table 6). Cartap and chlordimeform were highly effective against the stem borers, but were not so effective against the whorl maggots. Carbofuran, at all four rates used, was highly effective against the whorl maggot, but controlled borers effectively only at the 1 and 2 kg a.i./ha rates. Cytrolane at 1 to 2 kg a.i./ha was highly effective against the whorl maggot and the stem borer.

These results concur in general with those obtained by using the insecticides in gelatin capsules (Table 7), but the slurry method is less laborious. Significantly, when the plots were treated with one of several of these insecticides at only 0.5 kg a.i./ha, the insect infestations and yields were

Table 6. Effect of injecting an insecticide plus urea paste with a modified grease gun into the root zone of each hill of IR26 rice plants on insect control. IRRI, 1974 wet season.

Insecticide	Rate (kg a.i./ha)	Whorl maggot damage[a] 24 DT	Whorl maggot damage[a] 36 DT	Dead heart (%) 60 DT	Grain yield (t/ha)
Chlordimeform	0.25	3.0	2.8	4.0 ghijk	3.85 abcd
	0.50	2.5	2.8	2.2 bcdefg	3.86 abcd
	1.00	1.5	2.0	1.5 abcde	4.47 a
	2.00	1.0	1.2	1.0 abcd	4.17 ab
Carbofuran	0.25	1.0	1.0	8.6 lm	3.34 bcd
	0.50	0.2	0.0	5.0 hijkl	3.44 abcd
	1.00	0.0	0.0	2.9 defghi	4.16 ab
	2.00	0.0	0.0	0.4 a	4.30 ab
Cytrolane	0.25	1.2	1.0	5.8 ijkl	3.58 abcd
	0.50	0.5	0.0	3.6 efghij	3.74 abcd
	1.00	0.0	0.0	0.8 abc	4.06 abc
	2.00	0.0	0.0	0.4 a	3.76 abcd
Cartap	0.25	3.0	3.0	2.9 defghi	4.03 abc
	0.50	3.0	3.0	1.6 abcdef	3.91 abcd
	1.00	2.2	2.0	0.5 ab	3.86 abcd
	2.00	1.5	1.2	0.6 ab	4.15 ab
AC 64475	0.25	2.0	2.8	7.5 lm	3.71 abcd
	0.50	1.0	1.2	7.9 lm	3.32 bcd
	1.00	0.2	0.0	4.0 ghijk	3.80 abcd
	2.00	0.0	0.0	2.5 cdefgh	4.07 abc
Diazinon	0.25	3.0	3.2	5.8 ijkl	3.72 abcd
	0.50	3.0	2.8	7.0 jkl	3.51 abcd
	1.00	2.2	2.0	6.8 jkl	3.17 abcd
	2.00	1.0	1.0	12.5 m	2.90 de
Carbofuran broadcast[b]	8.00	1.0	0.0	0.3 a	4.32 ab
Carbofuran[c]	2.00	0.0	0.0	0.7 ab	3.31 bcd
No insecticide + 30 N	0.00	3.2	3.0	5.4 ijkl	3.05 cde
No insecticide, no fertilizer	0.00	3.5	3.2	3.7 fghijk	2.14 e

[a]Graded on a scale of 0-5. The higher number indicates greater damage. DT = days after transplanting. [b]Applied to the paddy water at 3, 23, 43, and 63 DT at 2 kg active ingredient (a.i.)/ha per application. Urea was injected in the root zone of each hill. [c]Same as footnote b except that no fertilizer was applied. In other plots the insecticide was injected along with a slurry of urea at 30 kg N/ha into the root zone of each rice hill.

similar to those treated with 1 or 2 kg a.i./ha. It is important to note that 0.5 kg a.i. of the toxicant/ha placed in the root zone of the rice plant provided insect control and a yield increase equivalent to those obtained by applying 8 kg a.i. of carbofuran/ha to the paddy water (Table 6). Previous studies showed that when the insecticide is applied to the paddy water, it must be applied again every 20 days to protect the crop from subsequent insect infestations since its residual effect lasts only 20 to 30 days.

In the initial experiments the insecticides were applied to the root zone of the rice plants by first placing them in paper capsules (1972 Annual Report). Subsequently gelatin capsules were used. Also some chemical companies formulated the insecticides in tablet or large granular forms – such as cartap tablets or chlordimeform jumbo granules.

Table 7. Effect of applying insecticides in different formulations to the root zone of IR20 rice plants on insect pest control. IRRI, 1974 dry season.

Insecticide	Formulation[a] 2 kg a.i./ha	Whorl maggot damage[b] 20 DT	Whorl maggot damage[b] 40 DT	Virus[c] infected hills (%) 88 DT	Dead heart (%) 50 DT	Leaf folder damage[b] 70 DT	Grain yield (t/ha)
Carbofuran	Gel	0.0 a	0.0 a	4 a	0.0 a	0.8 abc	5.21 a
Carbofuran	P	0.0 a	0.0 a	5 ab	0.0 a	1.0 bcd	4.89 abcd
Cartap	Gel[d]	2.0 bc	0.5 abc	10 abcde	0.1 a	0.0 a	4.79 abcde
Cartap	P[d]	1.8 bc	0.5 abc	7 abc	0.0 a	0.0 a	5.01 ab
Cartap	Tab[d]	4.0 d	1.0 cd	11 cdef	0.0 a	0.0 a	4.81 abcd
Chlordimeform	Gel	1.8 bc	0.8 bcd	8 abcd	0.7 abc	0.0 a	4.86 abcd
Chlordimeform	P	2.5 c	1.5 d	8 abcd	0.7 ab	0.2 ab	4.64 abcdefg
Chlordimeform	J. G.	2.2 c	1.0 cd	10 cdef	0.2 a	0.0 a	4.71 abcdef
AC 64,475	Gel[d]	0.0 a	0.0 a	4 a	0.2 a	1.2 cd	4.18 efghi
AC 64,475	P[d]	0.0 a	0.0 a	3 a	0.0 a	1.0 bcd	4.93 abc
Cytrolane	Gel	0.0 a	0.0 a	4 a	0.2 a	0.8 abc	4.53 bcdefgh
Cytrolane	P	0.0 a	0.0 a	4 a	0.1 a	0.5 abc	4.67 abcdef
Diazinon	Gel	0.5 a	0.0 a	10 bcde	0.6 ab	2.2 ef	4.30 cdefghi
Diazinon	P	1.5 bc	0.0 a	14 ef	2.6 de	3.0 fg	4.11 fghi
BPMC	Gel	1.0 ab	0.2 ab	12 cdef	2.0 cde	2.8 fg	3.90 hi
BPMC	P	1.8 bc	0.5 abc	16 ef	1.5 bcd	1.8 de	4.27 defghi
Acephate	Gel	0.0 a	2.8 ef	13 def	5.0 g	3.2 g	4.00 fghi
Acephate	P	0.0 a	2.2 e	12 cdef	4.7 fg	3.0 fg	3.79 i
Control	–	3.9 d	3.4 f	16 ef	2.5 de	2.6 fg	3.83 i

[a]Gel = gelatin capsules; P = paper capsules; Tab = tablet; J.G. = jumbo granules. a.i. = active ingredient. [b]Graded on a scale of 0-5. Higher number indicates greater damage. [c]Mostly grassy stunt. Observations made at 40 and 60 days after transplanting (DT) revealed no significant differences among various treatments. [d]Caused drying of leaf tips at the early stage of the crop.

When the effect of the different formulations on the effectiveness of the insecticides was studied, in most cases, the different formulations used did not significantly alter the effectiveness of the insecticides (Table 7). The cartap tablet appeared to be slow acting, but subsequently provided insect control similar to that of its other formulations. The gelatin and paper capsule formulations of acephate provided highly effective control of the rice whorl maggot at 20 days after treatment, but not at 40 days after treatment. Although acephate is known from previous field experiments to be effective against stem borers, leafhoppers, and leaf folders, it did not reduce virus infection, dead heart, or leaf folder damage. Probably, the poor effectiveness of acephate at and 40 days after treatment was due to its short residual period. The effectiveness of chlordimeform against the whorl maggot was low at 20 days after treatment, but subsequently its effectiveness improved to provide better control of the whorl maggot and the stem borer. There was a moderate incidence of grassy stunt virus during this experiment, and the plots treated with AC 64,475, carbofuran, and chlordimeform had a significantly lower incidence of the virus than the other plots. Except for acephate, the insecticides tested were also effective in controlling leaf folder damage. Maximum yields were obtained on those plots with the best insect control (Table 7).

Experiments conducted by the IRRI Agronomy Department have established that the placement of urea in mudballs at about 5 to 8 cm below the soil surface among four hills almost doubles the efficiency of nitrogen use by plants achieved when urea is incorporated into the soil during puddling. The feasibility of applying the fertilizer and insecticide together using the mudball technique

was studied in a cooperative experiment with the Agronomy Department at IRRI. Details of this experiment are described in the section on Fertilizer Management. Carbofuran, cartap, and chlordimeform provided insect control similar to that when they are placed in the root zone. There was neither a synergistic nor an antagonistic effect when they were applied with urea in the mudball. Apparently, these three compounds can be applied successfully with the mudball technique.

Paddy water application. Of the various insecticides tested, carbofuran and diazinon (floating liquid formulation) provided quick and effective control of the whorl maggot (Table 8). All of the insecticides used in this experiment were highly effective in protecting the crop from dead heart damage caused by stem borers. Only carbofuran, chlordimeform + MIPC, and chlordimeform were effective against the brown planthopper. Severe hopperburn occurred on plots treated with diazinon or gamma-BHC + MTMC.

Chlordimeform gave significant insect control when applied to the paddy water. In separate experiments, chlordimeform provided effective

Table 8. Effect of insecticides applied to the paddy water (2 kg a.i./ha) on the control of rice insect pests. Variety IR20. IRRI, 1974 dry season.

Insecticide	Formulation[a]	Whorl maggot damage[b]	Dead heart (%)	Virus hills (%)	Brown planthoppers (no./hill)			Hopper-burned area (%)	Grain yield (t/ha)
			52 DT	84 DT	59 DT Nymphs	73 DT Adults	83 DT Nymphs	96 DT	
Carbofuran	G	0.8	0.0 a	3 a	0 a	2 a	1 a	0 a	6.05 a
Chlordimeform + MIPC	G	2.2	0.3 bc	3 a	0 b	2 a	3 b	4 b	5.67 a
Chlordimeform	F	2.5	1.1 d	4 a	7 c	2 a	2 ab	0 a	5.71 a
Acephate	G	2.3	0.7 cd	2 a	168 d	6 b	3 b	0 a	4.73 b
Cartap	G	3.5	0.1 ab	3 a	141 d	15 bc	17 c	4 b	3.97 b
Gamma-BHC + MTMC	G	2.3	1.4 d	5 a	279 de	21 d	49 d	72 c	1.08 d
Diazinon	F	0.8	0.9 cd	[c]	406 e	[c]	[c]	96 d	0.19 e
No insecticide	–	3.4	2.8 e	5 a	298 de	15 cd	40 cd	4 b	2.53 c

[a]G = granules; F = floating liquid formulation. a.i. = active ingredient. [b]Graded on a scale of 0-5; the larger number indicates greater damage. Average of three observations made at 19, 32, and 41 days after transplanting (DT). [c]Hopperburned.

Table 9. The effect of the method of applying carbofuran on IR20 rice[a]. IRRI, 1974.

Method of carbofuran application (2 kg a.i./ha)	Whorl maggot damage[b] 20 DT	Dead heart (%) 50 DT	White head[c] (%) 100 DT	Grain yield (t/ha)
Gelatin capsule[d] in root zone of each hill	0.0	0.0 a	0.9	5.52 a
Granules broadcast on soil surface	0.0	0.4 b	2.6	4.71 b
Soil incorporation of granules[e]	0.7	0.0 a	1.2	5.30 a
Four gelatin capsules[d] placed at the center of 4 hills	2.7	2.2 b	0.7	4.62 b
Control	3.7	3.8 b	1.5	3.96 c

[a]Average of 4 replications. Carbofuran granules (3G) applied at the rate of 2 kg a.i./ha. Means followed by a common letter are not significantly different at the 5% level. [b]On a scale of 0 to 5. Higher number indicates greater damage. [c]Means are not significantly different. [d]Each capsule contained 0.4119 g of carbofuran 3G. [e]Applied just before transplanting. All other treatments were made at 1 day after transplanting (DT). a.i. = active ingredient.

control of the brown planthopper when used as a foliar spray or applied to the root zone of rice plants (1973 Annual Report). Chlordimeform appears to be a very promising insecticide for controlling rice insect pests.

Acephate is another promising insecticide for rice pests. It is a fast-acting compound, and is effective against the whorl maggot, stem borers, and the brown planthopper. However, it has a short residual effect, which becomes evident in root-zone application experiments. Acephate-treated plots are among the best plots a very few days after treatment, but are frequently severely damaged by insect pests 40 or 50 days after treatment. On the other hand, cartap and chlordimeform, though somewhat slow acting, when applied to the root zone provide long-lasting control. Thus, combinations of acephate and cartap, and of acephate and chlordimeform offer promising possibilities for root-zone application.

Residues and application efficiency of carbofuran. The relative pest control efficiencies of the root-zone method and other methods of application of carbofuran were compared in a field experiment using IR20 rice (Table 9). Each treatment plot was 5 x 8 m and was planted with single seedlings per hill at a spacing of 25 x 25 cm. The incidence of various insect pests, grain yield, and the concentration of the insecticide in the soil, water, and plants were recorded for each method of application.

Applying carbofuran by the root-zone, broadcast, and soil-incorporation methods provided highly effective control of the rice whorl maggot, as well as of dead heart and white head damage, but the placement of capsules in the center of four hills was only partially effective (Table 9). The plots receiving the root-zone treatment and the soil-incorporation treatment produced the highest yields which were significantly higher than the yield of the untreated control plots. The yields of plots where the insecticide was broadcast and those where capsules were placed in the center of four hills were comparatively lower. The broadcast method appears to have only a short residual effect, while the capsule placement provided poor protection of the crop from whorl maggot damage and dead hearts.

Analysis by gas liquid chromatography of the paddy water collected from the treated plots showed the lowest concentration of carbofuran in plots receiving the root-zone application of gelatin capsules, and the highest concentration in plots where carbofuran was broadcast on the soil surface (Table 10). These results were expected since the granules broadcast on the soil were in contact with the surface water, while the capsules were buried 2.5 cm below the soil surface. However, the reason is not clear why the concentration where the insecticide was applied in the center of four hills was lower than the concentration in the root-zone treatment. Whether the rice plant was instrumental in bringing the insecticide from below the soil surface to the paddy water needs to be investigated. The concentration of the insecticide in the paddy water was reduced to very low levels by about 60 days after application.

The fact that there was a lower concentration of insecticide in the plots receiving the insecticide via the root-zone method is particularly significant in that this method of application may be less toxic to fish in the rice paddies and also less likely

Table 10. Effect of method of application on the concentration of carbofuran in the paddy water.

Treatment[a]	Carbofuran concentration (ppm) in paddy water[b]				
	5 DT	10 DT	20 DT	40 DT	60 DT
Root zone, G. C.	0.016	0.041	0.038	0.023	0.009
Broadcast, G.	0.206	0.058	0.028	0.005	0.007
Soil incorporation, G.	0.055	0.040	0.035	0.011	0.010
Placement in center of four hills, G. C.	0.004	0.014	0.007	0.011	0.011
Control	0.006	0.013	0.010	0.003	trace

[a]Carbofuran granules (G) (3%) were applied at 2 kg a.i./ha. Formulated 3% carbofuran granules contained in gelatin capsules (G.C.) were applied at 0.4119 g/hill. [b]DT = days after treatment. Trace = less than 0.003 ppm.

Table 11. Effect of method of application on the concentration of carbofuran in IR20 rice roots and shoots.

Treatment[a]	Carbofuran concentration[b] (ppm, fresh weight basis)					
	5 DT	10 DT	20 DT	40 DT	80 DT	100 DT
			Roots			
Root zone, G. C.	0.535	0.764	1.605	0.312	0.031	0.010
Broadcast, G.	0.186	0.102	0.071	0.007	0.008	trace
Soil incorporation, G.	0.277	0.230	0.239	0.058	trace	trace
Placement in center of four hills, G. C.	0.009	0.009	0.013	0.016	0.038	0.015
Control	0.015	0.003	trace	trace	trace	trace
			Stem and leafblade			
Root zone, G. C.	1.383	18.831	69.240	6.929	0.186	0.063
Broadcast, G.	1.033	0.732	0.406	0.056	0.052	0.039
Soil incorporation, G.	0.332	3.136	4.831	0.490	0.114	0.018
Placement in center of four hills, G. C.	0.023	0.031	0.091	0.567	0.473	0.108
Control	0.024	0.025	trace	trace	trace	trace

[a]Carbofuran granules (G.) (3%) were applied at 2 kg a.i./ha. Formulated 3% carbofuran granules contained in gelatin capsules (G.C.) were applied at 0.4119 g/hill. [b]DT = days after treatment. Trace = less than 0.005 ppm.

to cause pesticidal contamination of the environment. The median tolerance limit of carbofuran for several species of fish was reported to be greater than 0.2 ppm.[1] Therefore, the root-zone method of applying carbofuran should not be toxic to fish in these rice fields.

The highest concentration of carbofuran in the roots and shoots of the rice plant occurred where the insecticide was applied to the root zone (Table 11). When carbofuran was broadcast or incorporated into the soil, the highest concentration of the insecticide in the roots was recorded at 5 days after treatment and declined subsequently to very low levels by about 40 days after treatment. The concentration of carbofuran in the rice roots was greater when the insecticide was incorporated into the soil than when broadcast, indicating the greater availability of the insecticide when incorporated into the soil. The concentration of the insecticide in the roots was highest in root-zone treated plots, and increased progressively from 5 days after treatment until 20 days after treatment (Table 11), declining to very low levels beyond 80 days after treatment. When an insecticide capsule was placed between four hills its concentration in the rice root was very low, but increased about 20 days after treatment when apparently the roots from the surrounding hills reached the location of the capsule.

A similar pattern was seen for the concentration of carbofuran in the shoots of the rice plant. The root-zone application led to the highest concentration in the plant tissues, which increased progressively up to 20 days after treatment, but declined to very low levels at 100 days after treatment (Table 11). This suggests a low residual hazard in the harvested crop, coupled with high insect control efficiency during the time of crop growth and development. These results are in general agreement with earlier data on the concentration of chlordimeform in rice plant tissues following various methods of application (1973 Annual Report). Both the root-zone application and the soil incorporation of insecticide were more efficient than the standard method of paddy water application of insecticide used at present.

BIOLOGICAL CONTROL OF INSECTS

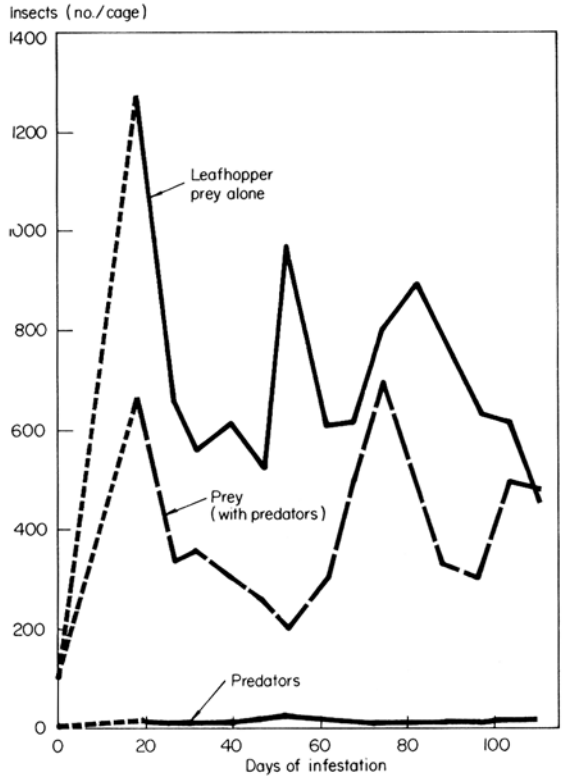
Entomology Department

Pathogens. Two commercial preparations of the entomogenous bacterium *Bacillus thuringiensis*,

[1]Toxicity and safe handling of Furadan insecticide. 1970. Niagara Chemical Company, FMC Corporation, Middleport, New York. 24 pages.

Dipel and Bactospeine, were tested in the greenhouse against stem borer and leaf folder larvae. The insecticidal material in a water carrier was sprayed on rice plants prior to infesting the leaves with leaf folders, and on cut stems prior to infestation with borers. Dipel was applied at 0.5 kg/ha (10 g/19 1) and Bactospeine at 1.5 kg/ha. About 100 percent mortality of leaf folder larvae (*Cnaphalocrosis medinalis*) was achieved with both preparations at 5 days after treatment. However, possibly due to the experimental techniques used, we obtained generally only moderate mortality values for stem borers (*Chilo suppressalis, Chilo polychrysus, Sesamia inferens*). Nevertheless, in one case, Dipel with *C. polychrysus,* all larvae died within 5 days of the treatment.

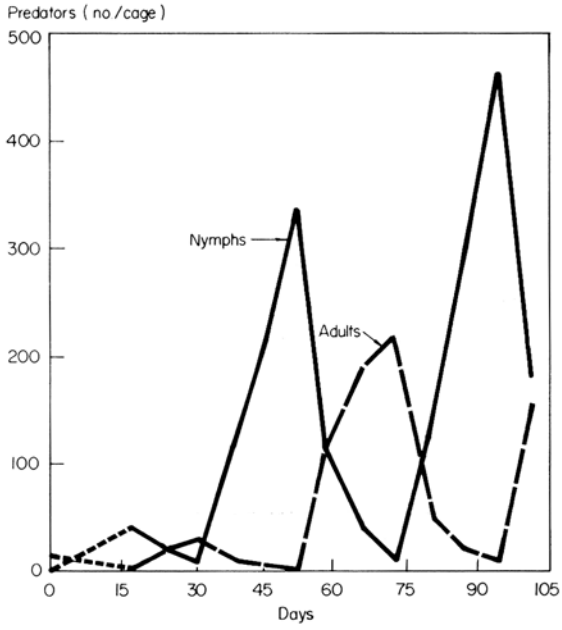
Predators. The predatory capabilities of *Cyrtorhinus lividipennis* when caged with *Nilaparvata lugens,* and especially with *Nephotettix virescens,* was reported previously (1972 and 1973 Annual Reports). To measure the long-term effect of predation on the control of a prey population, one pair of adult predators was caged with either 25 or 50 pairs of adult *N. virescens.* The insect populations were allowed to grow and to decline naturally for three generations. Potted plants about 70 days old were provided continuously in the cages which were located in an air-conditioned insectary. Even at this low predator-to-prey ratio, the predators had a substantial continuing control effect. The total reduction in prey density due to predation averaged between 34 and 42 percent (fig. 1).



1. Reduction in prey *(Nephotettix virescens)* population density due to predation by *Cyrtorhinus lividipennis* when caged with the prey in an air-conditioned insectary. Initial prey density was 50 pairs of adults; predator density was 1 pair of adults. First count of the populations made at 19 days after the initial infestation on about 70-day-old plants of IR22 rice (susceptible).

The pattern of population growth of the predator *C. lividipennis* was observed in cages in an insectary (air temperature about 29° C). In one experiment, *N. lugens* was provided as prey, in another, *N. virescens* was the prey. Five pairs of adult predators were put into a cage, and for more than 3 months, the generation time and rate of population growth were observed. The generations were quite distinct (fig. 2). The generation time was usually 5 or 6 weeks, which was equal to, or often longer than, that of the prey species in the same environment. As long as food appeared to be adequate, the predator population increased between 3 and 7 times from one generation to the next. This rate of increase was equal to, or higher than, that of the prey species.

A species of spider is known (1971 Annual Report) to prey upon *N. lugens* and thus, in the search for a predator more effective than *C. lividipennis* against *N. lugens,* this planthopper was caged with another known predatory spider species, *Lycosa pseudoannulata,* taken from the field. Only one adult spider was caged on potted plants together with different numbers of prey adults or nymphs. Each day the initial number of prey in each treatment was renewed to determine the daily feeding capacity of the predator in relation to prey density over three consecutive days. Sometimes a greater prey density increased the feeding rate of the predator (Table 12). The prey mortality ranged from 18 to 98 percent. In most cases, the predator did not exhibit any clear preference for nymphs to adults. Although the feeding rate often declined on the second and third days, *L.*



2. Population growth of rice plant predator *Cytorhinus lividipennis* for 3 generations on leafhopper prey *(Nephotettix virescens)* in an insectary. Population at 0 days consisted of 5 pairs of adult predators.

pseudoannulata was evidently a superior predator of *N. lugens* when compared with *C. lividipennis.* A predation rate of at least 14 nymphs or 8 or more adults killed daily by one predator (Table 12) was achieved when 50 or 100 hoppers were available.

The density of several different predator groups were monitored in 1973 and 1974 in 21 separate crops. Weekly observations in each of the crops showed that the dominant predators were *Cyrtorhinus lividipennis* and spiders. *C. lividipennis* was usually more abundant than spiders, especially during the first half of the crop period. While *C. lividipennis* reached a density of 32 per hill in one crop, the mean maximum density per crop was only about 12 per hill. The fluctuations throughout a given crop period seemed to follow no discernible pattern. Spiders once reached a density of eight per hill, but the mean maximum density per crop was about four per hill. The spiders exhibited fewer major fluctuations than *C. lividipennis* during a crop period.

Parasitism. Previously the parasitism of stem borer larvae and pupae was found to be quite low, but egg parasitism was often high (1973 Annual Report). In 1974, the percentage of parasitism of *Chilo suppressalis* and *Tryporyza incertulas* was monitored each week throughout one crop period (fig. 3). Eggs of *T. incertulas* were heavily parasitized for most of the crop. Egg parasitism of *C. suppressalis* and larval parasitism of *T. incertulas* reached above 40 percent in the middle of the crop period. The pupae of both species were rarely parasitized.

Table 12. Number of prey (*Nilaparvata lugens*) killed daily by one adult predatory spider (*Lycosa pseudoannulata*) when caged together in an insectary. For 3 consecutive days, a fixed number of prey was offered each day to the same spider.

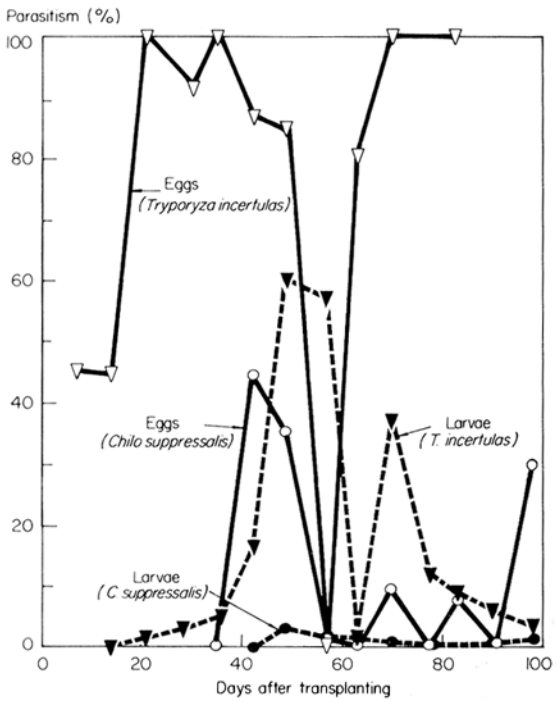
Prey (no.) offered each day	Prey killed (no.) daily by one predator[a]		
	1 day after caging	2 days after caging	3 days after caging
10 nymphs[b]	10 a	7 a	9 ab
10 adults	10 a	7 a	9 ab
50 nymphs[b]	40 c	24 ab	14 ab
50 adults	23 b	13 a	8 a
100 nymphs[b]	41 c	45 b	25 b
100 adults	40 c	17 a	30 b

[a]Values in a column followed by the same letter are not significantly different from each other at the 5% level using Duncan's Multiple Range Test. Values adjusted by Abbott's formula. [b]First and second instars.

CULTURAL CONTROL OF INSECTS

Entomology Department

Even though cultural practices are known to affect insects, few practices can be manipulated for pest control purposes because of conflicts with agronomic or economic concerns. In a study of the effect of plant spacing on stem borer and whorl maggot infestations, and the yield response to these infestations, insect density and damage were observed up to 50 days after transplanting. Then, the plants were protected from insects with insecticide up to harvest. For comparison, other plots were protected from transplanting to harvest. There was a tendency at first for more stem borer egg masses to be laid in the closely spaced plots and in insecticide-treated plots, possibly due to the heavier initial plant stand (Table 13). However, later borer infestation did not reflect this early oviposition behavior. Evidently whorl maggots



3. Percentage parasitism of eggs and larvae of two species of stem borers collected from IR127-80-1 rice. IRRI, 1974 wet season.

reacted the opposite to borer moths; whorl maggot damage occurred in the wider spacings. Yield loss was significant in the 30- x 30-cm and 40- x 40-cm plantings, probably because of early maggot damage (Table 13). Despite borer oviposition, the yield loss in the plots where the plant spacing was 10- x 10-cm and 20- x 20-cm was not significant. Apparently, the maggot problem can be minimized by planting seedlings relatively close together, 20 cm apart or less.

In another experiment where the effect of planting distance as well as other cultural practices on maggot damage was studied, the damage to the 10- x 10-cm planting was less than that to the 25- x 25-cm planting. The level of plant damage was as low when the seed was broadcast as when an insecticide treatment was used. Reducing the number of seedlings from four to two per hill reduced the damage significantly. Saturated rather than flooded soil reduced the damage level numerically, but not significantly. Thus, the major methods of cultural control of maggots appear to be broadcasting the seed or spacing transplanted seedlings close together.

INTEGRATED CONTROL OF INSECTS (PEST MANAGEMENT)

Entomology Department

Insecticides and varietal resistance. During part of 1974 at IRRI, the abundance of hoppers and the incidence of viruses were too low to cause a significant yield loss. At these times the value of plant resistance to these pests was in the form of insurance rather than an actual saving of pesticide costs. In two different experiments IR26 gave about the same, or only a slightly higher yield than a hopper- and virus-susceptible variety. However, when IR8 and IR26 rice varieties were compared both with and without pesticide treatment,

Table 13. Effect of spacing of transplanted rice seedlings (IR26) on infestation, damage, and grain yield loss caused by stem borers and rice whorl maggots. IRRI, 1974 wet season.[a]

Spacing (cm)	Stem borer egg masses[b] (no./1000 leaves) 20 DT	Dead heart (%) 35 DT	Dead heart (%) 50 DT	Whorl maggot damage[c] 30 DT	Yield loss[d] (compared with treated[e] plots) (%)
10 x 10	2.4 ab	10 a	6 a	0.8 a	– 2
20 x 20	2.3 a	16 a	3 b	1.0 b	+ 7
30 x 30	0.9 bc	15 a	3 b	1.3 c	+ 28 **
40 x 40	0.1 c	14 a	2 b	1.5 d	+ 39 **

[a]All means in one column followed by the same letter are not significantly different at the 5% level using LSD test. [b]*Tryporyza incertulas.* [c]Grade of leaf damage from 0 to 3, larger number means greater damage. [d]Asterisks (**) mean significantly greater than zero at the 1% level. [e]Treated plots had floating diazinon applied at 2 kg active ingredient (a.i.) /ha at 3, 17, 31, and 45 days after transplanting (DT). At 50 DT and at 70 DT *all* plots were treated with carbofuran at 2 kg a.i./ha to prevent insect damage beyond 50 days.

Table 14. Grain yield of five rice varieties given different pest control treatments. Bicol Rice and Corn Experiment Station, Philippines, 1974 dry season.

Type of treatment	Yield[a] (t/ha)				
	IR20	IR22	IR26	IR1561-228-3	IR1514A-E597-2
Prophylactic[b]	5.0 a	5.9 a	6.5 a	5.9 a	6.3 a
Prophylactic + threshold					
1[c]	5.1 a	4.6 b	5.2 b	5.4 a	6.0 ab
2[d]	4.4 ab	4.5 b	4.6 bc	4.3 b	4.8 cd
3[e]	4.7 a	4.3 b	5.3 b	4.4 b	5.6 abc
4[f]	4.9 a	4.0 bc	4.8 bc	4.4 b	5.2 bc
Control	3.5 b	3.3 c	4.1 c	3.7 b	3.9 d

[a]Values in the same column followed by the same letter are not significantly different at the 5% level (LSD test). [b]Carbofuran applied at 2 kg active ingredient (a.i.)/ha on seedbed at 3 and 13 days after seeding, and 1 kg a.i./ha to transplanted field at 3, 17, 31, 45, 59, 73, and 87 days after transplanting (DT); monocrotophos at 0.05% at maximum tillering, panicle initiation, and 1 week after flowering. [c]Diazinon applied at 1 kg a.i./ha at 3, 25, and 45 DT; gamma-BHC at 1.5 kg a.i./ha after panicle initiation. [d]Gamma-BHC applied at 1 kg a.i./ha at maximum tillering, and at 1.5 kg a.i./ha after panicle initiation. [e]Gamma-BHC applied at 1.5 kg a.i./ha after panicle initiation. [f]Gamma-BHC applied at 1 kg a.i./ha at about 5 DT, and at 1.5 kg a.i./ha after panicle initiation. MIPC (0.04%) applied to IR22 and IR1561-228-3-3 at 28, 35, and 49 DT before the estimated tungro-leafhopper threshold was reached.

Table 15. Net return from pest control treatments on five rice varieties. Bicol Rice and Corn Experiment Station, Philippines, 1974 dry season.

Treatment			Net return[b] (00 US$/ha)				
Type	Insecticide cost[a] (US$/ha)	Time spent applying insecticide[a] (man-h/ha)	IR20	IR22	IR26	IR1561-228-3	IR1514A-E597-2
Prophylactic	251	71	5.0 b	6.3 ab	7.3 ab	6.4 ab	6.9 cd
Prophylactic + threshold							
1	44	20	7.1 a	6.5 a	7.4 ab	7.6 a	8.6 a
2	16	10	6.4 ab	6.5 a	6.8 ab	6.3 ab	7.0 bcd
3	9	5	7.0 a	6.4 ab	7.9 a	6.5 ab	8.3 ab
4	19	24	7.1 a	5.8 ab	7.0 ab	6.3 ab	7.6 abc
Control	0	0	5.2 b	5.0 b	6.1 b	5.6 b	5.9 d

[a]Av. of 5 varieties. [b]Value of rough rice minus insecticide cost. Rice price: US$150/t. Values in one column followed by the same letter are not significantly different at the 5% level using LSD test.

there was a benefit from both plant resistance (IR26) (to grassy stunt virus and maybe brown planthoppers) and from pesticide application (probably control of whorl maggots). As expected IR8 benefited more from insecticide treatment than did IR26.

During the dry season five or six varieties and selections of rice that differed in their pest resistance were planted at three stations of the Philippine Bureau of Plant Industry – Visayas Rice Experiment Station, Bicol Rice and Corn Experiment Station, and Maligaya Rice Research and Training Center. Each line was given the same set of insecticide treatments, including the Philippine national pesticide recommendations, to determine the best treatment for each line at each location.

The pest problems were primarily whorl maggots and stem borers at all locations. Since the resistance in these rice lines to these pests is only moderate

Table 16. Percentage mortality of three adult arthropods at 3 days after treatment due to contact toxicity of various insecticides (0.05% concentration).

Insecticide	Formulation	Mortality[a] (%)		
		Lycosa pseudoannulata	*Cyrtorhinus lividipennis*	*Veranea crocea*
Perthane	EC	0 a	50 a	5 a
CPMC	EC	0 a	56 ab	72 b
Diazinon	EC	0 a	73 bc	25 a
Chlordimeform	EC	0 a	78 c	10 a
MIPC	WP	0 a	78 cd	15 a
Carbaryl	WP	0 a	89 de	100 c
Azinphos-methyl	EC	0 a	100 e	100 c
Monocrotophos	EC	0 a	100 e	100 c
Phosphamidon	EC	10 ab	92 de	92 c
Methyl parathion	EC	10 ab	100 e	20 a
Carbophenothion	EC	20 abc	56 ab	100 c
BPMC	EC	20 abc	97 e	92 c
Propoxur	WP	20 abc	100 e	20 a
Triazophos	EC	40 bcd	100 e	67 b
Endosulfan	EC	50 cd	54 ab	15 a
Metalkamate	EC	60 d	100 e	85 bc
Chlorpyrifos	EC	70 d	100 e	10 a
Carbofuran	WP	70 d	100 e	100 c
Acephate	WP	–	100 e	100 c

[a]EC = emulsified concentrate; WP = wettable powder. [b]Values adjusted using Abbott's formula. Means in one column followed by a common letter are not significantly different at the 5% level using Duncan's Multiple Range Test.

at best, the responses of the lines and varieties to the insecticide treatments were similar (Table 14). Apparently, in this case the pest-resistant features of a rice variety such as IR26 did not greatly influence the effects of the different treatments, but IR26 still gave the highest yield. At the Bicol station, yield increases were always achieved with regular prophylactic applications, and often with the fewer applications of the combination remedial and prophylactic treatments (Table 14). However the net returns were usually the highest when only moderate-priced treatments were applied (Table 15).

Insecticides and predation. As a first step toward conserving the beneficial effects of natural predation, some common sprayable insecticides were screened for contact toxicity to three predacious arthropods, *Cyrtorhinus lividipennis* (Miridae), *Veranea crocea* (Coccinellidae), and *Lycosa pseudoannulata* (Lycosidae). The insecticides were sprayed onto the anaesthetized predators in a Potter's Spray Tower. The insecticides differed in their toxicity to predators (Table 16). Perthane appeared to be the least toxic to the predators used. Such a selective chemical would be better than a wider spectrum insecticide for the control of brown planthoppers. The control value of predation would be at least partly maintained and, at the same time, hoppers can be killed with the insecticide. Some other insecticides also showed low toxicity to certain predators (Table 16).

Varietal resistance and predation. The effects of plant resistance to *N. virescens* and *N. lugens* on these pests, and the effects of the predator *C. lividipennis* were studied in combination in a greenhouse experiment. The combination gave a slightly better control of both pests by the second day than either method alone (Table 17), suggest-

Table 17. Mortality of nymphal prey, *Nephotettix virescens* and *Nilaparvata lugens*, caged separately with adult predators (*Cyrtorhinus lividipennis*) on TN1 rice plants, susceptible (S), and (1) IR8 rice plants, resistant (R) to *N. virescens*, or (2) Mudgo plants, resistant to *N. lugens*.

Variety	Treatment: Number at caging		Cumulative prey mortality[a] (%)	
	Prey	Predator	1 day after caging	2 days after caging
			Nephotettix virescens	
TN1 (S)	50	0	1 a	2 a
IR8 (R)	50	0	78 b	88 b
TN1 (S)	50	1	77 b	90 b
IR8 (R)	50	1	96 c	100 c
			Nilaparvata lugens	
TN1 (S)	20	0	7 a	9 a
Mudgo (R)	20	0	9 a	70 b
TN1 (S)	20	20	75 b	89 c
Mudgo (R)	20	20	74 b	100 d

[a]Means in a column followed by a common letter are not significantly different at the 5% level using LSD test.

ing that it could be beneficial to maintain predators in a rice field even when growing a resistant variety of rice.

SIGNIFICANT PLANT INJURY BY INSECTS
Entomology Department

Insects in general. Plant injury and yield loss caused by insects are measures of the practical importance of insect pests.

The timing and extent of damage to a crop is relevant to control procedures.

The yield loss from insects in 1974 at IRRI, as determined by the insecticidal check method, varied from 0 to 4.8 t/ha on an insect-susceptible selection of IR20 rice. The major pest was *N. lugens*, the brown planthopper.

Significant yield gains due to the use of an insecticide in upland rice fields could not be shown in trials in Batangas Province, Philippines in 1973, probably because of the experimental techniques employed. In 1974, significant yield gains were recorded in four of the six locations (Table 18). In a survey conducted in six other provinces, we found that some locations did suffer from insect

Table 18. Grain yield from upland rice plots untreated or treated with insecticide (regular application of carbofuran granules at 2 kg a.i./ha). Batangas province, Philippines, 1974 wet season.

Location	Variety	Yield[a] (t/ha)	
		Untreated	Treated
Luta del Norte, Malvar	Kinanda	3.9	4.4 *
San Pedro East, Malvar	Kinanda	1.9	2.7 *
San Isidro Sur, Sto. Tomas	Kinanda	2.7	2.9
Cale, Tanauan (Field 1)	Dagge	0.3	0.5
Cale, Tanauan (Field 2)	Dagge	1.0	2.0 *
Cale, Tanauan (Field 3)	Dagge	0.3	0.8 *

[a]Drought reduced potential yield at most locations. The asterisk (*) denotes that, at a given location, the treated plots yielded significantly higher than untreated plots at the 5% level. a.i. = active ingredient.

damage (Table 19). The major pests during the later stage of the crop period were stem borers and rice bugs, and occasional damage was caused by leaf folders, white grubs, mole crickets, and seedling maggots. Some pest control activity in upland rice may be economical.

Rice whorl maggot. Previously a significant yield loss due to whorl maggot (*Hydrellia philippina*) damage could not be shown in field trials at IRRI even though it could be demonstrated in the greenhouse (1973 Annual Report). Again in two field experiments in 1974, the yield loss from maggot damage was numerically large, but not statistically significant, despite the fact that the differences in the damage symptoms between the protected and unprotected plots were significant. However, in another experiment where the damage symptoms were more severe, a significant yield difference was obtained between untreated plots and plots treated during the first 50 days after transplanting (30- × 30-cm spacing) (Table 13). While it is very likely that there is a frequent economic yield loss due to this maggot, in many cases it cannot be demonstrated using the present field experimental techniques.

Planthoppers and leafhoppers. To assist in the development of suitable field thresholds for treatment, the concept of insect-days (number of insects

Table 19. Intensity[a] of insect problems as measured by pest incidence and damage symptoms in upland rice at the heading stage in seven provinces of the Philippines. 1974 wet season.

Province	Rice bug		White head (%)	Leaf folder-damaged leaves (%)	White grub-damaged hills[b] (%)	Mole cricket-damaged hills (%)	Seedling maggot-damaged tillers (%)
	No./hill	Damaged panicles (%)					
Isabela	–	–	–	6[b]	4	0[b]	0[b]
Batangas	–	4	3	0	0	0	0
Camarines Sur	0.2	20	3	1	0	2	0
	–	–	–	7[b]	–	3[b]	3[b]
Western Samar	1.0	35	1	0	–	0	0
Negros Occidental	0.5	4	3	6	–	0	0
South Cotabato	1.5	20	4	2	–	0	0
Bukidnon	0.5	4	4	2	–	0	0

[a]Each value is a mean from 6 to 35 fields per province. [b]At maximum tillering stage.

× length of infestations in days, 1 and 4 days) was tested, using *Nilaparvata lugens* and *Nephotettix virescens*. When using young TN1 seedlings (15 days old) and within a species and age group (nymph and adult), there appeared to be a constant level of damage caused by the same number of insect-days (20). However, other studies on older plants did not give similar results. More work is needed on this concept.

An attempt was made to define a tolerable level of brown planthopper infestation in the field. Susceptible varieties of rice could tolerate a limited number of insects for a limited period of time. Despite several experiments, we could not clearly define quantitatively the yield loss threshold because of difficulties in controlling the field population. However, a maximum density of at least 50 hoppers per hill was reached twice in one experiment without any apparent loss in grain yield.

To overcome the problem of uncontrolled pest densities, in the greenhouse, a known, but changing, number of brown planthoppers was caged on plants throughout the growth period. The artificially fluctuating populations in the different treatments were designed to reflect various realistic, yet stylized, field population growth patterns with three generations per crop period. Where the maximum density reached only about 25 insects per hill in either the second or third generation, usually there was no significant yield loss. This rough threshold level appears to be useful in guiding decisions regarding pesticide treatments during the last half of the crop period. More trials are needed for further confirmation.

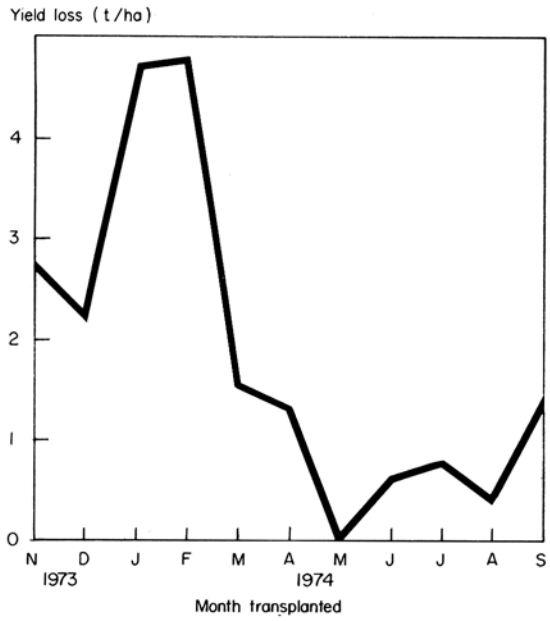
ECOLOGY OF RICE INSECTS

Entomology Department

Fluctuations in density. Each month the difference in yield between insecticide-treated and untreated plots of IR20 rice was monitored to measure the changing pest damage, and thus, pest density. The differences varied greatly over a period of one year (fig. 4). The damage was great in the dry season when the brown planthoppers were abundant; the damage was less in the wet season. If during certain periods of the year severe pest problems are not encountered, consideration should be given to adjusting the planting times to avoid rice pests.

Population dynamics of rice whorl maggot. Damage from the whorl maggot is becoming quite severe on the IRRI farm, but it is not uniform over time. In 1974, damage was greatest in April and again in August, probably a reflection of the two-crop-per-year system practiced at IRRI.

Population dynamics of stem borers. The weekly changes in the populations of *Tryporyza incertulas* and *Chilo suppressalis* were monitored for one season. *T. incertulas* eggs were laid directly after transplanting and the major larval density occurred within the first half of the crop period (fig. 5). However, *C. suppressalis* only developed in the last



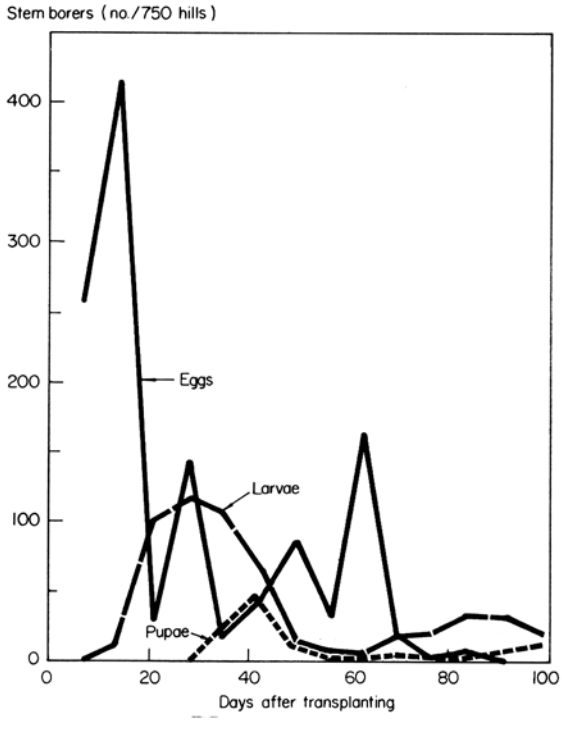
4. Grain yield loss of a selection of IR20 rice (susceptible to *Nephotettix virescens*) due to pests according to yield comparison of insecticide-treated and untreated plots. IRRI, 1973–1974.

half of the crop period, and it showed a higher survival.

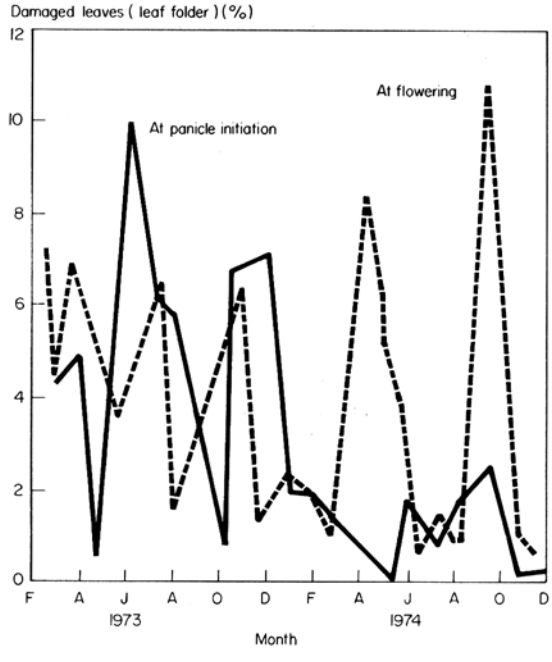
Population dynamics of rice leaf folder. As recorded over a 2-year period, the percent of leaves damaged by leaf folders changed frequently, two or more times per year, within a range of 0 to 10 percent. The infestation was lower at panicle initiation in 1974 than in 1973, but the madage at flowering was similar in the 2 years (fig. 6).

Population dynamics of green leafhopper. Green leafhoppers have been caught in the light traps at IRRI in ever-increasing numbers in recent years (fig. 7). A record catch was obtained in 1974, but no serious problems with either the virus disease or direct plant damage resulted. There were strong fluctuations during each year, with the catch returning to a low level at the end of each year. Probably some environmental factor(s), or the pests themselves, are slowly changing in some way(s) permitting the populations to increase each year.

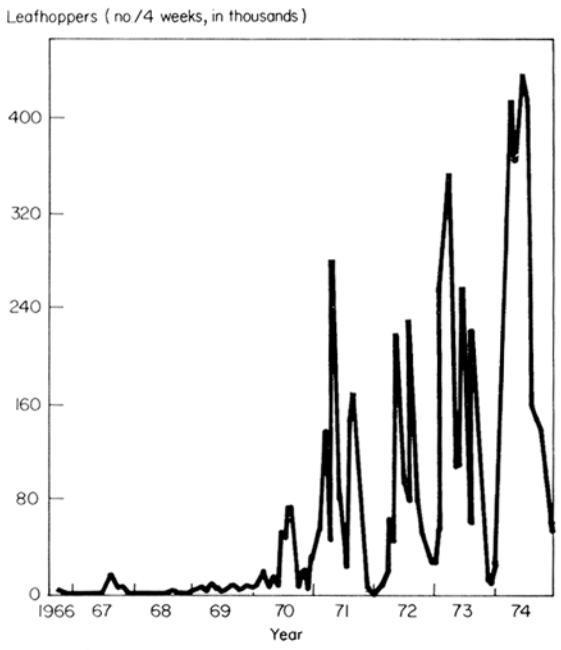
Population dynamics of brown planthopper. This insect has also increased in number in recent years at IRRI (fig. 8), but the reason is not clear.



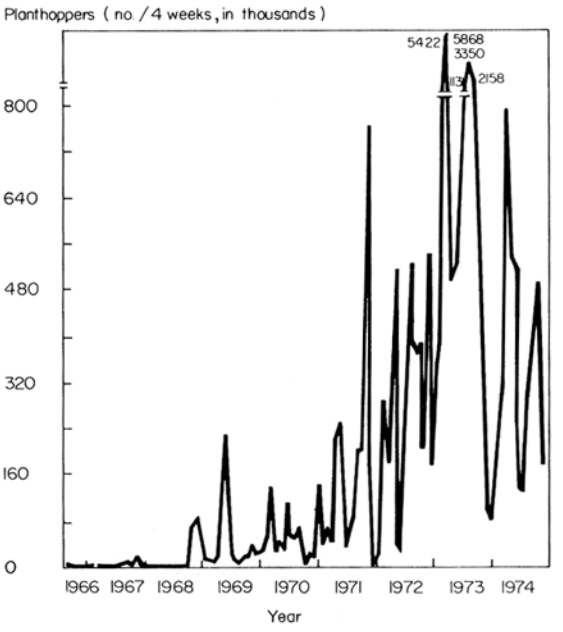
5. Stem borer *(Tryporyza incertulas)* density per 750 hills (30 sq m) of rice selection IR127-80-1. IRRI, 1974 wet season.



6. Percentage leaf folder *(Cnaphalocrosis medinalis)* damaged leaves at two stages of rice plant growth (IR20). IRRI, 1973–1974.



7. Abundance of adult green leafhoppers (*Nephotettix* spp.) according to catches in 3 light traps at IRRI, 1966–1974.



8. Abundance of adult brown planthoppers *(Nilaparvata lugens)* according to catches in 3 light traps at IRRI, 1966–1974.

Previous experiments have identified nitrogen fertilizer, high-tillering varieties and (or) close spacing, and good water management as factors that contribute to the increase in the population of this pest. Double or continuous cropping, and the associated good water management, may also have contributed to this gradually increasing pest problem. However, in all areas where these contributing factors are present, the infestation has not always been serious. More research is needed to learn whether, and in what way(s), climate, natural enemies, and insecticides effect and (or) affect the changing densities of brown planthopper poputions.

Fewer planthoppers were caught in light traps in 1974 as compared with the numbers caught in 1973. This suggests that the trend has been stopped or reversed, possibly due to the large-scale planting in the area surrounding IRRI with varieties or selections resistant to this rice plant pest.

There were usually two major peak catches each year, one in each cropping season. This is probably an effect of the double cropping system practiced in the area around IRRI.

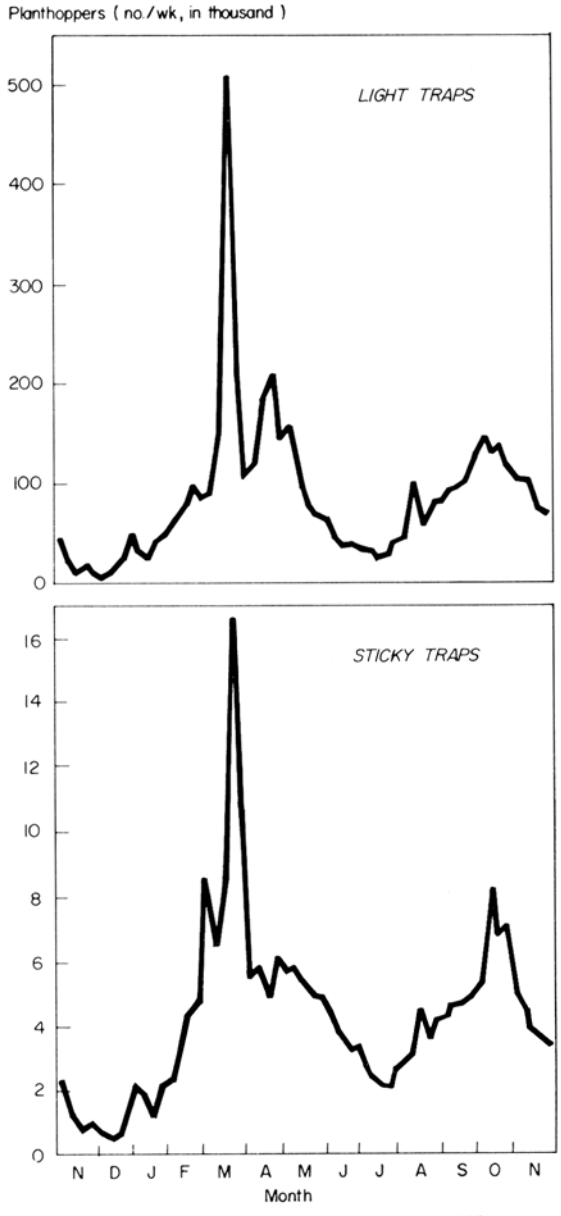
The flight of planthoppers was monitored at IRRI throughout the year on sticky traps, and the catches correlated closely with those obtained in light traps (fig. 9). Thus, simple sticky (Tanglefoot) boards set up around rice fields can be used to monitor flight behavior. However, actual field densities do not necessarily correlate with trap catches, and effective pest control still requires field surveillance.

BROWN PLANTHOPPER DISTRIBUTION AND SAMPLING TECHNIQUES

Statistics Department

In the 1973 wet season, an experiment was conducted on the IRRI experimental farm in order to (1) characterize the distributional patterns of brown planthoppers in the field; (2) study the effects of missing hills, virus-infected hills, varying tiller number, and border rows on the insect population; and (3) develop appropriate sampling procedures for estimating the density of nymphs and adults in experimental plots.

An area measuring 22.5 x 64.0 m was planted to the rice experimental line IR1917-3-17 under uniform management and spacing (25- x 25-cm).



9. Abundance of adult brown planthoppers *(Nilaparvata lugens)* according to catches in 3 light traps and 12 sticky traps at IRRI, November 1973–November 1974.

This area was divided into 40 equally sized plots, each measuring 4.5- x 8-m (18 x 32 hills).

Two types of data collection were used. (1) A complete enumeration of the number of tillers and of brown planthopper adults and nymphs per hill was performed for two sets of one peripheral plot and two inner plots each, at 28 days after transplanting (DT) for one set and at 76 to 78 DT for the other set. (2) At 28, 44, 71, and 83 DT, 10 scattered hills were sampled from each of the 40 plots under the specifications that (a) no two hills were adjacent, (b) all hills appeared to be normal, and (c) the hills were distributed throughout the plots. The numbers of brown planthopper adults and nymphs were recorded for each hill.

Distributional patterns. For all plots, the maximum number of nymphs per hill was observed at the first growth period (28 DT); whereas the number of adults reached a peak at the second growth stage (44 DT) and declined thereafter (Table 20). Some extremely large variances occurred among plots relative to within the plots. The largest ratios between these variances were attained at the highest insect densities for both adult and nymphs, suggesting that the insects are not evenly distributed over the experimental area. Comparisons between the average numbers per hill in peripheral and inner plots gave a significant difference in only one case – for adults at 44 DT. Apparently, the large variation over plots cannot be attributed primarily to the relative distance of plots from the edge of the experimental area. However, there was a large and highly significant difference between nymph densities of completely enumerated peripheral and inner plots (Table 21). At both sampling times, there were more nymphs per hill in the inner plots; a trend was not apparent for the adults.

For the completely enumerated peripheral plot at 28 DT, the nymph density in the outermost row (row 1) was significantly higher than that in the inner rows (row 5 to 10). The density in the second row was also higher, but not significantly so. The differences detected did not appear to be related to tiller number. The third and fourth rows did not differ significantly from the inner rows. No significant differences were detected among rows for the peripheral plot enumerated at 78 DT.

The serial correlation between the numbers of nymphs on adjacent hills was greater than zero at the 5-percent level of significance. Hills having high nymph densities were more frequent than expected. Apparently, nymphs tend to be clustered maybe because groups of nymphs originate from the same hills at the time of hatching and are limited in their ability to disperse due to their inability to fly.

Table 20. Means and variances in the measurement of the number of brown planthopper adults and nymphs per hill from sampled hills[a] in a rice field. IRRI, 1973 wet season.

Growth stage of rice plant (DT)	Plot mean (no./hill)	Within-plot variance	F-ratio[b]	Difference[c] between peripheral and inner plot means
		Adult		
28	0.62	0.55	1.12	−0.02
44	7.10	28.88	4.46**	1.34*
71	0.40	0.46	2.05**	−0.06
83	0.29	0.25	2.04**	0.00
		Nymph		
28	9.80	10.70	6.62**	−0.34
44	2.10	1.82	1.38	−0.19
71	3.20	4.64	3.01**	−0.26
83	0.28	0.45	2.31**	−0.02

[a]Ten hills sampled per plot for all 40 plots, resampling at each growth stage. DT = days after transplanting. [b]Ratio of between-plot and within-plot variances (39 and 360 degrees of freedom). [c]Difference based on 360 degrees of freedom. *, **Significant at 5% and 1% levels, respectively.

The clustering tendency was less marked for adults than for nymphs, probably because the density of adults was considerably less than that of nymphs at the time of complete enumeration. Had complete enumeration been made at the time of maximum population density for adults (44 DT), then a stronger clustering tendency may have been observed. Apparently, there is a tendency for adults and nymphs to be clustered together on the same hills.

Relation between density and hill characteristics. The correlation between the number of brown planthoppers and the number of tillers per hill was 0.281 and 0.456 for adults and nymphs, respectively. There was no consistent correlation between the number of insects per tiller per hill and number of tillers per hill. The relation between planthoppers per hill and tiller number appears to be linear, and the insects tend to distribute themselves over tillers rather than over hills, suggesting that hoppers per tiller may be a better unit of measure than hoppers per hill.

The correlation between tiller number and insects per hill only partially explains the clustering tendency described in the previous section. When the unit was placed on a per-tiller basis, the average serial correlation between nymphs on adjacent hills was still positive. This was also true of the correlation between nymphs and adults per tiller.

The average adult density and tiller number associated with virus-infected hills was somewhat less than that associated with normal hills; however, the differences were not significant at the 5-percent level. There was no apparent or significant difference in nymph density between diseased and normal hills, nor in adult or nymph density or tiller number between normal hills and hills surrounding missing hills.

Sampling procedures. No specific recommendation for sampling hills to determine brown planthopper density can be suggested at this time. Given

Table 21. Means and variances[a] of the number of brown planthoppers per hill in completely enumerated plots at 28 and 77 days after transplanting (DT). IRRI, 1973 wet season.

Plot	Adults		Nymphs	
	Mean	Variance	Mean	Variance
		28 DT		
Peripheral	0.21	0.20	2.60	5.97
Inner	0.20	0.25	5.06	9.62
Difference	0.01^{ns}	–	−2.46**	–
		77 DT		
Peripheral	1.27	1.20	0.46	0.55
Inner	1.29	1.49	2.51	4.82
Difference	-0.02^{ns}	–	−2.05**	–

[a]n.s. = not significant at 5% level; ** = significant at 1% level.

the non-random dispersion of the insects, consideration will be given to using sampling procedures which guarantee the dispersal of samples or sampling units throughout the experimental area. And since the hoppers appear to be distributed over tillers instead of over hills, the possible use of hoppers per tiller as a unit of measure will be investigated further.

Control and management of weeds

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231 WEED MANAGEMENT FOR CONTROLLING DIFFICULT WEEDS IN LOWLAND RICE

SUMMARY

Weed control is gaining increased recognition as an essential practice in the culture of lowland rice, because more Asian farmers are growing modern rice varieties. Hand weeding and (or) the use of the rotary weeder remain the methods most widely used in the Philippines and other Asian nations to control weeds in transplanted rice fields. Both methods are tedious, time consuming, and somewhat expensive.

2,4-D or MCPA appears to control annual weeds effectively in transplanted rice even with an unreliable water supply. Effective chemicals are used to a large extent in the Philippines to control weeds in transplanted rice.

Experiments were continued in the Philippines at the IRRI farm in Los Baños, Laguna, at the Maligaya, Bicol, and Visayas stations of the Philippine Bureau of Plant Industry (BPI), and in farmers' fields to identify suitable herbicides for these regions.

WEED CONTROL IN RICE

Agronomy and Rice Production Training and Research Departments

Transplanted rice *(Agronomy).* 2,4-D granules provided adequate weed control and gave one of the highest yields in the experiment conducted at the IRRI farm during the 1974 dry season (Table 1).

The grain yield was significantly higher for all plots where herbicides were applied, at the three BPI stations, as compared with the untreated control.

The granular herbicide butachlor plus 2,4-D IPE gave the highest rice yield at the Maligaya station. Similar yields were obtained with C-288 and C-19490/2,4-D IPE, two herbicides from Ciba-Geigy and this concurs with previous results (1973 Annual Report) of good performance. Additionally, two other herbicide treatments yielded results similar to the above three; bifenox (MC 4379), a new herbicide from the Mobil Corporation, USA, gave a yield of rice of 5.0 t/ha and USB 3584 (US Borax) in combination with 2,4-D IPE yielded 5.4 t/ha.

Due to the relatively lower temperatures during the first 1-2 weeks after herbicide application, the rice in most of the plots treated with herbicides exhibited slight phytotoxic effects at the Bicol station as shown by the toxicity ratings 19 days after transplanting. Plots treated with CNP/2,4-D IPE gave the highest rice yield of 6.3 t/ha at the Bicol station while the untreated control yielded only 1.4 t/ha. This high yield was significantly higher than the yields obtained from plots treated with USB 3584 + 2,4-D IPE, C-288, or C-19490/2,4-D IPE, but it was similar to the yields of plots treated with granular 2,4-D IPE or those of the twice-hand-weeded plots.

At the Visayas station, the commercial herbicide

Table 1. Effect of granular herbicides applied before weed emergence (4 days after transplanting) on the grain yield of transplanted IR26 rice at IRRI and three Philippine Bureau of Plant Industry (BPI) stations during the 1974 dry season. IRRI-BPI cooperative experiments.

Treatment[a]	Rate (kg a.i./ha)	Grain yield[b] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Bifenox (MC 4379)	3.0	8.0 a	5.0 abc	5.7 ab	5.5 bc
CNP/2,4-D IPE	2.0/0.3	7.8 ab	4.9 bcd	6.3 a	6.2 abc
USB 3584 + 2,4-D IPE	0.75+0.5	7.8 ab	5.5 ab	4.6 bc	6.8 a
C-19490/2,4-D IPE	0.75	7.7 ab	4.9 bcd	5.0 bc	6.6 ab
C-288	0.75	7.8 ab	5.4 ab	4.4 c	6.0 abc
2,4-D IPE	0.8	8.2 a	4.7 cd	5.6 ab	5.3 c
Benthiocarb/2,4-D IPE	1.0/0.5	8.4 a	5.4 ab	4.4 c	6.8 a
Butachlor + 2,4-D IPE	0.75+0.5	8.1 a	5.6 a	5.3 abc	6.4 abc
Hand weeding	twice	8.2 a	4.3 d	5.2 abc	6.4 abc
Untreated control	–	6.6 bc	2.6 e	1.4 d	1.2 d

[a] + = chemicals applied in immediate succession; IPE = isopropyl ester. [b] Average of four replications. Any two means in a column followed by at least one common letter are not significantly different at the 5% level.

Table 2. Effect of granular herbicides applied before weed emergence (4 days after transplanting) on the grain yield of transplanted IR26 rice at IRRI and three Philippine Bureau of Plant Industry (BPI) stations during the 1974 wet season. IRRI-BPI cooperative experiments.

Treatment[a]	Rate (kg a.i./ha)	Grain yield[b] (t/ha)			
		IRRI	Maligaya[c]	Bicol	Visayas
Bifenox (MC 4379)	2.0	5.0 a	3.8	4.3 ab	5.0 ab
CNP/2,4-D IPE	1.75/0.5	5.4 a	3.7	3.6 bc	6.3 a
USB 3584 + 2,4-D IPE	0.75+0.5	5.2 a	3.7	4.8 a	6.6 a
C-19490/2,4-D IPE	0.75	5.5 a	3.7	4.7 ab	5.4 a
C-288	0.75	5.5 a	3.5	4.2 ab	6.2 a
2,4-D IPE	0.8	5.3 a	3.8	4.7 ab	6.3 a
Benthiocarb/2,4-D IPE	1.0/0.5	5.9 a	3.7	4.3 ab	5.6 a
Butachlor + 2,4-D IPE	0.75+0.5	5.6 a	3.7	4.0 abc	6.6 a
Hand weeding	twice	5.2 a	3.3	4.8 a	6.0 a
Untreated control	–	1.9 b	3.5	3.1 c	3.8 b

[a] + = chemicals applied in immediate succession; IPE = isopropyl ester. [b] Average of four replications. Any two treatment means in a column followed by at least one common letter are not significantly different at the 5% level. [c] No statistical analysis was made as the crop was badly damaged by typhoons.

benthiocarb/2,4-D IPE gave a grain yield of 6.8 t/ha, which was not significantly different from the yields obtained with CNP/2,4-D IPE, USB 3584 + 2,4-D IPE, C-19490/2,4-D IPE, or C-288 and was similar to the yield of 6.4 t/ha from twice-hand-weeded plots. No appreciable crop injury was observed, as evidenced by the very low toxicity ratings.

In 1974, the same set of treatments were used in the wet season as in the dry season to confirm the findings from the dry-season trials conducted at the three BPI stations. In 1974, the rates used in both the wet and dry seasons were the same except lower levels of CNP/2,4-D IPE and bifenox were applied in the wet-season trials (Table 2).

As in the dry-season trials, all the treated plots showed good to excellent weed control in the wet season, recorded 18-20 days after transplanting and at panicle initiation (Table 2). In general the herbicides caused no crop damage at any of the stations, except C-288, which caused slight crop injury at panicle initiation at the Bicol station.

At Maligaya, USB 3584 + 2,4-D IPE, bifenox, and CNP/2,4-D IPE gave 70-90 percent weed control, which was comparable to the weed control obtained with C-288 or C-19490/2,4-D IPE, two new promising herbicides from Ciba-Geigy, or the standard herbicides benthiocarb/2,4-D IPE and granular 2,4-D IPE. Similar results were obtained at the Bicol station.

At the Visayas station, bifenox, CNP/2,4-D IPE, granular 2,4-D IPE, and benthiocarb/2,4-D IPE gave only 60-70 percent weed control due to faster regrowth of *Monochoria vaginalis* which had become the predominant weed species in the experimental area. Butachlor + 2,4-D IPE and USB 3584 + 2,4-D IPE adequately controlled all weed species present at the experimental area.

Evaluation of herbicides was continued during the 1974 dry season in farmers' fields in Laguna and Quezon provinces in the Philippines. At Famy, Laguna, no grain yield was produced on the unweeded control plots due to the heavy natural weed infestation, as evidenced by high weed weight (Table 3). Plots treated with USB 3584 + 2,4-D had the highest grain yield of 7.8 t/ha, which is significantly higher than yields obtained with two hand weedings. C-288 and C-19490/2,4-D produced grain yields similar to those obtained from the commercial herbicides benthiocarb/2,4-D, and butachlor+2,4-D, and from the two hand-weeding controls (Table 3).

At Candelaria, Quezon, despite high yields obtained in the unweeded control plots, the increase in grain yield due to weeding was at least 1.3 t/ha (Table 3).

Benthiocarb in combination with 2,4-D gave grain yields similar to those of the hand-weeded controls.

The results demonstrate that 2,4-D is one of the

Table 3. Effect of pre-emergence application (4 days after transplanting) of granular herbicides on weed control, crop tolerance, and grain yield of transplanted IR26 rice in the farmers' fields in the Philippines. 1974 dry season.

Treatment[a]	Rate (kg a.i./ha)	Famy, Laguna						Candelaria, Quezon					
		Grain yield[b] (t/ha)	Control rating[c] (rice heading)	Toxicity rating[d] (rice heading)	Weed wt[e] (g/sq m)			Grain yield[b] (t/ha)	Control rating[c] (rice heading)	Toxicity rating[d] (rice heading)	Weed wt[e] (g/sq m)		
					EC	S	B				EC	S	B
USB 3584 + 2,4-D IPE	0.75+0.5	7.8 a	9	0	17	0	3	9.4 a	9	0	0	8	0
C-19490/2,4-D IPE	0.75	7.1 abc	8	0	73	0	17	9.6 a	9	0	0	2	13
C-288	0.75	7.4 abc	9	0	0	15	3	9.4 a	10	0	0	0	0
Butachlor + 2,4-D IPE	0.75+0.5	7.5 ab	9	0	25	0	0	9.7 a	9	0	0	0	0
Benthiocarb/2,4-D IPE	1.0/0.5	7.2 abc	9	0	12	0	0	9.5 a	9	0	15	0	3
2,4-D IPE	0.8	6.4 c	7	0	38	2	3	9.8 a	9	0	30	2	23
Hand weeding	twice	6.9 bc	8	0	37	3	10	9.5 a	9	0	0	0	8
Untreated control	–	0 d	0	0	517	23	0	8.1 b	5	0	167	13	40

[a] + = chemicals applied in immediate succession; IPE = isopropyl ester; [b] Any two treatment means followed by the same letter are not significantly different at the 5% level. [c] Scale: 0–10; 0 = no control, 10 = complete control. [d] Scale: 0–10; 0 = no toxicity, 10 = complete kill. [e] Taken at heading of grasses; EC = *Echinochloa crusgalli* and similar species; S = sedges; B = broadleaves.

best herbicides to control effectively most annual weeds in transplanted rice.

Direct-seeded flooded rice (*Agronomy*). Selective herbicides identified earlier at the IRRI and the BPI stations continued to look promising for direct-seeded rice.

During the 1974 dry season, experiments were conducted at the IRRI farm and at the Bicol and Visayas stations to identify suitable herbicides for direct-seeded flooded rice.

At the IRRI farm, the grain yield of the untreated control plots was only 2.9 t/ha (Table 4) due to the dense weed population. AC 92553 (American Cyanamid Company) and oxadiazon with 2,4-D (Rhone Poulenc, France) were two herbicides tested for the first time and appeared to be promising. Several herbicides effectively controlled the weed species predominant in this area – *Echinochloa crusgalli, Monochoria vaginalis,* and *Cyperus difformis.* Bifenox was highly toxic to rice and gave low grain yields (Table 4).

Infestation of the experimental area at the Bicol station by weed species such as *E. crusgalli, M. vaginalis, C. difformis, Sphenochlea zeylanica,* and *Scirpus supinos* was so heavy that the untreated control plots yielded only 1.1 t/ha, which was markedly lower than the grain yields obtained from most of the herbicide-treated plots (Table 4).

Cyperus imbricatus, a perennial (rarely annual) sedge, appeared to be difficult to control with the herbicides tested, but competition from the dense community of other weeds readily smothered this sedge. Both *E. crusgalli* and *C. imbricatus* are more than 1 meter tall at maturity and, hence, compete with rice for light, nutrients, and space to a greater extent than do other weed species. This could explain in part why grain yields were generally lower in plots where either or both of these weeds were present.

The herbicide USB 3584 (U.S. Borax), when applied at 2.0 kg active ingredient (a.i.)/ha, showed slight toxicity to rice at the IRRI farm and severe initial crop injury at the Bicol station, giving a grain yield similar to that of the untreated control (Table 4). The sustained injury to the rice plants caused by the herbicides throughout the entire growth period of the crop caused *M. vaginalis, S. zeylanica,* and *S. supinos* to regrow in the vacant spots in the experimental plots faster than the rice could recover and become established.

At the Visayas station, the stand of *E. crusgalli* in the untreated plots was very heavy and grain yields were significantly lower than those in the treated plots (Table 4). The heavy growth of *M. vaginalis* and *C. difformis,* which was observed earlier in the untreated control, was suppressed later by the taller weed *E. crusgalli.* The annual sedge *C. difformis* was readily controlled by all of the chemicals tested.

C-288 and C-19490/2,4-D IPE provided excel-

Table 4. Effect of granular herbicides applied at 1- to 2-leaf stage of grassy weeds (6 days after seeding) on grain yield of direct-seeded flooded IR26 rice at IRRI and two Philippine Bureau of Plant Industry (BPI) stations during the 1974 dry season. IRRI-BPI cooperative experiments.

Treatment[a]	Rate (kg a.i./ha)	Grain yield[b] (t/ha)		
		IRRI	Bicol	Visayas
Butachlor + 2,4-D IPE	1.0+0.5	7.6 ab	5.8 ab	7.0 ab
Benthiocarb/2,4-D IPE	1.0/0.5	7.6 ab	5.1 bc	6.7 abc
C-288	1.0	8.0 ab	6.6 a	7.1 a
C-19490/2,4-D IPE	0.75	6.6 abc	4.4 c	7.1 a
USB 3584	2.0	7.4 ab	1.5 d	6.1 cd
USB 3153 + 2,4-D IPE	2.0+0.5	7.9 ab	4.4 c	6.3 bcd
Destun/2,4-D IPE	1.0/0.25	6.2 abc	4.6 bc	6.1 cd
CNP/2,4-D IPE	2.0/0.28	6.0 abc	3.8 c	5.9 d
Oxadiazon + 2,4-D IPE	0.5+0.5	6.5 abc	4.9 bc	6.5 abcd
AC 92553 (liquid)	2.0	8.1 a	–[c]	–
USB 3584 + 2,4-D IPE	1.0+0.5	8.0 ab	–	–
A-820 + 2,4-D IPE	1.5+0.5	6.1 abc	–	–
Bifenox/2,4-D IPE	2.0+0.5	4.9 d	–	–
Nitrofen/2,4-D BE	1.0/0.5	6.2 abc	–	–
K-223/2,4-D IPE	1.5/0.75	5.8 bc	–	–
Untreated control	–	2.9 e	1.1 d	2.6 e

[a] + = chemicals applied in immediate succession; IPE = isopropyl ester; [b] Average of four replications. Any two treatment means in a column followed by at least one common letter are not significantly different at the 5% level. Hyphens indicate the herbicides were only tested at IRRI, hence, no grain yield results from BPI stations.

lent control of the three weed species prevalent at the Visayas station – *E. vaginalis, C. difformis,* and *E. crusgalli* – and both herbicide treatments gave the highest yield of 7.1 t/ha. Similar grain yields were obtained with butachlor + 2,4-D IPE, USB 3153 + 2,4-D IPE, and benthiocarb/2,4-D IPE, all of which continued to look promising. Among the newer herbicides, USB 3584, oxadiazon + 2,4-D IPE, and destun/2,4-D IPE (3M Company) controlled weeds satisfactorily and gave grain yields exceeding 6 t/ha.

Experiments were continued during the 1974 wet season to identify suitable herbicides for direct-seeded flooded rice. At Maligaya, butachlor + 2,4-D IPE, C-19490/2,4-D IPE, and benthiocarb/2,4-D IPE were the only herbicides tested that gave adequate weed control with little or no crop injury, as shown in the toxicity ratings taken at 20 days after seeding and at panicle initiation (Table 5). The other herbicides such as C-288, USB 3584, destun, CNP/2,4-D IPE, and USB 3584 + 2,4-D IPE were either toxic to direct-seeded rice or gave inadequate weed control.

At the Bicol statior all herbicides provided adequate weed control when rated at 21 days after seeding with little or no toxicity to the rice except in the plots treated with USB 3584 and CNP/2,4-D IPE where the rice stand was reduced by 50 percent.

At the Visayas station, plots treated with C-288, USB 3584, and USB 3584 + 2,4-D IPE showed 50-60 percent stand reduction at 19 days after seeding. When the ratings were made at the panicle initiation stage, crop injury was still observed in the plots treated with USB 3584 and USB 3854 + 2,4-D IPE (Table 5). Several typhoons caused the crops to lodge at all sites, thereby precluding an accurate assessment of the effect of herbicide treatment on rice grain yield.

Weed control in upland rice (*Agronomy, RPTR*). Weeds are a more serious problem in upland rice than in lowland rice. Butachlor, USB 3153, and bifenox (MC 4379) continued to look promising for controlling annual weeds.

Weed infestation in the experimental area of the IRRI farm was very heavy and all untreated plots gave zero grain yield (Table 6). Almost all of the herbicides provided good initial and sustained weed control and significantly increased the grain

Table 5. Effect of granular herbicides applied at 1- to 2-leaf stage of grasses (6 days after seeding) on weed control and crop tolerance of broadcast-seeded IR26 rice applied during the 1974 wet season at three locations in the Philippines. IRRI-BPI cooperative experiments.

Treatment[a]	Rate (kg a.i./ha)	Maligaya				Bicol		Iloilo			
		Control rating[b]		Toxicity rating[c]		Control rating[b]	Toxicity rating[c]	Control rating[b]		Toxicity rating[c]	
		20 DAS	PI	20 DAS	PI	21 DAS	21 DAS	19 DAS	PI	19 DAS	PI
Butachlor + 2,4-D IPE	0.75+0.5	9	9	2	0	8	7	8	7	2	3
C-288	1.0	9	7	7	6	8	1	9	8	6	2
C-19490/2,4-D IPE	0.75	9	9	2	0	8	1	9	8	2	1
USB 3584	1.0	9	5	8	5	7	4	8	5	5	5
USB 3153 + 2,4-D IPE	1.0+0.5	8	8	4	0	8	3	7	7	1	2
Benthiocarb/2,4-D IPE	1.0/0.5	9	9	3	0	8	2	8	7	2	2
CNP/2,4-D IPE	1.75/0.5	9	6	3	0	7	4	8	6	1	2
Destun	0.75	8	5	1	0	8	2	8	6	0	2
USB 3584 + 2,4-D IPE	1.0+0.5	9	4	8	6	8	2	8	5	5	4
Untreated control	–	3	5	0	0	5	0	2	2	0	0

[a]+ = chemicals applied in immediate succession; IPE = isopropyl ester. [b]Scale: 0–10. 0 = no control; 10 = complete control. [c]Scale: 0–10. 0 = no toxicity; 10 = complete kill. DAS = days after seeding; PI = panicle initiation.

yield of the three rice varieties over that of the untreated control. Bifenox and fluorodifen (Ciba-Geigy) which initially provided satisfactory control of most weed species prevented neither the regrowth of *Echinochloa colonum* and *Eleusine indica* nor new growth of *Digitaria sanguinalis, Paspalum conjugatum,* and *Ischaemum rugosum,* and the grain yields of the semidwarf rice lines, IR937-55-3 and IR1480-147-3, from these two herbicide treatments were similar to those of the control plots

Table 6. The effects of liquid herbicides applied before weeds and crops emerge (5 days after seeding) on grain yield of direct-seeded rices grown in the Philippines under upland conditions at the IRRI farm, Philippine Bureau of Plant Industry station at Maligaya, and in a farmer's field at Cuenca, Batangas. 1974 wet season.

Treatment	Rate (kg a.i./ha)	Grain yield[a] (t/ha)				
		IRRI farm			Batangas[b]	Maligaya[c]
		IR1480-147-3	IR442-2-58	IR937-55-3	IR442-2-58	IR937-55-3
A-820	2.0	1.4 cd	1.5 abc	1.5 bc	1.5 bc	0 c
AC 92553	2.0	2.2 abc	1.7 ab	1.9 ab	1.7 ab	0.2 c
Butachlor	2.0	2.3 ab	1.5 abc	2.3 ab	1.5 bc	2.4 a
C-288	2.0	2.2 abcd	1.3 bc	1.8 ab	1.5 bc	2.8 a
Bifenox (MC 4379)	2.0	0 e	1.1 c	0.2 e	1.4 c	2.5 a
Oxadiazon	1.0	2.4 ab	1.7 ab	2.2 ab	1.6 bc	2.4 a
Fluorodifen	2.0	1.3 d	1.4 abc	0.8 cd	1.4 bc	2.4 a
USB 3153	2.0	1.5 bcd	1.2 bc	2.5 a	1.8 a	1.4 b
USB 3584	2.0	2.4 ab	1.9 a	2.3 ab	1.7 ab	2.2 a
Hand weeding	twice[d]	2.9 a	1.8 ab	2.5 ab	1.6 bc	2.5 a
Untreated control	–	0 e	0 d	0 e	0 d	0 c

[a]Average of four replications. Any two means in a column followed by the same letter are not significantly different at the 5% level. [b]All chemical and hand weeding treatments for varieties IR1480 and IR937 gave zero grain yield. [c]Only one variety was planted. [d]At 20 and 40 days after rice emerged.

(Table 6). On the other hand, IR442-2-58, a rice experimental line of intermediate stature, greatly helped suppress weed regrowth and to a greater extent than did the two semidwarf lines. Also, the grain yields of IR442-2-58 were considerably improved with the bifenox and fluorodifen treatments. USB 3584, butachlor, oxadiazon, and AC 92553 consistently provided good weed control for the three rice lines and the grain yields were about 2.0 t/ha.

In general the grain yields for upland rice were poor in 1974 because of the severe drought followed by typhoons. Additionally, diseases such as blast caused reduction in the grain yields of rice line IR442-2-58.

The grain yield of the untreated plots in the experimental area at Cuenca, Batangas, in the Philippines, was nil (Table 6) due to the initially heavy infestation of such tall and competitive weed species as *E. colonum, Celosia argentea, Ipomea triloba, Commelina diffusa,* and *Corchorus capsularis.* All of the herbicide treatments controlled these weeds equally satisfactorily. While butachlor, USB 3153, and USB 3584 gave excellent weed control, they caused severe temporary injury to rice line IR442-2-58 and caused sustained injury to the two semidwarf lines – IR937-55-3 and IR1480-147-3. Sixty days after seeding a second group of tall weeds started to become established.

This second group of weeds consisted of *Digitaria sanguinalis, Dactyloctenium aegyptium, Alysicarpus vaginalis,* and *Aeschynomene indica,* which completely suppressed the growth of the two semidwarf rice lines. The intermediate-statured rice line – IR442-2-58 – being somewhat taller, was able to suppress somewhat the weed regrowth and produced some grain yields (Table 6). Moisture stress and blast disease contributed to the reduced grain yield obtained by IR442-2-58.

At Maligaya, the dense infestation of the experimental area by the broad-leaf weed species, *Commelina diffusa,* resulted in a nil grain yield (Table 6) in the untreated plots, as well as in the plots treated with A-820 and AC 92553, which failed to control *C. diffusa.* The other herbicides gave about 60 percent control of this weed and provided a significant increase in grain yield to about 2.4 t/ha. USB 3153 reduced the crop stand, and the grain yield associated with this herbicide treatment was low (1.4 t/ha). No other weeds were present with *C. diffusa.* It is a perennial weed of the prostrate growth habit, but stands erect when in competition with other weed species and spreads rapidly. In fact, the semidwarf rice line IR937-55-3 was completely overgrown by this weed. Apparently, two hand weedings are not enough to remove weeds completely when growing late-maturing, semidwarf lines such as IR937-55-3.

Oxadiazon and USB 3584 continued to look promising as effective herbicides for upland rice.

The only herbicides currently marketed in the Philippines for upland rice and direct-seeded (dry seeded, bunded) rainfed rice are butachlor (Monsanto), A-820 (Amchem), and C-288 (Ciba-Geigy).

Two trials were conducted by the IRRI Rice Production and Training Department under upland conditions in which six herbicides were compared with hand weeding and no weed control. Two levels of butachlor and C-288 were tested under ten treatments. While the yields of all the treatments were low due to the severe drought in the area (Table 7), five of the herbicide treatments and the hand-weeded plots gave yields significantly higher than that of the control plot in trial 2, while four treatments produced yields significantly greater than did the control plot in trial 1.

Four trials were conducted under rainfed conditions comparing the same treatments. Three trials were direct seeded in moist to wet soil while one plot was seeded under puddled conditions. No

Table 7. Effects of liquid herbicides on direct-seeded IR1529-680-3 rice in the Philippines under upland conditions. Bulacan and Nueva Ecija, 1974 wet season.

Treatment	Yield (t/ha)		Mean
	Trial		
	1	2	
Butachlor	2.0*	1.4*	1.7
Butachlor	1.6	1.1	1.4
C-288	2.1*	1.5*	1.8
C-288	1.9	0.8	1.4
A-820	2.2*	1.3*	1.8
AC 92553	1.9	1.6*	1.8
Oxadiazon	1.7	1.3*	1.5
USB 3854	3.0*	1.1	2.0
Hand weeding (twice)	1.6	1.6*	1.6
Untreated control	1.3	0.8	1.1

*Significantly different from the control at the 5% level.

Table 8. Effect of liquid herbicides and hand weeding on grain yield of direct-seeded IR1561-228-3-3 rice in the Philippines under rainfed conditions. Bulacan and Nueva Ecija, 1974 wet season.

Treatment	Rate (kg a.i./ha)	Yield (t/ha)				Mean
		Trial[a]				
		1	2	3	4	
Butachlor	2.0	5.1	5.9	4.3*	4.6*	5.0
Butachlor	1.25	6.1	5.9	3.3	3.8*	4.8
C-288	2.0	5.2	5.9	4.9*	4.8*	5.2
C-288	1.0	6.6	5.7	3.8	4.9*	5.3
A-820	2.0	6.5	6.1	4.1	4.2*	5.3
AC 92553	2.0	6.0	5.6	4.6*	3.9*	5.0
Oxadiazon	0.75	5.6	5.7	3.3	4.2*	4.7
USB 3854	2.0	6.0	5.5	4.3*	3.8*	4.9
Hand weeding	twice	5.6	6.0	3.8	4.6*	5.0
Untreated control	–	5.8	5.6	3.1	1.8	4.1

[a]Trials 1, 2, and 3 were seeded in moist to wet soil, trial 4 in puddled soil. *Significantly different from the control at the 5% level.

differences were observed between the treated and control plots in trials 1 and 2 because of very low weed populations. In trial 3, butachlor and C-288 at 2.0 kg a.i./ha provided the most effective control of grasses at 20 days after seeding (Table 8). The other treatments provided 50-60 percent control of grasses.

In trials 1, 2, and 3, broad-leaf weeds were not present even in the control plots. Oxadiazon provided the best control of sedges followed by butachlor at 2.0 kg a.i./ha. The rest of the treatments provided poor control of sedges. Slight toxicity was observed in all treatments, but the plants recovered fully by 35 days after seeding.

In trial 4, although the C-288 plot treated with 2 kg a.i./ha exhibited severe toxicity at 20 days after seeding, the rice recovered and gave a good yield of 4.8 t/ha. However, in other studies, under field conditions in paddies where flooding with water took place following herbicide application, C-288 completely killed the rice crop on which it was applied. Oxadiazon was slightly phytotoxic to the rice crop in trial 4. No toxicity was observed with the other treatments.

None of the treatments provided effective control of broad-leaf weeds in trial 4, but butachlor, C-288 (at 2.0 kg a.i./ha), oxadiazon, and USB 3584 gave excellent control of grasses. AC 92553 and A-820 gave fair control of grasses and sedges. Butachlor (2.0 kg a.i./ha) and oxadiazon controlled sedges effectively up to 50 days after seeding.

Screening new herbicides (*Agronomy*). During the 1974 wet season, several new herbicides were found to be promising under rainfed conditions. MON 0358 (Monsanto, USA), K-223/2,4-D IPE (Showa Denko, Japan), LS721880 (PEPRO, France), RH 2915 (Rohm and Haas, USA), and RH 2915/2,4-D IPE were found to be effective in Controlling most weeds in transplanted rainfed rice. Each of these new herbicides increased the grain yield by at least 1 t/ha over that of the untreated control and gave a yield similar to that of the hand-weeded plots (Table 9).

MON 0358 was not only promising for transplanted rainfed rice, but also was found to control weeds effectively in direct-seeded rainfed rice while causing only a little crop injury.

ZERO TILLAGE IN RICE

Agronomy Department

During the 1974 dry season, when glyphosate was applied 13 days before seeding on no-tillage plots in an experimental area where *Paspalum scrobiculatum* and *Fimbristylis littoralis* were the most prevalent weeds, it gave grain yields similar to those obtained with one plowing and two harrowings (Table 10). Where glyphosate was followed with paraquat, the grain yields were no higher than when glyphosate was applied alone. Paraquat alone burned the foliage of most weeds present, but did not provide sustained control against *Paspalum* species, confirming previous findings that paraquat may not provide sustained control for all weeds, particularly *Paspalum* species, although it may give excellent initial control.

The herbicide K-223, which looked highly promising against the perennial nutsedge, *Cyperus rotundus*, gave poor control of *Paspalum* species. However, K-223 performs best when incorporated into the soil, which was not possible to use in the zero-tillage plots (Table 10).

Although glyphosate provides excellent sustained control of most weeds present at the IRRI farm, the time required for the weeds to decompose completely following an application of it (10-15 days) may limit its wide scale adoption in intensive

Table 9. Grain yield of transplanted rainfed IR26 rice as affected by promising new herbicides applied 4 days after transplanting (before weeds emerge) and 10 days after transplanting (after weeds emerge). IRRI, 1974 wet season.

Treatment[a]	Rate (kg a.i./ha)	Grain yield[b] (t/ha)	
		4 DT	10 DT
K-223/2,4-D IPE (G)	1.5/0.75	4.6	
K-1441/2,4-D IPE (G)	1.25/0.5	3.7	
LS 721880 (WP)	1.0	4.1	
MON 0358 (L)	0.5	4.2	
MON 0358 (L)	1.0	4.4	
MON 0358 (G)	0.5	4.0	
MON 0358 (G)	1.0	4.7	4.1
MON o358 (G) + 2,4-D IPE (G)	0.5+0.5	4.0	
MON 0358 (G) + 2,4-D IPE (G)	1.0+0.5	4.0	4.4
RH 2915 (G)	0.5	4.0	
RH 2915/2,4-D IPE (G)	0.5+0.5	4.4	
Standard treatments:			
Benthiocarb/2,4-D IPE (G)	1.0/0.5	3.3	
2,4-D IPE (G)	0.8	3.4	
Hand weeding	twice		5.0
Untreated control		2.7	

[a]G = granulated; WP = wettable powder; L = liquid.
[b]DT = days after transplanting.

rice cropping. On the other hand, while paraquat provides immediate weed control, some weed species escape damage and regerminate, causing poor stand establishment in the direct-seeded rice on zero tillage plots. The ideal herbicide should have the fast weed-killing capacity of paraquat and the sustained control of glyphosate.

WEED MANAGEMENT FOR CONTROLLING DIFFICULT WEEDS IN LOWLAND RICE

Agronomy Department

Hand weeding and rotary weeding are commonly used to minimize infestation of *Scirpus maritimus,* a perennial sedge infesting lowland rice fields in various tropical Asian countries. Bentazon and silvex were previously identified (1973 Annual Report) as effective in controlling *S. maritimus.* Also, medium-statured varieties of rice were found to compete more efficiently with this perennial sedge as compared with the semidwarf rices.

Field experiments were conducted during the 1974 dry and wet seasons at the IRRI farm in an area where the natural infestation of *S. maritimus* is heavy, and where lowland rice had been planted continuously for the past 8 years.

Three cropping patterns were used on the main plots – continuous lowland rice, corn intercropped with peanut followed by lowland rice, and corn followed by dry-seeded bunded rice. Then, weeding methods – chemicals, mechanical, or hand weeding – with a no-weeding control were used on the sub-plots. The plot size was 53 sq m. The experiment was replicated twice. For chemical weed control, bentazon was used for the lowland plots and butachlor followed by bentazon or oxadiazon was used for upland plots. Rotary weeding (mechanical control) was carried out on

Table 10. The effect of substituting chemicals for tillage on the grain yield, weed control, and crop tolerance of direct-seeded flooded IR2145-13-3 rice. IRRI, 1974 dry season.

Treatment	Application		Grain yield[c] (t/ha)	Control rating[d]			Toxicity rating[e]
	Rate[a] (kg a.i./ha)	Time[b] (DBS)		Ps	F1	Espp	
Glyphosate	2.0	13	5.1 a	8	8	7	0
Paraquat	1.0	2	0 c	2	5	9	0
Glyphosate fb paraquat	2.0 fb 1.0	13 fb 2	5.1 a	8	9	6	0
K-223 fb paraquat	6.0 fb 1.0	13 fb 2	1.5 b	2	6	9	0
One plowing + 2 harrowings	–	10 fb 2	6.5 a	8	10	9	0

[a]fb = followed by. [b]DBS = days before seeding. [c]Average of four replications. Any two means followed by the same letter are not significantly different at 5% level. [d]Taken at heading of weeds. Ps = *Paspalum scrobiculatum;* F1 = *Fimbristylis littoralis;* Espp = *Echinochloa crusgalli* and *E. cruspavonis.* Scale: 0–10; 0 = no control, 10 = complete control. [e]Taken at heading of weeds. Scale: 0–10; 0 = no toxicity, 10 = complete kill.

Table 11. The effect of weeding methods on yield and population density of *Scirpus maritimus* and other weeds on three irrigated cropping patterns. 1974 dry season.

Treatment	Yield[a] per hectare	Weed count (no./sq m)					
		Grasses	Broad-leaves	Annual sedges	*Scirpus maritimus*	*Cyperus rotundus*	Volunteer rice
		CONTINUOUS LOWLAND RICE					
	tons						
Bentazon	5.8 a	12	15	255	30	–	–
Rotary weeding	5.8 a	1	0	0	18	–	–
No weeding	3.2 b	10	54	351	289	–	–
		CORN					
	marketable ears						
Butachlor fb bentazon	21,500 a	62	0	0	19	58	39
Hand weeding twice	25,000 a	16	0	0	4	5	10
No weeding	9,500 b	166	5	0	65	99	48
		CORN + PEANUT					
	Corn, marketable ears						
Butachlor fb bentazon	32,000 a	56	0	0	19	31	61
Hand weeding twice	36,000 a	39	0	0	2	17	2
No weeding	16,500 b	206	0	2	59	90	65
	Peanut, kg						
Butachlor fb bentazon	438 b						
Hand weeding twice	835 a						
No weeding	146 c						

[a]Any two means followed by the same letter are not significantly different at 5% level.

the lowland plots 20-35 days after transplanting lowland plots, and upland plots were hand weeded 15-40 days after crop emergence.

In the wet season, the same weeding methods continued to be used, depending on whether the plots were lowland or upland.

In the 1974 dry season, in all the three cropping systems, yields from the treated plots were significantly higher than the yield of the untreated control (Table 11). Bentazon at 1.5 kg/ha and rotary weeding on continuous lowland rice gave the highest yields (5.8 t/ha). On the average, the treated plots produced 2.6 t/ha more grain than did the untreated control plots, because of the effective control of *S. maritimus* of the treated plots, as evidenced by the low weed count of the treated plots as compared with that of the untreated control (Table 11). Late-emerging annual weeds (mostly annual sedges) did not affect the grain yield of rice due to bentazon treatment.

For corn planted alone, two hand weedings gave the highest yield of 25,000 marketable ears/ha (Table 11). However, this corn yield was not significantly different from that obtained with the butachlor-followed-by-bentazon treatment. The heavy weed infestation, consisting mostly of annual grasses, of the untreated control plots causes a very low yield (9,500 marketable ears/ha). Interestingly, in the untreated control the *S. maritimus* population was sharply reduced by

Table 12. The effect of weeding methods and the population density of *Scirpus maritimus* and other weeds on the grain yield of lowland and dry-sown rainfed bunded rice. IRRI, 1974 wet season.

Treatment	Grain yield (t/ha)	Weed count (no./sq m)				
		Grasses	Broad-leaves	Annual sedges	*Scirpus maritimus*	*Cyperus rotundus*
		Continuous lowland rice				
Bentazon	4.6 a	0	0	0	0	0
Rotary weeding	4.6 a	0	0	0	11	0
No weeding	1.6 b	0	0	0	310	0
		Lowland rice (previously planted to corn + peanut)				
Bentazon	4.7 a	0	0	0	0	0
Rotary weeding	5.1 a	0	0	0	28	0
No weeding	2.6 b	0	0	0	236	0
		Dry-sown rainfed bunded rice (previously planted to corn)				
Oxadiazon	3.0 a	31	0	2	22	26
Hand weeding	3.3 a	39	16	0	18	20
No weeding	0 b	502	11	0	29	38

Table 13. Effect of cropping pattern and weeding methods on the population density of *Scirpus maritimus* and other weeds and grain yield of dry-sown rainfed bunded IR1561-228-3-3 rice. Third crop, IRRI, 1974 wet season.

Treatment	Grain yield (t/ha)	Weed count[a] (no./sq m)					Weed wt (g/sq m)				
		G	S	B	Cr	Sm	EC[b]	G	B	Cr	Sm
Oxadiazon	2.4	106	95	0	0	0	165	8	77	0	0
Hand weeding twice	2.1	232	65	66	0	0	45	4	2	0	0
No weeding	0	3104	74	150	0	0	200	15	20	0	0

[a]All grassy weeds including *Paspalum* species. S = sedges; B = broadleaves; Cr = *Cyperus rotundus;* Sm = *Scirpus maritimus.* [b]*Echinochloa crusgalli* and similar species excluding *Paspalum* species.

about 78 percent when a lowland field was converted to an upland field. Volunteer rice from the previous crop was observed. Also, under upland conditions, another perennial sedge, *Cyperus rotundus,* was observed, but it was less prevalent than the annual grasses.

Corn yields were numerically higher when corn was intercropped with peanut than when corn was planted alone (Table 11). The shift in weed population was similarly drastic in corn intercropped with peanut as compared with lowland rice. While the peanut yield of the chemically treated plots in the intercropping method was significantly lower than that from the hand-weeded plots, because of the competition with grasses which were not adequately controlled by butachlor, it was significantly higher than the peanut yield of the untreated control.

In the 1974 wet season, where rice was grown continuously, the yields obtained from the bentazon-treated plots and the rotary weeded plots were the same (4.6 t/ha) and were significantly higher than the yield from the no-weeding plots (1.6 t/ha) (Table 12). The low yield of the no-weeding plots was due to a heavy *S. maritimus* infestation, as evidenced by the high weed count 40 days after transplanting. The perennial sedge was the only lowland weed species present.

In the lowland plots that were previously planted to corn intercropped with peanut, rotary weeding produced the highest yield (5.1 t/ha) in the entire experiment, and this was similar to the yield (4.7 t/ha) obtained from the bentazon-treated plots. While the no-weeding treatment

yielded only 2.6 t/ha, this yield was 1 t/ha higher than the yield of the no-weeding treatment in the continuous lowland plots. Also, the weed count was reduced from 310 plants/sq m in continuous lowland rice to only 236 plants/sq m in the rotation with corn plus peanut followed by lowland rice. This demonstrates the vulnerability of the perennial sedge, *S. maritimus,* to land management conditions and cropping sequence manipulations which expose the weeds to a less advantageous situation in which to compete with the crop under cultivation. Furthermore, when an upland field is shifted to lowland conditions, weeds generally troublesome under upland conditions do not grow under lowland conditions and vice versa.

Hand weeding and oxadiazon treatments produced similar grain yields in a dry-sown rainfed bunded rice field that was previously planted to corn (Table 13). The no-weeding treatment produced no yield. Although the *S. maritimus* population was nearly eliminated, the annual weed population, particularly that of the annual grasses, increased to the point that the annual grasses became the predominant weed species. The *C. rotundus* population was lower in the 1974 wet season because of the increased competition from a very high population of annual grasses caused by two successive croppings under upland culture. The results demonstrate the manner in which various crop and soil management practices affect changes in the weed community from weed species that are more difficult to control to those that are easier to control. It is more likely that the results would have been similar if perennial weeds other than *S. maritimus* had been present in lowland rice.

These studies also demonstrated not only the advantage of growing crops in a planned sequence in rotation but also the advantage derived in reducing to a minimum the losses of grain yield caused by weed competition.

Irrigation water management

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SUMMARY

The amount of water available to farms from an irrigation system, and the incidence of drought on these farms, are inversely related to the distance from the beginning of the major canals to the farm sites. The extent of a tertiary network of on-farm canals was not related to drought incidence. After major droughts, substantially more water was found to be required to adequately irrigate rice even after the soil had been resaturated.

Dates of transplanting rice on farms served by those sections of irrigation canals farthest from their source of supply tend to be about the same as those for rainfed farms. However, with careful management of water flows within the canal, transplanting on these farms can be accomplished earlier than on rainfed farms, about 4 weeks earlier, which is about the same time as transplanting on farms located near the beginning of the canals.

A comparison of the Philippine model of rotational irrigation by farm ditch with continuous irrigation showed no significant differences with regard to grain yield, yield per unit of water, and date of planting, when water was supplied at the same rate to both types of irrigation.

Removal of topsoil from rice paddies due to on-farm canal construction and land leveling brought about considerable losses of soil nutrients, decreased grain yield, and greater susceptibility to deep flooding on the affected paddies.

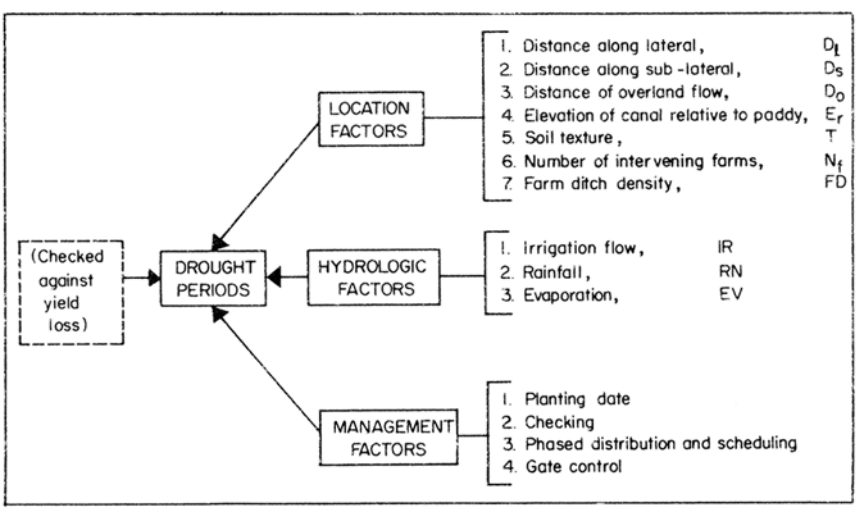
WATER MANAGEMENT

Our program focuses on the performance of canal irrigation systems. All the projects were carried out jointly with the Philippine National Irrigation Administration on irrigation systems in Central Luzon, Philippines.

DROUGHT INCIDENCE WITHIN IRRIGATED AREAS

Most irrigation systems cannot adequately serve all farms within their service areas all of the time. The most important reason for this is that most existing systems divert flowing river water into the canal networks and onto farmers' fields with essentially no water storage. As soon as the river flow drops off, such as during the dry season or during temporary dry periods in the wet season, the system no longer receives enough water to adequately supply all of its farms. The temporary periods of moisture stress or drought in different parts of the service area result in loss of grain yield (1972 Annual Report). This project was designed to find how certain factors affect the severity and distribution of these drought periods.

The build-up of drought in certain parts of a system can be attributed to unfavorable location within the system, to insufficient water entering the area, and to the forms and nature of water distribution within the system (fig. 1). Location factors include those effects that have been found



1. Factors affecting the severity and distribution of drought periods in canal irrigated areas.

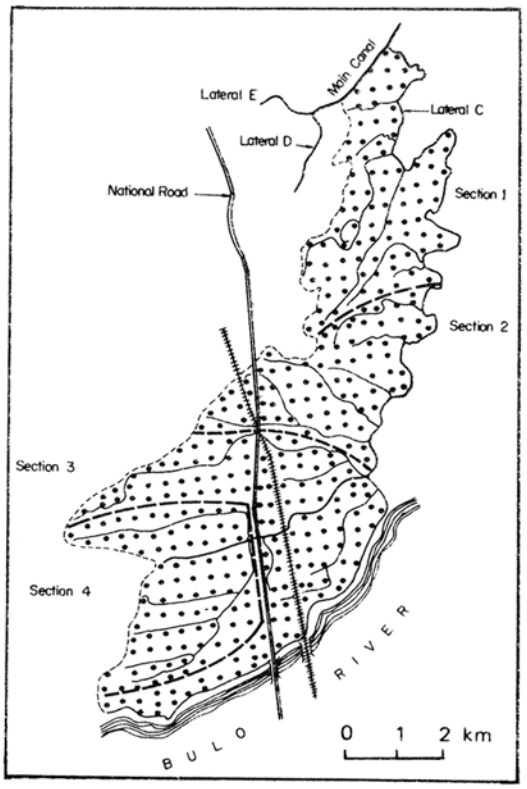
highly associated with stress (1973 Annual Report), such as distance of the farm from the beginning of the lateral canal (D_l), distance from the beginning of a sublateral if the farm is supplied by one (D_s), and overland distance of the farm from the point where water is released from the canal system (D_o). Other location factors include the command or elevation of the canal relative to that of the farm being served (E_r), the texture of the soil (T), the number of intervening farms along the overland distance of water movement (N_f), and the density of farm ditches (FD).

The hydrologic factors studied include the amounts of irrigation water supplied to different parts of the system (IR), and the climatic variables of rainfall (RN) and evaporation (EV).

The most important management effect studied was that of checking or temporarily obstructing water by placing wooden boards in the lateral canal. This raises the elevation of water upstream from the check, making irrigation more plentiful there, but it greatly reduces the flow downstream. Management practices to help those areas further downstream to receive more water are not very effective because turnouts along both the lateral and sublateral canals are usually fully open. This results in greater water discharges from the upper canals where the water elevation is higher than further downstream. Water flow was generally observed to respond to physical and hydrological factors rather than to human ones. In addition, management control varied little over the study area and was difficult to express quantitatively. Therefore, management was dropped from the model as a primary factor, leaving only the location and hydrologic factors.

The study was conducted during the 1973–74 and 1974–75 wet and dry seasons in a command area of about 5,700 ha served by Lateral C of the Peñaranda River Irrigation System, in Gapan, Nueva Ecija province, Philippines. Only the analysis of the 1973–74 data is presented here. Because major differences had been found between the upper and lower reaches of the canal systems (1973 Annual Report), we studied the entire command area to obtain results representative of whole systems (fig. 2).

More than 400 observation paddies were located within the area on a grid system of 360-m spacing. Each observation paddy represented about 13 ha of surrounding farms. We ran a differential level to establish each paddy's relative elevation; most other location variables were determined by scaling from detailed airphoto maps. Soil texture was estimated from a soil classification report issued with the maps. The exact length of farm ditches was not shown clearly on the maps, so we undertook low-altitude surveillance flights to sketch them in and examined their accuracy by spot checks on the ground. Farm ditch densities were then computed by dividing the total linear length of ditches by the area they served.



2. Map showing the grid of observation paddies for assessing water adequacy in the service area of Lateral C, Peñaranda River Irrigation System, Gapan, Nueva Ecija, Philippines.

Drought incidence was assessed three times a week throughout both growing seasons. Field personnel of the irrigation system took readings from a short piezometer tube in each observation paddy to measure the depth of water above or below the soil surface. These data were then converted to "stress days," or those days for which the water was below a certain depth in the tube.

These values were then related to loss of grain yield with results similar to those reported earlier (1972 and 1973 annual reports).

Daily values of rainfall and evaporation from Class A pans were recorded from four sites within the area. The flow of irrigation water was measured at the headworks of Lateral C, and, in the dry season, at points along that lateral corresponding to the first-, second-, and third-quarter sections of its service area (fig. 2). Application depths were computed on a daily basis and then summed to weekly values.

Looking first at the location factors, we computed a linear multiple regression equation relating D_l, D_s, D_o, E_r, T, and FD to the total number of stress days (SD) for each paddy. A stress day is defined here and throughout this section as the number of days the paddy does not have standing water, from transplanting until 25 days before harvest. The wet-season results had a low level of significance because of the low incidence of stress days in the area. Rainfall was quite uniformly distributed over the area during that season, and was sufficient to meet most of the water needs of the crop even if there had been no irrigation. For the dry season, the equation computed is:

$$SD = -5.38 + \underset{(5.92)}{0.12}\, D_l + \underset{(2.64)}{0.14}\, D_s + \underset{(1.98)}{1.42}\, D_o$$

$$+ \underset{(0.84)}{0.068}\, T - \underset{(-1.06)}{1.13}\, E_r + \underset{(1.70)}{0.18}\, FD$$

$$R^2 = 0.27^{**} \qquad \text{No.} = 206$$

where SD measures the number of days the field is without standing water. D_l and D_o are expressed in hundreds of meters; T is percent clay; E_r is in meters, and FD is in meters per hectare. T values are shown in parentheses. Only 206 observations were used in the dry season since about a third of the area was not planted because of insufficient water. The extent of variation explained by this model is not high, but that is partly because management and hydrologic factors are excluded.

All three distance variables in the model are highly significant. For both lateral and sublateral canals, the build-ups of stress days at increasing distances from the source were similar. Stress build-up per meter of distance is greatest for overland water movement, although the mean distances of such movement are much less than those along the lateral or sublateral canals.

The major reasons for the increased drought incidence further along major canals are the temporary checks that restrict the amount of water passing along the canal, and the fact that almost no turnouts are gated. This results in over-irrigation in the upstream sections and in serious shortages downstream. Greater overland distance provides more opportunity for water to be lost to drains, to seepage and percolation, and to crop production on farms over which it passes.

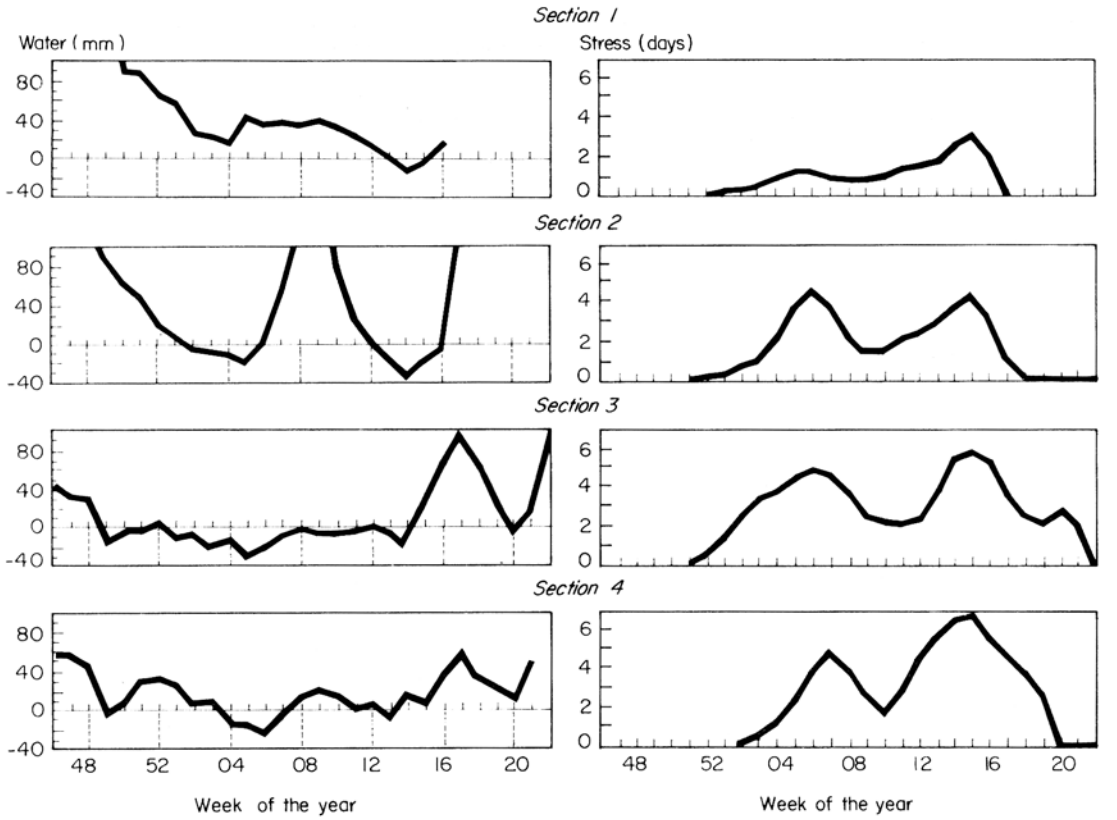
The model indicates that greater farm ditch density is not associated with fewer stress days; in fact, there is a tendency in the other direction. This was not expected, but could have been caused by the weak association of FD with increasing distance D_l, and the fact that most of the farm ditches were not well maintained. The simple correlation of SD and FD was insignificant.

A similar weak association was found between soil texture and distance along the lateral. This is due to the fact that heavier soils showing greater water-holding capacity are found in the farther reaches of the system, at greater values of D_l.

Additional trials were made with the original regression model using interaction terms and the number of intervening farms N_f. None of these terms were significant in their effects on drought incidence. In the case of N_f, it appears that the overland movement of water D_o accounts for stress days independently of the number of intervening farms.

By using the regression model and substituting the mean values for all nonsignificant factors, the mean number of stress days was estimated to be 12.5, 26.2, 34.9, and 35.4 for sections I, II, III, and IV, respectively, along the lateral canal. The respective mean measured values using actual observations were 13.3, 25.4, 36.3, and 41.3 stress days.

Turning to the effects of the hydrologic factors, we computed for each week the mean number of stress days in each of the four sections. Aggregate stress day data were used because the volume flow of irrigation was not measured at each paddy, but only at the section level. The maximum number of stress days in any week thus is seven. Weekly data were also computed for the application depths of irrigation (Q) by dividing the net volume flow diverted to each of the four sections by the area



3. Weekly values of excess water (irrigation + rainfall – evaporation) and stress days (mean days per week the paddies are not flooded) for 4 sections of Lateral C, Peñaranda River Irrigation System, dry season 1974.

planted. Weekly depths of rainfall (*RN*) and evaporation (*EV*) were also tabulated.

We examined only the dry season data since rainfall and irrigation were generally abundant in the wet season. The first approach using weekly data was the linear model:

$$SD = a + b_1 Q + b_2\ RN + b_3\ EV$$

The results showed *EV* to be the only significant term for each of the first three sections, with neither *RN* nor *Q* having a significant effect on stress days. In the fourth section, however, both *Q* and *EV* were found to significantly affect *SD*. Overall levels of significance were low. The significant relationship between evaporation and stress days should be interpreted with caution. The seasonal trend in rate of evaporation and that of stress build-up are correlated, but the relationship is only indirect. Stress day build-up is directly associated with the reduction in available water supply and indirectly with the higher levels of evaporation, during the latter part of the dry season.

We then looked at the combined expression $Q + RN - EV = EX$, which is the water available for crop production in excess of evaporative demand, for its effect on stress days. This term, *EX*, can be considered an index of water availability for crop production since evapotranspiration for flooded rice is approximately equal to the evaporative demand, *EV*. However, the expression does not account for field losses of *Q* or *RN* before the water is taken up into the plant. Seepage, percolation, and drainage losses are important, and explain why some stress days would still be expected for weeks when *EX* takes on positive but small values.

Three-week moving averages for *SD* and *EX* were plotted by week for each of the four sections (fig. 3). Sections I and II had greater values of *EX* and experienced less drought than sections III and IV, but stress was substantial in all four sections. A water shortage throughout the Lateral C service area is evident early in the season, but it was

Table 1. Regression coefficients[a] for stress days (*SD*) as a function of excess water (*EX*) for periods before first drought and after first drought, and estimated excess water to reduce stress days to zero. Four sections of Lateral C, Gapan, Nueva Ecija province, Philippines, 1974 dry season.

Section	Period	Duration of observations (wk)	Constant	Coefficient of *EX*	R^2	*EX* required to reduce *SD* to zero (mm/wk)
I	After	5	1.39	−0.020	0.73	69.6
	Before	11	2.34	−.035	0.87	66.9
II	After	5	1.42	−.029	0.65	49.0
	Before	12	3.43	−.017	0.85	201.8
III	After	5	1.69	−.130	0.76	13.0
	Before	17	3.55	−.013	0.14	273.1
IV	After	4	1.64	−.066	0.85	24.9
	Before	13	4.46	−.015	0.05	297.3

[a]For the model $SD = A + B\,(EX)$.

alleviated when supplementary water was made available from a newly completed storage reservoir outside the system. Another more serious drought period appeared during the middle and end of the season as water again became scarce.

A close inspection of these graphs indicates a lag of about 1 week between the week of extreme *EX* values and the corresponding response of *SD*. This is expected, for moisture is available in the soil to sustain the crop for a few days if the water supply is stopped. Similarly, when fields affected by drought are resupplied, the water advances, paddy by paddy, first satisfying the water requirements of the closer fields.

The graphs also show a marked difference in the response of *SD* to *EX* before and after the first period of drought. Relatively low values of *EX* are adequate to maintain low stress levels before the early drought periods, but much more water is required to achieve comparable *SD* levels thereafter. Therefore, we computed separately for the periods before and after first drought incidence the equation:

$$SD_{t+1} = A + B\,(EX_t)$$

The subscript t refers to the week number. Exploratory trials revealed that the most satisfactory cutoff point between the two phases is when *SD* values first exceed about 2.5 days.

The regression results (Table 1) are quite uniform among the four sections. The equations for the second phase (*B*) reflect greater drought propensity than those for the first (*A*), in both the expected *SD* level for zero *EX* and the reduction in *SD* expected for a given increase in *EX*. Results for Section I showed less difference between the two phases, but this was because the early drought period was not very severe. For the other sections, *EX* values estimated at between 13.0 and 49.0 mm/week were sufficient to eliminate drought (*SD*= 0) in the early phase, but after the drought period, 202 to 297 mm/wk were required to achieve zero stress levels. The chief reasons for this difference are changes in available soil moisture, and water losses to seepage, percolation, and drainage. Soil moisture content is highest right after puddling, and it decreases only slowly throughout crop growth provided the field is continually saturated. But a field that has been allowed to dry out will not incorporate the same amount of moisture in the soil if it is reflooded. Excessive water losses have been observed (1973 Annual Report) in experimental plots that are resupplied after being dried out. These losses are caused by irreversible deep cracking of the clay soil, which provides a conduit for subsurface water movement. Since many drainage creeks carry these losses away from the Lateral C service area, the *EX* values must be much higher to supply the needs of the crop under these conditions.

Although we have analyzed the location and hydrologic factors separately, it is clear that their effects on stress days interact and, in some cases, overlap. The effects of most of the location variables, for example, were greatly reduced during the wet season when water supply was abundant. And

the most important location variable, distance along the lateral, is really a reflection of decreasing water availability from sections I to IV (fig. 3). In future research, we will attempt to integrate these and other effects.

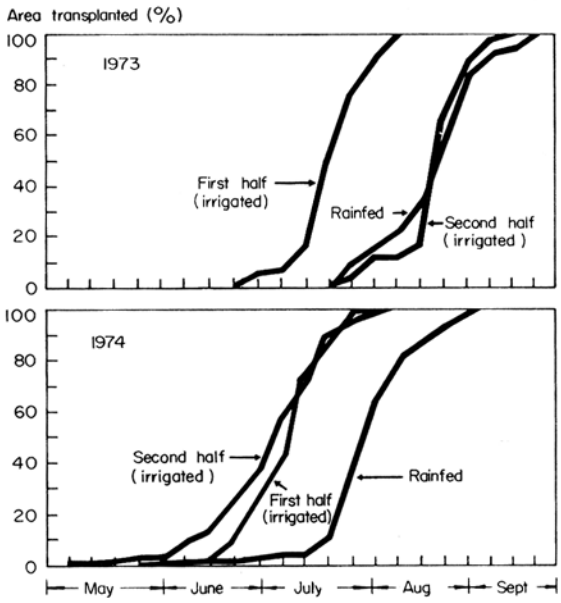
EFFECT OF IRRIGATION ON LAND PREPARATION

In 1973, we analyzed the duration of the land preparation period in relation to the amounts of water made available to large irrigated and rainfed areas (1973 Annual Report). We found that land in downstream portions of an irrigation system tends to be prepared much later than land in upstream portions, and is prepared at about the same speed as rainfed land. While water shortages extended the duration of land preparation, a generous supply of water did not shorten it to less than about 10 weeks from initial water supply to complete transplanting. In 1974, we further examined these two issues to find whether irrigation systems could be managed so that downstream farmers could plant as early as upstream farmers, and to determine if the form of power farmers use in plowing and harrowing affects the duration of land preparation when water is sufficient.

The time lag between upstream and downstream land preparation was studied on the 5,700-ha service area of Lateral C, described in the previous section. We arbitrarily divided the system into two parts: sections I and II; and sections III and IV (fig. 2). We recorded the dates of land soaking, plowing, harrowing, and transplanting from a sample of about 50 percent of the farmers in each half of the system. The net water supplied to each half was also measured throughout the period. We have prorated the supply of water on the basis of area still unplanted so that water applied to areas already transplanted is not counted as part of that for land preparation (1973 Annual Report). Our measure of area undergoing successive phases of land preparation is the percent of the total sample area falling in the categories of land soaking, plowing, harrowing, and transplanting for each week of the survey.

In the 1973 wet season, no special attention was given to the needs of the second half (sections III and IV) of the system, and transplanting in that half took place about 4 weeks later than in the first half (sections I and II). The progress of land preparation on farms in the second half was not appreciably ahead of adjacent rainfed farms outside the system (fig. 4). The amount of water entering the system was limited, and most of the water was used in the first half of the system, leaving farmers in the second half to rely mainly on rainfall.

In the 1974 wet season, two modifications were introduced in cooperation with authorities of the National Irrigation Administration (NIA) system in an attempt to even out the distribution of water. First, we tried to provide a discharge into the canal of at least 5 cu m/s throughout the land preparation period. This was possible since in 1974 that canal had a high priority in sharing the water available to the whole system. Second, we attempted to divert all canal flow for the first 4 weeks of the season to the second half of the system. To do this, we held a series of meetings with farmers in the first half explaining the idea. Special wooden gates were built and installed to prevent water from entering the sublaterals in the first half, and most of the turnouts were closed along that reach of the lateral. The canal was regularly patrolled to solicit compliance with the program, but most of the up-



4. Percent area transplanted by date in sections along an irrigation canal and in the adjacent rainfed area, Lat. C., Peñaranda River Irrigation System, Gapan, Nueva Ecija, 1973 and 1974 wet seasons.

stream farmers accepted the delay in water deliveries to their areas once they understood that they would have their chance by the end of May, and that we would attempt to guarantee a minimum flow.

These two measures enabled farmers in the second half of the system to start preparing their land and transplanting about 2 weeks ahead of farmers in the first half. This lead was steadily reduced once the farmers in the first half began transplanting, and the two groups finished almost exactly together (fig. 4). One reason why the farmers of the second half did not start faster was that a substantial area of the preceding dry-season crop was still not harvested by early May.

To examine the effect of different sources of power on the speed of land preparation, we surveyed the weekly progress of selected farmers in two well-irrigated areas. We relied on the NIA system's ditchtenders to record the week-by-week progress of land preparation of each farmer in his area of responsibility (about 150 ha), and then grouped the farmers' responses into categories of power use. About half of the farmers in each area were surveyed through complete enumeration of those farmers in every second ditchtenders' area. Four-wheel tractors with rotovators, two-wheel hand tillers, and carabaos were the most common power groups. A few farmers in one location used carabaos for the initial plowing operation, but harrowed by hand tiller. Because of their small sample size, other combinations that were used by a few farmers are not included in the results.

Table 2. Mean duration of land preparation period from first available water to transplanting by source of power.[a] Two irrigated systems, Philippines, 1974 wet season.

Source of power	Duration (days)	
	Bustos–Pandi[b] pump extension	Lateral C[c] (first half only)
Rotovator (4-wheel tractor)	34.0 a	37.4 b
Hand tiller (2-wheel tractor)	28.7 b	33.0 a
Carabao	32.8 a	32.6 a
Carabao + hand tractor	34.6 a	n.a.

[a]Means in the same column followed by the same letter are not significantly different at the 5% level. [b]Part of the Angat River Irrigation System, Bustos, Bulacan; area = 665 ha. [c]Part of the Peñaranda River Irrigation System, Gapan, Nueva Ecija; area (first half) = 2,355 ha. (n.a. = data not available.)

The two locations were the first half of the Lateral C service area described in the previous sections, and the Bustos-Pandi Pump Extension of the Angat River Irrigation System in Bulacan. Only the first half of the Lateral C command area was selected since we are looking at the effect of different power sources under conditions of ample water. In the second half, many farmers were constrained by water, not by power source. The Bustos-Pandi Pump Extension is a new canal extended into a formerly rainfed area of about 700 ha. Water is lifted by pump from the system to supply this canal.

There was no large difference in the mean duration of land preparation operations carried out by different sources of power (Table 2). Farmers who hired four-wheel tractors and rotovators averaged several more days to prepare their land than those who used carabao or two-wheel hand tillers, but the difference was not significant. One factor which tends to delay land preparation among four-wheel tractor users is the problem of hiring the tractor at the time the farmer wants it. Tractors are heavily in demand during the early months of the wet season, and farmers frequently have to wait until they are available. The ditchtenders in irrigated areas sometimes act as agents for groups of farmers in procuring tractor services for their areas since they are familiar with the schedule of irrigation and, therefore, with the expected dates of plowing.

Users of carabaos and hand tillers are able to finish as quickly as those using the four-wheel tractors, partly because of the customary delay after each plowing and harrowing. These delays partly decompose the weeds before the next pass over the field. Although large tractors can get over a farm much faster, the delay after using them tends to be at least as long as that observed after plowing and harrowing with carabao or hand tractor.

We conclude that the source of power does not explain much of the variation in the duration of the land preparation period where water is ample. It appears that farmers sow their seedbeds only when there is adequate water for planting and plowing, and prefer to transplant the seedlings

when they are 30 days old. Ways to shorten the period of land preparation should be sought, but it should be recognized that neither the farmers nor the managers of most irrigation systems feel the incentives for reducing that period, and, thereby, the water requirement.

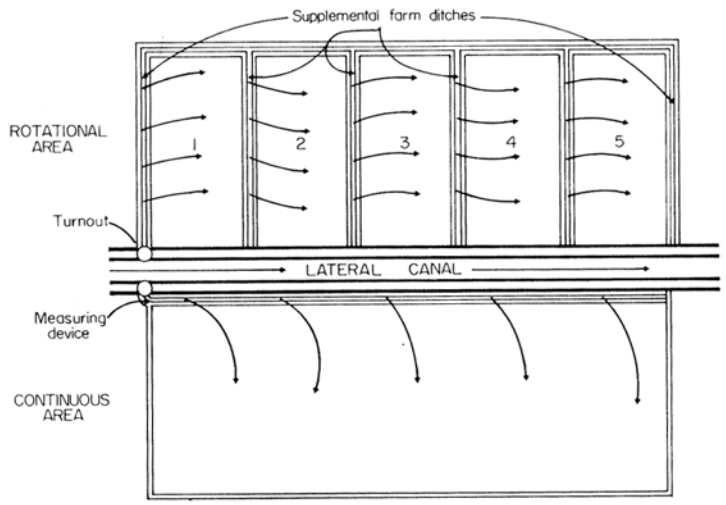
ROTATIONAL VS. CONTINUOUS IRRIGATION

Rotational irrigation, as practiced in Taiwan and Japan, is the concentrated application of several days' worth of irrigation water to a small area within several hours or, at most, a day. Other areas receive irrigation in successive days until the rotational pattern returns to the first area. The practice requires a rather intensive infrastructure of on-farm ditches and gates, and ongoing management by farmers and system personnel.

This type of rotational irrigation by farm ditch has not been adopted on a significant scale in Southeast Asia, including the Philippines, where continuous irrigation remains the usual form of on-farm distribution. Continuous irrigation does not mean that the fields are continuously flooded with water, but that there is no attempt to systematically concentrate and rotate the deliveries after they pass from the canal to the farm ditch or farmers' fields. Other forms of rotation, such as the rotation of available water among several major canals of a system during serious shortages, are often found in the Philippines, however.

Rotational irrigation in Taiwan has been credited with significant extensions of irrigated areas and, in some cases, with achieving higher grain yield. Similar results have not been found in Philippine experiments, however, and rotational irrigation has still not been implemented on more than a pilot basis in that country. Nevertheless, in the Philippines water-use efficiencies in major irrigation systems are not high (1972 Annual Report) and steps should be taken to better use the water. The importance of efficient water use became especially apparent as the country started building its first major storage system, the Upper Pampanga River Project (UPRP). Unlike diversion systems, storage systems depend upon saving excess river flow during the wet season for release during the following dry months. The extent and productivity of double cropping, as well as the design of the system, depend upon distributing the water throughout the service area with as few losses as possible. Rotational irrigation was selected by the UPRP as the on-farm distribution method most likely to achieve these savings over the 75,000-ha project.

The rotational area in the UPRP design is a 50-ha block composed of five rotational units of about 10 ha each (fig. 5). Enough water for 5 days' use is to be supplied to the first 10-ha unit for 24 hours; then the supply is rotated to the second unit, and so on until the fifth unit is supplied. After 5 days, the supply returns to the first unit. The discharge from the canal to the



5. Comparison of rotational and continuous irrigation in two adjacent 50-ha blocks, Upper Pampanga River Project, Nueva Ecija, Philippines, 1974 dry season.

whole 50-ha area should be approximately constant throughout the rotation, and a gated turnout and measuring device are specified to permit regulation and measurement of the flow at that point. After passing through the measuring device, the water is carried along a main farm ditch until it is diverted to the supplemental farm ditch serving the first 10-ha unit. Rotation is achieved by opening and closing successive supplemental farm ditches at the point where they branch off the main farm ditch (fig. 5).

Difficulties were anticipated in implementing this program, however, since most of the service area has received water from older diversion systems which do not offer much incentive for farmers to economize in water use. The UPRP, therefore, planned a pilot project involving farmers in the management of selected rotation areas. We joined them to help implement the rotational scheme, and, at the same time, instrumented adjacent 50-ha areas to be irrigated in the traditional continuous fashion for comparative purposes. The objectives of the joint project were then: 1) to implement rotational irrigation in selected areas of the UPRP; 2) to train field personnel and farmers in the measurement of water and management of the rotational irrigation areas; and 3) to compare the water use, yield, and economic performances of the two forms of on-farm distribution. This report reviews the findings of the last objective only.

The study was conducted at three locations in Nueva Ecija during the 1974 dry season. Each location included both the continuous and the rotational form of irrigation in roughly comparable areas (fig. 5). Soils and topography varied somewhat within the locations so that it was not possible to standardize the two alternatives in all respects, but the final selection did not appear to bias the results.

Water management technologists were trained at each location to give equal rates of water to each of the two areas. The measuring devices were instrumented with continuous water-level recorders so that we could compute the flow to each area, checking to make sure that it was approximately equal for each pair. We then monitored the progress of land preparation, water adequacy, and grain yield to assess performance differences.

Land preparation. During land preparation we began by supplying 1.5 liters $\cdot s^{-1} \cdot ha^{-1}$ to all three pairs of sites, but this rate was increased to the maximum possible discharge to each area, 2 to 3 liter $\cdot s^{-1} \cdot ha^{-1}$, as it became evident that land preparation was proceeding slowly and farmers were dissatisfied. Thus, water use was not held equal between the pairs during this period. We measured the amount supplied to each area, though, and recorded the number of days farmers took to finish the different stages of plowing, harrowing, and transplanting. There was essentially no difference between the rotational and continuous areas in the duration of land preparation and the total amount of water used (Table 3). The mean duration of about 7 weeks and the mean application of about 775 mm of water were higher than expected, but very similar to system-wide data (1973 Annual Report). Almost no water was drained from the areas since there was insufficient supply throughout the period. One reason for the long duration was the farmers' preference in all three locations for rather old seedlings, which means that seedbed establishment was a limiting step. The pilot areas at Kaliwanagan required over 1 m of water, almost double that of the other two locations, due to the light soils and deep water table there. The initial soil moisture content and the source of power for plowing were further analyzed in an attempt to explain differences in water use and mean durations, but these factors were quite uniform between the study pairs. Initial soil moisture content varied between 8 and 12 percent for all areas.

Water use during crop growth. After transplanting, we resumed equal water supply rates for each pair of areas. Because the area of the rotational and continuous sites were not exactly the same, we equated the unit flow (liters per second per hectare) rather than the total flow into the areas. We made further adjustments for the rotational areas in days when the units receiving water were slightly above or below average size.

We began by delivering 1.5 liters $\cdot s^{-1} \cdot ha^{-1}$ to all six pilot areas, but it soon became apparent that this supply rate was not enough for the Kaliwanagan sites, which had light soils, and was more than necessary for the other two locations. It was important to find the minimum rate of supply compatible with high yields in at least one of the two areas in each location to bring out any yield differences by the end of the season. We therefore

Table 3. Mean duration to complete the different operations of land preparation, and total water supplied during that period. Six pilot areas, Upper Pampanga River Project, 1974 dry season.

Site	Duration (days)					Water use [a] (mm)		
	Soaking	Seeding	Plowing	Harrowing	Transplanting	Irrig.	Evap.	Land soaking[b]
Kaliwanagan								
Rotational	13	n.a.[c]	26	36	59	1070	319	751
Continuous	13	n.a.	21	33	54	1039	286	753
Gomez								
Rotational	3	17	23	48	58	658	330	328
Continuous	7	14	30	46	65	600	353	247
Santa Arcadia:								
Rotational	10	21	20	38	43	594	228	366
Continuous	10	20	16	35	54	690	288	402
Means								
Rotational	9	19	23	41	53	774	292	482
Continuous	10	17	22	38	58	776	309	467

[a]Both irrigation and evaporation are prorated in proportion to the area still undergoing land preparation each week. Rainfall was negligible. [b]Land soaking, including seepage and percolation, is the balance of irrigation less evaporation. Surface drainage was negligible. [c]n.a. = data not available.

adjusted the supply rates up or down at each location until the crop's needs were just met, being careful to maintain equal rates between the paired areas at each location during this process. Within about 6 weeks after transplanting, the minimum rates of 2.2 liters $\cdot s^{-1} \cdot ha^{-1}$ for Kaliwanagan and 1.1 liters $\cdot s^{-1} \cdot ha^{-1}$ for the other two locations were fixed for the rest of the season.

Since the supply rates were equal between the pairs, we could not test for differences in water use. We accumulated the seasonal totals of the water balance components, however, and listed them (Table 4). Evapotranspiration values are computed (1972 Annual Report) from measured evaporation data, and seepage and percolation are estimated by the rate of fall in elevation of water in sample paddies at each location. Surface drainage is computed as the residual of rainfall plus irrigation less evapotranspiration, seepage, and percolation. Water use efficiency is the sum of evapotranspiration, seepage, and percolation divided by rainfall plus irrigation.

Total water use after transplanting averaged about 1 m of depth, although at Kaliwanagan it was about 1.75 m. These are relatively low values for the dry season, and only slightly exceed the amount of water applied to the areas during land preparation. The most important reason for the low water supply was the reduction of drainage losses by careful management of the turnout. The rate of water supply was so nearly balanced with crop and soil needs that drainage losses were very low. This also resulted in water use efficiencies of more than 90 percent, much higher than those achieved in typical irrigation systems (1972 Annual Report).

Grain yield. At the end of the season the water management technologists took two crop-cut yield samples of 4 sq m each from the holdings of almost every farmer within the pilot areas. About 90 percent of the samples were of IR20, and the remainder, of C4-63. Mean yields were not the same at the three locations, but there was no significant difference between the rotational and continuous areas at any location or their means (Table 5). This was not surprising, since essentially no differences were observed in the occurrence of drought between the two areas throughout the season.

Because we know the amount of water supplied to the crop, we can compute the yield efficiency, i.e. the grain produced per cubic meter of water applied. The range is from 0.12 to 0.24 kg/cu m, with the volume of water use causing most of the variation. Assuming that the price of rough rice is

Table 4. Water balance components after transplanting, seasonal sums of water. Six pilot areas and their means, Upper, Pampanga River Project, 1974 dry season.

Site	Water use (mm)						
	Irrigation	Rainfall	Total water	Evapotranspiration[a]	Seepage and percolation[a]	Estimated drainage[b]	Eff.[c] (%)
Kaliwanagan:							
Rotational	1540	128	1668	589	944	135	92
Continuous	1757	128	1885	635	1021	229	88
Gomez:							
Rotational	729	113	842	612	218	12	99
Continuous	765	107	872	573	202	97	89
Santa Arcadia							
Rotational	600	84	684	414	195	75	89
Continuous	606	84	690	403	190	97	86
Means							
Rotational	956	108	1065	538	452	74	93
Continuous	1042	106	1149	537	471	141	88

[a]See text for explanation of computations. [b]Total water less evapotranspiration, seepage, and percolation. [c]Eff = $\frac{(S \& P) + ET}{\text{total water}}$.

Table 5. Mean grain yield and yield efficiency.[a] Six pilot areas and their means, Upper Pampanga River Project, 1974 dry season.

Site	Observations (no.)	Yield (t/ha)	Yield efficiency (kg rice/cu m water)	
			Water for crop growth only	Water for land preparation and crop growth
Kaliwanagan				
Rotational	32	3.67	0.22	0.13
Continuous	35	3.66	0.20	0.12
Gomez				
Rotational	35	3.45	0.41	0.23
Continuous	29	3.11	0.36	0.21
Santa Arcadia				
Rotational	22	3.14	0.46	0.24
Continuous	19	2.97	0.43	0.21
Means				
Rotational	89	3.42	0.36	0.18
Continuous	83	3.25	0.33	0.16

[a]Differences between rotational and continuous areas are not significant at 5% for any location or their means.

US$0.15/kg, the productive value of irrigation water in the dry season can be estimated at about $0.017 to $0.034/cu m.

Costs. We estimated the additional cost for rotational irrigation based on actual costs for one of the UPRP divisions. The added costs included all costs of earthwork for the supplemental farm ditches, three-fourths of the cost of the farm-level structures beyond the measuring device, and one-fourth of the costs of right of way, engineering, supervision, and administration. Totalling these costs, the additional expense of building a 50-ha rotational area is $4,100, or $83/ha. This is not very high in view of the expected lifetime of a storage system, but it was apparent from the study that maintenance of the farm ditches and of the pre-fabricated structures would be a substantial additional expense to the system or to the farmers every year.

Two other costs of the rotational model are the production losses from land taken over for supplemental farm ditches, and the personnel costs of daily operation. About 1 ha of land is taken from every 50-ha area for supplemental ditches; this results in an annual production loss of about $1,000,

or $70/ha. Furthermore, for the first few seasons there are additional production losses stemming from excavations for the supplemental farm ditches. The costs to the system of managing the internal distribution of water among the rotational units would be low if farmers could see enough value in rotational irrigation to do the distribution themselves. But if that form of on-farm distribution is not demonstrably better than its alternatives, farmers probably would not be enthusiastic about the additional work it entails, and would leave most of the work to the system's personnel.

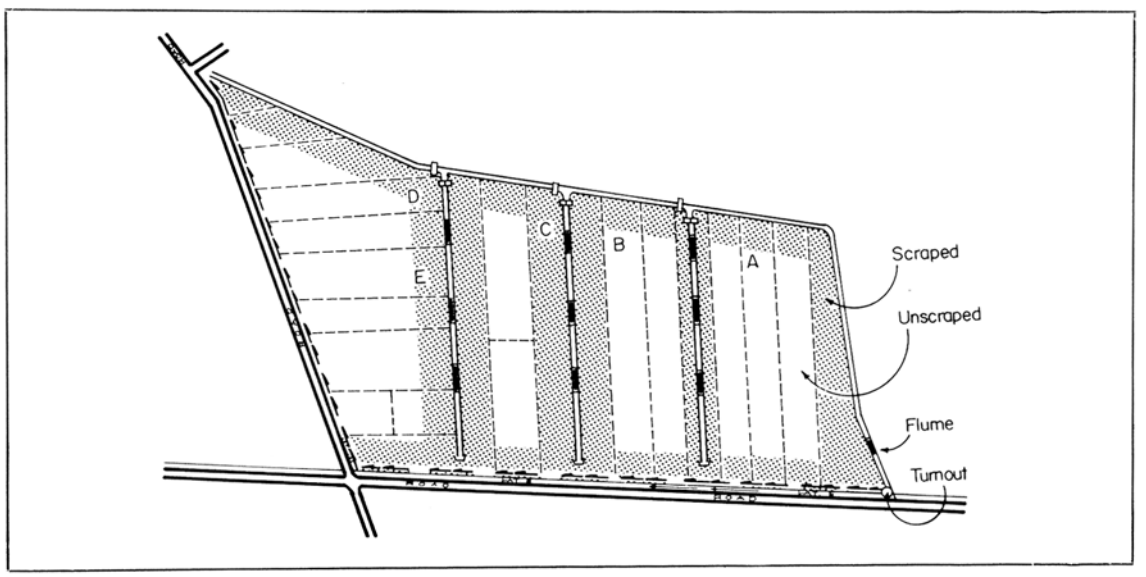
The study has shown that rotational irrigation can be carried out in the UPRP, and that water management technologists with some training can accurately deliver specified flows of water and rotate its distribution among the 10-ha units. High water-use efficiencies can be achieved for both forms of irrigation, but these high efficiencies will primarily result from careful measurement and control of water through the turnout. This control and its benefits are much greater than are normally found in Philippine systems, but if either of the two irrigation forms is adopted on a wide scale, there will be major new requirements for precise checking and water management within the canal to supply the many turnouts evenly and equitably.

No significant differences in yield or yield efficiency (kilograms of rice per cubic meter of water) were found between the two irrigation forms under the conditions of the study, although differences might have appeared if the supply of water had been substantially lower than that required for normal crop growth. We assume, however, that this is not a design aim of a modern system. We also believe that results from the dry season, when the project was undertaken, would bring out greater performance differences than those from the wet season, when the distinction between the two forms tends to become blurred. The most significant difference between the rotational and continuous irrigation models was the additional cost of the former, and the potential problems in its operation and maintenance.

EFFECTS OF REMOVING TOPSOIL IN IRRIGATED AREAS

We studied the effects of removing paddy topsoil in two areas, the rotational irrigation pilot areas described in the previous section and a pilot project in land consolidation. Both these pilot projects were undertaken in Nueva Ecija by the UPRP whose personnel did much of the field work.

Pilot rotational areas. The areas studied are the three pilot rotational areas (about 50 ha each in



6. Rotational area (43 ha) at Sta. Arcadia, Cabanatuan City, showing land scraped to provide fill for canal embankments and roads. Upper Pampanga River Project, 1974.

Table 6. Soil properties and grain yield of rice for paddies whose topsoil was partially scraped and for adjacent unscraped paddies of the same farmer, means for 3 pilot areas and their mean, UPRP, dry season 1974.

Pilot area	Observations (no.)	pH	Organic matter (%)	Nitrogen (%)	Phosphorous (ppm)	Potassium (meq/100 g soil)	CEC[a] (meq/100 g soil)	Exchangeable bases (meq/100 g soil)	Grain yield (t/ha)
Kaliwanagan									
Scraped	4	6.9	1.61	0.056	11.7	0.27	39.0	29.1	2.8[b]
Unscraped	4	6.6	2.04	0.093	8.5	0.44	42.8	31.0	4.2[b]
Gomez									
Scraped	5	6.8	1.31	0.045	5.4	0.07	13.6	8.9	n.a.
Unscraped	5	6.4	1.47	0.049	6.5	0.11	13.6	9.5	n.a.
Santa Arcadia									
Scraped	3	6.5	1.67	0.051	4.4	0.08	17.3	10.5	2.5
Unscraped	3	6.0	2.10	0.059	7.2	0.07	16.1	10.6	3.3
Means									
Scraped	12	6.7	1.50	0.050	7.2	0.14	23.0	16.1	2.6
Unscraped	12	6.4	1.82	0.066	7.3	0.21	23.9	16.9	3.7
Significant difference[b] (Paired *t*)		**	**	**	ns	*	ns	ns	*

[a]Cation exchange capacity. [b]Only 3 yield observations for Kaliwanagan. [c]** = 1%, * = 5%, ns = not significant. Only the means were tested.

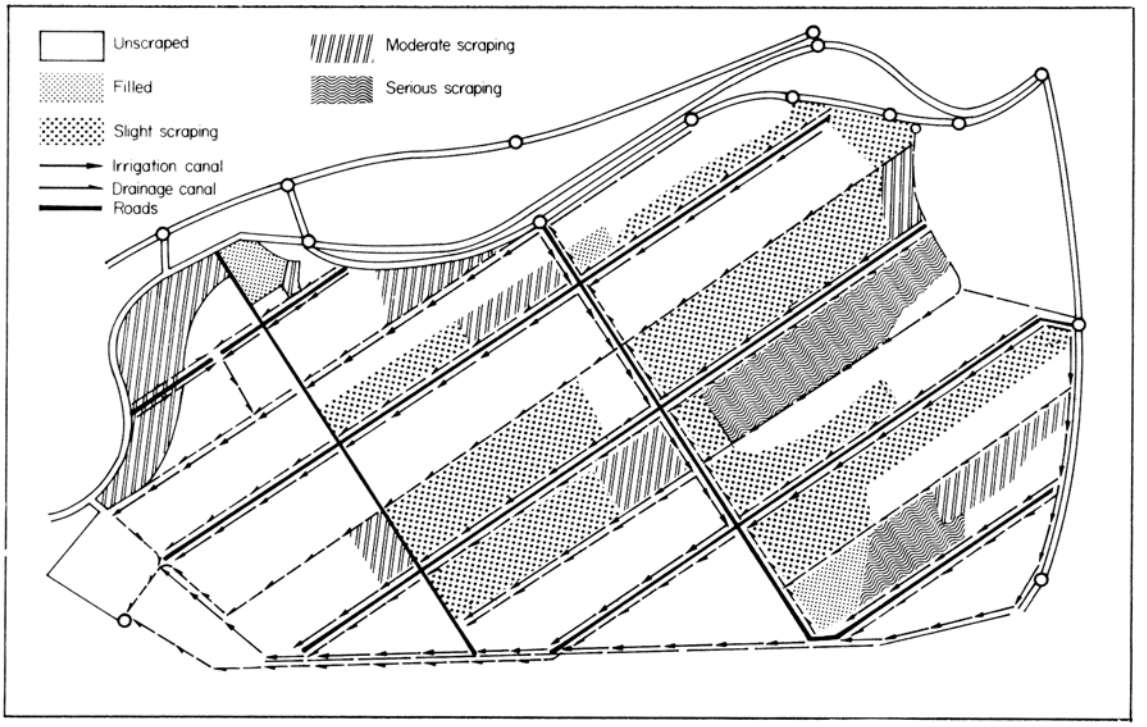
size) in Kaliwanagan, Gomez, and Santa Arcadia. In these three areas, and throughout the UPRP service area, supplemental farm ditches have been constructed by scraping with bulldozers the topsoil from adjacent paddies into an embankment, and then cutting a trench along the embankment. The scraped farms have lost part of their topsoil and, in addition, have become more susceptible to deep flooding. Farms located farthest from the canals generally were not scraped. In some cases about one-third of the total area was affected to moderate depths of about 20 cm, while in others the scraping was deeper but restricted to a smaller area (fig. 6).

In each area we collected soil samples from four scraped paddies and from four control paddies outside the bands of scraped land. Each scraped sample and unscraped control were taken from the same farmholding to minimize the likelihood of differential management. Five samples per paddy were mixed together and analyzed by IRRI's Soil Chemistry Department.

Scraped soils showed significantly less organic matter, total N, and K content than the unscraped soils, and significantly higher pH values (Table 6). Most of the samples analyzed, whether scraped or not, were highly deficient in K and moderately deficient in N and P.

Yield samples from harvested rice were also taken in each area from an average of four farms, portions of which were scraped and other portions unscraped. These were not necessarily the same farms as those from which the soil samples were collected, however. The mean grain yield from scraped areas was significantly lower by about 1 t/ha than that from unscraped areas. This difference may be due in part to rather deep flooding on some of the scraped areas. We cannot predict how long these effects of scraping and removal of topsoil from paddy land will be felt, but heavy applications of nitrogen, some of it in organic form, should increase the yields on the scraped soils.

Pilot land consolidation area. The pilot land consolidation project in Talavera, Nueva Ecija, involves leveling several hundred hectares of land, constructing an intensive network of on-farm canals, and roads, and rearranging farm holdings to conform with the canal and road networks. This study was conducted cooperatively with the University of the Philippines at Los Baños and the



7. Land consolidation area (258 ha) at Talavera, Nueva Ecija, showing extent of soil scraping for canal embankments, roads, and land leveling, Upper Pampanga River Project, 1974.

Table 7. Chemical properties of scraped and unscraped soils. Means of four observations land consolidation project, UPRP, Talavera, Nueva Ecija, Philippines, wet season 1974.

Profile	pH	Organic matter (%)	Available P (ppm)	CEC[a] (meq/100 g soil)	Exchangeable Ca (meq/100 g soil)	Exchangeable Mg (meq/100 g soil)
0 – 15 cm						
Scraped	6.4	0.2	1.8	13	5.69	1.57
Unscraped	6.1	1.4	5.6	20	7.10	2.62
15 – 30 cm						
Scraped	6.6	0.1	1.8	11	4.53	1.57
Unscraped	6.4	1.0	5.5	20	7.38	3.14
30 – 45 cm						
Scraped	6.6	0.0	0.8	11	4.80	1.49
Unscraped	6.6	0.6	2.8	25	9.33	3.96
45 – 60 cm						
Scraped	6.8	0.0	0.7	10	4.62	1.79
Unscraped	6.8	0.4	0.7	25	9.95	4.04

[a]Cation exchange capacity.

UPRP to find differences in chemical properties between the scraped and the unscraped soils; to determine which nutrient deficiencies limit crop growth; and to compare the yields of rice on scraped and unscraped soils. The objective of the research is to find ways to manage scraped soils for maximum production.

Soil samples were collected from four horizons in areas that were scraped and unscraped (fig. 7). Scraped samples had less organic matter, total N, and available P than samples from unscraped soils (Table 7). While part of the difference is attributed to the scraping, the scraped area appears to have been of a lighter texture deposit which would have shown lower nutrient content for most elements even if it had not been scraped.

A randomized complete block experiment was carried out in scraped and unscraped areas of the land consolidation project (fig. 7) to determine the effect of different fertilizer combinations on crop growth. Fifteen-day-old IR20 seedlings were transplanted into 4- x 5-m plots during the 1974 wet season, the first season since the soils were scraped. Land was prepared by carabao and hills were spaced 20 cm apart; plant protection practices included one hand weeding and spray applications of azodrin and carbofuran. The experiment was replicated three times.

Treatments for both the scraped and unscraped locations included a control in which no fertilizers were added, and two series of treatments with N fixed at 60 and 120 kg/ha. These two treatment series were the same for both nitrogen levels and

Table 8. Effect of fertilizer treatments on plant height, tiller number, and grain yield of IR20 on scraped soils, and on grain yield for unscraped soils, pilot land consolidation project, Talavera, Nueva Ecija, Philippines, wet season 1974.

Treatment	Plant ht (cm)	Tillers (no./hill)	Grain yield[a] (t/ha)	Grain yield[b] (unscraped control) (t/ha)
0 nitrogen	85	16	1.5 j	2.4*
60 kg/ha nitrogen	89	16	1.8 ij	2.8*
60 P_2O_5	90	20	2.1 h	2.9*
60 P_2O_5 + 30 K_2O	92	21	1.9 hi	2.8*
60 P_2O_5 + 30 K_2O + TS[c]	90	18	3.1 cd	
60 P_2O_5 + 30 K_2O + Zn[d]	98	19	2.2 gh	
60 P_2O_5 + 30 K_2O + ME[e]	97	16	3.4 bc	
60 P_2O_5 + 30 K_2O + CM[f]	96	19	3.1 cd	2.6
60 P_2O_5 + 30 K_2O + AL[g]	103	25	3.5 b	2.9
120 kg/ha nitrogen	92	18	*2.5* fg	2.6
60 P_2O_5	98	20	*2.9* de	3.2
60 P_2O_5 + 30 K_2O	99	20	*2.7* ef	3.1
60 P_2O_5 + 30 K_2O + TS[c]	95	18	*2.7* ef	
60 P_2O_5 + 30 K_2O + Zn[d]	102	18	2.7 ef	
60 P_2O_5 + 30 K_2O + ME[e]	102	20	4.0 a	
60 P_2O_5 + 30 K_2O + CM[f]	100	21	*2.9* de	2.8
60 P_2O_5 + 30 K_2O + AL[g]	97	26	*2.9* de	3.0
HSD 5%	11.9		0.4	
1%	13.8		0.4	
CV(%)	4.1		4.7	

[a]Yields followed by the same letter are not significantly different (0.05). Italicized values indicate some yield loss due to lodging. [b]*indicates significant yield difference for a given treatment between scraped and unscraped soils. [c]Top soil added at 50 t/ha. [d]$ZnSO_4$ added at 5 kg/ha. [e]Microelements $CuSO_4$, $(NH_4)_6\ Mo_7O_{24} \cdot 4\ H_2O$, $Na_2B_4O_7 \cdot 10\ H_2O$, $MnSO_4$. [f]Carabao manure added at 2.5 t/ha. [g]Acacia leaves added at 5 t/ha.

included: 1) N only, 2) N + P, 3) N + P + K, 4), N, P, K + topsoil, 5) N, P, K + zinc, 6) N, P, K + microelements, 7) N, P, K + carabao manure, and 8) N, P, K + leaves from acacia trees. Treatments 4, 5, and 6 were carried out only on the scraped soils. Phosphorus was applied at the rate of 60 kg P_2O_5/ha; potassium at 30 kg K_2O/ha; and zinc at 5 kg $ZnSO_4$/ha. Topsoil from the unscraped areas was incorporated at about 50 t/ha. The microelement treatment included copper sulfate, sodium borate, ammonium molybdate, and manganese sulfate, applied together at 5 kg/ha each. Partially decomposed carabao manure was applied at about 2.5 t/ha. Acacia leaves, used because they were the most plentiful source of organic matter in the area, were applied at approximately 5 t/ha. A third of all nitrogen applications was applied at about 30 days after transplanting (DT), and a third at about 60 DT; the first third of the nitrogen and all other materials were incorporated basally.

Plant height, tiller number, and dry matter production were determined on samples at various stages of crop growth. The treatments with zinc, microelements, carabao manure, and acacia leaves produced slightly taller plants at harvest, although final tiller counts were about the same as those in the other treatments (Table 8).

The grain yield from the zero-N treatment was significantly less than the grain yields from all but the 60 kg N/ha treatments for both scraped and unscraped soils. At zero N, there was also a significant yield difference of almost 1 t/ha between scraped and unscraped soils.

For both the 60 and 120 kg N series, the addition of P alone had a significant effect on yield, but the addition of K to N and P had no further effect (Table 8). At 60 kg N all treatments except Zn were significantly higher yielding than the basic NPK treatments. Microelements produced yields significantly higher than all but the acacia leaf treatment in the 60 kg N series, and higher than any achieved at 120 kg N.

The treatments at 120 kg N did not generally produce yields higher than those corresponding to the 60-kg-N treatments because crops lodged under most of the 120-kg-N treatments.

Therefore we conclude that 120 kg N/ha is not required for high production on scraped soils in the wet season, provided additional nutrients are available. While the yield response to P alone is modest, the higher yields achieved with the other nutrients probably depended on supplemental P since scraped soils had low available P. Microelement deficiencies appear to be the most important limiting factor in these soils; additional research is under way to determine the most important of the four microelements tested here.

Environment and its influence

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SUMMARY

Research programs at IRRI in this area of environment and its effect on rice are designed to determine how and to what extent individual climatic factors affect rice yield, in order to better undertand in what way(s) environmental factors account for differences in rice productivity in different localities.

In 1974, the effects of temperature, solar radiation, water stress, and photoperiod on the growth and yield of rice were studied. Additionally, the influence of root environment on root growth was examined.

In response to temperature, varieties of rice, which originated over a wide geographic range from 43°N to the equator differed markedly in sterility percentage and growth duration – factors that may be the major physiological determinants of the local adaptability of rice varieties to different local environments.

Experimental evidence from recent studies at IRRI suggests that the effect of sunlight on ripening, and hence yield, may have been overemphasized by some investigators. An experiment on shading in the field at IRRI under Los Baños, Philippines, conditions has shown that during the reproductive stage, sunlight is more critical to the yield of rice than it is during the ripening period. A yield of 4 t/ha was obtained with a solar radiation level of 200 $cal \cdot cm^{-2} \cdot day^{-1}$ during the reproductive stage of rice development. The available data on solar radiation in different rice-growing areas in the tropics reveal that, on a monthly mean basis, 200 $cal \cdot cm^{-2} \cdot day^{-1}$ would be the minimum level of solar radiation. Thus, it is unlikely that incident solar radiation limits rice yield in farmers' fields in most tropical countries where the national average yield is about 2 t/ha.

Under upland conditions, water stress often limits crop growth and yield. The use of a simulation model to estimate crop photosynthesis revealed that when plants are under water stress, photosynthesis is higher under a low solar radiation than under a high level of incident solar radiation. This suggests that a partially shaded environment, such as that occurring under coconut trees, would favor rice growth under water stress.

Root growth is regulated not only by varietal characteristics but also by the root environment. Water stress was found to increase root growth relative to shoot growth. Soil compaction had a profound effect on the penetration of rice roots into soil. At a bulk density of 1.4, only small fractions of rice roots penetrated into compacted layers of soil, while corn roots penetrated in much higher proportions. These differences may account in part for the differences in the resistance to drought of these respective crops.

Most of the 30 upland varieties of rice studied which originated in 12 countries with latitudes ranging from 2°S to 20°N were found to be insensitive to photoperiod, probably because upland rice is planted and matures during periods of long day length in many areas of Southeast Asia. Some rice varieties from Sri Lanka and Thailand, however, are photoperiod sensitive. These varieties have long growth durations and are better suited to the bimodal rainfall pattern prevailing in these regions.

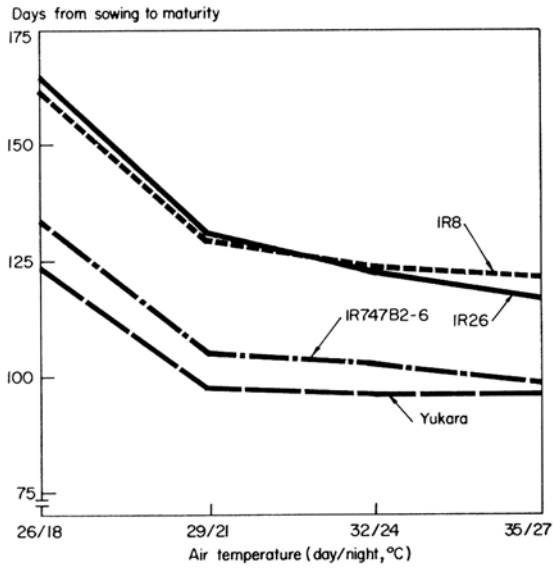
EFFECT OF TEMPERATURE ON GROWTH DURATION AND GRAIN YIELD

Plant Physiology Department

Varieties grown in particular localities should be better adapted than other varieties to the local environments. Varietal suitability for a given environment may largely be determined by growth duration and critical low and high temperatures. Outside of these normal ranges, grain yields are sharply reduced.

To collect basic information on how temperature affects growth duration and grain yield, we grew 19 varieties at four temperature regimes in the glasshouse rooms of the IRRI phytotron. These varieties originated over a wide geographic range, from 43°N (northern Japan) to the Equator (Indonesia). The four day/night temperature regimes were 26°/18°C; 29°/21°C; 32°/24°C; and 35°/27°C. Daytime temperature was maintained for 8 hours (from 0900 to 1700 hours) while daylength was under natural Los Baños conditions.

Growth duration. Nineteen varieties ranged in growth duration from 96 days at 35°/27°C for Yukara, to 165 days at 26°/18°C for IR26 (fig. 1). The growth duration of a variety did not vary much within a temperature range of from 29°/21°C to 35°/27°C. But temperature markedly affected growth duration between 29°/21°C and 26°/18°C.



1. Relationship of temperature regime and growth duration.

A difference in temperature of only 3°C extended the growth duration of IR26 from 130 days at 29°/21°C to 165 days at 26°/18°C.

Temperature summation, or heat sum, is a term frequently used to relate temperature to growth duration. From the above data, temperature summation does not appear applicable to temperature regimes higher than 29°/21°C. Temperature summation may remain useful, however, at temperature regimes lower than 29°/21°C.

Grain yield. Grain yields of 19 varieties differed significantly in response to air temperature. Responses may be categorized into four groups (fig. 2).

Grain yield of Fujisaka 5, a variety from northern Japan, was stable between 26°/18°C and 32°/24°C; it decreased slightly, however, at 35°/27°C. On the other hand, H4 yielded highest at 26°/18°C, and its yields decreased steadily as temperature increased. IR26 yielded highest at 29°/21°C, and yields decreased at both higher and lower temperatures. Pelita I/1 responded similarly, but was extremely low in yield at higher and lower temperatures.

Much of the variations in yields can be accounted for by variations in sterility percentage and in grain number. The 1,000-grain weight varied only slightly.

Interestingly, the performance of Fujisaka 5 was stable at both low and high temperatures. Yield stability over wide ranges of temperature regimes is desirable for commercial varieties.

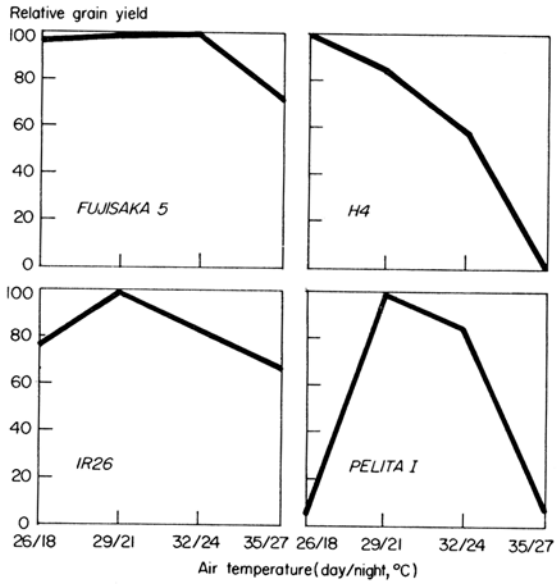
EFFECTS OF SOLAR RADIATION ON RICE YIELD

Plant Physiology Department

The effect of solar radiation on the yield of IR747B2-6 at the vegetative, reproductive, and ripening growth stages, was studied in IRRI's fields. The amount of incident solar radiation was varied by different degrees of shading.

Table 1 shows that shading from 75 to 25 percent of the sunlight during the vegetative stage (the first 25 days after transplanting) only slightly affected yield and yield components. Dry matter production at the end of the shading treatment during the vegetative stage varied from 256 g/sq m under 100 percent sunlight to 101 g/sq m under 25 percent sunlight. This difference, however, did not noticeably affect spikelet number per square meter and, hence, did not affect yield when the plants were subsequently exposed to normal sunlight during the reproductive stage.

Crops that were shaded during the vegetative stage had smaller crop sizes and lower leaf area indexes (LAI's); hence, light penetration was better among these crops than among the controls during the reproductive stage. The better light environment in those crops must have compensated for



2. Relationship of temperature and grain yield.

Table 1. The effect of shading at different growth stages on yield and yield components of the experimental line IR747B2-6. IRRI, 1974.

Sunlight (%)	Grain yield (t/ha)	Harvest index	Yield components		
			Spikelets (no./sq m)	Filled grain (%)	1,000-grain wt (g)
		Vegetative stage			
100	7.1	0.49	42	89	20
75	6.9	0.48	41	90	20
50	6.4	0.51	38	90	20
25	6.3	0.51	38	84	20
		Reproductive stage			
100	7.1	0.49	42	89	20
75	5.7	0.47	30	88	20
50	4.5	0.40	24	89	20
25	3.2	0.36	17	89	19
		Ripening stage			
100	7.1	0.49	42	89	20
75	6.5	0.49	41	81	20
50	5.2	0.44	41	65	20
25	3.9	0.38	42	55	19

the smaller crop size in spikelet formation during the reproductive stage.

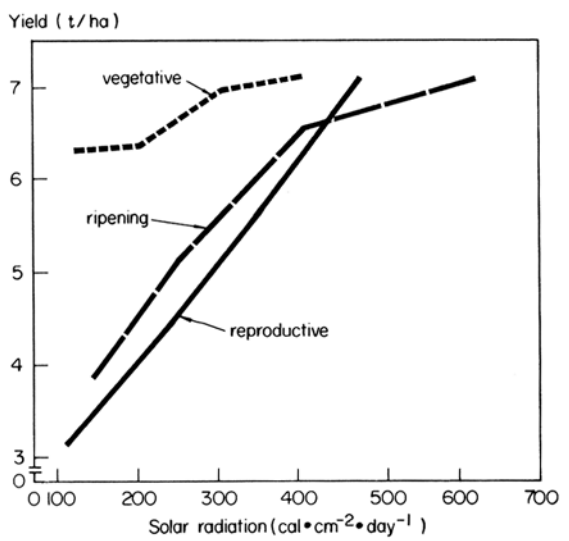
But in the next 25 days, during the reproductive stage, shading had a very pronounced effect on spikelet number and, hence, on yield. Spikelet number per square meter was positively and linearly correlated with dry matter production during reproductive stage (r = 0.994**), and with incident solar radiation during the same period. This implies that spikelet number is linked with photosynthetic production during the reproductive stage.

Shading during the ripening period also considerably reduced grain yields, largely because it decreased the percentage of filled grain. Unfilled grains were divided into non-fertile grains and partially filled grains. Examination showed that the decreased percentage of filled grain was largely due to increased percentage of partially filled grains, but not to non-fertile grains.

We cannot examine the relative importance of solar radiation at different stages of growth in Table 1, since the incident solar radiation differed from one stage to another. Figure 3 compares the effect of shading on grain yield at different growth stages. Solar radiation affects grain yield most remarkably at the reproductive stage, followed by the ripening stage. The overall effect of solar radiation on grain yield is extremely small during the vegetative stage.

Thus, the shading experiment demonstrates the importance of solar radiation during the reproductive stage, as well as during the ripening stage. During the reproductive stage, solar radiation affects spikelet number per square meter and during ripening it affects the percentage of filled grain.

Figure 3 also shows that a yield of 5 t/ha can be obtained at a solar radiation level of 300 cal·cm^{-2}·day^{-1} during the reproductive stage. Thus, incident solar radiation probably does not limit rice yields in farmers' fields in most tropical countries that have current national averages of about 2 t/ha.



3. Effect of solar radiation at different growth stages on grain yield of the experimental line IR747B2-6.

CROP PHOTOSYNTHESIS UNDER WATER STRESS

Plant Physiology Department

Under a constant degree of soil water stress, the stomata of rice leaves tend to close early during bright, sunny days, but to remain open throughout the day during cloudy days (1973 Annual Report). Therefore, a large portion of incident solar radiation obviously is not used in photosynthesis during

bright, sunny days and during soil water stress.

To determine which weather condition favors greater crop photosynthesis under soil water stress, we attempted to estimate crop photosynthesis by a simulation model.

Crop photosynthesis was computed by the following steps:

1) Diurnal changes in leaf resistance were measured under well-watered and water-stressed conditions (1973 Annual Report).

2) Light-photosynthesis curves were measured under well-watered and water-stressed conditions, and were related to leaf resistance (1973 Annual Report). Leaf resistance values for carbon dioxide were obtained by multiplying measured resistance values for water vapor by 1.7.

3) Constants a and b were estimated, using the following formula: $P = (a + b/I)^{-1}$ where P is gross photosynthesis in $g \cdot m^{-1} \cdot h^{-1}$ and I is irradiance in $cal \cdot cm^{-2} \cdot min^{-1}$. This equation was converted to: $\frac{I}{P} = aI + b$. Thus, constants a and b were obtained from a regression line between I/P and I.

4) We assumed a leaf area index (LAI) of 3 and a leaf angle of 70° for our upland crop model. With these assumptions, the sunlit leaf area was computed by the Warren-Wilson method.

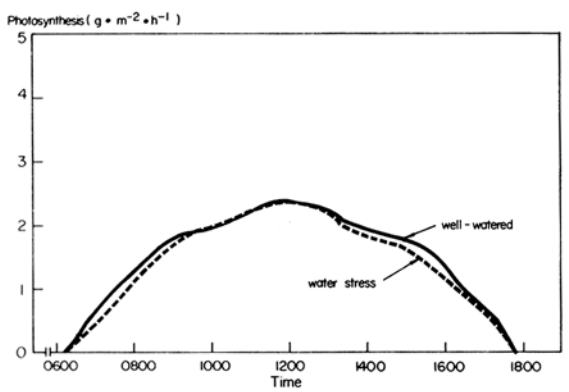
5) We assumed that incident radiation was composed only of direct light, which did not affect the conclusion. Irradiance on the leaf surface for a given daily level of solar radiation was computed by the Anderson and Reeve method.

As shown in fig. 4, crop photosynthesis during cloudy weather was about the same for both well-watered and stressed crops. But on a bright sunny day, crop photosynthesis of a stressed crop was much less than that of a well-watered crop (fig. 5), implying that much incident solar radiation is wasted under water stress.

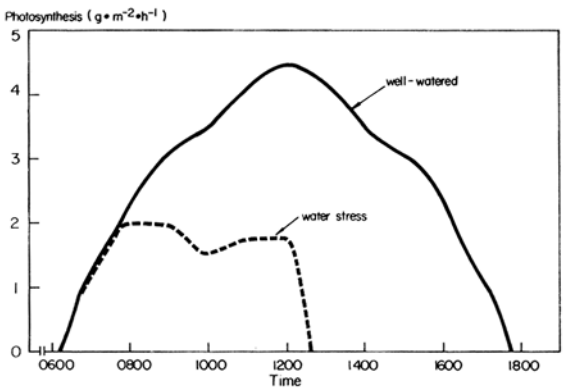
Table 2. Estimated gross photosynthesis of rice crops under well-watered and water-stressed conditions (leaf area index = 3, leaf angle = 70°). IRRI, 1974.

Solar radiation ($cal \cdot m^{-2} \cdot day^{-1}$)	Water supply	Gross photosynthesis ($g \cdot m^{-2} \cdot day^{-1}$)
200	Well-watered	18.1
200	Stress	17.2
600	Well-watered	33.1
600	Stress	10.4

In Table 2, the daily crop photosynthesis of well-watered and water-stressed crops is compared during cloudy and sunny days. Surprisingly, daily crop photosynthesis under water stress was about 70 percent greater during cloudy than during sunny weather. Because the proportion of diffuse radiation is higher on a cloudy than on a sunny day, and because diffuse radiation is more effective in photosynthesis than direct radiation, the estimated difference in crop photosynthesis could be even larger between cloudy and sunny weather. This may be explained in terms of evapotranspiration and efficiency of photosynthesis. Latent heat of water evaporation is about 590 cal/g; this value remains the same regardless of intensity and duration of light. Therefore, the amount of water lost from a plant is directly related to the amount



4. Estimated diurnal changes in photosynthesis on a cloudy day. August 4, 1973.



5. Estimated diurnal changes in photosynthesis on a sunny day. August 10, 1973.

Table 3. Shoot and root weights at different water depths and the root-to-shoot ratio of OS4 and IR20 at different regimes. IRRI, 1974.

Variety	Water supply	Shoot			Roots (mg/g shoot)			Root-to-shoot ratio (mg/g)
		Ht (cm)	Tillers (no.)	Wt (g/plant)	0-30 cm	30-60 cm	60-90 cm	
OS4	50 mm/4 wk	85	15	24	137	44	41	223
	50 mm/2 wk	108	15	32	132	32	40	204
	50 mm/wk	130	20	56	143	26	22	191
	50 + 200 mm/wk[a]	140	19	95	66	27	19	113
IR20	50 mm/4 wk	58	41	26	79	16	13	108
	50 mm/2 wk	66	47	37	78	10	6	94
	50 mm/wk	75	56	56	62	8	6	76
	50 + 200 mm/wk[a]	83	40	60	40	7	1	49

[a]50 mm/wk from 1 to 8 wk, followed by 200 mm/wk from the 9th week to sampling.

of solar radiation which strikes it. Thus, cloudy weather conditions conserve water, and lessen the acuteness of water stress. Consequently, plants can maintain physiological activity for a longer time under a lower light intensity.

But during a bright, sunny day, the leaves are exposed to higher light intensity for a shorter time. The light-photosynthesis curve shows that efficiency of photosynthesis per unit of light intensity is obviously higher at lower light intensities, so crops have greater photosynthetic efficiency during cloudy than during sunny weather. This suggests that a partially shaded environment favors crop growth under water stress, so upland rice cultivation under coconut trees, as is commonly practiced in Batangas province, Luzon, Philippines, and other areas, might insure reasonably high but stable yields under water stress.

ENVIRONMENT AND ROOT GROWTH

Plant Physiology Department

Root growth is regulated not only by varietal characters but also by the root environment. We studied the effects of water supply, soil texture, and soil compaction on root growth.

Water supply. To study how water supply affects root growth in root boxes, soil was initially maintained at about field capacity. During the growing period, water was applied at varying intervals at a rate of 50 mm per application. Water stress most severely affected dry weight of shoot growth, followed by plant height. Tillering was least affected (Table 3).

The root-to-shoot ratio (mg/g) of OS4 increased from 113 at 50 + 200 mm of water/wk to 223 at 50 mm/4 wk. IR20 also showed a similar change in the root-to-shoot ratio. In other words, water stress affected shoot growth more than root growth. The increased root growth relative to shoot growth was probably caused by the proximity of the roots to water. Vertical distribution of roots was also better under water stress.

Soil texture. Root growth was examined in three different soils and in one synthetic medium (peat moss plus vermiculite). There was little difference in the root-to-shoot ratios of four rooting media (Table 4). Peat moss plus vermiculite, characterized by low bulk density and low mechanical resistance, significantly increased root growth in the deep horizons, indicating that organic and deep-plowed soils provide a better environment for deeper penetration of rice roots.

Soil compaction. To examine root penetration into a hard pan, soil layers were "compacted" (10 cm thick) 30 cm below the surface in the root box. Two rice varieties, OS4 and IR20, and one corn variety were tested for their penetration into the compacted soil layers. Enough water to saturate the soil was applied once or twice per week.

Only small fractions of the rice roots penetrated into the compacted soil layers (30-40 cm) and there was no difference between the drought-susceptible variety, IR20, and the drought-

Table 4. Shoot and root growth of OS4 grown in different soils. IRRI, 1974.

Soils	Bulk density (g/cc)	Field capacity (g/cc)	Shoot wt (g/plant)	Root wt (g/plant)				Root-to-shoot ratio (mg/g)
				0-30 cm	30-60 cm	60-90 cm	Total	
Maahas clay	1.1	0.49	87	6.61	1.99	1.11	9.70	112
Cabuyao silty loam	1.1	0.44	98	6.00	2.46	0.93	9.39	95
Paliparan sandy loam	1.1	0.43	82	5.03	2.18	1.52	8.73	107
Peat moss plus vermiculite	0.3	0.50	98	4.78	2.98	3.93	11.69	119

resistant variety, OS4 (Table 5). However, more OS4 roots developed into soil layers below the compacted layers. Although there may have been no difference between IR20 and OS4 in root penetrating ability into the compacted layers, OS4, because of deeper growth habits, developed more roots below the compacted layers. Thus, the deep root growth habit of OS4, not its penetrating ability against increased mechanical resistance, appears responsible for its increased drought resistance.

Corn apparently has a greater ability for root penetration into the compacted soil layers than do the two rice varieties. In addition, at a bulk density of 1.4, corn developed a large number of roots into the 40-90 cm soil layer. A comparison of OS4 and corn indicates that the root system of OS4 develops as does that of corn in soft soil but it is much shallower in the presence of a hard pan. These results may explain differences in the drought resistance of IR20, OS4, and corn in fields with different degrees of mechanical resistance. Thus, to test root systems for drought resistance, scientists should examine not only deep roots in soft soil, but also penetration against increased mechanical resistance.

RESPONSE OF UPLAND RICE VARIETIES TO PHOTOPERIOD

Plant Physiology Department

A large percentage of the world's upland rice is grown in South America, northern Africa, and Asia at latitudes from 30° north to 30° south of the equator. Day lengths vary from 10 hours and 40 minutes to 14 hours and 30 minutes. In Southeast Asia, upland rice usually grows during day lengths that are usually long at seeding, and that decrease up to harvest. In Equatorial areas, such

Table 5. Effect of soil compaction on the root growth of two rice varieties and one corn variety. IRRI, 1974.

Variety	Bulk density[a] (g/cc)	Shoot wt (g/plant)	Root-to-shoot ratio[b] (mg/g)	Roots (mg/g shoot)		
				0-30 cm	30-40 cm	40-90 cm
IR20	1.2	39	66	53.5	5.0 (100)[c]	7.0 (100)[c]
	1.4	39	59	58.4	0.9 (18)	0 (0)
	1.6	39	59	58.8	0.3 (6)	0 (0)
OS4	1.2	72	110	72.6	11.3 (100)	26.2 (100)
	1.4	50	104	93.6	1.9 (17)	8.8 (34)
	1.6	56	108	103.9	0.8 (17)	3.5 (13)
Corn (Early Thai Composite)	1.2	83	112	75.8	10.7 (100)	25.5 (100)
	1.4	88	115	92.4	3.1 (29)	19.8 (78)
	1.6	82	110	94.2	0.9 (8)	5.0 (20)

[a]Of compacted layers at soil depths of 30-40 cm. [b]Above-ground portion of roots was excluded for corn. [c]Ratio of root weight at different densities.

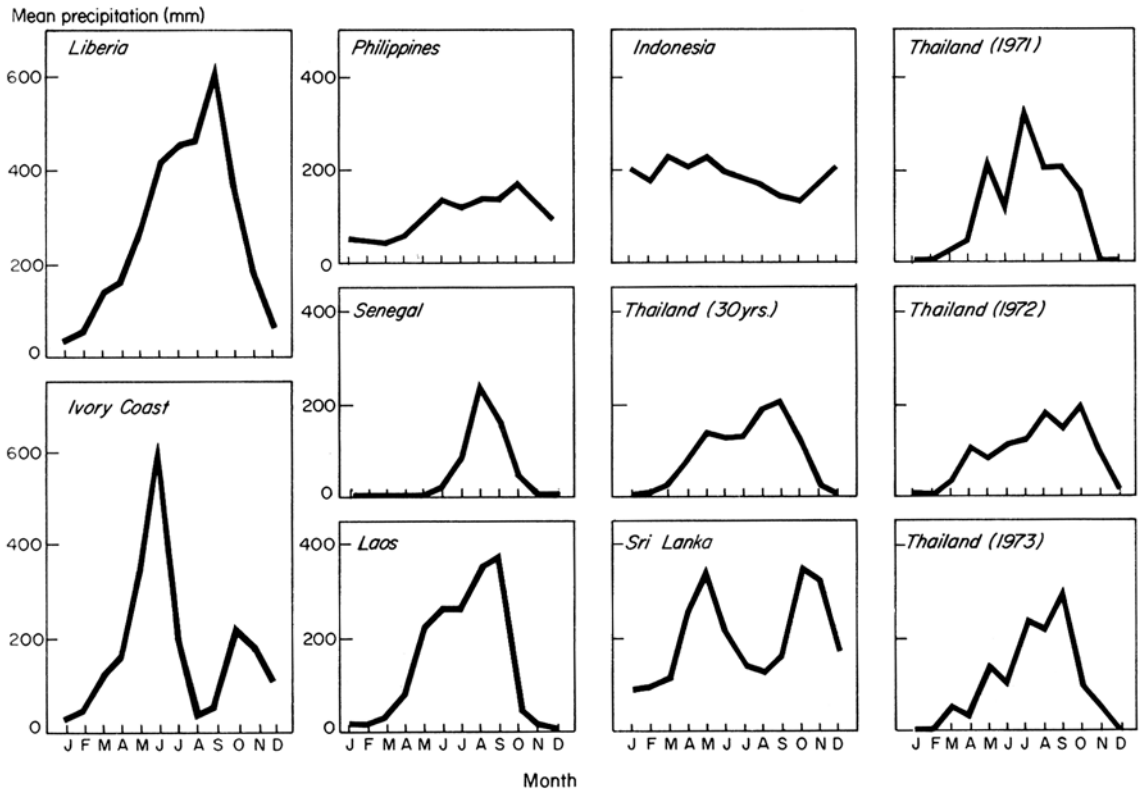
Table 6. Responses of 30 upland rice varieties to photoperiods of 10 and 14 hours. IRRI, 1974.

Designation	Origin	Days to flowering		Basic vegetative phase (days)	Photoperiod sensitive phase (days)
		10 h	14 h		
			Photoperiod-insensitive varieties		
Pate Blanc MN3	Ivory Coast	113	113	78	0
Colombia 1	Colombia	98	101	63	3
IAC 1246	Brazil	85	91	50	6
Seratus Molam	Indonesia	93	99	58	6
E-425	W. Africa	93	100	58	7
Perola	Brazil	82	89	47	7
Azmil	Philippines	90	98	55	8
Miltex	Philippines	95	104	60	9
Moroberekan	Guinea	94	104	59	10
Yassi	Ivory Coast	99	110	64	11
OS4	W. Africa	88	100	53	12
Palawan	Philippines	99	112	64	13
63-83	Ivory Coast	84	98	49	14
Lac 5	Liberia	96	111	61	15
Cartuna	Indonesia	72	89	37	17
Lac 23	Liberia	98	119	63	21
IR442-2-58	Philippines	84	108	49	24
			Weakly sensitive varieties		
M1-48	Philippines	78	112	43	34
IR5	Philippines	93	128	58	35
Ku 70-1	Thailand	58	105	23	48
Khao Lo	Laos	54	130	19	76
Ku-104	Thailand	55	205	20	150
			Strongly sensitive varieties		
Khao Phe	Laos	59	[a]	24	200+
Ku-113-1	Thailand	64	[a]	29	200+
Moddai Karuppan	Sri Lanka	84	[a]	49	200+
TD-47	Thailand	75	[a]	40	200+
TD-48	Thailand	71	[a]	36	200+
TD-51	Thailand	70	[a]	35	200+
Thiorno	Senegal	77	[a]	42	200+
Vanam Villai	Sri Lanka	84	[a]	49	200+

[a]No panicle primordia after 200 days of growth.

as Indonesia, Malaysia, Liberia, Colombia, and Brazil, the variation in day length is minimal.

The response was studied of 30 upland rice varieties to 10- and 14-hour photoperiods (Table 6). The varieties originated in 12 countries with latitudes ranging from 2°S to 20°N. The varieties were classified as follows: photoperiod-insensitive varieties which have long basic vegetative phases (BVP) and short photoperiod-sensitive phases (PSP); weakly sensitive varieties, which have short BVP's and long PSP's and will flower at long photoperiods; and strongly sensitive varieties, which have



6. Mean monthly precipitations of selected upland rice areas.

short BVP's and do not flower beyond the critical photoperiod.

No flowering occurred among the eight strongly sensitive varieties, even after 200 days of growth.

Most of the upland varieties tested were insensitive to photoperiod, probably because upland rice is planted and matures during long day length in many areas of Southeast Asia, so varieties must be either photoperiod insensitive or photoperiod sensitive with long critical photoperiods.

The BVP of the upland varieties tested was generally long (48 days), although several Laotian and Thai varieties, such as Kaho-Lo, Ku-104, and Ku-70-1, have extremely short BVP's and growth durations. Pate Blanc MN3 has the longest BVP (78 days, the longest ever recorded at IRRI). It is also the most insensitive variety tested. Pate Blanc MN3 would be an excellent gene source for varieties of medium-late growth duration that are insensitive to photoperiod.

In most countries where upland rice is grown, early maturing varieties have been selected. But in areas where the rainfall pattern is short and bimodal, such as Ivory Coast, Liberia, and parts of Thailand and Sri Lanka (fig. 6), varieties of early growth duration may suffer from moisture stress at the critical reproductive stage, after which recovery is usually poor. Varieties of longer growth duration might be better suited for these conditions because the plants might recover from moisture stress during the vegetative stage and perform better if sufficient moisture comes at later growth stages.

The two varieties tested from Sri Lanka are photoperiod sensitive. Because the day length in Sri Lanka is less variable, the growth duration of these two varieties does not vary as much as when they are planted farther from the equator. The two varieties also have long growth durations, probably selected for the bimodal rainfall distribution. We know of no tropical variety that has a relatively long growth duration and is not sensitive to photoperiod. Thus, the choice of photoperiod-sensitive varieties in Sri Lanka may be only secondary; they might have actually been preferred because of

Table 7. Days to flowering of some rice varieties from Italy, Portugal, and Spain under different photoperiods. IRRI, 1974.

Variety	Country	Days to flowering				Basic vegetative phase (days)	Photoperiod-sensitive phase (days)
		10 h	12 h	14 h	16 h		
Allorio	Portugal	62	63	71	75	27	13
Arborio	Italy	73	68	76	82	33	14
Bahia F13	Spain	62	61	90	92	26	30
Balilla	Italy	61	59	86	91	24	32
Carnaroli	Italy	77	70	78	91	35	21
Girona	Spain	65	61	93	149	26	88
Italpatna	Italy	76	74	79	90	39	16
Maratelli	Italy	68	62	68	85	27	23
Ponta Rubra	Portugal	67	67	72	74	32	7
Precoce 6	Portugal	74	75	77	83	39	9
Razza	Italy	76	72	76	83	37	11
Ribe	Italy	69	66	75	83	31	17
Roma	Italy	71	64	74	82	29	18
Romeo	Italy	65	61	73	84	26	23
Roncarolo	Italy	63	59	65	78	24	19
Rosa Marchetti	Italy	67	70	72	75	32	8
Sequial	Spain	64	60	87	92	25	32
BPI-76	Philippines	67	79	[a]	[a]	32	200+

[a]No flowering after 200 days of growth.

their long growth durations, which suit the local rainfall pattern. The present upland varieties being used in Sri Lanka are supposedly too long in growth duration.

Rainfall is more or less sufficient throughout the year in Belem, Brazil; Balikpapan, Indonesia; and Davao, Philippines. The day length in these countries does not vary much, so photoperiod sensitivity and duration requirements are more flexible.

Although most upland varieties are insensitive to photoperiod, the Thai varieties Ku-113-1, TD47, TD48, and TD51 are strongly sensitive to photoperiod. They are planted in the northern parts of Thailand as early as April or May and are harvested in September or October, so that they are better suited to the region's bimodal rainfall pattern (fig. 6). The photoperiod sensitivity of the upland varieties enables farmers to seed at any convenient time depending on the beginning of the monsoon, with assurance of enough moisture during the vulnerable reproductive stage. For such a long growth duration (140-180 days), photoperiod sensitivity is needed.

In Colombo, Sri Lanka, the bimodal pattern is quite marked and the rainfall is high.

Examination of the 30-year average rainfall at Lampang, Thailand (fig. 7), shows a slightly bimodal pattern of relatively low rainfall. These data are erroneous for developing cropping patterns or upland varieties for this area. Examination of the rainfall patterns in 1971 and 1973 shows a definite bimodal pattern, with a depression in June and July, which probably explains why photoperiod-sensitive varieties of long growth duration were selected for this area.

Most improved lowland varieties were selected for insensitivity to photoperiod, so they would have no disadvantage if grown under upland conditions. Photoperiod sensitivity is not generally a requirement for upland rice. Certain areas, however, might need varieties with longer growth durations (130-150 days). Such varieties which are also insensitive to photoperiod could possibly be developed by using parents with long BVP's, such as Pate Blanc MN3. For growth durations that exceed 150 days, photoperiod-sensitive varieties are needed.

PHOTOPERIOD RESPONSE OF EUROPEAN VARIETIES

Plant Physiology Department

Leading rice varieties of Portugal, Italy, and Spain, collected by Dr. Akira Tanaka during a study trip to Europe, were tested for their response to photoperiod.

All the varieties tested, except Girona, were insensitive to photoperiod (Table 7). They had short BVP's and short durations of growth. Girona is weakly sensitive, hairy, with a long PSP, but it flowered even at a 16-hour photoperiod.

Constraints to increased rice production

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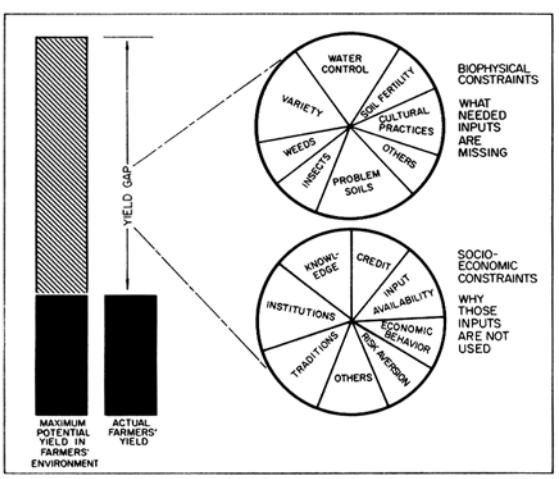
SUMMARY

To understand why rice production is not increasing as rapidly as demand, we expanded our efforts in 1974 to understand the constraints that prevent Asian rice farmers from more rapidly accepting and more effectively using technological innovations. We focused our attention on the difference between the yields that can be obtained under experimental conditions and the yields that farmers obtain. By understanding this difference, or "gap," we believe that faster progress can be made toward raising farmers' yields.

Figure 1 conceptualizes the difference between actual farmer yields and maximum possible yields. Environmental effects arise because of environmental differences between the experiment station and the average rice farm. Most farmers cannot obtain irrigation water throughout the year, so they cannot take advantage of the high solar radiation during the dry season. Although most experiment stations are located on soils that are almost ideal for rice production, most rice farms are not. High-cost inputs, such as rat fences and bird boys, are used to protect experimental plots, but are out of the question for farmers. The technology that gives high yields on experiment stations may not give yields nearly as high in the less favorable environments of most rice-growing areas.



1. The "yield gap" between potential and actual farmers' yields is due to both biophysical and socioeconomic constraints.

We are measuring the size of these environmental effects; other research programs are developing rice technology that is better suited to adverse environments.

The gap between the potential yields in farmer's environments and the actual yield exists because farmers' inputs or practices result in lower yields than are possible in *their* environments. This gap may be measured by identifying *what* biological or physical inputs or cultural practices account for the gap, or by identifying *why* farmers do not use these practices and inputs.

The biophysical explanation is that farmers would reach higher yields if they would use the highest yielding varieties, apply maximum yield levels of fertilizer and insecticide, correct existing soil problems, and use the best cultural practices. The most critical factors differ from region to region, but before remedies such as a package of improved practices can be recommended, we must understand the biological nature of the gap.

The socioeconomic explanation asks *why* farmers are not using the biophysical practices and inputs necessary to obtain maximum yields. The reasons may include economic calculations of costs and returns, lack of knowledge of how to use the technology, lack of credit, poorly operating irrigation systems, or other factors such as non-availability of inputs or traditional beliefs. These factors vary in importance from area to area, but understanding them will help in designing programs to provide the missing biophysical components to overcome the yield gap.

Our 1974 research activities in constraints include projects to describe and measure the environmental effects and yield gap and to identify and measure the relative contributions of the various biophysical and socioeconomic components.

TECHNOLOGICAL INNOVATION IN 36 ASIAN VILLAGES

Agricultural Economics Department

The initial results of a study undertaken cooperatively with Asian social scientists in six countries were reported in the 1973 Annual Report. Subsequent analysis was conducted to more clearly define those factors associated with variation in yield levels and fertilizer use *among* villages. The

influence of farm size on the uses and benefits of the new technology among farmers *within* villages was also examined.

Factors affecting yield and fertilizer use. The Asian village survey provides a unique set of cross-section data (village and farm) for examining the relative importance of various factors that affect yield and fertilizer use among Asian rice farmers. Two separate analyses have been conducted with the hypothesis that economic, environmental, institutional, and technological variables are all important in explaining differences in fertilizer use and, hence, in yields among farmers located in different villages.

Model I is based on data for village means. Model II, a more sophisticated analysis, makes use of farm-level observations for yield, acreage, and fertilizer input. In both models, regression equations are estimated with yield and with fertilizer input as the dependent variables. Estimates of production and demand elasticities of fertilizer with respect to rice are obtained from these results.

The conceptual framework of the models (fig. 2) shows the hypothetical relationship between the aggregate *(P')* and individual village level *(p', p'', p''')* response functions and the aggregate *(D')* and individual village level *(d', d'', d''')* demand functions. Shifts across locations in the response or demand functions may be due to differences in physical environment, irrigation, level of technology, institutional development, or management capacity. In our analysis we attempt to consider as many of these factors as possible to more realistically estimate the short-run elasticities of fertilizer production and demand with respect to rice.

Model I for the village level data is:

(1) $Y_j = a + b_1 N_j + b_2 I_j + b_3 C_j + d_1 T_j + e_j$

(2) $N_j = a + b_1' MN_j + b_2' I_j + b_3' C_j + b_4' PN_j + d_1' T_j + e_j'$

where:

Y_j = average yield in metric tons of rough rice per hectare in village j,

N_j = average kilograms of nitrogen applied per hectare on rice in village j,

MN_j = the nitrogen input in kilograms per hectare needed to obtain maximum yield based on experimental response functions from experiment stations near village j,

I_j = index of quality of irrigation (from 1–5) in village j where 1 means well-irrigated and 5 means poorly irrigated or rainfed,

C_j = average percent of farmers in village j borrowing from formal sources of credit – banks, cooperatives and government agencies,

PN and T have been defined earlier,

PN_j = average price per kilogram of nitrogen, divided by the price per kilogram of modern varieties (rough rice) for village j,

T_j = dummy variable for type of farming where mixed farming = 0 and mono-culture farming = 1. Mono-culture villages are those that plant 90 percent or more of their land suitable to rice production to rice only in both wet and dry seasons. Mixed farming villages are those where there is at least one crop other than rice of major importance.

e_j and e_j = disturbance terms.

Observations for variables Y, N, and PN refer only to modern varieties. The variable MN needs further explanation. Many experiments showing the yield response to nitrogen for modern varieties have been conducted at experiment stations throughout Asia. The approximate input of nitrogen necessary to maximize yield for each village was determined from such experiments, usually from stations reasonably near the study areas. Where such information was lacking, the N level was estimated. The range varied from 90 to 180 kg N/ha. This variable takes into consideration both soil and climatic factors. For example, the soils in India tend to be older and less fertile; consequently higher rates of nitrogen are needed to maximize yields than in the Philippines. The maximum yield and the nitrogen required to achieve that yield are both normally higher in the dry than in the wet season.

Village average data from 65 observations (36 in the wet and 29 in the dry season) were used to estimate the equations. Both linear and logarithmic regressions were estimated; the linear equations provided the best fit.

The estimated coefficients for equations 1 and 2 are presented in Table 1. In the yield response equation, nitrogen applied *(N)* and quality of irrition *(I)* are significant at the 1-percent level, while institutional credit *(C)*, and type of farming *(T)* are significant at the 5-percent level. In the fertilizer demand equation, maximum nitrogen *(MN)*, quality of irrigation, and the nitrogen-to-rice-price ratio

Table 1. Estimated rice response and fertilizer demand functions for Model I based on village averages from 36 Asian villages, 1971–72.[a]

Variable	Yield (t/ha)	Nitrogen (kg/ha)
Nitrogen (*N*)	0.015 (4.89)**	
Maximum N (*MN*)		0.682 (5.77)**
Quality of irrigation (*I*)	−0.324 (2.49)**	−16.281 (4.47)**
Institutional credit (*C*)	0.010 (1.95)*	0.304 (1.90)*
Fertilizer/MV price ratio (*PN*)		−9.020 (−3.29)**
Type of farming dummy (*T*)	−0.489 (2.10)*	−12.886 (1.70)*
Intercept	3.50	55.09
R^2	0.77	0.80

[a]36 wet-season and 29 dry-season observations; figures in parentheses are *t* values: * = significant at the 5-percent level, ** = significant at the 1-percent level.

(PN) are all significant at the 1-percent level. The signs of all variables in both equations accord with general expectations.

Fertilizer demand equations based on village- and farm-level data were estimated through two different approaches: Model IIa and Model IIb, which differ in the method of measuring inter-village differences in response to fertilizer. In Model IIa, the estimated parameters of the village fertilizer response functions are included directly in the demand equation. The relevant parameters are the slopes and intercepts of the village fertilizer response functions, shown hypothetically in fig. 1 *(p', p'', p''')*. Model IIb is similar to Model I, employing many of the same explanatory variables.

The initial step in Model IIa is to use covariance analysis to estimate the relevant parameters of the response function. This technique allows us to pool the farm observations for all sample villages and to partially correct for the problem of inter-village correlation between omitted and included variables in the equation.

A response function of the log-linear form is:

$$(3)\quad \log X_{ij} = \log a + d_2 D_2 \ldots + d_{36} D_{36} + c_1 \log H_{ij} + c_2 \log F_{ij} + d_2' (D_2 \log F_{ij}) + \ldots d_{36}' (D_{36} \log F_{ij}) + u_{ij}$$

where:

X_{ij} = rough rice output of farm i in village j in tons per hectare,

$D_2 \ldots D_{36}$ = intercept dummy variables where the values of D_2 for the farms in village 2 are equal to one and zero otherwise, the value of D_3 for the farms in village 3 is equal to one and zero otherwise, and so forth,

H_{ij} = crop area of farm i in village j in hectares,

F_{ij} = weighted sum of *N*, *P*, and *K* fertilizer input per hectare of farm i in the village j in kilograms of plant nutrient (weighted by prices),

$(D_2 \log F_{ij}) \ldots (D_{36} \log F_{ij})$ = slope dummy variables for fertilizer,

u_{ij} = disturbance term.

Both the level of fertilizer response (through the intercept dummy variable) and the elasticity of fertilizer response (through the slope dummy) are allowed to vary from village to village in this equation. The intercept of the first village is equal to $\log a$; for the second village it is $\log a + d_2$; and so forth. The output elasticity with respect to fertilizer, which measures the percent change in output as a result of a 1-percent change in fertilizer use, is equal to c_2 for the first village; to $c_2 + d_2'$ for the second village; and so on.

Because our major interest is the fertilizer response, the production elasticity for land is simply assumed to be constant between villages in order not to reduce the degrees of freedom.

We used the estimated fertilizer response parameters in equation 3 to specify a fertilizer demand function of the long-linear form:

$$(4)\quad \log F_{ij} = \log a + b_1 \log P_j + b_2 \log IN_j + b_3 E_j + b_4 PMV_{ij} + b_5 \log VX_{ij} + z_{ij}$$

where:

F_{ij} = is defined as in equation (3),

P_j = ratio of fertilizer (weighted *N*, *P*, and *K* price) price to rice price for village j,

IN_j = intercept of the underlying production function estimated from equation (3), $\log a + d_j$,

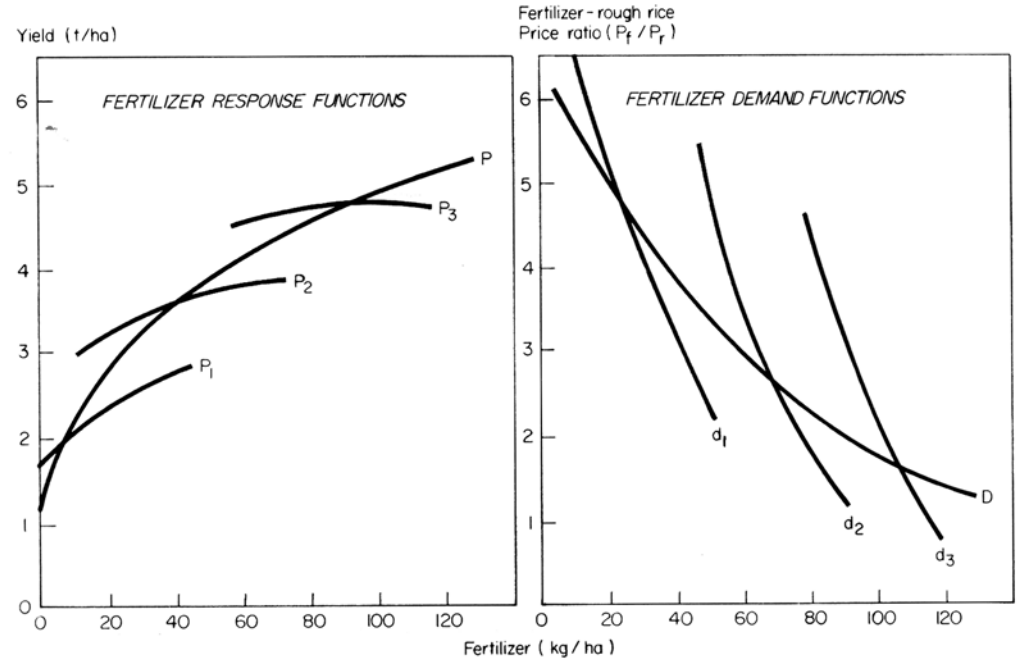
E_j = production elasticity of fertilizer also based on equation (3), $c_2 + d_j'$,

PMV_{ij} = proportion of area under modern varieties of farm i in village j,

VX_{ij} = value of output in U.S. dollars per farm,

bi = elasticity of fertilizer demand with response to changes in variable i,

z_{ij} = disturbance term.



2. Hypothetical shifts in fertilizer response functions and corresponding demand functions.

Equation (4) indicates that fertilizer use per hectare depends on relative fertilizer-rice prices *(P)*, measures of physical fertilizer response *(IN* and *E)*, and a measure of farmer's liquidity position *(VX)*. Note that the values of relative price, intercept level, and fertilizer elasticity vary by village; the data on fertilizer input per hectare and value of output are farm specific.

In the model IIb shown in equation (5), four explanatory variables have been substituted for the fertilizer response parameters *(IN_j* and *E_j)* in equation (4):

$$(5)\quad \log F_{ij} = \log a + b_1' \log P_j + b_2' \log MN_j + b_3' \log I_j + b_4' R_j + b_5' PMV_{ij} + b_6' \log VX_{ij} + e_{ij}$$

where:

F_{ij}, P_j, MN_j, I_j, PMV_{ij}, and VX_{ij} are defined in equations (2) and (4),

R_j = average proportion of rainfall for the 2 months prior to harvest (1967–71),

e_{ij} = disturbance term.

MN and *I* are identical to the variables in equations 1 and 2. *R*, the proportion of rainfall in the 2 months before harvest, is expected to be inversely correlated with the yield since high rainfall would be associated with low solar energy in the critical period before harvest.

Regression equations were estimated in the log-linear form for wet-season data in 33 villages (all values in logs except for zero-one dummy variable). Three villages were omitted where fertilizer use was extremely low.

Table 2 shows the statistical results of the response function regressions for Model II. A surprisingly high percentage of variation in farm output (87%) is explained by land and fertilizer.

The *t* values are highly significant and the parameters are of the expected magnitudes. Constant returns to scale are indicated by the sum of the coefficients, which is close to unity in all cases.

Table 2. Rice response function for Model II based on farm data of 33 selected villages in Asia, 1971 and 1972 wet seasons.[a]

Variable	II-A	II-B	II-C
Land (*H*)	0.813 (57.26)**	0.837 (48.13)**	0.880 (44.69)**
Fertilizer (*F*)	0.124 (13.93)**	0.095 (10.97)**	0.386[b] (4.51)**
Intercept (log *a*)	0.204	0.036[b]	−0.682[b]
R^2	0.868	0.928	0.935

[a]In addition to the coefficients shown, the covariance analysis procedure generated estimates of village-specific intercepts and fertilizer responses which make these different for each village. [b]These refer to the values of coefficients for the assigned base village, in this case Mahipon.

Table 3. Fertilizer demand functions for Model IIa based on farm and village data from 33 Asian villages. 1971 and 1972 wet seasons.

Variable	IIa-A	IIa–B	IIa-C	IIa-D
Fertilizer:rice price ratio (*P*)	−0.863 (7.87)**	−0.691 (6.24)**	−0.650 (5.53)**	−0.598 (5.06)**
Fertilizer response coefficients:				
Intercept (*I*)	–	0.584 (7.37)**	0.580 (7.31)**	0.540 (6.73)**
Elasticity (*E*)	–	2.326 (8.74)**	2.336 (8.77)**	2.294 (8.62)**
Percentage of area in MV (*PMV*)	–	–	0.038 (0.037)	0.037 (1.01)
Value of output (*VX*)	–	–	–	0.091 (3.22)**
Intercept (log *a*)	2.035	1.562	1.520	1.302
R^2	0.17	0.25	0.25	0.26

Because of the high collinearity between land and the omitted variable of labor, the large coefficient of land reflects the output contribution of labor as well. Similarly, the reduction in the coefficient of fertilizer from 0.124 to 0.095 when intercept dummies are introduced suggests some positive inter-village correlation between fertilizer and omitted variables, such as improved seeds or quality of irrigation.

The statistical results of fertilizer demand based on Model IIa and IIb are reported in Tables 3 and 4, respectively. The R^2s are low but all the coefficients of the independent variables are highly significant. Considering locational differences in fertilizer response functions improves the goodness of fit considerably, particularly in Model IIb, where

Table 4. Fertilizer demand functions for Model IIb based on farm and village data from 33 Asian villages, 1971 and 1972 wet seasons.

Variable	IIb–A	IIb–B	IIb–C
Fertilizer:rice price ratio (*P*)	−0.863 (7.87)**	−0.381 (3.44)**	−0.225 (1.99)*
Maximum nitrogen (*MN*)	–	1.986 (10.47)**	1.697 (8.74)**
Rainfall (*R*)	–	3.481 (22.63)**	3.444 (22.57)**
Quality of irrigation (*I*)	–	−0.803 (8.24)**	−0.942 (9.48)**
Percentage of area in MV (*PMV*)	–	0.472 (12.20)**	0.457 (11.87)**
Value of output (*VX*)	–	–	0.153 (5.96)**
Intercept (log a)	2.035	−3.113	−2.870
R^2	0.17	0.50	0.52

Table 5. Alternative estimates of production and demand elasticities of fertilizer with respect to rice based on village and farm level data from 36 Asian villages, 1971–72.

Production elasticities[a]	
Model I – village level[b]	0.27
Model II – farm level (pooled)	0.12
Model II – farm level (pooled with intercept dummies)	0.10
Demand elasticities[c]	
Model I – village level[b]	−0.44
Model II – farm level, long-run	−0.86
Model IIa – farm level, short-run	−0.60
Model IIb – farm level, short-run	−0.22

[a]Percent change in rice yield due to 1 percent change in fertilizer input per hectare. [b]The village level elasticities are calculated at the mean and are for the combined wet and dry season samples while the farm level elasticities refer to the wet season sample only. Fertilizer input in Model I is defined in terms of N only, while in Model II it refers to N, P, and K combined. [c]Percent change in fertilizer input due to a 1-percent change in the fertilizer: rice price ratio.

the four explanatory variables are specified instead of the parameters of the response function. In Model IIb, however, the positive sign for rainfall is not in accord with our expectations. As noted previously, the sign should be negative since high rainfall before harvest implies low solar energy and low nitrogen use.

The production elasticity is considerably higher for Model I than for Model II, perhaps because Model I contains both wet- and dry-season observations and is based on nitrogen only (Table 5). The efficiency of nitrogen input may be greater in the dry season. The low elasticity of response in Model II conforms with the information from other studies that fertilizer efficiency is very low in farmers' fields (1 kg of nutrients returning 10 kg of rough rice or less).

The long-run demand elasticity (*D* in fig. 2) for Model II is −0.86. When the variables explaining the shift in the demand function over locations are included, the estimates of short-run demand elasticity range between −0.60 (Model IIa) and −0.22 (Model IIb). It can be noted from Table 4 that omitting the variable *VX* in Model IIa results in an elasticity estimate of −0.38, approximately the same as that obtained in Model I.

Although nearly all the villages in the study were irrigated and reasonably well suited to the use of modern technology, fertilizer use and yield levels varied widely among villages. Tables 6 and 7 examine the factors that appear to explain the "gap" in fertilizer use and yield between the average and the highest level of fertilizer users, based on the regressions in Model I and II. The variables

Table 6. Percent contribution of various factors explaining differences in levels of fertilizer use between the average and top 20 sites based on Model I. 1971–72 wet and dry seasons.[a]

Factor	Means		Contribution (%) to change in fertilizer input
	Av.	Top 20 sites[b]	
Fertilizer:rice price ratio (*PN*)	3.3	2.9	7
Maximum N (kg/ha)	130.0	160.0	51
Quality of irrigation (*I*)	2.9	2.0	32
Institutional credit (*C*)	26.0	40.0	10
Type of farming (*T*)	–		
Nitrogen (kg/ha)	68.0	129.0	
Yield (t/ha)	3.6	5.3	

[a]Based on observations of modern varieties only in 36 wet-season and 29 dry-season sites. [b]Wet-season and dry-season observations.

Table 7. Percent contribution of the various factors explaining differences in level of fertilizer use between the average and top 4 village users of fertilizer based on Model IIb. 1971–72 wet season.

Factor	Mean		Contribution (%) to change in fertilizer input
	Av.	Top 4 village users	
Fertilizer:rice price ratio (*P*)	3.24	3.0	4
Maximum N (kg/ha) (*MN*)	126	165	84
Quality of irrigation (*I*)	2.7	2.0	52
Rainfall (*R*)	0.22	0.17	−73
Proportion of area under MV (*PMV*)	0.65	0.79	27
Value of output (US$/farm) (*VX*)	485	388	6
Intercept (log *IN*)	0.250	0.567	–
Elasticity (*E*)	0.102	0.036	–
Nitrogen (kg/ha)	63.0	130	–
Yield (t/ha)	3.3	4.9	–

Table 8. Percentages of farms which reported adoption of specified practices measured by farm size in 32 selected Asian villages during 1971–72.

Farm size (ha)	Farms (%) that reported adoption of									
	Modern varieties		Fertilizer		Insecticide	Herbicide	Hand weeding	Rotary weeding	Tractors	Mechanical thresher
	Wet season	Dry season	Wet season	Dry season						
Less than 1	84	89	76	84	79	6	82	3	13	36
1–3	86	91	75	83	81	20	83	20	41	43
More than 3	98	89	82	85	83	29	87	37	57	63

MN and *I*, which relate to the quality of the environment and of irrigation, are important variables contributing to the change in fertilizer input. The negative role of rainfall in Model II (Table 7) is difficult to interpret.

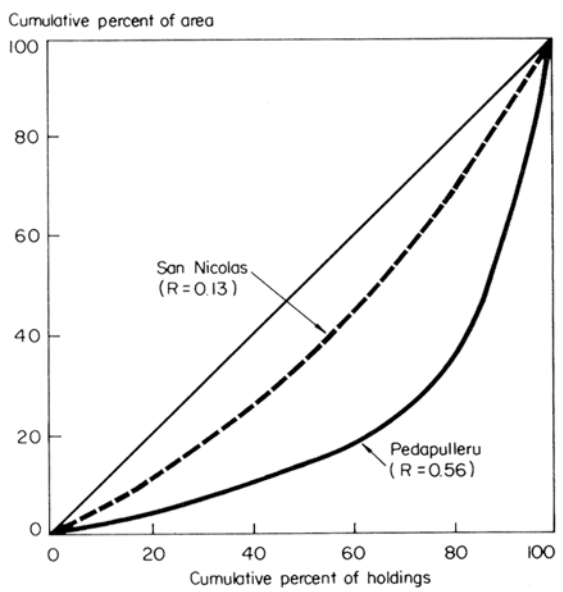
Our analysis does not indicate that improving the quality of irrigation or developing modern varieties suitable to a wider range of environmental conditions is the logical policy implication. Their large contributions, however, suggest that their relative cost in changing the fertilizer-to-rice price ratio should be considered in designing policies to raise fertilizer application on rice farms.

Farm size and new technology. There has been much discussion in the literature about the relationship between farm size and the use of modern rice technology. The farm size and distribution pattern in the 14 study areas (1973 Annual Report) tells much about the way in which the benefits of the new technology are likely to be distributed. While there are differences in size distribution among the two or three villages in each study area, the main difference is found between study areas.

We can distinguish between relative and absolute farm size. There is a close association between absolute farm size and the adoption of labor-saving technology (Table 8). Rotary and hand weeding are more commonly practiced on small farms, while herbicides were used only on sample farms larger than 1 ha. Tractors and threshers are more common on the larger farms. By contrast, yield-increasing technology – fertilizers, insecticides, and modern varieties – were widely used on all farms, irrespective of size.

We hypothesized that *relative* farm size within villages would be a significant factor in determining access to, and benefits from, the new rice technology only where there was a comparatively inequitable distribution in size of farm-operating units. We have computed a Gini coefficient for each village to reflect the degree of equity in the distribution of operating units. This coefficient was computed by using the percentage of farms and the percentage of total land area for each of seven farm-size categories, ranging from small (less than 0.41 ha) to large (over 3.1 ha). Figure 3 shows the Lorenz curve for the two villages with the highest and lowest Gini coefficients. If all the operating units were of equal size, the Gini coefficients would be zero. Alternatively, if the bulk of the land were operated in a few very large units, but there were many small holdings, the maximum coefficient would approach 1.

Sixteen villages were ranked according to their Gini coefficients (Table 9). The highest coefficient



3. Lorenz curves showing percent distribution of holdings for villages having the highest and lowest of Gini ratios.

Table 9. Size distribution of operating units for selected villages in Asia.

Location	Gini ratio	Pure owners (%)	Pure tenants (%)	Farm size (ha)	Operating units (%)		
					Less than 1 ha	1–4 ha	Above 4 ha
Pedapulleru, India	0.56	41	32	4.7	16	49	35
Manmalai, India	0.52	96	2	1.8	41	50	9
Tarna, India	0.42	100	0	1.2	37	58	5
Aroop, Pakistan[a]	0.38	65	4	6.7	1	43	56
Marcos, Philippines	0.38	14	86	1.5	39	56	5
Cidahu, Indonesia	0.36	90	1	0.5	82	18	0
Hosahally, India	0.34	n.a.	n.a.	4.8	7	40	53
Kandarpur, India	0.32	49	9	0.6	79	21	0
Kahuman, Indonesia	0.30	67	2	0.6	81	19	0
Beynte Nuwebe, Philippines	0.28	8	92	1.7	15	84	1
D. Vijaypur, India	0.28	100	0	6.0	0	39	61
Bulucaon, Philippines	0.25	6	91	2.0	0	100	0
Sidomulyo, Indonesia	0.25	86	7	0.5	100	0	0
Salor, Malaysia	0.24	58	11	0.9	66	34	0
Rai Rot, Thailand	0.18	75	6	7.0	0	17	83
San Nicolas, Philippines	0.13	16	56	2.5	0	92	8
Village average	–	–	–	–	35	45	20
Southeast Asia – 1960[b]	–	–	–	–	49	36	15

[a]Not based upon a random sample, but a sample of adopters only. The Gini ratio may be biased downward and the average farm size biased upward. [b]Based upon Country Census of Agriculture, 1960 as reported in the FAO Yearbook.

was 0.56 for Pedapulleru, and the lowest 0.13 for San Nicolas (fig. 3). In Pedapulleru, approximately 20 percent of the largest farmers operate 60 percent of the land. While operating units are fairly uniform in size in many of the Philippine villages, the Philippine study areas have the highest rate of tenancy.

There appeared to be no relationship between the degree of equity in the size distribution of operating units and the average size of farm in a village. For example, the Gini coefficient was relatively high, with large average farm size in Aroop, Pakistan, and high with small average farm size in Cidahu, West Java. But in Rai Rot, Thailand, the coefficient was low despite the large average farm size.

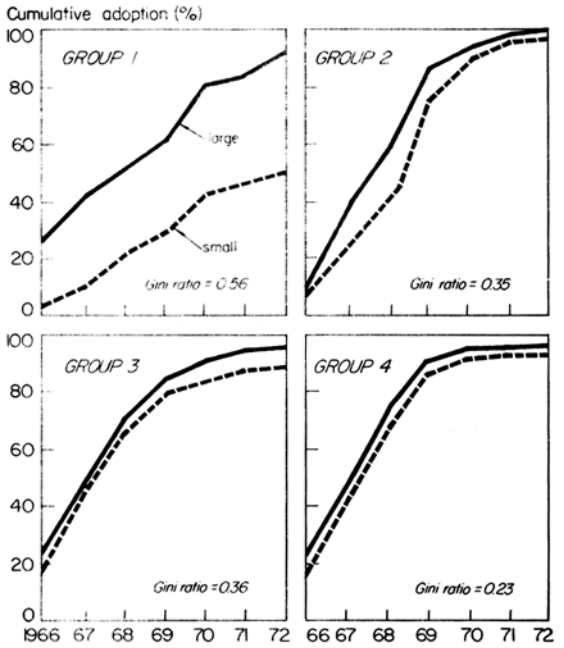
The impact of relative farm size was compared among villages by classifying farms as large or small based on the median of farm size within each village. Villages were grouped according to the level of the Gini Coefficient. Within these village groups, farm samples were pooled making a series of two-way tables between farm size and other factors related to adoption, input use, and benefits from new technology.

Farmers were asked in what year they first planted any of the modern varieties (wet or dry season). Taking the first year of adoption in each village as the base year, we plotted the cumulative frequency distributions of adoption for the four village groups (fig. 4).

Group I consists of only one village, Pedapulleru, India, which is unique among the study villages (although, undoubtedly, by no means unique in Asia) in terms of the very strong interaction between farm size and a number of factors relating to the introduction of the modern rice technology.

Group II consists of 10 villages in India and Pakistan. We divided the remaining villages in Southeast Asia into two groups: Group III (six villages with Gini ratios of 0.3 or above) and Group IV (10 villages with Gini ratios below 0.3).

The relationship between farm size and adoption is most striking in Pedapulleru where the new



4. Gini coefficients, farm sizes, and years of adoption of modern varieties.

varieties were planted on more than 90 percent of the large farms, but less than half of the small farms. Small farmers in Group II lagged behind the large farmers at the start, but caught up rapidly in the fourth and fifth year. In group III, small farms seem to have lagged in adoption after the third year. Clearly, the size of the Gini coefficient is not the only factor that influences the degree of lag in small farms.

Farmers were asked whether their profits from rice and their general levels of living had increased in the period after the introduction of modern varieties to their villages. They were also asked whether changes in their levels of living were due to increased rice profits. Most of those who reported a higher level of living attributed the change to higher rice profits.

The percentage of farmers who reported an increase in profits from rice tends to be higher than the percentage who reported a higher level of living (Table 10).

In groups I and II a significantly greater number of large farms, compared with small farms, reported an increase in profits from rice and in level of living. Farm size was not associated with increased benefits in groups III and IV.

ACTUAL AND POTENTIAL RICE YIELDS, PHILIPPINES

Agricultural Economics, Agronomy, Multiple Cropping, and Statistics Departments

Average rice yields in the Philippines have gradually increased to about 1.8 t/ha in recent years. Government sample surveys indicate that under irrigated

Table 10. Percent of farmers reporting increase in profit from rice and higher level of living principally as a result of adopting modern varieties for selected village groupings, 1971–72.

Village group[a]	Villages (no.)	Gini coefficient	Farmers (%) reporting increases	Farm size of those reporting increases		Chi-square significance level
				Small (%)	Large (%)	
			Profit from rice			
I	1	0.56	34	26	74	0.001
II	2	0.38	75	43	57	0.05
III	5	0.38	52	49	51	n.s.
IV	7	0.24	52	51	49	n.s.
			Level of living			
I	1	0.56	28	23	74	0.001
II	2	0.38	48	35	65	0.01
III	5	0.38	38	44	56	0.10
IV	7	0.24	45	50	50	n.s.

[a] I = Pedapulleru in India, II = Kandarpur, Barain in India, III = Marcos, Tab-ang, Sinayawan in the Philippines, and Cidahu, Nganjat in Indonesia, IV = Malimba, Canipa, Bulucaon, Beynte Nuwebe in the Philippines; Rai Rot, Nong Sarai in Thailand, and Meranti in Malaysia.

Table 11. Average yields of IR20 recorded at different levels of nitrogen at four locations for a specified number of seasons.[a] Philippines, 1968–1973.

Location	Seasons (no.)	Yield (t/ha) at 0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha	180 kg N/ha
				Dry season				
IRRI	5	4.7	–	6.2	6.8	7.1	6.8	–
Maligaya[b]	4	4.0	–	5.1	5.1	5.6	5.1	5.1
Pili[b]	5	5.0	–	6.6	7.7	7.8	7.6	7.3
La Granja[b]	4	4.1	–	5.7	6.1	6.9	6.6	5.9
Av.[c]		4.4	–	5.9	6.4	6.8	6.6	–
				Wet season				
IRRI	4	4.0	4.3	4.4	4.4	–	–	–
Maligaya[b]	6	3.8	4.6	5.1	5.1	5.0	4.4	–
Pili[b]	6	3.5	3.8	4.4	4.5	3.8	3.6	–
La Granja[b]	6	3.8	4.7	5.5	6.1	5.8	5.4	–
Av.[c]		3.8	4.4	4.8	5.0	4.7	–	–

[a]Compiled from data supplied by IRRI Agronomy Department. [b]Bureau of Plant Industry (Philippine Government) rice research station in Maligaya, Nueva Ecija; Pili, Bicol; and La Granja, Visayas. [c]Weighted by the number of seasons.

conditions on farmers' fields, the yields of modern varieties are generally about 15 percent higher than the yields of traditional varieties; under rainfed conditions, the difference is usually less. Despite the use of modern varieties on nearly 60 percent of the rice area, Philippine national yields are still disappointingly low. To determine why, we tried to establish the "true" national potential yield using the best technology available to farmers in 1973, and to explore the economic aspect of the difference between the maximum potential and the actual average yields.

Environmental effects *(Agricultural Economics, Agronomy, Statistics).* IRRI agronomy trials showed that yields of 8 t/ha are possible with IR20 (1971 and 1972 annual reports). However, such yields could not be achieved every year, even under experiment station conditions.

Table 11 summarizes the average yields of IR20 in agronomy nitrogen response trials between 1968 and 1973 at four Philippine locations. The average maximum yield in the dry season was 6.8 t/ha at 120 kg/ha of nitrogen – a reasonable estimate of the maximum yields possible with available technology in the Philippines. The difference between 8 and 6.8 t/ha is the year-to-year fluctuation caused by environment.

Table 11 also makes clear, however, that yields are significantly lower in the wet season – in fact, the average maximum was 5 t/ha at 90 kg N/ha. Since most Philippine rice is produced during the wet season, a realistic assessment of the maximum potential under farmers' environment must reflect this.

Rice is planted and harvested year round in the Philippines, but in most areas, July through December is the main wet season, when two-thirds of the country's rice is grown. Wet-season data are appropriate for determining the maximum potential yield for this part of production.

Weighting the maximum yields in each season by the proportion planted each season gives a yearly average maximum of 5.5 t/ha. The difference between 6.8 and 5.5 t/ha is considered an environmentally caused effect because most farmers can do little or nothing to change the season in which they grow rice. Most depend on the rainfall of the wet season, either directly or through irrigation systems lacking in water storage capacity.

This weighted average of 5.5 t/ha reflects maximum yields with good irrigation. Unfortunately, most rice in the Philippines is grown with poor irrigation and, hence, suffers considerable moisture stress. Data presented in the 1973 Annual Report show that in a 5,000-ha area of the Peñaranda River Irrigation System in Central Luzon, farmers

located along the quarter of the canal nearest the source had average yields of 2.5 t/ha during the dry season. Yields in the second quarter were 2.2 t/ha; in the third quarter, 1.5 t/ha; and in the fourth, 0.4 t/ha. In an earlier study (1973 Annual Report) 11 irrigated sites in Luzon were classified by their location along the first, second, or last third of the distribution canal. Yield losses, calculated on the basis of moisture stress days, showed that during the dry season those sites located in the first third of the canal suffered 7 percent yield loss due to moisture stress, those in the second third lost 20 percent; and those in the last third lost 25 percent. The average loss of 17 percent is considerably less than that in the 1973 Peñaranda study, but is more broadly representative. On this basis we argue that the maximum potential dry-season yields under farmers' environments are 17 percent less than those under the experiment station environment, or 5.6 t/ha rather than 6.8 t/ha.

Table 12. Experiments used to identify average maximum rainfed rice yields for IR20. Transplanted lowland rice culture, Philippines, 1972 and 1973.[a]

Location[a]	Av. yield (t/ha) of treatment at two-input levels		Main treatments in the trial	Levels (no.) of each treatment
	Maximum yield	Minimum yield		
IRRI	4.8[b]	3.2[b]	Land preparation	3
			planting method	2
			water availability	3
Central Luzon	5.0[c]	2.0[c]	Variety	2
			location	2
			elevation	13
Central Luzon	3.9	3.4	Soil type	5
			nitrogen	4
			phosphorus	3
			potash	3
Central Luzon	5.5	3.6	Package of fertilizer, insecticide, weedicide	5
Central Luzon	3.7	1.9	Nitrogen	3
			insecticide & herbicide	2
			soil type	4
Central Luzon	4.7	4.0	Nitrogen	4
			soil type	5
Central Luzon	4.1	3.5	Insecticide	8
			location	9
IRRI	4.7[c]	3.5[c]	Nitrogen	5
			variety	16
IRRI	5.8[b]	3.5[b]	Source of N	3
			water availability	2
			variety	2
			time of application	2
Nueva Ecija	4.5[c]	2.6[c]	Source of N	3
			variety	2
			time of application	2
Av.	4.7	3.1		

[a]Original data are all reported in IRRI Annual Reports for 1972 and 1973. [b]For rainfed IR20. [c]For IR20.

Yield reduction due to moisture stress was also measured in the wet season in the 11-site study, and was found to be considerably less than in the dry season. Loss was 4 percent in the first third, 4 percent in the second third, and 8 percent in the last third; average reduction was 5 percent. Thus the maximum wet-season irrigated yield is 4.7 t/ha instead of 5 t/ha.

The above data reflect yield potential under irrigated conditions, but about 45 percent of the Philippines' gross rice area is in rainfed lowland culture and 13 percent is rainfed upland. To determine the maximum potential yields for rainfed rice, we examined yield data from a number of 1972 and 1973 rainfed experiments carried out by the IRRI Agronomy Department and the applied research program.

The experiments were conducted on farmers' fields, usually in several locations in Central Luzon, under the direct control of researchers. All inputs, except the variables being tested, were supplied at their maximum yield levels. The treatment giving the maximum yield at most locations was selected, and yields for that treatment were averaged over all locations. The averages ranged from 3.7 to 5.8 t/ha (Table 12). These maximums were then averaged over years and trials giving 4.7 t/ha – an estimate of the potential maximum yield under rainfed conditions.

Less data is available on experimental yields under upland conditions, but agronomists have conducted some fertilizer response trials using IR5. These data, covering 3 locations, 2 seasons, and a number of planting dates, show maximum yields ranging from 1.3 to 7.0 t/ha and averaging 4.1 t/ha (Table 13). The rainfed and upland trials used as basis for potential yields were grown on fields that had a fairly high probability of escaping severe moisture stress. But the average rainfed farmer is in exactly the opposite situation. Moisture stress under rainfed conditions is probably more widespread and severe than under irrigated conditions because the irrigated areas benefit from both rainfall and supplemental irrigation. However, because we know of no research on the extent of moisture stress in rainfed and upland areas, we assume that under farmers' environments, moisture stress reduces rainfed and upland yields by 20 percent below the maximum experimental levels.

Summarizing these data and assumptions provides a fairly reasonable estimate of maximum potential yields under farmers' environments for the Philippines. Forty-five percent of the rice area is rainfed with a maximum potential yield of 3.7

Table 13. Nitrogen response of IR5 under upland conditions.[a]

Location	Seeding date	Grain yield (t/ha)		
		0 kg N/ha	60 kg N/ha	120 kg N/ha
IRRI	5/31/70	2.5	3.2	4.5
	6/15/70	2.3	3.1	4.2
	6/30/70	1.9	2.5	3.0
	7/23/70	1.6	2.1	2.6
Maligaya[b]	6/1/70	4.9	6.1	6.7
	6/17/70	4.1	5.8	7.0
	7/2/70	4.7	5.8	5.9
	7/17/70	4.6	6.1	5.8
Maligaya[b]	6/9/71	2.7	4.2	4.9
	6/29/71	2.4	3.9	5.0
	7/29/71	1.4	2.5	2.8
La Granja[b]	5/21/71	1.0	1.5	2.3
	6/17/71	0.4	1.0	1.3
	7/12/71	0.3	1.2	1.6
Av.		2.5	3.5	4.1

[a]Source: IRRI Agronomy Department. [b]BPI rice research station in Maligaya, Nueva Ecija; Pili, Camarines Sur; and La Granja, Negros, Philippines.

t/ha; 28 percent is wet-season irrigated with a maximum potential of 4.7 t/ha; 14 percent is dry-season irrigated with a maximum potential of 5.6 t/ha; and 13 percent is upland with a maximum potential of 3.3 t/ha. This gives a weighted average estimate of the maximum potential yield in farmers' environments, given the technology available to farmers in 1973–74, of 4.2 t/ha.

The difference between 4.2 and the actual yield of 1.8 t/ha – 2.4 t/ha – arises because not all the inputs and cultural practices that are used in yield experiments are used by farmers. Data are not

Table 14. Yield and economic performance of selected experimental treatments chosen by four alternative criteria in six multi-factor experiments in farmer's fields. Central Luzon, Philippines, 1972 and 1973.

Treatment trial	Increases over the control in			Return per dollar invested
	Yield (t/ha)	Net return (US$/ha)	Cash cost (US$/ha)	
Maximum yield				
irrigated, wet '72	1.3	87	24	3.6
rainfed, wet '72	1.2	14	60	0.2
irrigated, dry '72	1.2	67	22	3.0
irrigated, wet '73	1.3	57	30	1.9
rainfed, wet '73	1.0	43	34	1.3
rainfed, wet '73	1.8	86	52	1.6
Av.	1.3	59	37	1.9
Maximum net return				
irrigated, wet '72	1.3	87	24	3.6
rainfed, wet '72	0.6	20	15	1.3
irrigated, dry '72	1.2	67	22	3.0
irrigated, wet '73	1.3	57	30	1.9
rainfed, wet '73	1.0	43	34	1.3
rainfed, wet '73	1.3	89	10	8.9
Av.	1.1	60	23	3.3
Minimum added cost				
irrigated, wet '72	0.7	64	7	9.0
rainfed, wet '72	0.6	20	15	1.3
irrigated, dry '72	0.5	46	7	6.5
irrigated, wet '73	0.7	51	3	18.0
rainfed, wet '73	0.2	7	9	0.8
rainfed, wet '73	1.3	89	10	8.9
Av.	0.7	46	9	7.4
Maximum return per dollar invested				
irrigated, wet '72	0.7	64	7	9.0
rainfed, wet '72	0.6	20	15	1.3
irrigated, dry '72	0.5	46	7	6.5
irrigated, wet '72	0.7	51	3	18.0
rainfed, wet '73	1.0	43	34	1.3
rainfed, wet '73	1.3	86	10	8.9
Av.	0.8	52	13	7.5

available to identify how much of the 2.4 t/ha should be attributed to each input. Neither is there a complete explanation of why farmers do not use the maximum yield level of inputs, but economic considerations provide a partial explanation.

Economic behavior *(Multiple Cropping, Agricultural Economics).* Costs and returns in multifactor experiments carried out by the Agricultural Economics Department and by the Office of Rice Production Training and Research were analyzed. IR20 was grown in all but one of the trials. Each experiment was carried out at three or more farm locations in Central Luzon. Except where included as a treatment, cultural practices, insect and disease protection, water control, and other factors were at the farmer's level.

Table 14 shows that the maximum yield treatment in the six experiments produced an average of 1.3 t/ha more than did the control treatment (zero or the farmers' level of inputs), gave US$59/ha more than the control, cost $37/ha more than the control, and returned almost $2 for every $1 invested. Since farmers must bear the cost of the inputs used, it is unreasonable to expect them to produce maximum yields. Net return, cost, and return per unit of cash cost – three other criteria farmers may use to make decisions on the level and combination of practices to use – are also shown in Table 14.

The treatments that gave maximum net returns differed from the maximum yield treatments in two of the six experiments. On the average, net returns were $1.43/ha greater for the maximum net returns treatments, and yields were 0.2 t/ha lower, than the maximum yield plots. Costs were 40 percent lower and return on money invested was 75 percent greater for the maximum net return treatments than for the maximum yield treatments.

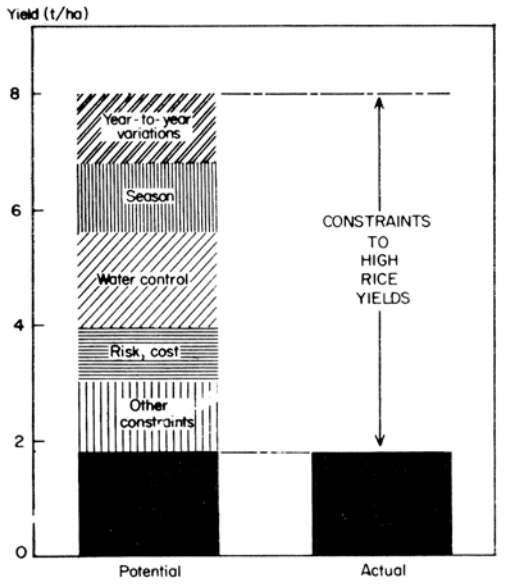
The treatments with the lowest added cost over the control involved an expenditure a fourth as great as that used on the maximum yield plots and gave about 75 percent as large a net return. The yield increase was only half the yield increase obtained on the maximum yield plots. The treatments giving maximum return on investment were almost always the same as the minimum-cost treatments.

While it is impossible to say which of the four criteria farmers use, it is highly unlikely that they try to maximize yield; it would seem that either low cash cost or high rate of return would be chosen at a small sacrifice in net return. If so, yield increases from input use would be only half the amount that could be experimentally demonstrated.

Given this general pattern, one might guess that economic factors reduce farmers' yields by 25 percent below the previously defined maximum potential of 4.2 t/ha. If this assumption is accepted, the economically attainable average yield using modern varieties, given existing water control, seasonal distribution of production, and normal weather variation, is about 3.1 t/ha, leaving an unexplained gap of 1.3 t/ha between actual and attainable yields.

This difference between the economically attainable and reported actual yield in the Philippines can be attributed to response biases, poorer soils than represented in the experiments, non-availability of inputs, economically irrational unwillingness to use available inputs, and the planting of the remaining rice area (about 40 percent) to traditional varieties.

The major factors that seem to be keeping Philippine national rice yields more than 6 t/ha below the demonstrated levels are summarized in fig. 5. Lack of water control, the single biggest



5. A preliminary identification of factors constraining rice yields in the Philippines.

yield constraint, is responsible for about 25 percent of the difference between maximum possible and actual yields. Available solar radiation and other factors associated with season account for another 20 percent of the difference. A lack of irrigation is also indirectly responsible for part of this effect because with greater irrigation capacity, more of the crop would be grown in the dry season. Economic factors, including risk, account for about 15 percent of the difference. Other constraints are combinations of factors, including year-to-year weather variability and pest damage (20 percent) and the non-availability of inputs and non-adoption of new technology (15 percent).

QUANTIFYING EFFECTS OF BIOLOGICAL INPUTS

Agricultural Economics, Agronomy, and Statistics Departments

We have tested an experimental approach to the identification and quantification of yield constraints in farmers' fields in actual experiments on sample rice farms in Laguna province since the 1972 dry season (1973 Annual Report). Although the data show that important yield constraints can be identified and quantified by the procedure used, the methodology must be simplified before the approach can be recommended for wide adaptation.

The size of the experiment should be kept small to facilitate actual tests in farmers' fields. But the number of factors and the levels of each factor that must be tested can result in a large number of treatments. To balance these opposite considerations, it might be necessary to undertake the study in two stages.

The first-stage experiment should: 1) identify the important yield constraints in the study area, and 2) indicate the relative importance of these constraints based on the yield increase possible with existing production technology. Factorial experiments involving several cultural practices, each at the farmer's level and the improved level, are adequate to achieve these objectives.

In the second stage, those factors identified as important yield constraints in the first stage should be more thoroughly analyzed. Several levels of each factor should be evaluated to pinpoint the optimum levels of the various constraints. Two different approaches could be used for the second-stage experiment: 1) testing several predetermined management packages involving the factors of interest, and 2) testing several levels of each of the factors through incomplete factorial combinations. The first alternative usually involves fewer treatments than the second, but it only tests preconceived management packages, so it cannot provide information on the effects of each separate factor. The second alternative is free of this limitation and proper management packages can be identified from the results. The relatively large number of treatments can be reduced if information is available on important interactions among factors tested in the first-stage experiment.

Regardless of the size of the experiment, field tests in farmers' fields can be costly. Hence, the number of sample farms would probably be limited. For certain management factors, small supplementary experiments should be used that involve predetermined levels of each given factor with all other factors at the farmers' level and, if desired, with all other factors at improved levels. Such a design would help expand the number of farms covered at minimum cost.

The results of three sets of experiments are presented: 1) simple 2^n factorial experiments with several variables held at the farmers level and at a high level of cultural practices, 2) methodological experiments to determine the appropriate way to simulate the farmers practices, and 3) management package experiments with cultural practices not included in the package held at the farmers' level and then at a high level.

Factorial experiments to measure yield constraints *(Statistics, Agricultural Economics).* A major part of our effort consisted of experiments to measure separately the yield effects of three or four inputs. We placed experiments on farmers' fields representing a series of water control conditions. A complete two-level factorial design was used with one level equal to the farmer's level and the second at a level believed necessary for maximum yield. All factors not being investigated were kept at the farmer's level. The farmer's level was determined by monitoring activities and inputs on a nearby paddy managed by the farmer, and was then duplicated on the experimental plots.

These same factors were included in a management package component. Several packages ranging

from low to high levels of inputs were investigated at various locations in the Philippines and compared with the farmer's level, in both yield and profitability.

Experiments were also conducted in Laguna to: 1) examine alternative techniques for reducing the complexity of certain procedures that were found difficult to carry out in the field; 2) evaluate the use of incomplete factorial experiments permitting additional levels of the factors of interest to be included; and 3) evaluate the use of supplementary mini-experiments on weed control as a constraint.

Laguna, 1974 dry season. Insecticide, weed control, and fertilizer were the variable factors used on six farms during the dry season in Laguna. On three farms, seed source was also a variable. Table 15 summarizes the high and average farmers' levels of these inputs.

When all other factors were held constant at the farmer's level, the high level of insect control gave an average yield increase of 1.7 t/ha (40 percent) and the high level of fertilizer, an average increase of 0.9 t/ha (22 percent) over the farmer's level (Table 16). Added insect control gave large in-

Table 15. High levels and farmer's levels of inputs in yield constraints experiments.[a] Laguna, Philippines, 1974.

Input level	Weed control (no.)		Insect control (no.)	Fertilizer (kg/ha)		Seed source
	Chemical	Mechanical		N	P_2O_5	
			Dry season			
Irrigated						
High	0	4	12	120	0	IRRI
Farmer's	0	2	2	54	12	1973 harvest or co-farmer
			Wet season			
Irrigated						
High	1	2	8	90	30	n.a.[b]
Farmer's	0	2	2	43	2	n.a.
Rainfed						
High	1	1	6	90	30	n.a.
Farmer's	1/2	1/2	1/2	10	0	n.a.

[a]Based on six farmers' fields for the dry season and eight irrigated and two rainfed fields in the wet season. [b]Not applicable because seed source was not a variable in this season.

Table 16. Contribution of four inputs to increased rice yields in yield constraints experiments in farmers' fields. Laguna, Philippines, 1974 dry season.

Cultivar	Yield (t/ha)		Contribution (t/ha) of other inputs							
			Farmer's level				High level			
	Farmer's inputs	High inputs	Weed control	Insect control	Fertilizer	Seed source[a]	Weed control	Insect control	Fertilizer	Seed source[a]
IR1561	2.2	7.3	0.4	5.0	0.9	1.9	1.9	2.4	0.3	0.2
IR1561	3.4	5.6	0.1	1.6	−0.1	0.1	0.3	1.1	0.3	0.1
IR1561	4.0	7.6	0.3	0.7	1.2	0.4	0.1	2.3	2.0	0.0
IR1561	5.5	7.0	0.1	0.7	1.1	n.a.	0.1	0.2	0.6	n.a.
"Atomic"	3.8	6.4	0.2	1.6	1.9	n.a.	0.3	0.2	0.9	n.a.
IR1561	6.2	7.0	0.3	0.5	0.4	n.a.	0.3	0.2	−0.2	n.a.
Av.	4.2	6.8	0.2	1.7**	0.9**	0.8[b]*	0.5	1.1**	0.7*	0.1[b]
	(3.2)[b]	(6.8)[b]								

[a]n.a. = not applicable. [b]For seed source, average of three farms.

creases on three farms and moderate increases on three. Added fertilizer slightly decreased yield on one farm and on another, only slightly increased it. The contribution of added weed control was not significant. Seed source contributed significantly, largely because of a very high contribution on one farm.

The individual contributions of insect control, fertilizer, and seed source were smaller when the other inputs were at the high levels than when other inputs were at the low levels. Weed control, although not statistically significant, had a higher measured yield contribution with other inputs at the high level, suggesting positive interaction effects. Although seed source gave a 0.8 t/ha (25 percent) average increase in yield when all other factors were held at the farmer's level, the high levels of the other inputs eliminated this advantage.

The contribution of variety was tested by including one or two plots on each farm planted to either IR26 or the experimental line IR1514A-E597, or both. With one exception, these two cultivars did not appreciably outyield the farmer's varieties. Variety apparently was not a constraint in Laguna for this particular season.

On four farms, we measured the effects of four levels of nitrogen fertilizer at the farmer's and at the maximum levels of weed and insect control. On three of these farms, the effect of phosphorus at the highest nitrogen level was tested on plots receiving maximum insect control.

The farmer's level of fertilizer increased yields by 1.0 t/ha over plots that received no fertilizer. When the farmer's fertilizer rate was increased to 90 kg N/ha, yields increased by 0.7 t/ha. When it was increased to 120 kg N/ha, yields increased by an additional 0.5 t/ha. Removing the constraints of insect damage or weeds did not substantially affect the yield increases from added fertilizer. Supplementing nitrogen with phosphorus increased yields modestly.

Laguna, 1974 wet season. Three factors were included in the wet-season experiments: insect control, weed control, and fertilizer (Table 15). Phosphorus was included in the high level of fertilizer application.

The high rate of fertilizer gave a 1.0 t/ha yield increase under both irrigated and rainfed conditions with other inputs at the farmers' levels (Table 17). Although in previous Laguna studies inadequate

Table 17. Contribution of three inputs to increased rice yields in yield constraints experiments in farmers' fields. Laguna, Philippines, 1974 wet season.

Cultivar	Yield (t/ha)		Contribution (t/ha) with other inputs					
			Farmer's level			Maximum level		
	Farmer's inputs	High inputs	Weed control	Insect control	Fertilizer	Weed control	Insect control	Fertilizer
			Irrigated sites					
IR1561-228-3-3	4.8	7.0	0.3	0.9	1.1	0.0	0.9	1.1
IR1561-228-3-3	4.1	7.1	0.6	1.1	1.5	0.4	1.3	1.9
IR1561-228-3-3	4.4	6.4	0.3	0.7	1.1	0.2	0.8	1.0
IR1561-228-3-3 & C4-137 (mixture)	1.9	3.6	0.2	0.5	0.8	0.2	0.9	1.0
IR26	5.3	8.2	0.2	0.8	1.0	0.5	1.5	2.0
IR1561-228-3-3	4.8	5.9	0.1	0.3	0.5	0.1	0.3	0.7
IR1561-228-3-3	3.5	4.7	0.2	0.8	0.6	0.2	0.3	0.5
IR1561-228-3-3	3.1	5.0	0.2	0.2	1.0	0.3	0.7	1.6
Av.	4.0	6.0	0.3	0.7**	1.0**	0.2	0.8**	1.2**
			Rainfed sites					
C4-137	4.0	6.4	0.4	0.7	1.0	0.1	1.1	1.3
C4-137	2.3	4.1	0.4	0.7	1.0	0.1	0.6	1.0
Av.	3.2	5.2	0.4	0.7*	1.0**	0.1	0.8*	1.2**

fertilizer generally was a constraint in dry seasons, it was not a constraint in earlier wet seasons (1973 Annual Report).

The yield increase in the 1974 wet season cannot be explained solely in terms of the additional phosphorus that was not included in maximum levels in previous wet seasons. Plots receiving 90 kg N/ha without P gave an average increase over the farmer's level of 0.7 t/ha (17 percent) under irrigated conditions and of 0.6 t/ha (19 percent) under rainfed conditions, with all other factors held at the farmer's level. So phosphorus contributed about 0.3 t/ha.

Experiments had been run on fields of five of the same farmers in the 1973 and 1974 wet seasons. With one exception, the farmers used less nitrogen in the 1974 wet season than in the previous year. Two of these farmers reported they used less fertilizer because fertilizer was more expensive in 1974.

Despite the general reduction in the amount of fertilizer applied, the yield at the farmer's level of inputs averaged 1.0 t/ha more in the 1974 wet season than in the 1973 wet season. Furthermore, yields increased by 0.8 t/ha when fertilizer level changed from zero to farmer's level.

Insects were less of a constraint in the 1974 wet season than in previous seasons (1973 Annual Report), possibly because brown planthoppers were less of a problem. To what extent this reflects the widespread adoption of varieties resistant to brown planthoppers is not known, but IR26 and the experimental line IR1561-228-3-3 both resistant cultivars, were grown in all but the two rainfed farms in the 1974 wet season. In the 1974 dry season, however, insect control was still the major constraint on more than half of the farms where IR1561-228-3-3 was planted.

Even though insects were not as important as in previous seasons, it was still a major constraint. At the farmer's level of all other inputs, the increase in average yield realized by going from the farmer's level to complete insect control averaged 0.7 t/ha (Table 17).

A level of insect control somewhat lower than the maximum was investigated at both the farmer's and the high levels of all other inputs. The average increase in yield attributable to this level was half the increase obtained from maximum control. The plots receiving this level of insect control, however, are on farmers' fields that receive farmers' levels of insecticide; consequently, the insect infestation is likely to be higher than if the whole farm were to receive the experimental level. Under these conditions, the farmer's level cannot realistically be compared with levels other than complete (maximum) control.

Under irrigated conditions, the farmer's level of weed control was not substantially different from the maximum level. The average yield increase attributable to weed control was 0.3 t/ha (8 percent) when all other factors were held at the farmer's level of inputs. Under rainfed conditions, the increase attributable to weeding was 0.4 t/ha (12 percent), but the increase was negligible if all other factors were held at the high levels of inputs.

These results do not imply that weeds cannot constrain rice yields, but rather that the level of weed control used by these farmers was adequate for high yields. This was demonstrated by studying the impact of zero weed control. In this experiment, the average yield increase realized by going from no weeding to the farmer's level was 1.5 t/ha (60 percent) under irrigated conditions and 1.1 t/ha (52 percent) under rainfed conditions, with all other factors held at the farmer's level.

Nueva Ecija, 1974 wet season. Ten farmers' fields were selected for factorial experiments in Nueva Ecija province, Philippines. We tried to include a range of water control conditions, including pump-irrigated farms (fully irrigated), canal-irrigated farms (poorly irrigated), and rainfed farms. All soils were clay loam with pH varying between 5.8 and 6.2. Soil fertility was lower on the rainfed sites than on the irrigated sites.

We studied four factors: land preparation, weed control, insect control, and fertilizer.

The 10 farmers selected applied little fertilizer; few controlled weeds by any method (Table 18). Those farmers who used weed control measures used them at inappropriate times. Little insecticide was used on the farms.

At the farmers' levels of all other inputs, the high level of insect control increased grain yields by 0.8 t/ha on fully irrigated farms and by 0.7 t/ha on rainfed farms (Table 19). This is because the most prevalent variety, IR20, was susceptible to certain insects such as brown planthoppers, leaffolders, and caseworms.

On the rainfed farms, high levels of weed control

Table 18. Average and high levels of inputs in farmers' fields in the yield constraints experiment. Nueva Ecija, Philippines. 1974 wet season.

Input level	Water control	Sites (no.)	Fertilizer (kg/ha)			Weed control[a] (no.)		Insect control[b] (no.)				Harrowings (no.)	Seedling age (days)
			N	P_2O_5	K_2O	M	C	Seedbed		Field			
								F	G	F	G		
High	All	10	120	60	60	1	1	4	1	5	3	12	40
Farmers'	Fully irrigated	4	43	20	0	1(4)	1(4)	2(4)	0	7(4)	0	7.5	35
Farmers'	Poorly irrigated	3	46	32	0	1(3)	1(3)	0	0	1	0	2.7	40
Farmers'	Rainfed	3	19	12	0	1(3)	1(3)	0	0	4(3)	0	5.3	45

[a]M = mechanical treatment; C = chemical treatment; figures in parentheses indicate the total number of farmers.
[b]F = foliar treatment; G = granular treatment; figures in parentheses indicate the total number of farmers.

increased grain yields by 0.4 t/ha over the farmers' levels of weed control (all other inputs at farmers' levels). Farmers generally waited until after panicle initiation – too late to minimize losses from weeds – before weeding. Land preparation only slightly affected yields.

Ironically, high levels of fertilizer application gave lower yields than did farmers' levels because of three factors. 1) Two typhoons hit during the vegetative stage (July and August), and five during the reproductive and ripening stages (October and November), causing severe lodging. Farmers could have avoided some of this typhoon damage by planting earlier. 2) Farmers transplanted seedlings that were far too old: from 31 to 51 days. Fertilizer response was poor because most were past the active tillering stage. 3) Seeds were often badly mixed.

Methodological studies in Laguna *(Statistics, Agronomy, Agricultural Economics).* Experiments

Table 19. Contribution of four inputs toward improving rice yields in constraints experiments in farmers' fields. Nueva Ecija province, Philippines, 1974 wet season.

Yield[a] (t/ha)		Contribution (t/ha) with other inputs							
		Farmers' levels				High level			
Farmers' inputs	High inputs	Fertilizer	Weed control	Insect control	Land preparation	Fertilizer	Weed control	Insect control	Land preparation
				Fully irrigated sites					
2.1	2.8	0.2	0.3	0.6	0.8	0.3	0.6	−0.2	0.0
1.1	2.4	−0.1	0.4	1.3	−0.7	−0.8	0.3	2.1	0.0
2.4[b]	2.3	−0.2	0.5	1.0	0.1	−1.1	−0.9	−1.6	−0.4
1.2	1.8	0.7	0.2	0.1	0.0	0.1	−0.3	0.4	0.2
				Poorly irrigated sites					
2.3[c]	1.4	−0.4	0.1	−0.1	0.3	−0.1	−0.9	−1.1	−0.4
2.3	2.2	−0.2	0.2	0.3	0.2	−0.4	−0.4	0.6	−0.1
1.5	2.0	0.5	0.4	0.7	0.6	−0.2	0.2	−0.1	0.0
				Rainfed sites					
2.4	4.0	−0.6	0.8	1.2	−0.4	−0.1	−0.3	1.5	0.0
1.8	2.0	0.0	0.2	0.7	0.3	−0.2	−0.6	0.4	0.5
1.1	2.1	0.3	0.3	0.3	0.0	0.2	0.2	−0.3	−0.2
				Av. of all sites					
1.8	2.3	0.0	0.3	0.6	0.1	−0.3	−0.2	0.2	0.0

[a]Using IR20 except where otherwise indicated. [b]IR1561. [c]C4-137.

in which we attempt to monitor and then duplicate the farmer's level of practices involve some conceptual and technical difficulties. How should farmers be chosen? Are we comparing farmers or farmer's fields? How can we effectively determine what the farmer is doing? How can we simulate the farmer's practices? To obtain the answers, we studied several modifications of our standard methodology in Laguna.

Simulating farmer's insect and weed control practices. We earlier reported difficulties encountered in simulating farmer's insecticide practices (1973 Annual Report). In 1974 dry-season trials, we evaluated two administrators of the farmer's insect control practices: the research worker and the farmer. The yields of plots that received common treatments but differed in the persons administering the insect control practices were not significantly different. We also observed that if all plots receiving the farmer's insect control practices were in a portion of the field maintained by the farmers, the farmers have no problem in treating these plots for insect control in the same manner as the rest of the field. A procedure that seems desirable is that which allows the farmer to administer his own insect control practices by separating plots receiving his insect control level from those receiving the high level. This would not only facilitate the practical operation of the experiment but also eliminate bias that could result when the two sets of plots, one with farmer's insect control level and the other with high level, are placed side by side.

Weed control study. In the 1974 dry season, an alternative methodology was investigated for evaluating the effects of weed control. Randomly selected areas from paddies in farmers' fields were roped off and divided into two portions: unweeded and weed free. Farmers were requested to treat the roped-off area like the rest of the paddy except that they were not to practice any weed control. At harvest, areas of 6 sq m were sampled from each portion. A crop cut was taken from the farmer's paddy at 1 to 2 m from the experimental area for yield comparisons.

A similar approach was used in the 1974 wet season except that the two treatments used were no weeding and two weedings, at about 20 days after transplanting (DT) and at about 40 DT. On about half of the farms, a weed-free plot was also included.

Table 20. Yields obtained from farmers' fields in weed control study. Laguna, Philippines, 1974.

Weeding level	Yield (t/ha)	
	Dry season[a]	Wet season[bc]
No weeding	2.7 a	2.8 (3.4) a
Farmer maintenance	3.1 b	3.7 (4.1) b
Two weedings	n.a.	4.2 (4.5) c
Weed-free	3.6 c	(4.8) c

[a]Based on 19 farms. [b]Based on 15 farms, values given in parentheses are for those 7 farms that included the weed-free treatment. [c]Means followed by a common letter are not significantly different at the 5% level.

In the dry season, the yield increase attributable to the farmer's weed control compared with no weed control was about 0.4 t/ha (14 percent) (Table 20). In the wet season, the increase was 0.9 t/ha (32 percent). These increases were substantially less than the 1.5 t/ha estimated from the yield constraints experiment (60 percent for the irrigated farms in the wet season).

The yield increase obtained by going from the farmer's level to weed-free conditions was 0.5 t/ha (13 percent) in the dry season and 0.7 t/ha (17 percent) in the wet season, considerably more than that measured in the yield constraints study.

In the wet season, yields in plots receiving two weedings were significantly higher than those in the farmer's field. Available information indicates that the average farmer in Laguna weeds his crop twice each season, so we would not expect this significant difference.

Based on this study, the weed control levels of Laguna farmers are not high enough to entirely remove weeds as a yield constraint. The question that arises is whether the yield constraints experiment or the weed control study best characterizes weed constraints. Both have limitations.

In the yield constraints experiment, the farmer is aware that the comparable paddy is under observation; therefore, he may use higher levels of inputs than he would otherwise. Alternatively, we may not be duplicating the farmer's inputs.

A second problem is that the plots in the yield constraints experiment may not be representative of the farmer's paddy. Levees are built to maintain different fertilizer levels in the small experimental plots. Consequently, it is not possible to exactly duplicate the farmer's level of land preparation, water control, and other cultural practices.

Table 21. Farmers' levels of inputs in management package experiments on farmers' fields. Philippines, 1974 dry season.

Location	Fertilizer (kg/ha)			Weed control[a]	Insect control[b]		Harrowings (no.)
	N	P_2O_5	K_2O		Seedbed	Field	
Nueva Ecija							
Muñoz	154	42	42	HW, C	0	F, G	3
San Jose	73	28	28	HW, C	0	0	3
Cuyapo	87	0	0	HW	0	F	3
Camarines Sur							
Pili	60	0	0	RW	0	F, G	3

[a]HW = hand weeding; C = chemical control; RW = rotary weeding. [b]0 = no weed control, F = foliar spray; G = granular application.

The weed control study could also be subject to bias. The farmer manages the roped-off area for all factors except weed control. The farmer may possibly treat the roped-off area differently from his own field.

Four farmers in the dry season and two in the wet season were cooperators for both the weed control and the yield constraints experiments. In the yield constraints experiment yields from plots with all factors set at the farmer's level were consistently higher than the yields from crop cuts in the weed control study. Similarly, those plots in the yield constraints experiment that had the maximum level of weed control and all other factors fixed at the farmer's level yielded higher than the most comparable plots in the weed control experiment. This suggests that the yield constraints experiment may overestimate farmers' yields. More attention must be given to identifying an appropriate methodology for quantifying the constraints of weeding.

Management package experiments on farmers' fields *(Agricultural Economics, Statistics, Agronomy).* Management package experiments were conducted in farmers' fields in three locations – Nueva Ecija, Camarines Sur, and Iloilo – in the dry and wet seasons of 1974.

Four combinations of inputs, each consecutively higher than that of the farmers (M_1) were investigated: M_2, M_3, M_4, and M_5. The farmer's level of all input factors was included as M_1; the input level in M_5 was the same as the maximum level in the factorial experiments. The farmer's level, M_1, was usually, but not always, lower then M_2.

In one series of experiments, all factors tested were held at the level required for maximum yield. In other experiments, these factors were held constant at the farmers' level. For convenience, the two series are distinguished as having "high cultural practices" and "farmers' cultural practices."

High cultural practices. The four factors included in the packages were the same as those used in the Nueva Ecija factorial experiments (Table 19). In addition, two varieties were used: the farmers' and IR26. Other inputs and management practices (seeds, seedlings, and plant spacings) were at optimum level.

Dry-season experiments were carried out at three locations in Nueva Ecija, and at one in Camarines Sur, Philippines. Farmers' practices are shown in Table 21. Soil texture varied from clay and clay loam to sandy clay loam; pH varied from 5.2 in Camarines Sur to 7.0 at San Antonio, Nueva Ecija.

Throughout the dry season, all the pump-irrigated (fully irrigated) areas suffered from inadequate water because of a shortage of diesel oil. The crop at several sites suffered from severe moisture stress which reduced grain yields. Such alternate dry and wet conditions usually caused nitrogen losses, further reducing yields. Granular herbicides controlled most annual weeds, but *Cyperus difformis* (sedge) became serious when the fields were dry, causing low increases in yields.

At Muñoz, where the farmer was using 154 kg/ha of N, 42 kg/ha of P_2O_5, and 42 kg/ha of K_2O, yields did not increase from M_2 through M_5 with either IR20 or IR26 (Table 22).

At San Jose and Cuyapo, Nueva Ecija, yields were generally low because of moisture stress. The M_4 treatment, however, yielded from 1 to 2 t/ha more than did the M_1 treatment.

Because of good irrigation, the yields were generally high at the Camarines Sur site. The two high packages (M_3 and M_4) gave higher yields than did M_1.

In the wet season, more experiments and a fifth-input level were added. Most farmers planted IR20, and all farmers applied fertilizer. Weed and insect control was better at the Camarines Sur and Iloilo sites than at Nueva Ecija (Table 23). Most seedlings were transplanted from 21 to 33 days after seeding. Soil texture at the experimental sites varied from clay to clay loam; pH values varied from 5.3 to 5.7; and CEC varied from 15 to 31 meq/100 g.

At all locations, IR26, because of its resistance to brownhoppers, yielded higher than did IR20 (Table 24). Brownhopper infestation was serious in Camarines Sur and Iloilo. *Cercospora* leaf spot was more serious on IR20 than on IR26 in Nueva Ecija.

In the fully irrigated (pump) area of Nueva Ecija, management packages M_2 through M_5 gave significantly higher yields than did M_1. In the poorly irrigated (canal) area of Nueva Ecija, leaf-folder infestation was heavy, particularly in M_1 plots. Weed control was generally poor because heavy rains washed away the herbicides.

Table 22. Yields of IR26 and farmers' varieties with four input management packages and optimum levels of cultural practices on farmers' fields, Philippines, dry season, 1974.

Input management package	Yield[a] (t/ha)							
	Nueva Ecija						Camarines Sur	
	Muñoz		San Jose		Cuyapo[b]			
	IR20[c]	IR26	IR20[c]	IR26	IR20[c]	IR26	IR579-48-3[c]	IR26
M_1	5.2 a	4.5 ab	0.9 cd	1.6 bcd	–	4.2 ab	5.0 d	5.0 d
M_2	2.8 c	2.7 c	0.7 d	0.7 d	–	3.5 b	3.6 e	4.8 d
M_3	4.4 b	3.1 c	0.9 cd	1.8 bc	–	4.7 ab	5.5 cd	6.0 bc
M_4	5.2 a	4.0 b	2.2 b	3.6 a	–	5.3 a	6.4 b	7.9 a
Av.	4.4	3.6	1.2	1.9		4.4	5.1	5.9

[a]For each location, means followed by a common letter are not significantly different at the 5% level. [b]IR20 plots damaged by rats at heading stage. [c]Farmers' variety.

Table 23. Farmers' levels of inputs in management package experiments on farmers' fields with optimal levels of cultural practices. Philippines, 1974 wet season.

Water control	Fertilizer (kg/ha)			Weed control[a] (no.)			Insect control[b] (no.)				Harrowings (no.)
							Seedbed		Field		
	N	P_2O_5	K_2O	HW	RW	C	F	G	F	G	
					Nueva Ecija						
Fully irrigated	50	30	0	0	0	0	0	0	2	1	12
Poorly irrigated	54	40	0	0	0	1	0	0	1	1	4
Rainfed	57	35	0	0	1	0	0	0	3	0	6
					Camarines Sur						
Fully irrigated	86	20	20	0	0	1	3	0	3	1	3
Rainfed	30	0	0	1	0	0	0	0	1	0	3
					Iloilo						
Fully irrigated	86	21	21	1	0	1	2	0	7	1	3
Rainfed	39	12	12	1	0	1	2	0	4	0	3

[a]HW = hand weeding; RW = rotary weeding; C = chemical control. [b]F = foliar spray; G = granular application.

Table 24. Yields of IR26 and of farmers' varieties with five input management packages and three water control levels with optimal cultural practices on seven farmers' fields. Philippines, 1974 wet season.

Input management package	Yield (t/ha)					
	Fully irrigated		Poorly irrigated		Rainfed	
	Nueva Ecija					
	IR20[a]	*IR26*	*IR20*[a]	*IR26*	*IR20*[a]	*IR26*
M_1	1.9 b	4.0 a	2.7 ab	2.6 c	2.6 c	3.3 c
M_2	2.7 a	3.5 a	2.6 b	2.7 c	2.2 c	2.6 d
M_3	2.8 a	3.8 a	3.0 a	3.8 a	3.5 b	4.1 b
M_4	3.1 a	4.0 a	2.7 ab	3.8 a	4.4 a	5.5 a
M_5	3.1 a	3.9 a	2.9 ab	3.6 ab	4.6 a	5.4 a
Av.	2.7	3.8	2.8	3.2	3.4	4.2
	Camarines Sur					
	IR579-48-3[a]	*IR26*			*C4-63*[a]	*IR26*
M_1	3.8 b	3.3 ab			3.0 c	2.6 d
M_2	2.5 c	2.8 b			3.4 bc	3.8 c
M_3	3.8 b	3.5 ab			4.4 ab	4.1 bc
M_4	4.2 ab	3.5 ab			5.4 a	4.9 ab
M_5	4.8 a	3.8 a			4.6 a	5.3 a
Av.	3.8	3.4			4.1	4.1
	Iloilo					
	IR20[a]	*IR26*			*IR20*[a]	*IR26*
M_1	2.3 a	2.6 b			3.7 b	4.4 bc
M_2	2.0 a	3.4 ab			3.4 b	4.0 c
M_3	2.3 a	3.4 ab			3.5 b	4.9 b
M_4	2.8 a	4.1 a			4.4 a	5.8 a
M_5	2.2 a	2.9 b			4.8 a	6.3 a
Av.	2.2	3.3			4.0	5.1

[a]Farmers' variety.

There was no moisture stress on the rainfed farm in Nueva Ecija. Yields were generally higher on rainfed sites than on other sites because the crops were harvested earlier and escaped severe typhoons in November. Furthermore, seedlings were 33 days old when transplanted on the rainfed farm, and 38 days when transplanted on the canal-irrigated farm.

In the irrigated farm in Camarines Sur, the early maturing line grown by the farmer, IR579-48-3, was harvested earlier than IR26, escaping the typhoons. A late infestation of rice bugs damaged IR26 but not IR579-48-3. At the rainfed farm, yields of the farmer's variety, C4-63, and IR26 were comparable.

On the irrigated farm in Iloilo, brown planthopper infestation was heavy, infecting IR20 with grassy stunt virus disease early in the season. Bacterial blight disease at heading also contributed to the uniformly low yields at all management levels.

The yields of IR26 were significantly higher than those of the farmers' varieties in management packages M_2 through M_4. Lodging due to typhoons reduced the yield of IR26 in the M_5 treatment.

On the rainfed site in Iloilo, the M_4 and M_5 management packages significantly increased the yields of IR20 and IR26 over those in M_2. Primarily because IR26 has higher resistance to bacterial blight, its yields were higher than those of IR20 at all management levels.

Irrespective of variety and management level, the yields of rainfed rice were higher than those of irrigated rice because rainfed rice was harvested

Table 25. Inputs in management package experiments on farmers' fields. Philippines, 1974 wet season.

Input package level	Fertilizer[a] (kg/ha)			Weed control[b] (no.)		Insect control[c] (no.)				Cost[d] (US$/ha)		
						Seedbed		Field				
	N	P_2O_5	K_2O	HW	C	F	G	F	G	Fertilizer	Weed control	Insect control
M_2	30	0	0	1	0	0	0	2	0	14	18	21
M_3	60	30	0	0	1	1	0	2	1	43	10	57
M_4	90	45	45	0	1	3	0	3	2	76	24	83
M_5	120	60	60	1	1	4	1	5	3	103	42	130

[a]In the Laguna trials, fertilizer rates were 20-0-0, 40-0-0, 60-30-0, and 80-30-0 kg/ha of N-P-K for M_2 through M_5. [b]HW = hand weeding, C = chemical control. [c]F = foliar spray, G = granular application. Fertilizer costs for the Laguna packages were $10, $19, $43, and $53/ha for M_2 through M_4.

earlier and escaped typhoons.

Farmers' cultural practices vs. high management. In the 1974 wet season, we initiated a second series of experiments on 10 farmers' fields in Laguna and 10 in Nueva Ecija provinces to evaluate the input management packages under farmers' levels of cultural practices. The five input combinations tested were similar to those tested in the dry season (Table 25).

In Nueva Ecija, the high-input packages increased yields by an average of 0.7 t/ha on the four fully irrigated farms (Table 26). On the three poorly irrigated farms, the M_4 package increased average yields by 0.6 t/ha over the farmers' package. Under rainfed conditions, the M_5 package averaged 1.1 t/ha increase in yields over farmers' practices on three farms.

In Laguna, the eight experiments on irrigated farms, the M_5 package increased yields by 1.3 t/ha over M_1, and by 1.6 t/ha on the two rainfed farms.

High management almost doubled the yields in Laguna over yields in Nueva Ecija, where the low yields may have been partly caused by typhoon damage and partly by poor cultural practices.

Table 26. Contribution of four inputs toward improving rice yields, in constraints experiments in farmers' fields. Nueva Ecija province, Philippines, 1974 wet season.

Yield[a] (t/ha)		Contribution (t/ha) with other inputs							
		Farmers' levels				High level			
Farmers' inputs	High inputs	Fertilizer	Weed control	Insect control	Land preparation	Fertilizer	Weed control	Insect control	Land preparation
					Fully irrigated sites				
2.1	2.8	0.2	0.3	0.6	0.8	0.3	0.6	−0.2	0.0
1.1	2.4	−0.1	0.4	1.3	−0.7	−0.8	0.3	2.1	0.0
2.4[b]	2.3	−0.2	0.5	1.0	0.1	−1.1	−0.9	−1.6	−0.4
1.2	1.8	0.7	0.2	0.1	0.0	0.1	−0.3	0.4	0.2
					Poorly irrigated sites				
2.3[c]	1.4	−0.4	0.1	−0.1	0.3	−0.1	−0.9	−1.1	−0.4
2.3	2.2	−0.2	0.2	0.3	0.2	−0.4	−0.4	0.6	−0.1
1.5	2.0	0.5	0.4	0.7	0.6	−0.2	0.2	−0.1	0.0
					Rainfed sites				
2.4	4.0	−0.6	0.8	1.2	−0.4	−0.1	−0.3	1.5	0.0
1.8	2.0	0.0	0.2	0.7	0.3	−0.2	−0.6	0.4	0.5
1.1	2.1	0.3	0.3	0.3	0.0	0.2	0.2	−0.3	−0.2
					Average of all sites				
1.8	2.3	0.0	0.3	0.6	0.1	−0.3	−0.2	0.2	0.0

[a]Using IR20 except where otherwise indicated. [b]IR1561. [c]C4-137.

Table 27. Yields (t/ha) with five input management packages and two levels of cultural practices on three farmers' fields. Nueva Ecija, Philippines, 1974 wet season.

Input management package	Yield (t/ha)			
	Fully irrigated	Poorly irrigated	Rainfed	Av.
	Farmers' cultural practices			
M_1	1.9 b	1.8 b	1.3 c	1.7
M_2	2.1 ab	1.7 b	2.0 b	1.9
M_3	2.3 ab	1.9 b	2.2 ab	2.1
M_4	2.6 a	2.4 a	2.1 ab	2.4
M_5	2.5 a	1.8 b	2.4 a	2.2
	High cultural practices			
M_1	1.9 b	2.7 ab	2.6 c	2.4
M_2	2.7 a	2.6 b	2.2 c	2.5
M_3	2.8 a	3.0 a	3.5 b	3.1
M_4	3.1 a	2.7 ab	4.4 a	3.4
M_5	3.1 a	2.9 ab	4.6 a	3.5

Table 28. Farmers' levels of inputs in the management package experiments at the IRRI farm. 1974.[a]

	Fertilizer (kg/ha)			Weed control[b]	Insect control[c]		Harrowings (no.)
	N	P_2O_5	K_2O		Seedbed	Field	
Dry (irrigated)	13	0	0	HW	0	0	2
Wet (irrigated) and rainfed	60	15	15	C	F	F, G	3

[a]Based on interviews of five farmers in the dry and seven in the wet seasons in Laguna province. [b]HW = hand weeding, C = chemical control. [c]F = foliar spray, G = granular application.

Experiments on three Nueva Ecija farms with both the farmers' and the high levels of cultural practices support this idea (Table 27). The average yield increase from M_1 to M_5 was 0.6 t/ha with farmers' cultural practices and 1.1 t/ha with the high cultural practices. In addition, the yields at all input levels were substantially higher with the high cultural practices, indicating that yield benefits cannot be fully exploited simply through a package of inputs without other management practices.

Management package experiments at IRRI *(Statistics).* We experimented with similar management packages on the IRRI farm using as the "farmers' level" the rates of inputs used by some Laguna farmers that season (Table 28). Because the price of agricultural chemicals suddenly increased, farmers in the Laguna area used low fertilizer rates and no insecticides in the 1974 dry season. Farmers' practices were adequate, however, in the 1974 wet season. In the 1974 dry season, the most widely grown variety in Laguna was IR20, which was severely damaged by brown planthoppers and grassy stunt virus disease. As in many farmers' fields in Laguna, the IR20 yields at the IRRI farm were zero at all management levels. With IR26, however, we obtained 5.3 t/ha with farmers' practices (Table 29). With two high levels of management (M_3 and M_4), the grain yields increased significantly over the treatment using farmer's practices.

In the 1974 wet season, all the farmers interviewed had switched to a line resistant to brown planthoppers, IR1561-228-3-3. This shift made possible yields of 3.7 t/ha with farmers' practices under irrigated conditions and 2.2 t/ha under rain-

Table 29. Yields of IR26 and farmers' varieties with five input management packages at the IRRI farm, 1974.

Input management package	Yield (t/ha)					
	Dry season		Wet season			
	Irrigated[a]		Irrigated		Rainfed	
	IR20[b]	IR26	IR1561-228-3-3[b]	IR26	IR1561-228-3-3[b]	IR26
M_1[c]	0	5.3 a	3.7 a	5.0 a	2.2 a	4.2 a
M_2	0	5.4 ab	3.5 a	4.1 b	2.7 a	4.3 a
M_3	0	6.3 bc	4.5 b	4.7 ab	4.3 b	5.3 b
M_4	0	6.4 c	4.5 b	5.1 a	4.9 b	5.7 bc
M_5	na	na	5.2 c	5.9 c	5.0 b	6.2 c
Av.		5.8	4.3	5.0	3.8	5.2

[a]IR20 plots suffered "hopper burn" damage. [b]Farmers' variety. [c]Cultural practices followed were averages of five Laguna farmers' practices in dry season and of seven in the wet season.

fed conditions (Table 29). The IR26 yields were consistently higher than IR20 yields in the irrigated and rainfed treatments. The yield response due to high management levels was significant in every case, and greater under rainfed than under irrigated conditions.

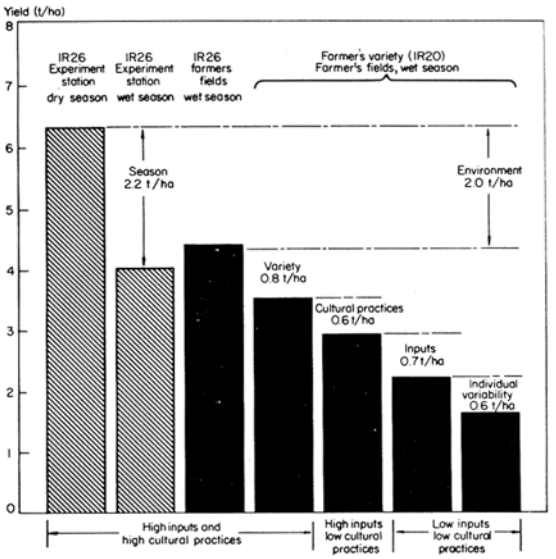
Poor insect control appeared to be the most serious constraint in the Laguna area. Once insect damage was minimized by growing varieties resistant to the locally important insects, the crop responded to high levels of management.

Yield constraints in Nueva Ecija compared with those in Laguna *(Agricultural Economics, Statistics, Agronomy).* Growing conditions in Nueva Ecija were very different from those that prevailed in Laguna during 1974 (fig. 6, 7). Although the maximum dry-season yields in management package experiments on experiment stations in the two areas were nearly the same, the average yields on farmers' fields using the farmers' inputs were 1.6 t/ha in Nueva Ecija and 3.8 t/ha in Laguna.

This difference appears largely traceable to environmental differences between wet and dry season conditions in the two areas. At the IRRI experiment station, the wet-season yields were 0.3 t/ha lower than the dry-season yields. In Nueva Ecija, the wet-season yields were 2.2 t/ha lower.

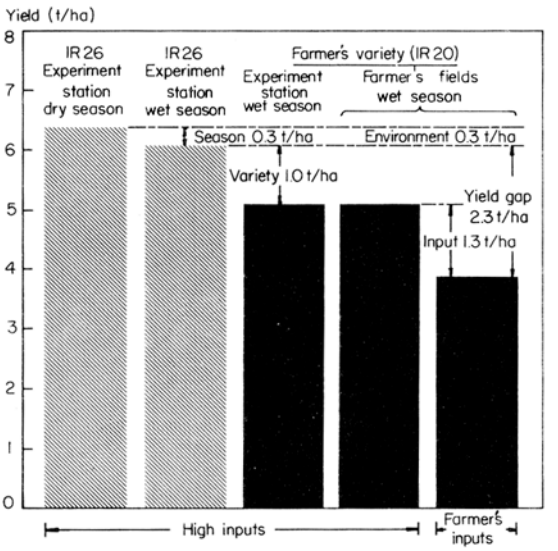
The yield gap traceable to other factors was 2.3 t/ha in Laguna and 2.7 t/ha in Nueva Ecija. Although an exact comparison of the breakdown of the yield gap is impossible, we made some interesting observations. Yields on the experiment station and on farmers' fields differed little in both areas when the same varieties, cultural practices, and inputs were used. The use of IR26 instead of the farmers' varieties contributed 1 t/ha in both areas.

The use of high levels of inputs gave a yield increase in Laguna that was almost twice that in Nueva Ecija. Yields on Laguna farms were equal to those obtained under comparable conditions on the experiment station. Inputs alone, however, did not raise the yields in Nueva Ecija to the experiment station level. There, the use of optimal cultural practices increased yields by 0.6 t/ha on three farmers' fields. Individual variability in management ability and environment seemed much greater in Nueva Ecija, where the average yields of 10 farms using farmers' practices was 1.6 t/ha, compared with the 2.2 t/ha on the three farms using the optimal cultural practices.

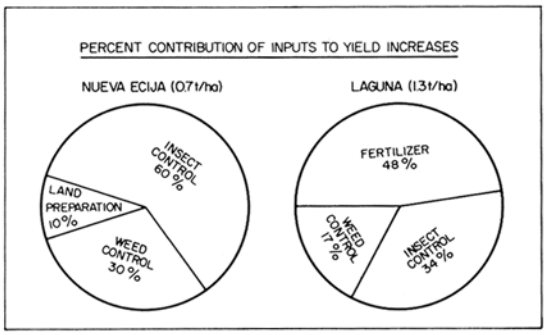


6. Using IR26 and an optimum level of chemical inputs and improved cultural practices, farmers in Nueva Ecija province, Philippines, produced yields comparable to those on experiment farms. But using IR20 (which has less pest resistance) and the same inputs and cultural practices, yields averaged 0.8 t/ha lower.

Figure 8 illustrates the percentage contribution of each input to the yield increase obtained from the high-level of inputs as compared with the farmer's level of inputs. Insect control predomi-



7. Estimated yield constraints in 1974 in Laguna.



8. Yield constraints attributed to experimentally measured input contributions.

nated in Nueva Ecija, while fertilizer contributed the most to increased yields in Laguna. This contrast may have been caused by the extensive typhoon damage in Nueva Ecija, which was accentuated by the high level of fertilization. Differences in water control were not perceptible because the rainfall was well distributed throughout the season, insuring an adequate supply of water to rainfed areas.

PROFITABILITY OF INPUT PACKAGES

Agricultural Economics Department

The economic performance of each of the input management packages was evaluated by comparing the costs and returns of each package with those of the input combinations used by farmers at 1974 prices. Application costs were excluded since it was assumed that family labor would be used to apply chemicals. Where hand or rotary weeding was part of an input package, its cost was included. The total input costs for the experimental packages ranged from \$53/ha for M_2 to \$275/ha for M_5. Input expenditures by cooperating farmers varied considerably from one area and farm to another, ranging from \$23/ha to \$174/ha (Table 30).

Net returns, or profits, were defined as the value of the output that remained after input costs had been deducted, not considering harvesting costs. An increased net return over farmers' levels indicates a higher profit for a given package. A "rule of thumb" often used to judge economic attractiveness is that the return for every \$1 invested must exceed \$2 (to break even it must equal one). The return per dollar invested was calculated on the cost and return in excess of the farmer's package.

Input package experiments in farmers' fields. In the irrigated experiments grown with farmers' cultural practices in Nueva Ecija, the low-input package, M_2, gave higher average profits than did the farmers' treatments (Table 31), while the other packages gave lower profits. With optimal cultural practices, however, both M_2 and M_3 gave higher profits than did the farmers' treatments. In Laguna, all four packages gave higher average profit than did the farmer's treatments, with M_4 giving the maximum increase of \$78/ha, nearly a 2:1 return on added investment. The contrast between Laguna and Nueva Ecija is apparently due to typhoon damage and better general growing conditions in Laguna.

Table 30. Average cost of farmers' input packages in management package experiments in farmers' fields. Philippines, 1974 wet season.[a]

Province	Sites (no.)	Water control	Cost (US$/ha)			
			Fertilizer	Weed control	Insect control	Total
Nueva Ecija	9	irrigated	34	7	15	56
	4	rainfed	15	8	16	39
Laguna	8	irrigated	21	35	22	78
	2	rainfed	5	12	6	23
Cam. Sur	1	irrigated	57	7	59	123
	1	rainfed	14	18	11	43
Iloilo	1	irrigated	57	25	92	174
	1	rainfed	28	25	45	98

[a]Levels of inputs in these sites are reported in Tables 15 and 23.

Table 31. Economic comparisons of four levels of input management packages in experiments on farmers' fields with two levels of cultural practices, irrigated, Philippines, 1974 wet season.

Input package level	Av. increase over farmer's level				Sites (no.) with net return	
	Gross[a] return (US$/ha)	Cost (US$/ha)	Net return (US$/ha)	Return[b] (US$/$ invested)	Higher than farmers'	Lower than farmers'
			Nueva Ecija, farmers' cultural practices			
M_2	10	−2	12	+	3	4
M_3	39	58	−19	0.7	3	4
M_4	95	129	−34	0.7	2	5
M_5	50	223	−173	0.2	0	7
			Nueva Ecija, optimal cultural practices			
M_2	51	−22	72	+	2	0
M_3	87	39	48	2.2	2	0
M_4	87	110	−23	0.8	1	1
M_5	101	203	−102	0.5	0	2
			Laguna, farmers' cultural practices			
M_2	−14	−26	11	+	5	3
M_3	43	18	26	2.4	7	1
M_4	159	82	78	1.9	7	1
M_5	188	160	28	1.2	5	3

[a]Price of rough rice = ₱1/kg. 1 US$ = ₱7. [b]+ indicates that the package involves a lower cost than the average farmer's package and hence gives a higher rate of return.

Table 32. Economic comparisons of four levels of input management packages in experiments on farmers' fields with farmers' level of cultural practices, rainfed. Philippines, 1974 wet season.

Input package level	Av. increase over farmers' level				Sites (no.) with net return	
	Gross (US$/ha)	Cost (US$/ha)	Net (US$/ha)	Return (US$/$ invested)	higher than M_1	lower than M_1
			Nueva Ecija			
M_2	101	16	86	6.4	3	0
M_3	130	77	54	1.7	3	0
M_4	116	147	−32	0.8	0	3
M_5	159	241	−82	0.7	1	2
			Laguna			
M_2	14	30	−15	0.5	2	0
M_3	87	74	13	1.2	2	0
M_4	203	137	66	1.5	2	0
M_5	232	216	16	1.1	2	0

In rainfed trials with the farmers' level of cultural practices (Table 32), the low-input management package (M_2) increased yields and profits substantially in Nueva Ecija, returning more than 6:1 on added input purchases. The moderate package (M_3) gave a profit that was somewhat lower than that of M_2, but still higher than that of the farmers' M_4 and M_5 gave lower profits than did the farmers' treatment. On the Laguna rainfed farms, M_2 was less profitable than the farmers' treatment while M_4 gave the highest increase in profit and rate of return.

Table 33. Economic comparisons of four levels of input management packages in experiments on farmers' fields with optimal levels of cultural practices. Philippines, 1974 wet season.

Input package level	Increase from input package over farmer's level with farmer's variety				Sites (no.) with net returns		Increase from IR26 over farmer's varieties	
	Gross return (US$/ha)	Cost (US$/ha)	Net return (US$/ha)	Return[b] (US$/$ invested)	higher than farmer's	lower than farmer's	Yield (t/ha)	Net return (US$/ha)
				Irrigated sites[a]				
M_2	−33	−58	25	+	3	1	0.7	94
M_3	43	1	42	30.0	4	0	0.5	75
M_4	76	74	2	1.0	2	2	0.7	94
M_5	83	168	−84	0.5	0	4	0.3	43
				Rainfed sites[a]				
M_2	−14	−24	10	+	1	2	0.5	67
M_3	101	37	65	2.8	2	1	0.6	81
M_4	237	107	129	2.2	3	0	0.7	96
M_5	213	201	11	1.1	1	2	1.0	145

[a]The same irrigated sites, and three of the rainfed sites in Nueva Ecija, Camarines Sur, and Iloilo reported in Table 23. [b]+ indicates that the package involves a lower cost than the average farmer's package and hence gives a higher rate of return.

In the irrigated experiments grown with optimal cultural practices in three Philippine regions, M_3 was the most profitable (Table 33). It gave higher net returns than did the farmers' treatments at all four sites. Its average cost was only $1/ha more than farmer's costs, but it returned $13/ha more profit. On the rainfed sites with optimal cultural practices, the high-input level M_4 consistently outperformed the farmers' treatments, averaging $129/ha more profit, with a return of more than 2:1 on added inputs purchased. The moderate package, M_3, gave a somewhat higher rate of return, but absolute profits were only half as high as those obtained with M_4.

Comparing IR26 with the farmers' varieties, we found that profits could be increased by about $75/ha at all input levels, simply by switching to the new variety. At the highest input level under rainfed conditions, IR26 averaged $145/ha more than did the farmers' varieties.

A PRODUCTION FUNCTION APPROACH TO INPUT EFFICIENCY

Agricultural Economics Department

We measured the interrelations of fertilizer, weed control, moisture stress, and solar radiation by experiments in farmers' fields in Bulacan and Nueva

Table 34. Non-manageable environmental factors in field experiments in the 1973 wet and 1974 dry seasons, Central Luzon, Philippines.

Factor	Solar radiation[a] (SR) (k-cal/sq cm)	Water rainfall (mm)	Early stress days (S_1)	Late stress days (S_2)	Soil characteristic			
					Clay content of the soils (% C)	Organic matter (% OM)	pH	Av. yield (t/ha)
				Wet season				
Gravity irrigated	15.6	763	1.1	0	22.1	1.13	5.6	2.38
Rainfed	15.4	715	7.2	17.2	18.8	1.25	5.0	1.53
				Dry season				
Gravity irrigated	22.4	449	0.8	1.7	26.6	1.31	6.1	2.74
Pump	21.5	261	2.3	8.1	33.0	1.49	5.2	2.28

[a]Solar radiation measured for the last 45 days before harvest.

Ecija provinces, Philippines, during the 1973 wet and 1974 dry seasons, to determine if higher levels of inputs would be profitable without modification of other practices.

All combinations of four nitrogen levels, three phosphorus treatments, and three weed treatments were tested. Six experiments with these 36 treatments, plus four selected replications, were laid

Table 35. Four alternative estimated regression equations for data from experiments in farmers' fields. Central Luzon, Philippines, 1973 wet and 1974 dry seasons.

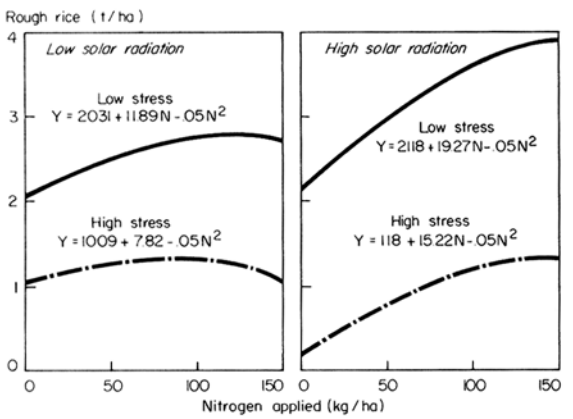
Independent variable	Equation (1)	(2)	(3)	(4)
Nitrogen	14.94 (7.24)**[a]	−2.82 (0.52)	−9.10 (1.69)	−6.24 (1.20)
(Nitrogen)^2	−0.029 (2.09)*	−0.051 (3.26)**	−0.065 (4.27)**	−0.051 (3.40)**
Early stress	30.14 (4.64)**	−2.59 (0.24)	69.52 (3.42)**	4.83 (0.217)
Late stress	−63.06 (10.99)**	−45.96 (0.698)**	−10.55 (0.578)	142.45 (4.72)**
Solar radiation	3.35 (2.69)**	−4.97 (2.60)**	−3.15 (1.68)	2.32 (1.16)
Age of seedlings	−4.14 (1.11)	8.17 (2.01)*	0.681 (0.125)	−12.04 (2.14)*
Hopperburn	−10.78 (1.81)	−12.55 (2.23)*	−23.60 (4.12)**	−29.27 (5.23)**
P_2O_5	5.02 (4.88)**	4.94 (5.12)**	4.64 (4.97)**	4.81 (5.34)**
Insect damage	4.19 (2.06)*			
% clay soil		27.50 (6.84)**	30.95 (7.80)**	19.82 (4.70)**
Weed control level 1	6.35 (7.61)**	341.97 (4.87)**	313.18 (4.61)**	339.20 (5.16)**
Weed control level 2		474.84 (7.41)**	456.47 (7.37)**	453.06 (7.58)**
Nitrogen × early stress		0.620 (3.51)**	0.884 (5.03)**	0.660 (3.81)**
Nitrogen × late stress		−0.625 (6.88)**	−0.618 (7.04)**	−0.472 (5.37)**
Nitrogen × total stress	−0.339 (5.42)**			
Nitrogen × solar radiation		0.100 (3.39)**	0.139 (4.74)**	0.112 (3.95)**
Early stress × % clay			−8.04 (5.72)**	−3.26 (2.09)*
Late stress × % clay			−1.29 (1.79)	−1.09 (1.57)
Late stress × solar radiation				−0.922 (6.24)**
Intercept	1009.69	1481.70	1455.43	1197.02
Multiple correlation coefficient	0.62	0.67	0.69	0.71

[a]Values in parentheses are "*t*" values, * indicates significance at 5%, ** at 1%.

out in the 1973 wet season; three in gravity-irrigated fields, and three in nearby rainfed fields. In the 1974 dry season, the gravity-irrigated locations were retained while two of the other three were relocated in pump systems within the rainfed area. In both seasons six additional "satellite" experiments, each with only four treatments and two replications, were located 1 km from the main experiments to test the representativeness of the main experiments.

The nitrogen levels 0, 40, 60, and 80 kg/ha during the wet season and 0, 50, 100, and 150 kg/ha during the dry season were combined with three phosphorus treatments (0, 60 kg applied basally, and 60 kg applied as a top dressing) and three weed control treatments (no treatment, 2,4-D granules, and 2,4-D granules with one hand weeding). Other cultural and managerial practices were not controlled, but were left in the hands of the farmers. If insects threatened to destroy the crop, however, emergency measures were taken to save it.

Factors thought to be most critical for yields were carefully measured or monitored through the growing season. These included number of harrowings, age of seedlings at transplanting, insect control, degree of insect damage, degree of disease damage, days of moisture stress, solar radiation, rainfall, soil texture, soil pH, and organic matter content of the soil (Table 34). Solar radiation was measured as the total radiation received for the 45 days preceding harvest. Stress days were defined as every day after the first 3 days that the field had been without standing water. Early stress days included the period from transplanting to 60 days after transplanting (DT); late stress days included the period from 60 DT to 20 days before harvest.



9. Response of IR20 to nitrogen at varying levels of solar radiation and water stress.

Table 36. Marginal product of applied nitrogen for IR20 at varying levels of solar radiation.[a]

Nitrogen (kg/ha)	Rough rice (kg/kg N)			
	Solar radiation[b] (k-cal/sq cm)			
	15.5	18.5	21.5	24.5
0	9.9	13.2	16.6	19.9
50	4.8	8.1	11.5	14.8
100	−0.3	3.0	6.4	9.7
150	−5.4	−2.1	1.3	4.6

[a]Calculated from equation (4), page 268, with all variables. [b]Solar radiation for the last 45 days before harvest.

Table 37. Marginal product of applied nitrogen for IR20 at varying levels of late water stress.[a]

Nitrogen (kg/ha)	Rough rice (kg/kg N)				
	Late water stress (days)				
	0	5	10	15	20
0	16.5	14.1	11.7	9.4	7.1
50	11.4	9.0	6.6	4.3	2.0
100	6.3	3.9	1.5	−0.8	−3.1
150	1.2	−1.2	−3.6	−5.9	−8.2

[a]Calculated from equation (4), page 268, with all variables at their average level.

Analysis of variance showed that the three controlled variable factors, N, P_2O_5, and weed control, significantly affected yields and interacted highly with location. The effects of location on yield are reflected in the environmental variables, so regression analysis was used to simultaneously measure the effects of controlled and environmental factors. Table 35 shows the results of four alternative regression models fit to data for all locations and both seasons.

The four equations are progressively more complex, with increasing numbers of interaction terms; hence, the direct effects of each variable are difficult to interpret from the equations alone. The large number of highly significant coefficients, however, is apparent. Solar radiation and moisture

Table 38. Optimal economic levels of fertilizer use in four different situations. Central Luzon, Philippines. 1973–74.[a]

Situation	At actual fertilizer price		At 2.5 times actual fertilizer price		At farmer's N level	
	Optimal N level (kg/ha)	Yield (kg/ha)	Optimal N level (kg/ha)	Yield (kg/ha)	Optimal N level (kg/ha)	Yield (kg/ha)
Wet season						
Gravity irrigated	88	2679	44	2447	68	2.0
Rainfed	46	1452	2	1220	40	1.2
Dry season						
Gravity irrigated	153	3500	109	3268	32[b]	1.7
Pump irrigated	123	2509	79	2276	36[b]	1.5

[a]Computed at US$0.20/kg of urea and US$0.14/kg rough rice. [b]Level of use was restricted by a national fertilizer rationing program.

stress are the two most important factors interacting with nitrogen.

This relationship can be more completely understood from fig. 9. The left side shows the response of yield to nitrogen as predicted by equation 4 at the level of solar radiation prevailing in the wet season for two levels of stress, with all other variables at their average level. The right side shows the same relationship for the level of solar radiation in the dry season. The moisture stress that occurred in the gravity irrigated sites (1.1 days of early stress and zero late stress) was taken as low stress. The level of stress in the rainfed areas (7.2 days of early stress and 17.2 days of late stress) was taken as high stress. Fertilizer is clearly more productive during the dry season, and at low levels of moisture stress. Tables 36 and 37 show the calculated marginal product of nitrogen (kg rough rice per kg N) at varying levels of solar radiation, late water stress, and nitrogen application.

With average observed values of the variables for four situations, the nitrogen response curves were used to calculate levels of nitrogen input at which profit is maximized, and the corresponding predicted yield (Table 38). These are also shown assuming a fertilizer price 2.5 times its 1974 wet-season level. These profit-maximizing yields are contrasted to the level of nitrogen applied by the farmers on whose fields the experiments were run.

In the wet season, optimal fertilizer use was predicted at 88 and 46 kg N/ha in gravity irrigated and rainfed situations. Farmers were using 68 and 40 kg/ha in those situations. Dry-season optima were 153 kg N/ha in gravity irrigated and 123 kg N/ha in pump-irrigated situations. Actual application levels were around 35 kg/ha, but these were restricted by a national fertilizer rationing program designed to cope with the 1974 fertilizer shortage. In similar 1973 dry-season trials, farmers with irrigation used about 100 kg N/ha (1973 Annual Report). These results indicate that the average farmers on whose fields these trials were located were using rates of fertilizer that were nearly optimal for their situations.

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SUMMARY

Agricultural Engineering Department

Past efforts to encourage the local manufacture of IRRI machines in developing countries began to yield results in 1974. Significant progress was achieved during the year in the local production of IRRI machines in developing countries. Additionally, nations in South America expressed an interest in IRRI-designed agricultural machinery.

Three IRRI machines – the 5-hp to 7-hp tiller, the axial flow thresher, and the power weeder – continue to be in widespread demand and are now being produced in large numbers, particularly in countries in South and Southeast Asia. More than 22,000 IRRI-designed machines (Table 1) have been produced commercially in Asia, with a concomitant sales volume of US$8 million. In the Philippines, 18 firms are manufacturing IRRI-designed machines.

Power tillers are now being produced by local manufacturers in the Philippines, Sri Lanka, Thailand, and Vietnam. A total of 20 companies produce the axial flow thresher in Ghana, India, Indonesia, Korea, Pakistan, Philippines, Thailand, and Vietnam. The power weeder continues to gain strength in the Japanese market. Companies are exploring its possible manufacture in India and Korea.

Two manufacturers in the Philippines expanded their operations and moved into larger premises during 1974 to meet the rapidly increasing demand for the IRRI machines they produce.

Table 1. Commercial production of IRRI-designed machines as of December 31, 1974.

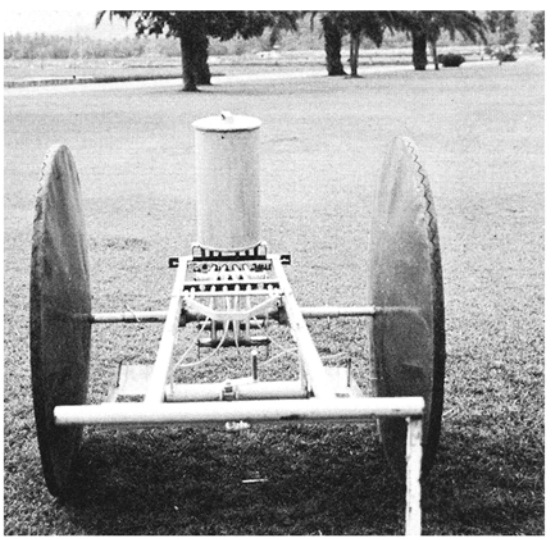
Description	Units (no.)	Sales volume (US$)
Single-hopper row seeder	388	25,220
Multihopper row seeder	378	24,570
Bellows pump	100	3,000
Grain cleaner	30	25,650
Dryer, batch type (flatbed)	295	202,075
Power tiller, 5–7 hp	6,021	5,147,955
Power weeder	14,550	2,328,000
Axial flow thresher	390	612,300
Total	22,152	8,368,770

Institute programs are giving increased attention towards providing technical assistance to cooperating manufacturers and towards extending IRRI machinery designs to other developing countries. Features of IRRI projects related to machinery design and development carried out in 1974 follow.

CONTROL AND MANAGEMENT OF PESTS

Agricultural Engineering Department

Deep-placement chemical applicators. Substantial savings in the use of herbicides and fertilizers through deeper placement in puddled soils, identified in field experiments conducted by the IRRI Entomology and Agronomy departments, prompted the initiation of a project to develop suitable deep-placement chemical applicators. A four-row liquid chemical applicator (fig. 1) with a peristaltic liquid metering pump was designed and further development work on this unit continues. A manually operated, single-row, push-type granular fertilizer applicator (fig. 2) deposits fertilizer at a 10-cm depth in puddled soils. The fertilizer drops at the bottom of a furrow which is then closed by the furrow closers. The applicator is simple in design and can be fabricated by small metalworking shops in the developing countries. The machine was released for production to two manufacturers in the Philippines.



1. Prototype four-row liquid chemical applicator with persistaltic liquid metering pump.

IRRIGATION WATER MANAGEMENT

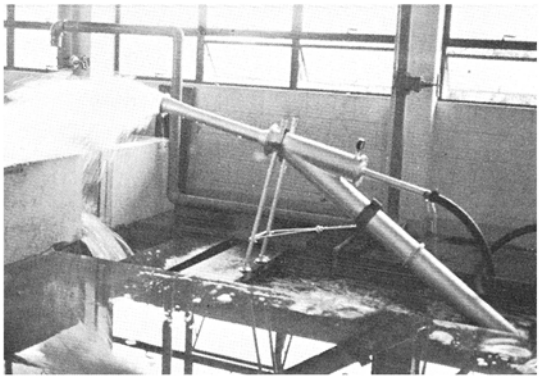
Agricultural Engineering Department

Jet pump attachment. Work was continued on the development of a jet pump attachment to use with conventional centrifugal pumps when high deliveries are needed at shallow lifts. In laboratory studies the shape of the performance curve for the jet pump was similar to that of centrifugal pumps. The maximum jet pump discharge was about fourfold greater than the flow of the primary centrifugal pump. A low-cost jet pump attachment (fig. 3) was developed with a tubular Y configuration. The output of a centrifugal pump can be connected through a flexible hose to the jet for pumping greater quantities of water through the jet pump attachment. Efforts are continuing on the development of a self-priming feature to eliminate the foot valve.

Windmill-operated tubular pump. A simple, inexpensive pump which uses the centrifugal concept to pump water at relatively shallow lifts is under development. It can be fabricated by small machine shops with a few pipes and other materials that are available in developing countries. Although this concept has been known for some time, industrialized countries have had little or no interest in its development.

The pump consists of a straight suction tube mounted vertically on two bearings. At the top end, the suction tube is connected to two slightly curved horizontal pipes which serve as the delivery tubes. The ends of the delivery tubes have a curve to help maintain the prime. A foot valve is installed at the bottom end of the suction tube. When rotated around the vertical axis, water in the two horizontal pipes is thrown outward from the axis of rotation by centrifugal action, which pumps additional water through the suction tube.

2. Prototype single-row, push-type granular fertilizer applicator.

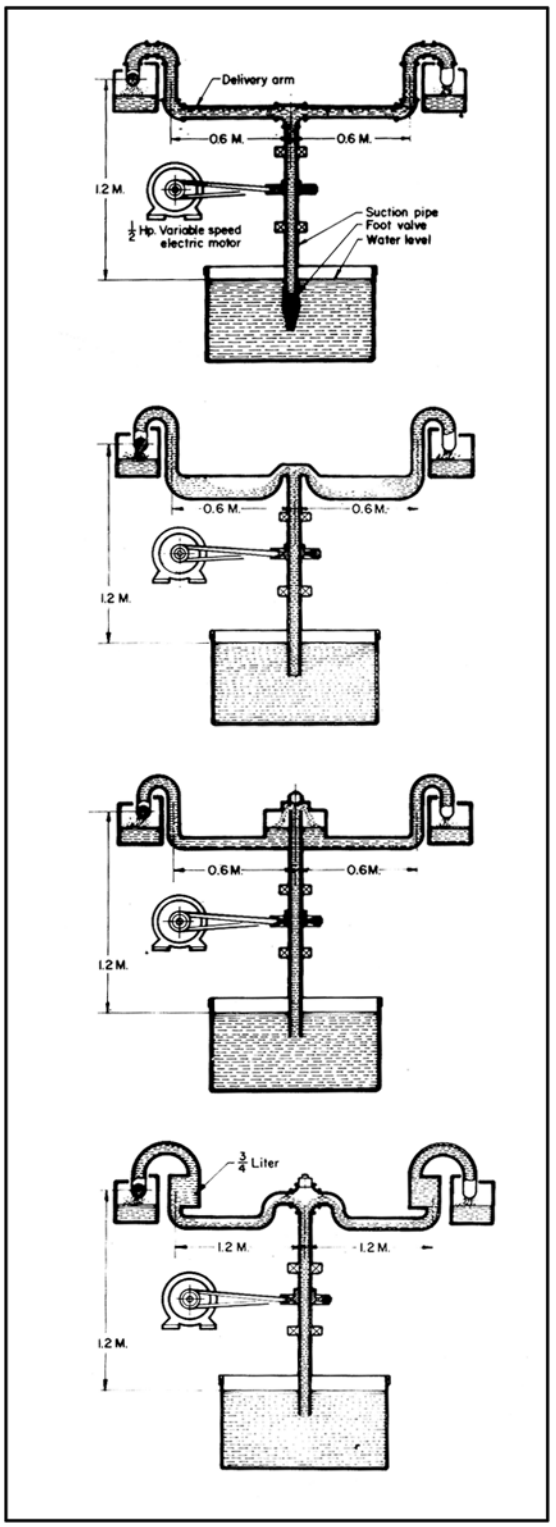


3. Laboratory unit of low-cost jet pump attachment for centrifugal pumps.

In an effort to make this pump self-priming without the use of foot valves, four different tubular pump designs (fig. 4) were evaluated and compared on a test stand. This led to the design of a full-scale pump for use with a vertical-axis windmill that is being developed at IRRI. This pump satisfactorily lifts water from a depth of 0.9 m to 3 m, delivering between 19 and 110 l/min (fig. 5) on the test stand. Efforts are continuing to couple the pump with a suitable vertical-axis windmill.

Vertical-axis windmill. The simplicity of design and ease of construction facilitate the use and manufacture of the vertical-axis windmill in developing countries. Existing vertical-axis windmill designs (the mills are omnidirectional) were evaluated in a program to develop a low-cost simple version which could be used for pumping water. The increased cost of fossil fuels and their shortage have created a greater need for such devices for rural areas.

A test rig was designed and mounted on a pick-up truck to evaluate power generation capabilities of various rotor designs. In addition to eval-



4. Four tubular pump concepts evaluated for self-priming characteristics.

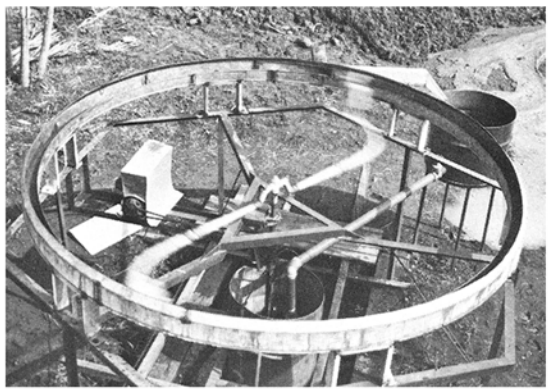
uating two existing rotors, the Savonius and the NRC rotor designs, other rotor design concepts will be tested to achieve an optimum design which can be coupled to the tubular pump.

SOIL AND CROP MANAGEMENT FOR RICE

Agricultural Engineering Department

Power tiller survey. A survey of owners and users of power tillers was undertaken in the Philippines to gather information which could be useful in the development and manufacture of IRRI power tillers. The power tillers in the survey areas varied according to type, size, origin, and the type of engine – 4-hp to 7-hp gasoline or 8-hp to 14-hp diesel. Most imported power tillers were equipped with generators, steering clutches and variable-speed drives, and they generally cost fourfold more than the locally produced tillers. The farmer's selection of a tiller brand was influenced by the brand of the tiller initially introduced in an area, the presence of dealers, and the price. The service problems generally encountered by tiller owners were associated with failures in the engine, belts, clutch axle, bearings, and oil seals. The heavy weight of the tiller was frequently identified as an undesirable feature. Power tillers were used for additional income through hauling and for driving irrigation pumps and threshers. The local power tiller manufacturers in the Philippine province of Camarines Sur initially started their production of tillers on a custom basis and then changed over to regular production as sales increased.

5-hp to 7-hp tiller. The 5-hp to 7-hp tiller continues to gain increasing acceptance in the Philippine market. A number of other manufacturers have entered production by either adapting the IRRI power tiller design or by developing their own machines. Manufacturers were given assistance in testing and improving their initial production machines. A high frequency of V-belt failures and uneven wear on the intermediate set of transmission sprockets were reported by owners of IRRI-designed tillers. Modifications in the transmission to solve these problems included replacing the idler-belt clutch arrangement with a sliding engine mount for clutching, replacing the No. 40 roller chain sprockets with No. 50 chain sprockets. and reinforcing the countershaft mounting. Development of a set of externally mounted steering clutches



5. Laboratory unit of tubular pump.

is under way to meet the farmers' desire for power steering on this tiller.

8-hp to 12-hp tiller. The design of the 8-hp to 12-hp tiller (fig. 6) was completed and engineering drawings were released to four manufacturers in the Philippines. The needed changes in the design identified during the endurance testing of the prototype unit were made. The double V-belt transmission from the engine was replaced with a triple-belt arrangement. The pivot-actuated mechanism of the steering clutches and its control linkages were redesigned for smoother operation. The idler-belt clutch arrangement was replaced with a disc clutch which was built integrally with the transmission input pulley. The standard three-speed automotive transmission case was replaced with a specially designed two forward and one reverse speed spur gear transmission box. A new handle bar assembly was designed to enclose the control linkages and to improve the tiller appearance. The machine successfully passed a rigorous endurance test before its release. Manufacturers are adapting its design to their production facilities and plan to start limited production soon.

Four-wheel riding tractor. The development of low-cost 15-hp riding tractors follows a design strategy for a basic lightweight riding tractor to be used in wetland fields with non-tractive implements. To gain experience and save on costs, a carefully selected 15-hp riding tractor (fig. 7) was imported and modified for wetland work. The PTO drive was redesigned and an extra-wide (132 cm) rotary tiller and two extendible lug wheels were developed. Additionally, a lightweight 15-hp air-cooled diesel engine was installed. When this modified tractor passes performance tests satisfactorily, a new 15-hp tractor can be designed to make maximum use of engine, transmission, and other components readily available in developing countries. Suitable equipment will be designed for upland and multiple cropping operations.

ECONOMIC STUDIES OF LAND PREPARATION TECHNIQUES

Agricultural Engineering Department

The use of animal and tractor power for land preparation has been under study in the Philippines since 1973 by the IRRI Agricultural Economics and Agricultural Engineering departments. In par-

6. Prototype 8-to 12-hp tiller released to manufacturers for fabrication of initial production units.

7. Imported 15-hp riding tractor undergoing tests after modification for wetland work.

Table 2. Characteristics of sample farms in three barrios in Nueva Ecija, Philippines, 1972–73.

Characteristic	Baluarte		Pulo	Kapalangan	
	Tractor or tiller renters	Tiller owners	Tractor or tiller renters	Tractor renters	Carabao users
Farms (no.)	49	21	23	21	20
Average farm size (ha)	3.5	4.1	3.0	4.3	3.1
Carabaos (av. no./farm)	1.6	1.2	1.3	2.0	1.8
Tenure status (%)					
Owner	6	19	4	29	5
Share tenant	18	24	17	33	70
Leasehold	72	52	75	38	20
Other	4	5	4	0	5
Soils described as hard to plow (%)	30	n.a.[a]	18	61	40
Mean date of first renting or owning	1963/64	1973/74	1963/64	1969/70	–

[a]Not applicable.

ticular, the factors that influence the decision to use tractors by both the individual farmer and the government policy maker were explored.

Three barrios in Nueva Ecija, Central Luzon, Philippines – Pulo in the municipality of San Isidro, and Baluarte and Kapalangan in the municipality of Gapan – participated in the field survey and experiments. Because both water and soil affect tractor performance, they served as a joint criterion for selecting the study barrios. Rice areas in Baluarte and Pulo are irrigated, but the soils in Baluarte tend to have a shallower plowing depth. In Kapalangan, the rainfed area to the east of Lateral C of the Peñaranda River Irrigation System was selected as the study location.

The survey. Farms were chosen to reflect different equipment combinations rather than at random. The major focus of the survey was on custom hiring services since this was a more common form of use for either four-wheel tractors and power tillers. Additionally, a few farmers who owned tractors and a few who had never used tractors were sampled for comparative purposes.

Farmers in Baluarte (49), Pulo (23), and Kapalangan (21) were interviewed. All indicated that they were currently using hired tractor services or in the recent past had hired such services for land preparation (Table 2). An additional 21 farmers who had recently bought the small 7-hp (IRRI-designed) power tiller and 20 farmers from Kapa-

Table 3. Power source and equipment rented for land preparation in three barrios in Nueva Ecija, Philippines.

Primary	Secondary	Farmers (%) reporting				
		Baluarte (n = 49)		Pulo (n = 23)		Kapalangan (n = 21)
		Wet season	Dry season	Wet season	Dry season	Wet season
4-wheel tractor	Carabao	23	63[a]	17	87[a]	85[a]
Large tiller	Carabao	14	27	–	9	5
Small tiller	Carabao	4	2	–	4	5
Small tiller	Small tiller	2	4	–	–	3
Carabao	Small tiller	–	4	–	–	5
Carabao	Carabao	27	–	83	–	–

[a]3 farmers in Baluarte, 1 in Pulo, and 12 in Kapalangan reported using four-wheel tractors for primary tillage on only a portion of the rice area.

Table 4. Farmers' first and second motivations for using rented tractor services, Nueva Ecija, Philippines

Factor	Farmers (%) reporting					
	Baluarte (n = 49)		Pulo (n = 23)		Kapalangan (n = 21)	
	1st motivation	2nd motivation	1st motivation	2nd motivation	1st motivation	2nd motivation
Ease	67	2	48	24	5	0
Quality	6	10	4	9	10	0
Timeliness	16	6	17	9	33	0
Risk of carabao becoming disabled	6	0	0	4	29	5
Curiosity	2	0	13	0	10	0
Cheaper cost	0	0	0	0	0	0
Decision made by others	4	0	17	4	10	5

langan who used only carabaos were also included in the survey.

Most of the farms selected in the irrigated barrios had used tractors as early as 1961, well before the introduction of the new rice varieties in 1966. Farmers in the poorer rainfed areas began hiring tractor services much more recently. The average farm size was larger in the rainfed barrio of Kapalangan than in the irrigated barrios, and there were more farm owners. In Kapalangan, the size of farm operating units increased since tractors were first introduced.

The pattern of tractor use among farmers renting tractors was extremely mixed. A relatively small number had used the tractor continuously since they first began hiring tractor services. The four-wheel tractor (65 hp) with rotary tiller was normally hired only for primary tillage, and was used in the irrigated areas principally during the dry season (Table 3). In the rainfed barrio four-wheel tractors were also used, but only for primary tillage and then often on only a portion of the land. The large power tillers (12 hp) were not widely used in this area. They were rented either for primary tillage or for harrowing or both, there being no general pattern. However, owners of small power tillers (7 hp) used the tiller on their own farms for both plowing and harrowing. A variety of equipment combinations and a number of factors appear to influence a farmer's decision to use mechanical power for preparing all or a portion of his land.

About 67 and 50 percent of the farmers surveyed in Baluarte and Pulo, respectively, referred to the fact that the tractor eased the work load (Table 4). This was a more critical factor than timeliness. Apparently farmers were willing to pay the tractor rental cost to reduce the pressure of work during the busy period when the dry-season crop is planted immediately after the harvest of the wet season crop.

A third of the farmers in the rainfed barrio of Kapalangan considered timeliness the most important factor. Many of them used the tractor on a portion of their land to help them catch up with the planting when the rains were late. Kapalangan farmers also seemed more concerned about the risk of the carabao being stolen or becoming disabled. Much of the sandy-clay soil in this area has a stony bottom which injures the feet of both men and animals during land preparation.

The amount of time required to prepare the land with only carabao power and also with mechanical power for a part or all of the operation was surveyed. Comparisons were made not only among farmers in the three survey barrios who rented four-wheel tractor services (used only for primary tillage), but also between users of tractors and power tillers in Baluarte (Table 5), where power tillers were assumed to be used for both primary and secondary tillage.

When using a carabao, man-hour requirements were higher in the dry than in the wet season and greater in rainfed than in irrigated fields. In rainfed areas, it appears that lack of water and the consolidated condition of the soil make land preparation more difficult. The introduction of mechanical power in the combinations shown in Table 5 tends to reduce by 3 to 4 weeks the duration of time between the first plowing and the last

Table 5. Time and labor required for land preparation: comparison of tractor and carabao and carabao only, and of power tiller with carabao in Baluarte, Nueva Ecija, Philippines.

Season	Mean duration (days/farm)		Labor input (manhours/ha)	
	Carabao only	Tractor or tiller	Carabao only	Tractor or tiller
		Renting tractors[a]		
Wet	29	20	94	58
Dry	29	21	126	53
		Renting tillers[b]		
Wet	31	21	108	50
Dry	[c]	23	–	34
		Owning tillers[b]		
Wet	–	22	–	37
Dry	–	27	–	50

[a]Tractor used for primary land preparation only. [b]Tiller used for primary and secondary land preparation. [c]Less than 5 observations.

harrowing. The number of carabaos per hectare declined only slightly, since farmers rent tractor services for only a portion of the land preparation work (Table 6). Tiller owners will most likely reduce the number of carabaos they use in the future. Many farmers using tractors report transplanting earlier than their neighbors, but since tractors are used sporadically their potential effect on reducing the time required for land preparation has yet to be fully realized.

Although most farmers reported that the weed growth was less with the use of mechanical power no significant difference in yield was noted (Table 6). The question of the impact of mechanization on crop production is examined in more detail in the field experiments.

The experiment. To determine whether different land preparation techniques or equipment combinations significantly affected crop yield and other measurable phenomena, such as soil compaction and weed growth, replicated field experiments were established in four locations in the three barrios in Nueva Ecija – Baluarte (shallow hardpan), Pulo (medium hardpan and deep hardpan), and Kapalangan (rainfed). The treatments (T) based upon knowledge gained from the survey of the most common equipment combinations for land preparation are described below:

T1 – Rotovate once using large tractor (65 hp) and harrow three times with carabao.
T2 – Rotovate once using large power tiller (14 hp) and harrow three times with carabao.
T3 – Plow once with a small power tiller (7 hp) and harrow three times using the same tiller.
T4 – Plow once with a carabao and harrow

Table 6. Impact of mechanization in three barrios in Nueva Ecija, Philippines.

	Baluarte			Pulo	Kapalangan
	Tractor rent (n = 39)	Tiller rent (n = 11)	Tiller owner (n = 21)	4-wheel tractor (n = 20)	4-wheel tractor (n = 18)
			Carabaos (av. no./ha)		
Before mechanization	0.4	0.8	0 3	0.6	0.4
After mechanization	0.3	0.4	–	0.4	0.3
			Farmers (%) transplanting earlier than neighbor		
Wet season	3	20	57	0	16
Dry season	23	0	40	15	–
			Farmers (%) reporting fewer weeds		
	68	80	68	65	56
			Farmers (%) reporting higher yields		
	21	10	n.a.[a]	10	11

[a]Not applicable.

Table 7. Labor, capital, and total costs per hectare for selected land preparation treatments in three barrios in Nueva Ecija, Philippines, 1974 and 1972 prices.[a]

Land preparation treatment	Labor cost 1974	Capital cost 1974	Total cost	
			1974	1972
		Baluarte – shallow hardpan		
T1 (tractor – carabao)	50	142	192	126
T2 (tiller – carabao)	54	116	170	113
T3 (tiller – tiller)	38	138	176	114
T4 (carabao – tiller)	588	105	163	104
T5 (carabao – carabao)	87	48	135	88
		Pulo – medium and deep hardpan		
T1 (tractor – carabao)	69	189	258	167
T2 (tiller – carabao)	73	138	211	139
T3 (tiller – tiller)	47	173	220	143
T4 (carabao – tiller)	77	166	243	156
T5 (carabao – carabao)	104	57	161	105
		Kapalangan – rainfed		
T1 (tractor – carabao)	81	280	361	235
T2 (tiller – carabao)	96	217	313	209
T4 (carabao – tiller)	123	206	329	214
T5 (carabao – carabao)	192	106	298	194

[a]Labor cost is computed at ₱8/day in 1974 and at ₱5/day in 1972; diesel fuel at ₱0.89/liter in 1974 and ₱0.18/liter in 1972; and interest at 12%; ₱7 = US$1.

three times using small power tiller (7 hp).

T5 – Plow once with a carabao and harrow three times using a carabao.

The three levels of weed control were:

W1 – Manual weeding 30 days after transplanting.

W2 – Chemical weed control (pre-emergence herbicide applied 4 days after transplanting).

W3 – Control (no weeding).

A modified split-plot design with two replications was employed. Land preparation treatments were assigned to the main plots and weeding techniques to the subplots. The intensity and the timing of harrowing following basic tillage was standardized for all methods. An interval of 1 week was allowed between primary tillage and the first harrowing and between the first and the second harrowing. Final harrowing was performed 1 day before transplanting of the IR20 rice during the first week of July. Each harrowing consisted of two passes over the paddy. A single topdressing of 60 kg N/ha was applied to all treatments after 3 weeks.

Despite the wide variation in labor and capital inputs among the five treatments, differences in yield among treatments at any of the locations were not significant, even when the use of mechanical power reduced weed weights significantly. Yields varied significantly according to location and weed treatment. One hand weeding was superior to 2,4-D pre-emergence application, yielding about 0.5 t/ha more grain.

The annual capital costs were computed for each of the five treatments assuming 1972 and 1974 prices for operating and investment costs for power (Table 7).The individual investment costs (1974) for a carabao and power tillers (7 hp, 12 hp, and 65 hp) were ₱1,200, ₱5,000, ₱18,000, and ₱70,000, respectively. The respective costs per horsepower were ₱1,200, ₱715, ₱1,500, and ₱1,077 [₱7 = US$1].

Since the cost of labor and capital for medium and deep hardpan soils did not differ significantly,

data for the two Pulo sites were averaged. Thus, these input requirements were given for only three soil conditions (Table 7). Based on previous data, it was assumed that tractors operated 120 days/year, while carabao and tillers operated only 80 days annually.

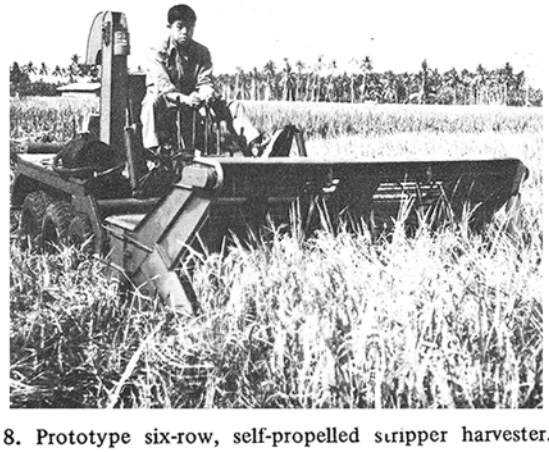
The labor cost was highest for the carabao and lowest where the tiller was used for both primary and secondary tillage, while capital costs were lowest for the carabao even in 1972 before fuel prices rose sharply.

POST-HARVEST MANAGEMENT OF RICE

Agricultural Engineering Department

Stripper-harvester. A prototype six-row stripper-harvester (fig. 8) was fabricated and modified according to field test data. To provide adequate power, the single-cylinder 15-hp Hertz engine was replaced with a two-cylinder 30-hp Thailand-made Winner engine. Cooling fins were added to the engine pulley to reduce overheating and improve belt life. The hydrostatic drive to the threshing belt was replaced with a positive chain drive to allow a uniform belt velocity. The modified machine was tested on a simulated field in which bundles of freshly harvested paddy were clamped in two rows on wooden planks anchored on the ground. Excessive grain loss and poor lifting of lodged rice continue to be the major problems. Work is continuing.

Thresher survey. To gather technical information that may be useful in the development of threshers for small and medium-size farms in the tropics, a survey on threshers and the problems associated with their use and ownership was conducted in the Philippines at the farmer and the manufacturer levels.



8. Prototype six-row, self-propelled stripper harvester.

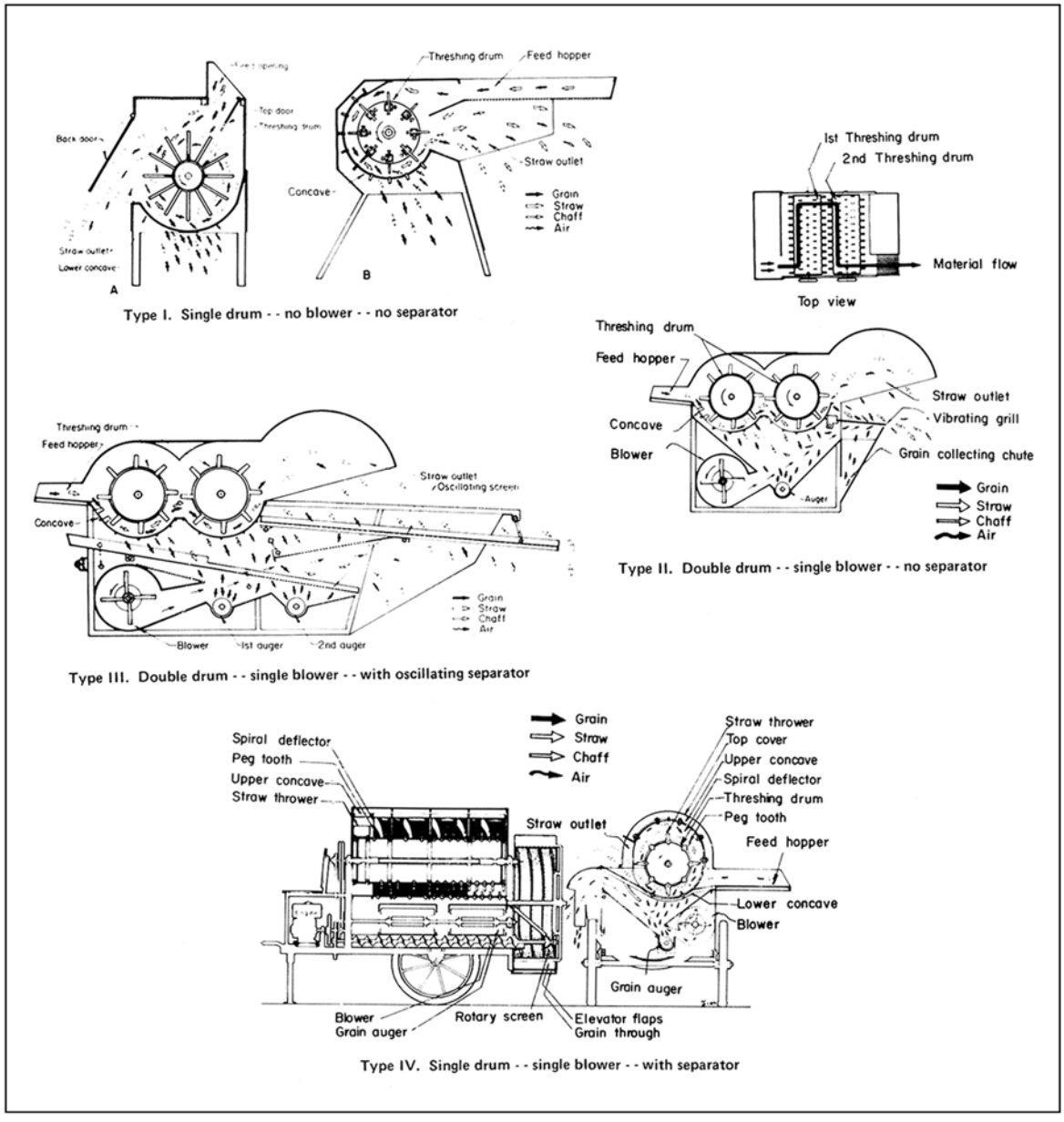
A survey of the contract threshing operations in the provinces of Camarines Norte, North Cotabato, and Laguna revealed that the individuals who do custom threshing in Laguna were also expected to weed the fields, free of charge, to claim the right to harvest the crop. They generally collect 15 percent of the threshed grain for harvesting and threshing services. Although most of the farmers interviewed in Camarines Norte and North Cotabato were tenants with 0.1- to 6.0-ha holdings, a large percentage owned locally made threshers. This accounts for the low popularity of custom threshing in the area. A lack of low-cost and lightweight threshers was one of the main problems identified by the farmers.

Rice threshers found in the area were divided into four types (fig. 9). The output per horsepower of type 1 thresher was maximum, but the threshing and separating losses were high (Table 8). The high air velocity from the blowers in types 2 and 3 machines accounted for the greater grain loss of 23 to 38 percent. The type 4 machine appeared to be the best because it combined high output per horsepower and man-hour with minimum loss.

Axial flow thresher. This machine received excellent response from manufacturers in the Philippines and many other developing countries. It can thresh paddy, sorghum, and soybeans, and efforts are being made to adapt it for threshing a wider range of crops including wheat. Some manufacturers in the Philippines have introduced useful improvements in the basic design. These include a spring suspension for high-speed transport, a simple arrangement for recycling semithreshed material through the threshing cylinder, and easily replaceable screens in the rotary screen cleaner. Two manufacturers have introduced machines which are equipped with oscillating grain-cleaning arrangements mounted under the full width of the cylinder. Most manufacturers have done some redesigning of the basic machine to adapt it to their production facilities.

PTO thresher. This PTO (power takeoff) thresher has a very high threshing output, and while many different rotary screens and blower arrangements have been tried, the machine's grain-cleaning

performance is not satisfactory. Efforts were made to improve the alignment of the rotary screen outlets and the straw thrower intake to permit smoother transfer of material. To establish the extent of the suction area inside the thrower opening, air pressure was measured inside the blower housing through a series of holes placed radially in the back wall (fig. 10). The effective suction area in the thrower opening appears to be a diameter of 75 cm and the diameters of the outer two rotary screens are 96 and 134 cm, indicating that the impurities for these screens cannot satisfactorily enter the straw thrower because of the blowback effect. The suction zone



9. Different types of small rice threshers.

Table 8. Rice thresher test results (November 1974)[a]

Item	Thresher type[b]			
	1	2	3	4
Operating speed (rpm)				
Threshing drum 1	1200	900	900	520
Threshing drum 2	–	1200	1200	–
Blower	–	1400	1400	1000
Auger	–	1200	1200	270
Separator	–	250	250	17
Horsepower rating	3	8	11	7
Crop condition				
Grain moisture content (%)	23	23	21.3	20
Material length (cm)	35	35	35	38
Grain:straw ratio	0.65	0.49	0.53	0.53
Labor requirement	4	6	7	4
Men feeding	1	1	1	1
Men handling	3	5	6	3
Test duration (min)	–	3.75	12.13	6.25
Total output (kg/test)	44	60.58	68.52	97.53
(kg/h)	704	249.65	1148.38	936.36
Labor output (kg/man-h)	176	49.9	164	234.09
Capacity (kg/hp-h)	234.6	27.24	104.40	105.19
Unthreshed loss (kg/test)	7.49	0.787	2.26	0.195
(%)	17	1.3	3.3	0.2
Separation loss (kg/test)	24.85	9.25	2.74	2.6
(%)	56	15.27	4.0	2.67
Blower loss (kg/test)	–	13.93	26.03	1.5
(%)	–	23	38	1.54
Purity (%)	92.1	98.1	98.3	97.4

[a]Average of three tests. [b]Threshers tested were all throw-in feeding.

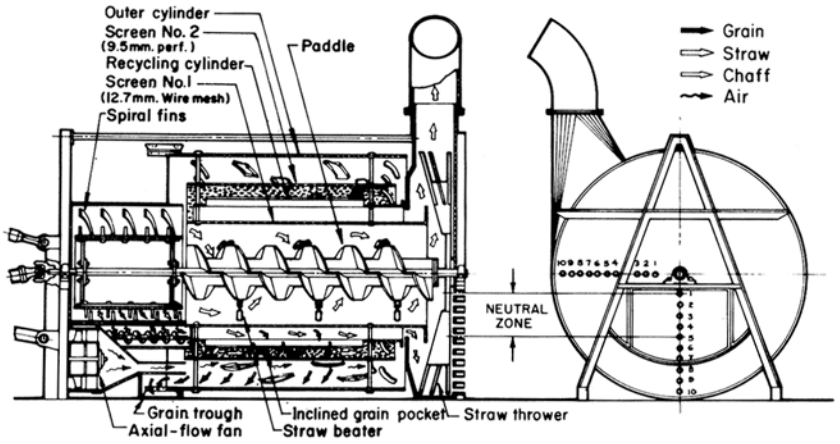
is being enlarged to improve transfer of the material from the rotary screens to the thrower.

Grain cleaners. While the rotary screen grain cleaner has performed satisfactorily in Indonesia, the Philippines, and Taiwan, its high cost precludes sufficient demand. A simplified cleaner, developed by a subcontractor in Taiwan, in which the screw conveyor feeding arrangement was replaced with a gravity-fed hopper also performed well. A cleaner similarly modified at the IRRI gave satisfactory results when the impurities were not excessive. Longer straw pieces and larger impurities which partially clogged the hopper opening lowered the output to only 1.02 t/h.

Moisture meter. Among the improvements made on the moisture meter was a new cabinet with a better mounting arrangement of the meter and the controls. The moisture meter was calibrated for measuring different moisture levels of paddy and suitable charts were developed. Engineering drawings were released to two manufacturers in the Philippines, who are being encouraged to start local production.

Rice mill evaluation studies. Laboratory and commercial hullers and polishers were tested and evaluated to determine their performance characteristics, identify design parameters, and make recommendations on the proper selection and use of the machine.

In a test of three laboratory machines – a rubber roll huller, a friction polisher used as a huller and polisher, and an emery stone polisher –



10. Schematic drawing of PTO-driven thresher.

91.12 percent of the grains was hulled and 7.56 percent was broken with the rubber roll huller. When the friction polisher was used as a huller, it required 15 seconds to hull the sample, giving 70.25 percent total rice recovery and 43.08 percent head rice recovery. Friction and pressure also removed the bran in the process. As a polisher, the machine was effective for the first 30 seconds, but after that, the grain slid and broke. The performance of the emery disc was affected by time, speed, and surface roughness which can be made variable. Since the grain was not subjected to pressure and the desired degree of polish was attained, the emery disc gave a better milling performance than did the friction polisher. Tests will be continued on the other laboratory mills.

Four commercial rice hullers – two rubber roll types, a centrifugal type, and an under-runner disc huller – were evaluated by the procedure developed by Kuprits[1], where efficiency (U_n) was based on hulled rice and whole grain recovered from the paddy.

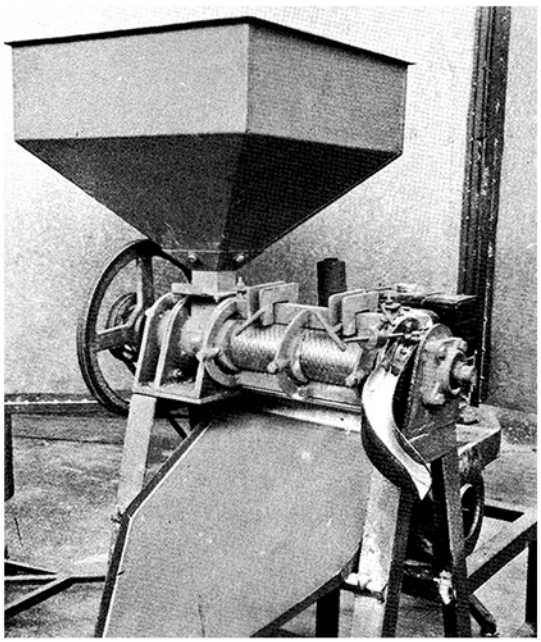
Differences in efficiency among hullers were highly significant. The rubber roll huller had the highest efficiency (U_n = 0.850) while the under-runner disc huller had the lowest (U_n = .417). The centrifugal huller had a high hulling rate, but produced many brokens. It will be tested further.

The commercial whitening machines used were divided into five types: type I horizontal friction; type II horizontal friction air jet; type III horizontal divided into five types: type 1 horizontal friction; type 2 horizontal friction air jet; type 3 horizontal abrasive-friction; type 4 vertical abrasive cone; type 5 horizontal abrasive cylinder. Machine types 1, 2, 3, and 4 were tested without the usual associated auxiliary equipment, such as bran aspirators, elevators, graders, and others.

The head rice recoveries differed significantly among the four types of whitening machines tested (Table 9). The whitening machines equipped with abrasive rolls (types 3 and 4) showed high head rice recoveries and hourly capacities per horsepower (Table 10). The Engleberg mill (type 1) when used as a whitening machine produced higher total and head rice recoveries, but exhibited the lowest hourly capacity per horsepower. All machines will be tested further.

Engleberg mill. When the modified Engleberg mill (1973 Annual Report) was compared with a commercial mill which has an airjet stream, the modified machine gave 2 percent more total rice and a 5.4 percent higher head rice recovery. Additional modifications were made on the Engleberg mill to reduce friction and pressure during milling. A new cylinder cover that can be fitted with a semicircular or lengthwise-bent screen and three test blades with a different depth of cut on the milling side were constructed. A commercially available screen with bigger perforations (1.19 x

[1] Israel Program for Scientific Translation, Ltd. 1967. Technology of grain processing and provender milling. Jerusalem. pp. 182–187.



11. Experimental single-pass rice mill.

Table 9. Percentage of total milled and head rice recovery of six whitening machines.

Whitening machine type[a]	Av. of total milled rice[b] (%)	Av. of head rice in milled rice[c] (%)
Type 2 (2)	62.62 (37.6)	61.80*
Type 2 (1)	63.54 (38.0)	70.21
Type 1 (1)	64.50 (37.6)	72.27
Type 3	64.82 (39.23)	75.80
Type 1 (2)	66.27 (36.83)	73.80
Type 4	66.65 (33.77)	75.17

[a]Type 1 (1) – horizontal friction, Korean made; Type 1 (2) – horizontal friction, Engleberg type; Type 2 (1) – horizontal friction-air jet, Korean made; Type 2 (2) – horizontal friction – air jet, Japanese made; Type 3 – horizontal abrasive-friction, Korean made; Type 4 – vertical abrasive cone type. [b]Figures in parentheses represent degree of whiteness, as measured by a Kett whiteness meter. [c]*Significant at 5% level.

12.70 mm) was used with the Engleberg mill when its performance with the latest modifications was compared with that of the mill with the previous modifications.

In one performance test, high head and total rice recovery was also obtained with the new cylinder cover fitted with a semicircular screen and test blades. The perforated screen resulted in cleaned milled rice. The capacity was reduced with the test blades. The wider perforation screen separated the smaller broken grains, reducing the milling recovery by 4.46 percent, compared with the original machine.

An experimental single-pass rice mill was designed and fabricated (fig. 11) to further investigate the effects of the parts that cannot be varied with commercial mills. The machine introduces an airjet to cool the grain during milling, a single spiral at the feeding end of the cylinder, a sectionalized cylinder, a weight-loaded gate for side and axial discharge, and two adjustable perforated screen covers. The individual combined effects of the

Table 10. Hourly capacities per horsepower of six whitening machines.

Item	Whitening machine type					
	Type 1[a] (2)	Type 1 (1)	Type 2 (1)	Type 2 (2)	Type 3	Type 4
Capacity in brown rice (kg/h)	68.1	92.6	359.5	520.0	421.9	261.3
Hp required	5*	4	7	7	10	7[b]
Capacity ($kg \cdot h^{-1} \cdot hp^{-1}$)	13.6	23.2	51.4	74.3	42.2	37.3
Capacity index	18.4	31.3	69.2	100[c]	56.8	50.2
Total head rice (%)	48.92	46.59	44.59	38.65	48.82	50.08
Temperature of milled rice (°C)	48.5	44.8	42.9	42.6	54.6	41.7
Passes (no.)	1	8–10	3	1	1	2

[a]*Significant at 5% level. [b]Estimated values. [c]The highest hourly capacity per horsepower was considered as 100 in computing the capacity index.

various parts will be studied for incorporation in existing commercial mills.

Rice hull furnace. Modifications made by one manufacturer included a small grill-type opening made at the combustion chamber to facilitate firing and a fix reduction in the fire brick linings to decrease weight. The modified model was evaluated in conjunction with the IRRI batch dryer.

The rice hull furnace achieved an air temperature of 43.3° to 55.5°C with an ambient temperature of 28.3°C and a hull feeding rate of 6 to 9 kg/h. It dried 1 ton of paddy from 22 to 14 percent moisture content in 3.6 to 5.5 hours. The manufacturing defects noted during the test included the fact that the reduction of the firebrick linings exposed some metal parts which were damaged during the test. Also, the location of the hopper above the furnace presented a fire hazard; the light steel gauge grate buckled when heated, and ashes were sucked in by the blower due to a defective baffle arrangement. The recommendations for improvements that were provided to the manufacturer were made and the furnace is now produced commercially.

Post production technology and management for rice

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318 ESTIMATES OF THE MARKETABLE SURPLUS FUNCTION

SUMMARY

Analysis of unmilled rice samples from 111 locations in the Philippines indicates that a majority of farmers deliver poor-quality materials to rice millers. Operations preceding milling, such as untimely harvesting, improper drying, and poor storage conditions, appear to account for much of the low quality observed. Experimental trials to test the efficiency of alternative solar drying surfaces indicate significant differences in both the rate of drying and the resulting quality of milled rice obtained from each treatment. Varietal characteristics such as grain length appear to be highly significant in determining the rate at which moisture is removed and the milling recoveries obtained, particularly for head rice. The relationship between production, consumption, and marketable surplus was examined. Price was found to have little influence on the amounts of rice retained for home consumption and on the amounts of rice sold in the market place, particularly for farms with low levels of output, large households, or some combination of these two factors. The results also strongly suggest that rice supplies moving into the nonfarm market are much more sensitive to changes in output than to changes in price.

ANALYSIS OF PADDY SAMPLES

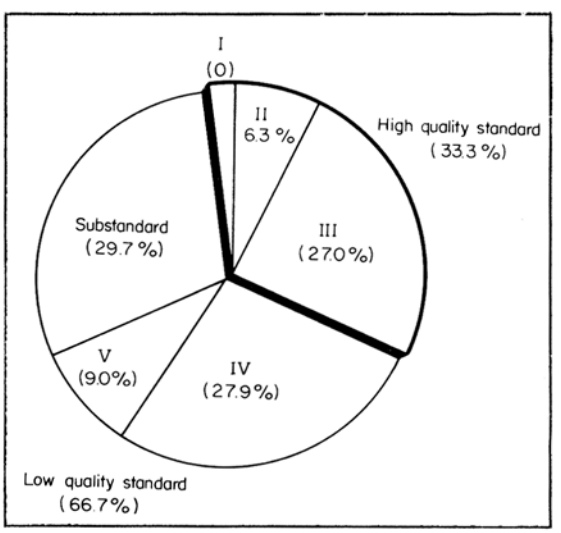
Agricultural Engineering Department

Several years ago, it was predicted that constraints in the food grain marketing chain would emerge from the seed-fertilizer revolution. These second-generation problems have recently become an issue of growing importance. While increased supplies have tended to strain available capacity in some elements of the post-production system, there is evidence that the sequence of post-production operations also embodies significant opportunities for increased output through the reduction of qualitative and quantitative losses.

Considerable attention has been focused on the mill level processing of rice in the belief that this is the point at which the greatest inefficiencies and losses occur. Research at IRRI indicates that processing is but one component which incurs losses and one which is contingent upon the effects of other operations which precede it, i.e., harvesting, threshing, handling, drying, and storage.

An analysis of unmilled paddy samples taken from 111 rice mills located in three regions of the Philippines support the above hypothesis. A number of factors cause losses during operations which precede the milling of paddy (Table 1 and fig. 1). The paddy samples contain a relatively high percentage of foreign matter which, in the absence of adequate cleaning equipment at the milling plant, reduce milling recoveries and exacerbate equipment wear and maintenance problems. The samples contain high percentages of cracked, damaged, fermented, and immature kernels caused by poor harvesting, threshing, handling, and drying procedures. Additionally, improper seed selection and poor production management contribute to the problems of mixed varieties, presence of weed seeds, and low quality. In this analysis the paddy samples were classified into six grades used by the Philippine government to assess paddy quality. Only 33 percent of the samples could be classified as being of high quality. The largest portion of the samples was graded as low quality, with 33 percent falling into the lowest or substandard category.

Even the most modern processing technology can only partially mitigate the inherent defects of poor quality paddy. Generally, the milling recovery from low grade paddy is low, and, in the majority of cases, the quality of the resulting milled rice will be poor.



1. Results of paddy analysis, 111 rice mills, Central Luzon, Southern Tagalog, and Camarines Sur, Philippines, 1973.

Table 1. Analysis of paddy samples based on Philippine Grade Standards, 111 rice mills, Central Luzon, Southern Tagalog and Camarines Sur, 1973.

Quality	Grade standards					
	Average	II	III	IV	V	Substandard
				Percent		
Purity	–97.62	98.47	98.36	97.80	97.14	96.79
Chaff, hulls and foreign matter	2.36	1.46	1.54	2.22	2.81	3.12
Weed seeds	0.02	0.00	0.01	0.02	0.02	0.05
Cracked kernels	1.07	1.23	1.33	1.85	2.40	6.47
Immature kernels	4.06	1.40	2.63	4.29	5.58	5.63
Damaged kernels	1.26	0.48	0.76	1.22	1.57	1.79
Other variety	4.02	2.30	2.40	2.44	6.09	5.80
Fermented kernels	1.13	0.04	0.20	0.27	0.41	3.12
Red rice	3.00	0.49	0.94	0.95	3.79	8.51
Moisture content	13.39	13.10	13.06	13.31	13.58	13.59

ALTERNATIVE SOLAR DRYING METHODS

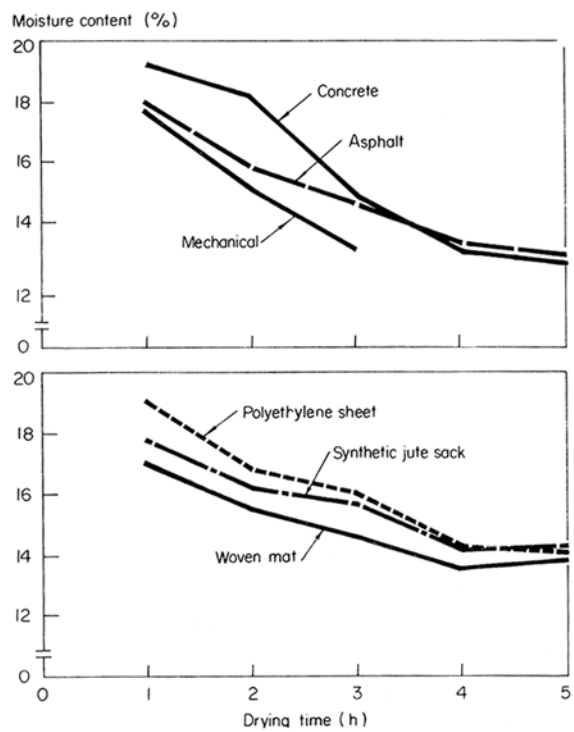
Agricultural Engineering Department

A crucial operation in the post-production system is the drying of paddy to a moisture content suitable for storage. During the 1974 dry season, several experimental trials involving alternative solar drying methods were carried out at IRRI in order to: 1) evaluate the efficiency of low-cost drying techniques; 2) determine which solar drying method produces the highest milling qualities; and 3) determine the relative rate of moisture reduction achieved with each method.

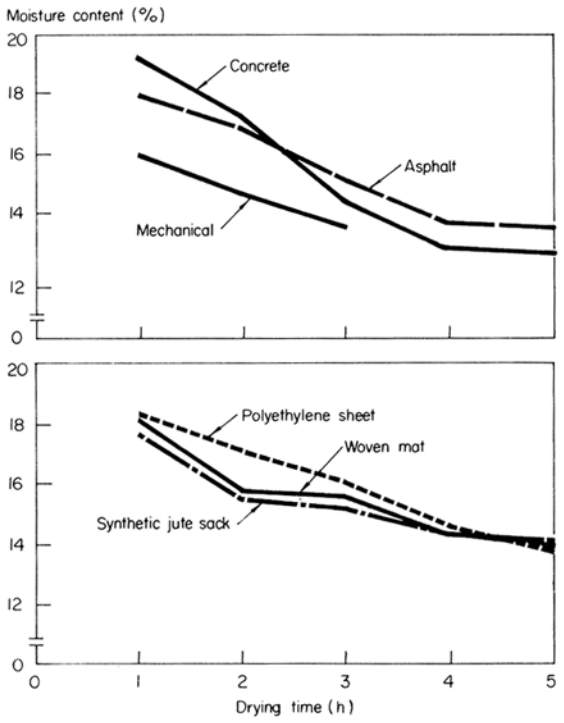
Concrete, clear polyethylene sheets, woven fiber mats, synthetic jute sacks, and asphalt pavement were the five drying surfaces studied, while a mechanical dryer served as the comparative check. Two high-yielding rice varieties, IR1561-228-3-3 and IR20, were used.

The moisture reduction relationships are shown in fig. 2 and fig. 3. Generally, the moisture content of both varieties decreased gradually at hourly intervals until it reached 14 percent or less at the fourth or fifth hour in the solar dried trials. The difference in the rate of drying between the two rice varieties was probably due to the relative size of exposed grain surface area. IR20 rice grains are shorter and thicker than IR1561-228-3-3 grains, and thus, IR20 rice dried somewhat faster.

When the rate of moisture reduction was compared among the five drying surfaces, asphalt, followed by concrete, had the fastest drying rate. As expected, dark objects absorb and retain heat energy more readily than objects with a lighter color. The absorption and retention of heat energy by asphalt and concrete partially explain the faster rate of moisture reduction. The rate of



2. Moisture content versus drying time of alternatively wet and dried IR20 rice.



3. Moisture content versus drying time of alternatively wet and dried IR1561-228-3-3 rice.

moisture reduction for samples dried on woven mats, synthetic jute sacks, and clear polyethylene sheets, followed in this relative order those dried on asphalt and concrete surfaces. Both woven mats and synthetic jute sacks had perforations allowing some aeration, resulting in a higher rate of moisture reduction than the clear polyethylene sheet. The polyethylene sheet was not perforated and condensation accumulated on the lower surface, resulting in longer drying times.

When the total milled rice from the IR20 and IR1561-228-3-3 samples was compared (Table 2, fig. 4, and fig. 5), IR1561-228-3-3 yielded a slightly greater amount of milled rice than IR20. However, IR20 produced higher head rice yields than IR-1561-228-3-3. As in the case of the drying rate, this may be partially attributed to the difference in grain type between these two varieties; IR20 grains are shorter than IR1561-228-3-3. Longer grains tend to be more susceptible to grain damage during milling than shorter grain types.

All solar drying surfaces produced approximately equal values of total milled rice (Table 2), but the values were lower than those obtained from mechanically dried samples. The head yield was also higher when the rice was dried mechanically as compared with the head yield of solar-dried rice.

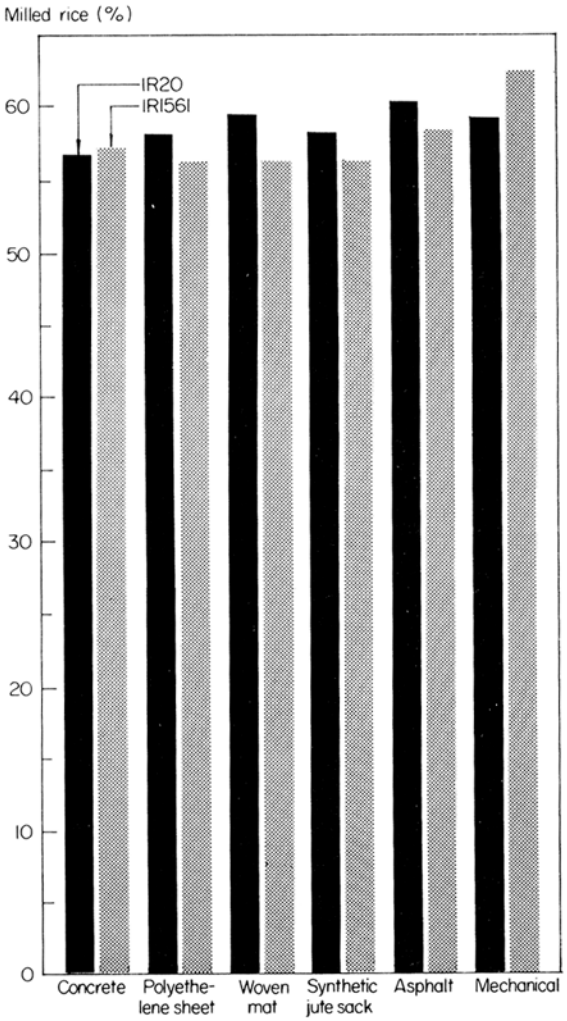
ESTIMATES OF THE MARKETABLE SURPLUS FUNCTION

Agricultural Engineering and Agricultural Economics Departments

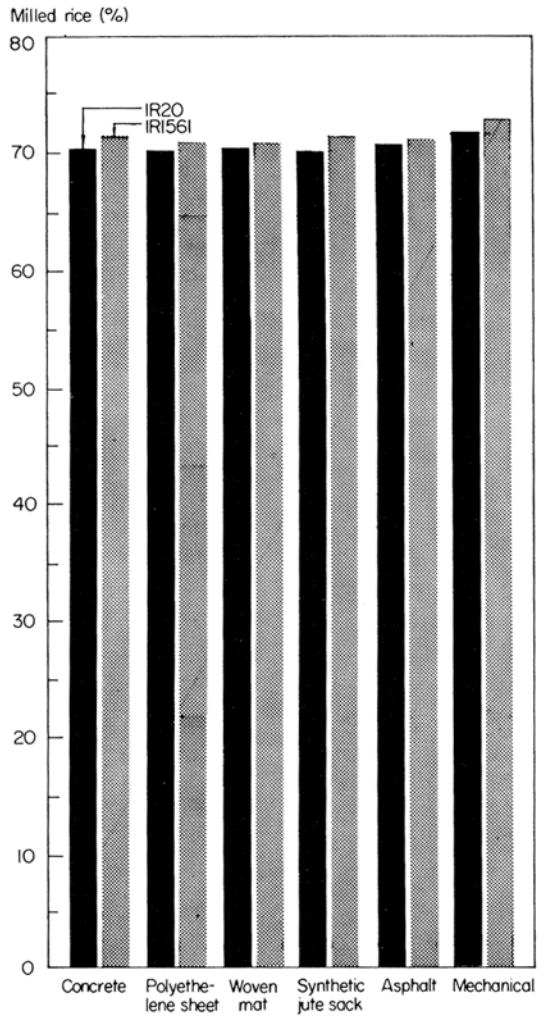
The marketable surplus, that portion of the crop sold for nonhousehold use, was studied empirically using data from an IRRI survey of nearly 600 rice farmers in three regions of the Philippines. The unavailability of adequate data relating the marketable surplus and (or) home consumption to price has made it difficult to derive empirical estimates of the price response for the marketable surplus and home consumption portions of the rice crop. To fill this critical gap, the price responses for both the marketable surplus and that

Table 2. Percent head and milled rice yields of IR20 and IR1561-228-3-3 for alternative drying methods, IRRI, 1974 dry season.

Drying method	IR20			IR1561-228-3-3		
	Head rice (%)	Broken rice (%)	Total milled (%)	Head rice (%)	Broken rice (%)	Total milled (%)
Concrete/cement	57.2	13.4	70.6	57.6	13.8	71.4
Polyethylene sheet (clear)	58.2	12.2	70.4	56.4	14.6	71.0
Woven mat	59.6	11.0	70.6	56.9	14.1	71.0
Synthetic jute sack	58.4	12.0	70.4	56.5	14.6	71.1
Asphalt	60.1	10.6	70.7	58.6	12.6	71.2
Mechanical (control)	59.4	12.5	71.9	62.6	10.6	72.6



4. Head rice yields of two rice varieties using alternative drying methods.



5. Milled rice yields of two rice varieties using alternative drying methods.

portion retained for home consumption were estimated using sample survey data showing patterns of disposal for 3 consecutive years.

The output of a subsistence crop is divided into the quantity consumed by the producer's household and the quantity sold in the market.

$$1) \quad Q = C + M$$

where Q is the disposable output of the rice producer's household obtained by subtracting rent and production expenses (in kind) from total rice output; C is the quantity of rice consumed by the producer's household and M is the quantity of rice offered for market sale.

The post-production marketable supply function can be expressed as

$$2) \quad M = f(P, Q),$$

where P is the price of output; and the demand function for home consumption is

$$3) \quad C = g(P, Q) = Q - f(P, Q).$$

From equation (3) the relation between the elasticities of marketable surplus and home consumption can be derived as follows:

$$4) \quad \beta = \beta_p + \beta_q \gamma$$
$$= -\frac{M}{C}\alpha_p + \left(\frac{Q}{C} - \frac{M}{C}\alpha_q\right)\gamma,$$

Table 3. Estimation of the marketable surplus function for rice.[a]

Regression number	Constant term	Regression coefficients of							
		P	Q	Q^2	N	Time dummies		Regional dummy	R^{-2}
						1973	1974		
1	− 2.64	1.208	0.739	0.00031	−5.960	−10.371	0.752	0.413	0.957
		(1.37)	(10.31)	(2.71)	(4.21)	(1.02)	(0.08)	(0.055)	
2	− 9.46	0.755	0.732	0.00032	−6.099			−0.172	0.957
		(1.05)	(10.45)	(2.86)	(4.33)			(0.024)	
3	− 9.58	0.753	0.732	0.00032	−6.089				0.958
		(1.06)	(10.55)	(2.89)	(4.57)				
4	−14.70		0.717	0.00035	−6.191				0.958
			(10.54)	(3.25)	(4.66)				
		P	Q/N	$(Q/N)^2$					
5	− 4.15	0.008	0.663	0.0041		0.156	0.799	−0.383	0.954
		(0.08)	(8.30)	(3.12)		(0.13)	(0.69)	(0.43)	
6	− 4.35	0.021	0.668	0.0040				0.229	0.955
		(0.23)	(8.51)	(3.10)				(0.27)	
7	− 4.37	0.018	0.666	0.0041					0.956
		(0.21)	(8.59)	(3.15)					
8	− 3.80		0.663	0.0041					0.957
			(8.81)	(3.35)					

[a]Figures in parentheses are t values.

where β and β_p are the total and the partial price elasticities of demand for home consumption, respectively, β_q is the elasticity of demand for home consumption with respect to output, γ is the price elasticity of output with respect to price, α_p is the partial price elasticity of supply for the marketable surplus, and α_p is the elasticity of market supply with respect to output.

Two models were used to estimate the market supply parameters

$$5) \quad M_{ti} = a_0 + a_1 P_{ti} + a_2 Q_{ti} + a_3 Q^2_{ti} + a_4 N_{ti} + e_{ti}$$

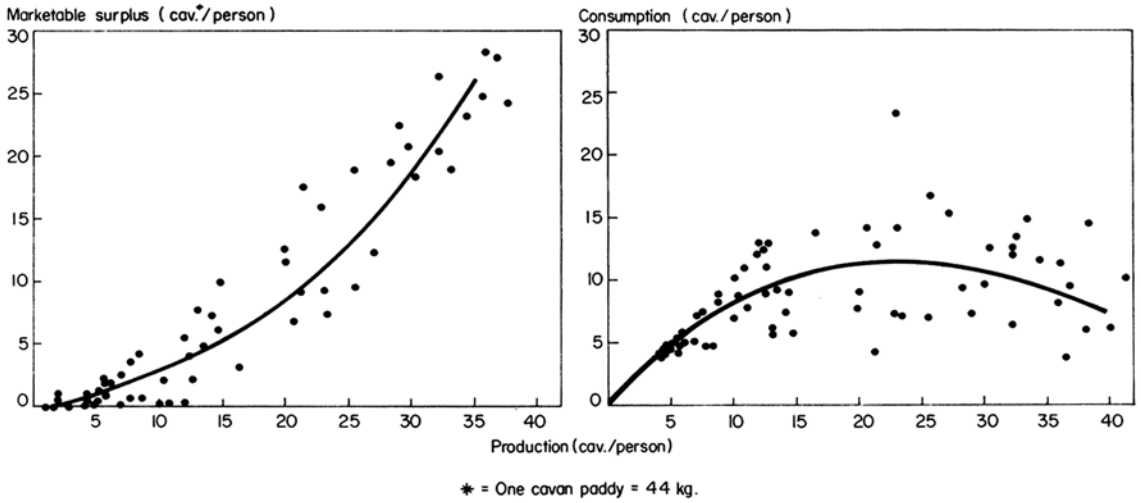
$$6) \quad \left(\frac{M}{N}\right)_{ti} = a_0 + a_1 P_{ti} + a_2 \left(\frac{Q}{N}\right)_{ti} + a_3 \left(\frac{Q}{N}\right)^2_{ti} + e_{ti},$$

where Q and M are as previously defined; P is the price of paddy received by farmers deflated by an index of prices paid by farmers for non-rice consumption goods; N is the number of farm household members per farm, e is the error term; and the subscripts t and i identify the crop year and farm, respectively.

The estimation results for equations 5 and 6 using ordinary least squares are shown in Table 3. The coefficients of the dummy variables are not statistically different from zero at standard levels of significance, indicating the stability of the specified relations between regions and years. The regressions estimated by deleting the price variable indicate virtually no change in the coefficients of other variables and the goodness of fit of the data indicated by the coefficient of determination adjusted for the degrees of freedom.

The results strongly support the hypothesis that the marketable surplus increases more than proportionally with output when home consumption demand for rice is close to saturation. As expected, the coefficients of N (household consumption units) are negative, showing an increase in home consumption in proportion to family size.

These regression equations indicate that the allocation of rice output between home consumption and market sale within producer's household is not sensitive to price changes, which seems



6. Relationships between household consumption, marketable surplus and total production for Philippine rice farms.

reasonable since rice is a commodity which fills a basic subsistence need.

There is no evidence to support a negative price response in the market supply at a given output as argued traditionally. An increase in output has a strong positive impact on the increase in marketable surplus. As a result, the total price elasticity in the supply of marketable surplus is positive. The relationships between marketable surplus (M/N) and consumption (C/N) as output per household member (Q/N) increases are summarized in fig. 6. These results suggest that increases in output attributable to the development of new technology, i.e., high-yielding varieties, or from improvements in basic infrastructure, i.e., irrigation, will have a strong positive influence on the increase in the marketable surplus for a subsistence crop; in most instances, an effect much greater than responses to price alone.

Cropping systems

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SUMMARY

The cropping systems program was expanded in 1974 with the addition of three international scientists. Programs for conducting cropping systems research were established not only in Los Baños but also at experimental sites across the Philippines and in other Asian countries. The objective of the expanded program is to develop improved and intensified rice-based cropping patterns for the vast numbers of small-scale Asian farmers. We will concentrate research on the development of cropping systems technology for rainfed rice areas where the present cropping intensity is low and where there is potential for increase.

ORGANIZATION AND NETWORK OF SITES

Multiple Cropping Department

Key to the expanded program is the establishment of a network of cooperating experimental sites in representative agroclimatic zones across South and Southeast Asia. This will make possible the sharing of results from these sites with other areas which have similar ecological characteristics. The first cooperators are in the Philippines, Indonesia, Bangladesh, and Vietnam. Others will later be added in other South and Southeast Asian countries.

A working group met at IRRI for 2 weeks and identified a number of agroclimatic zones in Southeast Asia based on rainfall patterns and physiographic and soil characteristics. They identified five macro soil/climate zones suited for multiple cropping. Later in 1974, test sites were selected in the Philippines, Indonesia, and Vietnam, using the following criteria: a) representative of major agroclimatic and soil conditions; b) in a rainfed rice area of low cropping intensity but with a potential for significant increase; c) potential priority development area of the host country; d) competent scientific leadership available to implement research and to help cooperatively plan overall research strategy; and e) country institutional support for the experimental sites.

Six cooperating experimental sites were selected this year outside of Los Baños. The IRRI station will be the central station for the network of cropping systems research.

We have conducted research for 2 years at Tanauan, Batangas, Philippines. The site has lighter soil than that at IRRI, but has a similar climate. Upland rice is the main crop. Sites were also selected in Pangasinan, which is part of Central Luzon, the rice granary of the Philippines, and at Iloilo, Visayas. Both provinces are top rice producers where rainfed rice constitutes more than 70 percent of the total rice area.

In Indonesia, sites were identified. Indramayu, West Java, is representative in terms of soils and climate of the North Coast of Java which grows approximately 1 million ha of rice, mostly rainfed. Cropping intensity is lower than for the other parts of Java and Madura. Central Lampung, southern Sumatra, is a transmigration area which is representative of future transmigration areas in Sumatra and Kalimantan. Upland rice is a main crop.

In South Vietnam, the experimental site is located at Long Xuyen, which is representative of the Mekong Delta, Vietnam's major rice-growing region.

Cropping systems research will be conducted in farmers' fields under farmer management in all outreach locations. Research teams, each composed of agronomists and an economist, will be assigned to each site to implement the cooperative research. In the Philippines, the outreach locations will be staffed cooperatively with the Philippine Bureau of Plant Industry and IRRI staff. Locations in other countries will be managed by the concerned research institutions. Baseline surveys and field experiments will begin during 1975 at the outreach locations in the Philippines (two), Indonesia, and Vietnam.

To follow up the macro agroclimatic and soil delineations submitted by the working group, a team began to survey in more detail the agroclimatic and soil zones of Bangladesh to determine more accurately the potential areas for intensified cropping and to enable research results and technology to be transferred to similar areas in Bangladesh and other countries. A climatologist collected climatic data which were already available and transferred it to cards for analysis. A soil survey will follow in 1975. After Bangladesh, the Philippines will be analyzed.

CROPPING PATTERNS FOR PHILIPPINE UPLAND RICE AREAS

Multiple Cropping Department

The major upland rice areas in the Philippines cover about 10 provinces with similar rainfall patterns. Although the southern areas have a lower

peak rainfall, at least 200 mm/mo falls for 5½ to 6½ months in all areas, and all have relatively well-drained soils. All have similar cropping system potentials, modified according to farm size and market availability. An intensive study of a Batangas upland rice area is now in its second year. Selected research trials were placed on 50 farms and weekly records were kept. We are also surveying the cropping intensity and socio-economic characteristics of 36 farmers in 4 barrios. They average 44 years of age, have 4 years of education, farm slightly less than 1 hectare, own one draft animal, and have a cropping intensity of about 1.8 crops/year.

Upland rice farms are divided into several land parcels, with a range of types of land use on each. The major cropping patterns are: mixed tree crops (homestead area); trees interplanted with annual crops; sugar cane; continuous vegetables; field crops with occasional vegetables; and field crops only. We are investigating the rice-field crop patterns which account for most of the areas in all upland rice-growing districts. The crops include upland rice, corn (grain and green ear), peanuts, mung bean, cowpea, sweet potatoes, sorghum, and soybeans. These crops represent the greatest potential for increasing cropping intensity across upland rice areas. In other upland rice areas, farm configuration changes mostly in the fraction of the farm devoted to each pattern.

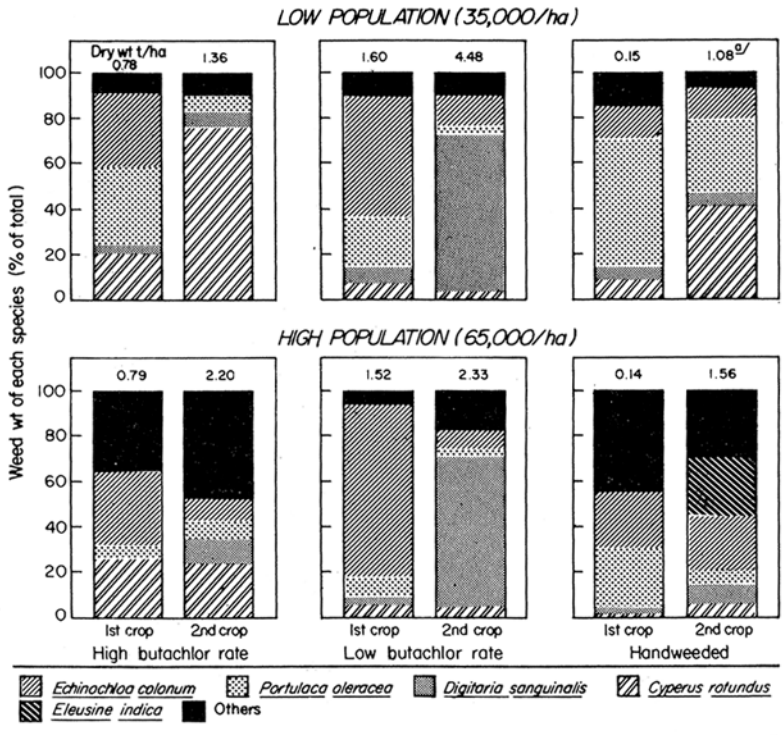
The most suitable field-crop pattern seems to be upland rice (planted in May-June) followed by corn (planted in Oct.). Depending on the timing of rains, soil pH, farm size, power availability, and markets, crops such as cowpea, mung bean, soybeans, sorghum, or peanuts can be grown instead of, or after, corn. The major factors that limit higher productivity for most crops following rice are weeds, white grub (*Leucopholis irrorata*), and low pH. Nematodes (*Meloidogyne incognita* and *Rotylenchulus* sp.) and insects (bean fly, *Ophiomyia phaseoli* Tryon, and aphid, *Aphis craccivora*) are particularly serious on legumes. Trials are in progress to determine ways to solve these problems.

A replicated trial in a farmer's field near IRRI was conducted on a soil type, and in a rainfall pattern, similar to that of Batangas. Corn, upland rice, and cassava were grown in monoculture and intercrop combinations beginning with the first rains in June. A June crop of upland rice was followed by a crop of sorghum. The corn/rice intercrop combination followed by sorghum yielded considerably higher than did the cassava/rice intercrop (Table 1). The corn-rice-sorghum system requires considerably more tillage than do cassava combinations but is more profitable under high management. Cassava intercrop combinations are better suited to areas where animal or tractor power is limiting. Sorghum as a second crop after rice is suited when the rice comes off late enough to ensure that the first crop of sorghum would be planted in dry weather. If the field is ready for a second planting in September or October, corn or cowpea for green harvest are suitable. Sorghum or soybeans are suited in November. The best time

Table 1. Yields of alternate cropping patterns of corn, rice, cassava, and sorghum under rainfed conditions. Farmer's field, Laguna province, Philippines, June, 1973 to April, 1974[a].

Crop	Yield (t/ha)							
	Monoculture			Intercrop			Sorghum main crop	Sorghum ratoon
	Corn	Rice	Cassava	Corn	Rice	Cassava		
Corn	4.2						3.7	2.5
Rice		3.8					3.8	2.5
Cassava			18.4					
Corn + rice intercrop				3.3	2.0		3.7	2.5
Corn + cassava intercrop				3.8		9.2		
Rice + cassava intercrop					0.3	14.7		
Corn + rice + cassava intercrop[b]				2.4	0.9	13.2		
Corn + rice + cassava intercrop[c]				2.6	0.5	13.3		

[a]Averaged across 4 nitrogen levels. [b]Corn at 20,000 plants/ha, cassava at 10,000 plants/ha. [c]Corn at 30,000 plants/ha, cassava at 15,000/ha.



1. The shift of weed species in response to corn plant population and weed control treatment. IRRI, February–July, 1974.

for dry cowpea or mung bean is from late November to early January. Upland rice is the best crop for the first season, with the second (or third) crops depending on the timing of the monsoon and the date of rice harvest. Most farmers should diversify their second crops.

A report on upland rice systems is being prepared.

WEED MANAGEMENT

Multiple Cropping and Agronomy Departments

Weed research in cropping systems concentrates on the management of weeds by all available methods throughout the cropping pattern. Because the weed community in our fields is determined largely by previous cultural practices, we are interested in the long-term effects of our control measures. With intensive cropping under high management, weed species commonly shift toward the difficult-to-control grasses and sedges. The control of such shifts is the objective of much of our weed management work. We have found that both the method of weed control and the crop density influence the weed community and its makeup in subsequent seasons. With high rates of chemicals continuously being applied, the weed community rapidly shifts. In a two-season weed study we found that butachlor at 1.2 kg a.i./ha shifted the weeds in the second season to an almost uniform stand of the difficult-to-control *Cyperus rotundus* under low corn population (fig. 1). At high populations, however, the shift was not significant. At lower levels of butachlor, the weeds shifted to *Digitaria sanguinalis.* Because this species grows slowly and appears in the field shortly before harvest, it has little effect on corn yields.

When hand weeded once at 21 days, the weed community remained more mixed. But at low corn populations, the weed population still shifted toward *Cyperus.* In all crops tested the weeds shifted toward *Cyperus* as chemical rates increased (Table 2). The effect of plant density seems greatest with corn. These and later results strongly suggest that for long-term control of the more difficult and persistent weed species, a low rate of herbicide followed by light weeding and relatively high plant densities (for some crops) is preferable. The

Table 2. The effect of weed control method on *Cyperus rotundus* in the second crop season for three crops at two planting densities. IRRI, February–July, 1974.

Treatment	*Cyperus rotundus* (% of total weed community)					
	Corn		Mung		Soybean	
	Low density	High density	Low density	High density	Low density	High density
Unweeded	0	0	2	9	3	5
Butachlor (0.4 kg a.i./ha)	3	4	20	21	16	19
Butachlor (1.2 kg a.i./ha)	76	24	27	59	52	59
Hand weeded	41	6	10	3	13	12

weed shift may differ for other crops, with *Digitaria, Portulaca,* or others assuming dominance. It seems relatively easy, however, to manage this shift.

A continuing weed shift experiment has demonstrated quite conclusively the effects of continuous management and amply verified the hypothesis that a combination of low rates of chemical combined with light mechanical tillage is superior to other methods. A field was allowed to produce crops of weeds for two crop seasons in 1973. The high weed population comprised seven species. Five successive crops have now been growing on the same land with rice in the wet seasons and continuous upland crops in the dry seasons. Corn was used as the main dry-season crop after two seasons because of increasing soil residual effects with legumes. The plots were split for the rice crop with half puddled and half nonpuddled. Four levels of weed control were used: high mechanical (one rotary weeding by hand tractor followed by one hand weeding); low mechanical (one rotary weeding only); high chemical (butachlor at 1.2 kg a.i./ha with 2.4 kg a.i./ha used for the fifth and sixth crops); and low chemical (butachlor at 0.6 kg a.i./ha followed by one light hand weeding). The yields for corn in the fifth crop show that the low chemical plus handweeding treatment gave better yields at high crop density (Table 3). All treatments, however, were designed to give a commercially practical level of weed control. One can see why low chemical treatments were superior to high chemical treatments, especially at low crop density, by looking at the weed species prevalence (Table 4). Total weed weight was considerably higher in the high chemical treatment. The weeds present were almost exclusively *Cyperus rotundus,* especially in the nonpuddled treatments. This rapid shift to *Cyperus* is common on experiment stations where chemicals are used at high rates, but it is seldom seen on farmers' fields where chemicals are not used. With low levels of chemicals and a single light hand weeding the weed number remains low and the species distribution remains mixed. Without chemicals, *Cyperus iria* comes in at lower crop densities. High crop density is especially effective in keeping out both species except when high rates of chemicals are applied. The effect of high crop density on light transmission through the canopy is seen throughout the growing season

Table 3. The effect of five continuous seasons of weed management on the yield of corn. IRRI, March–June, 1974.

Treatment	Yield (t/ha)			
	High crop density[a]		Low crop density[b]	
	Nonpuddled soil	Puddled soil	Nonpuddled soil	Puddled soil
Low mechanical	3.5	4.1	3.2	3.3
High mechanical	4.1	3.6	3.8	4.0
High chemical	4.1	3.7	3.0	3.2
Low chemical + handweeding	4.4	4.3	3.6	3.5

[a]40,000/ha. [b]80,000/ha.

Table 4. Effect of soil and weed management on four common weed species after five-crop seasons. IRRI, June 1974.

Species	Weed management	Dry weed weight at harvest (kg/ha)			
		High plant density		Low plant density	
		Puddled soil[a]	Nonpuddled soil	Puddled soil	Nonpuddled soil
Portulaca oleracea	Low mechanical	100	91	490	110
	High mechanical	6	110	94	123
	High chemical	311	9	307	54
	Low chemical	26	17	124	25
Digitaria sanguinalis	Low mechanical	3	288	49	307
	High mechanical	0	4	2	24
	High chemical	0	0	22	3
	Low chemical	0	0	0	6
Cyperus rotundus	Low mechanical	24	19	140	243
	High mechanical	0	0	50	80
	High chemical	318	550	657	1260
	Low chemical	18	19	184	283
Cyperus iria	Low mechanical	56	5	140	149
	High mechanical	26	7	134	143
	High chemical	0	0	0	0
	Low chemical	0	0	5	11
		Total weed weight			
	Low mechanical	204	580	849	993
	High mechanical	39	125	336	413
	High chemical	640	580	986	1449
	Low chemical	52	44	322	327

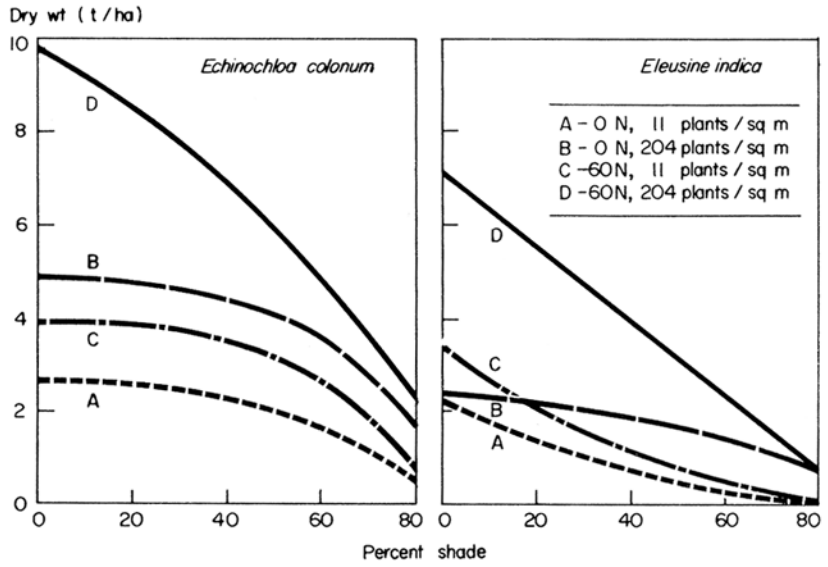
[a]For a previous rice crop.

(Table 5). *Digitaria* comes in at low rates of tillage where the soil has not been puddled. It is especially sensitive to puddling whereas *Portulaca* is more competitive after puddling. A knowledge of the responses of our major weeds to the various crops, cultural practices, and weed control methods (including response to chemicals) is extremely important to the design of weed management practices for intensive cropping systems. Because of the importance of the weed problem, we feel that knowledge of weed management principles will be one of the most important contributions of the cropping systems program.

Table 5. Percent light transmission of corn planted at two densities. IRRI, March–June, 1974.

Days after seeding	Light transmission (%)	
	High density (40,000/ha)	Low density (80,000/ha)
18	82	97
30	19	34
41	10	20
51	17	39

The response of weed species to management is learned both by observations under different management conditions and by weed studies. To study shade tolerance, slatted bamboo frames were used to simulate 50 percent and 80 percent shade patterns under a crop canopy. Previous studies had shown that *Cyperus rotundus* is highly sensitive to shade. In this year's trials, *Echinochloa colonum* was compared with *Eleusine indica.* The weeds were seeded at two plant populations in pure stands at two levels of nitrogen. *Echinochloa*



2. The response of *E. colonum* and *E. indica* to shade at two planting densities and nitrogen levels.

produced more dry matter at 50 percent shade than did *Eleusine,* especially at low plant populations (fig. 2). It responded much less than *Eleusine* to low levels of shade but its production dropped more rapidly at higher shade levels. *Cyperus,* on the other hand, is markedly reduced by even low levels of shade. *Portulaca oleracea* is relatively more shade tolerant than *Eleusine* but all are less tolerant than *Ipomoea triloba.*

Weed control in crops involving upland rice (*Agronomy*). During the 1974 wet season, herbicides which looked promising for upland rice were evaluated for corn, sorghum, soybeans, mung, and peanut in farmers' fields in Batangas, Philippines.

The crops were planted on May 23 and the herbicides sprayed 3 days after seeding. The crops did not emerge until 23 days later (June 15), however, due to lack of moisture. During the dry period *Cyperus rotundus,* as well as grasses, reproduced extensively in all treatments. By the time the crops emerged, *C. rotundus* was already well established.

Insufficient soil moisture not only kept grasses and broadleaved weeds from germinating, it also lessened somewhat the desired effectiveness of the herbicides, but without causing them to lose their lethal effects on some crops.

Strong wind caused lodging in mung and broke a number of corn plants at bearing stage, which explains the erratic yields of these two crops.

Furthermore, a dry spell during the rice reproductive stage caused severe yield reductions even in the treatments where weed control was adequate. IR442-2-58, whose vegetative vigor was hardly affected by moisture stress, outgrew most weeds. It suffered a mild blast infection, however, had even poorer grain filling than did the other two experimental lines, IR937-55-3 and IR1480-147-3. The rice yields, therefore, do not indicate the quality of weed control obtained with the herbicides (Table 6).

In general, control was a direct effect of the chemicals on the weeds in the early stages of crop growth. In later stages, however, weed regrowth was either a function of the weeds which were tolerant of the chemical, or of plant type of the crop. The weed species *Ipomoea triloba* and *Commelina benghalensis,* for instance, which were tolerant of the herbicides used in this experiment, grew profusely and suppressed second growth of such susceptible species as *Amaranthus spinosus* and most grassy weeds. In the untreated plots, weed density increased in the crops with shorter plants (rices except for IR442-2-58 and legumes) and decreased in the tall crops (corn and sorghum) toward later growth stages. Although shading by the tall crops did not alter the species of weeds, it reduced their population density.

Sorghum was highly susceptible to the herbicide

Table 6. Chemical weed control on upland crops for cropping systems program involving upland rice. First cropping, farmers' fields, Cuenca, Batangas, Philippines, 1974 wet season.

Chemical	Rate (kg a.i./ha)	Yield (t/ha)					
		Rice[a]	Corn	Sorghum	Peanut[b]	Mung	Av.
A-820	2.0	1.2	2.2	3.4	1.3	0.6	1.7
AC 92553	2.0	1.5	1.5	1.4	1.4	1.0	1.3
Butachlor	2.0	0.8	1.6	5.1	1.8	1.0	2.0
C-288	2.0	0.9	1.6	3.2	0.8	1.0	1.5
Oxadiazon	1.0	0.7	1.5	2.9	1.3	1.2	1.5
USB 3153	2.0	0.9	2.0	1.3	2.0	0.9	1.4
USB 3584	2.0	1.5	1.1	0.7	2.1	0.9	1.2
Hand weeding twice		0.9	2.5	3.9	1.3	1.1	1.9
Untreated control		0.5	1.4	4.0	0.3	1.2	1.4

[a]Average of 3 experimental lines: IR1480-147-3, IR442-2-58, and IR937-55-3. [b]Pod yields at constant moisture.

treatments; its stands were reduced as much as 90 percent from the application of USB 3153 and USB 3584. Plant recovery was highest with butachlor – from 60 percent initial injury down to 30 percent. The sorghum crop produced the highest yield, 5.1 t/ha., with butachlor. This treatment was significantly better than the check treatmen, hand weeding twice.

Because peanuts are of shorter height, the weed infestation was so heavy that the untreated plot yielded only 0.3 t/ha. *C. benghalensis* practically covered the plot treated with C-288; pod yield (0.8 t/ha) was the lowest among the chemical treatments. Pod yields of about 2 t/ha were obtained from plots treated with butachlor, USB 3153, and USB 3584 (Table 6).

VARIETAL INTRODUCTION AND TESTING

Multiple Cropping Department

Mung bean. Varietal trials at IRRI, supported by farmers' field trials, have indicated that several mung bean varieties have high degrees of season specificity. Several varieties which perform well under high light intensity and long day length, when planted from February through June, will not perform well when planted from November through January (when mung is normally grown). The usual photoperiod response, a shift in days to flowering, did not occur. Plant vigor and total growth, however, decreased markedly in the November–January season with sensitive varieties such as MG 50-10A. In farmers' fields, this lack of vigor resulted in a

Table 7. Second international mung bean variety trial. IRRI, January–April 1974.

Variety	Country of origin	Days to maturity	Plant ht (cm)	Grain yield (t/ha)
M 15	Taiwan	80	58	2.0
M 317	China	79	61	2.0
UPCA 293	Philippines	90	47	1.8
M 76	USA	81	53	1.7
M 409	Peru	81	60	1.6
M 61	India	81	50	1.6
CES 28	Philippines	82	61	1.6
M 350	Korea	76	60	1.6
M 543	South Vietnam	80	60	1.6
M 304	Korea	77	49	1.5
MG50-10-A(Y)	Philippines	77	45	1.2

Table 8. Third international mung bean variety trial. IRRI, May–August 1974.

Variety	Country of origin	Days to maturity	Plant ht (cm)	Grain yield (t/ha)
MG50-10A	Philippines	60	74	1.5
MG50-10A(Y)	Philippines	60	65	1.4
M 411	India (via USA)	66	84	1.3
M 1133	India (via USA)	62	64	1.3
M 76	USA	63	69	1.2
M 350	Korea	64	68	1.2
M 333	India	64	66	1.2
M 412	India	69	71	1.2
M 232	India	64	63	1.0
M 194	India	65	62	1.0

failure to achieve complete ground cover, aggravating an already difficult weed problem in the late season. It seems imperative, therefore, that varietal testing for mung in patterns involving rice be conducted from November through January. The most crucial time for testing is late November and early December. Tables 7, 8, and 9 compare varieties across seasons. The Philippine variety CES 28 does well in late-season plantings because it is less susceptible to *Cercospora* than is MG 50-10-A.

Seedling vigor, plant height, pods per plant, and seed size were all highly correlated with total yield.

Several introduced lines look promising but none yielded significantly more than did the better Philippine varieties, although some have better disease or insect resistance.

Since mung bean is used in our intercropping systems with corn, our better varieties were tested for performance when intercropped. Corn was grown at row spacings of 1 m at a rate of 25,000 plants/ha. Two replications of a mung variety trial were interplanted in corn at the time of corn planting. In general, the high-yielding varieties in monoculture plantings also yielded better when intercropped (Table 9), with a few exceptions. When intercropped, the mung plants were taller and had fewer pods per plant but the number of days to flowering, maturity, and seed size did not change (Table 10). The incidences of insects and diseases were higher in the intercropped plants. The magnitude of these effects is closely related to the density of corn plants as well as to the light intensity. Intercropping effects are much more pronounced in the wet season with cloudy weather and low light intensities. The variety CES 14 continued to be among the top varieties in the interplant combination across a range of conditions, yielding 72 percent as much as in monoculture.

Field corn. Several early maturing varieties of field corn were compared with later maturing lines in a split-plot design (Table 11). Early maturity is critical to many of the cropping patterns used in multiple cropping. While it does not yield as well as do other lines, it fits well in cropping patterns requiring early maturity. This 70- to 80-day maturity is critical in cropping patterns where corn

Table 9. Mung varietal evaluation in intercropping. IRRI, January–March 1974.

Variety	Mung yield (t/ha)		Relative yield when planted in corn (%)
	Without corn	With corn	
CES 55	1.6	0.7	46
M 350	1.6	0.7	43
MV 15-2	1.5	0.9	57
CES 28	1.5	0.7	48
MG50-10A	1.4	0.7	47
S-8 (yellow)	1.3	0.5	34
UPCA Acc. #291	1.3	0.7	57
M 304	1.3	0.5	34
M 198	1.2	0.4	36
UPCA Acc. #236	1.1	0.6	55
EG #3	1.1	0.6	50
UPCA Acc. #304	1.1	0.4	32
CES 14	1.1	0.8	72

Table 10. Response of mung varieties to intercropping with corn. IRRI, January–March, 1974.

Crop	Yield (t/ha)	Time of flowering (days)	Maturity (days)	Plant ht (cm)	Pods (no./plant)	1000-seed wt (g)	Insect damage[a]	Powdery mildew[b]
Mung	1.2	35	79	49	20	54	2.6	0.4
Mung + corn	0.6	35	79	55	9	54	3.5	0.6

[a]Taken at 48 days after seeding (1 = light damage; 5 = heavy damage). [b]Taken at 60 days after seeding (0 = no visible infection, 5 = severely infected).

is intercropped with annuals of longer duration such as rice or peanut. In the current trial, maturities of several varieties, such as Thai Composite, were somewhat later than usual. The Philippine variety Cale Orange Flint yielded well and had early maturity.

This trial demonstrates the availability of early maturing material for breeding programs and the potential for both high yield and earliness.

Soybean. Soybean varieties continue to vary in performance (Table 12). Requirements are extremely demanding for varieties adapted to specific locations and seasons. Plant height and number of pods per plant both increase under long day length. Seedling vigor is extremely critical in soybean. Because of its vigor, the variety Hsih Hsih, while not high yielding, is much easier to grow than are other varieties. Tainung 3 is also suitable, while Multivar 80 and Clark 63 give poor stand establishment and are difficult to manage in farmer field trials. For planting under long days (March–August), several varieties appear suitable, including Tainung #3. For the late rainy season plantings (September–December), when most soybeans would be grown, however, good varieties are not available which combine seedling vigor with yield.

Vegetable soybeans from Japan are available which combine good seedling vigor with both high seed yield and high green pod yield. The germination is low and seedling vigor poor from several Japanese lines produced from locally produced seed. Kuro-Daizu and Shiro-Daizu continue to excel in dry-season plantings.

Sweet potato. Thirty breeding lines from the Asian Vegetable Research and Development Center (AVRDC), Taiwan, are being increased for further testing.

Cowpea. More than 200 cowpea lines have been screened at IRRI. The top 10 are well adapted (Table 13). Under conditions of low management (minimum tillage after paddy rice), EG #1 is superior because of its vigorous growth and spreading plant type. With high management the determinate types of shorter stature are more

Table 11. Field corn variety trial. IRRI, February–June, 1974.

Variety	Days to 50% silk[a]	Days to maturity[b]	Plant ht (cm)	Yield (t/ha)
T 66	60	107	270	8.2
Thai composite (early)	52	99	260	7.1
UPCA Var. 1	56	108	300	6.5
Cale orange flint	49	95	250	5.1
DMR 2	55	100	280	4.7
BPI 1	55	101	320	4.7
UPCA Var. 3	57	100	255	4.7
UPCA Var. 2	51	100	275	4.4
Penjalinan	46	77	230	4.3
Kodok	42	75	200	2.6
CV[c] (%)	1.1	0.4	5.8	10

[a]When 50% of the plants had silked. [b]When all grain had a well-developed black layer. [c]Coefficient of variation.

Table 12. Soybean variety trials. IRRI, dry season (January–April) and wet season (May–September), 1974.

Variety	Seedling vigor[a] dry	Plant ht (cm)		Days to maturity		1000-seed wt (g)		Pods (no./plant)		Rust[b]		Yield (t/ha)		
		dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	av.
Shiro daizu	3.2	55	138	95	113	272	145	32	43	1.5	2.0	2.9	1.0	2.0
Multivar 80	2.5	49	87	90	88	189	120	32	50	3.5	4.0	2.5	1.6	2.1
CES 16-3	3.5	67	119	95	89	198	133	41	41	2.2	3.0	3.0	1.1	2.1
Clark 63	2.2	71	118	90	94	173	126	46	83	1.8	2.7	2.9	1.5	2.2
Tainung 3	3.8	43	65	95	96	219	163	29	58	1.5	3.0	2.6	1.9	2.3
Kailua	2.2	57	99	91	89	222	147	28	45	3.5	2.3	2.4	0.9	1.7
Hsih hsih	4.0	29	39	90	79	229	136	23	40	3.5	3.0	2.0	0.8	1.4
EG Special	3.5	51	72	95	88	256	166	23	43	4.0	5.0	2.1	0.7	1.4
TK 5	2.5	43	70	96	88	199	99	33	56	3.8	4.0	2.5	0.7	1.6
Kuro daizu	3.4	59	177	95	124	253	202	43	90	1.2	4.0	3.4	1.6	2.5
CV[c] (%)	16.3	9.4	8.6	0.9	1.5	6.2	11.0	14.6	16.1	14.3	7.5	7.7	17.0	

[a]Visual rating at 24 days after seeding (1 = low vigor; 5 = high vigor). [b]At 65 days after seeding (1 = none, 5 = solid coverage). [c]Coefficient of variation.

desirable because they are more concentrated and easier to harvest. All of the higher yielding varieties have good seedling vigor.

The correlation between seedling vigor and yield among 36 varieties in the early trial was 0.61 (fig. 3). More important, however, seedling vigor was correlated with seed size (fig. 4), which enables lines to be screened for seedling vigor simply by sizing the seed. In legumes, seedling vigor is extremely important in stand establishment, a major problem in farmers' fields. The correlation of seed size and yield was 0.33 in our trial, but it should be higher in farmers' fields. Under conditions of high virus infection, the red-seeded types would be hit especially hard.

SOIL TILLAGE STUDIES

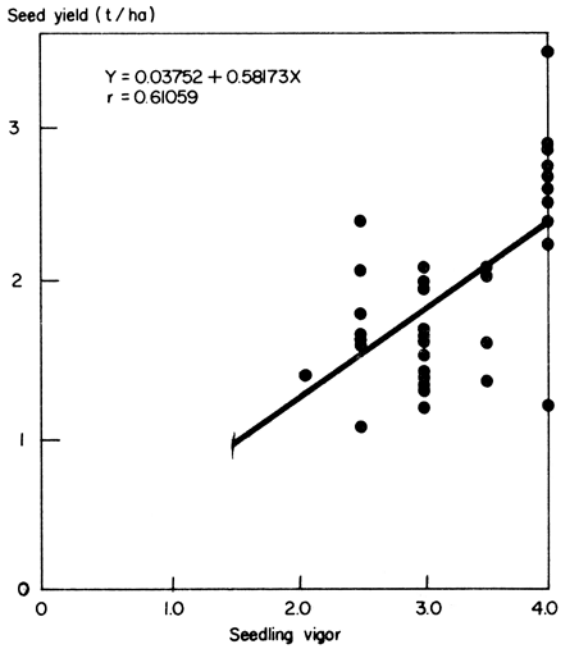
Multiple Cropping Department

Tillage problems are among the major factors which limit the intensification of upland crops on heavy

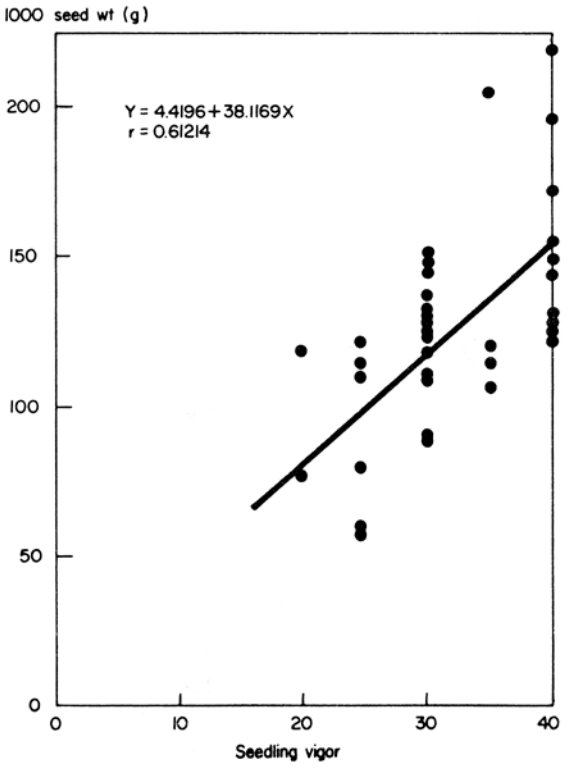
Table 13. Cowpea variety trials. IRRI, dry season (January–April) and wet season (May–September), 1974.

Variety	Seedling vigor[a] dry	Days to final harvest		Plant ht (cm)		1000-seed wt (g)		Powdery mildew	Rust[b]	Anthracnose[b]	Virus[b]	Dry seed yield (t/ha)		
		dry	wet	dry	wet	dry	wet	dry	wet	wet	wet	dry	wet	av.
EG #1	4.0	80	80	136	138	161	151	0	1.0	1.0	1.0	3.4	2.1	2.8
EG #2	4.0	78	80	90	94	124	111	0	1.0	1.0	1.0	2.7	2.1	2.4
EG #3	4.0	78	80	125	128	128	121	0	1.0	1.0	1.0	2.8	1.8	2.3
Red cowpea 6-12G	4.0	70	69	62	65	128	111	0	5.0	1.0	1.0	2.8	1.3	2.1
California blackeye	4.0	75	73	97	114	194	167	0	3.5	1.0	1.0	2.6	1.5	2.0
Red cowpea 6-1	4.0	73	73	60	62	117	108	0	5.0	1.0	1.5	2.5	1.5	2.0
AVRDC 6206	2.5	79	80	76	79	55	51	0	1.0	1.5	1.5	2.4	1.5	2.0
Red cowpea 6-12 W	4.0	71	69	70	69	115	107	0	5.0	1.5	1.5	2.6	1.0	1.8
Red cowpea 6-14	4.0	74	73	81	84	179	161	2.0	3.5	1.0	1.0	2.3	0.9	1.6
Cowpea #16	3.0	72	69	58	51	100	89	2.5	3.0	1.5	1.0	2.1	0.8	1.5
CV[c] (%)	12	1.9	–	12	11	4	4	50	21		10	17		

[a]Visual rating at 22 days after seeding (1 = low; 5 = high vigor). [b]0 = none; 5 = severely infected. [c]Coefficient of variation.



3. Yield and seedling vigor for 36 varieties of cowpea. IRRI, January–April, 1974.



4. Seedling vigor and seed weight for 36 varieties of cowpea. IRRI, January–April, 1974.

Table 14. The effect of different degrees of puddling on the bulk density of Maahas clay and the condition following conversion back to upland. IRRI, 1974.

Degree of puddling	Bulk density	Clods more than 26 m in diameter after conversion (%)
Undisturbed	1.5	
Flooded, not puddled	1.5	41
1 plow, 1 harrow (wet)	1.6	56
1 plow, 3 harrows (wet)	1.6	55
1 plow, 3 harrows, 1 transplant (wet)	1.6	55
1 plow, 1 harrow, 1 transplant, 1 rotary weed (wet)	1.7	63

rice soils. The response of different soil types to tillage at high moisture levels and the difficulty of converting from puddled to upland conditions are both important. A wide range of factors contributes to both aspects; soil texture and clay type are most important. Studies on Maahas clay show that bulk density changes considerably with degree of puddling (Table 14). This is typical of clay soils of 2:1 clay type. The degree of difficulty of conversion back to upland is directly related to the relative change in bulk density upon puddling. As bulk density increased, the soil became more cloddy when tilled to convert it back to upland. A soil's tillage capability may be closely related to the degree of change in bulk density upon puddling; this might form the basis for soil classifications.

CROP RESIDUAL EFFECTS

Multiple Cropping Department

At first, we emphasize the use of grain legumes to increase cropping intensity in rice-based systems. It soon became apparent, however, that the use of legumes in a rice-based cropping pattern more than once per year led to reduced yields of the legumes and of some other crops. In the case of bush sitao (*Vigna sinensis* Stick), the buildup of the soil-borne pathogens *Sclerotium rolfsii, Rhizoctonia solani,* and *Fusarium* sp. was a major factor in reducing yields. In most crop combinations, nematode counts have remained low and were not considered a factor. Growing seven crop species continuously on the same plots for 6 months signifi-

cantly affected growth of succeeding crops. Planting mung bean and soybean in previous mung plots reduced germination by a third compared with planting these crops in previously fallow plots. The plant height and yield of mung bean are most affected by previous crops (Table 15). Following mung bean with mung bean reduces plant vigor and yield, particularly in the wet season. Fertility differences in these trials were minimized by using equal amounts of fertilizer for all crops. In a similar trial in a farmer's field, yields of the second crop were similarly reduced under rainfed conditions (Table 16). A test of residual effects after mung variety trials generally showed little difference between lines in causing detrimental effects on following crops of mung. The line M90, however, seemed to have a more pronounced effect.

During 6 months of cropping we determined the residual effects of six crops: corn, cowpea, sweet potato, mung, soybeans, and peanut. We then tested the residual effects of these crops on eight weed species direct seeded in the same plots in the following season. Of the eight species *(Ipomoea triloba, Amaranthus* sp., *Eleusine indica, Digitaria sanguinalis, Echinochloa colonum, Rottboelia exaltata, Portulaca oleracea,* and *Cyperus rotundus),* only *Portulaca* significantly differed in total dry weight across treatments. Its growth was reduced on treatments where corn and sweet potato were previously grown. One difficulty was the high variability in weed stands and growth. The coefficient of variation was 22 percent for *Portulaca* and higher for other species. Some crops seem to adversely affect growth of weeds in subsequent seasons, but not enough to significantly influence the crop and weed combinations tested.

Several attempts were made to correct the adverse effects of mung on mung. Application of 200 kg/ha of N, P, and K, chicken manure, and foliar sprays of ferrous sulfate all partially corrected the effects.

Farmers who have experienced problems of growing successive crops of legumes say that a few months of drying during the dry season removes the effect of previous crops. In an experiment at IRRI we established a mung bean effect by growing three successive crops of mung, then allowed different periods of drying. The field was covered with rice straw and irrigated to keep the soil moist, then strips were allowed to dry for 30, 60, and 90 days. Crops of mung, bush sitao, soybean, and sweet potato were then grown on each subplot. The performance of soybean and sweet potato was not affected by drying treatments, but mung and bush sitao yields were lower in subplots that were not dried (Table 17). Drying for at least 30 days seems sufficient to eliminate the detrimental effect of mung.

Research on crop residual effects is difficult because the effects of diseases, nematodes, and fertility are hard to distinguish and are unstable under different soil and moisture conditions. Controlled studies under greenhouse conditions will probably be necessary to determine differences. Our data, however, suggest that soybeans, mung, and cowpea or bush sitao should not be grown in the same field more than once a year until tolerant varieties or suitable corrective measures are available.

Table 15. The effect of previous crops on mung bean. IRRI, January–May, 1974.

Previous crop	Plant ht at 30 days (cm)	Total dry matter (t/ha)	Grain yield (t/ha)
Bush sitao	14	3.3	3.1
Sorghum	16	3.7	2.8
Corn	13	4.1	2.9
Peanut	14	2.8	2.7
Soybean	12	2.2	2.4
Sweet potato	16	3.3	2.7
Mung bean	12	1.3	2.2
Fallow	17	3.7	2.8

Table 16. The effect of previous crops on seed yield of mung bean and cowpea. Farmer's field, Laguna province, Philippines, September–December 1973.

Previous crop	Yield (t/ha)	
	Mung	Cowpea
Mung	0.6	0.7
Cowpea	0.8	0.5
Sweet potato	0.7	0.6
Field corn	0.8	0.7
Soybean	0.9	0.6

Table 17. The effect of drying on removal of mung bean residual effects. IRRI, November 1973–March, 1974.

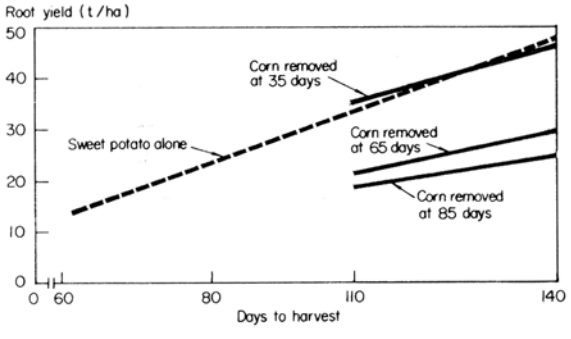
Treatment	Mung[a]			Bush sitao[a]		
	Grain yield (t/ha)	Total dry matter (t/ha)	Plant ht (cm)	Grain yield (t/ha)	Total dry matter (t/ha)	Plant ht (cm)
Continuously wet	1.6 b	4.5 b	65 c	1.6 b	3.6 a	73 a
30 days of drying	2.0 a	5.0 ab	68 bc	1.9 a	3.8 a	75 a
60 days of drying	2.0 a	6.0 a	72 a	1.8 a	4.4 a	76 a
Completely dry	1.9 a	5.6 a	71 ab	1.8 a	4.5 a	74 a

[a]For each column, means followed by a different letter are significantly different at the 5% level.

INTERCROPPING PATTERNS

Multiple Cropping Department

Continuing studies of planting arrangements and fertilizer practices for common intercropping patterns continue to shed light on the reasons for their use and on their potentials in modern agriculture. In corn-sweet-potato intercropping trials, corn markedly affected sweet potato (fig. 5). Corn was intercropped at a population of 40,000 plants/ha. The corn-alone check was at 60,000 plants/ha. Sweet potato was at 53,000 plants/ha, both in corn and alone. Both crops were planted at the same time using 50, 150, 150 kg/ha of N, P, K respectively, applied basally and 50 kg N/ha applied at 25 days after seeding. Yields of sweet potato (variety BNAS 51) increased almost linearly over time up to 140 days. Where corn (variety Thai Composite, early) was intercropped and left for more than 35 days, the total number of roots decreased. If the corn was left longer than 65 days, little further reduction in root numbers was seen. Thus, root number seems to be determined before 65 days of age, after which few new roots will be formed, even after removal of the corn (Table 18).



5. The effect of corn intercrop on sweet potato yield. IRRI, January–June, 1974.

When corn was intercropped, the corn yields at 85 days decreased from 2.8 t/ha to 2 t/ha. Green ear weight (65-day harvest) decreased from 9.3 t/ha to 5 t/ha; most ears were too small to be marketed green. Previous trials have shown that corn yields well when intercropped with sweet potato if nitrogen levels are high, but the sweet potato will remain vegetative with reduced root yields. The only way to make this system viable seems to be to relay plant the sweet potato under corn no longer than 35 days before harvesting the corn, either as green or dry ears. This method would also assure a good start for the sweet potato cuttings.

A preliminary trial to determine the feasibility of using sorghum in intercrop combinations showed little potential with combinations of soybeans, peanut, or corn (Table 19). The relatively short-statured sorghum variety Cosor 2 does not do well at 2-cm row spacing, and competes heavily with the intercrop at 1 m. When intercropped with mung, however, the mung matures early enough to avoid the severe competition. This combination shows promise for greater productivity.

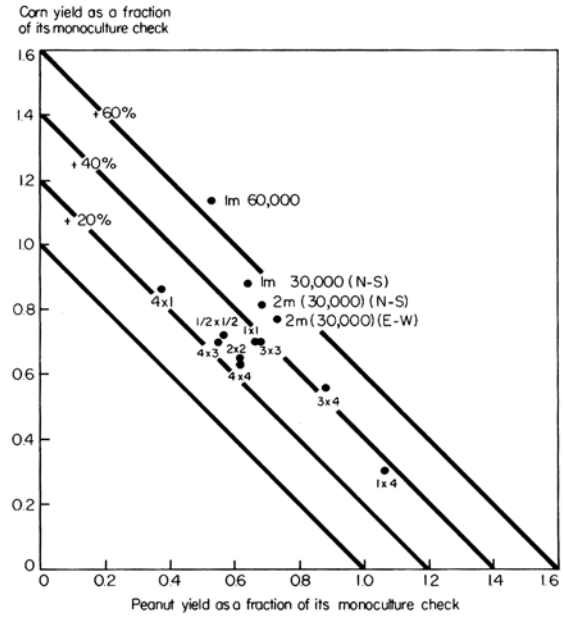
Intercropping patterns of corn-rice and corn-peanut – the most common intercropping patterns in the tropics – have been compared for responses to plant population and row arrangement. These patterns are similar in that they both use early maturing corn varieties with either rice or peanut underneath, which matures in 120–130 days. In each experiment, three types of treatments were used: 1) the row arrangements were modified without changing the numbers of plants; 2) the relative proportions of each crop were changed; and 3) the plant populations were increased.

Table 18. Effect of corn intercropping on number of roots of sweet potato. IRRI, January–June, 1974.

Days that corn was in the field	Roots[a] (103/ha)	
	110 days to harvest	140 days to harvest
0	190 a	245 a
35	194 a	174 b
65	128 b	118 c
85	133 b	123 c

[a]For each column, means followed by a different letter are significantly different at the 5% level.

In the first experiment corn was planted at 1-m spacing and peanut at 50-cm spacing, two rows per bed. NPK fertilizer was applied at 50-100-100 kg/ha at planting and 50 kg N/ha was applied as topdressing at 28 days. The experiment was irrigated, using Early Thai Composite corn variety and CES 101 peanut. In the first five treatments, each crop occupied half of the crop area, but yields were calculated on the basis of the total area (Table 20). Corn was planted in 4 rows alternated with 8 rows of peanut, then 3 rows of corn were alternated with 6 rows of peanut, 2 with 4, 1 with 2, and ½ with 1. Yields were then calculated as a fraction of the monoculture check, then the two fractions were added to give the Land Equivalent Ratio (LER) value. The LER is the amount of land needed (in hectares) to produce an amount of peanut and corn (at yield levels equal to the monoculture checks) equivalent to that produced by the intercrop treatment. The 4 rows alternated with 4 rows treatment had a 25 percent total productivity advantage, even though only half as many plants were in the field as in an equivalent monoculture area. The yield advantage did not change when row arrangement was changed or when the portion of the area planted to each crop was changed. When the peanut population was increased to that of the monoculture peanut planting, but with corn also interplanted, the LER increased to 1.5. Productivity was not affected by the row spacing of corn, whether 2 or 1, or by orienting the rows east-west or north-south. When the corn population was increased to 60,000/ha, the LER increased to 1.7, 67 percent more than monoculture. With corn-peanut, then, productivity depends mostly on total plant numbers rather than on arrangement. The LER values (fig. 6) show the cluster of treatments at a 40-percent advantage or less for low populations, and from 50 to 60 percent for higher densities.



6. Yield advantage of corn-peanut intercropping expressed in land equivalent units. IRRI, January–May, 1974.

A second experiment was conducted using the

Table 19. Yields of sorghum intercropped with soybeans, peanut, mung bean, and corn. IRRI, February–May, 1974.

	Yield (t/ha)											
	Sorghum	Soybean	LER[a]	Sorghum	Peanut[b]	LER	Sorghum	Mung bean	LER	Sorghum	Corn	LER
Sorghum alone	6.5			5.8			4.7			5.6		
Sorghum intercrop[c]	4.3	1.2	1.0	4.9	0.1	0.9	3.8	0.6	1.4	4.1	1.9	1.1
Sorghum intercrop[d]	1.9	2.4	1.0	2.5	0.7	0.9	2.1	0.9	1.3	3.4	3.1	1.2
Other crop alone		3.1			1.6			1.0			5.6	

[a]Land Equivalent Ratio. [b]Shelled nuts. [c]1-meter row spacing. [d]2-meter row spacing.

Table 20. Grain and seed yield of corn and peanut intercropped in different row arrangements and planting densities. IRRI, January–May, 1974.

Planting arrangement				Yield[a] (t/ha)		Yield as fraction of monoculture check		
Corn (1-m spacing)		Peanut (50-cm spacing)		Corn	Peanut	Corn	Peanut	LER
Row size (m)	Plants (no./ha)	Row size (m)	Plants (no./ha)					
4	40,000	8	160,000	2.7 de	1.0 cde	0.6	0.6	1.3
3	40,000	6	160,000	3.0 cde	1.1 cde	0.7	0.7	1.4
2	40,000	4	160,000	2.8 de	1.0 cde	0.7	0.6	1.3
1	40,000	2	160,000	3.0 cde	1.1 cde	0.7	0.7	1.4
½	50 cm	1	160,000	3.1 cde	0.9 de	0.7	0.6	1.3
1	40,000	8	160,000	1.3 f	1.6 a	0.3	1.0	1.3
3	40,000	8	160,000	2.4 e	1.4 abc	0.6	0.9	1.5
4	40,000	6	160,000	3.0 cde	0.9 de	0.7	0.6	1.8
4	40,000	2	160,000	3.7 bc	0.6 e	0.9	0.4	1.2
2	30,000	(N-S) Solid	160,000	3.5 bcd	1.1 cde	0.8	0.7	1.5
2	30,000	(E-W) Solid	160,000	3.3 cde	1.2 bcd	0.8	0.7	1.5
1	30,000	(N-S) Solid	160,000	3.8 bc	1.0 cde	0.9	0.7	1.5
1	60,000	(N-S) Solid	160,000	4.9 a	0.9 de	1.1	0.5	1.7
Corn alone	60,000			4.3 ab	–	–	–	1.0
Peanut alone	320,000			–	1.6 ab	–	–	1.0

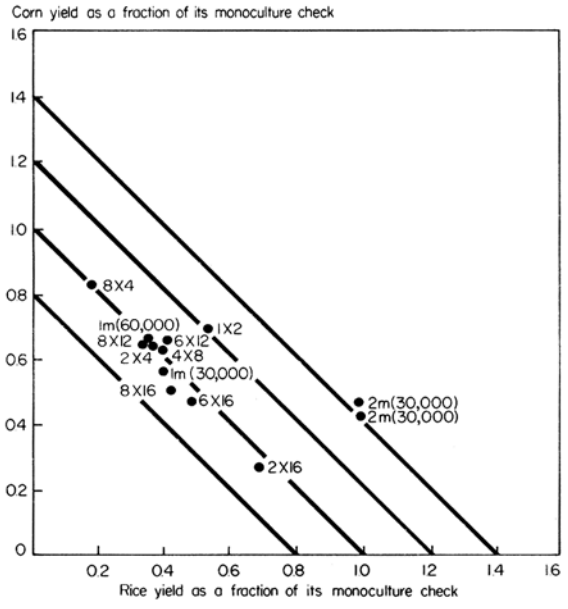
[a]Calculated for each crop as if it occupied the entire area devoted to both crops. For each column, means followed by a different letter are significantly different at 5% level.

Table 21. Yields of corn and rice intercropped in different row arrangements and planting densities. IRRI, May–September, 1974.

Corn row spacing (m)	Number of rows and arrangement		Corn-to-rice ratio	Corn yield (t/ha)	Corn yield as fraction of monoculture	Rice yield (t/ha)	Rice yield as fraction of monoculture	LER[a]
	Corn	Rice (25-cm)						
0.5	8	16[b]	1:1	2.5	0.5	1.5	0.4	0.9
0.5	6	12	1:1	3.7	0.7	1.4	0.4	1.1
0.5	4	8	1:1	3.3	0.6	1.4	0.4	1.0
0.5	2	4	1:1	3.2	0.6	1.4	0.4	1.0
0.5	1	2	1:1	3.6	0.7	1.9	0.5	1.2
0.5	2	16	1:4	1.4	0.3	2.5	0.7	1.0
0.5	6	16	3:4	2.4	0.5	1.7	0.5	1.0
0.5	8	12	4:3	3.2	0.6	1.2	0.3	1.0
0.5	8	4	4:1	4.2	0.8	0.7	0.2	1.0
2.0	continuous[c]	continuous[d]		2.2	0.4	3.6[e]	1.0	1.4
2.0	continuous[c]	continuous[f]		2.4	0.5	3.5	1.0	1.5
1.0	continuous[c]	continuous		2.9	0.6	1.4	0.4	0.9
1.0	continuous[g]	continuous		3.4	0.7	1.2	0.3	1.0
1.0	Corn alone[g]			4.0	0.8	–	–	–
0.5	Corn alone[g]			5.1[e]	–	–	–	–

[a]Land Equivalent Ratio. [b]Rice and corn rows not mixed. [c]30,000 plants/ha. [d]30,000 corn plants/ha, rice and corn rows mixed (Solid rice.) [e]Use of the monoculture check. [f]Corn and rice rows for this plant oriented east-west, all others north-south. [g]60,000 plants/ha.

same treatment on combinations of corn (Early Thai Composite) and rice (the experimental line IR2061-213-2), sown simultaneously under upland conditions. Rice yields were held down by bacterial leaf streak and bacterial blight. Table 21 shows that when half of the area was planted to each crop (1:1 ratio) there was no advantage in productivity until the row combinations were 1 × 2, or corn and rice were in close association. A similar but more pronounced effect was seen in a previous rice-corn trial using an earlier maturing, short-statured corn variety. Thai Composite matured in 90 days, which is a little too late for maximum effectiveness with rice. The productivity advantage was 42 percent when continuous rice was intercropped with corn at 2-m row spacing, but disappeared with 1-m spacing of corn. Therefore the corn-rice pattern seems to be more delicately balanced than seems corn-peanut. This may not be quite critical, however, if a taller, more vigorous rice variety is used. The distribution of LER values (fig. 7) shows that only the two high-density plantings gave a significant production advantage, and then, surprisingly, at high rice yield levels.



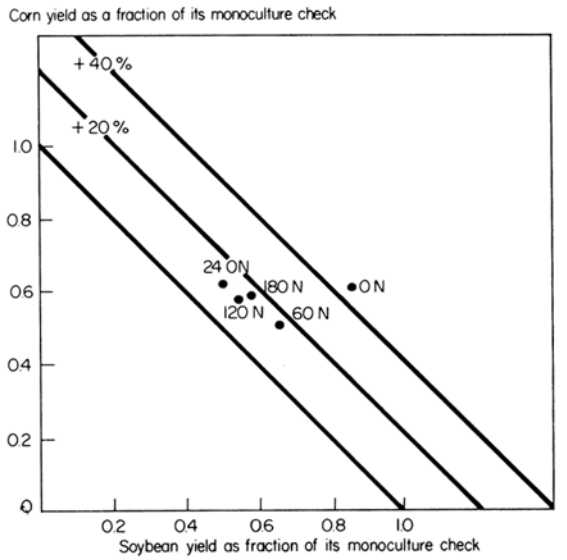
7. Effect of row arrangement and plant density on total productivity of corn-rice intercrop. IRRI, May–September, 1974.

INTERCROPPING FERTILITY STUDIES

Multiple Cropping Department

Several trials were conducted on a range of intercrop patterns to investigate if intercrop patterns are suited only to low management situations or if they can be used under higher levels of management. To test the comparative nitrogen response of a corn-soybean intercrop, corn (DMR2 variety) and soybeans (Multivar 80) were planted alone and in combination. The corn monoculture check was at 60,000 plants/ha in 1-m rows. Soybeans were planted at 400,000 plants/ha. Corn was planted at 30,000 plants/ha. Two-thirds of the applied nitrogen was placed on the corn and a third on soybeans in the intercrop. Soybean alone showed little nitrogen response (Table 22). Corn alone responded up to 180 kg/ha, giving the greatest return on applied nitrogen. The greatest yield advantage for intercropping was at zero applied nitrogen in spite of the low corn yield. The reduction in yield of intercropped soybean increased with increasing nitrogen levels as the crop balance was shifted in favor of corn. LER was constantly about 1.2 (Fig. 8). At higher nitrogen levels, therefore, there is little yield advantage to corn-soybean intercropping but there may be other advantages. The total nitrogen content of the above-ground plant parts was considerably higher in the intercrop than with either corn or soybeans for most nitrogen levels. An interesting side-effect can be seen in Table 22 in the corn + soybean treatment where the corn was planted 20 days after soybean was planted, and the corn was eradicated in the seedling stage by downy mildew. Because the corn never grew enough to compete with soybeans, the soybean yield was the same as for monoculture, showing that productivity is stable in intercropping if one component is removed early.

A phosphorus response trial of corn, mung bean, and corn-mung intercrop at IRRI showed that no combination responded to phosphorus up to 270 kg P_2O_5/ha. The corn, DMR 2, was planted at 80,000 plants/ha in monoculture and at 40,000/ha in intercrop in both 1-m and 2-m rows. The mung MG50-10A was planted at 400,000 plants/ha. The effects of several typhoons, combined with a crop residual effect, caused mung yields to be extremely poor (Table 23). Interestingly, the mung yielded poorly (100 kg/ha) but it still competed enough to cause a significant reduction in corn yield – by 0.8 tons at 1-m spacing and by 1.5 tons at 2-m



8. Yield advantage of corn-soybean intercrops across nitrogen levels. IRRI, March–June, 1974.

spacing. Contrast this with the previously reported corn-soybean trial where the corn was eliminated in the seedling stage, permitting full soybean yields. These data clarify the often-stated "insurance" factor for intercropping – if one crop fails, it will be compensated for by a second. This is true only when the crop is lost at the seedling stage early in the season before it competes with the other crop.

Equally illustrative, in a nitrogen response trial with corn-rice intercrop combinations, corn was planted alone; with rice at the same planting date; and with rice but planted 24 days later (Table 24). Rice yields were considerably lower than those of corn (2.3 t/ha compared with 6.8 t/ha). When intercropped and planted simultaneously, corn yield was reduced by 4.2 t/ha while rice added only 1.9 t/ha, illustrating the adverse competitive effect of a bad crop on a higher yielding one. When corn planting was delayed 24 days, downy mildew eliminated it in the seedling stage, removing it from competition and allowing full rice yields. The "insurance" factor is obviously not always a valid argument for intercropping, since most crop failures do not selectively remove one crop in the seedling stage. If this does destroy a seedling crop, the crop would normally be replanted. The "insurance" factor is an argument for crop diversity, not for intercropping.

A nitrogen response trial using intercropped

Table 22. Grain yield of corn (DMR2) and soybean (Multivar 80) intercropped with varying levels of nitrogen. IRRI, March–June, 1974.

Crop combination	Yield (t/ha)		LER	Total value[a] (US$/ha)
	Corn	Soybean		
		Control		
Corn	1.3	–	–	204
Soybean	–	2.0	–	600
Corn + soybean	0.8	1.7	1.47	636
Corn + soybean[b]	–	1.9	–	570
		60 kg N/ha		
Corn	3.9	–	–	612
Soybean	–	2.0	–	600
Corn + soybean	2.0	1.3	1.16	704
Corn + soybean	–	1.9	–	570
		120 kg N/ha		
Corn	4.8	–	–	754
Soybean	–	2.2	–	660
Corn + soybean	2.7	1.2	1.11	784
Corn + soybean	–	2.2	–	660
		180 kg N/ha		
Corn	5.0	–	–	785
Soybean	–	2.3	–	690
Corn + soybean	2.9	1.3	1.15	845
Corn + soybean	–	1.9	–	570
		240 kg N/ha		
Corn	5.3	–	–	832
Soybean	–	2.4	–	720
Corn + soybean	3.3	1.1	1.12	878
Corn + soybean	–	2.3	–	690

[a]At $157/ton for corn and $300/ton for soybean. [b]Corn planted 20 days after soybeans.

Early Thai Composite corn and IR2061-213-2 rice was conducted in the rainy season. Corn responded to nitrogen application, yielding from 2.1 t/ha at 20 kg N/ha to 5.4 t/ha at 150 kg N/ha. Rice, on the other hand, responded relatively less because of leaf disease (fig. 9). The intercrop combinations responded and returned intermediately except at the low nitrogen level, where they gave considerably higher returns. When intercropped, however, it seemed better to add the nitrogen to rice only, instead of adding it only to corn or splitting the application. We cannot explain this. These data

Table 23. Effect of intercropping corn and mung bean under conditions adverse to the growth of one crop. IRRI, April–August, 1974.

Crop combination	Grain yield[a] (t/ha)		LER[b]
	Mung	Corn	
Mung alone	0.7 a	–	–
Mung + corn (1-m corn rows)	0.2 b	3.8 b	1.0
Mung + corn (2-m corn rows)	0.1 b	3.2 c	1.0
Corn alone	–	4.6 a	

[a]Average of 4 replications and 4 phosphorus levels: each column, means followed by a different letter are significantly different at the 5% level. [b]Land Equivalent Ratio.

Table 24. Effect of crop failure in a rice-corn intercrop. IRRI, May-September, 1974.

Crop combination	Grain yield[a] (t/ha)	
	Corn	Rice
Corn alone	6.8	–
Corn and rice[b]	2.6	1.9
Corn and rice[c]	0.3	2.3
Rice alone	–	2.3

[a]Means across replications and nitrogen levels. [b]Planted at the same time. [c]Corn planted 24 days after rice.

differ from previous results which showed the rice-corn intercrop to be superior in nitrogen response mainly because rice performed poorly in 1974. Except for the relatively more stable corn-peanut pattern, most intercropping patterns seem to be delicately balanced and to depend on proper mixtures and good performance of both crops to be superior to a single crop grown well.

A similar trial using IR8 under irrigated conditions during the dry season gave identical results. Corn yields went to 7.8 t/ha at 180 kg N/ha, with rice yielding a maximum of 1.8 t/ha because of heavy disease infection (Table 25). In all intercrop treatments the corn yielded considerably less than its monoculture check. Total return for the intercrop combinations was less than for corn alone. The LER values averaged 1.37, indicating a 37 percent advantage of intercropping over monoculture if a farmer experienced similar conditions. Total nitrogen uptake reached a maximum of 173 kg/ha for corn, 149 kg/ha for rice, and 236 kg/ha

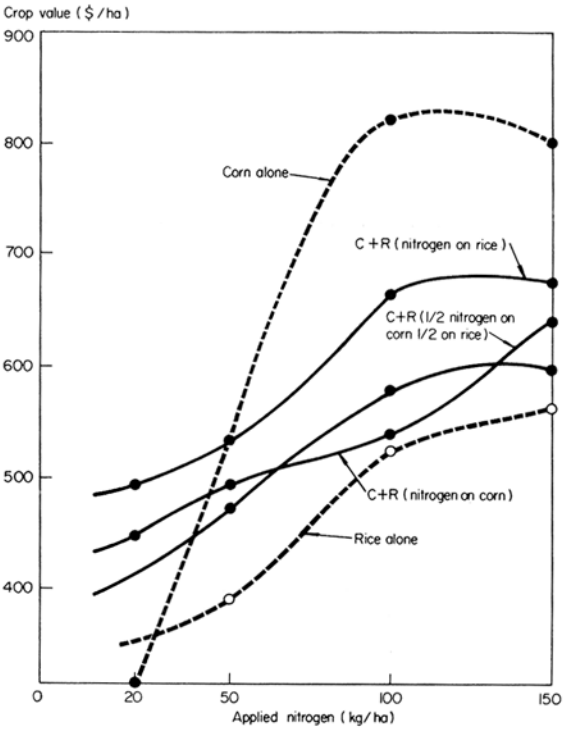
Light interception was higher for corn alone with no nitrogen applied, but was similar for all patterns at higher nitrogen levels.

In a farmer's field trial of corn-rice intercrop in Cale, Batangas, Philippines, the rice line IR2061-522-6 was completely destroyed by drought. The corn alone went from 1 t/ha at zero N to 2.5 t/ha at 210 kg/ha of N. When intercropped with rice, the corn yield averaged 68 percent of the monoculture check across nitrogen levels, falling below 50 percent only at the zero level of nitrogen.

YEAR-ROUND CROPPING STUDIES

Multiple Cropping Department

Seven crops (peanut, dry soybeans, green soybeans, sorghum, sweet potato, corn, and mung) have been grown continuously for several cropping seasons on a well-drained field at the IRRI farm with year-round irrigation (fig. 10). Varieties and management levels were selected to give maximum



9. The response of corn, rice, and corn-rice intercrop combinations to nitrogen levels and method of placement. IRRI, May–September, 1974.

Table 25. Yield of corn (Early Thai Composite) and rice (IR8) intercropped at varying levels of nitrogen. IRRI, February-May, 1974.

Crop combination	Yield (t/ha)		LER	Total value[a] (US$/ha)
	Corn	Rice		
		0 kg N/ha		
Corn	4.3	–	–	647
Rice	–	0.9	–	135
Corn + rice	2.4	0.7	1.33	467
		90 kg N/ha		
Corn	7.7	–	–	1161
Rice	–	1.6	–	246
Corn + rice	3.5	1.6	1.46	755
		180 kg N/ha		
Corn	7.8	–	–	1175
Rice	–	1.2	–	184
Corn + rice	4.3	0.9	1.34	795
		270 kg N/ha		
Corn	7.6	–	–	1140
Rice	–	1.8	–	284
Corn + rice	4.4	1.4	1.36	883

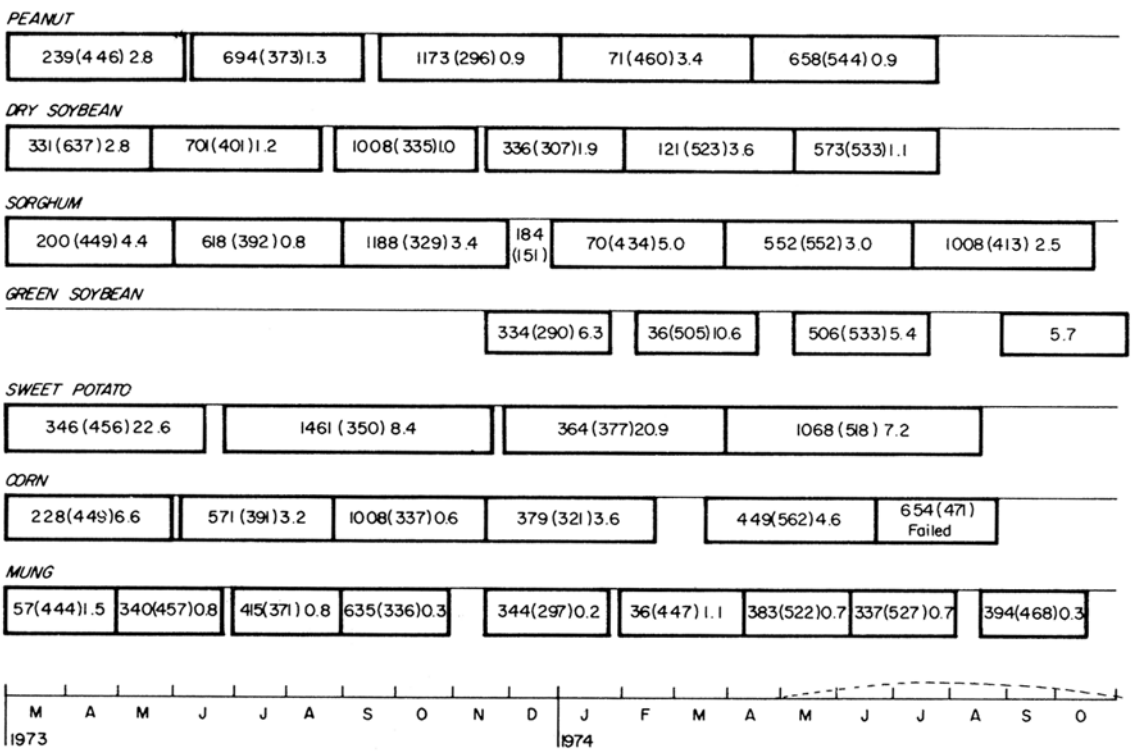
[a]At $157/ton for rice and $150/ton for corn.

yields. After the first few seasons the crops were rotated seasonally to avoid residual effects. Yields of all crops were negatively correlated with rainfall and positively correlated with light intensity. Total yearly production or production per hectare per day for these seven crops do not compare favorably with that of rice, which thrives in a wet environment. These data reflect average crop production under good management for our environment but do not represent potential cropping patterns, since different crops would normally be chosen to fit the season. Nor do the yields represent the maximum obtainable for any single season, since planting dates were determined by the crop timing and not necessarily by optimum planting time. Green soybean was added to the trials because of its relatively lower sensitivity to rainfall.

APPLIED RESEARCH

Rice Production Training and Research Department

Applied research in cropping systems was concentrated on rainfed and upland rice systems. The ongoing work in the Philippine provinces of



10. Planting dates, yields, rainfall, and solar radiation for 7 crops grown continuously. IRRI.

Bulacan and Nueva Ecija was expanded to 16 additional provinces representing the four rainfall belts in the Philippines.

VARIETY TRIALS

Rice Production Training and Research Department

Fourteen variety trials were conducted in Bulacan and Nueva Ecija provinces, Philippines, during 1974. In each trial, 19 rice selections and IR26 were used. Three were conducted under upland conditions, four broadcast under puddled conditions, six transplanted, and one direct seeded in dry soil.

The fertilizer application was 90-30-30 NPK with phosphorus and potash applied as basal and the N applied in three split doses at 15, 35, and 55 days after rice emergence.

Butachlor was used as the weed control treatment. Poor weed control was obtained on the three upland plots and on the rainfed plot when butachlor was applied on dry soil and seedbed preparation was inadequate. These plots later had to be hand-weeded. Butachlor sprayed on the plots that had been direct seeded on puddled soils provided excellent weed control. The transplanted plots were treated with butachlor granules at the rate of 2 kg a.i./ha. Weed control was excellent.

One of the trials which was direct seeded on dry soil was seeded May 30 in San Rafael. Yields were excellent on the light soil of San Rafael, however, because the rainfall was quite good in the area (Table 26).

The three upland trials were seeded from June 7 to 19. Trial 1 was located in San Rafael, trial 2 in San Miguel (Gregorio Araneta Machineries, Inc. farm), and trial 3 in Gapan.

Table 27 compares the yields of rice direct seeded on dry soil; direct seeded on puddled soil; transplanted rice; and upland rice. The plot direct seeded on dry soil yielded considerably higher than did the plots direct seeded on puddled soil, the transplanted plots, and the upland plots. The puddled plots were seeded somewhat later than the dry-seeded plots, and were exposed to more drought.

Table 28 indicates the performance of the 19 selections and IR26 when transplanted on upper and lower bunds. Disregarding trial 3 on the lower bund (where an unidentified soil problem was encountered), the average differences in yields were small – 0.4 t/ha. The higher yields of the upper bunds are not explained; yields are usually somewhat higher on lower bunds.

Table 26. Performance of 20 rices when direct seeded under upland conditions. Bulacan and Nueva Ecija provinces, Philippines, 1974 wet season.

Designation	Yield (t/ha)			Mean
	Trial 1	Trial 2	Trial 3	
IR26	0	0	0	0
IR2031-354-2	0.8	0.6	0	0.5
IR2031-724-2	0.7	0.2	0	0.3
IR1514A-E597-2	1.8	0	0	0.6
IR2070-747-6	1.8	1.6	0	1.1
IR2042-175-3	1.0	0	0	0.3
IR2035-290-2	0.9	0	0	0.3
IR2071-88-8	2.1	0.3	0	0.8
IR2071-179-9	0	0	0	0
IR2071-588-6	2.0	1.4	0	1.1
IR2071-625-6	3.4	0	0	1.1
IR2061-214-3	3.0	2.6	0	1.9
IR2061-213-2	1.4	0.3	0	1.6
IR2061-464-2	3.1	2.5	0	1.9
IR2061-522-6	3.5	1.8	0	1.8
IR2061-181-46	0	0	0	0
IR2053-522-2	1.3	0.4	0	1.6
IR2053-362-1	0	0	0	0
IR2153-189-2	0	0	0	0
IR2153-159-1	1.2	2.3	0	1.2

Table 29 shows the effect on grain yields of soil type, bund location, variety, and method of direct seeding. Good yields were obtained on both upper and lower bunds. The best yields were on rather heavy Sibul clay soil. The most important observation appears to be the difference in the yields of the different varieties. IR20 and IR2061-214-3 yielded significantly less than did IR26 and IR1561-228-3-3.

EXPANSION TO NEW AREAS

Rice Production Training and Research Department

Sixty trials were established in 20 locations to measure the effects of soil type, bund location, and method of stand establishment on the yield of four rice selections and varieties when direct-

Table 27. Performance of 20 rices when grown under three methods of stand establishment in rainfed paddies. Bulacan and Nueva Ecija provinces, Philippines, 1974 wet season.

Designation	Yield (t/ha)			
	Direct seeded in dry soil[a]	Direct seeded in puddled soil[b]	Trans-planted[c]	Upland[d]
IR26	6.3	4.2	4.2	0
IR2031-354-2	5.2	2.6	3.4	0.5
IR2031-724-2	5.3	3.5	3.2	0.3
IR1514A-E597-2	3.0	4.3	3.6	0.6
IR2070-747-6	1.6	3.1	3.4	1.1
IR2042-175-3	5.2	3.8	3.6	0.3
IR2035-290-2	3.4	3.4	3.4	0.3
IR2071-88-8	2.1	3.2	3.3	0.8
IR2071-179-9	3.1	2.7	2.8	0
IR2071-588-6	1.8	3.5	3.5	1.1
IR2071-625-1	5.2	3.6	4.1	1.1
IR2061-214-3	[e]	3.5	3.4	1.9
IR2061-213-2	1.6	2.9	3.3	1.6
IR2061-464-2	5.4	3.3	3.7	1.9
IR2061-522-6	5.8	3.9	3.8	1.8
IR2061-181-46	3.7	3.2	3.3	0
IR2053-522-2	1.8	3.5	3.6	1.6
IR2053-362-1	4.8	2.8	3.5	0
IR2153-189-2	5.9	4.8	4.0	1.0
IR2153-159-1	5.8	3.0	3.9	1.2

[a]1 location. [b]Mean of 4 locations. [c]Mean of 6 locations. [d]Mean of 3 locations. [e]Damaged by rats.

Table 28. Performance of 20 rices when transplanted under rainfed conditions. Bulacan and Nueva Ecija provinces, Philippines, 1974 wet season.

Designation	Yield (t/ha)							
	Upper bund				Lower bund			
	Trial			Mean	Trial			Mean
	1	2	3		1	2[a]	3[b]	
IR26	4.5	4.2	4.2	4.3	4.2	4.2	3.8	4.0
IR2031-354-2	4.4	3.7	3.4	3.8	4.0	2.3	2.5	3.3
IR2031-724-2	3.6	3.2	3.9	3.6	3.4	1.9	2.9	3.2
IR1514-A-E597-2	5.1	2.9	4.1	4.0	3.6	3.2	2.7	3.2
IR2070-747-6	4.3	3.4	4.2	4.0	3.4	2.5	2.4	2.9
IR2042-175-3	4.3	3.5	3.5	3.8	4.7	2.5	3.3	4.0
IR2035-290-2	4.6	3.2	3.9	3.9	3.7	2.3	2.9	3.3
IR2071-88-8	3.4	3.5	4.1	3.7	3.7	2.6	2.9	3.3
IR2071-179-9	3.3	2.4	3.2	3.0	3.5	1.7	2.8	3.2

Continued on next page

(Table 28 continued)

Designation	Yield (t/ha)							
	Upper bund				Lower bund			
	Trial			Mean	Trial			Mean
	1	2	3		1	2[a]	3[b]	
IR2071-588-6	4.4	3.0	4.6	4.0	3.7	2.3	3.2	3.5
IR2071-625-1	4.2	4.3	5.7	4.7	4.0	2.2	3.9	4.0
IR2061-214-3	3.8	3.6	5.9	4.4	[c]	1.2	2.5	2.5
IR2061-213-2	4.4	3.4	3.2	3.7	3.7	2.3	2.9	3.3
IR2061-464-2	3.8	4.2	4.8	4.3	3.8	3.1	3.4	3.6
IR2061-522-6	4.1	[d]	5.7	3.3	3.5	2.1	3.4	3.5
IR2061-181-46	4.1	3.1	3.5	3.6	3.6	2.4	3.1	3.4
IR2053-522-2	4.1	3.2	4.1	3.8	4.2	2.3	3.8	4.0
IR2053-362-1	4.2	3.1	3.8	3.7	4.0	2.5	3.5	3.8
IR2153-189-2	4.8	3.6	4.7	4.4	4.5	2.5	3.6	4.1
IR2153-159-1	4.3	4.2	5.7	4.7	3.6	2.3	3.0	3.3
Mean				3.9				3.5

[a]Planted late and with suspected soil problem. [b]Affected by drought. [c]Damaged by rats. [d]Missing data.

Table 29. Effects of soil types, bund location, and method of direct seeding on yield of four rices under rainfed conditions. Bulacan and Nueva Ecija provinces, Philippines, 1974 wet season.

Soil type	Location	Yield (t/ha)			
		IR1561-228-3-3	IR2061-214-3	IR20	IR26
			Lithao[a]		
Buenavista silt loam	Upper	5.3	1.7[b]	5.3	4.8
Sibul clay	Upper	6.7	5.7	3.1	5.5
	Lower	5.4	5.2	3.4	5.3
Bantog clay	Upper	2.6	3.0	2.1[c]	3.3
Mean		5.0	3.9	3.5	4.7
			Broadcast		
Buenavista silt loam	Upper	4.4	2.1[b]	4.5	4.8
Sibul clay	Upper	7.1	5.1	3.2	5.6
	Lower	4.0	4.5	2.9	5.9
Bantog clay	Upper	3.1	2.9	1.8[c]	3.4
Mean		4.6	3.7	3.1	4.9

[a]A native animal-drawn implement for making furrows. [b]Affected by sheath blight and rats. [c]Affected by drought.

Table 30. Effects of soil type, bund location, and method of stand establishment on yields of four rices when direct seeded under rainfed conditions. Philippines, 1974 wet season.

Area	Soil	Bund	Yield (t/ha)							
			Lithao				Broadcast			
			IR1561-228-3-3	IR2061-214-3	IR20	IR26	IR1561-228-3-3	IR2061-214-3	IR20	IR26
Aklan	Light	High	3.9	3.8	3.3	3.4	3.6	3.4	3.5	3.4
	Heavy	High	4.6	4.7	4.0	3.9	4.4	4.2	4.0	4.0
		Low	4.5	4.9	4.0	4.3	5.2	5.1	4.1	4.6
Camarines Norte	Light	High[a]	0	0	0	0	0	0	0	0
		Low	0	0	0	0	0	0	0	0
	Heavy	High[a]	0	0	0	0	0	0	0	0
Iloilo	Light	High[a]	2.0	1.5	1.1	1.4	1.4	1.4	0.2	1.0
		Low	4.4	3.9	4.5	4.8	4.2	3.8	4.7	4.9
	Heavy	Low[a]	2.7	2.1	2.4	2.4	2.4	2.1	2.3	2.5
		Low	6.2	3.0	3.8	6.5	6.4	3.1	4.3	6.9
Isabela	Heavy	Low	4.3	3.7	3.1	5.4	5.1	4.1	2.7	2.2
Leyte del Norte	Light	High[a]	0	0	0	0	0	0	0	0
		Low[a]	0	0	0	0	0	0	0	0
	Heavy	High[a]	0.8	0.8	1.0	1.1	0.8	0.6	0.9	0.7
		Low[a]	2.1	1.6	1.6	2.0	1.3	1.1	1.5	1.8
Pangasinan	Light	High[a]	2.6	0.9	1.5	1.4	1.5	0.5	1.5	0.9
		Low[a]	3.1	2.1	2.1	2.8	2.9	1.9	2.2	2.2
Misamis Occidental	Light	High[a]	0	0	0	0	0	0	0	0
		Low[a]	0	0	0	0	0	0	0	0
	Heavy	High	3.2	4.0	3.5	3.2	3.8	3.1	3.9	3.8
		Low[b]	0	0.7	2.5	4.5	1.8	0	0	3.1
Mean			2.1	1.7	1.8	2.2	2.1	1.6	1.6	2.0

[a]Damaged by drought. [b]Damaged by rats.

seeded under rainfed conditions. Only seven locations reported in 1974 (Table 30).

Table 31 compares the yields when the stand is established using the *lithao* (a native animal-drawn cultivation implement) and when broadcast. The methods used in stand establishment of direct-seeded rice do not appear to influence yields. This is important because establishing a stand of rice is considerably easier by broadcasting.

Table 32 compares the yields of the two selections and two varieties used in the trials when direct seeded on puddled soils. IR20 and IR26 performed best under this condition in the two locations that had to be puddled because of heavy early rains.

Table 31. Effect of method of direct seeding on average yield of four rices under rainfed conditions. Philippines, 1974 wet season.

Yield (t/ha)	
Drilled in row by lithao[a]	Broadcast
3.6	3.5
4.3	4.2
4.4	4.8
0[b]	0[b]
0[b]	0[b]
0[b]	0[b]
1.5	1.0

Continued on next page

(Table 31 continued)

Yield (t/ha)	
Drilled in row by lithao	Broadcast
4.4	4.4
2.4[b]	2.3[b]
4.9	5.2
4.1	3.5
0.6[b]	0.7[b]
0[b]	0[b]
0[b]	0[b]
0.9[b]	0.8[b]
1.8[b]	1.4[b]
1.6[b]	1.1[b]
2.5[b]	2.3[b]
0[b]	0[b]
0[b]	0[b]
3.5	3.7
2.6[c]	1.2[c]
2.0	1.8

[a]A native animal-drawn implement for making furrows. [b]Damaged by drought. [c]Damaged by rats and birds.

PILOT EXTENSION PROGRAM ON DIRECT SEEDING OF RAINFED RICE

Rice Production Training and Research Department

The National Food and Agriculture Council of the Philippine Government allocated a target of 10,000 ha in Bulacan province to be direct seeded at the beginning of the 1974 rainy season. Because of the fuel crisis and the late release of farmer loans for the preparation of the land at the end of the rainy season, the target was reduced to 7,000 ha in early March, and to 4,000 ha in early June. By mid-June, only 385 ha had been direct seeded.

The IRRI technician in charge of the project was selected to be rice project officer for the Philippine Government creating a leadership problem. After mid-June, it was decided to seed an additional 1,000 ha. This target was reached, but the seeding was 1 to 1½ months late. As a result, much of the seeding yielded poorly because of drought. In Santa Maria, where farmers were able to seed by May 20, yields averaged 3.4 t/ha, compared with only 1.9 t/ha when the crop was transplanted. In San Rafael, the yields were 3.8 t/ha for the direct-seeded crop, and 2.1 for the transplanted crop. In San Ildefonso, where the land was planted after May 20, the direct-seeded crops yielded less than did the transplanted crops (Table 33).

It seems essential to direct seed the crop early for good yields. To direct seed early, a good seedbed must be prepared at the end of the rainy season.

Table 32. Performance of four rices when direct seeded on puddled soil under rainfed conditions. Zambales and Camarines Norte provinces, Philippines, 1974 wet season.

Yield (t/ha)			
IR1561-228-3-3	IR2061-214-3	IR20	IR26
2.8	1.0[a]	5.1	4.6
4.0	2.9[a]	4.5	5.2
5.3	3.5	4.7	5.8
1.2[b]	1.6[b]	2.2[b]	3.8[b]
3.3	2.3	4.1	4.9

[a]Damaged by rats. [b]Damaged by drought.

Table 33. Performance of direct-seeded rice and transplanted rice under rainfed conditions. Bulacan, Philippines, 1974 wet season.

Area	Stand establishment	Farms (no.)	Area (ha)	Yield (t/ha)	Increase due to direct seeding (%)
Santa Maria	Transplant	36	59	1.9	
	Direct seeded[a]	42	59	3.4	77
San Rafael	Transplant	73	36	2.1	
	Direct seeded[a]	20	26	3.8	83
San Ildefonso	Transplant	23	36	2.1	
	Direct seeded[b]	29	44	1.1	−88

[a]Seeded early. [b]Affected by drought.

Associated formal training

SUMMARY

IRRI's training program provides trained people for all four categories of IRRI's international cooperative activities: 1) collaborative research; 2) international research networks; 3) strengthening of national capabilities; and, 4) coupling of action programs.

Staff members of government agencies and institutions concerned with rice research and extension, particularly in countries where IRRI has cooperative projects, participate in both degree and non-degree research and production programs at IRRI.

During 1974, 157 scholars, fellows, and production trainees from 24 countries studied at IRRI (Table 1). The Institute provided 80 man-years of training during the year.

Table 1. Countries which sent training participants to IRRI in 1974.

Country	Number of trainees					Total	Equivalent man-years of training
	Research-oriented			Production-oriented[a]	Others[b]		
	Scholars	Post-M.S. fellows	Post-doctoral fellows				
Bangladesh	2	2	1	3	–	8	5.83
Burma	2	–	–	5	–	7	3.58
Columbia	2	–	–	–	–	2	2.00
England	–	1	–	–	–	1	0.33
Egypt	–	–	–	2	–	2	1.00
Ghana	–	–	1	–	–	1	0.12
India	1	10	3	4	3	21	17.83
Indonesia	9	5	–	7	2	23	9.71
Iran	2	–	–	–	–	2	0.08
Israel	–	–	–	1	–	1	0.42
Italy	–	–	1	–	–	1	0.08
Japan	2	2	2	–	–	6	2.42
Korea	7	2	2	5	–	16	5.75
Liberia	–	–	–	1	–	1	0.50
Nepal	–	–	–	–	2	2	0.33
Nigeria	1	–	–	4	–	5	3.00
Pakistan	1	–	1	–	–	2	0.25
Philippines	6	1	2	9	3	21	10.33
Sri Lanka	2	–	–	2	–	4	2.92
Taiwan	4	–	–	–	–	4	3.12
Thailand	6	2	–	6	3	17	6.64
U.S.A.	2	1	–	–	–	3	1.16
Vietnam	1	2	1	–	2	6	1.71
West Germany	–	–	1	–	–	1	0.50
Total	50	28	15	49	15	157	80.11

[a]6-month rice production course and 5-month cropping systems course. [b]8-week rice field experimentation workshop.

RESEARCH PARTICIPANTS

Ninety-three individuals participated in research-oriented programs during 1974. All the research departments, as well as the library and documentation center, provided training. The demand for training was highest in rice breeding (24 trainees) and agronomy (12 trainees). Nine research trainees participated in agricultural economics, nine in entomology, seven in agricultural engineering, and seven in plant pathology. Table 2 shows the distribution of the research and research-support trainees among the disciplines at IRRI.

Research trainees have the opportunity to work for M.S. or Ph.D. degrees at the University of the Philippines at Los Baños (UPLB) while gaining research experience at IRRI. Forty-six percent of the 93 participants were enrolled in UPLB's graduate school during 1974; six received M.S. degrees.

Table 2. Distribution of different categories of research and research-support oriented trainees among departments, 1974

Department	Research scholars	Post-MS fellows	Post-doctoral fellows	Total
Agricultural Economics	5	4	–	9
Agricultural Engineering	5	2	–	7
Agronomy	7	3	2	12
Chemistry	–	1	1	2
Entomology	5	3	1	9
Library and Documentation Center	1	–	–	1
Multiple Cropping	4	–	1	5
Plant Breeding	14	5	5	24
Plant Pathology	2	4	1	7
Plant Physiology	2	2	–	4
Rice Production Training and Research	1	1	–	2
Soil Chemistry	–	1	1	2
Soil Microbiology	2	1	2	6
Statistics	2	1	–	3
Total	50	28	15	93

RICE PRODUCTION COURSES

Six-month rice production training program. Thirty-five trainees from 11 countries attended the annual 6-month rice production course from June to December. To date, more than 300 trainees from 28 countries have graduated from 10 courses.

As a benchmark, trainees are tested at the beginning and at the end of each program. Like that of other groups, the initial benchmark evaluation of the 1974 trainees was low, but the final evaluation showed that the trainees had progressed significantly (Table 3). The average score on the pre-training practical evaluation was 24 percent. It rose to 76 percent in the final evaluation. The average score for the pre-training written examination was 37 percent; final evaluation scores averaged 63 percent.

The 1974 trainees planned and implemented nine applied research trials (such as nitrogen x new selection experiments).

Short courses in rice production. Six short courses were conducted in 1974. Three 2-week courses in January and February trained rice technicians for the Philippine government's "Masagana 99" program of direct seeding rainfed lowland rice. A 3-week training program was also conducted for extension technicians who will work with applied research projects in the Institute's cropping systems program. The first 2 weeks were spent on cropping systems technology, and the third on planning, implementation, and management of applied research.

As part of their training program, the 6-month rice production trainees organized and conducted a 2-week short course for irrigated lowland rice production in November. The trainees were rice farmers; technical assistants of the joint IRRI-NIA (National Irrigation Administration of the Philip-

Table 3. Performance in practical and written examinations of participants in the 1974 6-month Rice Production Training Course.

	Pre-training evaluation (%)		Post-training evaluation (%)	
	Mean	Range	Mean	Range
Practical examination	24	3–47	76	45–95
Written examination	37	10–66	63	34–93

pines) Water Management Pilot Project in Gapan, Nueva Ecija; and South and Southeast Asian participants in the water management training program of the East-West Food Institute (Hawaii).

The sixth short course was held in December to familiarize the Institute's scholars and fellows in the disciplinary research programs with the latest improved rice technology.

CROPPING SYSTEMS TRAINING PROGRAM

Thirteen trainees from five Asian countries participated in the first 5-month training course for cropping systems, from January through May.

Several of those participating were research scientists from the network of programs in Southeast Asia.

RICE FIELD EXPERIMENTATION WORKSHOP

The Rice Field Experimentation Workshop was held from February to April to train technical staffs of rice experiment stations in the problems and practices of tropical rice production; the design and management of conventional field experiments; the use of experimental tools and scientific instruments; and the recording, analysis, interpretation, and reporting of experimental findings. Fifteen young researchers from India, Indonesia, Nepal, Philippines, Thailand, and Vietnam participated.

NAMES AND COUNTRIES OF PARTICIPANTS

The names, countries, and research project areas of individuals who completed their training during 1974 are given below. Included in the list are those studying abroad under IRRI scholarships provided by the different country programs. An asterisk (*) indicates completion of the M.S. program during the year.

RESEARCH SCHOLARS

Entomology

*Juan Gonzales**, Philippines. Resistance to the leaf folder in rice varieties.

Jeang Oon Lee, Korea. Causes of resistance to leafhoppers and planthoppers in the variety H5.

Multiple Cropping

*Mervyn Sikurajapathy**, Sri Lanka. Interplant relationships in multiple cropping systems.

Plant Breeding

Nam Kyu Park, Korea. General breeding program.

*Vichien Petpisit**, Thailand. Inheritance of amylose content and its relationship with some agronomic characters in two crosses of rice.

Ibrahim Sahi, Indonesia. General rice breeding with particular emphasis on handling the pedigree nurseries.

Plant Pathology

*Tin Win**, Burma. A study on the virulence of *Xanthomonas oryzae*.

Plant Physiology

Michi Shioya, Japan. Photosynthesis of rice under moisture stress.

Rice Production Training and Research

James R. Hoopper, USA. Possibilities of increasing rice production in rainfed areas of Central Luzon, Philippines.

Soil Microbiology

*Bonifacio Alimagno**, Philippines. Availability of nitrogen and phosphorus in the rice rhizosphere under submerged soil conditions.

*Antonio Alcantara**, Philippines. The atmospheric fixation of nitrogen by legumes, and its relation to fertility of rice soils.

RESEARCH FELLOWS

Post-M.S.

Boriboon Somrith, Thailand. A quantitative inheritance study of the relationship between yielding ability and grain quality in rice.

David Gee-Clough, England. 1) Development of planetary transmission using roller chains; 2) Development of improved test tube miller; 3) Measurement of forces on lugged wheels operating in soils of varying moisture content and comparison with theoretical analysis.

Gaya Prasad Gupta, India. Influence of soil temperature on chemical kinetics of waterlogged soils.

Nakatat Suchavadi, Thailand. Evaluation of some genetic analyses for rice data.

Nguyen Ngoc Oanh, Vietnam. Pathogenicity of *Pyricularia oryzae* isolates from resistant rice varieties.

Nguyen Van Huynh, Vietnam. A field experiment comparing plant resistance and various formulations of an effective insecticide to control brown planthopper.

O. R. Reddy, India. Variability of *Xanthomonas oryzae*.

Post-Doctoral

A. D. Pawar, India. Collection and identification of insect pests of rice in the Philippines.

Chung Ik Cho, Korea. General plant breeding with special emphasis on breeding for disease resistance.

Dafrosa del Rosario, Philippines. Organochlorine insecticide residues in soils, water, and agricultural products in the Philippines.

Gunter Trolldenier, West Germany. Microbial studies of the rice rhizosphere in relation to plant growth and soil fertility.

Hang-Tan Phung, Vietnam. Familiarization with IRRI's research programs, especially in agronomy and soil chemistry.

Hiroshi Suzuki, Japan. Varietal differences in alkali viscogram and other physicochemical properties of starch of waxy and non-waxy rices.

Joseph Quansah, Ghana. General rice breeding program.

Kil Ung Kim, Korea. Eradication of *Scirpus maritimus* in rice.

Muhammad Nasiruddin, Bangladesh. General plant breeding with special emphasis on breeding for disease and insect resistance.

N. S. Pasricha, India. Influence of salinity and alkalinity on the availability of nutrients under submerged soil conditions.

Romeo S. Raros, Philippines. 1) Integrated pest control in multiple cropping: (a) Complementary crop interactions affecting visual, olfactory, or gustatory perception of pest species. (b) The true spiders as predators of insect pest species. (c) Non-descriptive pesticide use – evaluation, application timing, and dosages; 2) Crop litter mineralization: (a) The role of soil arthropods in litter breakdown. (b) Arthropodal-microbial association in litter decomposition.

SHORT-TERM OBSERVERS AND TRAINEES

Ulfah Aliawati, Indonesia, 3 months. Training in the rice quality laboratory.

M. A. Farooq, Pakistan, 2 months. Orientation and study tour of the agricultural engineering program.

Maria Favali, Italy, 1 month. 1) Transmission of rice tungro viruses; 2) Varietal resistance to tungro.

Phan Hieu Hien, Vietnam, 1½ months. Orientation and training in agricultural engineering.

Up-dong Ryu, Korea, 1½ months. Training in library science.

Chalit Setabutara, Thailand, 2 weeks. Physiological aspects of deep water rice.

Niyom Thunyaprasart, Thailand, 2 months. Training in agricultural engineering.

Muhammad Tahir, Pakistan, 1 month. Genetic conservation of rice.

SCHOLARS ABROAD

Arumugam Kandiah, Sri Lanka. Ph.D. in soils and water conservation engineering at the University of California, U.S.A.

K. H. Piyatilaka, Sri Lanka. One-year training course in agricultural management, Indian Institute of Management, India.

N. Vignarajah, Sri Lanka. Ph.D. in plant breeding at Cornell University, U.S.A.

J. H. S. Wijeyasinghe, Sri Lanka. Two-year M. Tech. in agricultural engineering, Indian Institute of Technology, India.

RICE PRODUCTION TRAINEES

Ahmed, Ahmed Husain, Senior Scientific Officer, Bangladesh Rice Research Institute, Dacca, Bangladesh.

Ahmed, Akkas, Uddin, Scientific Officer, Bangladesh Rice Research Institute, Dacca, Bangladesh.

Anglacer, Telesforo, Research Chemist I, Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines.

Araga, Zubairu S., Higher Agricultural Superintendent, Ministry of Agriculture and Natural Resources, Ilorin, Nigeria.

Barsana, William, Sales Supervisor, Philamlife Insurance Company, Manila, Philippines.

Benjamin, J. M. D., Social Worker and Instructor, Diyagala Boys' Town, Ragama Sri Lanka.

Chai, Hee Gul, Information Officer, Agricultural Information Section, Office of Rural Development, Suweon, Korea.

Chiranjeevi, V., Research Assistant, All India Coordinated Rice Improvement Project, Rajendranagar, Hyderabad, India.

Cooper, Samuel, Field Instructor, Agricultural Extension Training Center, College of Agriculture and Forestry, University of Liberia, Monrovia, Liberia.

Cornelio, Rodolfo S., Agronomist I, Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines.

Dassah, Kefas B., Senior Agricultural Superintendent, Ministry of Natural Resources, Benue-Plateau, Jos, Nigeria.

Duqueza, Lorenzo, Agronomist I, Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines.

Esteban, Napoleon, Agriculturist, Training and Extension Section, Agricultural Development Division, Upper Pampanga River Project, National Irrigation Administration, Diliman, Quezon City, Philippines.

Fungvitaya, Polpat, Second Grade Agricultural Officer, Department of Agricultural Extension, Bangkok, Thailand.

Gun, Kim Seung, Rural Guidance Officer, Hadonggun Rural Guidance Office, Hadonggun, Korea.

Hlaing, Soe, Deputy Division Manager, Agricultural Corporation, Mandalay Division, Mandalay, Burma.

Lara, Renato de, Engineer-Trainee, Training and Extension Section, Agricultural Development Division, Upper Pampanga River Project, Na-

tional Irrigation Administration, Diliman, Quezon City, Philippines.

Krishna Rao, M. V., Research Assistant, All India Coordinated Rice Improvement Project, Rajendranagar, Hyderabad, India.

Lee, Ho Young, Researcher, Department of Plant Environment, Jeonbuk, P.O.R.D., Korea.

Lee, Jae Mahn, Researcher, Department of Plant Environment, Gangweon, P.O.R.D., Korea.

Lubis, Rusyid, Chief, Seed Production Section, Department of Agriculture, West Sumatra Province, Padang, Indonesia.

Moukeble, El Sayed Md., Assistant Researcher, Sakha Research Station, Kafr-Elshekh, Egypt.

Nanayakkara, J. M. D., Social Worker and Instructor, Diyagala Boys' Town, Ragama, Sri Lanka.

Odiachi, Paul C., Agricultural Officer, Ministry of Agriculture and Natural Resources, Benin City, Nigeria.

Pongsuwan, Saard, Second Grade Agricultural Officer, Department of Agricultural Extension, Bangkok, Thailand.

Rahman, Abdel, Assistant Researcher, Sakha Research Station, Kafr-Elshekh, Egypt.

Reddy, A. V., Research Assistant, All India Coordinated Rice Improvement Project, Rajendranagar, Hyderabad, India.

Sayankul, Jumpol, Second Agricultural Officer, Department of Agricultural Extension, Bangkok, Thailand.

Siddique, S. B., Chief Farm Superintendent, Bangladesh Rice Research Institute, Dacca, Bangladesh.

Skularywattana, Vatin, Agricultural Extension Worker, Agricultural Extension Office, Suphan Buri Province, Thailand.

Thant, Myo, Deputy Assistant General Manager, Agricultural Research Institute, Insein, P.O., Rangoon, Burma.

Thwin, Aye, Extension Officer, Agriculture Department, Rangoon, Burma.

Tin, Maung Maung, Deputy Assistant General Manager, Plant Pathology Department, Agricultural Research Institute, Insein, P.O., Rangoon, Burma.

Toe Sein, Deputy Assistant General Manager, Entomology Department, Agricultural Research Institute, Insein, P.O., Rangoon, Burma.

Udo, Ignatius Sam, Agricultural Superintendent, Ministry of Agriculture, Ikotekpene, Southeastern State, Nigeria.

CROPPING SYSTEMS TRAINEES

Amarante, Serafin, Research Assistant, Department of Soil Science, University of the Philippines at Los Baños, Los Baños, Laguna, Philippines.

Anwarhan, Hans, Junior Agronomist, Central Research Institute of Agriculture, Banjarmasin, Kalimantan, Indonesia.

Arocena, Arturo, Agricultural Engineer, Upper Pampanga River Project, National Irrigation Administration, Cabanatuan City, Philippines.

Azis, Azirin Asandhi, Agronomist (multiple cropping), Central Research Institute of Agriculture, East Java, Indonesia.

Hartzook, Avraham, Research Agronomist, Volcani Center, Department of Agronomy, Agricultural Research Organization, Bet Dagan, Israel.

Murdani, Assistant Leader of Seed Project, Directorate of Agricultural Extension, Pasar Minggu, Jakarta, Indonesia.

Panicksakpatana, Supamard, Junior Lecturer, Kasetsart University, Bangkok, Thailand.

Purwono, Dipowardoyo, Chief, Subdivision of Second Crop Farm Management, Directorate of Agricultural Economics, Department of Agriculture, Jalan Salemba, Jakarta, Indonesia.

Rasjid, Abdul Marzuki, Research Worker in Agronomy, Central Research Institute of Agriculture, Bogor, Indonesia.

Suwannarat, Chairerk, Junior Lecturer, Kasetsart University, Bangkok, Thailand.

Tambunan, Manungkol, Researcher, Central Research Institute of Agriculture, Bogor, Indonesia.

Villegas, Leopoldo, Rice Production Technician, Rice Production Training and Research Office, International Rice Research Institute, Los Baños, Laguna, Philippines.

Yun, Seong-ho, Junior Agronomist, Department of Rice Production, Crop Experiment Station, Office of Rural Development, Suweon, Korea.

RICE FIELD EXPERIMENTATION WORKSHOP PARTICIPANTS

Adhikary, Bharat Raj, Assistant Rice Breeder, National Rice Improvement Program, Department of Agriculture, Parwanipur, Nepal.

Amien, Le Istiqlal, Soil Specialist, Soil Fertility Division, Soil Research Institute, Bogor, Indonesia.

Bilbao, Eldegariza I., Plant Entomologist I, Visayas Rice Experiment Station, Bureau of Plant Industry, Iloilo City, Philippines.

Boonwite, Chaluay, Second Grade Officer, Rice Division, Department of Agriculture, Bangkhen, Bangkok 9, Thailand.

Dohare, Gopi Charan, Farm Superintendent, All India Coordinated Rice Improvement Project, Rajendranagar, Hyderabad, India.

Hasathon Yaovapa, Second Grade Officer, Rice Division, Department of Agriculture, Bangkhen, Bangkok 9, Thailand.

Kardin, Kojim M., Assistant Plant Pathologist, Department of Pests and Diseases, Central Research Institute of Agriculture, Bogor, Indonesia.

Koirala, Govind Prasad, Assistant Agronomist, Parwanipur Agri-Station, Department of Agriculture, Birganj, Nepal.

Maurya, Dhunmun, Rice Breeder (senior scientist),

Rice Research Station, Kalyampur, Kampur-24, U.P., India.

My Nguyen Thi, Agronomist, Agriculture Research Institute, Saigon, South Vietnam.

Quang, Huynh Van, Station Manager, National Testing and Training Center, My Tho, South Vietnam.

Ronduen, Agapito, Agronomist, Cagayan Valley Experiment Station, San Mateo, Isabela, Philippines

Shahi, Hari Narain, Agronomist (rice), Punjab Agriculture University, Rice Research Station, Kapurthala, Punjab, India.

Siriwong, Kamol, Second Grade Officer, Suphan Buri Rice Experiment Station, Suphan Buri, Thailand.

Valencia, Ludovico, Agronomist III, Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines.

International activities

IRRI activities conducted outside of the Los Baños research station comprise the international program. Although outreach service is the main component, certain core program activities, such as international testing and regional projects, are also included in the international program.

International testing. In 1974, six types of international nurseries were conducted:

	Sets (no.)	Countries (no.)
International Rice Yield Nursery (IRYN)	75	21
International Rice Observational Nursery (IRON)	75	20
International Upland Rice Yield Nursery (IURYN)	27	10
International Blast Nursery (IBN)	21	16
International Sheath Blight Nursery (ISHBN)	12	9
International Bacterial Blight Nursery (IBBN)	22	10

One hundred and fifty cooperative weed control experiments were carried out in 17 countries, 12 in Asia and five in Africa. Promising herbicides were evaluated for transplanted, direct-seeded, flooded, and upland rice.

IRRI machines were evaluated in India, Indonesia, Korea, Malaysia, Pakistan, Sri Lanka, Taiwan, Thailand, Vietnam, Guatemala, Ecuador, and Ghana.

Details of IRRI's cooperative testing programs are found elsewhere in the annual report.

Regional projects. The collection and preservation of rice germ plasm was continued in cooperation with national scientists. Field collections were conducted in Bangladesh, Burma, Indonesia, and Vietnam.

IRRI continued to cooperate in rice research with the International Institute for Tropical Agriculture (IITA) and the West African Rice Development Association (WARDA) in Africa, and with the International Center for Tropical Agriculture (CIAT) in South America.

International conference. One hundred and twenty rice scientists from 21 countries participated in the International Rice Research Conference, Apr. 22-25.

A general session was held for all participants on overcoming the constraints to increased rice production. Joint sessions of breeders, entomologists, and pathologists focused on breeding for disease and insect resistance in national programs; varietal development programs; international testing; and recommendations for cooperative research and testing programs. Agronomists and economists discussed common research goals and techniques, and plans for the International Agro-Economic Network. Agronomists and breeders held a joint session on approaches to developing upland rice varieties.

Scientists of various disciplines held sessions on: weed control; constraints to adoption and higher yields; ecology and chemical control of rice insects; new research results on fungal and bacterial diseases; socio-economic research networks; breeding for adaptability to deep water, tolerance to cold, grain quality, and resistance to problem soils; integrated pest control; new research results on virus diseases; results of 1973 cooperative upland rice yield trials; research for rice policies; and cooperative research projects.

A conference on "The Political Economy of Rice in Asia" was held at IRRI, July 1–15, organized and funded by Stanford University, U.S.A. Twenty-six scientists attended, including three from IRRI.

In conjunction with the inauguration of the IRRI phytotron, a symposium on "Climate and Rice" was held Sept. 23–27. Forty-eight scientists attended, presenting and discussing 25 papers on: the climatic environment of rice cultivation; the adaptability of rice varieties to climate; the physical environment of the rice crop; environmental control of growth and yield; climatic stress on growth and yield; climatic effects on incidence of diseases and insects; and the climate and crop productivity.

Outreach services. Cooperative activities consisted of: the supplying of improved genetic materials; the training of rice scientists; the exchange of visits and information; and the assignment of IRRI scientists to work with local scientists in national programs.

Because IRRI's international staff members function as parts of the national programs, only brief reports of research programs in which IRRI scientists participated are presented here.

Philippines. IR26 was released to the Philippine Government for multiplication in December 1973. By the end of 1974, it had become a leading variety, especially in those provinces affected by the brown planthopper. Dry-season yields of 6.5 t/ha were common on irrigated farms.

A four-municipality study was undertaken in Camarines Sur province by an IRRI doctoral scholar to compare the effectiveness of "compact farm" farmer coordinators with farmer leaders chosen by rice extension technologists in the diffusion of IR26. A compact farm is a group of from six to ten adjacent farmers cooperating for crop production credit. This is believed to be the first structured diffusion research study.

In December 1973, 396 kg of IR26 "foundation" seed was released in 1.0 and 0.5 kg "rice seeds for trial" kits to 700 small-scale irrigated farmers (1.7 to 3.8 ha each). A year later, 2,948 tons, valued at US$470,000, was harvested by nearly 800 farmers. Production per farm ranged from 2.2 to 9.0 t/ha.

In the second season, IR26 seed tended to remain concentrated on the compact farms of the original recipient farmers, whereas the non-compact farmer leaders selected by extension tended to disperse more of their first-season harvest among relatives and neighbors, even to the extent of selling bundles of IR26 seedlings.

On the compact farms, an average of 78 percent (2.8 ha) of the land on each farm was planted to IR26 in the second season; on non-compact farms, an average of 57 percent (1.4 ha) was planted to IR26.

Vietnam. A National Rice Research Program (NRRP), including research objectives and a 10-year training program, was designed and developed in 1974 by the Vietnam Institute of Agricultural Research (IAR) with the assistance of the IRRI-Vietnam team.

Research on deep water rice was recognized as a major objective for Vietnam, partly on the basis of a study conducted in December 1973, coordinated by the IRRI-Vietnam team. A deep water rice research station in the Mekong Delta was planned with the assistance of the IRRI team; actual site construction was expected to begin in 1975 with funds from the Ministry of Agriculture and the U.S. Agency for International Development (USAID) funds.

The IRRI team's increase from two to three foreign Ph.D. scientists, and from four to nine Vietnamese technical and administrative personnel, permitted attention to be devoted to cropping systems research, training of Vietnamese in statistical principles and procedures, teaching of English, and increased equipment and supplies purchases to improve the IAR's research capabilities. The third Ph.D. scientist for rice cropping systems research joined the IRRI team in December 1974. The IRRI team now has specialists in plant breeding, soil fertility, and cropping systems. Two part-time Vietnamese statistical consultants and two English teachers were hired to bring more expertise to the NRRP.

IR26 was released by the Ministry of Agriculture in November 1974, and named Than Nong 26. Genetic resistance to pests has already helped reduce pest-related yield losses and has cut costs for imported insecticides.

A national campaign to collect and preserve Vietnam's rice varieties was planned and initiated in August 1974, with the assistance of an IRRI consultant and of some IRRI funding.

Wet-season results showed the most promising lines to be: IR2151-957-5, which is non-glutinous, early maturing, and resistant to six major insects and diseases, including grassy stunt virus; and IR1717-77-6-2, which is glutinous and resistant to five major insects and diseases (but not grassy stunt).

All promising new lines have resistance to the brown planthopper, the major rice insect pest in Vietnam. Because grassy stunt virus disease increased in 1974, virus-resistant cultivars have been included among the most promising lines likely to be released.

More than 1,200 breeding lines, including 200 new IRRI lines, were tested in the 1974 wet season.

In upland varietal tests at Ban Me Thuot, traditional varieties such as Colombia I and Ha Lan, and the semidwarf Juma I, were identified as possessing good drought tolerance but low or limited yield potentials under dry conditions.

During the 1974 wet season, more than 80 breeding lines from the Thailand deep water rice breeding program were tested for the first time at Long Xuyen. One late-maturing, tall, non-floating Thai variety, Khao Pak Maw 148, shows some promise. It matures 2 weeks before the popular traditional Vietnamese floating variety, Nang Tay C.

The wet-season crop (Nov.-Apr.) at Hue suffered from the unusually cold weather which severely damaged most lines tested, except the late-maturing types. We have learned that the early maturing types such as IR1561-228-3-3 must not be grown in the cool areas of central Vietnam during the winter season.

In insecticide screening experiments, carbofuran 3G, chlordimeform, MIPC, proposur + diazinon, and diazinon alone were the most effective among granular insecticides. Under high brown planthopper populations, however, Diazinon 10G was less effective; plots treated with it had the highest percentage of hopperburned area.

We studied the interaction of insecticides, nitrogen levels, and varieties in a factorial experiment with three insecticide treatments, two nitrogen levels, and two rice cultivars.

All plots treated with insecticides yielded higher than did the untreated control plots.

At both 45 and 90 kg N/ha without insecticides, the line IR1561-228-3-3 yielded almost twice as much as IR8, demonstrating the value of varietal resistance.

At 90 kg N/ha, with insecticides, varietal resistance to insects, especially brown planthoppers, did not seem to greatly influence yields. At 45 kg N/ha with insecticide, however, IR8 yielded more than did IR1561-228-3-3. Many Vietnamese farmers still grow IR8, especially during the dry season, because of its high yield potential.

The 1973–74 dry-season trials at My Tho showed that granular and wettable powder forms of 2,4-D isopropyl ester are the most effective low-cost pre-emergence granular herbicides for direct-seeded rice.

Sowing rates of 80, 160, and 240 kg of seed per hectare did not significantly affect yield, whether or not herbicides were used.

On the basis of results obtained for 2 years from long-term N-P-K fertility trials conducted at IAR stations near Long Xuyen and My Tho and at the University of Can Tho, the Ministry of Agriculture lowered its P and K fertilizer recommendations for rice grown in the Mekong Delta. Results showed that no P and K is required for up to four seasons on rice grown on previously fertilized Mekong Delta soils.

Because only mixed NPK fertilizers were available to Vietnamese farmers, the use of only N forms saved Vietnam hundreds of thousands of dollars in foreign exchange.

Long-term N fertility trials at Long Xuyen and My Tho confirmed that 50-60 kg N/ha is an optimum economic level for the wet season and 80-90 kg N/ha for the dry season.

Thirty IRRI-designed 5- to 7-hp tillers were manufactured and sold, as well as bellows pumps and batch driers. About 100 IRRI axial flow threshers were manufactured.

IRRI-designed farm machines were displayed at the Vietnam Farmers' Day at Vung Tau in March and at the Agricultural Machinery Fair in Can Tho in October.

Training sessions were conducted for IAR personnel in the operation, care, and repair of IRRI machines.

The IRRI-Vietnam team and the IRRI Agricultural Engineering Department collaborated with the University of Can Tho on the planning and design of an experiment to evaluate the efficiency of several different methods of solar drying. The milling quality of rice dried by each method was also determined. The university staff conducted and analyzed this experiment.

The most efficient method of solar drying was that in which the paddy was placed on a nylon screen and suspended above the soil surface with a bamboo frame. It also gave a significantly higher percentage of whole milled rice than did the concrete floor, asphalt road, straw mat, and black polyethylene plastic methods.

Generally, drying on the concrete floor was the second most efficient drying method.

Bangladesh. The IRRI-Bangladesh project is primarily supported by a Ford Foundation grant. It was established to help develop the research

capabilities of the Bangladesh Rice Research Institute (BRRI), to stimulate coordinated interdisciplinary rice research, and to assist in the development of the physical facilities of the main research station at Joydebpur and the four substations. In late 1973, BRRI received a substantial loan for the development of its physical facilities at Joydebpur and at the substations and to complete part of the staff housing on the main farm. Recently, a new grant from the International Development Research Centre (IDRC) became available for developing a research division in rice cropping systems.

The IRRI team consists of three scientists. The team leader, an entomologist, arrived in Bangladesh January 1974; the agricultural engineer in August; and the rice production specialist in November. A multiple cropping specialist has been recruited and will move to Bangladesh in January 1975.

High-yielding varieties continued to spread in Bangladesh during 1974. IR8 continues to be an important variety in the winter season; IR20 is now grown on about 0.5 million ha, mainly in the monsoon season; and Chandina is being grown increasingly during the winter and early summer seasons. It is estimated that high-yielding varieties now make up 11 to 18 percent of the Bangladesh rice crop.

Three new research divisions were established at BRRI during 1974: rice cropping systems, economics, and applied research. The staff positions were increased. Field experiments conducted by most research divisions increased in number and in quality. Long-term research programs were initiated based on specific research objectives.

A 14,763-ha area around BRRI was identified as a pilot area for intensive extension and applied research activities. Applied research was conducted on farmers' fields in the monsoon season, and a similar series was planned for the following winter season.

BRRI breeders developed a new high-yielding variety, BR3, and released it in late 1973. Several promising new lines are in the final stages of testing before their release as varieties.

A dormitory-guesthouse block was near completion during 1974; construction work was resumed in June on three large blocks of staff housing; workshops and farm installations at Joydebpur were significantly improved and some farm development had taken place.

Six Ph.D. students continued to study in the U.S. and four M.S. students at IRRI and UPLB; three members of the BRRI staff completed a 6-month rice production training course; other staff members participated in several short overseas training or study tours, or both.

A large number of consultants assisted the project during 1974. A team of three experts developed a master plan for the physical development of the Joydebpur farm and substations, and prepared guidelines for a long-term research program. IRRI scientists who came as consultants for short period included plant breeders, a plant pathologist, a statistician, a librarian, a rice production specialist, and technicians in electrical and mechanical engineering.

BRRI conducted two rice production training courses for Bangladesh extension workers, and plans another 3-week course.

Two important workshops were organized and held by BRRI. The proceedings of both workshops are being published. The first workshop, held in May, concerned the feasibility of growing high-yielding rice varieties under rainfed conditions. In August, BRRI organized the first International Seminar on Deep Water Rice, which attracted more than 20 foreign scientists from major rice-growing countries.

An IRRI project office was established in Dacca.

The IRRI advisor on field collection visited Bangladesh twice in connection with a cooperative germ plasm collection and maintenance project between BRRI and IRRI. From 1,500 to 2,000 varieties were collected, analyzed, and catalogued from Bangladesh. One set of seeds was placed in BRRI's germ plasm collection and another was contributed to the IRRI germ plasm bank.

Fifty-six lines with multiple resistance to major insect pests were screened in the monsoon season as part of the proposed International Insect Resistance Nursery. At the same time, another 35 IRRI lines with multiple resistance to insects and diseases were screened. They differed in their reactions to tungro and kresek diseases, and to stem borers and gall midge.

Research work in Bangladesh on rice stem borers was reviewed.

On several field trips, rice pests were collected

as part of the Bangladesh insect survey. Three main species of stem borers were found in central, eastern, and southern Bangladesh.

Crop losses were assessed through three treatments: 1) total chemical control; 2) a corrective program based on insect counts; and 3) a check with no insecticides. The rice varieties, time of planting, and general agronomic practices corresponded to those used in surrounding farms. Yield differences and regular counts for insects and disease symptoms indicated no significant differences between treated and untreated plots in the *aus*[1] (early summer) crop. During the monsoon season, the most recent observations indicate, yield differences were due mainly to stem borers. A single or double application of granular insecticide at tillering stage, however, controls insects.

The study of the population dynamics of stem borers was continued in a large untreated field under simulated farmers' field conditions. Insects were sampled at all growth stages: as eggs and larvae (by random removal of hills at regular intervals) and as adults (light trapped). Borer populations were surprisingly low in the early summer and monsoon rice crops. The main species were *Tryporyza incertulas* and *Chilo polychrysa*. Powerful mortality factors evidently operated in the form of egg parasites, and microorganisms attacked larvae. These natural enemies were particularly active in the latter half of the monsoon season.

The agroclimatic study of Bangladesh was begun to identify potential areas for multiple cropping. Rainfall, temperature, vapor pressure, and winds were being analyzed.

Testing was initiated of the IRRI power tiller and the bellows pump under Bangladesh conditions. The IRRI engineer also assisted BRRI in developing the farm at Joydebpur, especially in making initial plans for land development, reorganizing the workshops, and building an adequate supply of parts and spares for vehicles and general engineering equipment.

Five research trials were conducted on farmers' fields in the new pilot scheme area during the monsoon season. The trials, which included three levels of fertilization and four varieties (BR3, IR5, IR20, and a selection, BR51), were conducted on two dominant soil types. A similar series of trials will be conducted in the winter season.

Egypt. Under a contract with the Ford Foundation/Arid Lands Agricultural Development (ALAD) Program, IRRI has provided a rice specialist to work with Egyptian scientists to help increase rice production by introducing IRRI selections with long and slender grains, by improving local short-grained varieties, and by improving cultivation practices.

IR579-48 was planted on 1,000 ha in 1974 and is expected to be planted on about 40,000 ha in 1975. The short-grained varieties, Giza 171 and Giza 172, were newly developed from the local breeding materials and will be released to farmers in 1975 to replace the variety Nahda.

The rice cultivars with long and slender grains are primarily for export. There is a need to further improve their grain quality and to increase their yielding ability. Several promising lines, including IR1541-76, a sister line of IR26, and some IR1626 lines, such as IR1626-8, IR1626-62, and IR1626-213, will be planted widely in 1975 experiments.

Yields were disappointingly low in trials of short-grained semidwarfs provided by IRRI. The crossing program was expanded for developing improved short-grained semidwarf varieties. Egyptian scientists are widening the genetic sources and increasing the number of crosses, pedigree lines, and advanced lines for yield trials in both programs for the long and short-grained semidwarfs. About 200 crosses were made; their progenies will be planted at IRRI in 1974 and 1975.

The Egyptian Rice Program cooperated in the International Blast Nursery and found a number of locally resistant lines. Some of these will be used as parental sources of broad-spectrum resistance.

About 10 percent of Egypt's rice land – about 40,000 ha – is affected by salinity. In extensive screening for tolerance to salinity, tolerant varieties from Sri Lanka and Pakistan were identified. A polycross program was initiated to incorporate salt tolerance from different varieties into single varieties.

As the semidwarf IRRI varieties and new short-grained varieties rapidly increase, improved cultural practices must be developed and recommended to farmers. Several agronomic experiments were conducted to determine economic cultural practices.

Cooperative weed control experiments were

[1] Dry season (March–April to July–August) in India.

conducted with transplanted, drilled, and broadcast rice in flooded land. In transplanted rice, benthiocarb/2,4-D IPE (G), butachlor/2,4-D IPE (G), C 19490/2,4-D IPE (G), USB 3584/2,4-D IPE (G), and C 288 (G) looked promising. Most herbicides were effective on drilled rice, including AC 92553, C 288, oxadiazon, USB 3153, and USB 3584. But many herbicides used on broadcast rice on flooded land had phytotoxic effects on seed germination and on young seedlings. Nevertheless, drepamon, benthiocarb/2,4-D IPE and butachlor/2,4-D IPE were promising.

Zinc application experiments indicated that grain yields significantly increased by 10 to 20 percent when seedling roots were dipped into 2 percent suspension of zinc oxide or when zinc sulfate was incorporated into the soil at 24 or 48 kg/ha before transplanting.

Experiments on fertilizer application methods and rates of nitrogen fertilizer showed that 50 to 75 kg N/ha is an economical rate for both IRRI and local short-grained varieties; 40 kg P_2O_5/ha is usually sufficient.

The date of sowing and the seedling age at transplanting clearly affected yield. The yields from April seedings were highest. Late seeding (June) caused a significant decline in yield. When transplanted more than 40 days after seeding, both IRRI and local varieties yielded remarkably lower; IRRI varieties seemed to have less latitude in optimum seedling age than local varieties. Population densities that varied from 20 x 15 cm to 20 x 30 cm did not greatly affect the yields of IRRI and local varieties.

India. The All-India Coordinated Rice Improvement Project (AICRIP), with headquarters at Hyderabad, has developed an effective multilocation testing program for new varieties and technological practices. Over the past 8 years, 16 varieties have been released by the Central Variety Release Committee and another 34 varieties by different states. Among these varieties, Jaya has shown the highest yield potential and a high degree of yield stability, and has been widely grown by farmers. The area now in Jaya exceeds the area in IR8. Two later releases, Sona and Jayanti, have improved grain type and yield potential close to that of Jaya.

The Assam Rice Collection continues to provide genotypes of value to the breeding program, including two sources of dwarf plant type. Reselections have been renumbered as RPA 5929 (mid-duration) and RPA 5924 (short duration). They offer potentials for yield and, preliminary studies indicate, their genetic mechanism is somewhat different from the Taiwan dwarf gene.

Seventeen coordinated variety trials involving different maturity groups and other attributes, such as gall midge resistance, were grown in more than 70 locations throughout India. In addition, the International Rice Yield Nursery (IRYN) was distributed to different locations. Promising among the more than 400 entries in the trials was a more recent selection, IET 2254 (T 90 x IR8). It has slender grains and yields well in national and international trials. A late-maturing selection, IET 2861 (IR400 / T 141), is potentially suitable for the problem-ridden monsoon season of low-lying coastal areas. This selection has excellent long, slender grains and has become popular with the farmers in coastal Andhra Pradesh. IRRI selections that have shown promise in these trials are IR1561-228-3-3, IR1529-680-3, IR2070-747-6, IR2061-214-3-8-2, IR2071-625-1, IR2151-159-1-4, IR2061-213-2-16, and IR2035-290-2-1.

IR578-48-1-2 was released in Punjab as Palman 579, where it is in demand as an early variety with good grain quality. New selections with good grain quality that have been widely tested in the coordinated program and in minikits include IET 2254 (T 90/IR8) and IET 2295 (IR8/CR 1014).

In breeding programs for resistance at the Coordinating Center, selections have been identified with higher levels of disease resistance. Noteworthy among these selections are RP 633 selections (IR8 /BJ 1//IR22 with higher levels of resistance to bacterial blight. Some selections also have moderate to high resistance to tungro virus. In developing resistance to bacterial blight, about 2,000 progenies of crosses involving BJ 1 and mainly IR20, IR22, IET 1136, Sona, Vijaya, and IET 2508 were screened at Maruteru during the two crop seasons of 1973. Promising selections from three crosses – RP 633 (RP 291-43/IR22), RP 611 (RP 291-1/Sona), and RP 612 (RP 291-3/Sona) – were included in 1974 yield trials. RP 633 selections showed a wide spectrum of resistance to different bacterial strains in the national and International Bacterial Blight Nursery screening trials. Among the released varieties, IR26 had very good blight resistance in all locations. Several blast-resistant

selections with good plant type have been identified. Several thousand entries have been tested for tungro resistance and for combined resistance to tungro and bacterial blight. Several promising lines have been identified and evaluated for yield in 1974.

Gall midge is a serious pest that causes substantial yield losses in some areas in Andhra Pradesh, Orissa, Kerala, Karnataka, Mahdya Pradesh, and Maharashtra. Until recently, high-yielding varieties resistant to gall midge have not been found for these areas. The dwarf selection IET 2885 (IR8/Siam 29) combines high yield potential with wide-spectrum resistance to the various biotypes of the pest within and outside the country. IET 2911 (IR8/Siam 29), a mid-late selection with gall midge resistance, consistently performed well in the multilocational testing. Other varieties identified with localized adaptability to gall-midge-endemic areas are Shakti in Orissa and Kakatiya in Andhra Pradesh. Selections tolerant of the brown planthopper have been tentatively identified and will be tested in farmers' fields during the 1974–75 *rabi*[2] season. Promising among these selections are IR26, Jyothi, IET 2815, and IET 2812. Recent breeding programs at CRRI (Central Rice Research Institute) and AICRIP identified some selections with multiple resistance. These selections include IET 2812 and IET 2815 (TKM 6/IR8), IET 2895 (IR8/W 1251), IET 1788 (IR8/Sigadis), IET 2790 (IR8/Ptb 21), and IET 4078 (Jaya/TKM 6). Promising selections that combine resistance to bacterial blight, tungro, gall midge, and stem borer have been identified from the cross RP 974 (Sona/RP 9-4). A good level of resistance to gall midge was combined with good grain type and with a wide range of maturity in the selections from the cross RP 919 (Sona/RP 8-8). Some selections in the cross IR8/TKM 6 showed consistently high tolerance to stem borers at both vegetative and flowering stages. Mass screening of varieties against green leafhoppers and brown planthoppers under greenhouse conditions led to the identification of the following promising varieties against each species: *Nephotettix virescens* – IET 2254 and T 90; *Nephotettix nigropictus* – IET 2790, IET 2254, IR1917-3-19-2, RP 5-12, RP 6-516-3-1-5, RP 633-1, Hashikalmi, Semora Mangga, Tao-Thobi; *Nilaparvata lugens* – Pb 97, Pelita I/1, PpB 270, IET 2812, IET 1788, RP 291-7-1, Djelita, and Hashikalmi.

Rice varieties were screened for their adaptability to low phosphorus fertility and to upland conditions. Among the varieties and lines tested, RPA 5929, RPA 5824, IR-514-E-666, and Kumar exhibited a good degree of tolerance to low phosphorus. Under upland conditions, IR1561-228-3-3, Karuna, MTU 17, MTU 8089, and MTU 8002 showed a minimum degree of iron chlorosis.

An experiment to determine economical chemical control measures showed that all treatments, including seedling dip with Dursban 0.02%, effectively reduced dead heart damage, but none could effectively control white ear damage, except the protection treatment that included late-season application of granules and spray. For yield, seedling dip alone doubled the yield of the untreated control. Preliminary results of an experiment to determine the influence of nitrogen on pest damage, however, revealed that, irrespective of variety, the lowest stem borer damage at the heading stage occurred in plots where no nitrogen was applied. Despite the damage, however, yields were higher with higher nitrogen applications.

Agronomic studies included trials on efficiency of moderate levels of nitrogen, and time, source, and rate of nitrogen application. The efficiency of use of applied nitrogen is determined by the management and not by the quantity of applied nitrogen. Effective nitrogen management can increase yield by as much as 30-40 kg grain/kg applied nitrogen. Split application of nitrogen can be a beneficial practice, if topdressing is properly managed. Topdressing may be considered primarily a corrective measure for any deficiency in previous applications. Studies to measure the value of basal application of nitrogen by using slow-release nitrogeneous fertilizer, such as sulfur-coated and shellac-coated urea, and also by mixing urea with neem cake, indicated that delayed release may not always be superior to split application of N, except under poor management situations. Among the sources tested, results have been more promising with sulfur-coated urea. Superphosphate smeared around the roots of seedlings remains in that vicinity during transplanting, promoting root growth and tillering. This treatment permits reduction in the quantity of phosphorus fertilizer

[2]Winter spring (December to April–May) in India.

from 26 kg P/ha to 14 kg P/ha for the same yields. With phosphorus available at moderate levels, NP complex fertilizer applied as topdressing 15 days after planting in *rabi* gave the same performance as when applied basally. In *kharif*[3] time-of-application, trials, applying the NP complex at 40 days after planting gave higher yields than did the other treatments. Basal applications are better on soils that are deficient in phosphorus.

Shading affected tillering, accumulation of dry matter, grain number, sterility, and yields. Sona was fairly tolerant of low light intensity during panicle development stage, while Vijaya was tolerant during maturity stage. IET 2254 appeared more tolerant of low light intensity than either Vijaya or Sona, and its tiller production was least affected.

While several high-yielding varieties have been developed through concerted research efforts, appropriate management practices need to be developed and tested to minimize the gap between the potential yields of these varieties and the yields that can be achieved under farmers' conditions with reliance on non-cash inputs. "Minikit trials" on farmers' fields have familiarized farmers with the new varieties and practices. Management trials in Andhra Pradesh in 1973–74 indicated that moderate fertilizer levels and good management practices produced higher yields than treatments with higher levels of fertilizer and sub-optimal practices. The adoption of new varieties and practices has led to increased production per hectare in Punjab, Haryana, West Bengal, Tamil Nadu, Kerala, and Andhra Pradesh. In *boro*[4] rice, both productivity and area increased substantially with the popularization of new dwarf varieties. Similarly alteration in cropping schedules such as "early *rabi*," which facilitates the use of more productive varieties, resulted in phenomenal yield increases in coastal Andhra Pradesh. The production impact has also been gradually felt in the *kharif* season in low-lying coastal areas. The available varieties and technology can significantly influence rice production in several states in India, except in the flooded areas in Assam and West Bengal and in higher altitude, hilly areas of Kashmir, Himachal Pradesh, Uttar Pradesh, and West Bengal. Efforts are under way to develop varieties and practices for these areas.

Indonesia. The IRRI program in Indonesia is conducted at four locations and is concerned with five types of research. The IRRI scientists work within the framework of Indonesia's research programs.

The project at the Central Research Institute for Agriculture (CRIA) in Bogor is supported by USAID. It is primarily concerned with rice breeding and agronomy, legume breeding, cropping systems, statistics, and economics. The branch station at Sukamandi, partly financed by credit from the International Development Association (World Bank Group), now concentrates largely on rice research. A new station and research program are getting under way. The Netherlands has provided a grant to assist in developing a branch station at Maros, South Sulawesi, which, like the Sukamandi station, is in the development stage. The fourth project is concerned with field testing and evaluation of IRRI farm machinery. The Ford Foundation has provided IRRI a grant for the support of Indonesia's National Rice Research Program.

The upland program is being enlarged to meet the demand for improved varieties in non-irrigated areas. The major objective of the breeding program for rice and secondary crops is to combine disease and insect resistance with improved plant type and high yielding ability. Studies on improved cultivation include experiments on fertilizer, cultural practices, and intercropping systems. The influence of high-yielding varieties and of technological changes associated with their use is under study. The adoption and use of improved agricultural machinery is also being studied.

The intermediate plant height of Pelita I/1 and of IR5, two commonly grown rice varieties, appears to be best suited to Indonesian conditions. In addition to multiple resistance to disease and insects, breeders are looking for earlier maturing types, for cold resistance, for drought resistance, for deep water tolerance, and for improved milling and eating characteristics. An integrated team approach is being followed.

More than 5,000 indigenous rice varieites have been collected in Indonesia, mostly within the last

[3] Autumn (October–November) in India.

[4] Rice harvested in the spring (April–may) in West Bengal, India.

2 years under a cooperative CRIA-IRRI program.

Laboratory equipment has been obtained and procedures have been set to determine cooking and eating quality. Amylose content has been determined for more than 4,000 samples.

Breeding lines have been successfully evaluated for resistance to tungro virus at Lanrang Station, South Sulawesi, where the virus and the insect vectors are always present. Almost 1,500 crosses have been tested, including material from both CRIA and IRRI. Promising resistant lines are being evaluated for yield and other characteristics.

F_2 and F_3 generations of multiple resistant crosses were grown in near Banyuwangi, East Java, to test for reaction to grassy stunt virus disease. Many lines were identified that are resistant to both tungro and grassy stunt.

CRIA entomologists used the seedling technique to screen the F_2 and F_3 generation materials for reaction to brown planthoppers; some were found resistant. Reaction to gall midge was tested in the F_3 generation. Advanced-generation lines of crosses involving parents with resistance to both gall midge and brown planthoppers are being screened; some are resistant to both insects. At Lanrang, several crosses were evaluated for such characteristics as dead hearts, white heads, whorl maggots, leaf folders, and seedbug infestations; 122 crosses have been selected for further testing.

A group of crosses involving Pelita I/1 and high-protein lines from IRRI have been advanced through the F_4 generation. Protein determinations in the F_3 and F_4 generations indicate that some lines may have higher protein than Pelita I/1. Many lines have good plant type, similar to Pelita I/1.

Breeding lines have been screened at three high-elevation locations to determine their reaction to low temperatures. Several indigenous varieties have been collected that are tolerant of low temperatures. They are being crossed with Pelita I/1 and similar varieties to transfer this resistance into varieties of improved plant type.

Carbofuran and Pretylane best controlled insects and yielded highest among the 19 insecticides included in a trial at Lanrang. Miral (CGA 12223) was particularly interesting since the plots treated with it had few plants with dead heart symptoms.

Placing systemic insecticide in the rice root zone proved successful in South Sulawesi. The insecticide was incorporated in mudballs which were placed below the soil surface. One mudball application compared favorably with five applications of insecticide granules to the paddy water or five spray applications. Carbofuran appeared best, but Cyroline, BPMC, and Padan also showed promise. In a small experiment, the application of carbofuran and Galecron EC around the rice roots with a knapsack sprayer gave good insect control.

Little is known about how defoliation by leaf-feeding insects affects rice yields. In a simulated experiment, the leaves or parts of leaves were cut from rice plants with scissors. When defoliated 5 weeks after transplanting, Pelita I/1 was not affected by 25, 50, 75, or 100 percent reduction in leaf blades. In another experiment, IR26 and C4-63 were defoliated to the same degree at weekly intervals until 11 weeks after transplanting. Up to 6 weeks after transplanting, 50 percent defoliation did not affect yield. Afterwards, yields were greatly reduced, with the maximum effect at 8 and 9 weeks. After flowering, defoliation appears to affect yields less.

An experiment was conducted at Lanrang to determine the optimum time to apply nitrogen fertilizer to the high-yielding varieties. For the early maturing varieties, applying all the nitrogen at one time up to the tillering stage gave higher yields than two or three split applications. For the medium-maturing varieties, a split application of one-fourth as basal and the remaining three-fourths at maximum tillering gave the highest yields.

From a trial on rate of nitrogen application using 0 to 180 kg/ha at 45-day intervals, 135 kg/ha gave the highest yield on IR20 and C4-63.

In South Sulawesi, four sources of nitrogen – urea, ammonium sulfate, and two sulfur-coated ureas – were applied to a variety under upland conditions at 60 and 120 kg/ha. No significant differences were found among nitrogen sources.

Sulfur-coated urea was tested during the 1973 dry season for effectiveness at several locations under four water management regimes: continuously flooded, 5-day rotationally flooded, 10-day rotationally flooded, and intermittently flooded. Both sources of nitrogen were applied at 60 and 120 kg/ha. Urea was applied in three equal applications: at transplanting, at active tillering, and at primordial initiation growth stage; sulfur-coated urea was applied once at transplanting or in three

equal applications. Plots that received sulfur-coated urea yielded better than plots that received urea at the same N rates. These increased grain yields were significant where there was significant interaction between water management regimes and N sources. Plots receiving sulfur-coated urea yielded more grain per unit of N applied, especially at 60 kg N/ha.

The row seeder, power tiller, table and axial-flow threshers, and bellows pump were tested and evaluated in Indonesia. The axial-flow thresher and power tiller were the most promising for production and farm sales.

The effects of power-tiller introductions into the rice production section were estimated from data from various sources. Given present labor and animal availability in West Java, no significant increases in production can be expected, either through crop intensification or by extending crop area, from the adoption of power tillers. Although production can be increased by more intensely cropping of available land, the capability to prepare land does not seem to be a constraining factor. Under certain conditions, larger farmers will benefit from adoption, but probably at the expense of increased rural unemployment and underemployment. In the outer islands, where land is relatively plentiful but labor is short in supply, increasing crop areas could become an important means of increasing crop production, if regional infrastructures can be improved and rights to land guaranteed.

At Indramayu, which is representative of the north coast of Java where lack of water control limits crop production, studies on farmers' fields showed that two rice crops and one upland crop can be grown where only one rice crop is usually grown. In a transmigrational area in Lampung, South Sumatra, where serious problems of erosion and decline in soil fertility and crop production predominate, good yields can be produced from intensive cropping patterns throughout the year if soil fertility is improved through applications of fertilizer and crop residues (Table 1).

New cultivars and accessions of soybean, peanut, cowpea, mung, pigeon pea, and sorghum have been introduced, evaluated, and incorporated into the breeding program. Genetic male sterility has been introduced to initiate population breeding schemes for sorghum and cowpeas. A variety of cowpeas has been identified with significant resistance to a nationally important insect, shootfly, and two widespread diseases, wilt and cowpea stunt. Early generations of peanuts are being selected for resistance to rust and *Cercospora* and for high yield potential.

Table 1. Crop yields for 1 year on the same area. Bandardaya, Lampung, South Sumatra, Indonesia, 1973–1974.

Crop	Full treatment[a] (t/ha)	Insecticide only (t/ha)
Rice	2.2	0.8
Corn	1.4	0.7
Rice Bean	0.6	0.9
Peanut	0.3	0.9
Sorghum	0.01	–
Cassava	21.4	14.6

[a]Lime, fertilizer, crop residue, and insecticide.

Sri Lanka. The IRRI-Sri Lanka rice processing project continued to assist the Paddy Marketing Board (PMB) in Sri Lanka with a systems approach to studying, planning, and implementing programs to develop and improve the country's paddy storage and processing industry.

The IRRI project consultant was assisted in 1974 by short-term consultants from IRRI and other organizations on: the organizational development of the PMB, and management training for it; new designs for storage and handling facilities; requirements of storage and processing of other food grains; and developing long-range processing and marketing plans.

A new training center, provided through the IRRI project, is now complete and technical training programs are in full operation. In the training center, courses are taught on cleaning, drying, storage, parboiling, milling, and quality control.

The project continued to support the foreign training of PMB staff in the U.S. and India, and to provide statistical training in India.

The project also worked with the PMB and Department of Agriculture to study paddy harvesting and drying, and to determine the optimum conditions for parboiling the major rice varieties. The results of these studies enabled the PMB to better direct its development programs and to optimize parboiling operations.

The IRRI-Sri Lanka project now assists the PMB in upgrading existing facilities for paddy storage and processing, and in constructing nine new storage-processing complexes; six are under construction and three are planned.

Through such cooperative activities, the PMB has reduced the losses of paddy that occur with the traditional methods and equipment, has improved the quality of rice, and has reduced operational costs.

After 7 years of operation, the IRRI-Sri Lanka rice project terminated on December 31, 1974.

During 1974, six individuals received scholarships for degree training at the University of the Philippines at Los Baños/IRRI and at universities abroad. Five completed their degree programs.

Following a widespread brown planthopper attack, which destroyed about 1,400 ha of paddy in Amparai district, 2.6 t of IR26 and 0.1 t of IR2035-290-2 seeds (both are resistant to hoppers) were purchased and airlifted into Sri Lanka. The bulk of the seed was increased in government farms during the 1974–75 *maha*[5] season for distribution during the 1975 *yala*[6] season. Part of the IR26 seed was distributed in recently devastated areas during the 1974–75 *maha* season in the form of "brown planthopper minikits."

Several new selections in the BG90, BG92, and BG94 series continue to show promise and may soon be released for production. Efforts are continuing to incorporate into existing varieties, such as BG 34-8, resistance to brown planthoppers, green leafhoppers, zigzag hoppers, and whiteback hoppers. Little success has been made in efforts to turn out a variety that is resistant to gall midge.

As a result of communication between IRRI and the Minister of Agriculture, a two-man survey team, Dr. Al Moseman and Dr. A. Colin McClung, toured rice research stations and talked with research officers from Apr. 27 to May 5 to recommend methods to strengthen the overall agricultural research program.

[5]Local name in Sri Lanka for a growing season when rice is planted in October–November and harvested in February–March of the following year.

[6]Local name in Sri Lanka for the second growing season when the rice is planted in April–May and harvested in September–October of the same year.

Information resources and experimental farm

LIBRARY AND DOCUMENTATION CENTER

International Bibliography. The 321-page (including indexes) 1973 Supplement to the *International Bibliography of Rice Research* was published in 1974. The supplement contains 3,247 references to the world's scientific rice literature; the majority of these appeared in journals in 1973. A total of 28 new serial titles, in addition to the present list of 1,988, were scanned and searched in the compilation. The items of reference are classified according to subject matter and, as with previous supplements, an author index and a manually produced keyword index are provided. A list of 26 rice literature translations, mostly from Japanese to English, is included.

The bibliography is distributed to agricultural libraries and documentation centers of the rice-producing regions for the use of rice research workers and those responsible for disseminating information on rice. The basic volume and the annual supplements list technical literature on rice published since 1951. Essentially all the citations included in these bibliographies are available in the library of the International Rice Research Institute (IRRI).

Reference and circulation. Numerous requests for information and photocopying services were accommodated in 1974. As in previous years, there were more requests for Japanese literature on genetics and breeding than on other aspects of rice culture, and these requests came mostly from India and Malaysia. The IRRI library furnished assistance in library organization and management, selection and acquisition of agricultural materials, and the processing of special materials such as microfilm, maps, and pamphlets to some overseas libraries. Requests for short, specific-subject bibliographies were also processed.

Within the Institute, the number of books and journals borrowed in 1974 increased to an all-time high of 35,067 from 31,297 in 1973. These figures do not include the books, journals, and other materials used in the library.

Library holdings. The addition of 2,660 monographs (books, pamphlets, and reprints) increased the total number in the monographic collection to 36,160. Subscriptions, exchanges, and gifts provided 165 additional serial titles in 1974. Maps, translations, microfilms, and microfiche (plus microfiche reader) were also added to the collection.

Other library activities. In 1974, a mimeographed list of doctoral dissertations and theses on rice that are available in the IRRI library was also issued.

The practice of circulating the table of contents of newly received journals to keep the scientists informed of the latest publications on rice was continued. As in previous years, this service was extended to the All-India Coordinated Rice Improvement Project in Andhra Pradesh, India, the Bangladesh Rice Research Institute, the Lembaga Penelitian Pertanian Maros in Indonesia, and to the West Africa Rice Development Association in Liberia. The monthly listing of new acquisitions of books, serial titles, translations, reprints, and microfilm was more widely distributed to overseas addresses in response to an increased number of requests.

Copies of English translations of foreign-language literature were sent regularly to the National Agriculture Library (NAL) of the U.S. Department of Agriculture. Eventually, these translations are listed in the NAL Bibliography of Agriculture to make them readily accessible and available to rice scientists throughout the world.

The library continued to purchase and distribute books to IRRI research scholars and trainees.

INFORMATION SERVICES

The Office of Information Services (OIS) in 1974 continued its program of support services for the IRRI research and training programs and for the seminars and international conferences held at the Institute. The support services include editorial

services, printing and publishing, graphic arts and design, photography, audio-visual services, visitor services, and preparation and dissemination of information about the Institute's programs, progress, and publications plus the distribution of the IRRI publications internationally and within the Philippines

Four new publications were completed and distributed: *An Agro-Climatic Classification for Evaluating Cropping Systems: potentials in Southeast Asian rice-growing regions; Planting Rice; Research Highlights for 1973,* and the *1973 IRRI Annual Report.* Four issues of the IRRI REPORTER were published, and each issue of this newsletter was sent to more than 7,000 addressees in countries around the world, as well as distributed to IRRI visitors and conference attendees. Five publications, including 40,000 additional copies of the English version of *Field Problems of Tropical Rice,* were reprinted.

Over 23,000 copies of *Field Problems of Tropical Rice* and more than 23,800 copies of other IRRI publications were distributed in 1974. The majority of these publications were sent to rice workers and investigators and libraries in Asia.

Over 50 journal articles were edited for publication in professional journals and periodicals. A publication on statistical procedures for agricultural research, with emphasis on rice, is in preparation and the proceedings of the September 1974 Symposium on Climate and Rice are being prepared for publication.

All issues of the IRRI annual report from the first issue, 1961–62, through the 1973 edition were put on microfiche.

Fifty sets of the set of 92 color slides on field problems of tropical rice, i.e., of nutritional disorders, insect pests, and diseases, were distributed in 1974. A dual-screen (2 projectors) 20-minute color slide presentation about the Institute its programs, goals, and mission was prepared with synchronized text and music. This is presented to visitors of IRRI as part of the general orientation program. Additionally, a 12-minute single screen color slide presentation on the IRRI training programs was prepared for use at IRRI and by the Institute staff during overseas visits.

An extensive photograph and accompanying text exhibit of black and white poster-size enlargements was prepared by OIS for the program of the dedication of the Institute's newly constructed Phytotron (a bioclimatic laboratory) in September which was held in conjunction with the IRRI Symposium on Climate and Rice. The photo exhibit highlighted the Phytotron, its staff, facilities, and projects. Another photograph exhibit featured the Institute and its goals and accomplishments and was presented at a special field days program at the neighboring University of the Philippines, Los Baños.

The OIS has attended to more than 8,000 visitors, with a program which includes a tour of the Institute, the dual-screen slide presentation about IRRI, and discussion of the Institute's research and training programs. Members of the press and other media are among the many visitors to the Institute and, thus, a press kit (photographs, publications, and other materials about IRRI) was assembled for distribution to media visitors.

EXPERIMENTAL FARM

The experimental farm area was expanded this year with the acquisition of additional land (192 ha) made possible through the cooperation of the Philippine Government. The newly acquired land is to be used exclusively for research and will be shared equally by the College of Agriculture of the University of the Philippines at Los Baños and the IRRI.

Preparations are under way to fence the new area. A bridge across the Maitim River and a road connecting the new area to the present IRRI farm area are planned.

As in previous years, the Experimental Farm Department continued to support the work of the research departments by furnishing such services as land preparation, planting, weeding, harvesting, and pest control, as well as by supplying both emergency and contract labor when needed.

In the dry season, IR26, the selection IR1514A-E597, and two Korean varieties – Milyang and Suwon 242 – were grown for seed production on 6.34 hectares. IR26 (3.07 ha) and IR1514A-E597 (1.60 ha) were planted on two rented farms outside the experimental farm and the total yield of each was 14.98 and 3.48 tons, respectively. Milyang (1.14 hectares) and Suwon 242 (0.63 hectares) were planted for rapid multiplication at the request of Korean scientists and yielded 2.2 and 1.63 tons,

respectively. These low yields were caused by tungro and grassy stunt infection.

In the wet season, a portion of the newly acquired land was planted to IR26, IR2071-88-3, IR2035-290-2-1-2, IR2061-213, IR2061-214, IR2061-255-3-6-3, IR2061-464-4-14-1, and IR-2153-159-1-4. IR26 was grown on the IRRI farm lands (1.3374 ha) and outside the station (1.09 ha). The total area of 24.58 ha planted for seed production during the wet season exceeded the area (5.78 ha) planted in 1973.

Although tungro infection this year was not as serious as that in 1973, grassy stunt was widespread throughout the IRRI experimental farm and caused low yields. Brown planthopper infestation was not heavy, but precautions were taken to check early signs of infestation. Insecticides were sprayed once or twice a week, especially in the experimental plots of the Plant Breeding Department.

The virus diseases were not as serious as those last year, and thus, less chemicals were used. The selection or lines and varieties planted on the newly acquired area and on rented farms received only one application of Furadan granules and no chemicals were sprayed. As in the previous years, Furadan, Hytox, lindane, and Azodrin were used widely on the experimental farm.

The area planted to rice this year increased by 50% over that in 1973 and the amount of fertilizer used increased correspondingly. More solophos, muriate of potash, and urea were used this year than in 1973. Zinc sulfate was used to correct zinc deficiency in the soil.

Machete, 2,4-D granules, and MCPA were used to control weeds in both the experimental and production plots. Herbicides helped greatly to lower the cost of handweeding since less was needed. Gramoxone was used exclusively for controlling weeds in the levees, fence lines, and roadways.

The total area planted to rice in 1974 was 114.86 ha, an increase of 42.85 ha over that of 1973. Substitution of animal power with hand-tractors decreased the cost of land preparation despite the increase in the area prepared and planted. This year the amount paid to birdboys (to keep birds out of the rice fields) was 50 percent of the total amount paid for labor. Consideration is being given to using radio-controlled airplane models to drive the birds away from the experimental plots. Even with the 50-percent increase in total area planted to rice, the cost of transplanting and weeding increased only slightly (over the 1973 expenses), accounting for about 17 percent of the total cost of contract labor.

There were indications that the rat population at the IRRI farm area was increasing. Efforts to minimize rat damage include continued baiting, dusting rat burrows with cyanogas, and providing neighboring farms with poisoned baits.

Publications and seminars

PUBLICATIONS

Administration

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SEMINARS

The following topics were the subjects of seminars held at the institute during 1974. Unless otherwise stated, the speakers were staff members.

Remote sensing in agriculture. Dr. Romeo Bruce, Associate Professor, School of Engineering, University of the Philippines, Diliman, Quezon City, Philippines.
Impact of new rice varieties in the Philippines. Dr. Dave Kunkell, Visiting Professor, Philippine Bureau of Agricultural Economics, Diliman, Quezon City, Philippines.
Agrarian Reform Institute. Dr. Jess Montemayor, Head, Research and Evaluation, Philippine Agrarian Reform Institute, Los Baños, Laguna, Philippines.
Human settlement. Dr. Onofre D. Corpuz, Director, Development Academy of the Philippines.
Genetic conservation in cereals. Dr. T. T. Chang.
Scientists, society, and social change. Dr. Tara Patel, Guajarat University, Ahmendabad, India (Visiting Professor, Department of Agricultural Education, University of the Philippines at Los Baños).
Changing objectives of the breeding program at IRRI. Dr. G. S. Khush.
Protein quality evaluation. Dr. B. O. Juliano.
Designing technology to fit diverse farming conditions. Dr. R. W. Herdt.
Rice nematodes. Dr. Cesar P. Madamba, Chairman, Department of Zoology, College of Sciences and Humanities, University of the Philippines at Los Baños.
Potential of an international testing network for rice. Dr. H. E. Kauffman.
Monocyclic epidemiological studies of rice tungro disease. Dr. K. C. Ling.
Feasibility of utilizing varietal resistance in insect control, with particular reference to rice pests. Dr. M. D. Pathak.
The germination and growth of a national agricultural research system for the Philippines. Dr. Joseph C. Madamba, Director-General, Philippine Council for Agricultural Research.
Biological control of insect pests: sterile insect technique. Dr. Romeo Rejesus, Assistant Professor, Department of Entomology, University of the Philippines at Los Baños.
IRRI's outreach program. Dr. D. S. Athwal.
Ideas for a program in field water management. Dr. T. H. Wickham.
The world energy crisis: 1975–2025. Dr. Serafin Talisayon, Assistant Professor and Chairman, Department of Mathematics, Statistics, and Physics, University of the Philippines at Los Baños.
Economic aspects of controlling sugarcane froghoppers in Trinidad. Dr. Geoffrey Norton, Research Fellow in Economics, Environmental Resource Management Unit, Imperial College, University of London, England.
A temperate plant breeder. Dr. Ralph Riley, Director, Plant Breeding Institute, Cambridge, England.
Meditations on cropping systems. Dr. R. R. Harwood.
IRRI training program. Dr. M. R. Vega
Philosophy of surveying cropping systems. Mr. Gordon R. Banta, Visiting Agricultural Economist, Multiple Cropping Project, IRRI.
Potential for agro-industrial systems. Dr. G. Alan Stewart, Officer-in-Charge, Agro-Industrial Research Unit, Commonwealth Scientific and Industrial Research Organization, Canberra, Australia.
Integrated vertebrate pest control (including a description of bat control programs in Latin America and South America, Quelea bird control programs in Africa, and rodent control programs in grain-producing countries in Asia). Dr. Nels Konnerup, Livestock Specialist, Technical Assistance Bureau, U.S. Agency for International Development, Washington, D.C.
The changing world fertilizer situation. Dr. R. Barker.

Agricultural education in the emerging society. Dr. Faustino T. Orillo, Dean, Graduate School, University of the Philippines at Los Baños.

Risk, efficiency, and public investment in rice production: the case of fertilizer use in Laguna and Albay. Dr. James Roumassett, Post-Doctoral Fellow, Agricultural Economics Department, IRRI.

Upland rice in West Africa. Dr. Bernard Le Buanec, Agronomist, Bouake Station of Ivory Coast.

Aquaculture here and there. Dr. H. R. Schmittou, Technical Adviser to the Inland Fisheries Project (IFP) under USAID contract; Mr. Rogelio O. Juliano, Director, the IFP; and Dr. John H. Grover, Technical Adviser to the IFP Freshwater Station, Central Luzon State University, Muñoz, Nueva Ecija, Philippines.

Philosophy of biological nitrogen fixation in the biosphere. Dr. T. Yoshida.

Energy alternatives (a discussion on the need for all countries to adopt solar energy practices in lieu of combustion and fission practices). Prof. William E. Heronemus, Department of Civil Engineering, University of Massachusetts, Amherst, Massachusetts.

A program of plant health. Dr. A. L. Hooker, Professor Plant Pathology, University of Illinois, Urbana.

Factors and consequences of rust uredospore germination and differentiation. Dr. Richard C. Staples, Plant Biochemist, Boyce Thompson Institute for Plant Research, Inc., Yonkers, New York, U.S.A.

Communicating science to the public. Mr. Victor McElheny, Science Writer, New York Times, U.S.A.

Chemical propagation of orchids. Mr. Felix Flores, Proprietor, Maine Manufacturing Enterprises, Manila.

Physiology of grain yield in wheat. Dr. F. A. Fischer, Wheat Physiologist, International Maize and Wheat Improvement Center (CIMMYT), Mexico.

Appropriate technology for agricultural development. Dr. A. U. Khan.

International developments in integrated pest control. Dr. V. A. Dyck.

Microbial degradation of [the herbicide] PCP [pentachlorophenyl] in soils under flooded and upland conditions. Dr. Iwao Watanabe, Associate Professor, Iwate University, Morioka, Japan.

Borobudur: the cosmic mountain in Indonesia (color film). Mr. Dik Trofeo, film maker, Quezon City, Philippines.

Experimental breeding designs for developing varietal mixtures. Dr. Douglas Neeley, Visiting Associate Scientist, Statistics Department, IRRI.

Bats and insecticides. Dr. Russ Reidinger, Research Biologist, Rodent Research Center, University of the Philippines at Los Baños.

Kingdom of Tonga: its people and agriculture with a reference to entomology. Dr. J. A. Litsinger.

Returns on the investment in rice research in Japan. Dr. Y. Hayami.

Efficient organization of agricultural research systems: evidence from developing country experience. Dr. Robert Evenson, Agricultural Development Council, University of the Philippines at Los Baños.

Nutrition development, some research findings for the Philippines and South Asia. Dr. Barry Popkin, Visiting Economist (The Rockefeller Foundation), University of the Philippines at Los Baños and University of the Philippines, Diliman, Quezon City, Philippines.

Problems of land use in the humid and arid tropics. Dr. H. W. Sharpenseel, Institut fur Bodenkunde Rheinischen Friedrich-Wilhelms-Universitat, Bonn, West Germany.

Asian music. Miss Lucrecia R. Kasilag, Director, Theater for the Performing Arts, Cultural Center of the Philippines.

The College of Forestry and its research programs. Dr. R. A. del Castillo, Dean, College of Forestry, University of the Philippines at Los Baños.

Finances

During 1974, the Institute received cash grants amounting to $7,109,248.

The Ford Foundation gave $1,376,040. Of this amount, $750,000 was toward the core operating and capital expenditures of the Institute. The remainder was in support of the rice research and development programs of five countries: Sri Lanka – $162,500 as part of a 2-year grant for the rice production and multiple cropping project and another $185,000 as part of a 2-year grant for the project on modernization of rice processing and distribution; Bangladesh – $85,200 which is part of a 2½ year grant to provide support for the Bangladesh Rice Research Institute; Indonesia – $127,900 which is part of a 2-year grant for an accelerated rice research program; Pakistan – $58,650 which is part of a 2-year grant to assist the Pakistan Agricultural Research Council, through the training of rice scientists and the exchange of breeding materials; and, Egypt – $6,790 which is part of a 2-year grant for the services of a project specialist with the Arid Lands Agricultural Program in the Middle East.

The Rockefeller Foundation contributed $829,990 during 1974. This amount included $700,000 for the core operating and capital expenditure needs of the Institute. The Rockefeller Foundation released: $28,700 as part of a 3-year grant to support the program to develop and introduce improved rice technology to disadvantaged Asian rice farmers in upland and rainfed areas; $3,915 as part of a grant for the collection of the world's rice germ plasm; $90,575 as part of a grant in support of the joint Ph.D. training program with the Indian Agricultural Research Institute; $5,000 as a grant toward the costs of a project to determine constraints to high yields in farmers' fields in the Philippines; and, $1,800 as a grant to study the effects of uncertainty on farmer decision-making in rice production in the Philippines.

From various grants, the U.S. Agency for International Development released a total of $1,787,767. The Institute received $1,000,000 for its core operating and capital expenditures and $230,000 in support of a project entitled "Research on Farm and Equipment Power Requirements for the Production of Rice and Associated Food Crops in the Far East and South Asia." Since 1972, a contract between IRRI and USAID has supported a project for the accelerated development and utilization of improved technology in agriculture in Indonesia with a budget of $640,050, in addition to a budget of Rp. 446,775,159 which is managed by the USAID mission in Djakarta for a period of 3½ years. In 1974, $191,761 was reimbursed to the Institute. Since 1971, a contract with USAID has supported a project to help the government of Vietnam accelerate rice research for a 3½ year period with a budget of $464,000 in addition to a budget of VN$43,070,000. In 1974, $96,349 was reimbursed to the Institute. Since July 1972, a contract between IRRI and USAID supported an intensified crop production and extension program in the Philippines for 2 years and 8 months with a budget of $113,789 in addition to a budget of $92,400 which is managed by the USAID mission in Manila. In 1974, $41,039 was released to the Institute. USAID contributed toward IRRI's training program by supporting scholars from various countries where USAID has active programs. The Institute received $55,720 for this purpose in 1974. The USAID mission in Bangladesh provided $90,500 to finance the training of staff from the Bangladesh Rice Research Institute in the Philippines and in the U.S. During 1974, $72,898 was released to the Institute.

The Overseas Development Administration of the United Kingdom gave $467,833 toward the support of IRRI's varietal improvement, cropping systems, and genetic resources programs.

The International Development Research Centre of Canada gave $626,330. As part of a 2-year grant to the Institute for cropping systems research in the Philippines in cooperation with the University of the Philippines at Los Baños, IDRC released $414,830. The centre also made the following grants in 1974: $10,000 for research on changes in rice farming in Asia; $125,488 as part of a grant to enable IRRI to finance and give technical guidance and support to a cropping systems research project at the Bangladesh Rice Research Institute; and $76,012 as part of a grant to enable the UPLB to conduct, in support of IRRI's cropping systems program, a varietal screening program for maize,

sorghum, mung bean, soybean, eggplant, tomato, and sweet potato.

The Japanese government gave $263,500 in 1974 toward the training program of the Institute, to purchase equipment required for research activities and support the institute's plant physiology department.

The International Development Association gave $1,155,000 in 1974 toward the core operating and capital expenditures of the Institute.

The West German government gave $252,221 toward the Institute's capital expenditures.

The Australian government gave $13,093 toward a short-term training program of the Institute.

The government of Indonesia, using a World Bank loan, released $141,481 to IRRI as part of a 5-year contract toward the development of research facilities at the Sukamandi Branch of the Central Research Institute for Agriculture (CRIA) and toward scientific and technical assistance to rice research in this branch of CRIA.

In 1967, IRRI entered into a cost-reimbursement contract with the U.S. National Institutes of Health to study ways to increase the protein and essential amino acids of the rice grain through plant breeding. During 1974, $55,041 was reimbursed to the Institute.

In 1974, the Netherlands government gave $78,752 as part of a 5-year grant for a project for regional station development in Indonesia.

The United Nations Development Programme gave $50,000 as a grant for the training of rice scientists and technicians.

The names of other donors along with the areas supported and the amounts received during 1974 are given below:

Imperial Chemical Industries, weed control, $5,000.

Potash Institute of North America and International Potash Institute, long-term fertility experiments, $3,200.

Stauffer Chemical Co., rice pest control, $3,000.

Minnesota Mining and Manufacturing Co, weed control, $1,000.

Staff changes

January:
Dr. Mano D. Pathak, entomologist, was promoted to Assistant Director for Research.

February:
Mr. Steven A. Breth resigned as editor of the Office of Information Services.

April:
Dr. Chul Choo Lee joined the Department of Agricultural Engineering as a visiting associate agricultural engineer for 14 months.

Dr. Joyce C. Torio joined the institute as head of the Office of Information Services.

June:
Mr. Fred E. Nichols, associate evaluation engineer in the Department of Agricultural Engineering, transferred to the IRRI-Ford Foundation-Bangladesh Rice Project as associate agricultural engineer.

July:
Dr. Dilbagh S. Athwal, Associate Director, began his one-year study leave at Harvard University, Cambridge, Massachusetts, U.S.A.

Mr. Gordon R. Banta completed his tour as visiting associate agricultural economist in the Multiple Cropping Department.

Mr. Joseph K. Campbell finished his one-year assignment as a visiting associate agricultural engineer in the Department of Agricultural Engineering.

Dr. Virgilio R. Carangal joined the cropping systems program as network coordinator.

Dr. Shu-Huang Ou, Plant Pathologist, began a one-year study leave at the Connecticut Agricultural Experiment Station, U.S.A.

August:
Mr. Angelito O. del Mundo joined the Manila Office as head.

Dr. Kwanchai A. Gomez, statistician, began a one-year study leave at Michigan State University, East Lansing, U.S.A.

Dr. Douglas Lee Roy Neeley joined the Statistics Department as a visiting scientist for 12 months to substitute for Dr. Gomez on study leave.

Dr. Leo Dale Haws joined the Rice Production Training and Research Office as a crop production specialist.

Dr. Yujiro Hayami joined the Department of Agricultural Economics as an agricultural economist.

Mr. Hugh T. Murphy joined the institute as the Assistant Director for Administration.

September:
Dr. James A. Litsinger joined the cropping systems program as an associate entomologist.

October:
Dr. Shohei Matsumoto joined the Department of Plant Pathology as a visiting scientist for 12 months.

Dr. Benito S. Vergara, plant physiologist, began a one-year study leave in Luzon, Philippines.

Dr. Thomas H. Wickham, associate agricultural economist, took a 1 year leave.

November:
Dr. John C. O'Toole joined the Agronomy Department as an associate agronomist.

December:
Dr. Tomio Yoshida resigned as soil microbiologist.

There were changes in the institute staff in international programs.

Dr. Jerry B. Fitts, agronomist (rice) and Dr. John M. Green, corn breeder-*cum*-seed certification specialist resigned their positions in Indonesia with the IRRI-Indonesia-USAID Cooperative Project and IRRI Sukamandi Project, respectively.

Dr. H. David Catling joined the IRRI-Ford Foundation-Bangladesh Rice Project in December 1973 (too late to be included in the 1973 Annual Report staff changes listing) as an entomologist and project leader.

Mr. Paul van Halteren joined the IRRI Maros

Rice Project in Indonesia in August as an entomologist.

Dr. Osamu Mochida, entomologist, joined the IRRI Sukamandi Project in Indonesia during September.

Dr. Richard L. Tinsley, associate agronomist (multiple cropping), joined the IRRI Cooperative Vietnam Rice Project in September.

Mr. William G. Golden, Jr., transferred from Sri Lanka to the IRRI-Ford Foundation-Bangladesh Rice Project as a rice production specialist in November.

Dr. Ram C. Khatter, Associate Engineer, joined the IRRI-Sri Lanka-Ford Foundation Rice Processing Project in December.

Crop weather

The amount of precipitation in 1974 (2,492 mm) at the International Rice Research Institute (IRRI) in Los Baños, Philippines was greater than that occurring in 1973 (2,206 mm) and exceeded the average (2,009 mm) of the 8 years from 1966 through 1973. The distribution of rainfall in 1974 differed from that of the average of 1966–1973 (fig. 1). There were four distinct peaks of rainfall (June, August, October–November, and December) and a sharp dry period in September. The first peak of rainfall (June) had no significant effect on the yield of rice, but did facilitate timely planting. The second peak of rainfall (August) promoted early vegetative growth of the rice which was at the tillering stage.

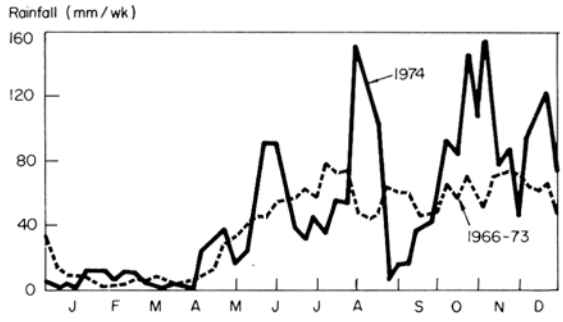
The dry period in late August which extended through mid-September caused severe moisture stress to the upland rice crop and thereby reduced the grain yield. There were at least 14

Table 1. Number of rainy days (0.25 mm or more rain/day) at IRRI, Los Baños, Philippines, av. 1966–1973, 1973, and 1974.

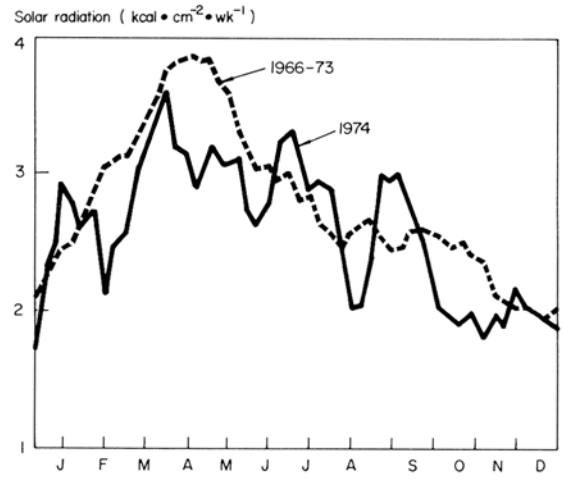
Month	Rainy days (no.)		
	Av. 1966–1973	1973	1974
January	12	9	6
February	6	6	9
March	7	7	10
April	5	6	3
May	15	9	20
June	19	16	14
July	23	19	23
August	21	24	22
September	22	23	14
October	18	22	26
November	19	21	22
December	18	23	21

Table 2. Tropical cyclones during 1974 in the area of Los Baños, Philippines.

Month	Date
June	June 10–11
	June 13–14
July	July 19–21
August	Aug 5–7
	Aug 8–10
	Aug 16–18
October	Oct 10–11
	Oct 16
	Oct 22–24
	Oct 28–29
November	Oct 31 – Nov 3
	Nov 5–7
	Nov 28
December	Dec 22



1. Rainfall (three-point moving weekly average) at IRRI at Los Baños, Philippines, av. 1966–1973 and 1974.



2. Solar radiation (three-point moving weekly average) at IRRI at Los Baños, Philippines, Av. 1966–1973 and 1974.

rainy days (0.25 mm or more rain/day) during June through December (Table 1) which prevented deleterious moisture stress in the rainfed lowland rice crops. However, eight tropical depressions occurring from October through December (Table 2) caused severe lodging of the lowland late-maturing varieties which were at the reproductive and ripening stages, causing low yields of many of these varieties.

Another factor which contributed to the low grain yields of rice in 1974, particularly in the wet season, is the lower solar energy received by the dry- and wet-season crops in 1974 as compared with the average for similar periods during the 8 years from 1966 to 1973 (fig. 2).

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as part of the Bangladesh insect survey. Three main species of stem borers were found in central, eastern, and southern Bangladesh.

Crop losses were assessed through three treatments: 1) total chemical control; 2) a corrective program based on insect counts; and 3) a check with no insecticides. The rice varieties, time of planting, and general agronomic practices corresponded to those used in surrounding farms. Yield differences and regular counts for insects and disease symptoms indicated no significant differences between treated and untreated plots in the *aus*[1] (early summer) crop. During the monsoon season, the most recent observations indicate, yield differences were due mainly to stem borers. A single or double application of granular insecticide at tillering stage, however, controls insects.

The study of the population dynamics of stem borers was continued in a large untreated field under simulated farmers' field conditions. Insects were sampled at all growth stages: as eggs and larvae (by random removal of hills at regular intervals) and as adults (light trapped). Borer populations were surprisingly low in the early summer and monsoon rice crops. The main species were *Tryporyza incertulas* and *Chilo polychrysa*. Powerful mortality factors evidently operated in the form of egg parasites, and microorganisms attacked larvae. These natural enemies were particularly active in the latter half of the monsoon season.

The agroclimatic study of Bangladesh was begun to identify potential areas for multiple cropping. Rainfall, temperature, vapor pressure, and winds were being analyzed.

Testing was initiated of the IRRI power tiller and the bellows pump under Bangladesh conditions. The IRRI engineer also assisted BRRI in developing the farm at Joydebpur, especially in making initial plans for land development, reorganizing the workshops, and building an adequate supply of parts and spares for vehicles and general engineering equipment.

Five research trials were conducted on farmers' fields in the new pilot scheme area during the monsoon season. The trials, which included three levels of fertilization and four varieties (BR3, IR5, IR20, and a selection, BR51), were conducted on two dominant soil types. A similar series of trials will be conducted in the winter season.

Egypt. Under a contract with the Ford Foundation/Arid Lands Agricultural Development (ALAD) Program, IRRI has provided a rice specialist to work with Egyptian scientists to help increase rice production by introducing IRRI selections with long and slender grains, by improving local short-grained varieties, and by improving cultivation practices.

IR579-48 was planted on 1,000 ha in 1974 and is expected to be planted on about 40,000 ha in 1975. The short-grained varieties, Giza 171 and Giza 172, were newly developed from the local breeding materials and will be released to farmers in 1975 to replace the variety Nahda.

The rice cultivars with long and slender grains are primarily for export. There is a need to further improve their grain quality and to increase their yielding ability. Several promising lines, including IR1541-76, a sister line of IR26, and some IR1626 lines, such as IR1626-8, IR1626-62, and IR1626-213, will be planted widely in 1975 experiments.

Yields were disappointingly low in trials of short-grained semidwarfs provided by IRRI. The crossing program was expanded for developing improved short-grained semidwarf varieties. Egyptian scientists are widening the genetic sources and increasing the number of crosses, pedigree lines, and advanced lines for yield trials in both programs for the long and short-grained semidwarfs. About 200 crosses were made; their progenies will be planted at IRRI in 1974 and 1975.

The Egyptian Rice Program cooperated in the International Blast Nursery and found a number of locally resistant lines. Some of these will be used as parental sources of broad-spectrum resistance.

About 10 percent of Egypt's rice land – about 40,000 ha – is affected by salinity. In extensive screening for tolerance to salinity, tolerant varieties from Sri Lanka and Pakistan were identified. A polycross program was initiated to incorporate salt tolerance from different varieties into single varieties.

As the semidwarf IRRI varieties and new short-grained varieties rapidly increase, improved cultural practices must be developed and recommended to farmers. Several agronomic experiments were conducted to determine economic cultural practices.

Cooperative weed control experiments were

[1] Dry season (March–April to July–August) in India.

RESEARCH HIGHLIGHTS

GENETIC EVALUATION AND UTILIZATION (GEU) PROGRAM

SOIL AND CROP MANAGEMENT

CONTROL AND MANAGEMENT OF DISEASES

CONTROL AND MANAGEMENT OF INSECTS

CONTROL AND MANAGEMENT OF WEEDS

IRRIGATION WATER MANAGEMENT

ENVIRONMENT AND ITS INFLUENCE

CONSTRAINTS TO INCREASED RICE PRODUCTION

MACHINERY DEVELOPMENT AND TESTING

POST-PRODUCTION TECHNOLOGY AND MANAGEMENT

CROPPING SYSTEMS