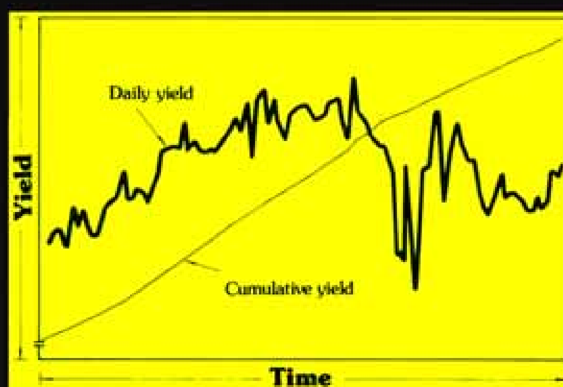
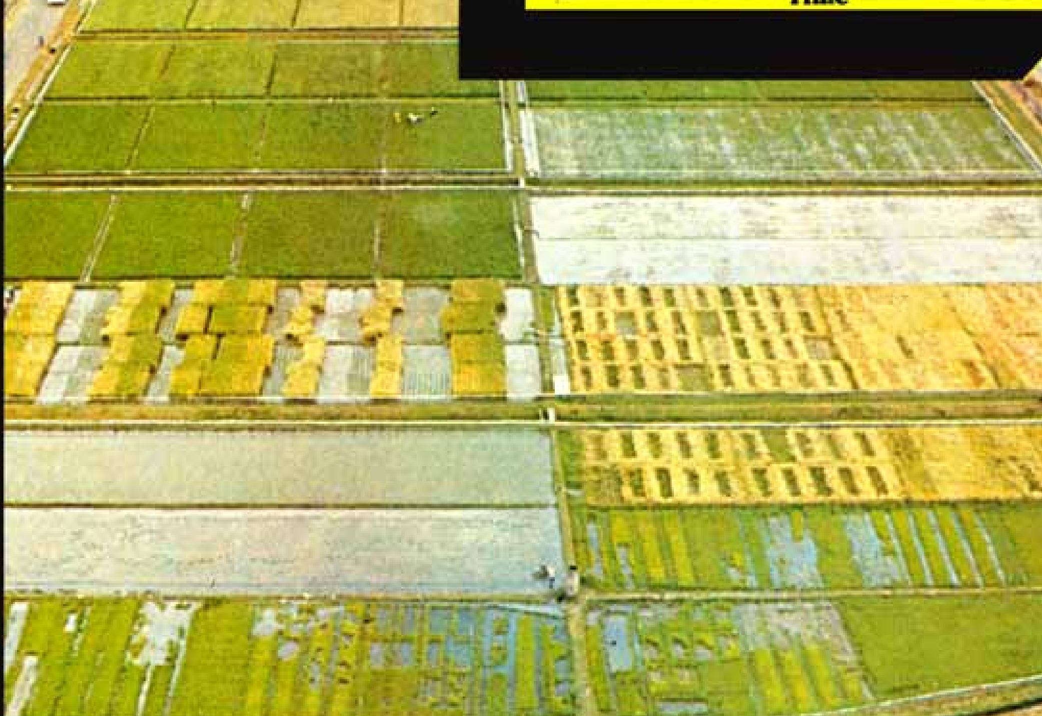
The International Rice Research Institute
Annual Report for 1976





The International Rice Research Institute

Annual Report for 1976

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The International Rice Research Institute

Annual Report for 1976

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*Left during year.
**Transferred during year.
***On study leave.
†On part-time basis.

About this report

The 15th annual report covers research during 1976. The various sections of the report deal with the interdisciplinary approach to problem areas. The department or departments that performed the research are identified in italics below the topic heading, i.e.

EVALUATING DISEASE RESISTANCE OF
BREEDING MATERIALS
Plant Pathology Department

In collaborative work, the department that did one phase of the research is identified in italics in parentheses following the subtopic. For example, the Chemistry, Plant Breeding, and Statistics Departments cooperated in the project FACTORS THAT AFFECT GRAIN QUALITY. Because the Chemistry Department bore responsibility for one phase of this effort, its name follows the subtopic:

Internal check samples for amylose test (*Chemistry*).

Data in this report are given in metric units, e.g., " t/ha" means metric tons per hectare. The International System of Units (SI) is not, however, completely adopted for abbreviations. Unless otherwise stated, "control" or "check" means untreated control, grain yield is calculated as rough rice at 14% moisture, and protein content is calculated as a percentage of brown rice at 14% moisture. A single asterisk (*) means significant at the 5% level and two asterisks (**) mean significantly different from the control at the 1% level.

The report makes liberal use of abbreviations of names and terms often repeated within sections, e.g., brown planthopper (BPH), green leafhopper (GLH), modern variety (MV), and traditional variety (TV). Such abbreviations are spelled out when first used.

Pedigrees are indicated by a slant bar (/) rather than by the multiplication sign (×). For example, IR32 × IR34 is now written IR32/IR34. The sequence of crosses is indicated by the number of slant bars: (IR32 × IR34) × Bg90-2 is now written IR32/IR34//Bg90-2. The third and further crosses are designated /3/, /4/, /5/, and so on. Backcrosses are indicated by a superscript numeral.

The report makes reference to 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 the major sections, 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. A subject index appears in the back of the report.

Research highlights

The ledger barely balances

TODAY'S WORLD FOOD SITUATION has something in common with the plight of an old man who lamented, "The hurrier I go the behinder I get."

A concrete expression of the Asian food situation is in the report of a task force set up last year by the Asian Development Bank (ADB) to review the status of agriculture in its region—"Overall, the most optimistic view which can be taken of the food situation is that the region is not much worse off now than at the time of the first Asian Agricultural Survey." That first survey took place 10 years ago.

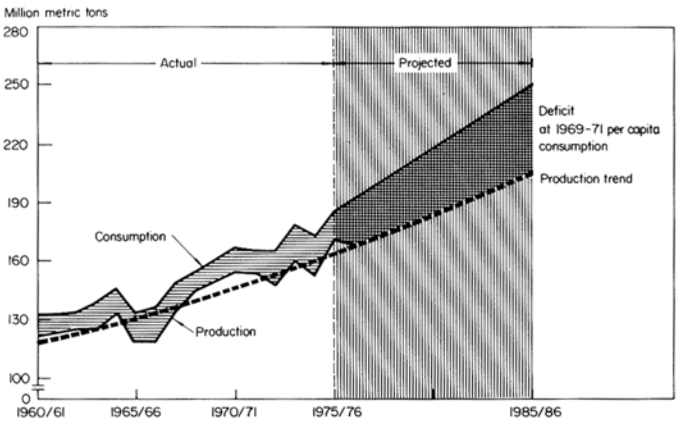
The ADB statement is sobering. And it is a poignant reminder of the seriousness of our task. But the ADB report is in harmony with other evaluations of the state of the world food situation (Fig. 1).

The past decade gave us remarkable scientific progress. Modern cereal varieties were adopted on millions of hectares by farmers, both small and large. Billions of dollars were invested in irrigation and other agricultural development projects. Even so, in Asia at least, these apparent marks of progress on the food side of the ledger have barely balanced population increases. Every day more than 100,000 added pairs of hands reach out for their bowls of rice.

In Africa and South America there are still possibilities for increased food production through expansion of areas under cultivation. In most Asian countries, however, the expansion option does not exist. Essentially all of Asia's arable land—including some steep hillsides that should never have been cultivated—is already farmed.

Two approaches to increased production remain open to Asian countries. They can increase yields from existing crops, or they can increase the number of crops grown each year. IRRI scientists are cooperating with their counterparts in national programs to focus on each of these possibilities.

Increased yields per hectare are sought through a massive international Genetic Evaluation and Utilization (GEU) Program. Tens of thousands of



1. Despite a steady increase in Asian cereal production since the advent of the green revolution in the mid-1960's, population increases leave us "not much worse off than 10 years ago." The projection of population increases (from an estimated 0.892 billion in 1970 to 1.3 billion in 1985) points to the threat of increased hunger. (Adapted from IFPRI, 1976)

rice seed samples are interchanged each year to permit their comprehensive testing and evaluation in a wide variety of agroclimatic and plant pest conditions. Teams of scientists from most of Asia's rice-growing countries are collaborating to identify and disseminate genetic materials resistant to pests and environmental stresses, ranging from fungal and viral diseases and the devastating insect pests, to drought, toxic soils, and deep water. The main aim is to provide the farmer in "disadvantaged" cropping environments with some of the benefits enjoyed by producers living in the "more attractive" environments.

Increased cropping intensities involve crops other than rice in most instances. Short-growth-duration rices make it possible to put rice in rotation with one or more upland crops, even in unirrigated areas. Such patterns have advantages because they break insect and disease cycles. And they provide farm families with a variety of nutritionally different foods to supplement their omnipresent rice diets.

IRRI's GEU and cropping systems scientists are not working alone or in isolation from scientists in other countries. Formal linkages exist within networks of scientists in the tropics who focus on the solution of common problems. Senior scientists from both the developing and more developed countries come to IRRI as short-term consultants to provide expertise we don't have.

The activities of those senior scientists—17 were at IRRI in 1976—integrate with those of IRRI's core staff and of about 20 postdoctoral fellows who concentrate on research to learn the "whys" and "hows" as well as the "whats" of rice production. In this way we attract the attention—and the scientific ability—of some of the world's best scientists to rice problems and their solution. We use the scientific talents of all these visitors to gain additional basic information about the rice plant and its enemies, and about its environments and its response to those environments.

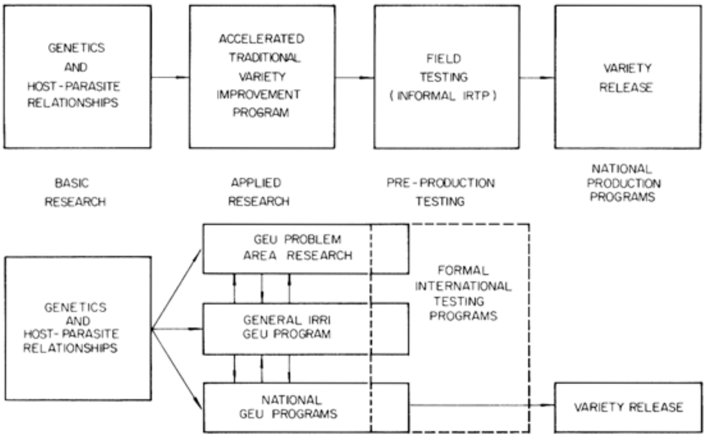
Through the research and training results presented in this publication, we illustrate the readiness of IRRI scientists to accept the challenges of the next decade. With counterparts in national programs, we can provide the technological basis for increased food production in the years ahead.

Progress in 1976

The favorable weather conditions that characterized 1975 continued during 1976. That gave farmers in most of Asia another "good" year and food production was comparable with that in the previous year. Even with good weather, however, most developing countries made little progress toward building reserve stocks to meet future food deficits.

Evolving GEU research strategies. In 1976 IRRI scientists and cooperators in national programs continued to evolve a research approach for the development of improved rice varieties. During the 1960's and the early 1970's we utilized a variety improvement program similar to that which characterizes an effective national research organization. The varieties that early programs produced, including IR8, IR5, and IR20, helped revolutionize the entire research approach to the support of the world's rice production complex.

As national research organizations gained strength and staff capability improved, IRRI served more as a catalyst for international cooperation and less as a model for a national research organization (Fig. 2). We no longer release varieties, even in the Philippines.



2. IRRI shifted emphasis in the mid-1970's from a pattern of variety development (top) to a multidisciplinary program of genetic evaluation and utilization (GEU) (bottom). The new pattern promotes and accelerates international cooperation rather than serving as a model for organization of national research as the old pattern did.

But we have greatly stepped up the supply of genetic materials for evaluation and testing in national programs. Early generation breeding materials (F_2's) are now sent directly to national cooperators without first being screened at IRRI. That arrangement assures evaluation under a range of environments and permits local scientists to select cultivars based on best performance in the local environment. We also have a program to produce F_5 seed of rices sensitive to day length, by a "rapid generation advance" procedure using both the phytotron and the field. The F_5 seeds are sent to national cooperators for evaluation in different rainfed and deep-water areas.

Through the International Rice Testing Program (IRTP), rices from national programs are evaluated along with IRRI genetic materials. National nominations for the IRTP increased 14% over those of 1975, indicating the growing strength of national research programs.

IRRI scientists contribute to the emerging international network of cooperating rice researchers through four major research streams.

- *Basic operations at Los Baños*—"working at home" we seek new knowledge, new biological materials, and new technology for the basic task of increasing rice production.
- *Collaboration with national rice research programs* on research activities we cannot do ourselves, or on activities that we feel can be done better by joint action.
- *Catalyzing the development and implementation of networks* of cooperating scientists to effectively test new biological materials, new technologies, or new research methodologies.
- *Assistance to national rice research programs* through training, conferences, workshops, and cooperation to improve their capacity to deal with problems.

GEU expansion. The germ plasm bank accessions reached nearly 40,000 in 1976. We accommodated the requests of 148 overseas researchers for about 5,000 seed samples from the germ plasm bank, and IRRI scientists drew 40,000 seed samples from the bank for inclusion in the various evaluation programs. The construction of a new Genetic Resources Laboratory to house 100,000 rice accessions started in 1976.

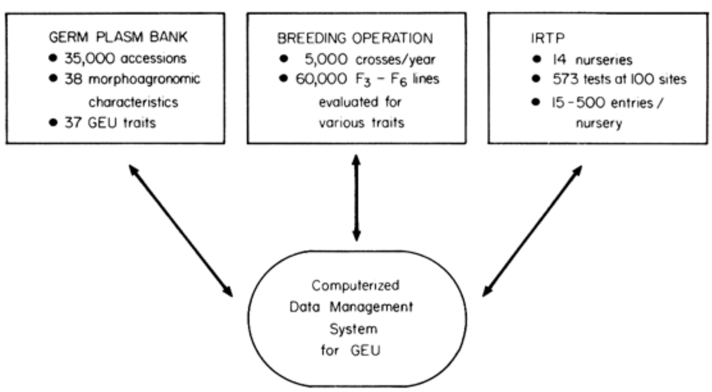
IRRI rice breeders increased the number of crosses to 5,000 in response to requests from scientists working in the different problem areas. All breeding lines at various stages of development were screened for resistance to the major rice diseases—75,000 for blast, 15,000 for sheath blight, 50,000 for bacterial blight, 44,500 for tungro virus, and 7,057 for grassy stunt. Similarly, we expanded screening for resistance to insect pests. Special efforts were devoted to screening rice varieties for resistance to biotypes of the brown planthopper. We found about 30 germ plasm accessions to be resistant to three biotypes of this major pest.

Screening of the germ plasm collections for drought resistance in a newly constructed greenhouse supplemented our extensive field screening of previous years. We studied adverse soil areas and pin-pointed about 100 million hectares of land suitable for rice production, lying idle largely because of soil toxicities. We are developing genetic lines that will produce well when planted in toxic soil. The evaluation of rices tolerant of floods and deep water was expanded in cooperation with scientists in Thailand and other Asian countries.

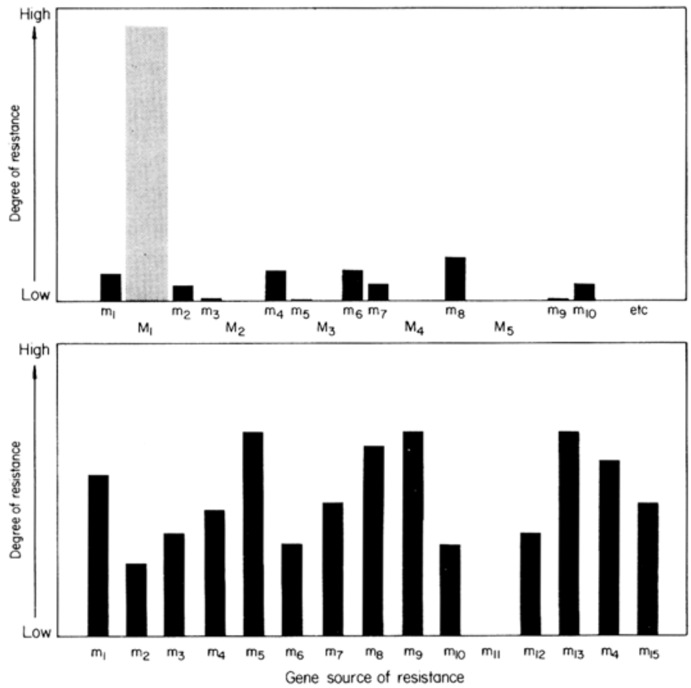
During 1976, the GEU program prepared and distributed 614 sets of 14 nurseries to scientists in 40 countries. Of these sets, 573 went to organized IRTP trials; the remainder went to collaborative research projects.

Computerized data processing. During 1976 we began the development of computerized systems for handling the volumes of data from our GEU program and the associated IRTP tests. Each year, more than a million bits of data from the overall GEU program must be tabulated, summarized, and disseminated. They include observations on 38 morphoagronomic characteristics of each of the more than 35,000 germ plasm accessions, field observations on thousands of lines in IRRI's internal breeding program, evaluations from screening of about 50,000 accessions and lines, and data submitted by cooperators in the IRTP program (Fig. 3).

Monogenic versus polygenic resistance. We accelerated our efforts in 1976 to broaden the genetic base of resistance to major rice pests and diseases. The emergence of at least four biotypes of the brown planthopper reconfirms the soundness of this approach. The so-called "vertical" or major gene resistance, which has proved successful for pests such as the green leafhopper and grassy stunt virus, is not effective for the brown planthopper or the rice blast disease



3. A computerized system allows tabulation, summarization, and dissemination of more than a million bits of data annually from the overall GEU program. Prompt analysis of data and fast response to IRRI and national rice program scientists are main benefits of the system.



4. Monogenic resistance (from only one major gene) is extremely effective and can be long lasting (for example, the *O. nivara* gene for grassy stunt resistance). But if such resistance is overcome by the plant pest, as was the case with the brown planthopper, the carrier variety with no other gene for resistance (A) may become highly susceptible. IRRI scientists worked in 1976 to broaden the genetic base for resistance and to develop varieties with polygenic resistance (from many genes). Plants with polygenic resistance may carry a single gene conveying a high level of resistance (B), but they retain an acceptable level of resistance if that gene is overcome by an organism. M = major gene for resistance; m = minor gene.

(Fig. 4). Fortunately we have genetic materials and advanced breeding lines resistant to each of the newly identified biotypes of the brown planthopper, and we are expanding our efforts to provide varieties with broad-based general types of resistance.

Production research. We continued efforts to increase the efficiency of nitrogen utilization and decrease costs for this important fertilizer element. Significant losses as ammonia gas were noted on alkaline paddy soils. Biological fixation of nitrogen by the *Azolla-Anabaena* complex was found to be dependent upon the phosphorus status in the floodwaters.

Ineffective pest management, along with inadequate fertilizer application, constrained rice yields in tests on farmers' fields. The economic control of pests continued to be a major problem for these farmers.

We found fairly equitable distribution of the benefits of the new rice technology among farmers with either small and large holdings. Likewise, the landless laborer benefited from the new technology because, in general, it was more labor intensive than the technology that prevailed when traditional varieties were grown.

Increased cropping intensities are already resulting from IRRI's research on cropping systems. Year-round continuous rice trials are under way on some farmers' fields. A province-wide program of double cropping has been launched in Iloilo in the Philippines. It is based largely on the results of IRRI-sponsored field research.

Genetic evaluation and utilization (GEU) program

Summary

GENETIC RESOURCES PROGRAM

IRRI now has about 34,200 accessions and 3,800 new seed samples of *O. sativa*, 1,372 strains of *O. glaberrima*, 866 wild taxa, and 637 genetic testers in the germ plasm bank. About 17,690 accessions of *O. sativa* are completely described and the basic morphoagronomic data entered on computer tape. Similarly, 664 strains of *O. glaberrima* are completely characterized.

In 1976, IRRI staff, in collaboration with national rice research programs, collected 1,520 samples of indigenous rice varieties, many of which were being replaced by modern varieties in Bangladesh, Indonesia, and Sri Lanka. Local extension workers in six other countries added another 134 samples to the collection.

Since 1972, such collaborative efforts have led to the acquisition of 18,007 samples, of which 7,502 samples were collected with IRRI's direct participation. About 4,850 of the samples have one or more special features—resistance to pests, tolerance to adverse soils, adaptation to cool temperatures, or resistance to drought.

The Institute has taken steps to develop a global network of genetic resources centers toward the overall preservation of rice germ plasm. Seed banks in Japan, the USA, and West Africa were enlisted to share the responsibilities in seed rejuvenation, storage, and distribution.

In response to 137 requests in 1976, IRRI sent foreign researchers 5,226 seed samples. Within IRRI, 40,203 seed samples went to scientists in the Genetic Evaluation and Utilization (GEU) program. The Institute began a systematic exchange of rice germ plasm with the People's Republic of China and with the USSR. It also made progress in acquiring seed stocks from different rice collections in India.

AGRONOMIC CHARACTERISTICS

Several promising lines with high yield potential were identified. IR2071-586-5-6 gave outstanding yields at both low and high fertility levels for the second consecutive year. Other high yielding lines with medium growth duration are IR2071-588-6-2 and IR2863-38-1. IR2070-414-3-9 is a promising line with short growth duration.

Studies indicate that the grain-filling period in rice ranges from 12 to 21 days. Higher rates of grain growth are correlated with larger grains. Large-grain varieties are more efficient in starch accumulation (grain production) during the ripening period than small-grain varieties. A comparison of six varieties with different grain sizes indicated that the larger the grain, the higher the yield potential.

Allele tests between different dwarfs indicated that the gene for dwarfism of Chin-nan-ai 11 from China is different from that of Dee-geo-woo-gen.

GRAIN QUALITY

The breeding program continues to emphasize intermediate-amylose rice with soft gel. Promising lines with intermediate and low amylose were identified.

Variability of amylose content of rice due to samples was found greater than variability due to replication of the same sample. Temperature during ripening was negatively correlated with amylose only in low-amylose rice. The correction due to omitting the cold ethanol defatting step in the amylose test was low and constant. Automatic correction can be made using undefatted check rice samples by predetermining their amylose content on defatted flour at a pH of 9.

The alkali concentration of 1.7% KOH was confirmed as the most sensitive for general screening for starch gelatinization temperature. The classification of alkali digestibility (gelatinization temperature) of samples that give extreme values may be verified in 1.15% or in 1.85% KOH for alkali spreading values of 7 and 2 to 3, respectively. All high-amylose rices that gave type B reaction in the alkali test and showed low dissolved solids on cooking had hard gel and may be readily detected by the IRRI gel consistency test.

The gel consistency test developed for high-amylose rice is readily applicable to intermediate-amylose rices. With low-amylose rices, adjusting the flour concentration from 100 to 120 mg/2 ml 0.2 N KOH discriminated between rices differing in eating quality. But the spread of values for both low- and intermediate-amylose samples was narrower than for high-amylose samples.

During grain development of IR28 and IR29, level of free sugars and their fractions closely followed the rate of starch accumulation and showed maximum values at about 9 days after flowering. The level of free sugars remained high in the caryopsis after starch accumulation had ceased, suggesting that the supply of sugar precursors does not limit starch accumulation in the rice grain. Properties of the starch granule, such as gel consistency and gelatinization temperature, were fixed early during grain development.

DISEASE RESISTANCE

Several of IRRI's elite breeding lines have a good level of resistance to all major diseases. The *xa 5* gene for resistance to type 2 of *Xanthomonas oryzae* from IR1545-339 was extensively used in crosses among promising advanced lines.

Distinct pathogenic patterns were demonstrated between rice varieties and strains of *X. oryzae*. Three types (races) are recognized in the Philippine isolates of the bacterium. Inheritance studies of bacterial blight identified two more new resistance genes.

In the search for more and better donors of resistance to major diseases from the IRRI germ plasm collection, many new sources were identified; they will be further evaluated using different strains of pathogens. Thirty-eight varieties show resistance to all three types of *X. oryzae* found in the Philippines.

The relationship between quantitative resistance (number of lesions) and qualitative resistance (to races) to blast was also shown by artificial inoculations, indicating many races in single-spore cultures.

Studies on inheritance of resistance to bacterial blight showed that some varieties are resistant at the maximum tillering stage and continue to be resistant at later growth stages while others are resistant at the adult stage only. Two additional resistance genes were found in the 68 varieties studied—a new dominant gene that is independent of *Xa 4* and conveys resistance at the adult stage, and a new recessive gene that is independent of *xa 5*.

INSECT RESISTANCE

Insect resistance investigations concentrated on the striped borer *Chilo suppressalis*, the yellow borer *Tryporyza incertulas*, the brown planthopper *Nilaparvata lugens*, the whitebacked planthopper *Sogatella furcifera*, the green leafhopper *Nephotettix virescens*, and the rice whorl maggot *Hydrellia philippina*. Major emphasis was on new sources of plant resistance, genetics and nature of resistance, occurrence of biotypes, and breeding for resistance.

PROTEIN CONTENT

Evaluation trials verified that IR2153-338-3 is a promising high-protein line and identified another high-protein line, IR2863-35-3-3. Solar radiation 45 days before harvest correlated negatively with protein content of brown rice and positively with grain yield of IR26 and IR28 in monthly plantings in 1976. Compared with early application, late (5–7 days before panicle initiation) single or split application of nitrogen fertilizer increased rice protein in IR26 and IR28 without decreasing the yield.

In a cross involving IR480-5-9, the IRRI high-protein check line, protein per seed (P/S) appeared to be more effective than protein percentage as a selection criterion. Heritability estimates for P/S were higher than those for protein percentage. Low values of protein percentage, P/S, and grain weight were found dominant over high values.

Cooking reduced the digestibility of milled-rice protein in growing rats, but a corresponding increase in biological value resulted in net protein utilization similar to that of raw rice. Fecal protein particles of children on a cooked rice diet showed protein bodies similar to those in milled rice.

Milled-rice globulin was composed of only one major protein, which tended to aggregate at pH 6–9. It was characterized as an α-globulin, poor in lysine but rich in methionine. Prolamin was also characterized as having molecular weight (MW) 17000 and can be prepared free of phenolic and carbohydrate contamination from the crude ethanol extract. During grain development, appearance of a second slower protein band in the electrophoretic pattern of crude prolamin coincided with a decrease in its lysine and methionine content.

Reduced and alkylated crude glutelin of milled rices of 11 varieties and lines showed a similar electrophoretic pattern and identical ratio 1 : 1 : 1 of the three subunits with MW 17000, 25000, and 38000. Their lysine contents were similar to those of milled-rice protein. The results indicate little probability of finding in cultivated rice variants that differ in the ratio of glutelin subunits. Among the grain parts, only the aleurone layer showed an electrophoretic pattern of glutelin subunits similar to that of milled rice. A restudy of solubility subfractions of glutelin also showed that its major fraction extracted with sodium dodecyl sulfate—β-mercaptoethanol in borate buffer was the closest to crude glutelin in amino acid composition and in the electrophoregram of subunits. During grain development, changes in amino acid composition and appearance in the electrophoretic pattern of MW 38000 and 25000 subunit of crude glutelin coincided with the known appearance of protein bodies in the endosperm about 7 days after flowering.

DROUGHT RESISTANCE

During 1976 crosses made for the drought resistance program included 178 double crosses, 352 topcrosses, and 200 single crosses. The production of a range of plant types suitable for upland, rainfed-lowland, or relatively deep-water (0.5–1.0 m) areas was emphasized. Among the parents chosen for rainfed-lowland culture, BPI-76 (nonsensitive), Sigadis, Nam Sagui 19, and Nahng Mon S4 were involved in many crosses. Crosses intended for upland culture included sources with resistance to cool temperatures or to problem soils.

Field screening of traditional varieties from the germ plasm bank and of breeding lines continued. A total of 6,774 rices were screened, bringing the total to 14,123 entries since 1973. During the wet season, a field experiment to develop field screening criteria for rainfed-lowland culture was initiated. The new drought screening greenhouse facility made screening in year-round dry-season field conditions possible.

Adequate rainfall during 1976 at IRRI and at off-station sites gave upland field performance trials a chance to show that many promising upland lines have considerably greater yield potential than traditional varieties. An increase in drought resistance in short-statured lines was also achieved through hybridization and selection.

Evaluation of deep-root systems in the cultivated and 11 wild species of the genus *Oryza* continued. Studies of root development in the field with both upland and submerged culture demonstrated two potential problems in the exploitation of genetic differences in deep-rooting ability—mechanical impedance in upland soils and lack of oxygen in submerged soils.

Greenhouse studies on tolerance for severe drought stress continued. The 1976 work confirmed earlier observations on varietal differences in recovery ability and identified several promising lines from the elite breeding material.

Studies on the physiological basis of dry-season field screening proved that visual scoring was highly correlated with varietal differences in ability to maintain high leaf water potential. In other studies, varietal differences in cuticular resistance to water vapor were related to the amount of epicuticular wax on the leaf surface. Cuticular resistance increased when plants were stressed.

Studies of the soil-plant-atmosphere water continuum under upland conditions in Batangas province continued for the second year. The significant contribution of atmospheric evaporative demand on determining leaf water potential showed the importance of considering that factor as well as decreased soil moisture in the assessment of probabilities and severity of drought.

TOLERANCE FOR ADVERSE SOILS

About 100 million hectares of land in South and Southeast Asia that are physiographically and climatically suited to rice culture lie uncultivated largely because of salinity, alkalinity, strong acidity, and excess organic matter. There are also vast areas of land where toxicity of iron, aluminum, or manganese, and deficiency of iron, phosphorus, or zinc cause reduced rice yields (see Soil characterization, this report). Although most adverse-soil conditions may be alleviated by chemical amendments or by treatments requiring large amounts of capital investment, varietal tolerance may be a simpler solution—especially for the small Asian farmer.

The objectives of IRRI research on tolerance for adverse soils are to select and breed rice varieties suited to adverse soils, to evaluate promising lines from the general breeding program for tolerance for adverse soils, and to ascertain the extent to which varietal tolerance for adverse-soil conditions can replace or supplement costly soil amendments.

The main activity in 1976 was the screening of varieties, lines, and hybrids on adverse soils. Several IR varieties and many IRRI elite lines with good agronomic characteristics and resistance to diseases and insect pests did well on adverse soils although no effort was spent to achieve that result.

Four IR4630 and IR4763 lines showed high tolerance for salinity. IR30, IR32, IR36, and 13 advanced breeding lines had moderate salinity tolerance. IR4227-28-3 and IR4227-104-3 revealed outstanding tolerance for alkalinity, and 52 advanced breeding lines showed moderate tolerance. IR20, IR29, IR32, and many elite lines from the crosses IR2031, IR2070, IR2071, and IR2153 showed tolerance for iron toxicity. IR20, IR34, BG90-2, and several elite lines were tolerant of zinc deficiency. IR28, IR29, IR30, IR34, IR1514A-E666, and several IR2061 lines tolerated phosphorus deficiency.

DEEP WATER AND FLOOD TOLERANCE

Crossing of improved semidwarfs with varieties having elongation ability and flood tolerance continued. Breeding lines of different growth durations and plant heights were tested in the first International Rice Deep Water Observational Nursery (IRDWON).

Varieties and breeding lines at the seedling stage continued to be screened for elongation ability, flood tolerance, and drought tolerance.

A method was developed to screen for kneeing ability, a plant character needed for deep-water rice culture. Studies on nodal rooting ability and the effect of moisture stress at seedling stage on elongation ability were conducted.

Forty rice scientists who work on deep-water rice participated in a workshop jointly sponsored by IRRI and Thailand, which reviewed 2 years of deep-water rice work.

TEMPERATURE TOLERANCE

During the year, 3,572 germ plasm collection entries were screened for cold tolerance based on optimum growth duration, proper plant height at maturity, low spikelet sterility at harvest, anthesis at flowering, and green leaves at the seedling stage.

An expanded breeding program for cold tolerance continued to combine cold tolerance with other desirable agronomic traits.

A method of predicting the growth duration of IR8 at a given place when temperature data are available was formulated.

Results from phytotron experiments indicate that leaf angle is greater at places where diurnal fluctuations in temperature are wide.

The mechanism of sterility induced by high temperature at flowering time was investigated. Sterility was caused either by poor shedding of pollen grains on a stigma or failure of germination on a stigma. However, high temperature did not affect the ability of the pistil to be fertilized. Varietal differences in sterility induced by high temperature were largely related to the dehiscence characteristic of the anther.

The mechanism of field heat tolerance by heat avoidance and true heat tolerance was proposed.

INTERNATIONAL RICE TESTING PROGRAM

The International Rice Testing Program (IRTP) initiated early in 1975 aimed to develop a network of collaborating scientists to work with diverse rice germ plasm under a wide range of agroclimatic and local conditions. The program expanded in 1976.

The IRTP serves as an integral evaluation component of each nation's rice improvement program and of IRRI's Genetic Evaluation and

Utilization (GEU) program. IRTP policies and programs are developed cooperatively with rice scientists from many countries. The testing and utilization of breeding materials and varieties from IRRI's germ plasm bank and from national programs are integrated into a national GEU-type program in each participating country. Leading local scientists coordinate the nurseries within each country, and IRRI provides international coordination.

The analysis and interpretation of the 1975 IRTP data reflect solid progress, which includes the isolation of some germ plasm that showed excellent potential as a means of overcoming some serious constraints in rice improvement.

In 1976, IRTP's second year of operation, 573 sets of 14 different nurseries were distributed to 40 countries around the world. Seven regional monitoring programs were conducted. The second GEU Training Program was attended by 27 trainees from 9 countries. A special conference attended by representatives of 17 Latin American countries was held at the International Center for Tropical Agriculture (CIAT), Cali, Colombia, to expand the international rice testing program in Latin America. Improved communication links were established with country coordinators, contact scientists, and collaborators in Asia and Africa.

The joint coordinators—a plant pathologist, a plant breeder, and an agronomist headquartered in the Philippines, and an IRRI plant breeder stationed in Indonesia with the Central Research Institute for Agriculture, Bogor—were assisted by some 50 national coordinators and contact scientists in 40 countries.

INTEGRATED GEU PROGRAM

The crossing program continued to expand to meet the demand of national programs for assistance. Other aspects of the integrated GEU program expanded as a delayed reaction to the rapid growth in crossing work in previous years.

About 90% of IRRI's advanced breeding lines tested during 1976 were resistant to at least five of the major diseases and insect pests of rice in the Philippines. Several hundred promising advanced lines were developed and will be extensively tested by the International Rice Testing Program (IRTP) in 1977.

IRRI sent 10,365 seed packets of breeding lines in response to special requests from scientists in national programs during 1976. An additional 42,867 packets were distributed through IRTP.

COMPUTERIZED DATA MANAGEMENT

The increased size of the IRRI germ plasm bank, and the expanded breeding program and International Rice Testing Program (IRTP) necessitated the development of a computer-based data management system to integrate all available information. A computerized system was designed for IRRI's germ plasm bank that can store available information on all accessions and can retrieve any accession that combines a specified set of characters. IRRI's hybridization block and replicated yield trials are supported by computer-generated field books, which are directly converted into computer-readable forms for inclusion in the data bank after data collection is completed. The history of more than 17,000 crosses is now on computer tapes. Analysis, summarization, storage, and retrieval of data from the IRTP yield nurseries are completely computerized.

GENETIC, PROFESSIONAL, AND SOCIOLOGICAL ASPECTS OF RICE BREEDING IN ASIA

During 1975–76, IRRI surveyed 41 rice breeders at 28 research centers in 10 Asian nations: Bangladesh, India, Indonesia, Iran, Korea, Nepal, Pakistan, Philippines, Sri Lanka, and Thailand. The project was conducted in collaboration with the Agricultural Education Department of Iowa State University and was partially funded by a research grant from the Rockefeller Foundation.

Among environmental and biological conditions surveyed, diseases and insect pests were perceived by all breeders as main factors that limit farmers' rice production. They were followed in importance by drought, injurious soils, excessive monsoon cloudiness, floods, cold temperature, and deep water. Among specific pests, the rice stem borer was considered serious in about 60% of the region, followed by bacterial blight, brown planthopper, blast, gall midge, tungro, sheath blight, and grassy stunt.

The farmers' rice-growing conditions, the surveyed scientists' research efforts, and the varieties released during the previous 5 years were compared. About 43% of the farmers' fields were presumed irrigated, 40% were presumed rainfed lowland; about 60% of the research efforts went to irrigated rice and 22% to rainfed lowland rice. Fifty-seven percent of the newest varieties were suited to irrigation and 32% to rainfed lowland.

Twenty-six research centers were growing 119 IRTP nursery sets—about 4.6/station.

During a 5-year period, 165 new varieties were released for 28 areas, or slightly more than 1 variety/year. Sixty-five percent of the new varieties were either progeny of IRRI rices or had been developed at IRRI.

In 27 advanced yield trials, 4,021 lines were being grown. Fifty-nine percent of the lines originated from local crosses and 41% were introduced from other stations. Sixty percent of the introduced lines came from crosses made at other research centers in the same countries; 39% came from IRRI; and about 1% from other Asian nations. The breeders selected 3,791 advanced lines from 443 local crosses, an average of 8.6 lines/cross. Fifty-four percent of the breeders felt that IRRI should stop releasing varieties with the IR designation.

The breeders surveyed had an average age of 41 years. Fifty-three percent came from agricultural backgrounds and 85% worked exclusively with rice. Seventy-five percent of them had traveled outside their countries during the past 5 years to attend professional conferences and for training. Ninety percent of their most recent trips were to IRRI.

Half of the breeders hold the Ph.D. degree, 65% of which were obtained from universities in highly developed countries. Sixty-two percent of the breeders had participated in the IRRI nondegree training program and about 10% had received degrees from the University of the Philippines at Los Baños, through the IRRI degree-training program.

Thirty-eight of the breeders had published scientific papers during the previous 2 years. Fifty-three percent of 183 articles appeared in national publications, 23% in institutional publications, 18% in journals from highly developed countries, and 6% in international publications. Ninety-two percent of the scientific literature read by the breeders was in English. In a rating of importance and percentage of use of 76 publications and information sources, the *IRRI Annual Report* received the highest importance and source-of-information score. Local problem-area scientists—agronomists, entomologists, and pathologists—ranked second as a source of information.

Genetic evaluation and utilization (GEU) program

Genetic resources program

Plant Breeding Department, Administration, and International Rice Testing Program

FIELD COLLECTIONS
Plant Breeding Department

IRRI staff members continued field collection of rice germ plasm in Bangladesh, Indonesia, and Sri Lanka, upon the invitation of the national research centers concerned.

The IRRI field advisor travelled extensively in northeast and southwest Bangladesh in January to collect 232 samples of aman[1] varieties that could tolerate deep waters or salinity, or both. From October to December, the northwestern region and the deltas in southeast Bangladesh were canvassed for aman varieties. Three hundred fifty-one samples were collected.

Extensive travel in Java, Indonesia, during April and May covered 26 towns, most of which were at elevations from 800 to 1,500 m. A total of 550 varieties and 4 wild rices were collected.

The field advisor spent August and September in Sri Lanka to complete the canvassing of the yala[2] varieties. Extinction of those varieties was imminent as modern varieties spread rapidly following intensive extension efforts. Four hundred seed samples, including those of 10 wild rices, were collected.

Local extension workers in Bhutan, British Solomon Islands, Burma, Malaysia, the Philippines, and Thailand also collaborated with IRRI in the collection of indigenous varieties. They collected 134 samples with technical assistance from IRRI.

Table 1. Indigenous rice varieties collected with IRRI's direct or indirect participation in 13 collaborating Asian countries, 1971 to 1976.

Country	Years	Indigenous varieties (no.)	
		Direct participation	Indirect participation
Bangladesh	1973–75, 1976	1,381	2,473
Bhutan	1975–76	—	119
Burma	1973–74, 1976	225	406
Cambodia	1973	280	—
Indonesia	1972–76	4,366	2,861
Laos	1972–73	—	898
Malaysia	1973–76	—	584
Nepal	1971	—	907
Pakistan	1972–73	—	750
Philippines	1972–76	62	278
Sri Lanka	1972, 1975–76	1,080	355
Thailand	1973, 1975–76	—	225
Vietnam	1972–75	108	649
Total		7,502	10,505

Table 2. Indigenous rice varieties with special traits collected and preserved in national programs and in the IRRI germ plasm bank, 1972–1976.

Reported features	Samples (no.)
Upland types/drought-resistant types	2739
Floating/flood-tolerant types	651
High-elevation/cool-tolerant types	645
Tolerance to salinity	280
Tolerance to acid soils (lowland)	209
Aromatic types	101
Resistance to diseases	88
Resistance to insects	42
Multiple tolerances	38
Semidwarfs	23
Tolerance to alkaline soils	14
Resistance to nematodes	5
Tolerance to iron toxicity	4
Tolerance to iron deficiency	3
Tolerance to phosphorus deficiency	3
Total	4845

A cumulative summary of field collection activities from 1971 to 1976 is in Table 1.

The field collection efforts emphasized the search for cultivars with special characteristics. Table 2 shows the breakdown of 4,845 samples gathered since 1972 under 15 categories of special traits.

SEED INCREASE, REJUVENATION, AND DISTRIBUTION
Plant Breeding Department

A substantial proportion of the seed samples received for the germ plasm collection was either small in quantity or low in viability, or both. In such cases, an initial cycle of seed increase under intensive protection in a screened nursery area became necessary to obtain seed for systematic characterization and further seed increase. Some new accessions were so susceptible to the diseases and insects prevalent at IRRI that an additional cycle of seed increase was needed to produce sufficient seed for planting. In 1976, 933 accessions were grown for initial seed increase.

In the 1976 dry and wet seasons, 3,770 and 3,180 plots, respectively, provided material for both characterization and seed increase. Plants of photoperiod-sensitive accessions in the dry-

[1] Local name for long-duration varieties planted March–June and harvested November–December.

[2] Local name for the second growing season. Planting is April–May and harvest is September–October.

season planting did not flower at the end of June. About 360 accessions were removed from the field, replanted in pots, and subjected to artificial short-day treatment. Small amounts of seed were eventually harvested in October–December.

A group of 1,353 strongly photoperiod-sensitive accessions were planted in November of 1975 for seed increase. Hundreds of the accessions were poor seed producers even under short day length.

During the last 5 years, the seed viability of varieties from temperate regions dropped at a faster rate than that of varieties from the tropical regions. By the end of 1975, the viability of the temperate-zone control variety Chianan 8 had dropped to about 50%, while that of the tropical varieties remained above 94%. To prevent the loss of the temperate-zone varieties, 2,467 accessions from China, Japan, Korea, United States, South America, and several European countries were grown during the dry season to rejuvenate the seed stock.

During the wet season, 712 plots of the cultivated African rice (*O. glaberrima*) were grown for seed increase and characterization. Although a large proportion of the African rices is resistant to the green leafhopper, and in spite of intensive insect measures, a tungro epidemic in September rendered 682 plots completely sterile.

Foreign requests for seed of *O. sativa* accessions numbered 137 in 1976; 5,226 seed samples were provided. Another 250 packages of *O. glaberrima* strains and wild species were sent abroad in response to 11 requests. For tests under the GEU program, 40,203 seed packages were provided to IRRI research departments. That was nearly double the 22,155 samples supplied in 1975.

INVENTORY, CHARACTERIZATION, AND DATA PROCESSING
Plant Breeding Department

IRRI received 5,710 seed samples from different institutions in 1976. At the year's end, the IRRI germ plasm bank had 34,229 registered accessions of *O. sativa*, 1,372 accessions of *O. glaberrima*, 866 strains of wild species or taxa, and 637 genetic testers and mutants. The *O. sativa* accessions include IRRI breeding lines with special characteristics or those used in the hybridization program. Moreover, 3,848 newly received seed samples of *O. sativa* await planting and registration. In recent years, 4,465 duplicate accessions and 1,822 dead samples were identified and deleted from IRRI inventories.

Of the *O. sativa* accessions, 17,689 are completely characterized for the 37 basic morphoagronomic characteristics. Of the *O. glaberrima* accessions, 664 strains are completely characterized for 39 traits. All those data, plus information on the varietal origin, seed source, and variety-group designation were placed on computer tapes.

PLANNING THE GENETIC RESOURCES LABORATORY
Plant Breeding Department, Administration, and International Rice Testing Program

The volume of seeds being processed, stored, and distributed under the Genetic Resources Program, the GEU program, and the IRTP has rapidly increased in recent years. In early 1976, consultations with engineers from Australia, Canada, and Japan identified essential engineering features for a Genetic Resources Laboratory that will meet the combined needs of the three programs. The new facility will house the laboratories and offices of the Plant Breeding Department and the IRTP. The storage facilities will provide ranges of temperature and relative humidity (RH): short-term—20° ± 2°C, 45–60% RH; medium-term—4° ± 1°C, 45 ± 5% RH; and long-term—−10° ± 2°C, 30 ± 5% RH.

The design of the Laboratory and of its storage facilities was reviewed and endorsed by the International Board for Plant Genetic Resources (IBPGR) Working Group on Long-term Seed Storage. Construction started in November.

INSTITUTIONAL EXCHANGES
Plant Breeding Department and Administration

Discussions between the Indian Council for Agricultural Research (ICAR), the Central Rice Research Institute (CRRI) at Cuttack, India, and IRRI paved the way for the systematic transfer of genetic stocks in India's national and state collections into the IRRI germ plasm bank for preservation and evaluation. The holdings in India total about 31,700 accessions, which include many duplicate accessions and foreign introductions. ICAR and CRRI have copies of the IRRI inventory of accessions of Indian origin, and the Indian institutions will provide those accessions that are not yet in the IRRI germ plasm bank.

In 1976, IRRI received 482 seed samples from two experimental stations in West Bengal, India. The field advisor visited West Bengal in December to assist in selecting and processing genetic stocks from different collections for shipment to IRRI. The Chinsurah Rice Research Station and its branch stations at Kalimpong, Darjeeling, Bankura, and Purulia hold about 5,000 varieties. Of those, 2,821 varieties that were identified as nonduplicated will be added to the IRRI germ plasm bank in 1977.

Exchange of seed stocks was initiated with the All-Union Vavilov Institute of Plant Industry, the All-Union Research Institute of Rice, and the Kuban Agricultural Institute of the USSR. The exchanges amounted to 123 samples received and 121 samples given.

Seed exchanges were made when a delegation from the People's Republic of China visited IRRI in March and when a group of IRRI scientists visited China in October. IRRI received 77 samples and gave 553 samples to Chinese researchers. Since 1974, it has received 146 seed samples from China; 119 were viable and distinct accessions.

GLOBAL NETWORK FOR GENETIC CONSERVATION
Plant Breeding Department and Administration

Although IRRI has global responsibility for the long-term preservation of rice germ plasm, the climatic and biotic environments at Los Baños do not allow IRRI to carry out the seed increase, rejuvenation, and characterization operations for diverse ecotypes. To do so, it risks the loss of unadapted or susceptible accessions and changes in the genetic composition of the original samples. The difficulties reported in the growing of the African rices (*O. glaberrima*) at Los Baños indicate that genotypes with a narrow range of adaptiveness or susceptibility to pest damage should be grown and maintained in their indigenous habitat, or at a site with similar ecological conditions.

During 1976, IRRI made good progress in developing a network to cope with the enormous genetic diversity in the genus *Oryza*. At the first meeting of the IBPGR Advisory Committee on Rice held at IRRI, the members agreed:

1. IRRI will preserve and rejuvenate the indica and javanica varieties of *Oryza sativa* and other species of *Oryza*, except those from Africa. IRRI will also store all conserved stocks of rice.
2. Japan will preserve and rejuvenate the japonica (or *keng*) varieties.
3. The United States will preserve and rejuvenate varieties from the US, the temperate zone of South America, and the Mediterranean area. The US will also continue to assist IRRI on the duplicate storage of conserved stocks.
4. A center, or centers, in West Africa (to be designated) will increase and rejuvenate varieties of *O. glaberrima* and wild species from Africa.

At the West Africa Rice Development Association (WARDA) Variety Improvement Seminar held in Liberia in September, the representatives of WARDA, the International Institute of Tropical Agriculture (IITA), the Institut de Recherches Agronomiques Tropicales (IRAT), and IRRI reached initial agreement on sharing and dividing responsibilities related to exploration and collection, seed rejuvenation and distribution, and long-term preservation of the African rice germ plasm.

MANUAL ON GENETIC CONSERVATION
Plant Breeding Department

A Manual on Genetic Conservation of Rice Germ Plasm for Evaluation and Utilization was published in December. The manual will help rice researchers to conserve, evaluate, and use existing gene pools of the genus *Oryza*. Operations on the scientific management of diverse genetic resources for varietal improvement are outlined, and interdisciplinary collaboration and interinstitutional cooperation on the operational aspects are emphasized in the discussions.

Genetic evaluation and utilization (GEU) program

Agronomic characteristics

Agronomy, Plant Physiology, and Plant Breeding Departments

PERFORMANCE AND NITROGEN RESPONSE OF IRRIGATED RICE

Agronomy Department

The performance of 27 promising IRRI breeding lines was evaluated during the dry and wet seasons under protected conditions. IR8 and IR26 served as checks.

IRRI. The yield of selected lines under different nitrogen levels is shown in Table 1. The lines IR1632-93-2-2, IR2823-399-5-6, IR2863-38-1, and IR2061-522-9 had dry-season yields of more than 7.0 t/ha at 150 kg N/ha; IR26 had 6.9 t/ha. IR1632-93-2-2 exhibited excellent seedling vigor, establishing quickly and producing tillers rapidly. Those characteristics are highly desirable on the farm to minimize the hazard of too much or too little water in the paddy soon after transplanting.

Among the lines that produced high yield without added nitrogen, IR2058-78-1 and IR1632-93-2 appeared promising. During the dry season, planthopper infestation was light and IR8 yielded higher with 150 kg N/ha than it did during the 1975 dry season (6.6 t/ha vs 4.9 t/ha).

Of the promising lines that produced 7.0 t/ha or higher in the dry season, only IR2823-399-5-6 held up well in the wet season: it yielded 4.4 t/ha at 120 kg N/ha, while IR26 yielded 3.2 t/ha.

In the wet season, IR2071-586-5-6-3 gave high yields at all nitrogen levels, followed closely by IR2071-588-6-2-6-4. It was the second consecutive wet season (1975 Annual Report) that IR2071-586-5-6-3 produced the highest yield without added nitrogen. Its yield stability at 0, at 30, or at 60 kg N/ha may make it valuable for areas of low fertility.

There was no serious brown planthopper infestation in the wet season but because of continuous rains, many varieties and lines suffered from bacterial leaf streak.

Philippine experiment stations. The yields of 18 rices were evaluated during the dry and wet seasons at the Philippine Bureau of Plant Industry experiment stations at Maligaya, Bicol, and Visayas. IR8 and IR26 were the check varieties.

In the dry season IR1632-93-2-2, which gave the highest dry-season yield at IRRI, 6.2 t/ha at 120 kg N/ha (average of three stations), was among the highest yielders at the BPI stations. IR36 and IR2823-399-5-6 gave average yields similar to that of IR1632-93-2-2 (Table 2).

In the wet season, IR2071-586-5-6-3, IR2863-38-1, and IR2823-399-5-6 gave similar high grain yields of 5.8 t/ha (Table 3). They also

Table 1. Yields of rice varieties and promising lines at five levels of nitrogen,[a] average of three replications. IRRI, 1976.

Variety or line	Dry season						Wet season					
	Maturity (days)	Yield[b] (t/ha)					Maturity (days)	Yield[c] (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	134	4.2	5.1	6.0	6.1	6.6	126	1.4	1.9	1.8	1.9	1.4
IR20	131	4.3	5.8	6.0	6.5	6.5	126	2.1	3.0	3.3	3.5	3.5
IR26	134	4.2	5.9	6.2	6.2	6.9	126	2.4	3.2	3.6	4.0	3.2
IR36	110	4.1	5.4	5.7	6.3	6.8	103	2.6	2.8	3.6	3.4	3.4
IR38	131	4.5	6.3	6.9	6.7	7.0	131	2.8	4.0	3.8	4.2	4.2
IR1632-93-2-2	118	4.1	6.3	6.3	6.7	7.8	109	1.9	2.2	3.1	3.4	3.2
IR2058-78-1-3-2	134	4.8	5.8	6.3	6.5	6.1						
IR2061-522-6-9	110	4.5	5.2	6.4	6.8	7.1	103	2.5	2.9	2.5	3.4	3.4
IR2071-586-5-6-3	145	4.3	5.6	5.6	6.6	6.5	134	4.4	4.4	4.3	5.2	5.1
IR2071-588-6-2-6-4							134	4.0	4.6	4.9	4.8	4.7
IR2798-88-3-2							131	3.2	3.9	4.1	4.4	4.9
IR2823-399-5-6	131	4.0	6.1	6.5	7.2	7.5	131	3.2	3.5	3.8	3.9	4.4
IR2863-38-1	138	3.9	6.0	6.7	7.0	7.4	134	3.4	4.3	4.1	4.3	4.9
IR4432-52-6-4							131	3.6	4.5	4.3	4.8	4.4
Peta	145	3.4	4.4	3.9	2.6	2.3	144	3.2	2.8	3.3	2.8	2.3

[a]Includes 30 kg N/ha topdressed at panicle initiation. [b]LSD (5%) = 1.0 t/ha. [c]LSD (5%) = 0.8 t/ha.

Table 2. Yields of rice varieties and elite lines at six levels of nitrogen[a] at three locations: Maligaya Rice Research and Training Center, Bicol Rice and Corn Experiment Station, and farmer's field near the Visayas Rice Experiment Station, Philippines. 1976 dry season.

Variety or line	Maturity (days)	Yield[b] (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	Av.
IR8	137	3.8	5.1	5.2	5.3	5.4	4.9	5.0
IR20	127	3.3	4.8	5.1	5.2	5.3	4.7	4.7
IR26	132	3.8	5.1	5.4	5.6	5.9	5.4	5.2
IR34	134	4.1	4.7	4.6	4.4	4.2	3.5	4.2
IR36	115	4.0	5.1	5.8	6.2	6.0	5.5	5.4
IR1632-93-2-2	126	3.8	5.6	6.0	6.2	5.9	5.6	5.5
IR2058-78-1-3-2	140	4.2	5.2	5.1	4.7	4.7	4.0	4.6
IR2061-465-1-5-5	114	3.7	5.1	5.5	5.9	5.7	5.6	5.3
IR2061-522-6-9	120	3.7	4.7	4.9	5.1	5.0	4.1	4.6
IR2061-628-1-6-4-3	123	4.2	5.2	5.6	5.4	5.3	5.6	5.2
IR2070-414-3-9	122	3.7	4.7	5.3	5.4	5.3	4.8	4.8
IR2070-423-2-5	134	3.7	4.8	5.2	5.0	4.9	4.3	4.7
IR2071-105-9-1	139	3.7	4.8	5.4	5.5	5.3	4.8	4.9
IR2071-137-5-5-1	114	3.4	4.7	4.9	5.3	5.4	5.4	4.8
IR2071-586-5-6-3	145	3.8	4.7	5.3	5.7	5.1	5.0	4.9
IR2681-163-5-2	140	3.2	4.4	4.8	5.0	5.1	4.1	4.4
IR2823-399-5-6	132	4.1	5.1	5.6	5.7	6.2	6.2	5.5
Peta	152	3.0	2.8	2.3	1.7	1.8	1.6	2.2

[a]Includes 30 kg N/ha topdressed at panicle initiation, except in the 0 kg N/ha treatment. [b]Av. of three locations, each with three replications. LSD (5%) = 0.6 t/ha.

performed well without added nitrogen. IR1632-93-2-2, which looked promising during the dry season, gave good wet-season yields.

Farmers' fields. IRRI varieties and lines were tested at different nitrogen levels in farmers' fields under management practicable for most Asian farmers.

With irrigation during the dry season, IR36 produced the highest yield of 6.2 t/ha at 150 kg N/ha (Table 4). Without applied nitrogen, all varieties and lines produced about 3.0 t/ha.

During the wet season, IR38 and IR2071-586-5-6-3 produced the highest yield of 6.0 t/ha at 120 kg N/ha. IR26, IR2823-399-5-6, and

Table 3. Yields of rice varieties and elite lines at six levels of nitrogen[a] at three locations: Maligaya Rice Research and Training Center, Bicol Rice and Corn Experiment Station, and Visayas Rice Experiment Station, Philippines. 1976 wet season.

Variety or line	Maturity (days)	Yield[b] (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	Mean
IR8	125	3.5	4.3	4.6	4.8	4.6	3.6	4.2
IR20	121	3.5	4.2	4.8	4.4	4.2	3.8	4.1
IR26	124	4.1	4.5	5.1	4.9	5.0	4.4	4.7
IR34	126	4.4	4.6	4.2	3.7	3.2	2.7	3.8
IR36	112	4.1	4.6	5.2	4.9	4.6	4.1	4.6
IR1632-93-2-2	118	4.6	5.4	5.3	5.1	4.6	4.6	5.0
IR2058-78-1-3-2	126	4.5	5.2	4.8	4.4	4.2	3.8	4.5
IR2061-465-1-5-5	112	3.6	4.4	4.9	5.0	4.7	4.5	4.5
IR2061-522-6-9	108	3.7	4.4	4.4	4.3	4.2	3.5	4.1
IR2061-628-1-6-4-3	112	3.5	4.6	4.5	4.4	3.9	3.1	4.0
IR2070-414-3-9	115	4.2	4.4	4.1	4.1	3.8	3.0	3.9
IR2070-423-2-5	124	4.5	5.2	5.3	5.1	4.6	4.2	4.8
IR2071-105-9-1	130	4.7	5.0	5.4	5.2	4.8	4.0	4.8
IR2071-137-5-5-1	113	3.5	4.1	4.8	5.0	5.2	4.7	4.5
IR2071-586-5-6-3	131	5.0	5.8	5.8	5.8	5.2	4.6	5.4
IR2863-38-1	120	4.6	5.5	5.8	5.2	5.0	4.5	5.1
IR2823-399-5-6	124	4.8	5.4	5.8	5.4	5.2	4.3	5.1
Peta	135	3.2	3.0	2.5	2.3	2.1	1.8	2.5

[a]Includes 20 kg N/ha topdressed at panicle initiation, except in the 0 kg N/ha treatment. [b]Av. of three locations, each with three replications. LSD (5%) = 0.6 t/ha.

anther dehiscence; thus, it has few pollen grains on a stigma at high temperatures. Timing of the anther's dehiscence and its position relative to the stigma are believed to be the major characteristics that ensure enough pollen grains on a stigma. Another important characteristic is the ability of pollen grains to germinate at high temperature.

Field heat tolerance. IR747 has been observed to start flowering at least 30 minutes earlier than N22 and BKN 6624. *O. glaberrima* also flowers early in the morning. Rice plants that flower early in the morning when the temperature is still low avoid high temperature. The following mechanism of field heat tolerance is proposed:

- True heat tolerance—characteristic anther dehiscence, and ability to germinate at high temperatures.
- Heat avoidance—early morning anthesis.

Plants can be tested for true heat tolerance by subjecting them to high temperature at flowering time. Heat avoidance may be estimated by examining the time of flowering at relatively low temperatures.

Table 6. Effects of nitrogen[a] levels on the grain yield of rice varieties and promising lines (average of three replications). Rainfed farmer's field, Cabuyao, Laguna, 1976 wet season.

Variety or line	Maturity[b] (days)	Yield[c] (t/ha)			
		0 kg N/ha	40 kg N/ha	80 kg N/ha	120 kg N/ha
IR8	130	5.2	5.7	5.0	4.0
IR26	123	5.7	6.2	5.5	4.8
IR24	135	4.7	4.6	2.2	2.6
IR36	123	5.4	5.5	5.1	4.3
IR38	123	5.3	5.4	4.9	4.2
IR2071-586-5-6-3	137	6.0	5.6	5.7	4.7
IR2823-399-5-6	137	6.1	5.9	5.3	4.8
IR2863-38-1	135	6.6	6.4	5.2	5.9

[a]Includes 20 kg N/ha topdressed at panicle initiation stage. [b]The seedlings were 1 month old at transplanting. [c]LSD (5%) = 1.1 t/ha.

GROWTH DURATION, PLANT HEIGHT, AND YIELD
Plant Physiology Department

Intermediate plant height continues to receive attention because varieties with intermediate plant height, when planted in areas of less dependable water control, give more stable yields than short-statured varieties. However, increase in plant height normally results in decreased resistance to lodging. In addition, increase in plant height is related to decrease in harvest index (HI) (Fig. 1), which is defined in the equation

$$\text{Grain yield} = HI \times \text{total dry matter}$$

Indications are that intermediate-height varieties will produce moderately high, stable yields —about 4 t/ha—at only moderate levels of nitrogen.

It appears that early maturing varieties are not clearly understood. It is not true that they are inevitably short because of a short growth period. Dular, a 100-day variety, is as tall as Mahsuri, a 134-day variety.

Growth rate is a varietal characteristic under a given environment. If growth rate is sufficiently high to compensate for limited time, the rice plant can produce a large amount of growth —an intermediate or long culm—within a limited time. Thus, there is no physiological barrier to combining intermediate plant height and short growth duration.

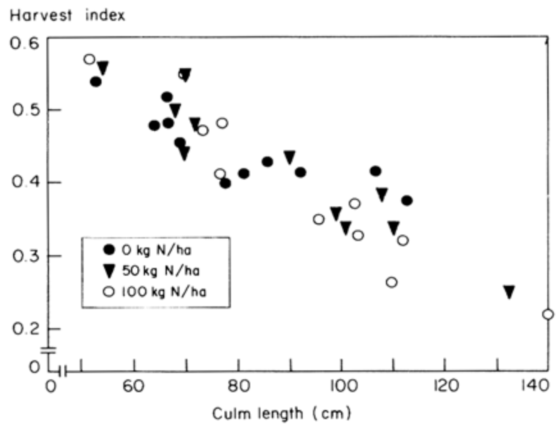
Mahsuri has become popular in some areas of India and Bangladesh where water control is undependable. Mahsuri is characterized by medium growth duration and intermediate plant height. To determine its advantages and disadvantages, it was grown with 10 other varieties at three nitrogen levels at IRRI. Attention was focused on growth duration and plant height.

The growth duration of the varieties ranged from 93 to 134 days (Table 7). At 0 kg N/ha, no lodging occurred, and grain yields ranged from 2.7 t/ha to 3.9 t/ha. No clear relationship between growth duration and yield was observed. Mahsuri, however, was the second highest yielder.

At 50 and 100 kg N/ha, tall and intermediate varieties lodged, and their grain yields decreased at different degrees. Grain production per day, however, appears to be inversely related to growth duration: the shorter the growth duration, the higher the daily grain production (Fig. 2).

Mahsuri gave reasonably high yields at 0 and 50 kg N/ha. It is shorter and more resistant to lodging than Peta. IR34, which is slightly shorter than Mahsuri, had more stable grain yields at all nitrogen levels. IR32 matures in the same number of days as Mahsuri, but is much shorter and more resistant to lodging. Consequently, IR32 responded to nitrogen up to 100 kg/ha.

IR34 and Mahsuri, because of their greater plant height, should perform better than IR32 in areas of less dependable water control. At moderate levels of nitrogen or soil fertility,



1. Relation between culm length and harvest index of 11 varieties. IRRI, 1976 wet season.

Table 7. Growth duration, grain weight, plant height, and grain yields at three levels of nitrogen of 11 varieties, IRRI, 1976 wet season.

Variety	Growth duration (days)	1000-grain wt (g)	Culm ht (cm)		Yield[a] (t/ha)		
			0 kg N/ha	100 kg N/ha	0 kg N/ha	50 kg N/ha	100 kg N/ha
IR5	134	25.7	78	96	3.2	4.8	4.8
IR32	134	23.0	64	77	3.9	4.4	5.2
Mahsuri	134	16.2	92	110	3.7	3.9	2.4
Peta	134	26.1	113	140	3.2	2.2	1.7
IR34	125	23.9	86	103	3.4	3.9	3.9
BPI 76-1	125	18.6	81	104	2.7	3.1	3.6
IR20	120	19.1	69	77	3.4	4.4	4.7
IR29	105	22.1	66	73	3.1	3.6	4.9
IR28	100	20.8	67	70	3.6	4.2	4.4
Dular	97	21.9	107	112	2.9	3.0	2.6
IR747B2-6	93	17.8	52	53	2.9	3.5	3.9

[a]LSD (5%) = 0.4 t/ha.

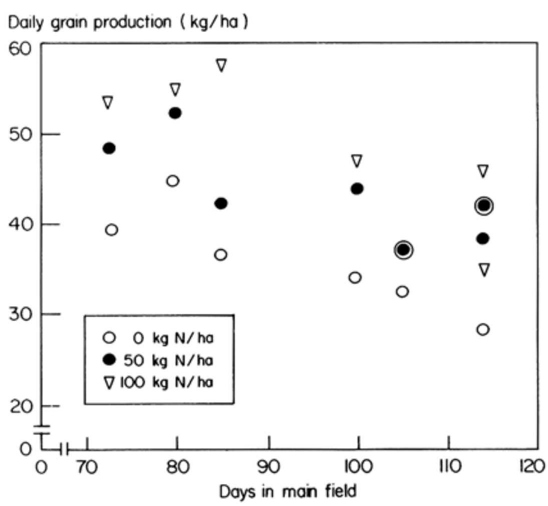
Mahsuri should perform as well as IR34 and much better than Peta. Mahsuri's good cooking quality may explain its popularity in some areas.

GRAIN SIZE

Plant Physiology Department

The grain weight of 14,128 accessions from the IRRI world collection varies from 6 to 52 mg/grain. Grain size is one of the most stable varietal characteristics, but it is the characteristic that has been least studied.

Proportion of hull weight to whole grain. A geometrical consideration suggests that the proportion of hull weight of rice grains increases with decrease in size, or as the grain shape varies from "short" to "long." Table 8 gives the weight percentage of the hull in the whole grain for 11 varieties. The percentage ranged from 18.6 to 25.4, but it was around 21 in most varieties, regardless of grain size and shape.



2. Relation between growth duration and daily grain production of seven improved varieties at three nitrogen levels. IRRI, 1976 wet season.

Duration of grain-filling period. The grain-filling period (GFP) of rice varieties is largely determined by two factors—varietal characteristics and temperature. The GFP ranged from 12 to 21 days. Small-grain varieties tended to have a short GFP, but among medium- and large-grain varieties, there was no clear relationship between grain size and GFP (Table 9). Final grain weight is the product of GFP and mean daily grain growth rate. Higher grain growth rates were correlated with larger grain size. That implies that large-grain varieties are more efficient in starch accumulation (grain production) during the ripening period than are small-grain varieties.

Temperature has a paramount influence on GFP. The GFP of Bomdia varied from 12 days at 32/24°C (day/night) to 27 days at 20/12°C (Fig. 3). Similarly, the GFP of Khao Lo changed from 18 days at 32/24°C to 36 days at 20/12°C.

Nitrogen content. The nitrogen content of grains varies from one variety to another. The content per grain (μg N/grain) appears to correlate with grain size (Fig. 4). The larger the grain, the higher the nitrogen content is per grain. Variation in grain size is much greater than variation in nitrogen percentage.

Table 8. Characteristics of grain of 11 varieties differing in grain size.

Variety	Origin	Dry wt (mg/grain)	Length (mm)	Width (mm)	Thickness (mm)	Hull (%)
Khao Lo	Laos	44.4	11.30	3.20	2.53	18.6
Cseljaj	Hungary	36.6	9.43	3.67	2.52	21.5
Ku 70-1	Thailand	34.7	8.91	3.93	2.32	19.6
Hiderishirazu	Japan	26.4	7.98	3.66	2.21	20.9
Rikuto Norin 21	Japan	23.1	6.94	3.48	2.19	20.6
Bergreis	Austria	21.8	6.81	3.25	2.21	19.3
Ai Yeh Lu	China	20.8	6.82	3.08	2.05	20.8
IR747B2-6	IRRI	16.4	7.61	2.46	1.81	20.4
Bangarsal	India	14.7	7.73	2.03	1.72	20.1
Bomdia	Portuguese Guinea	11.6	5.89	2.45	1.65	25.4
Kalajira	Bangladesh	11.9	5.81	2.43	1.89	21.8
Mean						20.8

Yield potential. The grain yield of rice can be calculated with the formula

$$\text{Yield (t/ha)} = N \times W \times F \times 10^{-5}$$

where N is number of spikelets per square meter, W is weight in grams per 1,000 grains, and F is percentage of filled grain. N is determined before flowering, W is largely a varietal characteristic, and F is largely determined by environmental factors at flowering and during the ripening period. Thus, $N \times W$ represents maximum achievable yield potential. To determine any relationship between grain size and yield potential, six varieties were grown at 10- × 10-cm spacing with 120 kg N/ha.

Number of spikelets per square meter decreased with increased grain size. Yield potential, however, was greater for large-grain varieties than for small-grain varieties (Table 10). Sink-to-source ratio, defined as the ratio of yield potential to leaf area index at flowering, tended to be greater with large-grain varieties than with small-grain varieties. Khao Lo, a local traditional variety from Laos, has a higher yield potential than IR747B2-6, an improved line from IRRI.

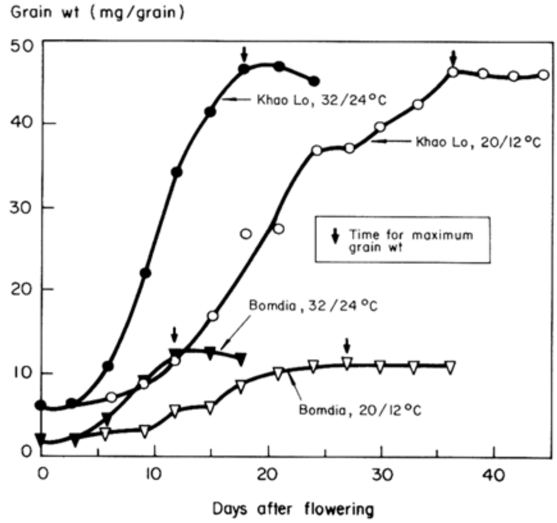
Table 9. Grain-filling period, grain weight at maturity, and daily grain growth rate of 11 rice varieties differing in grain size.

Variety	Grain filling (days)	Grain wt at maturity (mg/grain)		Mean daily grain growth rate (mg/grain)
		Panicle grain	Upper grain	
Khao Lo	18	44.4	46.7	2.59
Cseljaj	18	36.6	40.2	2.23
Ku 70-1	21	34.7	35.8	1.71
Hiderishirazu	18	26.4	27.5	1.53
Rikuto Norin 21	18	23.1	24.2	1.35
Bergreis	21	21.8	22.8	1.09
Ai Yeh Lu	15	20.8	21.6	1.44
IR747B2-6	18	16.4	17.8	0.99
Bangarsal	12	14.7	14.3	1.19
Bomdia	12	11.6	12.5	1.04
Kalajira	12	11.9	13.2	1.10

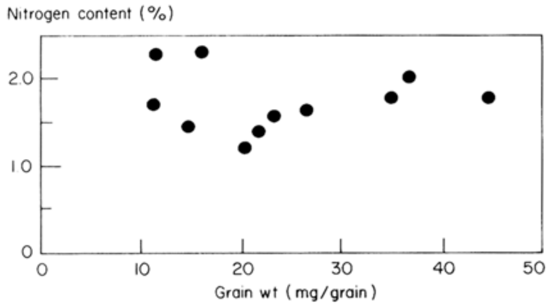
COMPETITION FOR ASSIMILATES

Plant Physiology Department

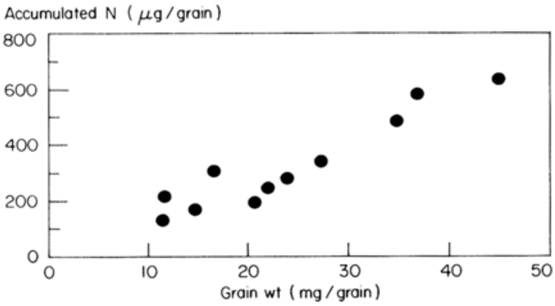
The different plant organs compete for assimilates during the growth of the panicles before heading.



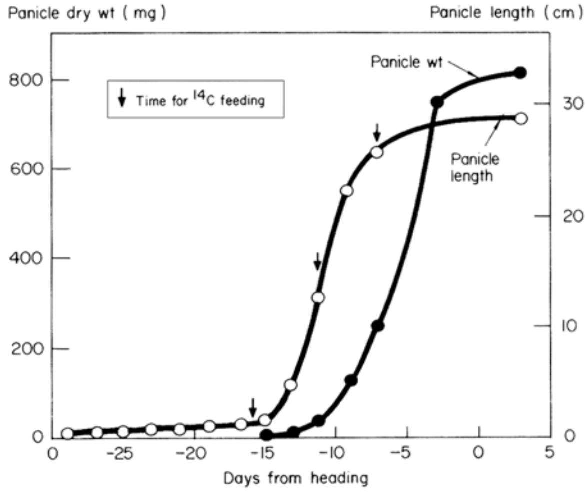
3. Effect of temperature on duration of grain filling in rice varieties differing in grain size.



4a. Relationship between grain weight and nitrogen content of brown rice.



4b. Relationship between grain weight and the amount of nitrogen of brown rice.



5. Length and dry weight of panicle of Khao Lo at successive growth stages.

Panicle-length growth is easily measurable as early as 25 to 30 days before heading. Panicle-weight growth, however, becomes measurable only 8 to 11 days before heading (Fig. 5).

Figures 6 and 7 show that the last three leaves and the culm grow at the same time until spikelet differentiation is completed, which is about 2 weeks before flowering. During that period, the demand of the panicle for assimilates is negligible compared with the demands of the other organs. After that period, the flag leaf and the culm compete with the growing panicle for assimilates. The final culm weight was about four times greater than panicle weight in Khao Lo and about two times greater than panicle weight in IR747B2-6. Apparently, more assimilates were used for culm growth relative to panicle growth in Khao Lo than in IR747B2-6.

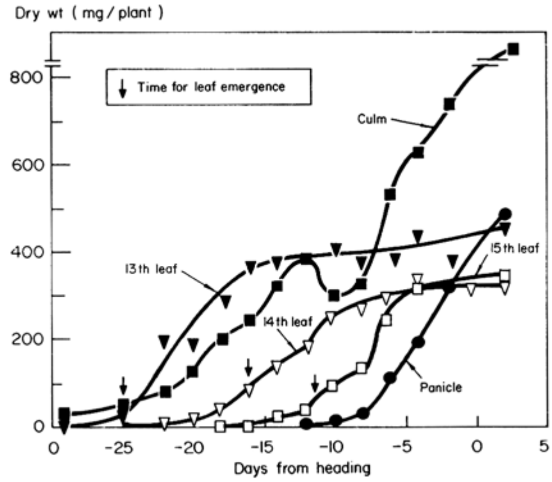
To better understand the partition of assimilates between the growing panicle and other organs at later stages of panicle growth, labeled ^{14}C feeding was done at three stages of panicle growth (Fig. 5). The results indicate that a higher proportion of new assimilates went to the growing panicles in IR747B2-6 than to those in Khao Lo (Table 11).

The competition for assimilates during the later stages of panicle growth may affect the degeneration of already differentiated spikelets and the final size of the hull. Such competition may become critical in determining the final spikelet number in the wet season when the level of solar radiation is relatively low and

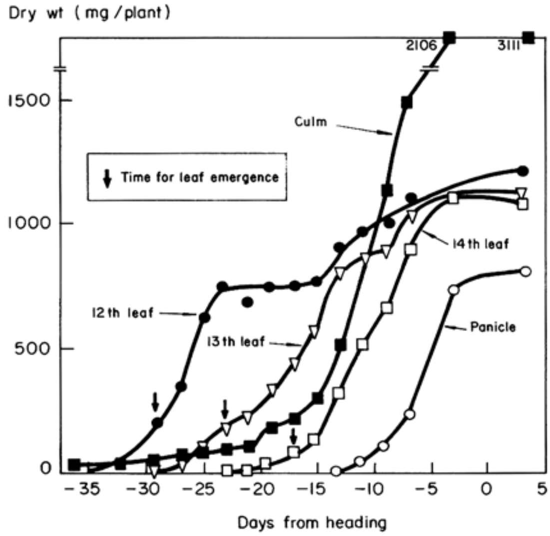
Table 10. Yield potential of six varieties differing in grain size. IRRI. 1976 wet season.

Variety	1000-grain wt[a] (g)	Spikelets (no./sq m)	Yield potential (t/ha)	LAI[b]	Sink-source ratio (t/LAI)	Culm ht (cm)
Khao Lo	51.6	17,085	8.82	5.26	1.68	111
Ku 70–1	40.3	20,838	8.40	5.31	1.58	92
Hiderishirazu	30.7	29,182	8.96	5.62	1.59	84
Rikuto Norin 21	26.9	25,657	6.90	4.40	1.57	74
IR747B2-6	19.1	38,638	7.38	5.92	1.25	68
Bomdia	13.5	33,802	4.56	7.54	0.60	105

[a]At 14% moisture. [b]Leaf area index.



6. Dry weight of leaves, culm, and panicle of IR747 at successive growth stages.



7. Dry weight of leaves, culm, and panicle of Khao Lo at successive growth stages.

when a large amount of nitrogen is applied and, hence, a shortage of assimilates is likely to occur.

The results suggest that a short culm not only is essential for lodging resistance but also may contribute to increased panicle size. A combination of short culm and large grain size may significantly increase the yield potential of rice varieties. To test that possibility, a breeding program to develop varieties with short culm and large grain is now under way.

SOURCES OF SEMIDWARFISM
Plant Breeding Department

The primary source of semidwarfism in the IRRI breeding program and in many national rice breeding programs in tropical Asia has been Dee-geo-woo-gen. Several spontaneous and induced semidwarf mutants obtained by Asian research centers have turned out to be allelic to the recessive gene for semidwarfism in Dee-geo-woo-gen.

In recent years IRRI acquired, or collected, a total of 23 semidwarf varieties from diverse countries including Burma, China, India, and Indonesia. Most of the new semidwarf parents were crossed with Taichung Native 1, IR8, or IR20. Because the semidwarf parents and their F_1 hybrids were highly susceptible to the virus diseases and their insect vectors prevalent at IRRI, several seasons were required to com-

Table 11. Distribution percentage of ^{14}C assimilated at various growth stages during panicle development, IRRI, 1976.

Panicle growth stage (days before heading)	Assimilated ^{14}C (%)					Starch fraction[a]	
	Leaf blade	Leaf sheath	Culm	Panicle	Root	Leaf sheath	Culm
				Khao Lo			
16	30.9	33.5	19.2	0.3	16.2	6.5	3.9
11	15.3	30.3	33.7	7.5	13.4	5.3	7.0
7	4.9	40.2	27.1	19.5	8.5	0.7	7.1
				IR747B2-6			
16	15.5	45.7	19.8	0.9	18.3	13.6	7.7
11	16.0	35.3	28.2	10.3	10.3	12.1	13.6
7	12.4	25.7	26.0	25.3	10.7	6.7	11.0

[a]The ratio of the amount of ^{14}C in the starch fraction to the amount of ^{14}C in the whole plant.

plete a series of crosses or to obtain F_1 plants that could set F_2 seeds.

The plant height of the small number of F_1 plants that survived the tungro epidemics of 1975-76 indicated that Chi-nan-ai from China is genetically different from Taichung Native 1 or Cheng-nan-ai 11 (also from China) and that ARC 5929 and ARC 5981A from India, and Djamadi from Indonesia may be allelic to the Dee-geo-woo-gen gene. That preliminary indication must be confirmed by F_2 results.

Comparing the 1976 results with the data obtained in 1972-73 (1973 Annual Report) led to the conclusion that the "Cheng-chu-ai 11" and "Chi-nan-ai" in the earlier study were mislabeled in the process of being handled by different researchers in three countries. The short-stature Chi-nan-ai, which had variable culm length in different plantings at IRRI, was not allelic to Taichung Native 1 or Cheng-chu-ai 11. Because of its variable plant height and growth duration, its potential as a semidwarfing source appears limited.

PLANT TYPE

Plant Breeding Department

The proportion of fixed-generation breeding lines with intermediate stature increased considerably in 1976. Many improved plant type lines in the 120- to 130-cm height range were evaluated in replicated yield trials in the dry and wet seasons. The lines showed sturdy stems, erect leaves, and high tillering ability; they yielded well under the medium fertility levels characteristic of rainfed, lowland areas. They inherited intermediate stature from well-known parents such as C4-64, Pelita I/1, IR5, and IR34. IR34 has proven an excellent combiner for intermediate stature. Some intermediate-stature selections are listed in Table 12.

Table 12. Promising breeding lines with intermediate stature evaluated in 1976, IRRI.

Selection	Cross
IR3454-104-3-2	IR1539-823-1/IR1416-131-5//IR34
IR3464-75-1-1	IR1628-68-3/IR841-67-1-1//IR34
IR3464-217-1-3	" " "
IR4215-409-2-6	IR34/C4-63
IR4219-35-3-3	IR34/IR480-5-9
IR4219-39-2-2	" "
IR4405-287-3-2	IR2031-238-5/IR2061-464-2
IR4608-6-2	IR1544-340-6/IR442-2-58//IR34/C4-63
IR4613-54-5	IR1702-74-3/IR1544-340-6// IR1545-339-2/IR1721-11-6
IR4625-219-2-2	IR2049-170-3/IR2061-464-4// IR2055-253-3/IR34

Table 13. Promising early maturing selections evaluated in 1976, IRRI.

Selection	Growth duration (days)	Cross
IR2061-465-1-5	105	IR833-6//IR1561-149-1/IR1737
IR2070-414-3-9	110	IR20²/*O. nivara*//CR94-13
IR2071-486-9-2	100	IR1561-228-3/IR1737//CR94-13
IR2307-217-2-3	105	CR94-13/IR1561-228-3
IR3941-25-1	100	CR126-42-5/IR34
IR3941-58-3	105	" "
IR5853-118-5	105	Nam Sagui/IR2071-88// IR2061-214-3-6
IR7149-17	105	BG34-8/IR28

EARLY MATURITY

Plant Breeding Department

Wide acceptance of early maturing varieties such as IR28, IR30, and IR36 in the irrigated areas indicated a future demand for germ plasm with early maturity. Consequently inputs for developing such germ plasm increased in 1976. Numerous crosses between breeding lines and varieties with short growth duration were made. The plan was to select for early vegetative vigor and shorter growth duration in the segregating populations. It appears feasible to develop genotypes with a growth duration of 90 to 95 days and a yield potential equal to that of IR36, which matures in 110 days. Some of the most promising early maturing selections evaluated in 1976 are listed in Table 13.

Genetic evaluation and utilization (GEU) program

Grain quality

Plant Breeding, Statistics, and Chemistry Departments

BREEDING PROGRAM
Plant Breeding Department

The breeding program continues to emphasize the development of lines with intermediate amylose and soft gel. Several advanced-generation, promising lines with intermediate amylose are now available (Table 1). They are resistant to major diseases and insect pests. A few low-amylose lines, such as IR3351-38-3-1 (IR841-85//IR20³/*O. nivara*/3/CR94-13) and IR3880-10 (IR841-67/C22-51//Pelita I-2/IR1541-76), were also evaluated during the year. Among the waxy lines, IR3464-75-1-1 (IR1628-68-3/IR841-67//IR2061-213) is promising.

Intermediate-amylose lines in the replicated yield trials were also rechecked for amylose content and gel consistency.

FACTORS THAT AFFECT GRAIN QUALITY
Plant Breeding, Statistics, Chemistry Departments

Variability in amylose content of rice (*Plant Breeding, Statistics*, and *Chemistry*). A detailed study of sources of variability of amylose content was made. Temperature during grain development was negatively correlated with amylose in low-amylose rice, but showed no distinct trend in either high- or intermediate-amylose rices, in agreement with 1975 results. Nitrogen fertilizer application tended to reduce the amylose in rice—split application more than basal application—probably because the increase in protein from the nitrogen applied reduced starch content.

The variation in amylose among panicles in the same hill was larger than the variations among hills and among bulk samples within a hill. Twenty rice grains and 100 mg of rice flour were found to be optimum sample sizes for amylose assay. Rice milled by a test tube miller had lower amylose values than rice milled by a McGill No. 2 miller. In addition, storing rice before milling (but not storage of milled rice) resulted in an apparent drop in amylose content. Aging increased grain hardness and resulted in undermilled rice. Undermilled rice had low amylose because of the lower starch and higher fat contents that interfere with the amylose assay. The variance component due to samples was consistently much higher than that due to determinations of the same sample. On the other hand, the relative magnitudes of the variations due to runs and to determinations within samples were not consistent for all varieties.

Table 1. Promising breeding lines with intermediate amylose content. IRRI, 1976.

Selection	Cross
IR2049-104-2	IR1539-823-1/BPI 121-407
IR2055-451-3-3-2	BPI 121-407//IR1416-131-5/IR22
IR2055-481-2-6-2	BPI 121-407//IR1416-131-5/IR22
IR4427-279-4-1	IR2055-451-2/IR2061-464-4
IR4427-315-2-3	IR2055-451-2/IR2061-464-4
IR4228-78-2-1-3	IR34///IR1416-131-5/IR22//C4-63
IR4215-4-3-1-1	IR34/C4-63
IR6863-68	IR32/IR2055-219-1-3

Internal check samples for amylose test (*Chemistry*). Because of the widespread adoption of the simplified amylose assay that IRRI developed in 1971 and the interference of amylopectin and residual lipid on amylose-iodine blue color at an acid pH, measures that would ensure reproducible results with the method were studied.

Rice flours prepared with the Wig-L-Bug amalgamator and with the Udy/Tecator cyclone mill with 60-mesh sieve gave similar results (Table 2). Defatting at room temperature with 4 ml alcohol improved the apparent amylose content by a mean of 0.9 and 1.2% in the two flours. Mechanical loss may result when alcohol is decanted. Defatting by refluxing 85% methanol or 95% ethanol further improved the amylose reading of all samples by 1.4 to 2.0% (mean of 1.7%) over cold defatted flour.

The results indicate that cold ethanol defatting is not efficient for defatting milled rice, but because the original method used the cold ethanol technique, the amylose content of standard or check samples should be determined on defatted samples at pH 9. Subsequent amylose runs can use the same check samples (undefatted), which had been milled to the same degree as the experimental samples.

In contrast with the reported constant percentage of increase in amylose-content reading due to defatting, the 1976 results demonstrated an almost constant increase in amylose readings

Table 2. Effect of defatting with 85% methanol and grinding method on apparent amylose content of milled rice. IRRI, 1976.

Variety or line	Amylose content (%)				
	Defatted			Undefatted (Simplified method)	
	Refluxing 85% MeOH (10 h); Wig-L-Bug[a]	4 ml cold MeOH (Williams method)			
		Wig-L-Bug[a]	Udy[b]	Wig-L-Bug[a]	Udy[b]
IR2071-137-5-5	11.8	9.8	9.8	9.3	8.8
IR2071-588-4-4	18.2	16.7	16.8	15.6	15.6
C4-63G	23.9	22.6	22.8	21.5	21.2
IR8	30.1	28.3	28.2	27.7	27.3
Mean	21.0	19.4	19.4	18.5	18.2

[a]10 grains ground for 40 s in a Wig-L-Bug amalgamator. [b]Udy cyclone mill with 60-mesh sieve.

with defatting, regardless of amylose content. The trend may be due to the almost constant low fat content (0.3–0.6%) of milled rice. Fatty acids derived from that fat content readily form a complex with amylose, and interfere with the amylose-iodine blue color.

Survey of world rice varieties (*Chemistry*). Monitoring of the physicochemical data of principal rice varieties in rice-producing countries was resumed (1973 Annual Report), and data on rice from 40 countries were updated. Table 3 indicates the diversity of quality factors preferred in 10 countries. The protein content of most samples was close to 7% (normal value) but many samples had 5% protein. Intermediate- to low-amylose rices were generally preferred in the countries studied.

In Burma, the variety D25-4 (Nga Kywe) was one of the four intermediate-amylose varieties. Although all five Nepalese varieties tested were high in amylose, low-amylose rices predominated in the 13 breeding lines. Basmati varieties are among the intermediate-amylose rices from Pakistan. Aromatic, intermediate- to low-amylose rices are preferred in Thailand. Soft gel and low gelatinization temperature are preferred in those four countries.

Alkali test and KOH concentration (*Chemistry*). In the alkali test for estimation of gelatinization temperature of starch granules, milled rice is soaked in 1.7% potassium hydroxide (KOH) for 23 hours at 30°C. The reading is inversely proportional to gelatinization temperature: 6–7 is low, 4–5 is intermediate, and 2–3 is high. Recent Indian studies suggest that better results are obtained with 1.4% KOH. The effect of KOH concentration on alkali spreading value was studied, including the concentration that would further discriminate

Table 3. Range of physicochemical properties of milled rice from 10 countries. IRRI, 1976.

Country	Milled rices (no.)	Protein (%)	Amylose type[a]	Gel consistency type[b]	Alkali spreading value[c]
Argentina	20	6–9	I > L > H	S > M	L > I
Brazil	10	5–8	L > I	S	L > I, H
Burma	10	5–8	H > I > L	S > H > M	L > I
Indonesia	5	5–8	I > H	S > M	L > I
Korea (Republic of)	3	7–8	L	S	L
	8		waxy	S	L > H
Malaysia (Sarawak)	8	6–14	L > I, H	S > M, H	L > I, H
Nepal	5	5–9	H	H > S, M	L > I
	13[d]	7–9[d]	L > H > I[d]	S > M > H[d]	L > I[d]
Pakistan	11	7–10	I, H	S > M > H	L > I
Thailand	6	5–9	H > I > L	H > S	L > I
USA	4	5–7	L > I	S > M	L > I

[a]L = low, 9–20%; I = intermediate, 20–25%; H = high, >25%; and waxy, 1–2% dry basis. [b]S = soft, 61–100 mm; M = medium, 41–60 mm; and H = hard, 26–40 mm. [c]Gelatinization temperature type based on alkali degradation: L = low, 6–7; I = intermediate, 4–5; and H = high, 2–3. [d]Parents in the breeding program.

Table 4. Effect of KOH concentration on alkali spreading values of rices differing in gelatinization temperature. IRRI, 1976.

Variety or line	Alkali spreading values in			
	1.15% KOH	1.4% KOH	1.7% KOH	1.85% KOH
IR8	6.0	7.0	7.0	7.0
Jinheung	5.0	6.0	7.0	7.0
Tongil	3.0	5.5	7.0	7.0
IR20	2.0	2.0	5.8	7.0
C4-63G	2.0	2.6	5.0	6.1
Century Patna 231	2.0	2.0	2.0	4.8
IR2071-137-5-5-1	2.0	2.0	3.0	3.0

among rices with values of 7 and of 2 to 3 in 1.7% KOH.

At 1.4%, KOH discriminated among low gelatinization-temperature rices better than at the other concentrations (Table 4). In 1.7% KOH, the rices gave spreading values of 7.0. Rices with spreading values below 7 (2–6) in 1.7% KOH tended to crowd around high gelatinization-temperature readings (2–3) in 1.4%. Thus, 1.7% KOH is still best for classifying rices into gelatinization-temperature types.

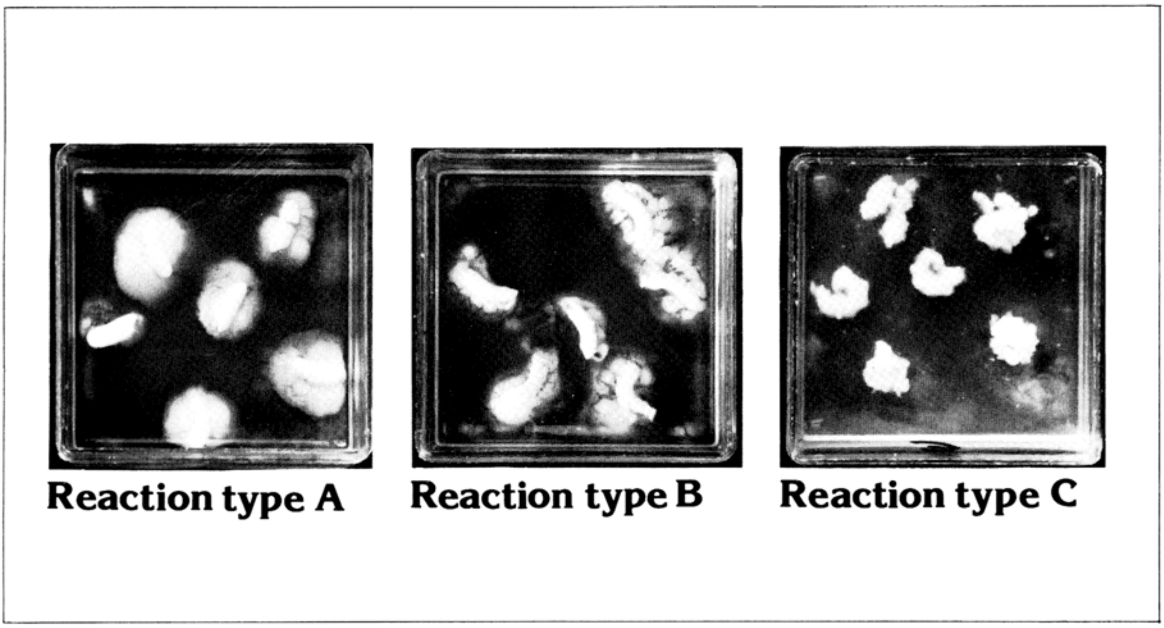
An alkali level of 1.15% KOH was better than 1.4% in further classifying the low gelatinization-temperature rices. Extremely alkali-digestible IRRI varieties, such as IR8, gave higher alkali digestion values than japonica rices, such as Jinheung, which in turn were more digestible in 1.15% KOH than were indica × japonica hybrids, such as Tongil.

Rices that are not so digestible in 1.7% KOH are readily separated by 1.85% into high gelatinization-temperature rices, such as Century Patna 231 and IR2071-137-5-5-1, and intermediate gelatinization-temperature rices, such as IR20 and C4-63G. Note that IR2071-137-5-5-1 was less digestible than Century Patna 231 in 1.85% KOH, the reverse of their relative values in 1.7% KOH.

Gel consistency, alkali digestion, and apparent solubility (*Chemistry*). The Indian studies noted in the preceding section classified the degradation patterns of rice with alkali into three types: type A with progressive cracking and corrosion characteristic of indica rices, type B with progressive grilling and cottony transformation, and type C with opening and splitting of grain and a gradual dense cottony transformation characteristic of japonica rices (Fig. 1). IRRI studies, however, showed many rices with atypical degradation patterns. Only high-amylose rices with hard gel showed a type B pattern, intermediate between A and C patterns. They may have low or intermediate gelatinization temperature (alkali spreading values 5 to 7 in 1.7% KOH).

British food technologists correlated an apparent solubility in water of milled rice during cooking with the type of degradation pattern in KOH. Type A rices had 28–40% solubility; type B, <28%; and type C, >40%. Because type A is characteristic of indica rice, type B is characteristic of hard-gel, high-amylose indica rice, and type C is characteristic of japonica rice, the relationship between those properties and gel consistency was verified. In 13 samples tested, the apparent solubility of milled rice was negatively correlated with amylose content (Fig. 2). Khao Dawk Mali, a low-amylose (15.8%) rice with type A and C corrosion patterns in KOH, had solubility properties similar to those of japonica rices of similar amylose content. C556-3, an indica waxy rice, gave type C reaction and had the highest apparent solubility among the 13 samples.

The results indicate that among rices with soft (61–100 mm) to medium (41–60 mm) gel, apparent solubility was negatively correlated with amylose content, regardless of alkali reaction type. Among high-amylose rices, those with hard gel (26–40 mm) had the least apparent solubility and low water-soluble amylose, and tended to have type B alkali reaction. A low proportion of the amylose of hard-gel, high-amylose varieties dissolves in hot water at 100°C (1974 Annual Report). Thus, amylose content and gel consistency are more reliable



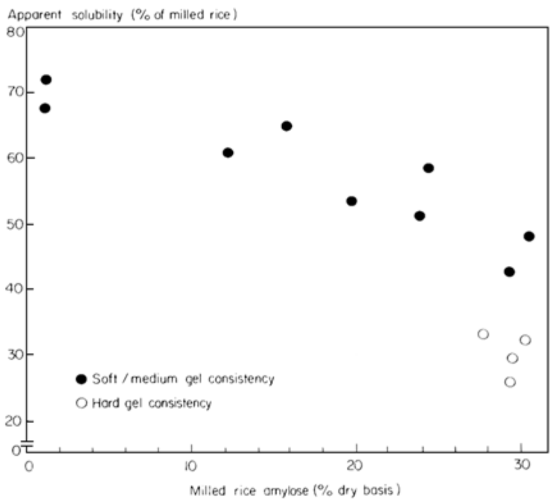
1. Three types of degradation patterns with KOH exhibited by milled rice. Different KOH concentrations were used to obtain intermediate spreading values for the three samples. IRRI, 1976.

indicators of apparent solubility of rice during cooking than is the type of alkali-degradation pattern.

Gel consistency tests (*Chemistry*). Gel consistency tests have been successfully applied to high-amylose nonwaxy (>25%) and to waxy (1–2% amylose) rices. In those rices, gel consistency and viscosity were correlated with molecular size of amylopectin, the major branched fraction of starch. Because varietal differences in eating quality have been observed among intermediate-amylose (20–25%) and low-amylose (10–20%) rices, the applicability of gel consistency tests to those rices was investigated. Rice samples solicited from countries where intermediate- and low-amylose rices are popular—South Korea, Malaysia (Sarawak), Indonesia, Thailand, and the Philippines—and intermediate-amylose IRRI lines were included in the tests.

Intermediate-amylose rices. A study of the effect of rice concentration, KOH normality, and use of the 0.15 N potassium acetate indicated that the standard procedure of 100 mg rice flour/2 ml 0.2 N KOH, developed for high-amylose rices, gave the best spread of gel consistency values in selected intermediate-amylose rices.

Application of the test to five Indonesian rices that differed in eating quality revealed the importance of gel consistency, in addition to amylose content and gelatinization temperature (alkali test), in classifying those rices (Table 5). Intermediate-amylose content, low gelatiniza-



2. Relationship between amylose content and apparent solubility of milled rice during cooking. IRRI, 1976.

Table 5. Physicochemical data on five Indonesian rice varieties listed in decreasing order of eating quality,[a] 1975–76 crops. IRRI, 1976.

Variety	Amylose (% dry basis)	Protein (%)	Alkali spreading value	Amylograph viscosity (B.U.)			Gel consistency (mm)
				Peak	Setback	Consistency	
Rojolele	23.8	8.0	5.9	710	–110	210	82
Seratus malam	24.0	6.6	6.0	925	–130	260	62
Bengawan	24.4	5.3	6.0	915	–165	270	61
Pelita I-1	23.4	6.7	3.6	960	–175	270	80
Dewi Ratih	28.3	5.1	5.9	1050	+235	465	52

[a]Samples and eating quality ratings from the Central Research Institute for Agriculture, Bogor.

tion temperature, and soft gel were preferred qualities. The first two highly acceptable varieties were either "bulu" or javanica types.

Previously prepared samples of starch and corresponding amylose and amylopectin preparations were tested for gel consistency and viscosity at 135 mg starch/2 ml 0.2 N KOH. Gel consistency values for starch were 100 mm for all low- and intermediate-amylose rices, and 28–38.5 mm for the high-amylose rices. The gel values were 100 mm for amylose and 54 to 100 mm for amylopectin. In samples with less than 1% residual protein, the gel viscosity of starch was lower than that of amylopectin but higher than that of amylose.

A study of selected intermediate-amylose rices from different countries showed a wide range of gel consistency value in milled-rice (100 mg/2 ml 0.2 N KOH) and starch (135 mg) samples (Table 6). Two varieties that showed extreme elongation on cooking, Dum Siah and Basmati 370, had medium gel values. Two samples of milled rice with hard gel (<40 mm) had soft or medium starch gel values, again indicating the interference of protein. The starches had a narrow range of residual protein content (0.4–0.6%).

Table 6. Protein and gel consistency of milled rice and starch of intermediate-amylose rices.[a] IRRI, 1976.

Variety or line	Sample source	Milled rice protein[b] (%)	Gel consistency (mm)	
			Milled rice	Starch
Dum Siah	Iran	9.4	46	42
Basmati 370	Pakistan	7.5	54	55
C4-63G	Philippines	6.6	92	78
Intan	Philippines	5.7	62	60
Rojolele	Indonesia	8.0	82	92
Pelita I-1	Indonesia	8.5	76	100
Nahng Mon S-4	Thailand	8.6	38	62
Labelle	USA	6.9	68	98
IR2003-P5-15	IRRI	8.5	56	45
IR2071-636-5	IRRI	9.0	28	48
IR2699-18-2	IRRI	6.7	50	52

[a]Amylose content (dry basis) ranged from 20.8 to 25.7% in milled rice and 26.0 to 28.7% in starch. [b]Protein content of starch ranged from 0.4–0.6% at 14% moisture.

Low-amylose rices. All rice samples from South Korea have low amylose content, but the high yielding, semidwarf varieties from indica × japonica crosses, particularly Tongil, have poorer cooking quality than the traditional japonica varieties, such as Jinheung. An amylograph of 10% paste and a standard gel consistency test of rice using 100 mg rice/2 ml 0.2 N KOH did not discriminate between Tongil and Jinheung (Table 7). Yushin is a newer variety that is intermediate in quality between Tongil and Jinheung. Increasing the rice concentration to 120 mg/2 ml 0.2 N KOH gave lower gel consistency readings for Tongil than for Jinheung in both milled-rice and starch samples.

Even after the rice concentration was adjusted to 120 mg, both the milled-rice and starch samples of low-amylose rices showed a narrower range of gel consistency values than did the samples of intermediate-amylose rices (Table 6, 8). Protein removal made the gel softer. The sensitivity of the test for low-amylose rice requires further improvement.

The purified starch of the three Korean rices showed no differences in gel consistency at the usual level of 135 mg/2 ml 0.2 N KOH (Table 9). A higher starch concentration was needed to show that Tongil had harder gel than Jinheung, as was shown by milled rice. Thus, the regular amylograph and gel consistency tests are insensitive for low-amylose rices and are useful mainly for intermediate- and high-amylose rices.

An interesting low-amylose variety is Adan Buda from Sarawak. Although it has 9% amylose, it is opaque and is used like a waxy rice (1–2% amylose). It is unlike IR2071-137-5 (11% amylose), which is semiopaque. Adan Buda has contaminant translucent grains with 25% amylose. The 14% amylose of its starch indicates that it is a true nonwaxy rice.

STARCH ACCUMULATION IN DEVELOPING RICE GRAINS

Chemistry Department

Water-soluble sugars. Study continued on water-soluble sugars in the developing grains of the nonwaxy variety IR28, and its sister waxy line IR29 as precursors of adenosine diphospho glucose in starch accumulation. Changes in levels of reducing and nonreducing sugars and their fractions closely followed changes in rate of starch accumulation in both rices. The peak value occurred 9 days after flowering (Fig. 3). However, the level of soluble carbohydrates, particularly sucrose, remained high in the caryopsis and also in milled rice after starch accumulation ceased, suggesting that the supply of sugar precursors does not limit starch accumulation in the rice grain (Fig. 3). Because of a higher level of reducing sugars, the level of free sugars in the grain of waxy IR29 was higher than that in nonwaxy IR28 grain.

In dehulled mature grain milled to 9–10% by weight (bran removal), the milled rice fraction (endosperm) retained 59.5% of total reducing sugars in IR28 and 58.7% in IR29. The remainder was in the bran-polish. In contrast, milled IR28 rice contained only 20.2% of nonreducing sugars, while milled IR29 rice contained 26.4%.

Table 7. Effect of rice concentration (100, 110, and 120 mg) on gel consistency values of low-amylose Korean rice varieties, 1973 and 1975 crops.[a] IRRI, 1976.

Variety	Amylose (% dry basis)	Protein (%)	Gel consistency (mm)		
			100 mg	110 mg	120 mg
		1973 crop			
Tongil	18.5	7.2	100	91	77
Jinheung	18.5	5.6	100	100	86
Yukara	15.7	8.6	100	98	88
		1975 crop			
Tongil	19.9	7.0	86	66	54
Yushin	19.2	7.8	100	84	66
Jinheung	19.1	7.0	89	82	78

[a]Samples from Seoul National University, Suwon.

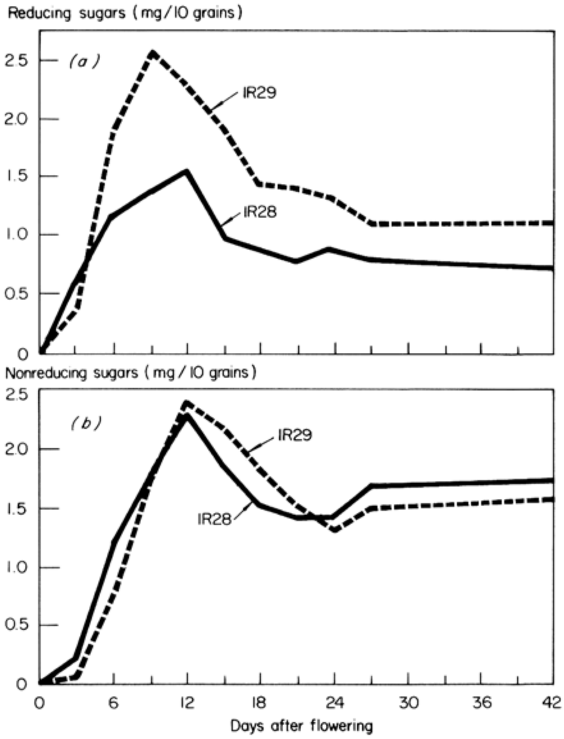
Table 8. Protein, amylose, and gel consistency of milled rice and starch of selected low-amylose rices. IRRI, 1976.

Variety or line	Sample source	Milled-rice protein[a] (%)	Amylose (% dry basis)		Gel consistency (mm)	
			Milled rice	Starch	Milled rice	Starch
Adan Buda	Sarawak	9.7	9.1	14.0	48	100
Khao Dawk Mali 105	Thailand	5.4	15.6	18.4	94	100
IR2071-137-5	IRRI	10.5	11.4	16.0	74	100
IR2071-588-4	IRRI	8.0	15.6	23.0	74	70
Century Patna 231	IRRI	9.4	12.9	17.4	80	60
Jinheung	Korea	7.0	19.1	22.6	89	100
Tongil	Korea	7.0	19.9	24.0	86	98
Yushin	Korea	7.8	19.2	22.6	100	100

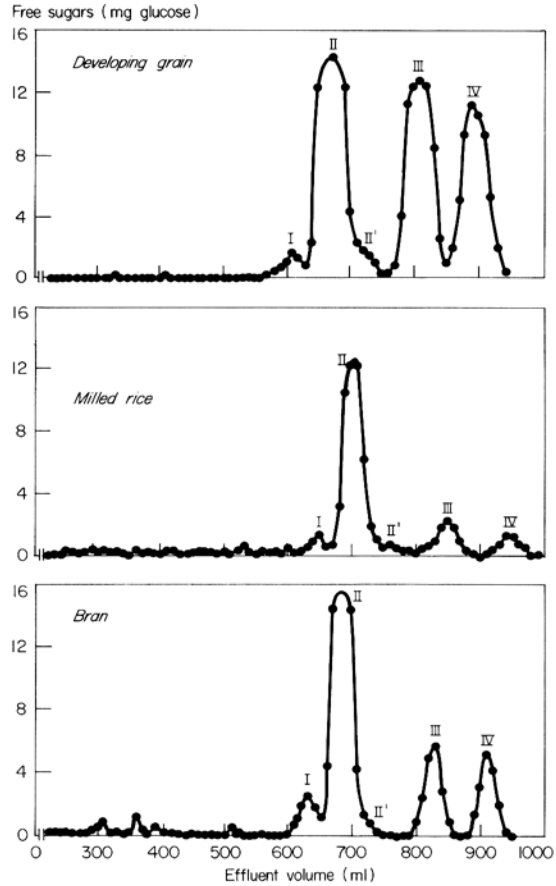
[a]Protein content of starch ranged from 0.2–0.7% at 14% moisture.

Table 9. Effect of starch concentration (135, 150, and 165 mg) on gel consistency and viscosity in 0.2 N KOH of starch of three Korean rices differing in eating quality. IRRI, 1976.

Variety	Amylose content (% dry basis)	Gel consistency (mm)			Gel viscosity (cps)		
		135 mg	150 mg	165 mg	135 mg	150 mg	165 mg
Jinheung	22.6	97	91	70	874	1130	1600
Yushin	22.6	100	92	73	851	1150	1690
Tongil	24.0	94	82	56	931	1320	1880



3. Changes in a) reducing sugars and b) nonreducing sugars of dehulled rice grain at different stages of development. IRRI, 1976. LSD (5%, reducing sugars) = 0.12 (IR28) and 0.17 (IR29). LSD (5%, nonreducing sugars) = 0.19 (IR28) and 0.20 (IR29).



4. Fractionation of free sugars of developing grain, bran, and milled rice of dehulled IR29 grain in a column (90 × 4.3 cm) of Dowex 50W × 4 (K^+ form, 200–400 mesh). IRRI, 1976.

Column chromatographic fractionation of the sugars of IR29 milky-stage grain in a 90- × 4.3-cm column of Dowex 50W × 4 (K^+ form, 200–400 mesh) showed one minor fraction and three major fractions (Fig. 4). Little polyglucan or glucofructosans was observed before the minor peak. The minor peak I was identified as raffinose by the nature of its products obtained in both invertase and acid hydrolysis. Peak II was mainly sucrose mixed with maltotriose and maltotetraose as indicated by paper and thin-layer chromatography. A shoulder after peak II (Peak II′) contained maltose and melibiose besides sucrose. Melibiose is derived by the action of invertase on raffinose. Peak III was glucose and peak IV was fructose. Sucrose was the major free sugar of developing grain of IR29, in agreement with the analytical data. Stachyose and glucodifructose were not detected by the procedure, reflecting their possible presence in much smaller amounts than those of these major sugars.

A similar Dowex 50W × 4 fractionation of free sugars was performed on bran (5% outer milling fraction) and milled rice of IR29 and IR28. In milled IR29 rice, four peaks were also obtained but the peaks for glucose (III) and fructose (IV) were much lower than in the developing grain (Fig. 4). Peak I was also raffinose, which was preceded by a minor front of higher malto-oligosaccharides, rather than glucofructosans. In contrast to that in the developing grain, peak II was mainly sucrose. Maltose, maltotriose, and maltotetraose could not be detected by thin-layer and paper chromatography. A small distinct peak II′ of melibiose was noted between peak II and peak III. Similar results were obtained with IR28.

In the bran of both rices, peak I, III, and IV were more prominent, but sucrose (II) was still the principal sugar. The melibiose peak was more prominent in IR28 than in IR29.

Grain weight and starch accumulation. To further study the relative importance of factors affecting the rate of starch accumulation in the developing grain, three rice varieties (Kalajira, IR8, and Khao Lo) and two IR747B2-6-3 lines differing in grain weights were grown in pots in the screenhouse. The midmilky grain was analyzed for metabolites and adenosine diphospho/uridine diphospho (ADP/UDP) sucrose synthetase and ADP/UDP glucose pyrophosphorylase. The weight of brown rice was 4 mg for Kalajira and IR747B2-6-3-1, 8 mg for IR747B2-6-3, 12 mg for IR8, and 20 mg for Khao Lo. Mature brown rice weights were 11, 15, 21, and 42 mg, respectively. The dehulled-grain weight tended to correlate with the weight of total and soluble protein, free sugars (both reducing and nonreducing), starch, inorganic phosphate, and K^+ in the midmilky grain. The levels of 3-phosphoglycerate and adenosine triphosphate were not correlated with the starch and protein content of the grain. The activities of UDP glucose pyrophosphorylase were better correlated with starch content than were the activities of UDP sucrose synthetase. The activities were lower with the ADP glucose system than with the UDP glucose system, and were poorly correlated with starch content. Further verification with the use of detached panicles grown in nutrient medium is needed to eliminate genetic variation among samples differing in grain weight.

Properties of starch granules. A corresponding starch study was made on the changes in properties of purified starch granules of IR28 and IR29 during grain development. Starch granules increased in mean size 5 days after flowering (DAF) from 3.7 μm for IR28 and 3.8 μm for IR29 to 4.8 μm at maturity for both rices. The gelatinization temperature of starch remained between 63 and 64°C during grain development for both varieties. In IR28, gel consistency was 38 mm 5 DAF but changed to 30 mm at maturity. In IR29, it was almost constant at 100 mm. The residual protein of the preparations ranged from 0.2 to 0.5% for IR28 and from 0.1 to 0.3% for IR29. The amylose content of IR28 increased from 32.4% at 5 DAF to 34.8% at 9 DAF, and was 35.2% at maturity. In contrast, the amylose content of IR29 was 2.5% at 5 DAF, 1.5% at 9 DAF, 1.2% at 15 and 21 DAF, and 1.0% at maturity. The results indicate that many properties of the starch granules are fixed or determined early during grain development.

Genetic evaluation and utilization (GEU) program

Disease resistance

Plant Pathology and Plant Breeding Departments

Table 1. (continued)

Breeding line	Blast	Sheath blight	Bacterial blight	Bacterial streak	Tungro	Grassy stunt
	IRRI and Leyte					
IR2071-105-9-1	R	M/MR	MR	MR	R	R
IR2071-137-5-5-1	R/M	M	MR	MR	M	R
IR2071-486-9-2-6	R	M/MR	R	S	M	R
IR2071-586-5-6-3-4	R/S	M	R	MS	M	R
IR2071-588-6-2-6-4	R/S	M	MR	MS	M	R
IR2071-625-1-252	M/S	M	R	MS	M	R
IR2307-84-2-1-2	S	M	MR	MS	S	S
IR2307-86-1-2	S	S/MR	MR	MS	S	S
IR2307-217-2-3	S	M	MR	MS	S	S
IR2688-39-4-2-3	R	M/MR	R	MS	S	R
IR2797-105-2-2-3	R	M/MR	R	MR	M	R
IR2798-88-3-2	R	M/MR	R	MR	S	M
IR2823-103-5-1	M	M	MR	MR	S	S
IR2823-399-5-6	R	M	R	MS	S	R
IR2832-141-2-1	R/M/S	M	MR	MR	S	R
IR2863-38-1	R	M	R	MS	M	M
IR2863-39-2-1	R	M	MR	MS	S	S
IR3351-38-3-1	M	M	R	MS	M	R
IR3393-56-2	R	M	R	MR	M	M
IR3449-172-2-1	R/S	M/MR	MR	MR	R	R
IR3464-75-1-1	M	M/MR	MR	MS	M	S
IR3464-126-1-3	R/S	M	R	MR	M	R
IR3464-217-1-3	M/S	M	R	MS	M	R
IR3839-1	S	M/MS	MR	MS	S	S
IR3880-2	S	M/MS	MR	MR	M	S
IR3880-13	M	M	R	MR	S	M
IR3880-17	M	M	MS	MS	S	M
IR3941-9-2	R	M	R	MS	M	R
IR3941-97-1	R	M	MR	MR	M	R
IR4215-4-3-1	M	M	R	MR	R	M
IR4227-28-3-2	R/S	M	MR	MS	R	R
IR4227-109-1-3	R/S	M	MR	MS	R	M
IR4227-164-1-1	R/S	M	MR	MS	R	R
IR4422-6-2	R	M	MR	MS	R	R
IR4422-51-1	R	M	R	MS	R	R
IR4422-143-2-1	R	M	MS	MS	M	R
IR4422-164-3-6	R	M	R	MS	M	R
IR4427-51-6-3	R	M	R	MS	R	R
IR4427-58-5-2	R	M	R	MS	R	M
IR4427-279-4-1	R/S	M	R	MR	R	R
IR4427-315-2-3	R/S	M	R	MR	R	S
IR4432-28-5	R/S	M	R	MR	M	S
IR4432-38-6	R/S	M	R	MR	M	M
IR4432-52-6-4	R/S	M	R	MS	R	R
IR4432-103-6-4	R/S	M	R	MS	R	R
IR4432-45-2-1	R	M	R	MS	M	R
IR4442-165-2-4	R/S	M	MR	MS	M	R
IR4608-6-2	R/S	MR/MS	MR	MR	M	R
IR4613-54-5	R/S	M	R	MR	R	R
IR4683-54-2	R	M	R	MR	R	R
IR4707-123-3	R	M/MS	R	—	M	R
IR4712-208-1	M	M/MR	MR	MR	M	M
IR4722-36-1	R/S	M	MR	MR	M	R
IR4816-70-1	R	M	R	MR	M	R
IR4819-77-2	R	M	R	MR	R	R
IR4829-89-2	R	M	R	MR	R	R
IR4859-38-3	R	M	R	MR	M	R
Mahsuri	M/S	M/MR	MS	MR	S	S

[a]Reactions are R = resistant; MR = moderately resistant; M = intermediate; MS = moderately susceptible; S = susceptible. Two reactions separated by a slash (/) indicates tests at different sites or times.

EVALUATING DISEASE RESISTANCE OF BREEDING MATERIALS

Plant Pathology Department

Reaction of elite lines to major diseases. Eighty-three promising elite lines or new varieties were evaluated for resistance to six major rice diseases. Many lines have a good level of resistance to all diseases, but are not sufficiently resistant to blast for planting in epidemic areas. Resistance to sheath blight is not high, but many lines are as resistant as any of the donors. Bacterial blight resistance to the common bacterial type is satisfactory, but inadequate for protection against types of the bacterium found in some areas of the Philippines. Several lines are resistant to tungro, and many lines are resistant to grassy stunt (Table 1).

Screening breeding materials for disease resistance. All breeding materials were screened for resistance to major diseases.

Blast. More than 70,000 lines were screened for resistance to blast in 1976. The percentage of resistant lines has progressively increased through continuous screening (Table 2).

Sheath blight. None of more than 5,000 advanced breeding lines had a high level of resistance to sheath blight, but many were moderately resistant. Lines that were moderately resistant in previous tests were subjected to a confirmation screening (Table 3).

Bacterial blight. A high percentage of more than 58,000 lines at different stages of breeding were found resistant to the common strain of *Xanthomonas oryzae* (Table 4).

Tungro. Of more than 44,500 lines from 716 crosses in the tungro-infested pedigree nurseries, about 66% were rated 3 or less on the international scale for resistance to rice tungro.

About 49,000 seedlings of 1,927 entries from 152 crosses and IRRI varieties were artificially inoculated and tested for resistance to tungro in the greenhouse. Of those 43% had less than 30% infected seedlings.

Grassy stunt. More than 7,000 entries of 198 crosses and IRRI varieties were mass screened for resistance to grassy stunt. More than 80% had less than 30% infected seedlings.

Table 1. Reaction[a] of elite breeding lines to major diseases. IRRI, 1976.

Breeding line	Blast	Sheath blight	Bacterial blight	Bacterial streak	Tungro	Grassy stunt
	IRRI and Leyte					
BG 90-2	R	M/S	MR	MR	S	S
BPI 76[9]/Dawn	M	M	MS	MR	S	S
BR 51-91-6	R	MR	R	MR	S	S
IR8[3]/Carreon	R	M/S	MS	MR	S	S
IR20	M	M	R	MS	S	S
IR26	S	M	MR	MR	M	S
IR28	R/S	M	R	MS	R	R
IR29	R/S	M	R	MS	R	R
IR30	M	M	MR	MS	M	R
IR32	M	M	R	MS	M	R
IR34	R/S	M	R	MS	R	R
IR1529-430-3	R	M	R	MS	S	S
IR1632-93-2-2	S	M	S	MR	S	S
IR1750-F_5B-3	S	M/S	S	MR	S	S
IR1754-F_5B-22	S	M	MS	MR	S	S
IR2035-108-2	M	M/MS	MR/S	MS	S	M
IR2035-242-1	R	M	MS	MR	S	R
IR2042-178-1	R	M	R	MR	S	R
IR2058-78-1-3-2-3	R/MS	M/VS	MR	MR	S	M
IR2061-465-1-5-5	R/M	M/VS	MR	MR	M	R
IR2061-522-6-9	R	M	MR	MS	R	R
IR2061-628-1-6-4-3	R	M/VS	R	MS	R	R
IR2070-414-3-9	R/MS	M	R	MR	S	R
IR2070-414-3-9-E	M	M	R	MR	S	R
IR2070-423-2-5-6	R/M	M	R	MR	M	R

Table 2. Summary of blast screening. IRRI, 1976.

Source	Entries (no.)		
	Resistant	Intermediate	Susceptible
Elite breeding lines	79	31	16
World collection	316	625	1,690
Pedigree lines	24,412	15,172	8,507
Observational yield trial	999	1,625	2,131
Replicated yield trial	380	298	166
Hybridization block	218	185	237
International Rice Yield Nursery	18	3	31
International Rice Observational Nursery	44	103	198
International Upland Rice Observational Nursery	44	37	104
IRBN seed list (76)	262	91	125
International Rice Cold Tolerance Nursery	1,205	1,050	752
Upland material	198	139	144
Korean material	1,115	1,242	1,746
Plant pathology lines	2,286	2,496	1,162
Blast-resistant material	20	171	100
High-protein material	177	420	198
Early maturing material	7	35	82
Total (no.)	31,780	23,723	17,389
Total (%)	42.6	32.0	23.3

Monitoring minor diseases in advanced lines. There was an upsurge of leaf scald at IRRI in 1976. Almost half of the more advanced lines were susceptible to natural infection. In some experiments IR36 was severely damaged. More than 70% of the leaves, including the flag leaves, were infected. Many leaves in both the low- and the high-nitrogen plots were half destroyed.

IDENTIFYING NEW AND BETTER SOURCES OF RESISTANCE

Plant Pathology Department

Blast. From the world germ plasm collection, 2,631 varieties were screened for blast and 316 showed a resistant reaction at IRRI (Table 2). IR1905, IR3259, IR3273, IR4547, IR5533, and IR9559—progenies of Tetep, Pankhari 203, and Carreon—showed a broad spectrum of resistance. They have good agronomic traits and resistance to some other major diseases. They may be used as donors for further crosses, or as interim varieties in blast-epidemic areas.

Sheath blight. Among the 7,839 varieties screened from the world germ plasm collection, none were highly resistant to sheath blight, but many were moderately resistant. The moderate resistance of many varieties identified earlier was confirmed (Table 3).

Table 3. Summary of sheath blight screening. IRRI, 1976.

Source	Entries (no.)	Disease reaction[a]					
		R	MR	M	MS	S	VS
Elite breeding lines	129	0	18	103	1	2	5
Replicated yield trial	812	0	49	644	67	33	19
Observational yield trial	2,401	0	222	1,794	226	86	73
Pedigree nursery	153	0	18	118	16	0	1
International Rice Observational Nursery	284	0	119	161	4	0	0
Germ plasm bank	7,839	0	951	6,621	221	42	4
Photoperiod-sensitive materials	1,218	0	544	594	72	8	0
Upland materials	32	0	5	21	5	1	0
4th International Rice Sheath Blight Nursery	190	0	40	149	0	1	0
Korean materials	20	0	1	8	11	0	0
Confirmation tests							
Elite breeding lines	31	0	6	20	4	0	1
Replicated yield trial	146	0	41	103	2	0	0
Observational yield trial	400	0	83	311	6	0	0
W'72 entries from hybridization	10	0	1	8	0	0	1
Plant pathology lines	75	0	9	65	1	0	0
Upland breeding lines	12	0	0	12	0	0	0
Assam Rice Collection	89	0	2	85	1	0	1
Germ plasm bank	650	0	30	613	6	1	0
3rd International Rice Sheath Blight Nursery	137	0	3	112	8	7	7
All India Coordinated Rice Improvement Project	28	0	2	23	2	0	1
Malaysian varieties	3	0	0	3	0	0	0
Irradiated entries	28	0	0	28	0	0	0
Total (no.)	14,687	0	2,144	11,596	653	181	113
Total (%)			14.60	78.95	4.45	1.23	0.77

[a]R = resistant; MR = moderately resistant; M = intermediate; MS = moderately susceptible; S = susceptible; VS = very susceptible.

Table 4. Summary of screening for resistance to bacterial blight. IRRI, 1976.

Source	Entries tested (no.)	Entries (no.) rated as[a]					Entries not tested (no.)
		R	MR	MS	S	R/S	
Observational yield trial	2,551	830	466	52	1,151	46	6
Replicated yield trial	876	574	156	3	70	54	22
Hybridization block varieties	286	164	28	39	47	8	
Pedigree nurseries	47,737	39,538	650	0	1,243	6,220	1,227
World collection	5,712	490	175		4,893	102	52
Confirmation test	1,365	183	677	290	168	47	
Total	58,257	41,777	1,502	384	7,572	6,369	1,307

[a]R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible; R/S = segregating.

Bacterial blight. Of 5,712 varieties from the world collection, 490 entries (8.6%) were rated as resistant and 175 (3.7%) as moderately resistant to the common strain of bacterial blight. A group of 1,365 varieties selected in 1975 were retested for confirmation. Among them 183 (13.4%) were resistant and 677 (49.6%) moderately resistant (Table 4). Virulent *X. oryzae* strains that infect formerly resistant rice genotypes have been found in many areas of the Philippines. Screening for broad-spectrum resistance becomes necessary. About 500 varieties selected from the general *X. oryzae* screening were tested against representative isolates of the three strains of the pathogen. Thirty-eight varieties were resistant to all three strains, 128 to strains 1 and 2, five to strains 1 and 3, and three to strains 2 and 3 (Table 5).

Tungro. With the improved mass-screening method, 11,000 entries representing 4,849 varieties were screened for resistance to tungro disease in the greenhouse. About 2,850 entries of 1,214 varieties showed less than 30% infected seedlings.

Grassy stunt. None of 1,114 entries of 513 varieties mass screened in the greenhouse for resistance to grassy stunt had better resistance than *Oryza nivara*.

INCORPORATING NEW SOURCES OF RESISTANCE

Plant Breeding Department

Resistance to bacterial blight. IRRI breeding lines resistant to bacterial blight are conditioned by *Xa 4*, which is resistant to the common type 1 of the bacterium. The gene *xa 5*, which controls the resistance to type 2, originally found in DZ 192 from Bangladesh, was also found in some lines, e.g. IR4563-52-1-3-6 and IR4613-54-5. They have been intensively used in crossing with lines that are resistant to other diseases.

Resistance to sheath blight. A high level of resistance to sheath blight has not been found despite an extensive search. A modest breeding

Table 5. Varieties with resistance to three pathogenic strains of *Xanthomonas oryzae* in the Philippines.

Variety	IRRI acc. no.	Origin
Andel	17153	Indonesia
ARC 5756	20220	India
ARC 7207	20545	India
ARC 7326	12367	India
ARC 10313	20845	India
ARC 10351	12439	India
ARC 10376	20887	India
ARC 10674	12567	India
ARC 10696	12580	India
ARC 10959	12686	India
ARC 10968	12690	India
ARC 12172	21960	India
BJ 1	3711	India
Bowalia (2)	27537	Bangladesh
Bulu Putih	17350	Indonesia
Buri Katari	27539	Indonesia
Camor	17366	Indonesia
Chinsurah Boro II	11484	India
Dahrial		Korea
DD 100	8649	Bangladesh
DV 29	8816	Bangladesh
DV 85	8839	Bangladesh
DV 86	8840	Bangladesh
DZ 78	8555	Bangladesh
Hanumanjata	25860	Bangladesh
Hashikalmi	3397	Bangladesh
India Dular (Ord. 7)	26070	Brazil
Kaika	26361	Bangladesh
Kaliboro 600		Bangladesh
Kasia Panja	27558	Bangladesh
Katokhandi	26360	Bangladesh
Ketan Tolo	17975	Indonesia
Kokuya	26364	Bangladesh
Kolongi Bao	24135	Indonesia
Lakhsini Digha	26390	Bangladesh
Matury	16190	Nepal
UCP 28	8728	Bangladesh
Vella Peruvazha 0. 68-12	19588	India

Table 6. New pathogenic races of *Pyricularia oryzae* identified in 1976 in the Philippines.

Philippine differential	Reaction[a] of differentials to																											
	P263	P264	P265	P266	P267	P268	P269	P270	P271	P272	P273	P274	P275	P276	P277	P278	P279	P280	P281	P282	P283	P284	P285	P286	P287	P288	P289	P290
Chokoto	S	R	S	S	S	R	R	S	R	S	R	S	S	S	S	S	R	S	R	S	S	R	S	R	S	R	S	R
CI 5309	R	R	S	S	S	S	R	R	R	S	S	R	S	S	S	S	R	R	R	S	R	R	R	R	R	R	R	R
CO 25	R	R	S	R	S	R	R	S	S	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	S	R	R	S
Kataktara DA 2	R	R	S	R	S	R	R	R	R	S	S	S	S	R	S	S	R	R	R	S	S	S	S	R	R	R	S	R
Khao-tah-haeng 17	S	R	S	S	S	S	R	S	S	S	S	S	S	S	S	S	R	R	R	S	S	S	S	S	S	R	S	S
Lacrosse	R	R	S	S	S	S	R	S	S	S	R	S	S	R	S	S	S	S	R	R	R	S	S	R	S	R	R	R
Pai-kan-tao	R	R	R	S	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R
Peta	S	R	S	R	S	S	S	R	R	S	S	S	S	S	R	R	S	R	R	S	R	S	S	R	S	R	R	S
Raminad Str. 3	S	R	S	S	R	R	R	S	S	S	S	S	R	R	R	R	R	R	R	S	R	S	S	R	R	R	S	R
Sha-tia-tsao(s)	S	S	R	S	S	R	S	S	S	S	S	S	S	S	S	R	S	R	R	S	R	S	S	R	R	S	S	S
Taichung T.C.W.C.	R	R	S	S	S	S	R	S	R	R	S	R	R	S	R	S	S	R	R	R	S	S	S	S	S	R	S	S
Wagwag	S	S	S	S	S	R	R	S	S	S	R	S	S	R	R	R	R	R	R	S	R	R	S	S	S	R	S	S

[a] R = resistant; S = susceptible.

program crossed many tall and improved varieties or lines with moderate sheath blight resistance and topcrossed the F_1 s to bring about a higher level of resistance.

Resistance to blast. To further broaden the spectrum of blast resistance, particularly for upland and cooler regions where blast is usually severe, a modified scheme of hybridization was adopted. Many advanced lines that showed resistance at IRRI and in the International Rice Blast Nursery were intercrossed and further crossed with resistance-donor varieties such as Tetep, Carreon, and Pankhari 203. An additional site at San Isidro, Leyte, Philippines, was used for testing and selection of progenies. Blast development at San Isidro was severe and many lines resistant at IRRI were susceptible and vice versa, indicating differences in the fungus races at the two locations.

STUDIES ON DISEASE RESISTANCE

Plant Pathology Department

Pathogenic races of *Pyricularia oryzae*. Monitoring of the races of *P. oryzae* was continued in the blast nurseries. Many different races were observed each month. Artificial inoculation identified 28 new races in 1976. Philippine races now total 290. Table 6 shows the reaction of the 12 Philippine differential varieties to these races.

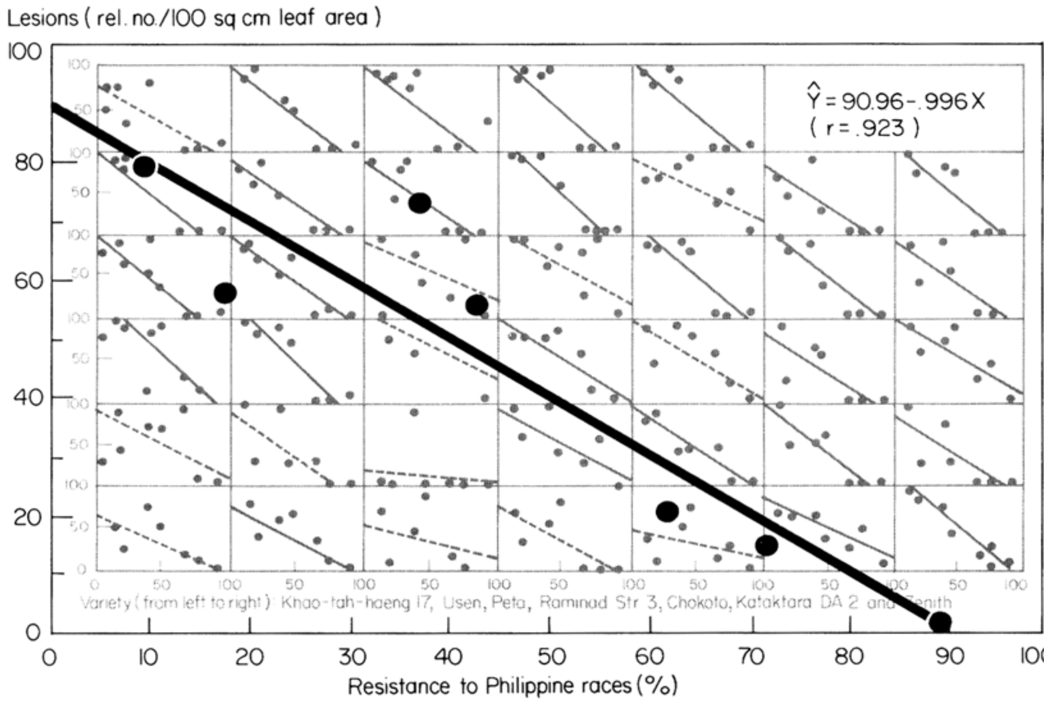
Qualitative and quantitative resistance to blast. Previous reports showed a close correlation between qualitative (resistant to races) and quantitative (number of lesions or disease intensity) resistance among varieties under natural infection in the blast nursery. Since the spore population originating from a single-spore culture is believed to consist of various kinds of races, it is assumed that the same correlation will occur in varieties artificially inoculated with individual monoconidial isolates. Forty monoconidial isolates from different varieties, collected at one time in the blast nursery, were artificially inoculated to seven varieties with different degrees of quantitative resistance. The susceptible-type lesions per 100 sq cm of leaf area were counted on three replicates for each isolate.

The close correlation between the quantitative and the qualitative resistance of the varieties used with the 40 isolates confirms the heterogeneity in race composition of spore populations. Twenty-seven isolates showed significant correlations. The others appeared to be less differentiated and to have specialized pathogenicity to a certain variety or varieties (Fig. 1).

The result demonstrated that the quantitative resistance of a variety reflects the spectrum of qualitative resistance of each variety against the heterogeneous racial population of *P. oryzae*. A variety with a broad spectrum of resistance may appear to have horizontal resistance, although the relationship between the individual race and rice variety is basically differential or vertical.

Kresek phase of bacterial blight. In 1976, kresek was frequently observed in IRRI fields. IR20 and IR22, which carry a dominant gene (*Xa 4*) for bacterial blight resistance, suffered from kresek infection. A 20–30% incidence was recorded 1 month after transplanting. The bacterial isolates (designated PXO 82) from the IR20 and IR22 plants caused susceptible-type leaf blight lesions on the varieties inoculated by the leaf-clipping method. The isolates were similar to type 2, previously known as the Isabela or Davao strain. When tested on pot-grown rices in the greenhouse, the isolates also caused kresek on IR1545-339, which has the recessive gene *xa 5* for resistance.

Methods of inoculation. A preliminary study compared two methods of inoculation for kresek. Leaf clipping was used to test leaf blight resistance. Root dipping assumed that kresek in natural conditions results from bacterial invasion through the root system. Root tips were cut before the seedlings were dipped in a bacterial suspension for 1 to 5 minutes before transplanting. Root dipping usually yielded more kresek than leaf clipping did.



1. Correlation between qualitative and quantitative resistance from artificial inoculation of 40 single-spore cultures. IRRI, 1976.

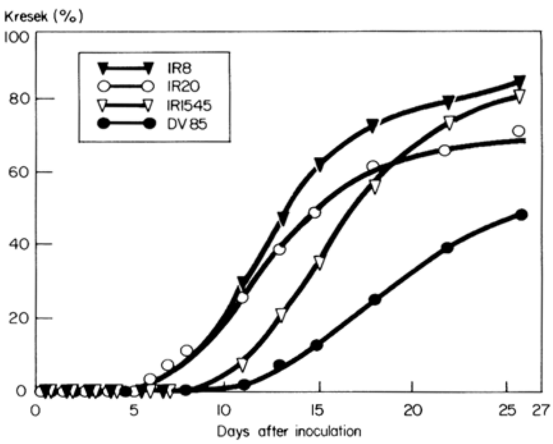
Table 7. Effect of plant age on reactions of five varieties to isolate PXO 79 of *X. oryzae*.

Variety or line	Lesion length[a] (cm)		
	30 DS	60 DS	90 DS
ARC 6076	20.6 a	16.9 b	8.4 fg
Djawa Srie	11.0 ef	2.9 h	1.0 h
K116	10.7 ef	6.4 g	10.7 defg
IR22	16.2 bc	12.4 de	13.4 cde
IR8	17.1 b	14.8 bcd	8.4 fg

[a]Means followed by the same letter are not significantly different at the 5% level. DS = days after seeding.

Seedlings of five susceptible varieties or lines at different ages were inoculated by the two methods. The data (Table 7) show no clear-cut difference in the initiation of kresek among the varieties or lines. However, kresek infection appears higher in young seedlings than in old ones, and higher from root dipping than from leaf clipping.

Kresek development and leaf blight infection. Kresek development on seedlings of four rice varieties was studied in the greenhouse. Nine-day-old seedlings were inoculated with isolate PXO 82 of type 2 by the root-dip method. IR8, IR20, and IR1545 had higher kresek incidence —83.7, 72.0, and 82.9% respectively—than DV 85, which had 49.2%. The difference in kresek incidence among IR8, IR20, and IR1545 was not significant but that between DV 85 and



2. Development of "kresek," induced by isolate PXO 82 of *X. oryzae*, on 9-day-old seedlings of four rice varieties. IRRI,1976.

the three varieties was significant. Although the final percentage value of kresek incidence in IR1545 did not differ from that in IR8 or IR20, the lag phase of kresek development was considerably lower in IR1545 than in IR8 or IR20 (Fig. 2). Isolate-variety interaction, inoculum density, and level of varietal resistance are under study.

IR8 and IR20 were susceptible to isolate PXO 82, and vulnerable to kresek. DV 85 was resistant to PXO 82, and had considerably lower kresek incidence. IR1545 appeared to be as vulnerable as IR8 to kresek caused by isolate PXO 82. It appears that factors controlling leaf blight resistance differ from factors controlling resistance to kresek.

Pathogenic variability of *Xanthomonas oryzae*. *Variation in colony types.* Three types of colonies for *X. oryzae* are recognized: mucoid-large, mucoid-small, and a third type, which is non-mucoid-small but translucent on modified Wakimoto's medium. The three types all caused typical blight-susceptible lesions on IR8, but the translucent type produced fewer lesions (Table 8). Although it has been reported that the mucoid-small type was less virulent than the mucoid-large type, the difference was not observed in this study.

Virulence of X. oryzae *in the Philippines.* Isolates of *X. oryzae* collected in the Philippines from 1963 to date were evaluated on three host varieties: IR8, with no gene for bacterial blight resistance; IR20, with the dominant gene *Xa 4*, and IR1545-339 with the recessive gene *xa 5*.

The results show that there are strains or races in the population of *X. oryzae* in the Philippines. Most of the 83 isolates belong to one group, called the common strain or strain 1, exemplified by isolate PXO 61.

The strain is distinguished by the resistance to it of host genotypes carrying either of the two major genes, *Xa 4* and *xa 5*. Strain 2 is exemplified by the isolate PXO 79 collected in Davao. The host genotype carrying the recessive gene *xa 5* is resistant; while that carrying *Xa 4* is susceptible. Strain 3, which makes up a small portion of the present isolate collection and is typified by PXO 71 from the Palawan area, overcomes the resistance of host genotypes that carry both the dominant and recessive genes.

Table 8. Virulence of *X. oryzae* in relation to colony types of the isolates on IR8. IRRI, 1976.

Colony type	Consecutive subculture	Lesion length[a] (cm)	
		10 DAI	14 DAI
PXO 61—Mucoid-large	1	14.42	20.89
	2	21.83	31.35
	3	21.62	30.85
	4	22.60	31.25
	5	22.39	25.19
	6	17.79	28.04
PXO 82—Mucoid-small	1	16.28	30.38
	2	12.27	30.07
	3	21.11	30.63
	4	16.95	28.35
PXO 32—Mucoid-large	1	15.24	24.07
	2	20.81	30.00
	3	21.38	31.10
	4	21.40	28.23
PXO 61—Translucent-small	1	3.30	5.60
	2	5.21	9.58
	3	5.08	9.58
	4	7.27	14.25
	5	5.99	8.89
	6	7.01	9.09
PXO 10		9.83	14.63

[a]DAI = days after inoculation.

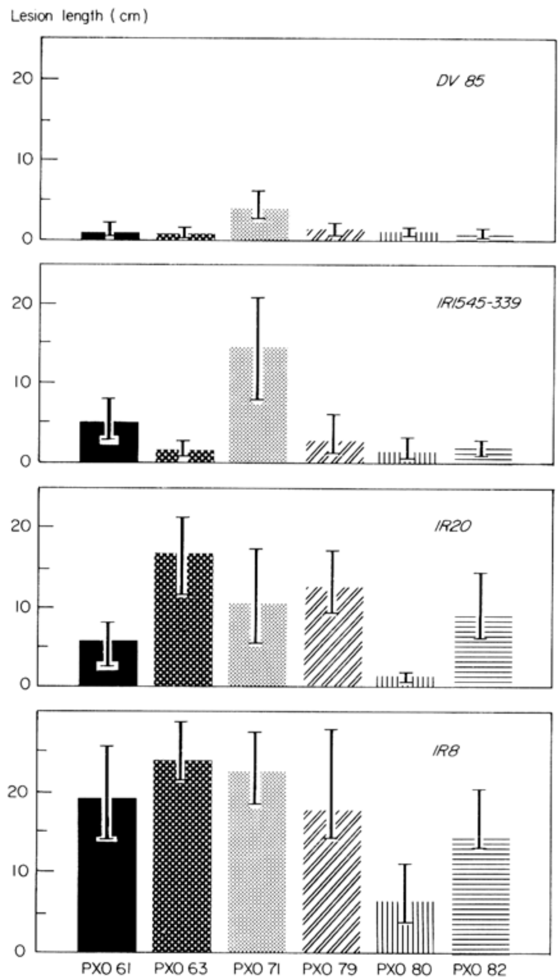
It appears that PXO 71 is more compatible with genotypes with *xa 5* than with those with *Xa 4*. PXO 71 always produces more lesions on IR1545-339 than on IR20 (Fig. 3).

During the dry season 126 isolates were sampled from rice plants infected naturally with bacterial blight at IRRI. The isolates were tested against IR8, IR20, IR1545, and DV 85. IR8 was susceptible but IR1545 and DV 85 were resistant to all isolates. IR22, IR20, and IR36 were infected by bacterial blight in the wet season.

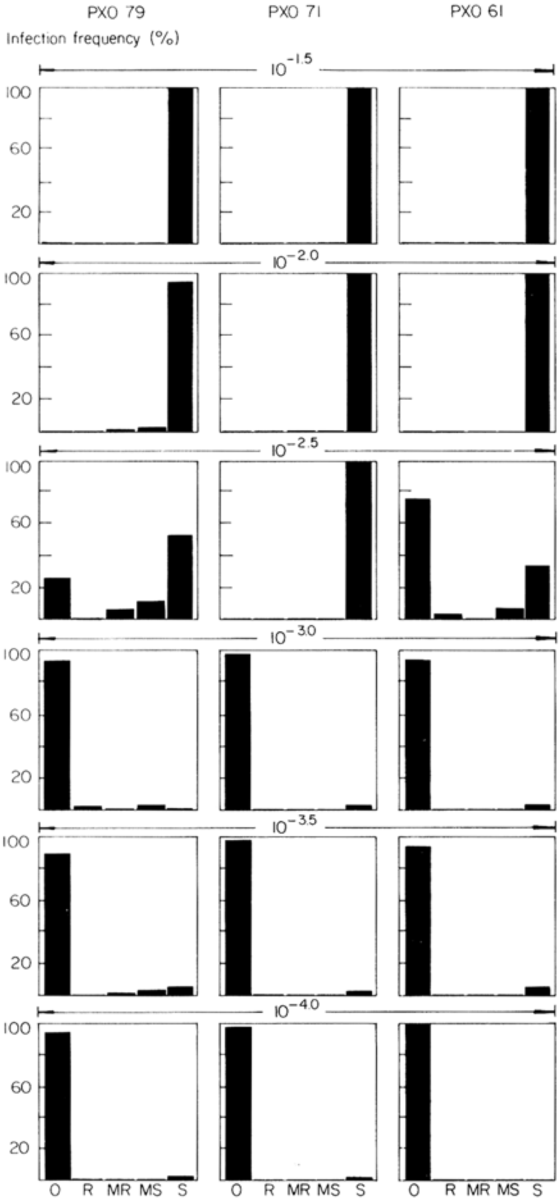
Differential varieties for X. oryzae. A preliminary 1975 screening tested 426 varieties against three relatively distinct isolates—PXO 61, PXO 63, and H100. Differential reactions between some of the varieties and the isolates were observed (1975 Annual Report). Differential patterns of the three isolates on selected varieties were monitored in 1976. Six of the eight possible patterns were observed.

The results suggested that some varieties could become good candidates for the differentials. Further evaluation showed that the interactions between some varieties and isolates were affected by the age of the plants and by the age of the leaves. Whether or not such variations in reactions are due to the nature of resistance in the varieties, to the instability of virulence, or to unobservable change in the environment requires further study. As more varieties from the germ plasm bank are tested and the genes for resistance are identified, a better set of differentials will be formulated.

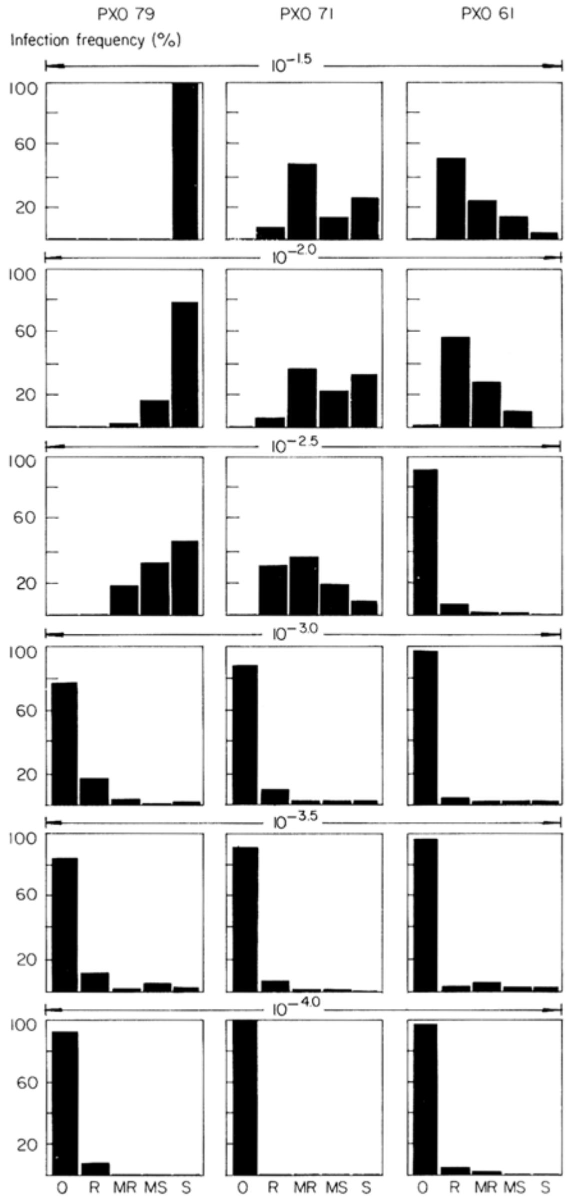
Inoculum density and infection. The extent of bacterial blight produced by *X. oryzae* is related to the number of cells in the inoculum, as well as to the virulence of the isolates and the resistance of the varieties. The relationship between inoculum density of PXO 61, PXO 79, and PXO 71, and bacterial blight infection on IR8 and IR22 was studied.



3. Reaction of specific host genotype to specific virulent isolates of *Xanthomonas oryzae*. IRRI, 1976.



4. Relationship of inoculum density of three pathogenic strains of *Xanthomonas oryzae* to the reaction to bacterial blight on IR8.



5. Relationship of inoculum density of three pathogenic strains of *Xanthomonas oryzae* to the reaction to bacterial blight on IR22.

On IR8, all three isolates caused 100% susceptible lesions at the highest concentration of the inoculum (dilution of culture at $10^{-1.5}$). As dilution increased, the frequency of R, MR, or MS type of lesions increased and the S-type lesions decreased proportionally (Fig. 4). At dilution $10^{-3.0}$ and regardless of the isolates, the rate of infection (leaves with all R, MR, MS, and S lesions/total leaves inoculated × 100%) significantly differed from that of leaves with no infection (Table 9). It indicates that there is an infection threshold at a given inoculum density.

IR22, which is conditioned by the dominant gene *Xa 4* for bacterial blight resistance, is resistant to PXO 61 but susceptible to PXO 79 and PXO 71. It has been observed that PXO 79

Table 9. Infection rate of three pathogenically distinct isolates of *X. oryzae* on IR8 and IR22.[a] IRRI, 1976.

Isolate	Infection rate (%) at dilution					
	$10^{-1.5}$	$10^{-2.0}$	$10^{-2.5}$	$10^{-3.0}$	$10^{-3.5}$	$10^{-4.0}$
			IR8			
PXO 61	100.0 a	100.0 a	49.5 a	3.0 a	6.4 a	0.0 a
PXO 71	100.0 a	100.0 a	100.0 b	1.9 a	1.5 a	2.9 a
PXO 79	100.0 a	100.0 a	43.9 a	6.4 a	9.6 a	3.5 a
			IR22			
PXO 61	100.0 a	66.6 b	4.0 a	1.0 a	3.2 a	2.7 ab
PXO 71	100.0 a	100.0 c	100.0 c	7.8 a	9.8 ab	0.0 a
PXO 79	100.0 a	45.9 a	44.7 b	22.2 b	16.2 b	8.3 b

[a]In each column and variety, means followed by the same letter are not significantly different at the 5% level.

usually causes larger lesions on IR22 than PXO 71 does. The data suggest a similar trend of infection as dilution of the inoculum increased. However, at the highest inoculum concentration, the types of infection differed among the three isolates. PXO 61 caused more R-type lesions, PXO 79 caused 100% S-type lesions, and PXO 71 was intermediate (Fig. 5). As the dilution increased to the $10^{-2.5}$ level the rate of infection by PXO 61 was significantly lower. PXO 79 seems more compatible with IR22 than is PXO 71 at the low level of inoculation (Table 9).

Field reactions to tungro. Field infection by rice tungro refers to infection of rice plants in the field without direct manipulation of insect vectors. Field infection varies from place to place and from time to time.

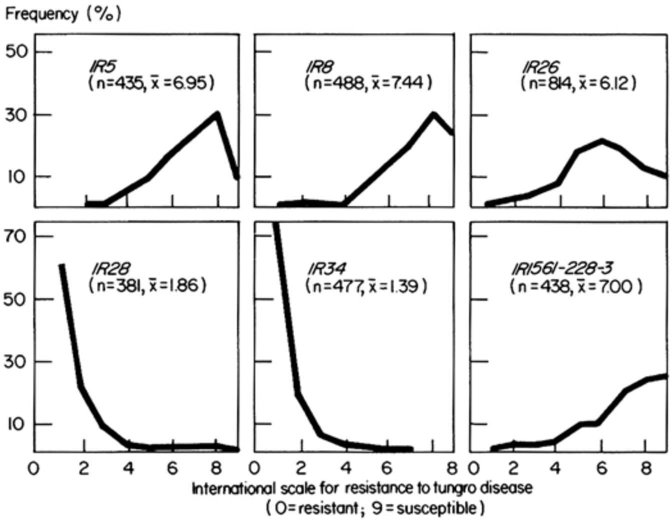
The field reactions of a rice variety constitute not only the range of reactions to tungro but also the frequency with which the variety shows each field reaction in replicated tests. The field reactions of replications of IR5, IR8, IR26, IR28, IR34, and IR1561-228-3 obtained at IRRI in 1975 and 1976 indicate that the ranges of reaction and the frequency of each reaction differed. For instance, IR34 showed field reactions ranging between 1 and 6 on the international scale for tungro resistance, and IR8 showed reactions ranging between 2 and 9. IR34 showed field reactions of 4 or higher in only 2.7% of 477 replicated tests. IR8 showed field reactions of 4 or higher in 98.3% of 488 replicated tests. Apparently IR34 is much more resistant to tungro in the field than is IR8 (Fig. 6).

The comparison may not be reliable, however, because field infection essentially is not constant. The different reactions to tungro may be due to the different levels of field infection to which the two varieties were exposed. Therefore, it is essential to specify the level of field infection to which a variety was exposed. For that purpose, the term "tungro pressure" is proposed. It tentatively refers to the average tungro reaction (based on the international scale for resistance to tungro) of other rice varieties or lines that are grown adjacent (1 to 10 rows on each side) to a test variety or line.

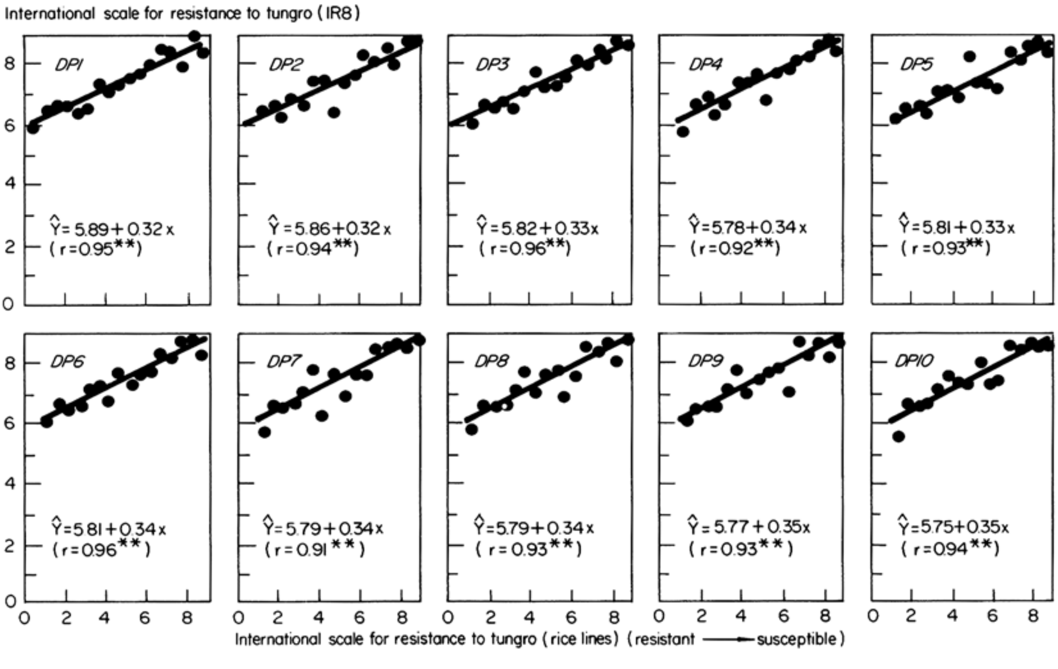
The field reaction of a variety to tungro is not only controlled by the intrinsic disease resistance of the variety but is also influenced by the disease pressure. In field infection by tungro in 1975, the reactions of the tested varieties (IR5, IR8, IR20, IR26, IR30, IR34, and IR1561-228-3) increased as the tungro pressure increased. That was true whether the tungro pressure was applied by 1 adjacent row of rice plants on each side of the test variety, or by 2 to 10 rows on each side. However, the rate of change in field reaction of varieties in relation to the increase of tungro pressure was not constant. For instance, the susceptibility of IR8 (Fig. 7) increased much more rapidly with increasing disease pressure than did that of IR34 (Fig. 8). The 1976 data are being statistically analyzed.

Screening for *Cercospora* leaf spot resistance. Narrow brown leaf spot of rice (*Cercospora oryzae*) has become an important disease in recent years. Experiments in 1976 sought a method for screening varieties for resistance to *C. oryzae*.

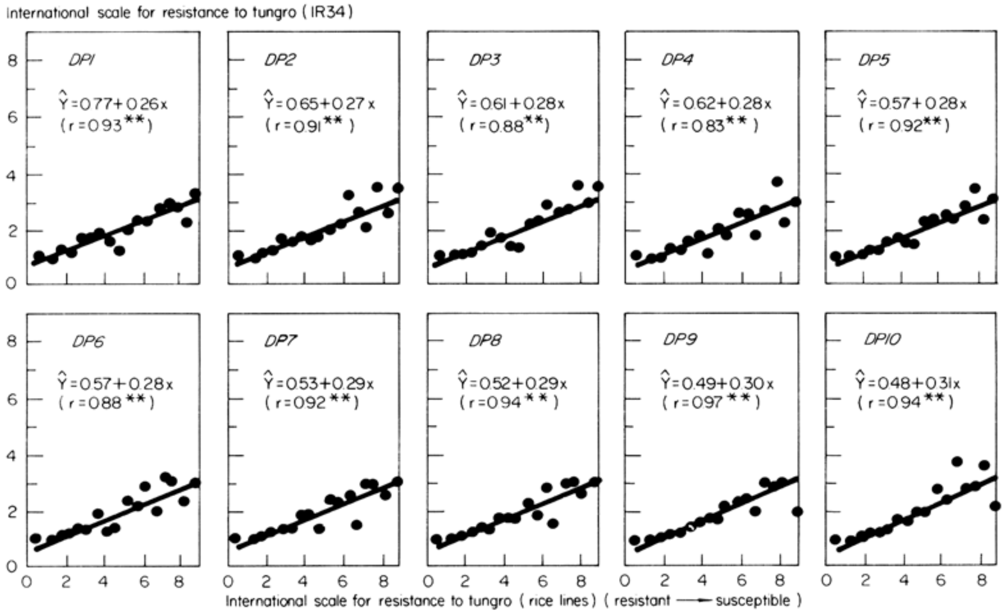
Isolation and spore production. A node technique was developed to isolate *C. oryzae*. In-



6. Frequency distribution of replications of rice varieties by their field reactions to tungro. IRRI, 1975–76.



7. Field reactions of IR8 (n = 232) to tungro at different disease pressures (average reactions of other rice lines to tungro) at IRRI in 1975 (DP1–DP10 refers to disease pressure based on the average tungro reactions of 1 to 10 adjacent rows of rice plants on each side of the IR8).



8. Field reactions of IR34 (n = 199) to tungro at different disease pressures (average reactions of other rice lines to tungro) at IRRI in 1975 (DP1–DP10 refers to disease pressure based on the average tungro reactions of 1 to 10 adjacent rows of rice plants on each side of the IR34).

fected leaf tissues were cut into small pieces (2 × 5 mm) and surface sterilized. Each piece was placed on a rice stem node in a test tube with 0.5 ml prune juice. (Prune juice was made by boiling 1 dry prune in 1 liter of water for 15 minutes.) The fungus grew on the node and was transferred to prune juice agar media to become a pure culture. It produced spores only sparingly in ordinary media, but produced abundant spores on stem-node and prune juice medium in 4 to 5 days and continued to produce spores for 2 more weeks.

Greenhouse inoculation. In greenhouse inoculation experiments, the disease developed slowly. Lesions began to appear 3 weeks after inoculation and reached the maximum number 30 days or more after inoculation. The fungus infected a plant at all ages, and not only at late stage of rice growth, as generally observed.

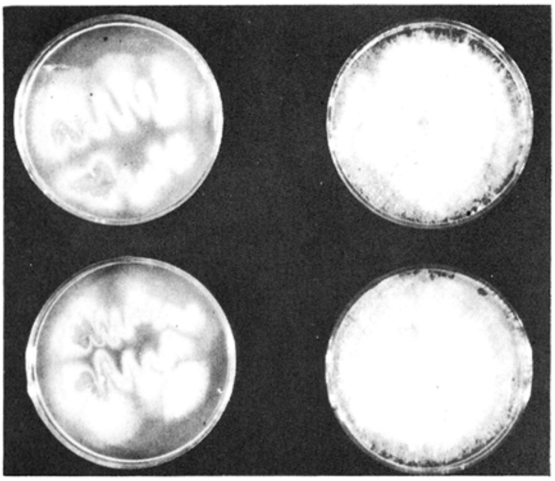
Field screening trial. Ten rice lines that showed resistant, intermediate, and susceptible reactions to leaf spot in previous seasons were selected and planted in 2-m rows. At booting stage, an area of about 0.5 m at the end of each row was sprayed with a spore suspension late in the afternoon. When the rice plants were near maturity, the lesions on the flag leaves were counted. The findings agreed with those in previous field observations (Table 10).

Screening for leaf scald resistance. The recent upsurge of leaf scald (*Rhynchosporium oryzae*) prompted a search for a method for screening rice varieties resistant to the disease. Because natural infection of *R. oryzae* fluctuates from season to season, artificial inoculation is needed.

Table 10. ***Cercospora*** **lesion count (flag leaves) on susceptible, moderate, and resistant lines inoculated with** ***Cercospora oryzae*** **under field conditions. IRRI, 1976.**

Line[a]	Lesions[b] (no.)	
	Inoculated	Natural infection
Susceptible		
IR1487-372-1-1	184.8 (8)	49.8
IR3184-62-1-2	219.5 (9)	19.4
Moderately resistant		
IR2805-72-5-3	58.5 (4)	21.2
IR2562-61-5-2-1	35.5 (3)	5.4
IR2798-99-3-2	30.2 (3)	7.1
Resistant		
IR2061-281-53-1	7.0 (1)	3.4
IR2071-843-1-1-6	5.6 (1)	2.1
IR2808-21-3-2	5.1 (1)	0.4
IR2070-132-2-2-5	2.5 (1)	0.9
IR2836-78-4-2	1.8 (1)	0.5

[a]Susceptible and resistant varieties are grouped on the basis of several field observations of previous seasons. [b]Numbers in parentheses indicate rating on a scale of 1 to 9: 1 = most resistant; 9 = most susceptible.



9. Cultures of *Rhynchosporium oryzae*: (left) mycelial growth with small sporulating sector; (right) sporulating cultures. IRRI, 1976.

Isolation of the fungus from diseased tissues usually gives rise to whitish, mycelial growth that produces few spores. Transferring spores from that pink sporulating sector by streaking on agar produces copious spores (Fig. 9).

Two methods of inoculation—spraying rice seedlings with spore suspension, and leaf clipping—were tried in the greenhouse and in the field. In the greenhouse both methods caused infection, but leaf clipping was more effective. Lesions developed 3 to 4 days after inoculation. In an initial field trial, lesions developed slowly, probably because of the physical environment at the time of inoculation.

Field molds of rice grains. Mature rice grains in the field are infected or contaminated with many kinds of fungi. In 1976 more than 100 varieties and lines were sampled in the replicated yield trial plots during both cropping seasons to determine the molds involved and the extent of damage they cause.

The molds were detected by plating washed seeds on agar medium. To detect the molds affecting the endosperms, the glumes were removed and their surface was sterilized before plating. Each of the 8,100 sample seeds produced one to four kinds of fungus colonies. The most common molds were *Trichoconis* sp., *Curvularia* sp., *Fusarium* sp., and *Nigrospora* sp. *Curvularia* and *Nigrospora* were detected more often in the wet than in the dry season. About 70% of endosperms were infected.

The predominant fungus was *Trichoconis* sp. About 50% of the samples yielded this fungus in both cropping seasons. *Trichoconis* occasionally caused leaf lesions but was surprisingly common on and in grains.

The damage caused by fungi varies from spots invisible to the naked eye to complete rot of the endosperm. Further damage may occur during storage. Whether or not the molds produce toxins is not known.

INHERITANCE OF DISEASE RESISTANCE

Plant Breeding and Plant Pathology Departments

Inheritance of resistance to bacterial blight. Studies of the inheritance of resistance to bacterial blight continued. To identify more loci for resistance, 68 resistant varieties from different geographic areas were tested. The PXO 61 isolate, representative of the Philippine isolates of the bacterium, was used in the study. It was noticed that some varieties are resistant at the maximum tillering stage and continue to be resistant at later growth stages. Some varieties, however, are susceptible at the maximum tillering and earlier stages of growth but become resistant at the booting and flowering stages. Most varieties from Sri Lanka belong to the latter group.

All resistant varieties were crossed with TN1, which is highly susceptible to bacterial blight. The F_1 hybrids were inoculated at two growth stages. The reactions of the F_2 populations from varieties that were resistant at the maximum tillering and adult stages were determined at the maximum tillering stage. The reactions of F_2 populations from varieties showing resistance at the adult stage but susceptibility at earlier stages were determined at the adult stage.

The data indicate that 33 varieties have a single dominant gene for resistance and 32 have a single recessive gene for resistance. The X^2 values for 3 : 1 or 1 : 3 ratios in all cases except three were not significant. The X^2 values for F_2 data in the crosses TN1/DV 85, TN1/DV 86, and TN1/DZ 78 were highly significant and deviated from the 3 : 1 ratio for monogenic control of resistance. It appears that more than one gene confers resistance in DV 85, DV 86, and DZ 78. To elucidate the mode of inheritance of resistance in those varieties, the reactions of F_3 lines from the crosses of those varieties with TN1 were determined at the maximum tillering and adult stages. The classification of F_3 lines into resistant, segregating, and susceptible groups at the maximum tillering stage showed good fit to a 1 : 2 : 1 ratio. In general, segregating families had more susceptible plants than resistant ones. The F_1 hybrids of those varieties with TN1 were also susceptible at the maximum tillering stage. Thus, at the maximum tillering stage, a single recessive gene seems to confer resistance in those varieties.

However, because the F_1 hybrids of the varieties were resistant at the adult stage, at least one dominant gene must be involved at that stage. At the adult stage, classification of F_3 families into resistant, segregating, and susceptible groups agreed with the 7 : 8 : 1 ratio expected for two independently segregating genes. Thus, at the adult stage, resistance is conferred by one dominant and one recessive gene.

Varieties found to have a single recessive gene for resistance were crossed with IR1545-339, which is homozygous for *xa 5*, a recessive gene for resistance. The F_1 hybrids of all the varieties, except PI 231129, were resistant, indicating that all of them, except PI 231129, have *xa 5* for resistance. The F_1 hybrid of IR1545-339/PI 231129 was susceptible. Thus PI 231129 appears to have a different recessive gene than *xa 5*.

An F_2 population of 528 plants and 120 F_3 families from the cross of IR1545-339/PI 231129 were examined to study the relationship of the recessive gene of PI 231129 with *xa 5*. In the F_2 population, the 249 resistant and 279 susceptible plants, approximated the 7 : 9 ratio (X^2 = 2.40) expected for two independently segregating recessive genes. Similarly, the F_3 families had 48 resistant, 65 segregating, and 7 susceptible families, fitting into the ratio of 7 : 8 : 1 (X^2 = 0.79). It appears that PI 231129 has a single recessive gene that segregates independently of *xa 5*. PI 231129 was also crossed with IR22, and the F_2 population of 516 plants from that cross was examined. The proportion of resistant (437) and susceptible (79) plants agreed with the 13 : 3 ratio (X^2 = 4.00) expected for independent segregation of a dominant and a recessive gene for resistance. The data show that the recessive gene of PI 231129 also segregates independently of *Xa 4*.

The varieties that showed monogenic dominant control of resistance were crossed with IR22. The F_1 hybrids, as expected, were all resistant. The F_2 populations were similarly resistant. It appears that all of them have *Xa 4* for resistance.

The inheritance of resistance at maximum tillering stage appears to be controlled by a single recessive gene in DV 85, DV 86, and DZ 78. The reactions of the F_1 hybrids and F_2 populations from the crosses of those varieties with IR1545-339 were investigated. The F_1 hybrids were resistant at the maximum tillering and adult stages. The F_2 populations of 405, 392, and 506 plants, respectively, had no segregation for susceptibility. The data confirm that DV 85, DV 86, and DZ 78 each has *xa 5* gene for resistance.

To study the relationship of the dominant resistance gene of DV 85, DV 86, and DZ 78 with *Xa 4*, the reactions of F_2 populations and F_3 families from the crosses of those varieties with IR22 were investigated at the adult stage. The F_2 data agreed with the ratio 61 resistant : 3 susceptible plants expected for independent segregation of two dominant and one recessive gene. Similarly, classification of F_3 families into resistant, segregating, and susceptible groups showed close fit to the ratio 37 resistant : 26 segregating : 1 susceptible expected for independent segregation of two dominant and one recessive gene. The observations suggest that resistance in DV 85, DV 86, and DZ 78 is under digenic control. One of those genes is *xa 5*, which conveys resistance at maximum tillering stage; the other gene, which is expressed at adult stage of plant growth, is dominant and is independent of *Xa 4*.

Genetic evaluation and utilization (GEU) program

Insect resistance

Entomology and Plant Breeding Departments

SOURCES OF RESISTANCE
Entomology and Plant Breeding Departments

Stem borers. Work on the striped borer and the yellow borer concentrated primarily on further buildup of plant resistance by diallel crossing of moderately resistant lines, and evaluation of promising breeding lines for their reactions to borers (Table 1). Several progenies from diallel crosses showed higher levels of resistance than those of any of the parents. Those lines were tested intensively at controlled levels of borer infestation. In a screenhouse experiment, the progenies of TKM 6, of CR 94, or of both, had lower deadheart incidence than those of other crosses (Table 2). TKM 6 and CR 94 are moderately resistant to the striped borer.

In a similar experiment on yellow borer, the progeny of IR1820-52-2, which is resistant to this insect, had significantly lower incidence of deadhearts than other test lines. The line IR4442-45-2-1 had the least incidence of deadhearts caused by the yellow borer, and is also promising for several other desirable attributes. Another cross, IR5793 (IR1820-52-2-4-1/IR1721-11-6-8-3-2//IR2061-213-2-16), had nine F_3 lines whose resistance is equal to or slightly better than that of the donor parent (Table 3).

Green leafhopper. The 430 varieties selected from the mass screening test (Table 1) as resistant to the green leafhopper (GLH) will be retested for resistance. Most of IRRI's elite breeding lines have resistance levels equal to or better than those of released IRRI varieties. Lines with the highest level of resistance are IR2061-464-2-4-4-6, IR2061-522-6-9, IR2061-628-1-6-4-3, IR4432-103-6-4, IR4215-4-3-1, IR4422-164-3-6, IR4613-54-5, IR4683-54-2, and IR4859-38-2. Of 330 entries scored in the Third International Rice Observational Nursery, 174 were rated resistant to GLH. Many wild rice collections were resistant (Table 1).

Brown planthopper. Earlier studies on the brown planthopper (BPH) consisted of screening the rice germ plasm against biotype 1 only. Because rice susceptible to biotype 1 might not be necessarily susceptible to biotypes 2 and 3, the germ plasm collections were mass screened and about 6,000 entries each were tested against the two biotypes.

About 40 rices that showed resistance to all three BPH biotypes were identified (Table 4). Many more accessions exhibited resistance to only one or two of the biotypes. No variety was susceptible to biotype 1 but resistant to biotypes 2 and 3. In the future, the germ plasm collections will be evaluated only against biotype 1, and only lines resistant to it will be tested against biotypes 2 and 3.

Breeding for resistance to different BPH biotypes, a major objective of the GEU program, constitutes an important objective for almost all crosses made at IRRI. Several breeding lines from IRRI and India are resistant or moderately resistant to all three BPH biotypes (Table 5). Some were resistant at all the test sites of the International Rice Brown Planthopper Nursery.

Whitebacked planthopper. A major study of the whitebacked planthopper (WPH) was completed. Of 430 accessions selected from a mass screening, 30 were resistant and 50 were moderately resistant.

Table 1. Volume of rice materials selected for resistance to rice insect pests. IRRI, 1976.

Insect pest	Germ plasm		Breeding lines		Wild rice	
	Tested	Selected	Tested	Selected	Tested	Selected
Green leafhopper	4,724	430	980	635	49	44
Whitebacked planthopper	4,009	450	129	6	0	0
Brown planthopper						
Biotype 1	7,492	145	21,800	14,308	56	13
Biotype 2	6,640	43	17,737	7,791	56	11
Biotype 3	6,107	95	2,051	1,020	56	12
Stem borer						
Striped borer	0	0	1,080	19	0	0
Yellow borer	0	0	1,034	68	0	0
Whorl maggot	8,557	4	128	1	0	0

Table 2. Deadheart incidence for elite breeding lines in a screenhouse test with high density of striped borer. IRRI, 1976 dry season.

Designation[a]	Cross	Deadhearts (%)
IR4422-51-1	IR2049-134/IR2061-125	70
BG 90-2	Peta³/TN1//Remadja	63
IR2035-117-1	IR1416-128-5/IR1364-37-3-1///IR1539-269//IR24³/*O. nivara*	62
IR2058-78-1-3-2-3	IR1416-131/IR1364-37//IR1366-120/IR1539-111	57
IR2061 (4)	IR833-6///IR1561-149//IR24⁴/*O. nivara*	56
IR4816-70	IR1737-19///BRJ-1-13-B-10/IR1541-76//IR1103-15/IR1514A-E588	53
IR1561-228-3-3	IR8/Tadukan//IR737B-6-3	53
IR2863 (4)	IR1529-680/CR 94-13//IR480-5-9	52
IR1632-93-2-2	IR24/Co 13	49
IR2832-141-2-1	IR946-33/IR1529-680//IR1364-37/IR1721-11-5	46
IR2328-51-1-2-1	IR1514A-E666/IR1364-37-3-1-3	46
IR2070 (2)	IR20²/*O. nivara*//CR 94-13	43
IR2823-399-5-6	CR 94-13/IR1529-680///IR24³/*O. nivara*//IR1416-131	41
IR2071 (6)	IR1561-228//IR24⁴/*O. nivara*///CR 94-13	41
IR4432-103-6	IR2061-125/CR 94-13	39
IR2798 (2)	IR1529-680/IR1913-41//IR1514A-E666	38
IR2688-39-4-2-3	IR790-28///IR20²/*O. nivara*//CR 94-13	34
IR2307 (2)	CR 94-13/IR1561-228	32
IR2153 (2)	IR24/TKM 6//IR20³/*O. nivara*	30
IR2681-163-5-2-2	CR 94-13///IR20³/*O. nivara*//IR24/TKM 6	21
IR8 (Check)[b]		65
IR20	Peta³/TN1/TKM 6	40

[a]Numbers in parentheses are numbers of lines tested. Deadheart data are based on average number of lines tested. [b]The deadheart incidence for IR26, IR28, IR30, IR32, IR34, and IR36 which were also used as checks, ranged from 41–44%, except that of IR36, which was 48%. The checks were replicated 4 times; the lines were replicated twice.

The WPH had significantly lower survival on the resistant varieties—even at 4 days after infestation—than on the susceptible variety Taichung Native 1 (TN1). In subsequent observations insect survival on the resistant plants was further reduced. The insects that survived on the resistant plants were smaller and weighed less than those reared on TN1.

The results show that the resistant varieties are not suitable hosts for the WPH and possess some antibiosis factors. In a follow-up study, adult insects had much shorter life span on the resistant varieties and laid significantly fewer eggs than they did on susceptible varieties (Table 6).

Table 3. Reaction of selected pedigree lines to yellow stem borer. IRRI, 1976.

Line	Deadhearts[a] (%)
IR5793-12-1	33
IR5793-21-1	33
IR5793-26-1	33
IR5793-26-2	33
IR5793-31-3	30
IR5793-34-1	33
IR5793-43-1	33
IR5793-55-1	28
IR5793-55-3	33
IR1820-52-2 (resistant check)	34
Rexoro (susceptible check)	74

[a]At 63 days after transplanting.

Table 4. Total number of accessions showing reactions to the three brown planthopper biotypes. IRRI, 1976.

Accessions (no.)	Reactions[a] to		
	Biotype 1	Biotype 2	Biotype 3
48[b]	R	R	R
110	R	R	S
95	R	S	R
12	R	S	S
6000	S	S	S

[a]R = resistant; S = susceptible. [b]Including 10 wild rice collections.

Table 5. Breeding lines resistant or moderately resistant to the three biotypes of the brown planthopper. IRRI, 1976.

Rice selection	Source of test materials	Damage rating[a]		
		Biotype 1	Biotype 2	Biotype 3
IET 5118	AICRIP[b]	3.0	4.3	3.7
IET 5119	AICRIP	3.0	2.3	5.0
IET 5120	AICRIP	1.7	4.3	3.7
IET 5122	AICRIP	1.0	1.0	1.0
IR32	IRRI	1.7	1.7	3.7
IR2071-137-5-5-1	IRRI	1.7	4.3	1.7
IR4432-28-5	IRRI	1.0	1.0	3.7
Mudgo (resistant check)	IRRI	1.0	9.0	1.0
ASD 7 (resistant check)	IRRI	1.0	1.0	9.0
Taichung Native 1 (susceptible check)	IRRI	9.0	9.0	9.0

[a]Av. of three replications using the seedling test method. The moderately resistant varieties were killed under heavy insect infestations. [b]All India Coordinated Rice Improvement Project.

An experiment with 23 varieties further confirmed the differences in number of eggs laid by the WPH on resistant and susceptible varieties. On all those varieties most eggs were laid in the leaf sheath, and only a few were laid in the midrib or the leaf blades.

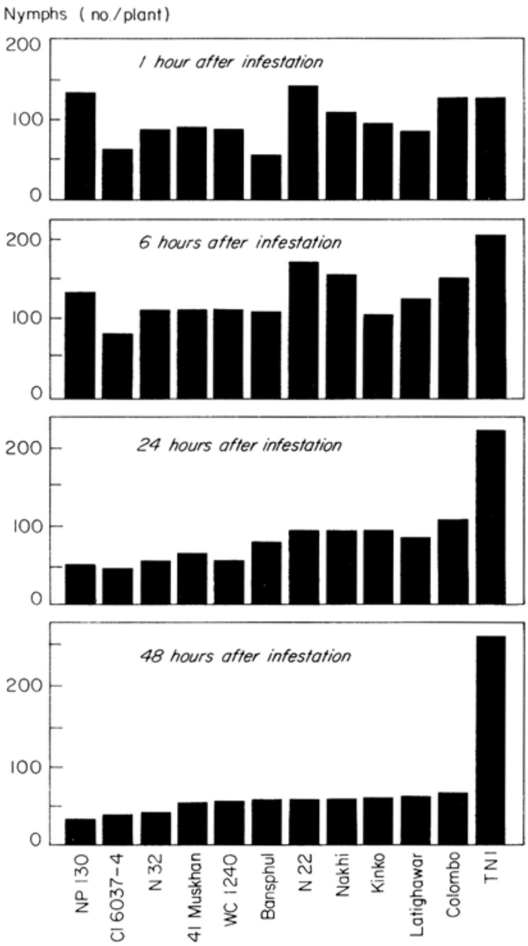
Table 6. Life span and oviposition of adult whitebacked planthopper on selected varieties. IRRI, 1976.

Variety	Life span (days)				Preoviposition period (days)		Eggs laid (no.)	
	Male		Female					
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Muskhan 41	2–7	3.4	3–5	4.0	3–5	3.2	0–21	8
WC 1240	2–7	3.4	3–8	4.8	3–5	3.3	0–11	6
Colombo (resistant check)	2–9	4.0	3–8	4.4	3–5	3.4	2–35	11
TN1 (susceptible check)	3–31	14.4	6–65	20.3	2–3	2.7	2–425	162

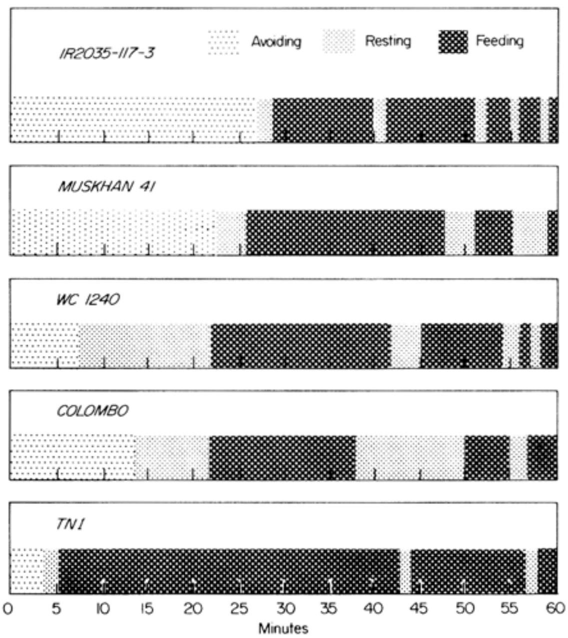
The WPH exhibited a random selection pattern for different varieties within an hour after its introduction in a cage containing potted plants of different varieties. But after 1 hour, both the nymphs and adult insects moved off the resistant plants (Fig. 1). Thus, the insects' taste reaction appears important in determining its preference or nonpreference for the different varieties.

In another experiment, insects caged separately on each variety started feeding on the susceptible plants within a few minutes and fed continuously; those on resistant plants often did not start feeding during the first 20 to 39 minutes and their feeding durations were short (Fig. 2). The insects on resistant varieties did much less feeding, excreted smaller amounts of honeydew, and usually lost weight; those on susceptible varieties gained weight.

The use of higher levels of nitrogenous fertilizers is conducive to BPH population build-



1. Preference of *Sogatella furcifera* nymphs for resistant and susceptible (TN1) rice varieties (as indicated by insect density). IRRI greenhouse, 1975.



2. Whitebacked planthoppers on the susceptible variety Taichung Native 1 fed almost without interruption; those caged on resistant varieties did little feeding. IRRI,1976.

up (1971 Annual Report). Similar results were obtained with the WPH but the relative ratings on resistant and susceptible varieties at different fertilizer levels did not change (Table 7). Generally, insect survival on resistant varieties did not differ significantly on plants grown with 0, 40, and 80 kg N/ha, but was significantly higher on the plants treated with 120 kg N/ha.

Three varieties resistant to WPH—N22, ARC 6003, and Dharia—are being used as sources of resistance. Because these donor varieties have poor plant type, they were backcrossed using IR28, IR30, IR32, IR34, IR36, and IR38 as recurrent parents. F_2 and F_3 populations from the second and third backcrosses will be grown in 1977.

Whorl maggot. The world collection and breeding lines continued to be field screened for additional sources of whorl maggot resistance. An additional 8,557 varieties from the germ plasm collection brought to about 28,000 the total number of varieties screened since 1975. No highly resistant varieties were identified, but individual undamaged plants of 293 varieties were selected in 1976.

The most resistant were four varieties from Indonesia—Rodjolele, Tjempo Beton, Tjempo Buntut, and Tjere Betawen. Retesting will determine the consistency of the resistant reactions of the 293 varieties.

The sister lines of IR2070 were further screened to determine if any of them were superior to IR2070-414-3-9. IR2070-414-3-6 and IR2070-85-1-1-2 had the least damage. IR2070-414-3-6 is used as a parent in the whorl maggot-resistance breeding program.

The IRRI breeding line IR2070-414-3-9, found to possess a moderate degree of resistance to the whorl maggot (1975 Annual Report), was released by the Philippine Government as IR40. A field experiment was conducted to determine whether its resistance level was high enough to minimize the use of insecticide. Chemical control of the whorl maggot increased

Table 7. Effect of nitrogen (urea) application on the survival of whitebacked planthopper on selected rice varieties 4, 8, and 12 days after infestation.[a] IRRI, 1976.

Variety	Survival (%) 4 days	Survival (%) 8 days	Survival (%) 12 days	Av. wt (mg/insect)
		No fertilizer applied		
Muskhan 41	54 a	22 a	12 a	0.4
WC 1240	88 cd	60 c	32 abc	0.8
Colombo (resistant check)	64 ab	52 bc	34 abc	0.6
TN1 (susceptible check)	100 d	100 c	98 d	2.0
		40 kg N/ha		
Muskhan 41	58 ab	30 ab	12 ab	0.4
WC 1240	74 abc	58 c	48 bc	1.2
Colombo	56 ab	44 abc	28 abc	0.9
TN1	100 d	100 c	98 d	2.6
		80 kg N/ha		
Muskhan 41	80 bc	66 cd	22 ab	0.4
WC 1240	74 abc	68 cd	58 c	0.6
Colombo	70 abc	68 cd	52 bc	0.6
TN1	100 d	100 c	92 d	2.2
		120 kg N/ha		
Muskhan 41	24 abc	52 bc	42 bc	0.4
WC 1240	68 abc	64 cd	52 bc	0.6
Colombo	92 bc	84 d	56 c	0.9
TN1	100 d	100 c	92 d	1.7
		F values		
DMRT	8.25**	15.91**	13.72**	
N levels (N)	2.36	6.25**	2.78*	
Varieties (V)	31.56**	67.11**	60.72**	
NYV	2.44*	2.06*	1.70	
CV (%)	18.0	19.3	28.0	

[a]Analysis based on values transformed to arcsin. Any two means followed by the same letter are not significantly different at the 5% level; 5 replications.

Table 8. Response of selected lines with varying levels of resistance to whorl maggot.[a] IRRI, 1976 wet season.

Line	Resistance level[b]	Whorl maggot damage[c]		Yield (t/ha)	
		Chemical	No chemical	Chemical	No chemical
IR40 (IR2070-414-3-9)	MR	0.0	5.6	5.0 a	4.9 a
IR2070-423-2-5-6	MR	0.2	8.4	5.2 a	4.9 a
IR34	MS	0.6	8.0	5.7 a	4.1 b**
IR2798-15-2-3	MS	0.6	8.8	5.1 a	3.4 bc**
TKM 6	S	0.6	9.0	3.7 b	2.8 c*

[a]Means followed by the same letter are not significantly different at the 5% level. [b]MR = moderately resistant; MS = moderately susceptible; S = susceptible. [c]Based on damage scale 0–9: 0 = no damage; 9 = more than 50% damaged leaves.

yields in only the susceptible lines (Table 8).

A greenhouse study on the nature of resistance to the whorl maggot indicated the insect's ovipositional preference among varieties (Fig. 3); in field tests, however, TN1 (the susceptible variety) and IR2070-414-3-9 did not significantly differ. Larval survival and the ability of the plants to recover from whorl maggot damage may be more significant than ovipositional preference.

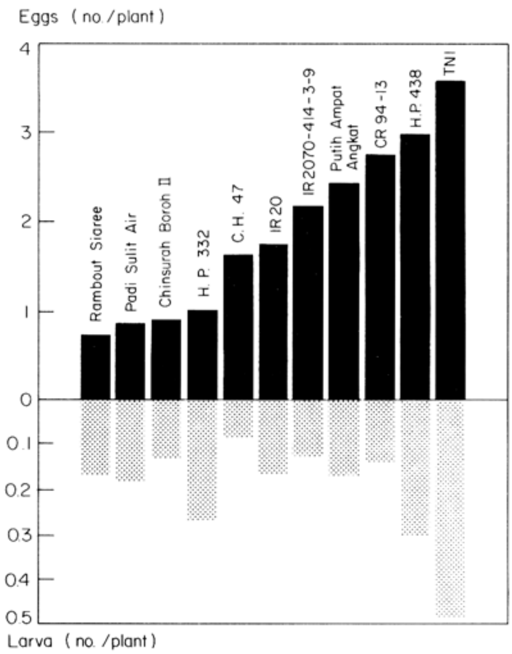
CAUSES OF RESISTANCE
Entomology Department

Striped borer. Studies using steam distillates of TKM 6 and Rexoro leaves demonstrated that the nonpreference reaction of the striped borer for TKM 6 is of a biochemical nature. Striped borer moths oviposited on a muslin cloth coated with the distillate of the susceptible variety Rexoro, but not on a cloth treated with the solvent alone. No eggs were laid on the muslin cloth when it was coated with the distillate of TKM 6. In a simultaneous experiment, moths in plastic cages containing the odor of the TKM 6 distillate did not lay any eggs, but moths in cages with the odor of Rexoro distillate laid large egg masses on the cage walls and the glass vials that contained the distillate.

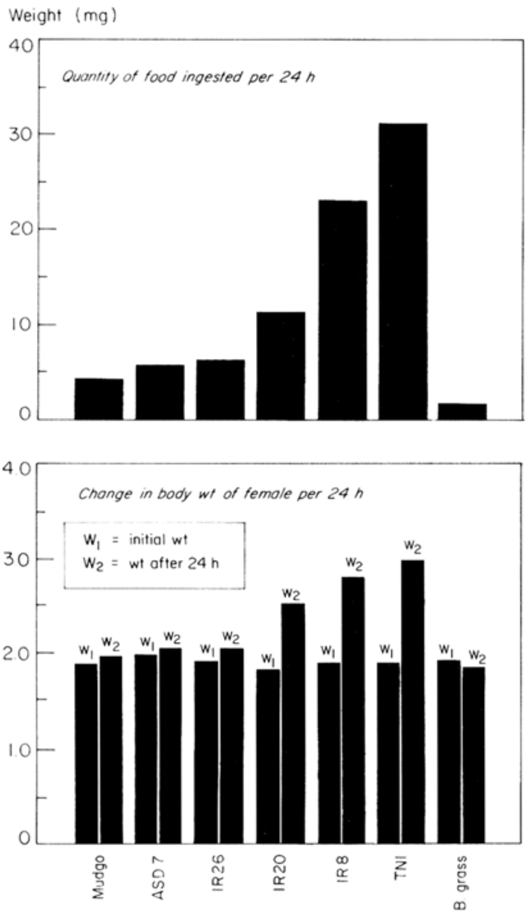
Brown planthopper. Several experiments examined the causes of BPH resistance in rice varieties.

The BPH appears to be attracted to the odors of rice varieties. Odors emitted by steam distillates of the resistant varieties Gambada Samba, Gangala, Mathumanikam, Ptb 19, Ptb 21, Ptb 33, Sinnanayam 398, Sudu Hathiyal, Sudu Hondarawala, Sulai, and Thirissa, and the susceptible IR20, IR8, and TN1, attracted the BPH. The odor of ASD 7 and IR26 were only moderately attractive, but those of the resistant Babawee and Mudgo rice varieties and of barnyard grass repelled the BPH. The odors of Mudgo, tested as a steam distillate, strongly attracted biotype 2, and the distillate of ASD 7 attracted biotype 3. Mudgo is susceptible to biotype 2, and ASD 7 is susceptible to biotype 3.

None of the tested varieties gave evidence of a mechanical barrier to feeding by BPH biotypes. On resistant varieties the insects made more feeding punctures but fed at those punctures for considerably shorter time than on



3. Ovipositional preference and larval survival of rice whorl maggot *Hydrellia philippina* on rice varieties. IRRI greenhouse, 1976.



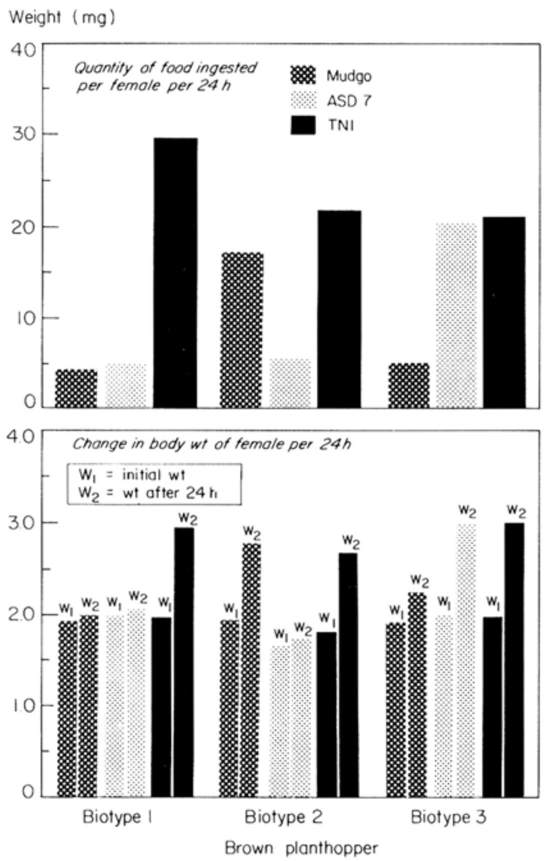
4. Metabolic utilization of ingested food by *Nilaparvata lugens* (biotype 1) on resistant and susceptible rice varieties, and on barnyard grass (*Echinochloa crusgalli*). IRRI, 1976.

susceptible plants. Biotype 1 ingested the maximum quantity of food from TN1—about 5 to 8 times more than the amount from resistant IR26, ASD 7, and Mudgo varieties, and about 15 times more than that from barnyard grass (Fig. 4).

On the other hand, biotypes 2 and 3 ingested food from Mudgo and ASD 7 almost equal in amount to that ingested from TN1 (Fig. 5). The body weight of the biotype 1 insects increased a maximum of 56% on the susceptible TN1 variety, and 46% on IR8 and IR20. The weight gain on resistant Mudgo, ASD 7, and IR26 varieties was only slight, 4 to 8%. On barnyard grass, the insects lost weight (Fig. 4).

Biotype 2 and 3 insects, on the other hand, ingested sufficiently large amounts of food from the biotype 1-resistant Mudgo and ASD 7 rice varieties, respectively and used them as efficiently as they did the food from susceptible TN1. Biotype 2 insects increased about 50% in body weight on susceptible Mudgo and TN1, but only about 10% on the biotype 2-resistant ASD 7 (Fig. 5). Biotype 3 insects increased in weight by 45% on ASD 7 and 53% on TN1, but only by 20% on biotype 3-resistant Mudgo.

Further studies on causes of resistance to BPH show the resistance to be primarily of biochemical nature, which exerts both nonpreference and antibiosis effects. Significantly fewer eggs hatch on certain resistant varieties than on susceptible ones (Table 9). This finding was confirmed by transplanting BPH eggs laid



5. Quantity of food ingested and change in body weight of three biotypes of *Nilaparvata lugens* that fed on Mudgo, ASD 7, and TN1 rice varieties. IRRI, 1976.

Table 9. Ovipositional response, and comparison of *Nilaparvata lugens* (biotype 1) eggs hatched on resistant and susceptible rice varieties, and on barnyard grass. IRRI, 1975–76.

Plant	Eggs laid daily[a] (no./10 females)	Eggs hatched[a] (%)
Mudgo	328 ab	68 b
ASD 7	348 ab	78 b
IR26	292 ab	74 b
IR20	325 ab	95 a
IR8	309 ab	90 a
TNI	400 b	91 a
E. crusgalli (barnyard grass)	205 a	18 c

[a]In a column, any two means followed by the same letter are not significantly different at the 5% level.

on a susceptible variety to a resistant and to another susceptible variety.

Preliminary investigations show the presence of greater amounts of phenolic in the resistant than in the susceptible rice varieties. The concentration of phenolic glycosides in the barnyard grass, which is virtually immune to BPH attacks, is several times higher than that in the resistant varieties.

INHERITANCE OF RESISTANCE
Plant Breeding and Entomology Departments

The inheritance of resistance to the WPH was studied in the cross IR30/N22. IR30 is susceptible, N22 is highly resistant. The F_1 showed resistance and the F_2 population had 774 resistant and 279 susceptible seedlings. The proportion fits the 3 : 1 ratio indicating that the resistance to WPH in N22 is controlled by a single dominant gene. Out of 352 F_3 families, 92 were resistant, 165 segregating, and 95 susceptible. The result agrees with the 1 : 2 : 1 ratio expected for monogenic control of resistance.

IR30 is resistant to BPH and bacterial blight, and is a dwarf. N22 is susceptible to BPH and bacterial blight, and is tall. The F_3 families from IR30/N22 were classified according to resistance to BPH and bacterial blight, and by plant height. The segregation for the three traits fitted the 1 : 2 : 1 monogenic ratio as expected. No association was apparent between resistance to WPH and plant height on the one hand, and resistance to BPH and bacterial blight on the other hand.

BROWN PLANTHOPPER BIOTYPE STUDIES
Entomology Department

So far three BPH biotypes have been identified in the Philippines. BPH continued to be reared on the varieties Rathu Heenati and Babawee, which possess genes for resistance different from those in Mudgo and ASD 7. No BPH colony that developed on Rathu Heenati or Babawee survived.

Differences in the basic bionomics, interbiotype competitions, and genetics were studied in greenhouse experiments. The biotypes are biologically similar except that biotype 3 appears to be somewhat less fecund than biotypes 1 and 2.

Large areas of the Philippines are being planted to BPH-resistant varieties. In most of them the BPH population appears to shift from biotype 1 to biotype 2.

MULTILINES FOR BROWN PLANTHOPPER CONTROL
Entomology Department

Multiline approach for BPH control. Plants with multigenic resistance should minimize the development of BPH biotypes. The BPH resistance in most varieties studied is monogenic. So far four different pairs of genes responsible for resistance have been identified. The first two pairs (*Bph 1* and *bph 2*) have a strong linkage and are difficult to incorporate in a plant. The other two (*Bph 3* and *bph 4*), identified only recently (1975 Annual Report), are inherited independently of others. Lines that carry more than one resistant gene are being developed.

As an alternative to multigenic resistance, a multiline approach was investigated in greenhouse and field experiments. Although the multilines are somewhat difficult to develop, their resistance is expected to be lasting.

In a greenhouse experiment, three varieties—IR20 (susceptible), IR30(with resistant *Bph 1* gene), and IR32 (with *bph 2* gene)—were grown in clay pots. Different proportions of each plant were grown in separate cages. When the plants were 20 days old, 50 newly hatched nymphs of different BPH biotypes were placed in each cage and the BPH population buildup was

Table 10. Brown planthopper (BPH) population in field plots planted with different mixtures of resistant and susceptible plants.[a] IRRI, 1976.

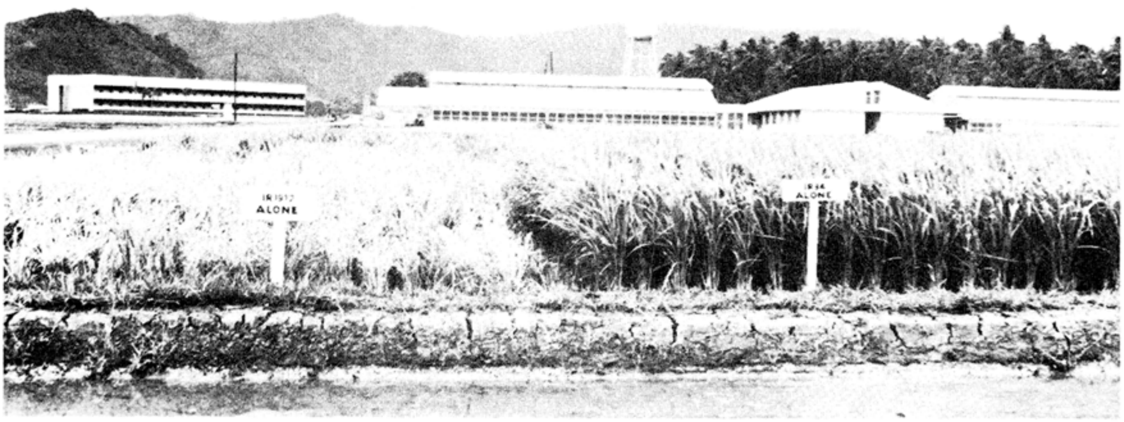
Plants (%) in each plot			Average no./plot		Yield (kg/ha)
IR1917 (susceptible)	IR34 (*Bph 1* gene)	IR36 (*bph 2* gene)	70 DT	85 DT	
0	0	100	126 a	294 a	2356 a
0	100	0	449 cd	738 a	2671 a
17	17	66	260 b	604 ab	2395 a
17	66	17	351 bc	736 bc	2179 ab
33	33	33	512 cd	824 bc	2268 ab
60	20	20	954 ef	3032 de	1816 bc
66	17	17	684 de	8629 cd	1538 c
100	0	0	1147 f	19938 e	736 d

[a]Av. of 4 replications. In each replication all BPH on 20 hills were counted at 70 and 85 days after transplanting (DT).

observed until 34 days after caging.

The cage with the smallest proportion of susceptible plants had the smallest BPH population. The populations of biotypes 2 and 3 increased considerably as the proportion of the susceptible plants increased. The population of biotype 2, however, was much larger than that of biotype 3, even when the proportion of susceptible plants to the respective biotypes was the same. The indication that biotype 3 is less fecund than biotype 2 was confirmed in another experiment.

A field experiment used IR1917 (resistant to tungro but susceptible to BPH), IR34 (with resistant *Bph 1* gene), and IR36 (with resistant *bph 2* gene). The number of insects declined with increase in resistant plants (Table 10). IR1917 had the highest BPH population. The much lower BPH populations in plots with IR34 or IR36 may imply that the BPH population at IRRI has high proportions of biotype 1. In observations 85 days after transplanting, the BPH population in IR1917 was about 20,000 insects/sq m; the plots were hopperburned (Fig. 6). The population in the other varieties was comparatively light.



6. IR1917 were hopperburned. The number of brown planthoppers decreased with the increase in population of resistant plants.

Genetic evaluation and utilization (GEU) program

Protein content

Plant Breeding, Agronomy, Statistics, and Chemistry Departments

EVALUATION TRIALS

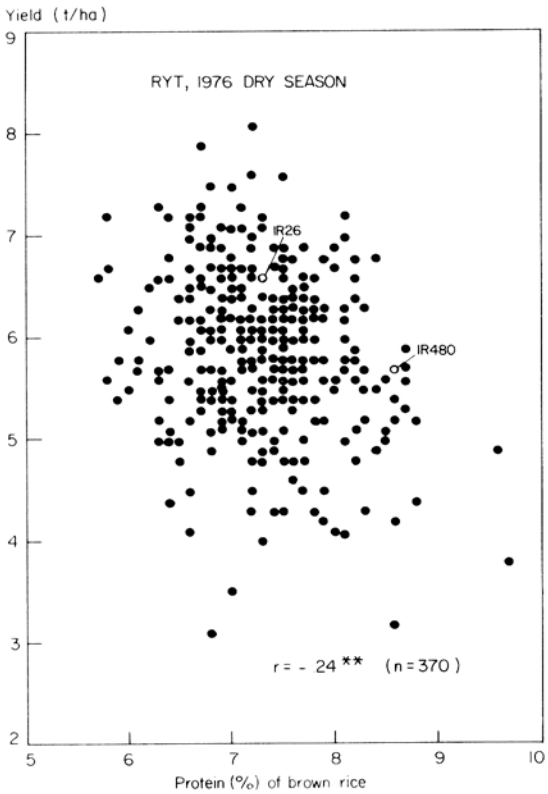
Plant Breeding, Agronomy, Statistics, and Chemistry Departments

Evaluation for protein content consists of selection in early generations for agronomic type, disease and insect resistance, and other essential traits. Protein per seed (P/S) values are determined for promising early generation selections. Selections with low P/S values are discarded, and the better lines go to replicated yield trials. Lines that consistently have higher protein content without sacrifice in yield, as well as lines that are outstanding during a single season, advance to agronomy evaluation trials. Those elite lines are tested at three levels of nitrogen fertilizer, and the best performers advance to the international nurseries.

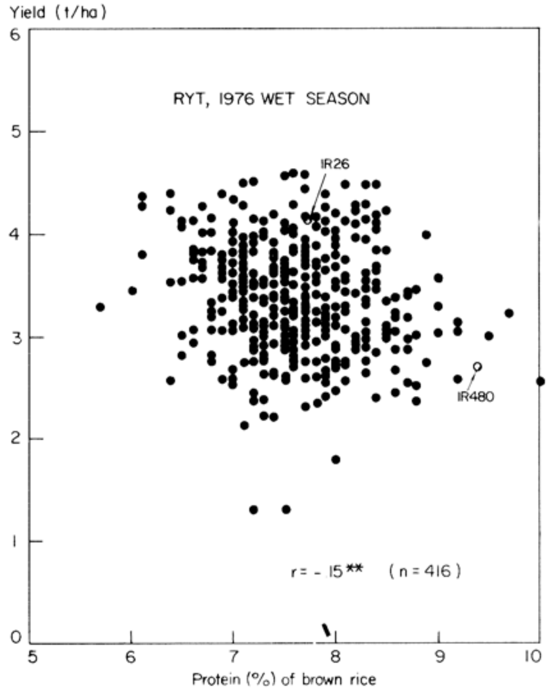
Plant breeders evaluated 370 varieties and lines for protein content in replicated yield trials during the dry season (Fig. 1) and 416 varieties and lines during the wet season (Fig. 2). Outstanding lines were promoted to agronomy evaluation trials (Table 1). The negative correlation between brown-rice protein (BRP) content and grain yield in these trials was lower than that in 1975 trials, particularly in the wet season.

Yield potential of high-protein rice (*Agronomy*). Agronomists evaluated the yield and protein potentials of 17 promising high-protein lines using IR8, IR26, and the high-protein line IR480-5-9 as standard controls under fertilized and unfertilized conditions. IR480-5-9 was not higher in protein content than the other check varieties in the dry season, but was about 2 percentage points higher in the wet season (Table 2). The most promising selection reported last year, IR2153-338-3, continued to perform favorably, compared with IR480-5-9 in terms of both protein content and grain yield. As expected, fertilizer application increased protein content and grain yield in both crops.

A similar agronomy trial of promising high-protein lines in the 1976 dry season better



1. Grain yield of rough rice and protein content of brown rice of 370 entries in yield trials (4 replications). IRRI, 1976 dry season.



2. Grain yield of rough rice and protein content of brown rice of 416 entries in yield trials (4 replications). IRRI, 1976 wet season.

Table 1. Brown-rice protein and rough-rice yield of two high-protein lines in agronomy trials during six seasons (mean of three nitrogen levels). IRRI, 1974 dry season-1976 wet season.

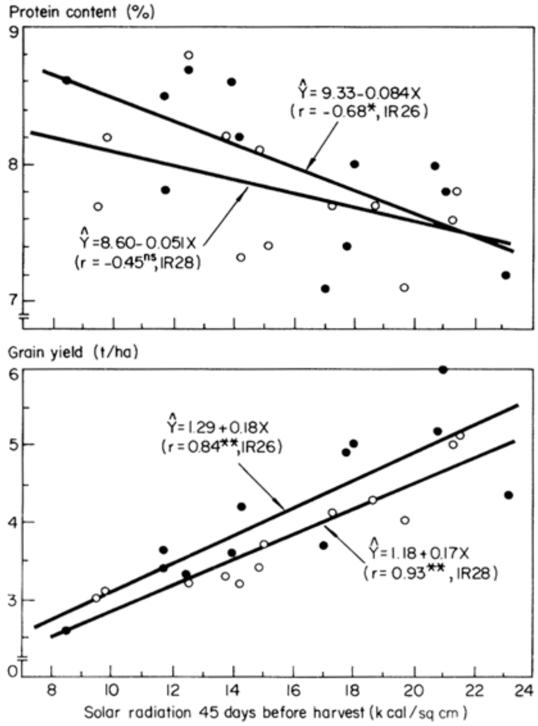
Variety or line	Protein (%)		Yield (t/ha)	
	Range	Mean	Range	Mean
IR8	7.2–8.4	7.8	3.5–5.5	4.6
IR26	7.7–8.5	7.9	4.1–7.3	5.4
IR480-5-9	8.4–9.3	8.8	3.0–5.2	4.0
IR2153-338-3	8.7–9.1	8.9	3.2–6.8	4.6
IR2863-35-3-3[a]	8.8–9.0[a]	8.9[a]	4.5–4.7[a]	4.6[a]

[a]Data for 1976 seasons only.

discriminated protein content among the entries (Table 3). IR2153-338-3 performed well in the trial, but some entries (particularly Boon Nahk 16-1-21) with as much protein as IR480-5-9 had low yields.

Solar radiation, nitrogen fertilizer, and protein (*Agronomy*). In monthly plantings of IR26 and IR28 in 1975–76, solar radiation totals for 45 days before harvest correlated negatively with protein content and positively with grain yield (Fig. 3).

A similar study was made to determine the interaction of time and rate of nitrogen application on protein content and grain yield. A single application of 120 kg N/ha at 5 to 7 days before panicle initiation consistently gave the highest protein content for both IR26 and IR8 in most planting times (Table 4). Split applications adding nitrogen at panicle initiation gave better results than single and split applications that excluded the panicle initiation period.



3. Relationship between solar radiation 45 days before harvest and protein content of brown rice and grain yield of rough rice in monthly plantings of IR28 and IR26 (mean of three N levels). IRRI, 1976.

PROTEIN SELECTION CRITERIA
Plant Breeding Department

The effectiveness of P/S as a selection criterion for high-protein rice was studied in the F_3 and F_6 data of the cross IR480-5-9-3/IR1529-680-3.

Table 2. Brown-rice protein and rough-rice yield of selected high-protein lines compared with those of IR8 and IR26 in agronomy yield trials. IRRI, 1976.

Variety or line	Dry season				Wet season			
	0 N		150 kg N/ha		0 N		150 kg N/ha	
	Protein (%)	Yield (t/ha)	Protein (%)	Yield (t/ha)	Protein (%)	Yield (t/ha)	Protein (%)	Yield (t/ha)
IR8	7.3	2.0	9.0	5.3	6.3	2.7	7.7	3.9
IR26	7.5	2.1	8.9	5.6	6.8	3.0	7.9	4.7
IR480-5-9	7.1	1.8	9.0	5.2	8.9	2.3	9.4	3.3
IR2006-P12-12-2-2	6.5	2.0	10.6	4.5	8.1	2.4	9.9	3.9
IR2061-P7-4-3-5	8.0	1.3	11.6	3.2	7.6	2.8	9.5	3.4
IR2153-338-3	7.4	2.8	9.4	5.9	8.3	2.0	9.2	3.9
IR2863-35-3-3	7.0	2.5	9.8	5.8	8.3	3.2	9.3	5.1
IR2863-38-1-2	6.8	2.6	9.5	5.2	6.8	3.4	8.4	5.1
IR3536-31-1	7.5	2.2	9.9	5.2	7.0	3.0	8.4	4.5
LSD (5%)	0.7	0.6	0.5	0.4	1.0	0.5	0.7	0.3

Table 3. Brown-rice protein and grain yield of selected varieties and lines at two fertilizer levels. IRRI, 1976 dry season.

Variety or line	0 N Protein (%)	0 N Yield (t/ha)	150 kg N/ha Protein (%)	150 kg N/ha Yield (t/ha)
IR8	7.3	3.5	8.8	6.0
IR26	7.6	3.1	8.3	5.9
IR480-5-9	8.5	3.7	10.5	5.8
IR2153-338-3	8.6	3.8	9.2	7.0
B2927-20-2-2-5	9.1	2.1	11.4	4.2
Boon Nahk 16-1-21	8.2	1.0	10.1	1.2
IR2006-P12-12-2-2	7.8	3.5	11.4	4.2
LSD (5%)	0.6	0.8	0.6	0.9

The performance of the parents during the study indicated that environmental factors greatly influenced the protein content. Low values of BRP percentage, P/S, and 100-kernel weight were dominant over the high values. The transgressive segregants observed in all characters further suggested the predominance of low values. The heritability estimates for P/S were relatively higher than those for BRP percentage (Table 5). Selection for BRP percentage may be effective as early as in the F_5 generation, and selection for P/S may be done in earlier generations. Both BRP and P/S were negatively correlated with grain yield and resistance to bacterial blight. The correlation coefficients were -0.68^{**} and -0.67^{**} with yield, and -0.42^{**} and -0.48^{**} with blight resistance. IR480-5-9-3 is susceptible to blight, IR1529-680-3 is moderately resistant.

BIOLOGICAL EVALUATION OF RICE PROTEIN

Chemistry Department

Effect of cooking on protein properties. Experiments show that the protein of raw milled rice has 100% digestibility in growing rats, and the protein of cooked milled rice has about 85% digestibility in preschool children. In contrast, wheat protein has almost the same digestibility value of 90% in both rats and children. A cooperative nitrogen-balance study on growing rats at the Agricultural Research Laboratory, Copenhagen, Denmark, used raw and cooked, freeze-dried milled rices prepared at IRRI. Cooking produced a consistent drop in true digestibility for all samples (Table 6).

Table 4. Mean effect of time of application of 120 kg N/ha fertilizer on brown-rice protein and grain yield of six plantings of IR26 and IR28. IRRI, 1975–76.

Time of application	IR26 Protein (%)	IR26 Yield (t/ha)	IR28 Protein (%)	IR28 Yield (t/ha)
Basal	7.7	5.6	8.2	5.1
10 days after transplanting	7.8	5.2	7.8	4.7
Tillering	8.1	5.4	8.0	5.2
5–7 days before panicle initiation	8.9	5.5	8.5	5.2
Basal + tillering	8.0	5.2	8.0	5.0
Basal + panicle initiation	8.5	5.4	8.4	4.9
Tillering + panicle initiation	8.4	5.5	8.2	4.8
Basal + tillering + panicle initiation	8.3	5.8	8.2	5.1
LSD (5%)	0.2	0.7	0.2	0.7

Although cooking reduced the digestibility of milled-rice protein, a corresponding increase in biological value was observed in the growing rats. Cooked rice had significantly higher net protein utilization than raw rice in two of the three samples. The results confirm that cooking has no adverse effect on the nutritional value of rice proteins. They also suggest that the proteins that become denatured or resistant to digestion are of the poorest nutritive value. This selective proteolysis of protein bodies was also evident in in vitro digested rice protein bodies discussed in the next section.

Raw and corresponding cooked and freeze-dried milled IR480-5-9 rice, and concentrated rice protein prepared by α-amylase treatment of cooked IR480-5-9 rice (Kyoto Prefectural University) were tested for protein solubility in 0.1 N NaOH (sodium hydroxide) and 0.5% SDS (sodium dodecyl sulfate)-0.6% β-ME (β-mercaptoethanol). Cooking had relatively less effect (7% drop) on protein solubility in NaOH, but it reduced solubility in SDS-β-ME drastically (60%), probably because NaOH is a better starch solvent than SDS-β-ME and the gelatin-

Table 5. Heritability estimates for percentage of brown-rice protein and protein per seed (P/S) in the cross IR480-5-9-3/IR1529-680-3. IRRI, 1973–76.

Seed generation	Pairs (no.)	Heritability: Protein content	Heritability: P/S
F_3–F_4	316	0.32**	0.44**
F_4–F_5	787	0.39**	0.50**
F_5–F_6	88	0.57**	0.81**

Table 6. Properties of protein and nitrogen balance in growing rats fed raw and cooked, freeze-dried milled samples of three rices. IRRI and Agricultural Research Laboratory, Copenhagen, 1976.

Property	IR29		IR32		IR480-5-9		LSD (5%)
	Raw	Cooked, freeze-dried	Raw	Cooked, freeze-dried	Raw	Cooked, freeze-dried	
Crude protein (%)	8.09	8.36	7.48	7.59	11.2	11.17	NS
Lysine (g/16 g N)	3.59	3.54	3.80	3.70	3.42	3.34	NS
Amino acid score[a] (%)	65.3	64.4	69.1	67.3	62.2	60.7	NS
N balance							
True digestibility (%)	100.7	91.5	98.1	86.6	100.4	87.8	0.7
Biological value (%)	66.3	76.4	70.0	81.5	66.8	76.6	1.3
Net protein utilization (%)	66.7	69.9	68.7	70.5	67.1	67.3	1.3
Utilizable protein (%)	5.40	5.84	5.14	5.35	7.53	7.52	0.12

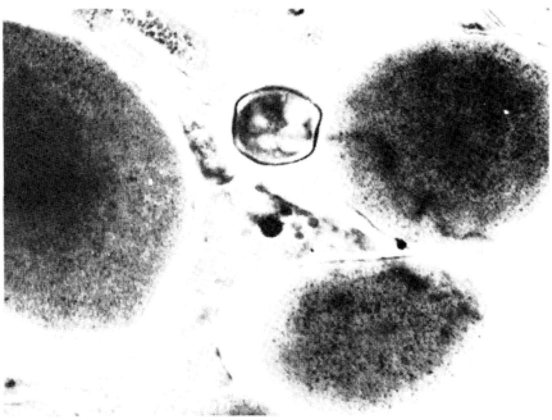
[a]Based on 5.5 g lysine/16 g N as 100%.

ized starch adhered better to the protein than did raw starch. Concentrated rice protein showed 86% solubility in SDS-β-ME (measured against solubility of raw-rice protein), supporting the results obtained for cooked and freeze-dried rice. SDS-β-ME is a more sensitive indicator of glutelin denaturation on cooking than 0.1 N NaOH, as was shown last year (1975 Annual Report) by prolonged treatment of rice flour with 70% ethanol.

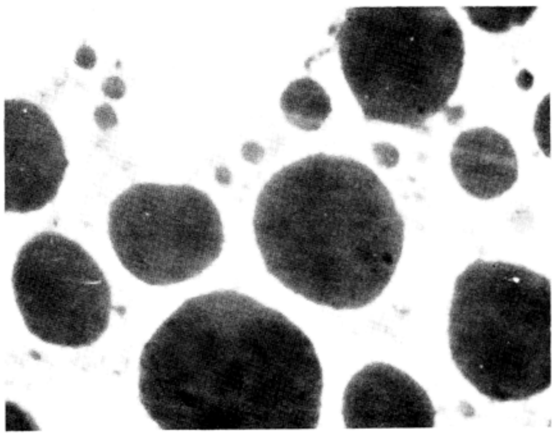
Fecal protein particles and protein bodies. Protein particles isolated from the feces of Filipino preschool children on a rice-casein diet showed rice protein bodies on electron microscopy (Fig. 4). Some showed cottony or fuzzy edges indicative of proteolysis. The solubility of this crude preparation was poor (4%) in SDS-β-ME, but it dissolved readily in 98–100% formic acid.

Electron microscopic examination of concentrated rice protein revealed intact protein bodies even after boiling, α-amylase treatment, and drying (Fig. 5). Amino acid analysis of the 40% protein preparation was verified to be similar to that of raw milled rice.

Endosperm protein bodies were prepared from whole milled rice for characterization. Japanese workers previously found that 14% of the protein bodies extracted from the outer layer of milled rice by overmilling were poorly digested by proteases in vitro. The finding suggests that protein of raw rice is partly indigestible before cooking. Electron microscopic examination in 1975 at Durham, England, and in 1976 at the US Grain Marketing Research Center demonstrated, however, that



4. Transmission electron micrograph of crude protein particles isolated from the feces of a Filipino preschool child on rice-milk diet. Department of Botany, University of Durham, England, 1976.



5. Transmission electron micrograph of concentrated rice protein derived by treating boiled milled rice flour with crystalline α-amylase. Protein bodies ranged from 1 to 4 μm. Department of Botany, University of Durham, England, 1976.

the outer or subaleurone layer of rice endosperm was not typical of the whole endosperm because the subaleurone layer contains crystalline-type protein bodies besides the normal protein bodies. Because of the more orderly arrangement of their contents, crystalline protein bodies are probably less digestible than normal bodies.

The wet-milling technique of disintegration for physical separation of starch granules and protein bodies was tried, but recovery of protein bodies by differential centrifugation was poor, probably reflecting fragility of the protein bodies.

Amylolysis of raw starch granules was also tested as a means of concentrating rice protein. *Rhizopus* glucoamylase gave a more complete digestion of starch than did fungal *Aspergillus* α-amylase. No blue color was observed on iodine staining of the residue of glucoamylase treatment for 24 hours. Protein content (N × 5.95) of the milled-rice residue was 74% for the glucoamylase treatment and 56% for the α-amylase treatment. Protein recovery, however, was better (63%) for the α-amylase treatment than for the glucoamylase treatment (45%), indicating a higher concentration of acid protease contamination in the glucoamylase preparation.

Amino acid analysis of these native protein preparations showed variable lysine content. Milled IR480-5-9 rice had 3.4% lysine, wet-milled protein bodies had 5.0 g lysine/16 g N which, on purification by sucrose density gradient centrifugation, dropped to 3.4%. Raw milled rice treated with crystalline pancreatic α-amylase had 3.3% lysine, that with *Rhizopus* glucoamylase 2.2%, and that with *Aspergillus* amylase 2.9%. The results suggest selective proteolysis of the protein bodies, particularly by the crude enzyme preparations from *Rhizopus* and *Aspergillus*. Similar selective digestion of the better quality proteins occurs for ingested rice in the mammalian digestive tract.

PHYSICOCHEMICAL PROPERTIES OF RICE PROTEIN

Chemistry Department

Globulin. Among the salt-soluble proteins, globulin constitutes about 10% of milled-rice protein, and albumin about 5%. Because little work has been done on these proteins of milled rice, the major globulins were studied in the rice endosperm of well-milled (12% bran-polish removal) IR480-5-9 rice with 11% protein. Freshly harvested grain was air dried at room temperature to minimize protein denaturation during hot-air drying. Such precautions had little effect on globulin and albumin properties.

Salt-soluble proteins were extracted from defatted milled-rice flour with 5% NaCl, and the globulin was precipitated either by dialysis against water or by adding $(NH_4)_2SO_4$ (ammonium sulfate) to 30% saturation. Although higher recoveries were obtained by dialysis than by $(NH_4)_2SO_4$ precipitation (4% of total protein vs. 2.4%), the globulin prepared by the latter method was relatively free of nucleic acid.

Both crude globulin preparations showed essentially the same polyacrylamide disc gel electrophoretic patterns—two major slow bands and three minor faster migrating bands. The slowest migrating minor band had the same migration rate as the major band of crude globulin of IR480-5-9 rice bran. Milled IR32 rice (to 10% bran-polish removal) also had the three slowest bands as the major globulins. The results indicate that the two slowest migrating bands are the major globulins of rice endosperm and the third slowest band is a bran globulin. The slower of the two bands was the main globulin. On the other hand, albumins had faster migrating bands than globulins on polyacrylamide disc gel electrophoresis (PAGE).

Purification and separation of the two major globulins were attempted. Gradient (0–1 M NaCl) elution chromatography of crude globulin on a diethyl aminoethyl (DEAE) cellulose column in 0.03 M Tris-HCl pH 8.7 resulted in two discrete peaks. The first peak eluted at 0.22 M NaCl and was shown by disc electrophoresis to be a mixture of the two major globulins. The second peak eluted at 0.34 M NaCl and did not give any distinct pattern on disc electrophoresis, but had high UV absorbance. Gel filtration in Sephadex G-100 showed a major peak with MW 20000 and a minor peak with MW 98000. Both fractions, however, had identical electrophoretic patterns, showing a mixture of the two major globulin proteins.

Isoelectric precipitation of crude globulin at pH 4.5 also removed the three minor faster migrating protein bands in the electrophoregram. Fractional precipitation of the globulin could not be achieved below pH 4.5. Isolating the slowest band from unstained disc gels and rerunning through disc electrophoresis showed a redissociation into the two globulin bands. The results indicate that an equilibrium mixture exists between the two globulin bands. The purified globulin gave only one subunit with MW 18000 on SDS-PAGE, which is similar to the gel filtration data of MW 20000. The major globulin of the developing rice grain also had a MW of 20000 (1975 Annual Report).

Amino acid analysis of the purified milled-rice globulin showed lower levels of lysine, histidine, threonine, aspartic acid, and isoleucine and higher levels of arginine and methionine than those in total milled-rice protein (Table 7). In contrast bran globulin is richer in lysine (5.0%), but poorer in cystine (0.8%) and methionine (0.9%) than milled-rice globulin. The purified globulin had 8% carbohydrate and is probably a glycoprotein.

Sedimentation coefficient determined on the purified globulin in 1% acetic acid showed only one protein peak, corresponding to an α-globulin. Disc gel electrophoresis of the purified globulin at acid pH also revealed one protein band. The results suggest that the aggregation of rice globulin is pH dependent and occurs only at pH 6–9.

Prolamin. Prolamin is the term used to signify alcohol-soluble storage proteins that are high in proline. Prolamin has the poorest amino acid balance among the four Osborne solubility fractions of rice protein. Rice is unique among the cereals in having only about 3% prolamin. Earlier studies (1969 and 1975 annual reports) showed carbohydrate and phenolic contamination in IRRI prolamin preparations. As part of the study of proteins of milled rice, the properties of milled-rice prolamin and the changes in its properties during grain development were studied.

Prolamin of milled rice. Phenolic contamination of the preparation from IR480-5-9 was reduced by preliminary extraction of milled-rice flour with 95% ethanol. Further removal of phenolic contamination from the subsequent 70% ethanol extract of rice flour was achieved by treatment with polyvinyl pyrrolidone, which binds phenolics from solution. These prolamin preparations were still positive for carbohydrates. Precipitation of prolamin from ethanolic extract by the addition of three volumes of acetone verified earlier finding (1969 Annual Report): a preparation of higher purity (16.8% N) and the least carbohydrate contamination. Analytical and SDS disc gel electrophoresis gave only one major protein band for the prolamin preparations. The MW of the only subunit of prolamin was 17000, which is similar to previous results of 20000 (1975 Annual Report). Linear gradient elution chromatography in a DEAE cellulose column of prolamin (0.1 M TRIS-HCl buffer pH 8.9 from 0 to 1 M NaCl) resulted in only one protein peak, which eluted at 0.42 M NaCl and had the same electrophoretic properties as the starting protein.

Amino acid analysis of the purified prolamins showed lower lysine, threonine, histidine, arginine, cystine, and methionine for all preparations than for milled-rice protein (Table 7). Their glutamic acid, tyrosine and leucine contents were higher than those of whole milled-rice protein, and of glutelin. This finding agreed with earlier results (1969 Annual Report).

Prolamin changes during grain development. Changes in the properties of crude prolamin were also studied in dehulled developing grains of IR26 and IR480-5-9 rices. Analytical PAGE

Table 7. Amino acid content of globulin, prolamin, and glutelin of milled IR480-5-9 rice compared with that of whole protein. IRRI, 1976.

Amino acid	Amino acid content[a]				
	Total protein	Globulin (purified)	Prolamin (acetone ppt)	Glutelin (crude)	LSD (5%)
Arginine	8.7	15.2	6.1	8.0	1.2
Aspartic acid	10.4	4.9	8.2	10.1	1.3
Cystine	1.6	2.2	0.2	1.7	0.9
Glutamic acid	21.2	27.8	29.0	16.1	3.7
Histidine	2.5	0.4	1.1	2.1	0.3
Isoleucine	4.3	1.8	4.9	4.0	0.4
Leucine	9.1	6.6	13.7	7.9	1.2
Lysine	3.6	1.1	0.1	3.2	0.4
Methionine	2.4	4.0	0.2	2.1	1.5
Proline	4.7	5.9	5.6	4.0	1.0
Threonine	3.9	2.2	2.3	3.3	0.4
Tyrosine	5.0	6.7	10.2	4.9	0.7

[a]In g/16.8 g N for all except globulin, which is in g/16 g N.

Table 8. Changes in the content of selected amino acids of crude prolamin of brown rice in developing grain of IR26 and IR480-5-9.[a] IRRI, 1976.

Amino acid	Amino acid content (g/16.8 g N)						LSD (5%)
	IR26			IR480-5-9			
	4 DAF	10 DAF	21 DAF	4 DAF	10 DAF	21 DAF	
Alanine	13.4	13.7	11.0	13.4	12.2	6.4	0.9
Arginine	2.9	2.1	4.0	1.7	2.2	5.0	0.3
Aspartic acid	11.0	8.4	7.1	11.2	9.7	7.6	1.0
Histidine	0.1	0.1	0.5	trace	trace	1.0	0.1
Leucine	6.2	6.4	8.5	4.7	6.0	10.8	1.2
Lysine	2.8	1.9	1.3	1.6	1.3	0.3	0.1
Methionine	2.6	1.7	0.7	1.6	1.4	0.4	0.4
Valine	8.5	7.4	6.3	7.2	6.0	5.4	0.5

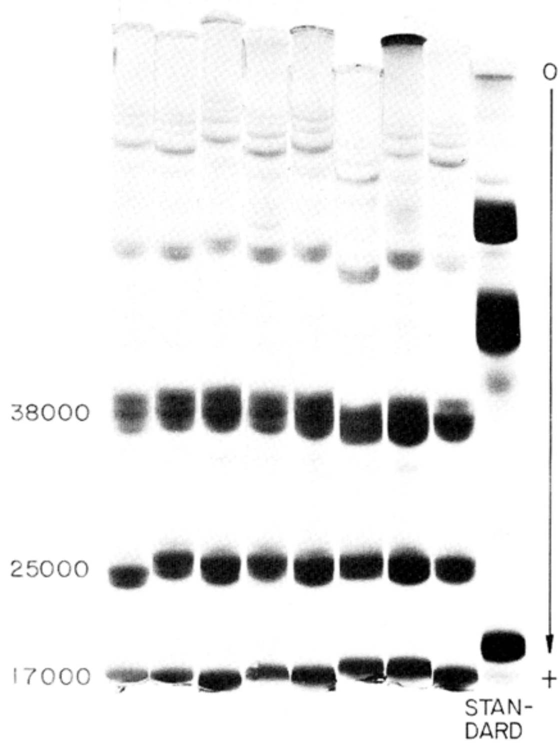
[a]DAF = days after flowering.

of both rices showed only one protein band in the sample about 4 DAF (days after flowering). Subsequent samples (7 DAF onward) showed a faint, slightly slower moving protein band in addition to the major prolamin band. SDS-PAGE of prolamin extracts showed only one subunit band MW 17000 in the earlier samples. A second faint subunit band MW 20000–24000 was observed in the older grain samples (10 DAF in IR26 and 14 DAF in IR480-5-9).

Amino acid analysis of prolamins from developing grains of both rices 4, 7, 10, 14, and 21 DAF showed progressive decrease in lysine and aspartic acid. Appearance of the slower electrophoretic band coincided with a drastic drop in lysine, aspartic acid, alanine, valine, and methionine, and increases in histidine, arginine, and leucine in both rices (Table 8). Varietal differences were noted in the aminogram of the two prolamins.

Glutelin. *Glutelin of milled rice.* Study of varietal differences in the properties of crude glutelin in various types of rice and the differences in properties of solubility subfractions of crude glutelin was continued. Crude glutelin was prepared by sequential extraction of albumin-globulin by 5% NaCl, and of prolamin by 70% ethanol-0.6% β-ME. The rice samples included three indica, two japonica, two indica x japonica, two javanica, one *O. nivara* (Acc. No. 101508), one *O. glaberrima* (Acc. No. 101890), and two IR4432 sister lines differing in protein content. Crude glutelins accounted for 77–94% of milled-rice protein in the 13 samples. Milled-rice lysine ranged from 2.8 to 4.4 g/16.8 g N (mean of 3.8%), whereas crude glutelin lysine ranged from 3.2 to 4.4 g/16.8 g N (mean of 3.9%).

Glutelin was extracted with 0.5% SDS-0.6% β-ME in 0.1 M phosphate buffer pH 7.0 and alkylated with acrylonitrile as previously described. Crude glutelin extraction by SDS-β-ME was at least 93%. SDS-PAGE showed the same three subunits of glutelin with MW 38000, 25000, and 16000. All the glutelin preparations essentially showed a 1 : 1 : 1 densitometric tracings of the subunits in Amido-Black stained SDS-PAGE electrophoregrams, in contrast with 1975 results on IR480-5-9 and a commercial rice flour sample (Fig. 6). The results indicate the low probability of finding genetic variation in the subunit ratio of glutelin, the major protein



6. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis of reduced and alkylated crude glutelins from milled rices. IRRI, 1976.

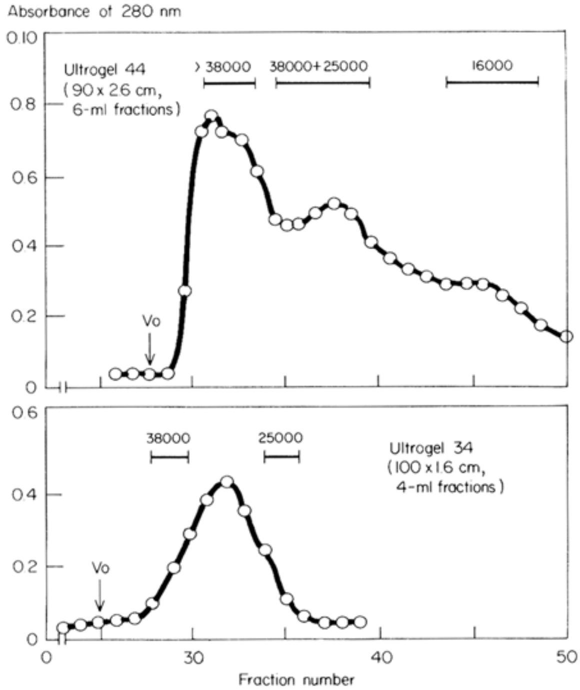
Table 9. Amino acid content of subfractions of crude glutelin of IR28 milled rice. IRRI, 1976.

Amino acid	Amino acid content (g/16.8 g N)				
	2-PrOH-β-ME "Prolamin"	NaCl pH 10-β-ME "Globulin"	NaCl pH 10-β-ME SDS	Total glutelin	LSD (5%)
Glutamic acid	33.1	14.6	20.8	20.8	2.7
Lysine	0.1	3.6	4.3	4.4	0.4
Tyrosine	6.7	4.2	5.6	4.0	0.7

fraction of rice. Only the *O. nivara* glutelin showed a different ratio (1 : 1 : 2). *O. nivara* has been the source of grassy-stunt resistance in the GEU program.

Earlier results showed that crude rice glutelin can be fractionated into subfractions differing in amino acid composition and starch gel electrophoretic pattern (1969 Annual Report). Alcohol (2-propanol)-β-ME extracted a prolamin-like subfraction with MW 17000 subunit on SDS-PAGE. 2-Propanol extract (prolamin) gave an identical electrophoregram. Their aminograms showed both a lysine content below 0.4% and high tyrosine and glutamic acid values (Table 9). Borate buffer pH 10 with β-ME extracted a fraction with 3.8% lysine (globulin-like) and also with essentially the MW 17000 subunit on SDS-PAGE, which is identical to the MW obtained for the major milled-rice globulin with 1.1% lysine content. The 3.8% lysine fraction contained more than 90% carbohydrate. The major glutelin subfraction extracted with SDS-β-ME in borate buffer had 4.2% lysine and a SDS-PAGE pattern identical with that of crude glutelin, having all three major subunits with MW 16000, 25000, and 38000.

The three major subunits of *S*-cyanoethyl glutelin (acrylonitrile-alkylated glutelin) were separated in IR480-5-9, IR28, and Kolamba 540 by gel filtration in polyacrylamide-agarose gel (Ultrogel) columns using 0.05 M Tris-HCl pH 8.6, 0.5% SDS, and 0.2% Na azide as solvent. An Ultrogel 44 column (2.6 × 90 cm) separated the MW 16000 subunit completely from the higher MW subunits, but the separation of the latter was incomplete (Fig. 7). The two heavier subunits were separated by rechromatography through an Ultrogel 34 column (1.6 × 100 cm). Purity was assessed by SDS-PAGE. Molecular

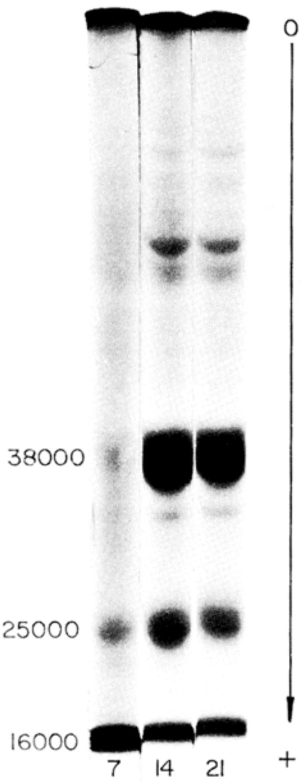


7. Molecular weight fractionation of the three major subunits of S-cyanoethyl glutelin by gel filtration in two polyacrylamide-agarose gel columns in 0.05 M tris-HCL pH 8.6 buffer—0.5% sodium dodecyl sulfate—0.2% sodium azide. Vo = void volume. IRRI, 1976.

weights of the purified subunits were 17000–18000, 22000–25000, and 35000–38000. The use of smaller protein loads and Commassie Brilliant Blue G-250 in place of Amido Black 10B further resolved the MW 38000 band into three fine bands, and the MW 25000 band into two bands.

Glutelin in grain parts. The differences in SDS-PAGE pattern of crude glutelin from previously prepared IR8 pericarp, aleurone, embryo, and milled rice (1974 Annual Report) were investigated. Pericarp glutelin showed mainly the MW 16000 subunit of milled-rice glutelin; the MW 38000 and 25000 subunits were absent. The embryo glutelin showed the most complex subunit pattern, with the MW 16000 subunit as the major protein band. Aleurone glutelin was similar in electrophoretic pattern to milled-rice glutelin.

Glutelin changes during grain development. A study was made of the changes in electrophoretic properties and amino acid composition of crude



8. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis of reduced and alkylated crude glutelin of dehulled developing IR480-5-9 grain, 7, 14, and 21 days after flowering. IRRI, 1976.

glutelin of brown rice during grain development of IR26 and the high-protein rice IR480-5-9. Glutelin was extracted with 0.5% SDS-0.6% β-mercaptoethanol from defatted brown-rice flour after successive extractions of albumin-globulin with 5% NaCl, and of prolamin with 70% ethanol-0.6% β-mercaptoethanol. The

Table 10. Changes in content of selected amino acids of crude glutelin of brown rice from developing grain of IR26 and IR480-5-9.[a] IRRI, 1976.

Amino acid	Amino acid content (g/16.8 g N)						LSD (5%)
	IR26			IR480-5-9			
	7 DAF	14 DAF	21 DAF	7 DAF	14 DAF	21 DAF	
Glycine	5.3	4.4	4.7	5.3	4.4	4.3	0.3
Lysine	5.2	4.0	4.0	6.6	4.0	3.8	0.4
Threonine	4.9	4.2	4.5	5.1	4.3	4.1	0.4
Tyrosine	3.0	4.6	4.2	3.7	4.8	4.9	0.7

[a]DAF = days after flowering.

glutelin of brown rice during grain development increased from 5.1% to 8% for IR26 and from 9.8% to 11% for IR480-5-9.

Glutelin showed mainly the MW 16000 subunit band on SDS-PAGE for both rices at 4–7 DAF (Fig. 8). The two other subunits of milled-rice glutelin with MW 38000 and 25000 were faint. Older samples at 14 and 21 DAF showed all three subunits of glutelin. Amino acid analysis of the crude glutelins also showed more lysine in young samples (7 DAF) than in the older samples (Table 10). Noted between 7 and 14 DAF were slight decreases in threonine and glycine, and an increase in tyrosine.

Earlier studies on milled-rice glutelin and other protein fractions (1975 Annual Report) revealed that the MW 38000 subunit was unique to glutelin and was not a major subunit in albumin-globulin and prolamin. The present data support the previous findings. The change in amino acid pattern and the appearance of the MW 38000 subunit of glutelin coincided with the initial accumulation of protein bodies in the rice endosperm about 7 DAF (1975 Annual Report).

Genetic evaluation and utilization (GEU) program

Drought tolerance

Plant Breeding, Agronomy, and Plant Physiology Departments

HYBRIDIZATION AND SELECTION
Plant Breeding Department

During the year 178 double crosses, 352 topcrosses, and 200 single crosses were made for the drought resistance program. The F_2 populations of 23 topcrosses were grown under simulated upland conditions at IRRI, and 241 plants were selected during the dry season. Expanded breeding nurseries during the wet season permitted the growing of F_2 bulk populations of 340 topcrosses.

It was observed that topcrosses involving either BPI-76 (nonsensitive), Kn-lb-214-1-4-3, or Nam Sagui 19 and a drought-resistant parent, such as lines from IR1746 or IR1754, Moroberekan, and 63–83, produced progenies with good panicle exsertion, sturdy culms, moderately high tillering, late senescence, long panicles, and heavy grains. On the other hand, crosses involving BPI-76 and Sigadis produced many progenies highly susceptible to sheath blight or bacterial leaf blight, or both.

Most plants selected in the wet season for upland culture were early maturing and of intermediate stature. The cutoff date for making plant selections was 130 days after seeding.

VARIETAL SCREENING
Agronomy and Plant Breeding Departments

Field screening (*Agronomy*). During the dry season, 1,016 rices were field screened for drought resistance. Plots were direct seeded in furrows, and fertilizer and sprinkler irrigation were applied to ensure good establishment of stand. The plots were last irrigated 20 days after rice emergence. The plants were first scored at 1-bar soil moisture tension (SMT), 47 days after emergence, when only the early maturing rices were at the panicle initiation stage. Several rices looked promising at the 1-bar stress. Rices from

Table 1. Promising varieties (seeded 30 January 1976) screened in the field for drought resistance. IRRI, 1976.

Designation	Origin	IRRI acc. no.	First scoring		Second scoring		Third scoring			
			26 March (1 bar)		6 April (4 bars)		5 May (10 bars)			
			Growth stage[a]	Drought resistance[b]	Growth stage[a]	Drought resistance[b]	Growth stage[a]	Drought resistance[b]	Growth stage[a]	Recovery[c]
ARC 7303	India	12359	2	2	2	3	5	5	7	2
ARC 10372	India	20884	2	2	2	3	5	4	7	2
ARC 10952	India	12682	2	2	2	3	5	5	7	3
ARC 10959	India	12686	2	2	2	3	6	5	8	3
DNJ 60	Bangladesh	8375	2	1	3	3	6	4	8	3
DNJ 146	Bangladesh	8425	2	1	2	3	4	5	6	2
DNJ 177	Bangladesh	8408	2	1	2	3	5	5	7	3
Mimidim Alang	Bangladesh	25899	3	2	4	2	8	4	9	2
G11b-Si-207	Indonesia		2	2	2	3	2	3	2	3
B981d-Si-19-2	Indonesia		2	2	2	4	2	4	2	2
BKN 6986-147-2	Thailand		2	1	2	3	2	4	2	2
Kinandang Patong	Philippines	23364	2	2	2	3	2	5	2	2
Pinursigi	Philippines	26889	2	2	2	3	2	4	2	2
Lua Ngu	Vietnam	16852	2	2	2	3	2	4	2	2
20-A	Liberia	14838	2	1	2	3	2	4	2	3
30-A	Liberia	14848	2	1	2	3	2	4	2	3
Speed 70			2	2	2	4	6	5	8	4
IR8	IRRI		2	2	2	3	2	7	2	3
IR36	IRRI		2	2	2	4	2	7	3	4
IR2035-117-3	IRRI		2	2	2	3	2	7	2	2
IR442-2-59-2-3-3	IRRI		2	2	2	2	2	2	2	2
IR1754-F5B-19	IRRI		2	2	3	3	5	4	7	3
IR442-2-58 (tolerant check)	IRRI		2	2	2	4	2	5	2	2
IR20 (susceptible check)	IRRI		2	4	2	8	2	9	2	5

[a]1976 Standard Evaluation System for Rice (SES) scale 0–9; 2 = tillering; 3 = stem elongation; 4 = booting; 5 = heading; 6 = flowering; 7 = filling (milk stage); 8 = dough stage; 9 = ripe/mature. [b]SES scale 1–9: 1 = none to slight effects of stress; 3 = slight leaf tip drying extended up to one-quarter length in most leaves; 5 = one-quarter to one-half of total number of leaves fully dried; 7 = two-thirds of total number of leaves to all leaves fully dried; 9 = all plants apparently dead. [c]SES scale 1–9: 1 = 90%; 3 = 70 to 80%; 5 = 40 to 50%; 7 = 20 to 30%; 9 = no plants fully recovered.

Table 2. Selected varieties (from a total of 1016) that scored 3 or better for resistance to and recovery from drought stress. IRRI Agronomy Department, 1976 dry season.

Variety	IRRI acc. no.	Origin	First scoring (2 bars)		Second scoring (4 bars)		Third scoring (10 bars)		
			Growth stage[a]	Drought resistance[b]	Growth stage[a]	Drought resistance[b]	Growth stage[a]	Drought resistance[b]	Recovery[c]
Bakka Bandjar	13508	Indonesia	2	1	2	3	2	3	3
Salumpikit	5423	Philippines	2	1	3	2	5	3	2
G11B-51-142			2	2	2	3	2	3	3
IR442-2-59-2-3-3			2	2	2	2	2	2	2
Oryza glaberrima	G1869		2	1	2	2	2	3	2
Oryza glaberrima	G2595		2	1	2	3	5	3	3

[a]1976 Standard Evaluation System for Rice (SES) scale 0–9: 2 = tillering; 3 = stem elongation; 5 = heading; 9 = ripe/mature. [b]SES scale 1–9: 1 = none to slight effects of stress; 3 = slight leaf tip drying extended up to one-quarter length in most leaves; 9 = all plants apparently dead. [c]SES scale 1–9: 1 = 90%; 3 = 70 to 80%; 9 = no plants fully recovered.

India and Bangladesh obtained most of the better scores.

At a high drought stress of 10 bars, only a few lines looked promising (Table 1). Table 2 lists six rices that had scores of 3 or better for resistance and recovery.

Reproducibility of field screening. When the 1975 and 1976 field screening data for drought resistance were tabulated, the scores were highly consistent (Table 3). The consistency confirms that dry-season field screening and scoring methods to determine varietal differences in drought resistance, using tensiometers and gypsum blocks to monitor the level of drought, should give results reproducible by the IRRI GEU program.

Mass screening (*Plant Breeding*). During the dry season 5,758 varieties and lines were mass screened in nonreplicated rows in simulated upland conditions. The 15 groups tested are listed in Table 4. The traditional upland varieties had the largest, and the *O. sativa* collection from West Africa and many upland breeding lines the second largest proportion of entries that are

Table 3. Comparative drought resistance ratings of promising varieties screened for 2 successive years. IRRI, 1975 and 1976 dry seasons.

Variety	Origin	First scoring (1–2 bars)				Second scoring (3–4 bars)			
		1975		1976		1975		1976	
		Growth stage[a]	Drought resistance[b]	Growth stage[a]	Drought resistance[b]	Growth stage[a]	Drought resistance[b]	Growth stage[a]	Drought resistance[b]
ARC 7001	India	3	1	2	2	4	2	2	3
ARC 7046	India	2	2	2	2	4	3	2	3
ARC 10372	India	2	2	2	2	5	3	2	3
Dular	India	3	3	3	2	7	3	4	3
Surjamukhi	India	2	2	3	1	4	3	4	2
CTG 1516	Bangladesh	2	2	3	2	2	4	4	4
DJ 29	Bangladesh	2	3	2	2	3	3	2	2
DM 59	Bangladesh	2	2	2	2	2	4	2	3
DV 110	Bangladesh	2	2	3	2	4	3	4	3
DZ 41	Bangladesh	3	2	3	2	6	4	5	3
Bakka Bandjar	Indonesia	2	2	2	1	2	4	2	3
Olek Bandung	Indonesia	2	3	2	2	2	3	2	3
Lua Ngu	Vietnam	2	2	2	2	2	4	2	3
Binaritos	Philippines	2	2	2	2	3	4	2	4
Salumpikit	Philippines	2	1	2	1	4	2	3	2
IR442-2-58 (check)	IRRI	2	1	2	2	2	3	2	4

[a]1976 Standard Evaluation System for Rice (SES) scale 0–9: 2 = tillering; 3 = stem elongation; 4 = booting; 5 = heading; 6 = flowering; 7 = filling (milk stage); 9 = ripe/mature. [b]SES scale 1–9: 1 = none to slight effects of stress; 3 = slight leaf tip drying to tip drying extended up to one-quarter length in most leaves; 5 = one-quarter to one-half of total number of leaves fully dried; 7 = two-thirds of total number of leaves to all leaves fully dried; 9 = all plants apparently dead.

Table 4. Summary of field scores on drought resistance of 5,758 varieties and lines. IRRI Plant Breeding Department, 1976, dry season.

Groups	Entries tested (no.)	Vegetative score (%)									Reproductive score (%)								
		1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
Lowland breeding lines of IRRI	1300			0.5	5.8	17.2	52.6	19.6	3.8	0.5			0.1	0.1	1.6	1.6	37.0	4.7	54.9
100-day varieties	969	0.1	21.1	9.9	20.9	28.6	16.7	1.8	0.6	0.2	0.6	1.6	6.8	3.0	9.7	6.3	25.6	11.8	34.6
Upland breeding lines of IRRI	639		0.3	3.4	8.3	24.4	51.0	11.4	1.1				0.6		2.5	0.6	42.1	3.3	50.9
Traditional rainfed-lowland varieties	525	0.4	11.2	14.1	27.8	22.1	21.3	2.7	0.4			0.2	0.7	0.7	5.3	1.3	26.3	4.6	60.7
ARC varieties (India)	361		11.4	13.6	28.2	24.6	19.4	2.8				0.2	2.4	1.7	8.9	4.7	19.7	1.7	60.7
O. glaberrima varieties	350	1.4	73.7	12.0	6.3	4.3	2.0	0.3					34.6	13.1	8.0	4.3	15.4		24.6
Traditional upland varieties	329		9.4	33.4	20.4	21.3	15.5				0.3		7.3	6.9	12.2	9.4	43.3	2.7	19.8
African *sativa* varieties	303		0.2	10.2	17.8	35.6	30.0	4.9	2.3	0.2	0.2		4.6	0.9	6.3	4.6	31.6	2.0	51.1
KLG and BKN lines (Thailand)	230			3.9	7.4	28.7	53.0	6.5	0.4				0.4	0.4	1.3	0.4	13.0	3.5	80.9
Bulu varieties of Indonesia	211		2.8	11.4	16.6	25.6	42.7	0.9					1.4	0.5	4.7	1.9	16.1	1.9	73.5
Cool-tolerant varieties	151				29.8	68.9	1.3								4.6	0.7	7.3	7.9	79.5
Saline-resistant varieties	127			3.9	32.3	46.5	17.3									1.6	33.8	11.8	52.8
Upland breeding lines from other countries	94		2.1		3.2	46.8	46.8	1.1					2.1		1.1		45.7	9.6	41.5
IURON and IURYN entries	90			14.4	47.8	27.8	10.0					1.1			2.2	4.4	52.2	1.1	38.9
Floating varieties	36			11.1	8.3	27.8	50.0	2.8						2.8	5.6	11.1	47.2	8.3	25.0

resistant to drought at both the vegetative stage and the reproductive stage. The results of the mass screening generally agreed with those obtained in the past, except the results for the *O. glaberrima* varieties recently collected from Liberia.

Recovery from drought was also scored. Among the 15 groups tested, entries from the IRRI lowland breeding nursery and the IRRI upland breeding nursery showed a high proportion of lines that quickly recovered. The traditional rainfed lowland varieties showed quick to moderately quick recovery, and most traditional upland varieties and the *O. sativa* collection from Africa showed moderately quick recovery. The early maturing (100-day) varieties showed a high proportion of entries that slowly recovered or did not recover.

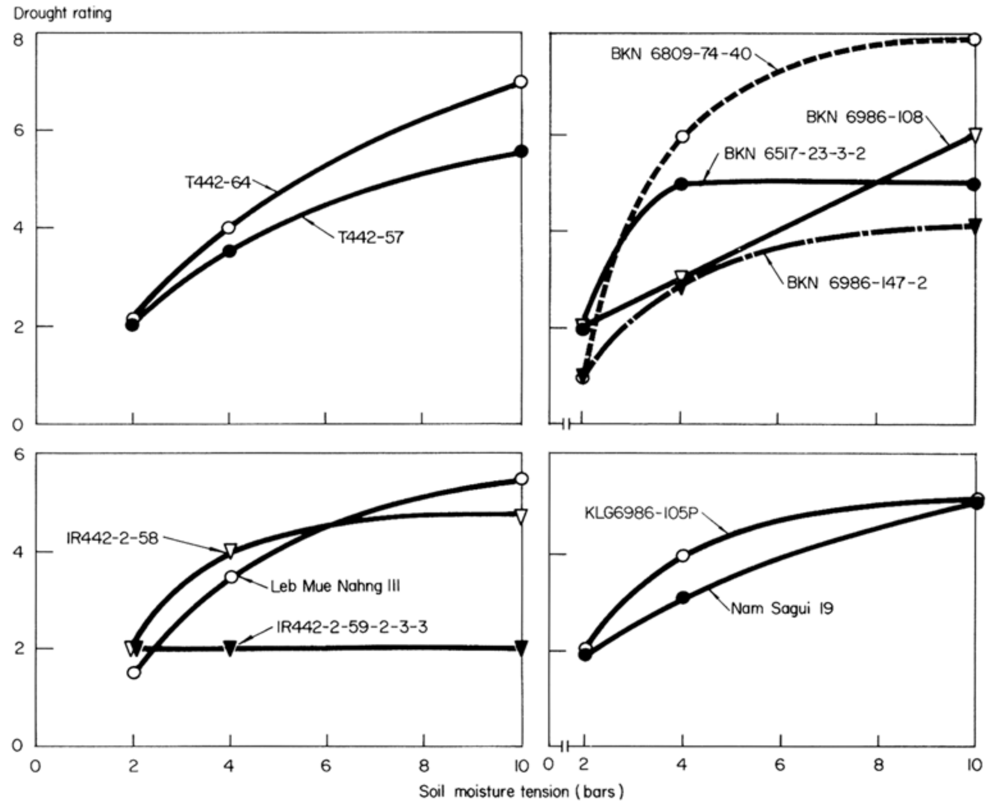
Promising lines for deep-water rice areas (*Agronomy*). Drought resistance in rices for deep-water areas will help ensure good stand establishment and reduce the risk of floodwater destroying young seedlings.

Among the 1,016 rices screened, several showed drought resistance. Leb Mue Nahng 111 had a score of 2 at 2 bars, and a score of 5 to 6 at 10 bars SMT, indicating good drought resistance (Fig. 1a). The line IR442-2-59-2-3-3, with a stable score of 2 at 2, 4, and 10 bars SMT performed better than IR442-2-58 and T442-57. The stability of IR442-2-59-2-3-3 makes it useful for the incorporation of drought resistance into deep-water and other rainfed rices. Nam Sagui, a variety grown in drought-prone areas of Thailand, appeared promising (Fig. 1b). Two BKN lines (BKN 6986-108 and BKN 6989-147-2) that appeared promising in greenhouse screening were also promising in the field screening.

Phytotron seedling test (*Agronomy*). Tests in the IRRI phytotron, which subjected 10- to 12-day-old seedlings to periods of severe soil and atmospheric drought, continued.

A total of 206 rices selected from the germ plasm bank to represent different geographical and hydrological origins were screened. Fifty-one rices that had better survival than the check variety Sigadis were retested at 12- and 15-day exposure periods (Table 5).

The more extensive 1976 tests confirmed 1975 findings (1975 Annual Report) that seedlings of



1. Effects of levels of soil moisture tension on the reactions to drought stress (1 to 9 scale: 1 = no stress symptoms; 9 = completely dead) during seedling and vegetative stages of field screened rices. IRRI, 1976 dry season.

many traditional upland varieties cannot tolerate sustained moisture deficits. The most tolerant rices were the traditional deep-water varieties from Bangladesh. The deep-water cultural system is characterized by dry seeding and dependence on erratic monsoon rains for crop establishment before flooding occurs. The system partially justifies selection for seedling drought resistance in deep-water areas.

Because phytotron space limitations prohibited large-scale screening, a greenhouse procedure was tried with the check variety as an indicator of exposure period. Figure 2 shows the agreement between the results from testing selected varieties in the phytotron and those from testing in the greenhouse. The linear correlation coefficient ($r = 0.59^{**}$) is highly significant; a paired *t*-test applied to the two data sets showed nonsignificance. The coefficient of variation between the methods varied by 2.6%. The greenhouse screening procedure, with careful attention to design and to use of a check variety, should be a useful empirical tool.

Greenhouse screening (*Agronomy*). A special greenhouse for screening rices for drought tolerance was inaugurated in early 1976. It has 12 concrete tanks, each 6.8 × 3.5 × 1.35 m. Each tank contains 1-m-deep upland soil placed on a 0.35-m-deep sand and gravel drainage bed. Irrigation may be subsurface—by a perforated-pipe system laid in the gravel—or may take the form of simulated rainfall on the soil surface. Soil moisture is monitored by tensiometers and electrical resistance blocks.

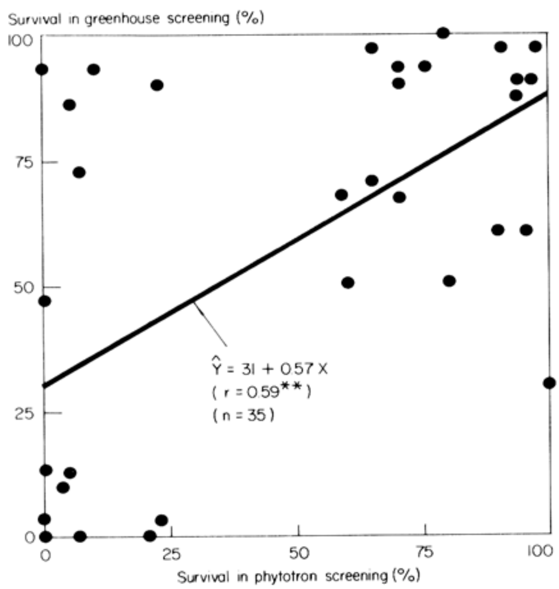
Attention has also been given to greenhouse atmospheric conditions. An intake and exhaust fan system changes the greenhouse air every 6

Table 5. Selections from 206 varieties of varying geographical and hydrological origins tested for seedling drought tolerance at four levels of growth-chamber exposure (7, 10, 12, and 15 days). IRRI phytotron, 1976.

Variety or line	Origin[a]	Survival (%) after exposure for[b]			
		7 days	10 days	12 days	15 days
Rikuto Norin 21	Japan (U)	0	0	—	—
Kinandang Patong	Philippines (U)	3	3	—	—
30-E	Liberia (U)	5	0	—	—
63–83	Ivory Coast (U)	65	5	—	—
Monura	Bangladesh (DW)	85	37	—	—
Rangi Khama	Bangladesh (DW)	95	90	5	0
BKN 6986-44	Thailand (DW)	95	95	5	0
KLG 6986-133-4-P	Thailand (DW)	100	90	10	0
KLG 6987-2-1-P	Thailand (DW)	93	75	10	0
Gonak Kay	Bangladesh (DW)	100	100	10	0
KLG 6987-59-P	Thailand (DW)	95	60	15	0
KLG 6987-108-P	Thailand (DW)	95	91	20	0
Goda	Bangladesh (DW)	100	100	20	0
Maijam	Bangladesh (DW)	98	97	25	0
Laki 192	Bangladesh (DW)	98	88	25	0
Sigadis (check)	Indonesia (RL)	98	83	26	0
Khao Dawk Mali 4-2-105	Thailand (RL)	100	75	30	0
Chanda Amon	Bangladesh (DW)	100	100	42	0
Fulkari 715	Bangladesh (DW)	100	95	45	0
Badal 672/2	Bangladesh (DW)	100	100	50	0
Goirol	Bangladesh (DW)	100	100	60	5

[a]U = upland; DW = deep water; RL = rainfed lowland. [b]Rices with low survival percentage were not tested at 12 and 15 days.

minutes, and maintains temperature and relative humidity close to those of the outside ambient air.

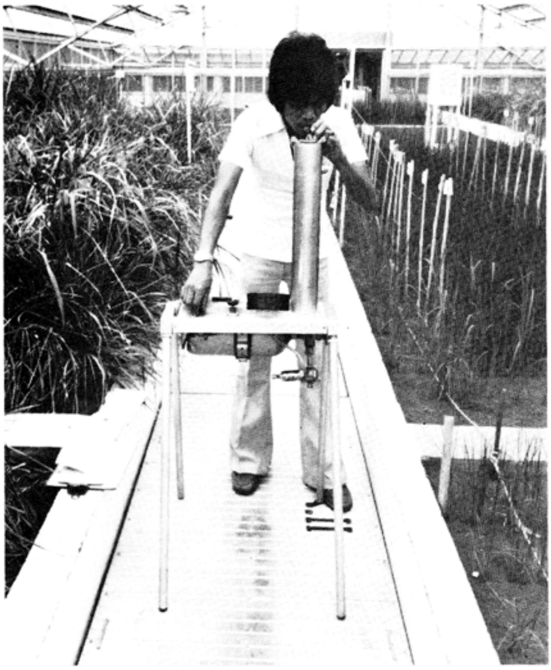


2. Relationship between percentages of seedling survival of 35 varieties tested in the phytotron and the greenhouse. IRRI, 1976.

Greenhouse screening is similar to dry-season field screening except that the soil moisture regime is more controllable. As a starting point for the screening, SMT is manipulated until it is about 10 cb at 60-cm depth and about 20 cb at 15-cm depth.

Fertilizer is applied basally at 80 kg N/ha, 40 kg P/ha, and 40 kg K/ha. After dry soil preparation, entries are seeded in 1-m rows. A single tank accommodates 66 entries and 2 check varieties at 3 places for a total of 72. The crop receives a 50-mm sprinkler irrigation for establishment. Second and third 50-mm irrigations are applied if SMT at 15 cm exceeds 30 cb. Each irrigation wets to a depth of about 25 cm. After crop establishment (judged by check variety growth) irrigation is stopped. The tank soil is allowed to dry until the susceptible check variety has a drought score of 6–7.

On the day of scoring, the leaf water potential of all entries is measured at 0500 h (Fig. 3), and visual scoring is done at 0900 h. The leaf water potential gives information on the degree of plant water stress and indication of the drought-resistance mechanism influencing each entry's score. As in field screening (see page 90, Physiological basis of drought screening criteria), entries with desirable visual scores generally



3. The pressure chamber is used to monitor dawn leaf water potential the same day visual scoring is done.

maintain a high leaf water potential. After scoring, the tanks receive 50-mm sprinkler irrigation. The entries are scored 4 to 5 days later for recovery from drought.

The results of the greenhouse screening are similar to those of dry-season field screening with close agreement between check varieties of both tests. The fact that greenhouse results are less affected by disease and insect pressure partially explains the differences between them and field results.

Figure 4 illustrates some varietal differences seen in the greenhouse screening. Salumpikit was outstanding in the 1975 field screening. IR5817-68-1 (IR2061-213-2-16 // IR442-2-58/ MTU 17) has two parents—IR442-2-58 and MTU 17—previously reported to have a high degree of drought resistance.

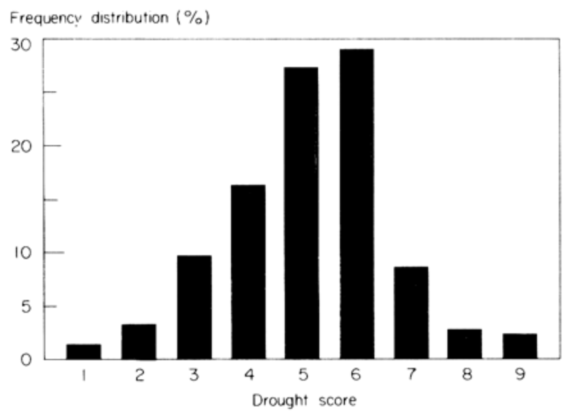
During the last half of the year, 494 entries were screened for drought resistance in the new greenhouse. Figure 5 demonstrates the extremes of variability found in the initial months of the greenhouse operation. Most of the entries that received a score of 1 or 2 were the traditional tall upland varieties, but many of IRRI's

4. Varietal differences in drought-screening greenhouse. Salumpikit is an outstanding variety in IRRI dry-season field screening, IR20 is a susceptible check, and IR5817-68-1 represents some encouraging breeding material in the GEU program. IRRI, 1976.

advanced upland breeding materials also were in the group. Among the entries with scores of 3 or 4 were many elite materials from the International Rice Observational Nursery. They may have immediate use in drought-prone, rainfed-lowland cultural systems.

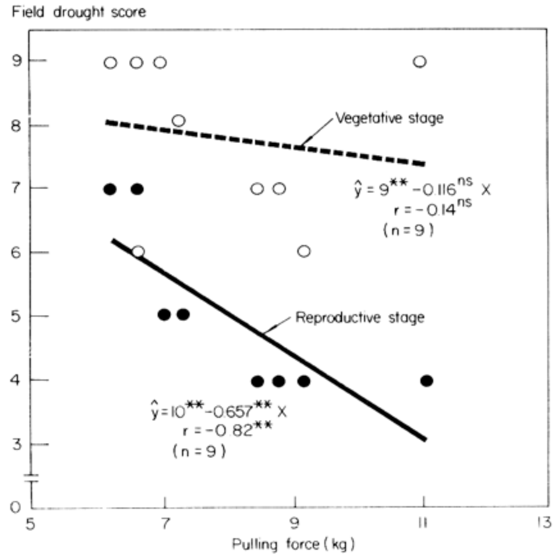
The drought greenhouse, which has a capacity of 2,000 entries a year, will primarily screen elite germ plasm evolving in the GEU program.

Root systems characterization (*Agronomy*). Previous work (1971–75 annual reports) demonstrated that rice varieties significantly differ in rooting habit. Screening techniques employed



5. Frequency distribution of 494 entries screened in the drought-screening greenhouse. Drought score: 1 = none to slight effect of stress; 9 = all plants dead. IRRI, 1976 wet season.

6. The force required to extract a rice plant from the soil can be quickly measured with suitable spring balance. IRRI, 1976.



7. Relationship between pulling force and 1976 dry-season field drought score for the vegetative and reproductive growth stages. IRRI.

to date have not, however, been able to handle the large number of entries required by the GEU breeding program.

Several screening techniques were evaluated in the greenhouse and in the field. One of the simplest and most encouraging is the measurement of the force required to extract a rice plant from the soil (Fig. 6). Preliminary experiments with selected varieties showed that pulling force was correlated with field drought-screening scores (Fig. 7).

Experiments on the appropriate sampling age of plants showed that the varietal variance-to-total variance ratio was maximum at 3 to 4 weeks after emergence. Thus, screening could be accomplished rapidly on 3- to 4-week-old plants.

The work is preliminary and the root-pulling force method needs refinement. Nevertheless, the method demonstrated the simplicity of the required equipment, a capability to differentiate varieties, and a correlation with field-screening results.

EVALUATION FOR DROUGHT RESISTANCE IN RAINFED-LOWLAND CULTURE

Plant Breeding Department

Until 1976 nearly all field experiments on drought resistance were conducted in upland fields. The obvious problem was that a larger proportion of the rice hectarage that chronically suffers from drought is grown to rainfed-lowland rice rather than to upland or deep-water rice. Upland and deep-water rices are similar in that both are directly seeded in granulated soil; soil in rainfed-lowland fields is puddled.

Field screening. During the wet season a field experiment was initiated to study the drought resistance of diverse germ plasm in rainfed-lowland conditions. The experiment had 803 entries, including traditional upland varieties, early maturing (100-day) lowland varieties, traditional lowland varieties, breeding lines from the lowland nurseries, and breeding lines from the upland nurseries. Because the fields differed in internal drainage, one replication often showed more severe drought stress than the other.

A drought prevailed at the reproductive phase, but only a few entries showed sustained leaf rolling—the sign of extreme drought stress. Many accessions showed markedly reduced plant height or tillering and delayed heading. The reductions were more obvious among replicates of the check variety BPI-76 (nonsensitive), or between two replicates of the same accession that differed in soil moisture conditions during the stress periods. Many early maturing accessions showed marked bending and spreading of the culms during the stress period.

The agronomic characteristics of 485 accessions from the germ plasm bank were statistically compared with those of the same accessions obtained earlier in fully irrigated plots. The comparison showed highly significant differences between the stressed and irrigated plants in plant height, tiller number, panicle exsertion, and maturity. The stressed varieties were, nevertheless, not significantly lighter in 100-grain weights than the plants grown in irrigated plots. Tiller number varied markedly from one replicate to the other, but did not show a consistent trend in relation to soil moisture conditions, probably because the seedlings were transplanted 35 days after seeding.

The statistical analysis confirmed that the visually observable marked reduction in plant height, poor panicle exsertion, and delayed heading indicated susceptibility of rainfed-lowland cultures to drought. The manifestations were similar to the principal signs of varietal differences found in the dry-season mass-screening test in simulated upland culture. The entries that were more drought resistant showed relatively smaller differences in the above characteristics, however (Table 6).

A number of upland and lowland breeding lines as well as traditional rainfed-lowland varieties that could be used in the 1977 hybridization program were identified. The varieties are Kuan Tung Tsao Sheng, BK88/BR 6, BR 3, Carreon, DJ 29, Intan, Pelita I-1, Pelita I-2, JC 81, and Niaw San Pahtawng. Promising breeding lines are the IR3646 lines selected from the upland nurseries, and IR2035-108-2, IR3941-25-1, and IR4707-123-3 selected from the lowland nurseries.

Table 6. Differences in five agronomic traits between accessions grown in replicated rainfed-lowland plots[a] (1976 wet season) and those grown in fully irrigated plots (in other years). IRRI Plant Breeding Department.

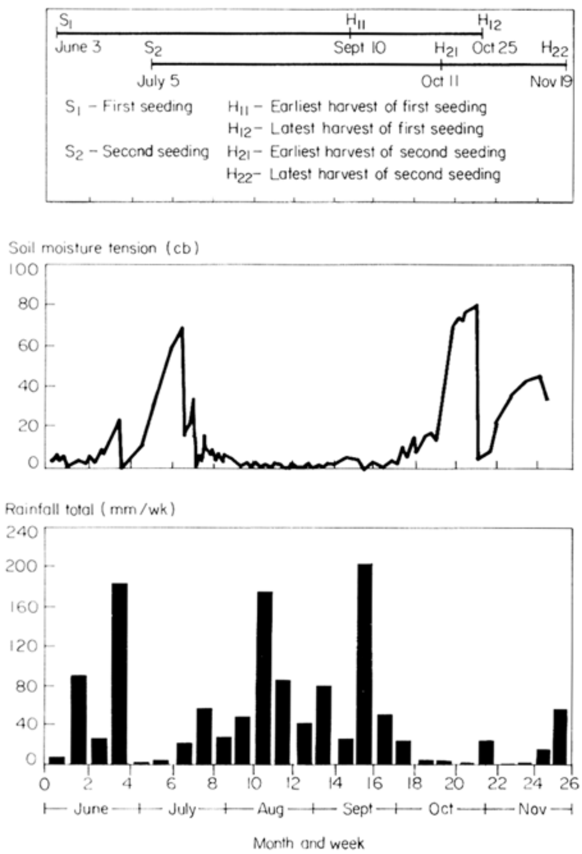
Acc. no.	Variety	Soil moisture[b]		Plant ht		Tiller no.		Panicle exsertion		100-g wt		Days to maturity	
		Difference (%) in											
		I	II	I	II	I	II	I	II	I	II	I	II
Susceptible													
3579	Fowel	1	5	86	82	50	90	100	100	110	70	111	108
5868	Doc Phung Lun A R16	2	3	82	84	48	48	150	100	105	81	128	128
7091	Nang Chet Cut	2	3	81	81	40	33	33	33	115	96	111	108
9128	JW 103	2	2	82	83	45	40	33	33	87	90	91	90
20471	ARC 7060	1	4	62	62	44	56	67	100	104	100	96	123
Resistant													
172	Nahng Mon S4	3	3	96	82	28	20	67	100	—	94	88	88
857	Niaw San Pahtawng	3	3	92	93	27	23	67	100	86	89	86	84
1173	Kuan Tung Tsao Sheng	3	5	94	94	50	33	100	100	105	114	120	116
5993	Carreon	2	5	93	95	75	65	100	100	100	100	91	94
6357	BR 3	2	2	99	102	60	80	100	100	109	109	92	93
6654	BK 88/BR6	2	2	90	72	75	45	100	100	105	110	90	93
8505	DJ 29	3	5	92	106	40	60	100	100	96	92	93	95
Check													
9790	BPI-76 (nonsensitive)	3	3	102	101	120	110	100	100	110	105	90	92
9790	BPI-76 (nonsensitive)	1	4	89	97	90	90	100	100	115	105	91	92
9790	BPI-76 (nonsensitive)	4	5	96	99	110	120	100	100	105	100	90	92

[a]I and II = replications of the rainfed-lowland experiment. [b]Soil moisture condition of plot, in coded numbers, varying from very dry (1) to very wet (5).

FIELD PERFORMANCE OF RICES
IN UPLAND CULTURE
Agronomy and Plant Breeding Departments

Upland variety trials (*Agronomy*). The 1976 upland rice variety trials, aimed at selecting promising lines with high yield potential combined with pest resistance, and resistance to, and good recovery from drought, were conducted on two sites at IRRI and on farmers' fields in two locations in Batangas, Philippines.

The entries were lines found promising in previous tests, and upland varieties recommended by the Philippine Seed Board. The first seeding was at the start of the region's rainy season, and the second was about a month later. At three sites, 81 rices were tested in the first seeding and 64 in the second. At one IRRI site both seedings had the entire set of 81.



8. Rainfall distribution, drought tolerance, and growth stage of crop at Cuenca, Batangas, Philippines. IRRI upland rice yield trial, 1976 wet season.

Drought resistance. Sufficient rain fell throughout the wet season at both test sites at IRRI and at Santo Tomas, Batangas, and drought scoring was not done. The seedlings of the 3 June seeding at Cuenca, Batangas, were exposed to a 1-week dry period during the tillering stage. The exposure caused SMT to reach 70 cb, but the plants showed no signs of moisture stress. Another 11-day dry period occurred during the heading and flowering stages of the medium maturing rices in the 5 July seeding (Fig. 8). No drought scoring was done, however, because all the early maturing rices had been harvested.

Diseases. The major diseases at all sites were sheath blight, bacterial leaf blight, bacterial leaf streak, false smut, leaf scald, and leaf smut. Some entries at IRRI were moderately affected by neck rot and *Cercospora* leaf spot; at Batangas a few were infected with brown spot. The incidence of leaf blast at Santo Tomas, Batangas, was moderate. At IRRI, IR442-2-58 was slightly infected with leaf blast.

Yield. IR36 not only yielded the highest (4.4 t/ha) in the early maturing group (110 days or less after seedling emergence), but also had the highest mean yield among all entries (Table 7). IET 1444 averaged 4.1 t/ha, and IR3839-1, 3.9 t/ha. The upland variety Binaritos, which had shown high drought resistance for 2 consecutive years (Table 3), averaged only 2.2 t/ha. Of the promising drought-resistant lines selected from 1,003 entries in the 1975 dry-season screening nursery, only ARC 10372, Surjamukhi, and DJ 29 averaged 3 t/ha.

The relatively lower yield at IRRI, particularly for the 10 July seeding, was attributed to delayed and insufficient hand weeding—a consequence of continuous rains. Moreover, sheath blight and bacterial leaf blight caused moderate to severe effects. At Santo Tomas, heavy rains delayed hand weeding in the 2 July seeding and caused a reduction in tiller number.

On the basis of yield, the lines and varieties that show promise for upland culture are IR36, IR3938-1, IR2061-522-6-9, and IET 1444 for early maturity; and IR26, IR1529-430-3, IR1154-243-1, IR2042-178-1, and IR1480-147-3-2 for medium maturity. IR36, which is more resistant to insects and diseases, should replace

IR1561-228-3 in rainfed rice culture.

Toposequence evaluation of rice yield stability. The use of a "stability index" measure, in combination with a hydrological toposequence, for evaluating rice performance in rainfed upland culture continued. The toposequence area was expanded on IRRI's new upland farm and in a suitable farmer's field in Bulacan province, Philippines.

Late in 1975 the toposequence was planted

Table 7. Growth duration, incidence of important diseases, and yield of early and medium maturing rices under upland conditions in the Philippines. 1976 wet season.

Variety or line	Growth duration[a]	Affected by[b]	Grain yield (t/ha)									
			IRRI				Batangas					
			Block H		New farm		Santo Tomas		Cuenca		Mean	
			9 June seeding	10 July seeding	5 June seeding	11 July seeding	2 June seeding	2 July seeding	3 July seeding	5 July seeding	First seeding	Second seeding
IR36	105	123457	3.4	3.1	4.8	4.4	4.6	3.0	4.7	2.0	4.4	3.2
IET 1444	103	1234 10	3.5	2.9	3.7	4.0	5.1	1.1	4.0	2.9	4.1	2.7
IR3839-1	105	123479	3.3	2.8	4.1	4.1	4.1	2.8	4.0	3.2	3.9	3.2
IR2061-522-6-9	104	123579	2.7	2.8	3.6	3.7	4.3	2.8	4.4	2.7	3.8	3.0
FH 109	106	12345	3.0	2.4	3.7	3.3	4.6	2.4	4.1	2.7	3.8	2.7
B9C-Md-3-3	105	125 10	2.8	2.3	3.4	3.6	4.2	1.6	3.6	2.5	3.5	2.5
Kn 361-1-8-6	107	12346	2.2	2.7	2.3	3.4	4.8	3.0	4.2	2.8	3.4	3.0
Se 302G	96	145	2.3	1.3	3.1	2.8	3.6	1.6	3.4	2.5	3.1	2.0
IR1545-339	110	12345	2.0	2.1	2.9	2.6	3.2	2.1	3.7	2.5	3.0	2.3
IR1750-F5B-5	104	12345789	2.6	2.0	2.2	3.8	3.7	2.0	3.5	2.5	3.0	2.6
Surjamukhi	100	123	2.5	1.7	2.6	2.0	3.3	2.2	3.4	2.7	3.0	2.2
ARC 10372	100	1235	2.5	—	2.0	—	3.4	—	4.3	—	3.0	—
Aus 8	110	123456	1.6	2.2	2.2	2.4	4.1	2.6	3.8	2.1	2.9	2.3
DJ 29	110	1235	2.4	—	2.2	—	2.9	—	4.0	—	2.9	—
DV 110	98	1235	1.6	—	1.8	—	3.2	—	3.7	—	2.6	—
IRAT 13	105	123458 10	2.3	1.2	1.6	2.5	3.1	2.1	3.0	1.2	2.5	1.8
Ctg. 1516	98	125	2.2	1.6	1.6	1.6	2.2	2.2	3.5	2.1	2.4	1.9
DZ 41	95	145	1.8	2.0	1.8	1.7	1.8	2.7	3.4	2.8	2.2	2.3
DM 59	98	1235	2.0	—	1.6	—	1.7	—	3.7	—	2.2	—
ARC 7060	97	1235	2.4	—	1.6	—	1.8	—	3.0	—	2.2	—
Dular	96	12345	2.4	—	1.5	—	1.6	—	2.6	—	2.0	—
ARC 7102	97	1235	1.4	—	1.3	—	1.5	—	2.0	—	1.6	—
ARC 7001	101	1245 10	1.7	—	1.8	—	1.0	—	1.8	—	1.6	—
ARC 6565	98	1345	1.3	1.5	1.0	1.7	1.5	1.1	2.4	2.2	1.6	1.6
Binaritos (check)	110	12345	2.1	2.3	2.0	2.8	1.9	0.9	2.6	1.9	2.2	2.0
IR26	122	123469	4.0	3.4	3.4	3.9	4.9	2.0	4.5	1.3	4.2	2.6
IR1529-430-3	120	12346	2.7	2.4	3.6	3.6	4.8	3.0	4.9	1.5	4.0	2.6
IR1154-243-1	116	1234567 10	3.5	3.1	4.1	3.7	3.8	2.4	4.3	2.0	3.9	2.8
IR2042-178-1	122	12345	4.0	3.4	3.5	3.8	4.0	1.7	4.0	0.9	3.9	2.4
B541b/Kn/19/3/4	116	12348	3.3	3.2	3.0	3.2	4.3	2.3	4.9	2.4	3.9	2.8
IR8[3]/Carreon	122	12346	2.6	2.5	3.3	3.5	4.9	2.4	4.5	1.0	3.8	2.4
IR2035-242-1	121	12345	3.7	2.5	3.5	4.1	3.9	2.2	4.3	1.4	3.8	2.6
IR1480-147-3-2	113	1234678	3.5	3.0	3.7	4.6	4.0	2.3	3.8	2.9	3.8	3.2
IR2035-353-2	122	123457	3.1	2.5	3.1	3.6	4.1	2.3	4.2	1.9	3.6	2.6
IR2035-108-2	122	12345678	3.1	2.5	3.5	3.2	4.2	2.8	3.8	1.6	3.6	2.5
IR2035-227-1	119	12345	3.0	2.1	3.7	3.8	3.5	1.9	4.1	2.6	3.6	2.6
IR3880-13	113	12349	2.9	2.7	3.5	4.1	4.2	2.5	3.7	2.0	3.6	2.8
IR2043-104-3	118	12457	3.1	3.4	3.0	3.9	4.1	2.6	4.4	2.8	3.6	3.2
IR661-1-170-1-3	117	123478	2.6	2.4	3.6	4.2	4.1	2.5	3.8	2.1	3.5	2.8
IR3259-P_5-160-1	124	123457	2.2	1.9	2.7	2.5	4.7	1.4	4.4	1.0	3.5	1.7
MRC 172-9	120	12347	2.7	3.4	2.8	3.1	4.0	2.1	4.4	1.6	3.5	2.6
IR5	126	1234	2.2	2.2	2.0	2.6	4.5	1.6	4.9	0.5	3.4	1.7
C46-15/IR24[2]	114	123456	2.3	2.8	2.5	3.3	4.0	2.7	4.1	2.8	3.2	2.9
IR2035-117-3	125	12346	2.5	2.7	3.0	3.3	3.0	1.3	4.0	0.4	3.1	1.9
C22	119	128	2.4	2.8	2.6	2.7	3.6	2.9	3.6	2.0	3.0	2.6
IR442-2-58	114	123478 10	2.3	2.0	2.7	3.0	2.3	2.6	4.2	2.6	2.9	2.6
IR9575	118	1234	2.1	2.2	2.7	3.2	3.4	2.3	2.9	2.6	2.8	2.6
Salumpikit	115	12345	2.4	—	1.2	—	3.8	—	2.8	—	2.6	—
Kinandang Patong	111	12345	1.9	2.0	1.6	1.7	2.7	1.6	3.2	2.1	2.4	1.8
M1-48 (check)	112	123458	2.3	2.4	2.3	1.7	3.6	1.9	3.8	2.0	3.0	2.0

[a]Average growth duration of 8 or 4 seedings in four sites in days after rice emergence (DRE). [b]1 = sheath blight; 2 = bacterial leaf blight; 3 = leaf scald; 4 = false smut; 5 = leaf smut; 6 = bacterial leaf streak; 7 = *Cercospora* leaf spot; 8 = neck rot; 9 = brown spot; and 10 = leaf blast.

Table 8. Mean yield of 17 rices grown (3 replications at 10 slope positions) on a toposequence. New IRRI farm, 1976 wet season.

Variety or line	Mean yield[a] (t/ha)
IR36	3.48 a
IR2035-120-3	3.26 b
IR937-76-2	3.24 b
IR8	3.21 b
IR5	2.93 c
IR480-5-9-3-3	2.77 cd
IR661-1-170-1-3	2.70 de
IR20	2.70 de
BPI-76⁹/Dawn	2.54 def
IR26	2.52 ef
IR2043-104-3	2.44 fg
IR28	2.23 gh
IR30	2.12 h
IR1746-226-1-2-2	2.06 h
M1-48 (check)	1.52 i
M1-48 (check)	1.50 i
Palawan	1.49 i

[a]Means followed by the same letter are not significantly different at the 5% level.

with 35 varieties. December 1975 and January 1976 rains were unseasonably well distributed and vegetative growth was good. When the dry season started, however, the water table dropped below 1.25 m all along the toposequence within a few days. Only IR1746-226-1-2-2, IR1750-F5B-3, IR1750-F5B-5, and IR2035-227-1 gave some yield. All had about a 120-day maturity and low yields ranging from 0.1 to 0.6 t/ha.

Sixty-three days after seeding, IR1746-226-1-2-2 had the highest leaf water potential among rices sampled across the top slope position. It also had the lowest percentage of unfilled grains, an observation which suggests that the variety escaped or avoided internal stress longer than others in the test did.

During the wet season, two replicated trials were conducted on the IRRI toposequence. One trial used 16 varieties and the other, 42 varieties. The water table fluctuated less, and the average water level was higher than in 1975 (1975 Annual Report). The rainfall distribution produced a high frequency of surface soil wetting and constant yield levels along the toposequence. The average yield of all varieties at each slope position had a narrow range.

Because the weather conditions were favorable, a high mean yield or a high yield potential under upland conditions was the only practical selection criterion for 1976. Tables 8 and 9 show the mean yields of varieties and lines grown on the IRRI toposequences. Table 10 shows the results from Bulacan. In Bulacan, the rices were transplanted onto a 100-m slope. However, as at IRRI, the rainfall and the toposequence effects were masked by even distribution of rainfall.

Table 9. Mean yield[a] of 45 rices grown on a toposequence (2 replications at 10 slope positions). New IRRI farm 1976 wet season.

Variety or line	Mean yield (t/ha)	Variety or line	Mean yield (t/ha)
C 171-136	3.37 a	IR5	2.36 jklmnopq
IR8	3.18 ab	M1-48 (check)	2.32 klmnopq
IR2070-423-2-5-6	3.10 abc	IR3154-4	2.31 klmnopq
IR2070-414-3-9	3.10 abc	IR2153-338-3	2.20 lmnopqr
MRC 172-9	3.09 abc	IR2071-636-5-5	2.19 mnopqrs
IR2071-625-1-252		IR2735-F3B-6-2	2.15 nopqrs
(IR36)	3.05 bcd	IR2071-179-9-5-6	2.12 pqrs
C 166-135	3.02 bcde	M1-48 (check)	2.12 pqrs
IR2061-465-1-5-5	2.93 bcdef	IR2071-176-1-1	2.05 qrst
C 22	2.90 bcdefg	IR30	1.98 rstu
IR20	2.82 cdefgh	BPI-76⁹/Dawn	1.96 rstu
IR2071-105-9-1	2.77 defghi	IR1746-226-1-1-2	1.94 rstu
IR24	2.76 defghi	M1-48 (check)	1.94 rstu
IR1632-93-2-2	2.72 efghi	M1-48 (check)	1.88 stuv
IR2061-628-1-6-4-3	2.67 fghij	IR1746-88-1-2-1	1.80 tuvw
IR2061-522-6-9	2.61 ghijk	IR2035-290-2-1-2	1.74 tuvw
IR34	2.55 hijk	IR1746-226-1-1-4	1.74 tuvw
IR1529-680-3-2	2.53 hijk	IR2070-747-6-3-2 (IR 32)	1.69 uvw
IR29	2.52 hijkl	IR2031-724-2-3-2	1.61 vw
IR28	2.48 ijklm	IR2071-588-5-4-5	1.50 wx
IR2070-863-1	2.47 ijklm	IR1746-194-1-1	1.31 x
IR1750-F5B-5	2.46 ijklmn	IR1746-F5B-24	1.28 x
IR3179-27	2.39 jklmnop		
IR26	2.37 jklmnopq		

[a]Means followed by the same letter are not significantly different at the 5% level.

Table 10. Mean yield[a] of 36 rices grown on a toposequence (2 replications at 10 slope positions). Bulacan, 1976 wet season.

Variety or line	Mean yield (t/ha)		Variety or line	Mean yield (t/ha)	
IR2071-105-9-1	5.58	a	IR29	4.16	hij
IR2070-423-2-5-6	5.19	b	IR28	4.07	ij
IR2071-588-5-4-5	5.12	b	IR2070-747-6-3-2	4.06	ij
IR2071-625-1-252 (IR36)	5.05	bc	IR3179-27	3.86	jk
IR1632-93-2-2	4.97	bcde[b]	IR2071-176-1-1	3.64	kl
IR2035-290-2-1-2	4.93	bcd	C 171-136	3.46	lm
IR26	4.93	bcd	IR24	3.34	lmn
IR2061-628-1-6-4-3	4.74	cdef	C 166-135	3.24	mn
IR30	4.69	cdef	IR20	3.24	mn
IR2061-465-1-5-5	4.65	defg	C 22	3.22	mn
IR2071-179-9-5-6	4.63	defg	BPI-76⁹/Dawn	3.22	mn
IR2031-724-2-3-2	4.53	efgh	IR8	3.20	mn[b]
IR2070-414-3-9	4.53	efgh	IR1750-F5B-5	2.97	n
IR2071-636-5-5	4.50	efgh	IR1746-88-1-2-1	2.55	p
IR34	4.50	efgh	IR1529-680-3-2	2.44	p
IR2153-338-3	4.36	fghi	IR5	1.98	q
IR2070-863-1	4.28	ghi	M1-48 (check)	1.61	qr
IR2061-522-6-9	4.26	ghi	M1-48 (check)	1.38	r[c]

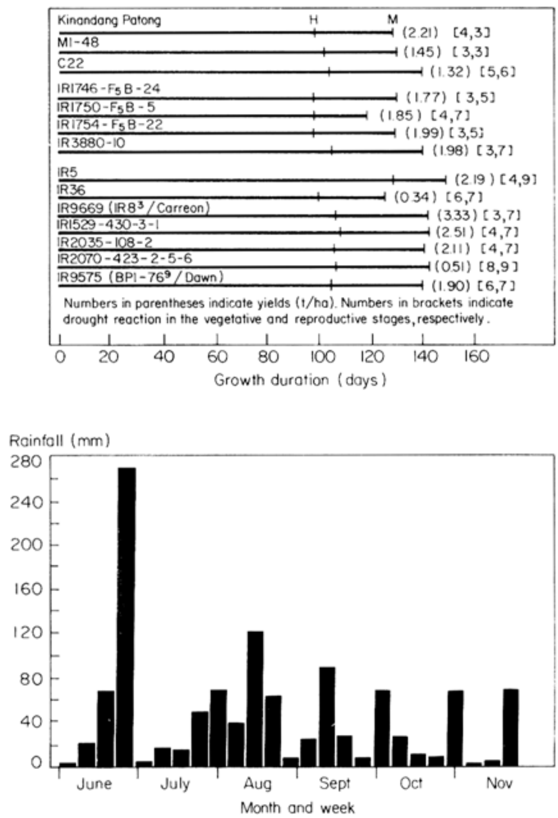
[a]Means followed by the same letter are not significantly different at the 5% level. [b]Averaged over 10 slope positions and 1 replication. [c]Averaged over 7 slope positions and 1 replication.

Because of the rainfall distribution, these data are of little use in stability analyses. They will, however, be needed for stability analysis of varieties through time as well as along the toposequence in succeeding years.

Yield and drought resistance (*Plant Breeding*). During the wet season 69 varieties and lines were entered in replicated yield trials at two IRRI sites and a farmer's field in Batangas that represent different soil moisture and fertility levels.

At one IRRI site (dry soil, poor fertility) 1,105 mm of rain fell during the crop-growing period. A short dry period occurred at the early vegetative phase and during the reproductive phase. The line IR9669, a late maturing selection, gave a top yield of 3.3 t/ha, which was significantly higher than that of the traditional upland variety Kinandang Patong (2.2 t/ha). The yields of the upland breeding lines (IR1746-F5B-24, IR1750-F5B-5, IR1754-F5B-22, IR2992-22, and IR3880-10), which ranged from 1.8 to 2.41 t/ha, did not differ significantly from the yield of Kinandang Patong at the 5% level.

Among the upland breeding lines, the early maturing lines were able to produce well-filled grains even when drought stress occurred at the booting stage (Fig. 9). The late maturing lines benefited from late rains. These lines generally have a lower level of drought resistance but



9. Yield performance on a well-drained site of three upland varieties, four upland breeding lines, and seven lowland breeding lines in relation to field resistance to drought, growth duration, and rainfall distribution. IRRI Plant Breeding Department, 1976 wet season.

they possess good ability to recover quickly when rains come after the stress period.

Four entries from the lowland nurseries gave low yields—IR30, 0.43 t/ha; IR36, 0.34 t/ha; IR2035-290-2-3, 0.60 t/ha; and IR2070-423-2-5-6, 0.51 t/ha. These varieties and lines have low levels of drought resistance at both the vegetative and reproductive stages. The dry period at the vegetative stage stunted the plants, while the drought during the reproductive phase led to sterile panicles and small grains.

At the second IRRI site (new farm, fertile soil), rainfall was generally adequate and evenly distributed. An upland breeding line, IR3880-10 (from IR841-67/C22//Pelita I-2/IR1541-76), produced the highest mean yield of 4.58 t/ha (Table 11), which was comparable with the yields (between 4.0 and 4.5 t/ha) of several high yielding lowland lines, such as IR2070-423-2-5-6, IR36, and IR1529-430-3-1. The yields of the better performing upland breeding lines—IR1750-F5B-5 and IR1754-F5B-22—and of those selected from lowland nurseries—IR9669, IR2035-290-2-3-1, and IR9575—were not significantly different from those of the local upland varieties M1-48 and C22. Kinandang Patong gave a low yield (2.4 t/ha) because it lodged early on the fertile soil, but its yield did not differ significantly from that of M1-48.

The Santo Tomas, Batangas, site, which was intermediate in soil fertility between the two IRRI sites, received abundant rainfall. The total rainfall during the crop season was 2,224 mm. The 69 varieties and lines suffered only moderate drought stress in late July and early August. The top yielders were IR1529-430-3 (5.2 t/ha), IR5 (5.09 t/ha), IR9669 (4.41 t/ha), IR2042-178-1 (4.85 t/ha), and IR2035-108-2 (4.57 t/ha). They had a high level of drought resistance at the vegetative phase and good recovery ability. Their yields were not affected by moderate drought stress. Abundant rains during the reproductive phase favored the high yielding lines bred in lowland nurseries.

The upland line IR3880-10 gave a yield of 4.18 t/ha, which was comparable with that of the top yielders. Most upland breeding lines were similar in yield to Kinandang Patong (3.29 t/ha) and the improved Philippine upland variety C22 (3.62 t/ha). Their yield potential,

Table 11. Grain yield[a], maturity, and drought resistance of selected entries from three upland test sites. IRRI Plant Breeding Department, 1976 wet season.

Variety or line	IRRI[b]		Santo Tomas[c]		IRRI new farm[d]		Field reaction to drought[e]	
	Yield (t/ha)	Maturity (days)	Yield (t/ha)	Maturity (days)	Yield (t/ha)	Maturity (days)	Vegetative stage	Reproductive stage
Check varieties								
Kinandang Patong	2.21 bcd	130	3.29 ef	121	2.40[f] f	127	4	3
M1-48	1.45 de	130	2.93 f	127	3.26 def	126	3	3
C22	1.32 de	140	3.62 def	133	3.33 de	130	5	6
Breeding lines from upland nurseries								
IR746-F5B-24	1.77 bcd	130	2.06 gh	121	1.83[f] g	122	3	5
IR1750-F5B-5	1.85 bcd	119	3.24 ef	121	3.34 def	118	4	7
IR1754-F5B-22	1.99 bcd	130	3.23 ef	121	3.49 bcd	122	3	5
IR2992-22	2.41 bc	150	3.59 def	140	3.83 abc	138	4	7
IR3880-10	1.98 bcd	140	4.18 cd	128	4.58 a	132	3	7
Breeding lines from lowland nurseries								
IR5	2.19 bcd	150	5.09 ab	151	3.54 cd	140	4	9
IR30	0.43 ef	125	2.26 g	113	3.80 abc	115	6	8
IR36	0.34 f	125	3.40 def	122	4.01 abc	122	6	7
IR9669 (IR8³/Carreon)	3.33 a	145	4.41 abc	139	3.61 bc	138	3	7
IR1529-430-3-1	2.51 b	145	5.21 a	133	3.97 ab	136	4	7
IR2042-178-1	2.18 bcd	145	4.85 ab	132	4.45 ab	131	5	7
IR2035-108-2	2.11 bcd	140	4.57 abc	135	3.97 ab	136	4	7
IR2035-290-2-3-1	0.60 def	150	3.85 cde	138	2.86 def	136	4	7
IR2070-423-2-5-6	0.51 def	145	4.28 cd	132	4.47 ab	132	8	9
IR9575 (BPI 76⁹/Dawn)	1.90 bcd	140	3.79 de	127	2.87 def	130	6	7

[a]Any two means followed by the same letter are not significantly different at the 5% level. [b]Dry site. [c]Intermediate site. [d]Wet and fertile site. [e]Scale of 1–9: 1 = none to very slight effects of stress; 9 = all plants apparently dead. [f]Yield affected by early lodging.

Table 12. Roots and other agronomic characteristics of varieties identified as donors of a deep-root system. IRRI, 1976.

Selections	Days to flower	Plant ht (cm)	Tillers (no.)	Total root:shoot	Deep root:shoot	Field resistance[a] to drought
Bantia	98	182	7	159	59	R
Ku 78	92	130	8	183	69	R
Ku 86	84	160	18	152	67	R
Ma Wai	91	137	20	189	95	R
8 CD	100	208	14	153	76	R
10-A1	102	176	6	168	57	R
610	101	176	6	194	106	R
IR20 (check)	82	92	22	52	7	MS
OS 4 (check)	90	180	17	78	28	R

[a]From mass screening by Plant Breeding Department. R = resistant; MS = moderately susceptible.

however, is somewhat lower than that of the lowland breeding lines.

At Santo Tomas, IR36 yielded only 3.40 t/ha, which was comparable with the yield of Kinandang Patong and C22. IR30 and IR1746-F5B-24 gave the lowest yields (slightly above 1 t/ha).

Eighteen entries with different levels of drought resistance are shown in Table 11 to illustrate the effect of drought resistance on yield performance and stability as affected by soil moisture conditions and fertility at the three sites. Kinandang Patong, which gave the lowest mean yield, was high in yield stability. IR1754-F5B-22, IR3880-10, and IR2035-108-2 produced higher yields than Kinandang Patong at the IRRI new farm site and at Santo Tomas, but at the drier IRRI site their performance was comparable with that of Kinandang Patong. The lines have moderately high levels of drought resistance and good ability to recover. The more drought-susceptible IR9575 line (BPI-76^9/Dawn) and IR36 yielded higher at the wet and fertile IRRI site, but yielded much lower at the dry site. Obviously yield stability requires a good level of drought resistance and the ability to recover.

ROOT STUDIES

Plant Physiology Department

Donors of deep-root systems. Screening rice varieties for deep-root systems by the root-box technique continued. Table 12 lists donors of deep-root systems screened from 313 varieties for ratio of deep root to shoot. The table supplements the list in the 1975 Annual Report. All the deep-rooted varieties have been rated as resistant to drought in the fields. They are medium maturing and intermediate to tall in plant height. Tillering capacity varies from 6 to 20 tillers/plant. Among them, Ma Wai is intermediate in plant height, tillers well, and has a high ratio of deep root to shoot.

Species differences in root systems. The root systems of 2 cultivated species and 11 wild species of genus *Oryza* (total of 392 varieties or strains) were examined. Because the number of samples for each species differed widely, it was difficult to draw any definite conclusion from the study. It seems, however, that the ratio of deep root to shoot of *O. sativa* ranges from low to high, covering most of the recorded ratio values for other species (Table 13).

Some strains of *O. australiensis* have highly developed rhizomes, which, when separated, can produce new shoots. The reserve carbohydrate of the rhizomes is composed largely of starch.

Table 13. Species differences in root:shoot ratio of genus *Oryza*. IRRI, 1976.

Species	Samples (no.)	Total-root: shoot ratio		Deep-root: shoot ratio	
		Min	Max	Min	Max
O. sativa	313	15	253	5	106
O. glaberrima	42	36	109	14	62
O. australiensis	4	181	319	41	78
O. brachyantha	3	55	184	8	19
O. barthii	8	45	150	8	52
O. grandiglumis	1	151		52	
O. latifolia	7	78	138	28	71
O. minuta	1	185		104	
O. nivara	5	76	138	22	62
O. punctata	3	231	253	101	114
O. rufipogon	2	59	84	16	
Spontanea forms of *O. sativa*	2	52	67	13	18

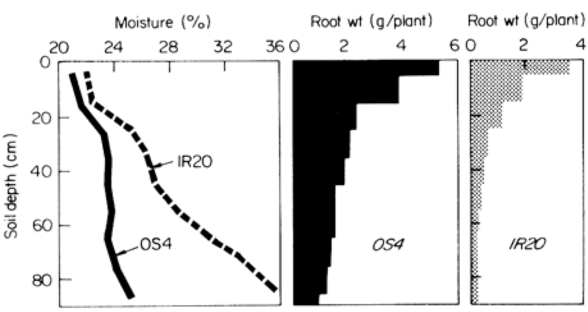
Table 14. Root-to-shoot ratio of weed species. IRRI, 1976.

Species	Total root:shoot ratio	Deep root:shoot ratio
Ageratum conyzoides	138	35
Commelina benghalensis	87	38
Digitaria sanguinalis	127	62
Echinochloa colonum	103	41
Eclipta alba	140	51
Eleusine indica	114	45
Ipomea triloba	101	58
Portulaca oleracea	68	16

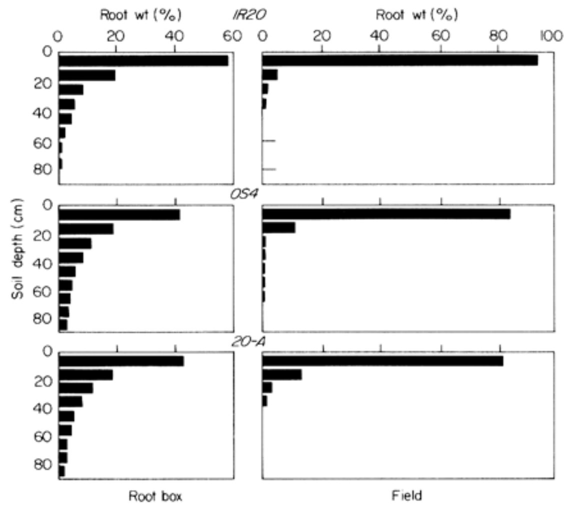
Root systems of weed species. The root systems of eight weed species were examined by the root-box technique. The weed species, except *Portulaca oleracea*, appear to have a relatively deep root system. In particular, *Digitaria sanguinalis*, *Ipomea triloba*, and *Eclipta alba* have good deep root systems. Most of the tested weed species have much deeper root systems than the lowland improved varieties (Table 14).

Water absorption by deep- and shallow-rooted varieties. Studies in 1975 demonstrated that deep-rooted rice varieties have a high level of ability to absorb soil nitrogen and to take applied fertilizer nitrogen from deep soil horizons. In the same manner, a deep-rooted variety can use soil water from the deeper soil horizons better than can the shallow-rooted variety (Fig. 10). IR20, a shallow-rooted variety, can deplete soil water in the surface as efficiently as OS 4. In the deep horizons, however, IR20 failed to deplete water that OS 4 was able to utilize.

Environmental factors affecting root growth. The genetic potential of the deep-root growth



10. Depletion by two varieties of water at different soil depths. Sampling was made 6 days after the last watering. IRRI, 1976.

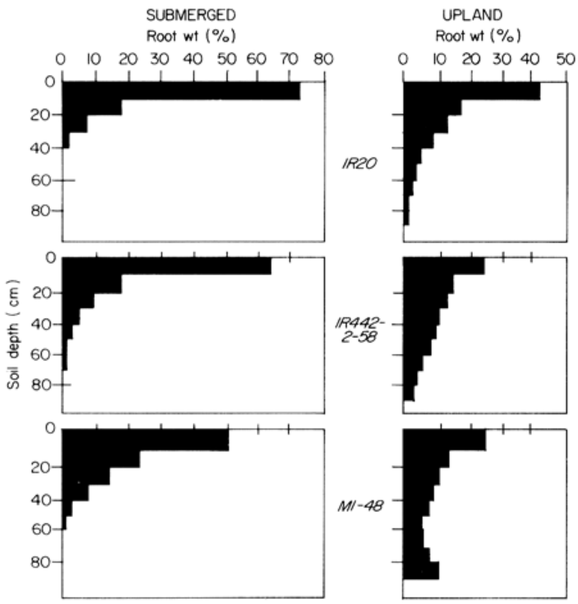


11. Vertical root distribution (by weight) at soil depths of three varieties grown in root boxes and in the field. IRRI, 1976.

habit may not be realized under some environmental conditions. To supplement 1975 results, root development was examined in the root box, in the field, and with submergence. Vertical distribution of roots in the field differed greatly from that in the root box (Fig. 11). More than 95% of root fractions was found in the first 20 cm from the surface in the field, apparently because of high mechanical impedance from the field soil. Soil bulk density was adjusted to about 1.0 in the root box, but it was much higher in the field, especially as soil depth increased.

Rice roots in flooded paddy soils develop only in the surface soil. The reason may be that the root systems of lowland rice varieties are genetically shallow, or that submergence impairs deep-root growth because it results in almost total lack of oxygen in the soil except in the thin layer of surface soil, or that a hard pan near the soil surface restricts root growth.

In most upland crops, submergence or excess soil moisture impairs deep root growth because it decreases partial pressure of oxygen in the soil. Rice possesses an efficient air passage system from shoot to root. An oxygen diffusion model of rice roots predicts, however, decrease of the partial pressure of oxygen at the root tip as the root lengthens. To test that prediction, root boxes were placed in a water tank where



12. Root development of three varieties under upland and submerged conditions. IRRI, 1976.

water was allowed to flow only at the soil surface so that no water moved downward.

Submergence impaired the deep-root growth of both lowland and upland rice varieties (Fig. 12). The finding agrees well with the prediction from the oxygen diffusion model. According to one model, relative partial pressure of oxygen decreases from 1.0 at the base of the root to about 0.12 at 40 cm from the base.

The lack of oxygen in submerged soils prevents rice roots from growing deep. Thus, root systems of rice on submerged soil may become shallower because of lack of oxygen or because of the presence of a hard pan.

SOIL-PLANT WATER RELATIONSHIPS IN RICE

Agronomy Department

Water stress effects at various evapotranspiration levels. A lysimeter study at IRRI during the dry season evaluated rices for drought tolerance at various moisture regimes, which were determined by evapotranspiration (ET) values. Pregerminated seeds were drilled into a dry granulated soil in lysimeter tanks at a 20-cm row spacing. Soils in the tanks were irrigated to saturation with overhead sprinklers. Two rices with similar growth duration were seeded in each tank.

ET in the control tanks (5-cm continuous flooding) was measured daily. At the end of each week, ET values were added and the fraction of ET values—3/4, 1/2, or 1/4—was used in adding water to the respective tanks. That procedure gave quantitative basis to the control of the moisture regime based on ET value of a specific rice variety. One treatment consisted of daily water supply 25% of ET measured the previous day. Tensiometers and precalibrated gypsum blocks were installed to monitor SMT. At the panicle initiation stage, SMT was relieved.

The ET value was greatest (15.8 mm/day) in the tanks containing Moroberekan and IR1750-F5B-3 rices with 5 cm of continuous flooding. ET values were highest at the maximum tillering stage. Because no border plants surrounded the tanks, ET values obtained in this experiment were higher than those reported in previous experiments.

Scoring drought tolerance. Initial scoring for drought tolerance 45 days after rice emergence showed that IR36 was the most tolerant regardless of moisture regime (Table 15). IET 1444 was least tolerant of drought stress. Scoring at 59 days after seeding resulted in a similar trend, showing IR36 and IR2035-117-3 as the most drought tolerant. The results confirmed field-screening results where both rices showed promise up to a 4-bar SMT. IR442-2-58 was affected by leaf blast in all moisture regimes and, therefore, visual scores may not be completely attributed to water stress.

Proline assay made at 37 and 52 days after rice emergence showed that most entries accumulated higher amounts of proline at higher stress.

Methodology studies. Work continued on improved techniques for screening rices for tolerance for and ability to recover from drought stress. In 1975 a new greenhouse technique measured the reactions to drought stress of rices planted on dry soil.

In the 1976 trial, SMT was allowed to rise above 30 bars instead of 19 bars as in 1975.

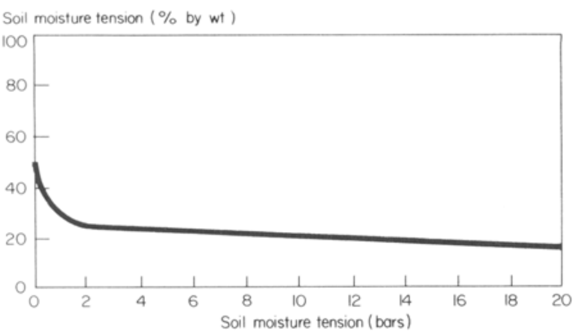
Table 15. Drought tolerance ratings[a] of 12 rices grown at different evapotranspiration (ET) levels. Lysimeter study in the field, IRRI, 1976 dry season.

Moisture regime	Drought tolerance rating											
	Moroberekan	IR1750-F5B-3	IR1529-430-3	IR2035-117-3	IR442-2-58	IR1746-226-1-1-3	IR2070-423-2-5-6	IR2071-586-5-6-3	IR28	IR36	IET 1444	IR2153-26-3-5-2
					45 days after rice emergence							
1/2 of ET	1	1	2	1	3	1	3	1	3	1	3	1
1/4 of ET	1	2	3	2	3	3	4	2	4	1	6	2
Continuous 1/4 of ET	2	2	4	2	2	3	4	2	4	1	5	1
					59 days after rice emergence							
1/2 of ET	1	2	3	1	3	2	3	1	3	1	4	1
1/4 of ET	3	3	3	2	3	3	4	4	4	1	6	3
Continuous 1/4 of ET	3	3	6	2	3	3	4	3	4	1	6	2

[a] 1976 Standard Evaluation for Rice (SES) scale of 1–9: 1 = none to very slight effects of stress; 9 = all plants apparently dead.

Figure 13 shows the desorption curve for the soil collected from the new IRRI farm. Leb Mue Nahng 111 was the only variety that had 100% survival (Table 16). Most of the IR442 lines died at high SMT, but IR4215-41-3-2 and IR4219-64-1-3 looked promising.

During the 1976 wet season, 84 elite breeding lines were compared with Leb Mue Nahng (tolerant check) and Moroberekan (susceptible check) for drought tolerance. Figure 14 shows a positive linear relationship, indicating that the drought tolerance rating increased with increased SMT. Compared with Moroberekan and Leb Mue Nahng, IR3464-75-1-1, IR3941-25-1, IR4442-165-2-4, IR4422-6-2, IR4432-28-5, and IR3880-13 appeared promising. All had a relatively lower drought score, particularly at high SMT. When SMT of 30 bars was relieved after 65 days without added moisture (Fig. 15), IR4422-6-2 and IR4442-165-2-4 bore panicles while many other entries did not. IR3464-75-1-1 had the lowest drought score—indicating its high drought tolerance—but Moroberekan died at about 30 bars SMT.



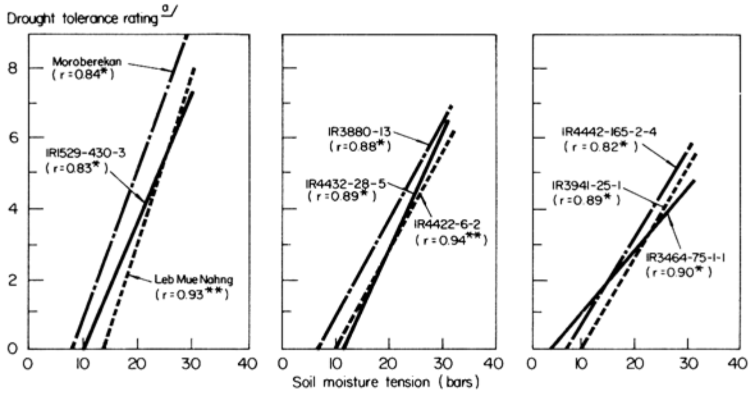
13. Desorption curve for soil from the new IRRI farm used in the greenhouse experiment. IRRI, 1976.

Physiological basis of drought-screening criteria. Annually during the dry season, thousands of rice varieties and lines are screened at IRRI for response to drought stress in upland fields. Two visual scoring systems, one weighted by leaf rolling and the other by leaf drying, evolved. To better understand the physiological adaptation responsible for visual scores, the leaf water potential (estimated from leaf xylem pressure potential) of 17 diverse rices was monitored during the 1976 dry season.

After cessation of irrigation, visual scoring was done periodically by individuals familiar with the two scoring systems. Leaf water

Table 16. Effects of high soil moisture tension (30 bars) at vegetative stage (63 days without water starting 9 days after seeding) on survival percentage of rice tillers. IRRI greenhouse study, 1976 dry season.

Variety or line	Origin	Tillers (no. /8 plants)	Survival (%)
Leb Mue Nahng 111	Thailand	29	100
IR4215-41-3-2	Philippines	20	80
B995-Si-12-3 (20069)	Indonesia	52	67
IR4219-64-1-3	Philippines	32	50
B995-89-1 (20105)	Indonesia	50	48
G14-Si-66-3 (20692)	Indonesia	39	41
B981-Si-35-1 (20016)	Indonesia	29	41
IR1529-430-3	Philippines	29	31
G11-Si-213 (5023)	Indonesia	60	25
BKN 6986-108	Thailand	59	15
BKN 6986-147-2	Thailand	48	6
Dular	India	35	0
IR442-2-58	Philippines	59	0
G11-Si-142 (5018)	Indonesia	39	0
IR442-2-59-2-3-3	Philippines	59	0

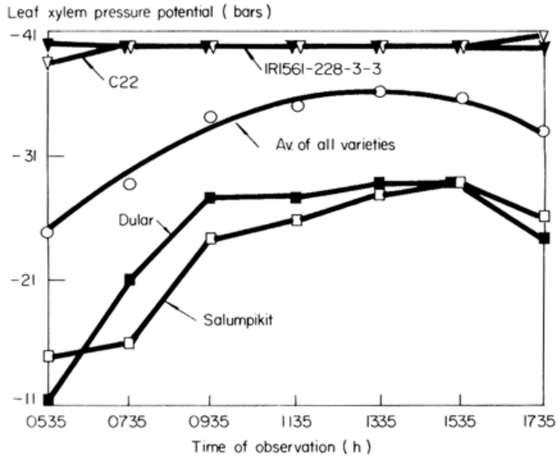


14. Drought tolerance rating of rices under varying soil moisture tensions. IRRI greenhouse, 1976 wet season.
[a]0 = none to slight effects of stress; 9 = all plants apparently dead.

potential was measured concurrently. Figure 16 illustrates the daily trend in leaf water potential when stress was severe and differentiation of varietal response by visual scoring was considered optimal. Considerable variation is evident in the leaf water potential of the varieties regardless of time of day. Extreme differences were detected in the varieties' ability to maintain high leaf water potential throughout the day and in the capability to increase the leaf water potential overnight. Table 17 shows the response of the 17 varieties. The higher leaf water potentials (smaller negative number) indicate better leaf water status or lower degree of plant water stress.

Figure 17 shows the close correlation between

15. When a soil moisture tension of 30 bars was relieved after 65 days without added moisture, IR4422-6-2 and IR4442-165-2-4 bore panicles while four other entries died. IRRI greenhouse, 1976.



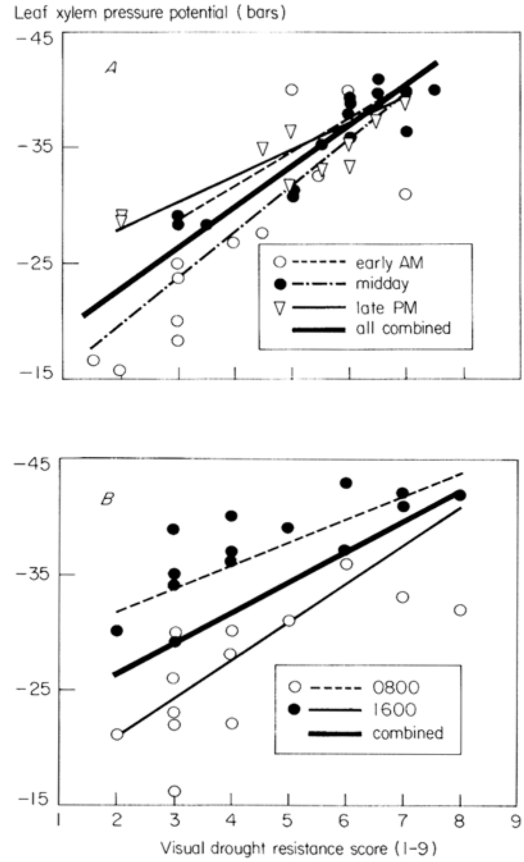
16. Daily changes in leaf xylem pressure potential of rices during upland field screening for drought response. IRRI, 1976 dry season.

maintenance of leaf water potential and visual drought score regardless of the criteria used. The slope relating leaf water potential and visual scoring becomes flatter during midday and late afternoon. Thus, the most effective time of day to select for maintenance of leaf water potential appears to be early morning.

Daily trends in leaf rolling were also observed. Leaf rolling changes during the day followed a trend similar to that of leaf water potential.

Table 17. Ranking of 17 diverse rices by leaf water potential at dawn and their midday and late afternoon leaf water potentials (av. of two replications). IRRI, 1976.

Variety or line	Leaf water potential (bars)		
	0535 h	1335 h	1735 h
Salumpikit	-11.5	-29.0	-25.0
IR442-2-58	-14.6	-36.6	-30.4
Dular	-15.2	-28.0	-26.5
IR8	-16.3	-39.2	-34.0
IR5	-21.5	< -40.0	< -40.0
IR2071-586-5-6-3	-22.5	-33.2	-30.0
IR2061-427-1-17	-23.2	-31.5	-28.0
IR2035-117-3	-23.5	-35.0	-31.2
IR2071-105-9-1	-26.5	-36.2	-27.5
IR26	-26.6	-37.8	-34.4
IR20	-26.7	< -40.0	< -40.0
ASD7	-27.5	-35.5	-34.2
IR36	-28.5	< -40.0	-38.6
M1-48	-29.8	< -40.0	-34.9
IR1561-228-3-3	-38.3	< -40.0	< -40.0
C22	< -40.0	< -40.0	< -40.0
IR30	< -40.0	< -40.0	-37.2

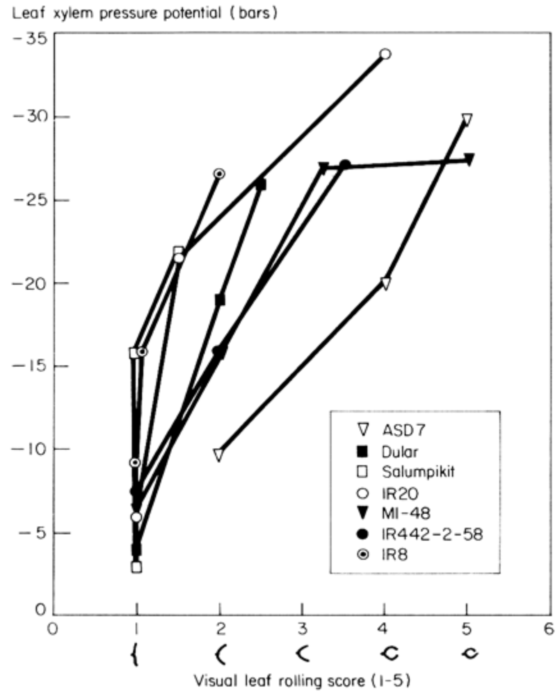


17. Relationship between leaf xylem pressure potential and visual drought score (1 = good; 9 = poor). A) Visual scoring system weighted by leaf rolling as a drought susceptibility symptom. B) Visual scoring system weighted by leaf drying as a drought susceptibility symptom. IRRI, 1976 dry season.

Figure 18, however, shows that rice varieties differ in degree of leaf rolling at a particular leaf water potential. Thus, caution should be used in equating leaf rolling with the degree of internal water stress.

Although the mechanisms involved may be many and varied, avoidance of physiological stress by the maintenance of high leaf water potential is a primary characteristic currently being studied in upland field screening of rices for drought response.

Cuticular resistance. Varietal differences in cuticular resistance were reported in 1974 (1973 Annual Report). To effectively evaluate this trait for incorporation into the GEU breeding



18. Relationship between leaf xylem pressure potential and visual leaf rolling score among diverse rice varieties. IRRI, 1976 dry season.

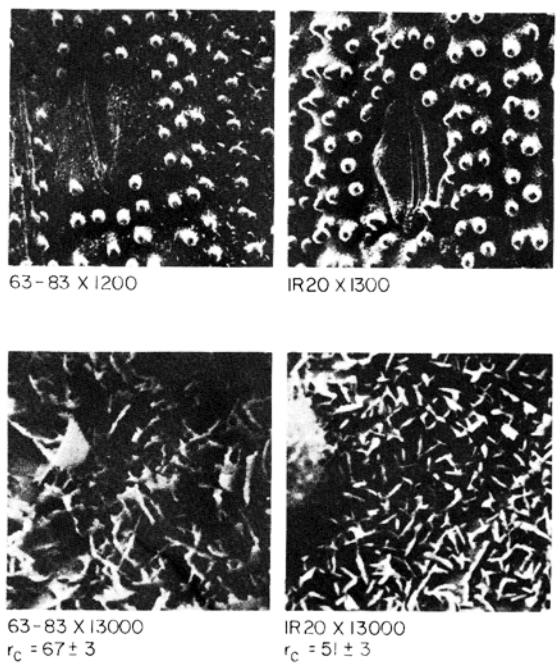
program and to develop a sound screening technique, more fundamental studies were initiated. The studies examined the leaf characteristics involved in cuticular resistance of varieties to water vapor diffusion.

Figure 19 shows scanning electron micrographs of two rice varieties grown in growth chambers at Rothamsted Experiment Station, England. Visual inspection of the leaf surfaces and comparison with cuticular resistance values suggested an association between the extent of epicuticular wax formation and resistance to water vapor movement from the leaf.

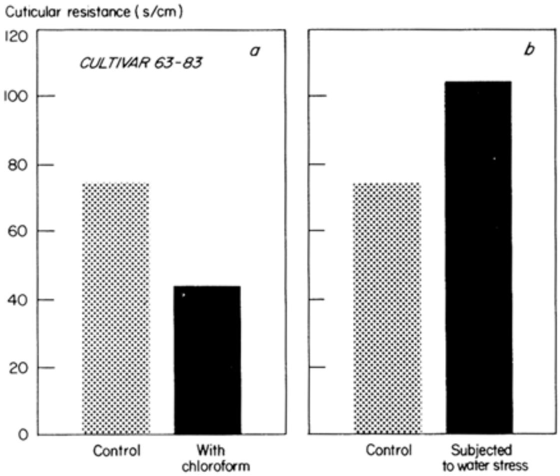
An experiment with the West African upland variety 63–83 indicated the role of epicuticular wax in the control of extrastomatal water loss. The experiment also demonstrated an interesting genotype x environment interaction. Cuticular resistance was measured during the day after stomatal closure by carbon dioxide. In 1973, the influence of stomatal resistance was negated when cuticular resistance was measured after a dark period. In the 1976 study, stomatal closure induced by carbon dioxide under dark, low-light, or high-light conditions proved more effective than closure in the dark alone.

The relevance of the epicuticular wax as a barrier to water vapor flux was investigated. Cuticular resistance was measured before and after the removal of leaf surface wax by a 2-second dip in chloroform, a nonpolar solvent. Figure 20a demonstrates the role of epicuticular wax as a significant component of cuticular resistance to water vapor.

The effect of plant pretreatment was studied by measurements on plants after two different water regimes—control (continuous saturation) and stress (a prolonged period of soil drying followed by return to a saturated condition before measurement). Figure 20b shows the increased cuticular resistance of 63–83 to water stress. This genotype x environment interaction has been documented in other species where it was related partially to increased wax deposition induced by drought stress.



19. Scanning electron micrographs of the leaf surfaces of four rice varieties from varying hydrological conditions. 63–83 = West African upland variety; and IR20 = Philippine hybrid, irrigated lowland variety. r_c is the cuticular resistance (s/cm) measured for each variety (1973 Annual Report and current report). Electron micrographs courtesy of Rothamsted Experiment Station, England.



20. Cuticular resistance to water vapor diffusion is reduced by removal of epicuticular wax by chloroform, and is increased by subjecting plants to prolonged water stress. The cultivar 63–83 is of West African upland origin. (All measurements made after Co_2-induced stomatal closure.)

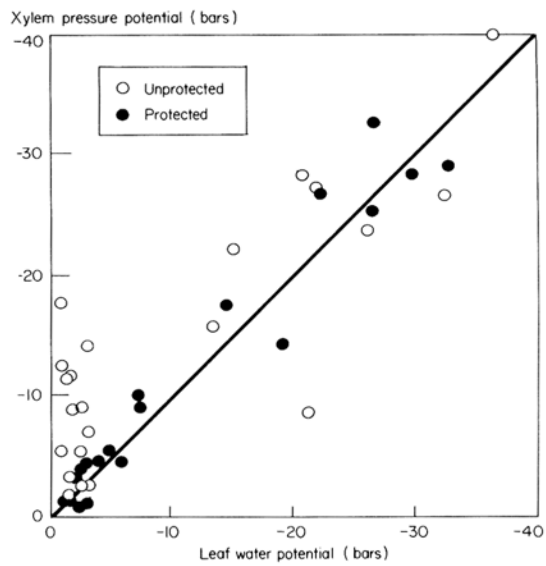
Estimation of leaf water potential. The measurement of tissue water potential, especially for field studies, is greatly facilitated by the use of the pressure bomb or pressure chamber technique. However, accurate estimates of leaf water potential (ψ_l) by measurement of xylem pressure potential (ψ_x) require calibration with a thermodynamically based or psychrometric method.

Measurements of ψ_x were made on protected and unprotected leaf samples of two rice varieties. Before excision, protected leaf samples were enclosed in a damp, cheesecloth-lined, aluminum-covered, plastic leaf holder. Unprotected samples were exposed to ambient atmospheric conditions during excision and subsequent transport to the pressure chamber. The samples were unprotected inside the pressure chamber, but a wet sponge spiral hydrated the incoming nitrogen gas. During sampling, leaf punches were made for psychrometric determination (dew-point hygrometer method) of ψ_l from a leaf that was immediately used for ψ_x determination.

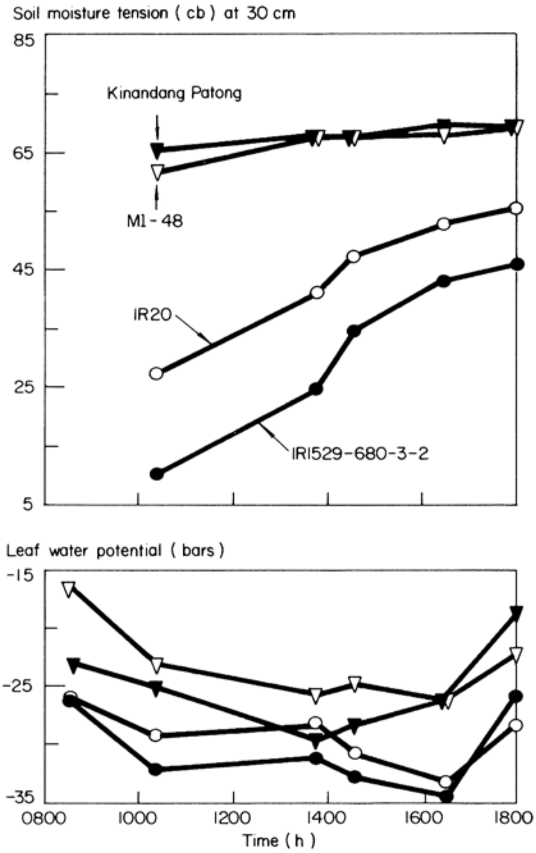
The analysis of variance indicated a highly significant difference between the two measurement techniques when all treatments were combined. Figure 22 shows that a greater error is present when higher water potentials (> -10.0 bars) are estimated with the pressure chamber. A better agreement between the methods is apparent in the lower water potential range (< -10.0 bars). The relative leaf resistance in these "wet" and "dry" ranges of leaf water potential may contribute to that observation.

Figure 21 also illustrates the comparative benefit of protecting the leaf sample for pressure chamber measurement. The practice showed significant effects on correcting ψ_x measures with respect to the ψ_l measured by the dew-point hygrometer as standard. The varieties used also significantly differed in the unprotected control (high water potential) sampling observation. Dular showed an average of -6.5** bars difference between ψ_x and ψ_l, while IR2035-117-3 showed only -1.0 bar. The differences disappeared with the protected sampling procedure or stressed (lower water potential) plants.

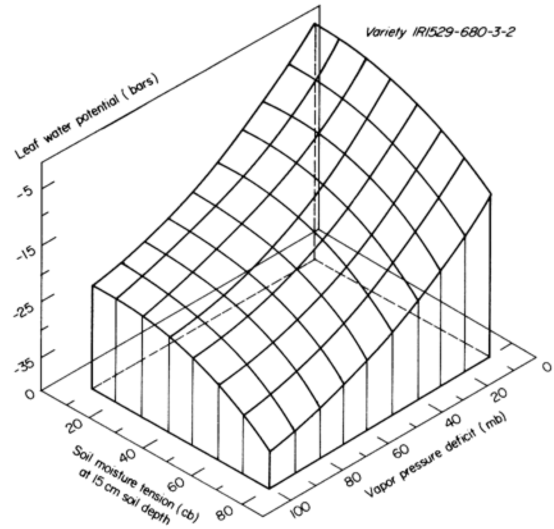
The conclusion is that the pressure chamber, when used with protected leaf samples, gives accurate and rapid field estimates of the actual leaf water potential.



21. Comparison of two estimates of leaf water potential. Xylem pressure potential was measured by the pressure chamber, and leaf water potential by the dew-point hygrometer method.



22. Comparison of leaf water potential and soil moisture tension (30-cm depth) of upland plots of two lowland and two upland varieties or lines (no varietal difference in soil moisture extraction was apparent at 15-cm depth). Cuenca, Batangas, 1976 wet season.



23. Response surface showing leaf water potential response to the combined influence of soil moisture tension at 15 cm soil depth and vapor pressure deficit integrated through the day. Multiple coefficient R = 0.81**. Data from 1975 and 1976 wet season, Cuenca, Batangas.

Varietal differences in water relations. During the wet season, monitoring of moisture in soil, plant, and atmosphere continued in an upland-rice farmer's field. Significant rainfall deficits occurred only twice—July and September. Observations during the July dry period complemented 1975 data (1975 Annual Report) which illustrated varietal differences in leaf water potential and soil moisture extraction patterns during drought periods.

By maintaining higher leaf water potential through the day, the upland varieties M1-48 and Kinandang Patong appear to extract more water at lower soil depth than the hybrid lowland semidwarfs IR1529-680-3-2 and IR20 (Fig. 22). On the day the data were recorded, both the upland and the lowland varieties showed extensive but similar water extracting patterns at the 15-cm depth.

Soil moisture, evaporative demand, and plant-water status of upland rice. The rice crop's response to water stress is often associated only with soil moisture. But under tropical drought conditions, high solar radiation, evaporative demand, and winds can cause significant increase in the degree of plant stress (decreased leaf water potential). Figure 23 illustrates the leaf water potential response to water vapor pressure deficit (saturation vapor pressure-actual vapor pressure) integrated through a day in relation to SMT. Obviously through a period of several rainless days, both degree and duration of plant water stress would be affected by the atmospheric component of drought.

A practical interpretation of the effect of atmospheric conditions on plant water stress could lead to investigations of genetic improvements in the upland rice crop to alleviate the effect of high evaporative demand (see Cuticular resistance). Cultural practices that ameliorate atmospheric drought stress should also be investigated.

Genetic evaluation and utilization (GEU) program

Tolerance for adverse soils

Soil Chemistry and Plant Breeding Departments

SALINITY

Soil Chemistry and Plant Breeding Departments

More than 60 million hectares of current and potential rice land in South and Southeast Asia contain toxic amounts of salt. The varieties presently grown in coastal saline soils have salt tolerance but low yield potential because of poor plant type and susceptibility to diseases and insect pests.

IRRI has screened more than 5,500 varieties from the germ plasm bank, elite breeding lines, and the salt tolerance hybridization program. Two hundred and thirty-seven rices had acceptable salt tolerance. Four lines with high salt tolerance were found in two Pokkali crosses, and IR30, IR32, IR36, and 13 advanced breeding lines showed an acceptable degree of salt tolerance.

Screening for salt tolerance (*Soil Chemistry*). During the year 4,525 varieties and lines were screened for salt tolerance in the greenhouse or in an artificial saline field at IRRI; 192 entries were found tolerant.

The salt-tolerant varieties from the IRRI germ plasm bank were Lal Buchi, Mala Kuta, Mi Pajang, Moisha Bida, Tao Binho, C8435, Bendang Harum, Sri Malaysia II, KLG 6987-133-2, BG11-11, Ketan Kunir, PN 4 Rambagan, Sriurdjaja, BM5, Dee Gee Woo Gen, Saradek Kolang, Siranda Tjogok, Nona Bokra, Pokkali, and ARC 10959.

Greenhouse screening techniques. Greenhouse screening using salinized Maahas clay in small trays was completed for 2,300 entries. The salt concentration was increased to 0.5% to give an EC_e (electrical conductivity of the saturation extract) of 10 mmho/cm, and 6 seedlings were planted per tray. The soils were reused wet, and the concentration of sodium chloride was adjusted after every third test. The method of scoring salt injury according to the percentage of dead or discolored leaves was replaced by visual scoring on a scale of 1 to 9 (Table 1, Fig. 1) because the visual score ($\hat{Y}$) was highly correlated with the leaf-count score (X):

$$\hat{Y} = 0.8 + 1.1\,X \quad r = 0.86^{**} \quad n = 1590$$

Figure 2 confirms the reliability of visual scoring in 20 sets of observations. The two tolerant

Table 1. Scoring salt injury. IRRI greenhouse, 1976.

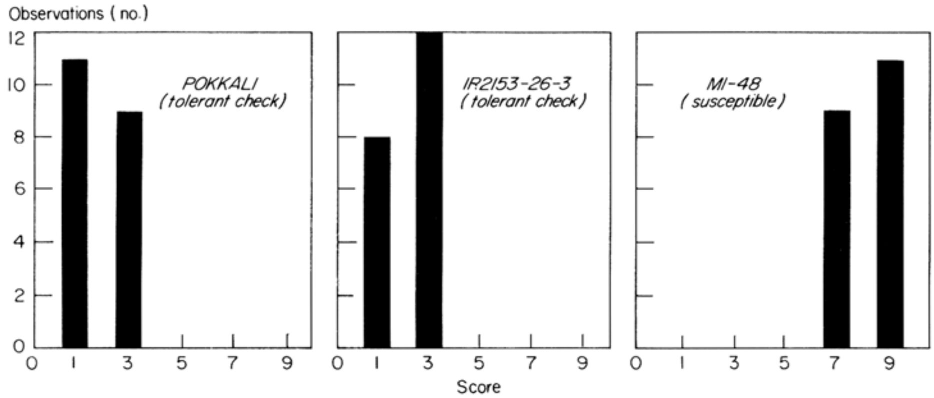
Observation	Score
Nearly normal growth and tillering	1
Nearly normal growth and tillering, but leaf tips or upper halves of the leaves are white and rolled	2
Growth and tillering retarded; some rolled leaves	3
Growth and tillering severely retarded; most leaves are rolled; only a few elongating	5
Complete cessation of growth; most leaves dry; some plants dying	7
Almost all plants dying	9

varieties had no injury score higher than 3, while the susceptible variety did not score below 7.

To ascertain whether salt tolerance present 4 weeks after transplanting persisted until maturity, 17 rices and a susceptible control were grown to maturity in 16-liter pots in a salinized soil with a mean EC_e of 8.7 mmho/cm. Ten weeks after transplanting, 12 entries were scored as tolerant, 2 as moderately tolerant, and 4 as susceptible. Table 2 shows that relative grain yield was highest in those varieties with continuing low scores.

In a similar unreplicated experiment, the score 12 weeks after transplanting was highly correlated with the score 4 weeks after transplanting ($r = 0.88^{**}$). Seven of eight rices rated as tolerant at 4 weeks after transplanting on the salinized soil (EC_e: 9.5 mmho/cm) gave grain

1. Scoring salinity in the field. IRRI, 1976.



2. Frequency distribution of visual scores for salt injury of three rices. IRRI, 1976.

yields that exceeded 70% of the corresponding yields on the nonsalinized soil.

These observations show that the visual score of seedlings 4 weeks after planting in a soil with an EC_e of 10 mmho/cm is a good measure of salt tolerance.

Field screening. Field screening in two salinized blocks at IRRI used 1,920 pedigree lines from the salinity hybridization program and 70 entries in the International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON). The electrical conductivity (EC) of the plots was monitored monthly and salt was added to maintain the EC at about 8 mmho/cm. Loss of salt by leaching and seepage as well as by dilution with rain water caused problems.

Out of 14 crosses made to incorporate salt tolerance, 60 lines that performed well in the IRRI saline field were subsequently tested in the greenhouse. Four lines from IR4630 and IR4763 crosses were highly tolerant of salt and also showed insect and disease resistance (Table 3).

Each season, some moderately salt-tolerant lines are identified among IRRI's elite GEU lines. Most of them have good agronomic characteristics and resistance to insect pests and diseases. The lines are being tested in saline fields in the Philippines, India, Sri Lanka, and Thailand. One line (IR2153-26-3) has been multiplied and is ready for distribution to Philippine farms with saline soils.

The IRSATON entries were tested on salinized and normal soils in adjacent sub-blocks. Three weeks after transplanting, many of the plants in the normal soil showed a discoloration that varied from orange to yellowish brown. The discoloration was much less prominent in the salinized sub-block. The disorder was diagnosed as tungro, but chemical analysis revealed less zinc in both the soil and the plant in the normal soil than in the saline soil. Apparently both tungro and zinc deficiency were present, but the effect of both disorders was less severe in plants on the saline soil.

Table 2. Mean scores for salt injury and relative grain yield of 18 rices in a replicated pot experiment. IRRI greenhouse, 1976.

Variety or line	Mean score[b]		Relative grain yield[a] (%)
	4 wk after transplanting	10 wk after transplanting	
IR28	3.0	8.3	7
IR32	1.7	2.7	75
IR2061-465-1-5-5	1.0	4.3	38
IR2071-88-8-10	1.0	3.0	29
IR2153-26-3-5	1.0	1.7	65
IR2681-163-5-2-2-2	1.7	4.3	35
IR4432-103-6	1.7	3.3	41
Banih Kuning	1.0	2.3	76
Kalarata 1-24	1.0	1.0	98
Kuatik Putih	1.0	1.3	68
Kuatik Serai Rendah	1.0	3.0	61
Kuatik Serai	1.0	1.0	70
Lal Buchi	3.7	7.7	4
Mala Kuta	1.7	8.0	10
Merak	1.0	2.0	78
Mi Pajang	2.3	7.7	8
Mosiha Bide	3.7	8.0	5
Pulot Daeng Maradka	1.7	1.0	92

[a]Relative grain yield $= \frac{\text{Yield in saline soil}}{\text{Yield in normal soil}} \times 100$. [b]Salt-injury score equivalents are in Table 1.

Table 3. Reactions of four salt-tolerant lines to diseases and insect pests. IRRI, 1976.

Line	Source	Score[a]				
		Bacterial leaf blight	Blast	Tungro	Brown planthopper (biotype 1)	Green leafhopper
IR4630-22-2-5-1	43605	1	1	1	1/9	1
IR4630-22-3-3-2	43611	1	1	1	1/9	1
IR4763-141-2-3-1	43613	1	1	1	3	1
IR4763-145-1-2-3	43692	1	1	2	1	1/9

[a]Score is by a range from 1 to 9 with 1 = no symptoms and 9 = plants almost dead. Score 1/9 = results ranging from 1 to 9.

In an unreplicated test of 60 entries in a saline soil in outdoor concrete beds, the five top yielders were IR2071-588-5-4-5, IR32, Bilat Kolom, IR36, and IR2070-433-2-5-6.

Breeding for salinity tolerance (*Plant Breeding*). Of the varieties from the germ plasm bank that had been previously identified as salt tolerant, Annapurna, BR4-10, Getu, Khao Dawk Mali 105, Kao Tah-Haeng, Kalarata 1-24, Nona Bokra, Orkayama, Patnai 23, Pokkali, and SR 26B were used in hybridization. Because those varieties are either tall, photoperiod-sensitive, or poor, short-season rices, they were backcrossed with improved lines that have moderate salinity tolerance, such as IR2153-26-3, IR2035-290-2, and IR2071-88-8. Subsequent crosses were made between improved tolerant varieties and newly identified, tungro-resistant advanced breeding lines, which, in some cases, were moderately salt tolerant.

Four lines with high tolerance for salinity were found in two crosses involving Pokkali: IR4630 (Pelita I/Pokkali//IR2061-464-2/IR-1820-52-2) and IR4763 (IR2035-290-2/Pokkali//IR2035-290-2/IR2061-464-2).

Fourteen advanced breeding lines from the general breeding program and two varieties showed a level of salt tolerance only slightly inferior to that of the salt-tolerant line IR2153-26-5-2. Table 4 lists the lines and varieties and their parentage.

Although breeding emphasis was on salt tolerance, attention was paid to breeding photoperiod-sensitive, intermediate-stature rices that could stand waterlogging. Rices with those attributes are needed in coastal saline areas that have a monsoonal climate.

Table 4. Salt-tolerant varieties and advanced breeding lines. IRRI, 1976.

Designation	Parents
IR30	IR24/TKM 6//IR20^4/*O. nivara*
IR36	IR1561-228-1-2//IR24^4/*O. nivara*//CR 94-13
IR2035-290-2-1-1	IR1416-128-5/IR1364-37-3-1///IR1539-260//IR24^3/*O. nivara*
IR2058-78-1-3-2-3	IR1416-131-5/IR1364-37-3-1//IR1366-120/IR1539-111
IR2061-465-1-5-5	IR833-6-2-1-1///IR1561-149-1//-IR24^4/*O. nivara*
IR2061-522-6-9	"
IR2070-464-1-3-6	IR20^2/*O. nivara*//CR 94-13
IR2070-423-2-5-6	"
IR2071-88-8-10	IR1561-228-1-2/IR1737//94-13
IR2071-105-4	"
IR2071-586-5-6-3	"
IR2071-588-5-4-5	"
IR2153-26-3-5-2	IR1541-102-6-3//IR20^4/*O. nivara*
IR2681-163-5-2-2	CR 94///IR20^3/*O. nivara*//IR1541-102-6
IR2823-399-5-6	IR1529-580-3/CR 94-13//IR480
IR4432-103-6-4	IR2061-125-37//CR 94-13

ALKALINITY

Soil Chemistry and Plant Breeding Departments

There are more than 370 million hectares of alkali soil in the tropics and subtropics. They can be reclaimed by application of gypsum and leaching. During reclamation—usually about 5 years—alkali-tolerant rices can be grown in the moderately alkaline areas.

Since the start of its GEU program, IRRI has screened 6,052 rices for alkali tolerance. Of that number 357 were found tolerant. Alkali-tolerant varieties from the germ plasm bank were used in the breeding program. The breeding lines IR4427-28-3-2 and IR4227-104-3-3-1 showed outstanding alkali tolerance and, with about 30 other breeding lines, are ready for field testing in Australia, Chad, India, Mexico, Pakistan, and Peru, where the alkali problem

Table 5. Distribution of alkalinity tolerance within crosses in the Replicated Yield Trial, 1976 wet season.

Cross[a]	Score[b] of (alkalinity) tolerance									
	1	2	3	4	5	6	7	8	Mean	Total
IR4422, F6		6	7	6		1			3.5	20
IR4427, F5	2	1	3	3	8	8	2	1	6.0	26
IR5105, F5					2	4	5	2	6.7	13
IR4707, F5		3	4	1	1				3.2	9
IR4442 } IR5201 } F5				2	5	4	2	1	5.8	14

[a]IR4422: IR2049-134-2/IR2061-125-3, IR4427: IR2055-451-2/IR2061-464-4, IR5105: IR841-85-1-1/IR2061-464-4, IR-4707: IR1888-156/IR2061-213-2//IR1561-228-3-3, IR4442: IR2061-464-2/IR1820-52-2, IR5201: IR1820-52-2/IR2061-464-2. [b]1 = no symptoms, 9 = plants almost dead. LSD = 1.8 and 2.3 at 5% and 1%, respectively, for 2 lines within the same cross.

is severe. Nine breeding lines had greater alkali tolerance than varieties from alkali-affected areas.

Screening for tolerance. Of more than 4,400 entries screened for alkali tolerance, 230 entries exhibited tolerance. The alkali-tolerant varieties from the germ plasm bank include 60-283, Bali 1, Bali 2, Basmati C622, Burarata 4-10, Cheriviruppu, Giza 159, Karekagga 78, Nabatat Asmar, Sabieny UAR, Pokkali, Nagpili, Getu (2), Urarkondam, Cadung Phen, Pulut Canteng, Joalbanga, Kumari, AC 440, Billekagga 36, Getu (1), Jhona 349 (1), Jhona 349 (2), Ratrio (1), Ratrio (2), BG 79, Cadung Ket Lo, Doc Phung Lun, Phung Lun AR 16, Berlin, and Salumpikit.

Damodar, DA-29, Benzer, Basmati 370, Ainan tsao-1, and MI 273 (all of which had earlier shown alkali tolerance), and several advanced breeding lines with high tolerance for alkalinity were used for hybridization. Many advanced breeding lines showed greater tolerance for alkalinity than Damodar, DA-29, and others. Those lines include IR1628-632-1, IR1632-93-2-2, IR1820-210-2, IR2035-290-2-1-1, IR2053-436-1-2, IR2058-78-1-3-2-3, IR2073-86-1-2, IR2061-465-1-5-5, IR3941-97-1, IR4227-164-1-3, IR4227-28-3-2, and IR4227-104-3.

In addition, 43 lines of 450 entries of the 1976 wet-season Replicated Yield Trial (RYT) were identified as highly tolerant of alkali. Alkali-tolerant varieties with high yield potential are available to countries where alkalinity is a serious soil problem.

Table 6. Correlation between tolerance for alkalinity and agronomic characters in 416 entries in Replicated Yield Trial, IRRI, 1976 wet season.

	Panicles (no.)	Plant ht	Maturity date	Yield[a]
Alkalinity tolerance	−0.13*	−0.17**	−0.11**	−0.17**
Panicle number		−0.35**	−0.32**	−0.38**
Plant height			−0.51**	−0.05[ns]
Maturity date				−0.01[ns]

[a]ns = not significant at 5% level.

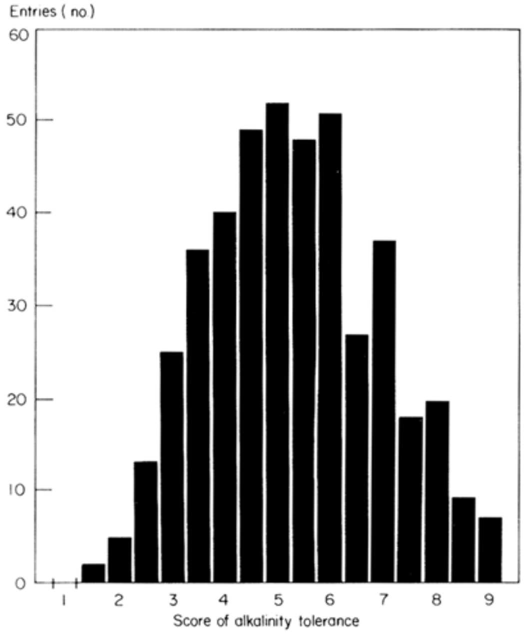
Because of space limitations, emphasis was placed on screening the advanced breeding lines included in the RYT, the Observational Yield Trials (OYT), and the Hybridization Block. In the RYT the reactions of plants within a cross and among crosses significantly differed (Table 5, Fig. 3). Alkali tolerance was positively correlated with improved plant type (Table 6).

Screening techniques. Both greenhouse and field screening used Maahas clay amended with sodium carbonate to give a pH of 8.3–8.6. Much less alkali than salt was lost by leaching, seepage, and surface runoff in the salinized fields. A zinc deficiency that affected earlier tests (1975 Annual Report) was corrected by the application of zinc sulfate.

Because of the high correlation (r = 0.84**, n = 1,066) between the visual scores and the scores based on the percentage of dead and discolored leaves, visual scoring was used in both the greenhouse and the field. Scoring of alkali injury is outlined in Table 7 and illustrated in Fig. 4.

Table 7. Scoring alkali injury in IRRI greenhouse and field, 1976.

Observation	Score
Nearly normal growth and tillering	1
Nearly normal growth and tillering, but leaf tips or upper halves of the leaves discolored	2
Growth and tillering retarded; some leaves discolored	3
Growth and tillering severely retarded; most leaves discolored, only a few elongating	5
Complete cessation of growth; most leaves dry; some plants dying	7
Almost all plants dying	9



3. Distribution of alkalinity tolerance among the entries to Replicated Yield Trial. IRRI, 1976 wet season.

L.S.D. = 2.2 and 2.9 at 5% level and 1% level, respectively.

ACID SULFATE SOILS
Soil Chemistry Department

Acid sulfate soils occupy more than 15 million hectares of the subtropics and tropics that are climatically and physiographically suited to rice. Nearly 10 million hectares of that land are in South and Southeast Asia. Submerged, acid sulfate soils remain nearly neutral and may be suitable for rice. But a rice crop on a submerged acid sulfate soil may suffer from aluminum toxicity in the early stages of submergence, and may suffer as well from iron toxicity or phosphorus deficiency. Rice varieties with resistance to or tolerance for those problems can grow on moderately acid soils without costly, recurrent expenditures.

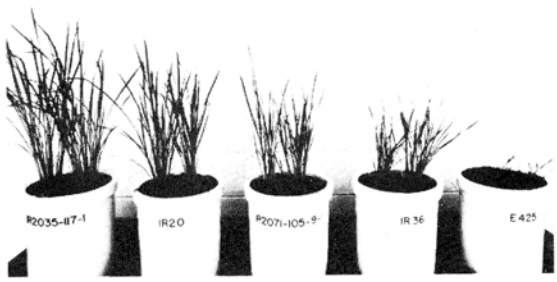
Because acid sulfate soils vary greatly in chemical and hydrological properties, screening for tolerance is best done where such soils occur. Arrangements were initiated in 1976 to start such screening in the Philippines and in Malaysia.

4. Scoring alkalinity in the field. IRRI, 1976.

HISTOSOLS
Soil Chemistry Department

Histosols, or organic soils, cover more than 30 million hectares in Southeast Asia that are suited to rice production. Of that area more than 27 million hectares are in Indonesia. Preliminary tests at IRRI with 195 rices on three Histosols indicated marked varietal differences in tolerance for the adverse effects of the three soils (Fig. 5).

Fifteen rices were grown in pots on a peat soil (pH: 6.0; O.M.: 36%; available zinc: 0.8 ppm). None showed normal growth, but among those with the least injury were IR20 and IR1514A-E666—two rices that have consistently shown tolerance for zinc deficiency. The variety E425, used as the susceptible check in screening for zinc deficiency, fared the worst.



5. Varietal tolerance for Histosol problems. IRRI, 1976.

Histosols vary so much in composition and hydrology that screening is best done in situ. In a test of 180 rices at Kalayaan, Laguna, Philippines, 15 were moderately tolerant. Five of them were IRRI advanced breeding lines— IR2070-413-3, IR2307-112-3, IR4227-103-1, IR4432-103-6, and IR4683-54-2.

IRON-TOXIC SOILS
Soil Chemistry and Plant Breeding Departments

Iron toxicity of rice occurs on strongly acid Oxisols, Ultisols, and Histosols, and on acid sulfate soils. It has been identified as a problem in the Philippines, Malaysia, Indonesia, Thailand, India, Sri Lanka, Liberia, Sierra Leone, Senegal, and Colombia.

Nineteen of 279 rices screened in the IRRI greenhouse during the past 3 years were found tolerant of iron toxicity. The insufficient amount of a suitable soil hampers greenhouse screening for iron toxicity.

Screening techniques (*Soil Chemistry*). Several strongly acid soils were studied for use in iron toxicity screening and only a red-yellow podzolic soil from Taiwan maintained a high concentration of iron in the soil solution after submergence. The quantity of that soil available permits screening 60 entries at a time. Screening by solution culture is difficult because of oxidation of ferrous iron. Screening with sand culture or amended Luisiana clay holds promise.

Screening for tolerance for iron toxicity (*Soil Chemistry and Plant Breeding*). In 1976, 120 entries (mainly 1976 elite breeding lines) were screened in the greenhouse, and 750 entries were field screened in Sri Lanka.

In the greenhouse tests, tolerance for iron toxicity was shown by IR20, IR29, IR32, Banih Kuning, Kuatik Putih, IR2070-413-3, IR2071-137-5, IR2071-586-5, IR2307-217-2, IR2798-88-3, IR2798-115-2, IR2863-38-1, IR3864-217-1, IR4427-164-1, and IR4613-54-5. Several of these breeding lines, some of which were more tolerant than the tolerant controls Pokkali and Devarreddi, included one or more of the sources IR20, IR1416-131-5, and CR 94-13, found earlier to be tolerant of iron toxicity. To increase the existing level of tolerance, crosses using Cadung Go Gung 1601, Mahsuri, IR34, IET 1444, IR2031-238-5, and IR2151-190-3 have been made.

A mass screening project for iron toxicity was initiated in cooperation with the Central Agricultural Research Institute of Sri Lanka. About 400 breeding lines from RYT, and 250 breeding lines from the first group of OYT are being tested in Sri Lanka. Also included are 36 varieties and breeding lines from IRRI and 24 varieties tolerant of iron toxicity.

ZINC DEFICIENCY
Soil Chemistry and Plant Breeding Departments

Zinc deficiency is the third most important problem that limits the yield of wetland rice. It occurs on alkali, calcareous, and neutral soils, on Histosols, and on continuously wet soils regardless of pH. In Asia the deficiency is found in the Philippines, India, Indonesia, and Sri Lanka.

Of 6,768 rices that IRRI screened for zinc deficiency in concrete beds and in the field, 171 were moderately tolerant. IR30, IR32, and IR34, and many IRRI breeding lines were tolerant.

In IRRI, the symptoms were generally most severe on Lipa clay loam (pH: 8.2; O.M.: 10.0%; available Zn: 0.2 ppm) and on Langa silty clay loam (pH: 5.8; O.M.: 3.2%; available Zn: 0.6 ppm). The varieties differed in time of appearance of symptoms, intensity of the symptoms, and speed of plant recovery. By those criteria, E425 was the most susceptible and IR1514A-E666 the least susceptible.

The varieties also differed in color of the affected leaves. All varieties showed a characteristic blanching of the base of the emerging leaf 2 to 4 weeks after sowing. A week later, brown spots were clearly visible on all leaves of E425 and IR26 (susceptible varieties). The older leaves then turned brown and brittle.

In IR4-11 (moderately tolerant), the older leaves turned yellow without displaying brown spots, and then became brown and dry. In IR1514A-E666 (tolerant), only a slight yellowing of the older leaves was observed.

E425 died on Lipa clay loam and hardly recovered on the other soils. After 6 weeks, IR26 and IR4-11 recovered on all soils except

Lipa clay loam and Langa clay loam, on which the recovery was slight.

Because of varietal differences in the manifestation of symptoms, zinc deficiency may be mistaken for nitrogen deficiency, or iron toxicity, which is characterized by brown spots and orange-brown discoloration of older leaves.

Screening for tolerance for zinc deficiency. IR30, IR34, and many of IRRI's breeding lines that are tolerant or moderately tolerant of zinc deficiency, were grown on the slightly zinc-deficient soils of IRRI. They emerged without specific selection for zinc deficiency.

Screening 1,768 rices on a moderately zinc-deficient soil in concrete greenhouse beds showed 278 tolerant, 458 moderately tolerant, 773 moderately susceptible, and 263 susceptible.

Among 3,391 varieties from the germ plasm bank and 43 elite breeding lines, 171 were found moderately tolerant of severe zinc deficiency in a farmer's field at Tiaong, Quezon, Philippines. The most tolerant varieties were BG90-2, IR20, and IR34. The best breeding lines were IR2070-423-2-5, IR2071-137-5, IR2307-64-2, and IR2823-399-5.

The Tiaong tests revealed two aspects of the plant's response to zinc deficiency. Brown lesions appeared at the four- to five-leaf stage and the plants died when the deficiency was severe; when the deficiency was not severe, the plants recovered, manifesting strong varietal differences.

Screening techniques. Zinc deficiency has been observed on soils with pH of 5.4 to 8.7, from 1.7 to 37% organic matter content, and from 0.4 to 1.8 ppm available zinc. Screening is best done in the environment in which the deficiency occurs. If the deficiency is acute, no variety may appear tolerant.

PHOSPHORUS DEFICIENCY
Soil Chemistry and Plant Breeding Departments

Phosphorus deficiency occurs on millions of hectares including Vertisols, Ultisols, Oxisols, and acid sulfate soils. Some of those soils not only are low in phosphorus but also fix large amounts of applied phosphate fertilizers.

Of 314 rices (chiefly 1976 elite lines and OYT and RYT entries) screened in a culture solution, 74 were found tolerant of phosphorus deficiency. Outstanding among them were IR28, IR29, IR30, IR1514A-E666, IR2061-464-2, IR2061-465-1, IR2061-628-1, and IR2061-522-6. Five hundred entries are being field tested in Sri Lanka and 400 in the Philippines, on phosphorus-deficient soils.

Of 30 varieties grown on a phosphorus-deficient soil in a replicated field experiment, IR8, IR34, IR2071-586-5, IR2153-26-3, IR2832-141-2, and IR4432-103-6 gave grain yields exceeding 4 t/ha in the no-phosphate treatment and produced yield increases of less than 25% where 25 kg P/ha was added. These varieties may be considered tolerant of phosphorus deficiency. Other rices that have consistently shown tolerance for phosphorus deficiency are IR1514A-E666, IR2061-464-2, IR2061-465-1, and IR2061-628-1.

IRON DEFICIENCY
Soil Chemistry Department

Iron deficiency is an important factor limiting the growth and yield of upland rice on most soils. It also limits yields of wetland rice on alkali soils and, regardless of pH, on soils that dry out when the rains fail.

Work at IRRI has shown that varieties markedly differ in tolerance for iron deficiency. The traditional upland varieties are less susceptible to iron deficiency than are wetland varieties. Of the IR hybrids, IR1561-228-3 is one of the most tolerant.

MANGANESE AND ALUMINUM TOXICITIES
Soil Chemistry Department

Manganese and aluminum toxicities limit the growth of upland rice on acid Oxisols and Ultisols. The typical upland varieties Palawan, Azucena, OS 6, and M1-48 have high tolerance. IR1754-F58-23, a hybrid between OS 6, a typical upland variety, and an improved line showed remarkable tolerance for manganese and aluminum toxicities. Among the most susceptible were Peta and IR20.

Genetic evaluation and utilization (GEU) program

Deep water and flood tolerance

Thai-IRRI Cooperative Deep-Water Project, Plant Breeding, Agronomy, and Plant Physiology Departments

BREEDING PROGRAM AT THAILAND AND IRRI

Thai-IRRI Cooperative Deep-Water Project and IRRI Plant Breeding Department

The current deep-water rice breeding program primarily concentrates on improved semidwarf and intermediate-height varieties that tolerate water depths ranging from 50 to 150 cm. About 50% of Asia's rice is grown in such water depth. By using floating varieties in the crossing program, it may be possible to retain, in addition to elongation ability, such characters as fast seedling growth, photoperiod sensitivity, and drought tolerance.

Some breeding of rice for deeper water (150–300 cm) is also under way with basic studies on such characteristics of the traditional floating varieties as "kneeing," nodal roots, and tillering at the upper nodes.

The breeding lines that resulted from the numerous crosses made in 1976 were screened both at IRRI and in Thailand for the different important characters needed in deep-water rice areas. The promising lines from IRRI and from other countries were planted at IRRI for seed increase and subsequent distribution to other plant breeders.

With the use of F_3 and F_4 material (parent-progeny regression), the heritability of elongation was estimated in two crosses of an ordinary semidwarf line with two Thai floating varieties. The highest value for one cross was 44%, that for the other was 35%. The results suggest that screening tests for that character should be repeated during several seasons to ascertain the readings obtained. The information should be useful to breeders who have begun to make such crosses for their own programs.

A recently concluded study viewed the elongation ability of segregating lines in relation to their respective seedling heights before the increase in water depth, and also in relation to their respective plant heights in a parallel shallow-water planting. A strongly positive correlation was obtained, which suggests that plant height in shallow water is an important variable contributing to elongation ability. Elongation tests should, whenever possible, group those entries without too much difference in plant height.

Semidwarf types are being bred for greater tolerance to complete submergence, an advantage for plants that do not elongate but are planted in places where floodwater recedes rapidly.

SCREENING DEEP-WATER RICES FOR DROUGHT TOLERANCE

Agronomy Department

In rainfed, deep-water rice areas, an early seeding date assures seedlings of sufficient size when elongation is required by rising water levels. However, the uncertain onset of monsoon rains—and the possibility of drought—increases the farmer's risk from early planting.

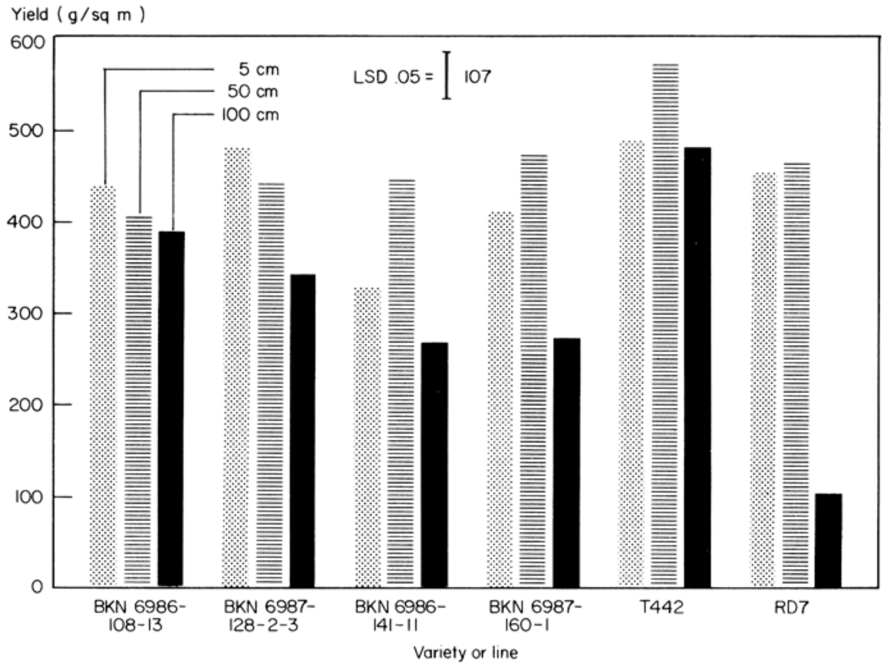
Greenhouse, phytotron, and field screening techniques developed at IRRI identified varietal differences in response to seedling-stage drought. The results are in Table 5, p. 110, and illustrate the great difference among rice germ plasm of different geographical and hydrological origins. The results show that drought tolerance and deep-water tolerance can be incorporated into the same variety. Several traditional varieties of deep-water origin as well as some selected hybrids attest to that concept's validity.

RESPONSE TO WATER DEPTHS OF SEMIDWARF LINES WITH ELONGATION ABILITY

Thai-IRRI Cooperative Deep-Water Project

Exposing four new photoperiod-insensitive, deep-water, experimental lines to increasing water depths of 5, 50, and 100 cm during the 1976 dry season generally decreased their grain yields, but the decreases were not statistically significant (Fig. 1). The near-zero yield of the nonelongating entry (RD7) at a 100-cm water depth suggests the advantage of the new semidwarfs with elongation ability in areas where flooding for long periods of time is a problem.

Although the entries used were relatively photoperiod insensitive, they exhibited delayed flowering at the 100-cm water depth. That



1. Yields of six varieties and experimental lines of rice grown at 13 water depths at the Huntra Rice Experiment Station, Thailand, 1976 dry season.

suggests competition between the elongation process, and the leaf- and panicle-formation processes. The delay in flowering may also be seen in the photoperiod-sensitive varieties so that flowering dates, although controlled by day length and therefore relatively fixed, may vary depending on the water regime.

Except T442-57, entries with elongation ability showed no significant yield increases with added nitrogen. That result may be partly due to high soil fertility as evidenced by the high yields without added nitrogen. The results obtained with T442-57 suggest, however, that nitrogen fertilizer can increase grain yields even under medium water-depth conditions.

MULTILOCATION YIELD TRIAL
Thai-IRRI Cooperative Deep-Water Project

A multilocation yield trial of 25 new photoperiod-insensitive, deep-water lines and 2 high yielding varieties were conducted under shallow-water conditions on Thailand's Central Plain.

The results suggest that the elongation character can be transferred to ordinary high yielding varieties without sacrificing grain yields (Table 1), and that the new lines for deep-water rice areas can be used in shallow-water areas.

SCREENING FOR ELONGATION ABILITY
Plant Breeding and Plant Physiology Departments

An additional 311 entries from the IRRI germ plasm collection were screened for ability to elongate when subjected to a 100-cm water depth. The varieties with good elongation ability, erect tillers, and relatively high tiller number are shown in Table 2.

More than 500 lines from the IRRI crosses were also screened; the few plants that showed good elongation ability will be further evaluated. Backcrosses or better materials may be needed. The tested IRRI crosses and their parents were

- IR5857 = Tarao Bao/IR2055-481-2//IR2061-214-3-6

Table 1. Grain yield of some deep water-tolerant lines grown under shallow-water conditions. Data from the multilocational yield trial of 25 lines and 2 high yielding varieties. Central Plain, Thailand, 1976.

Selection number	Yield (t/ha)
BKN 6986-68-7	4.3
BKN 6986-136-2	4.2
BKN 6986-108-3	4.1
BKN 7022-6-4	4.2
BKN 6986-66-2	4.1
BKN 6986-128-2-1	4.1
RD7 (control)	4.3

- IR5890 = CR94-13/Saleth Yuon Vear// IR2055-462-3
- IR2956 = Kekowa Bao/IR2061-213-3// IR34
- IR9290 = Tarao Bao/IR2153-26-3// IR2153-26-3

Several lines from the IR5857 cross had elongation ability and good plant type. Some lines from crosses made in Bangladesh were also screened for rapid elongation.

SCREENING FOR SUBMERGENCE TOLERANCE

Plant Physiology Department

About 1,500 varieties from the IRRI germ plasm collection were screened for submergence tolerance. Several varieties, which had good submergence tolerance (Table 3), will be further evaluated as possible entries into the hybridization program.

A total of 1,532 lines, which represent the progeny of 59 crosses, were also evaluated for submergence tolerance. Many IR lines were identified as highly tolerant even after 7 days of complete submergence in water at the seedling stage. Lines from IR5857, IR5853, and IR5825 were selected for their high submergence tolerance.

Table 2. Varieties with rapid rate of internode elongation, erect tillers, and good tillering capacity screened from 311 entries. IRRI, September, 1976.

Variety	Country	Tiller angle (°)	Plant ht (cm)	Tillers (no.)
Bir-Co-Shoa-Yen-Tsan	China	19	97	21
Kendal Mordo	Portugal	21	83	13
Lung-An-Shuang-Chiang Pai	China	20	91	20
Nen-Oh	China	21	104	18
Os Wied	India	23	96	14
Thou-46-16	China	20	103	15
Thou-Dau-Bir-Goo	China	22	105	13
Thou-Hsu-Dau	China	24	94	20

Table 3. Varieties tolerant of submergence, screened from 1506 varieties under severe testing conditions.[a] IRRI, August 1976.

Variety	Acc. no.	Origin	Survival (%)
Betichikon	26303	Bangladesh	45
Hida	26471	Bangladesh	45
ARC 12038	21853	India	38
Kakua	26482	Bangladesh	33
Duda Monor	26335	Bangladesh	28
Pani Torong	26411	Bangladesh	28
Cai Don	26196	Vietnam	28
ARC 12059	21874	India	25
Laha dup	26387	Bangladesh	23
Dudhsar	26458	Bangladesh	23
ARC 12037	21852	India	20
ARC 12172	21960	India	20
ARC 12503	22108	India	20
ARC 12606	22185	India	20
Depu Sail	26328	Bangladesh	20
Kaika	26361	Bangladesh	20
Kanial	26489	Bangladesh	20
SML Temerin (check)	10870	Surinam	15
Nam Sagui 19 (check)	11462	Thailand	1

[a]Retested from previously screened varieties reported as equal to or better than Nam Sagui 19. Seedlings were submerged for 8 days instead of 7.

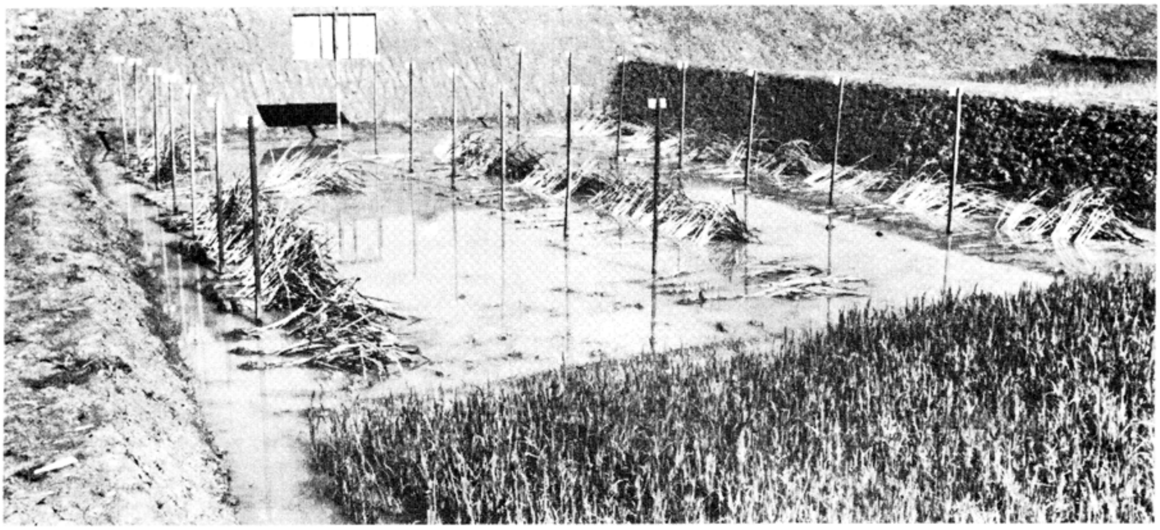
TESTING FOR KNEEING ABILITY

Thai-IRRI Cooperative Deep-Water Project and IRRI Plant Physiology Department

After the internodes have elongated and the floodwaters have receded, deep-water plants usually lodge. The varieties for deep-water rice areas must have the ability to bend ("knee") toward the vertical axis so that the first three leaves are above the water level. The "kneeing" ability prevents the decay of the leaves, provides better leaf arrangement, puts the panicle above the reach of feeding fish, and prevents seed damage by water.

A simple test was developed to screen rice plants for kneeing ability. The kneeing test is best conducted on plants that are at least 2 months old. The soil is carefully cut around the base of the plant and the plant is gently pulled out. The pulled plants are placed horizontally on the puddled field (Fig. 2). Eight days later they are scored for kneeing ability, according to the reactions shown in Figure 3. The test should have at least four replicates.

Of 50 entries tested, ARC 5955, BKN 6986-29,



2. A kneeing ability demonstration plot shows improved lines with good kneeing ability 4 days after horizontal placement in a puddled soil. The front center of the plot shows T442 57, a line with no kneeing ability. Huntra Rice Experiment Station, Thailand, 1976.

BKN 6986-59-12, BKN 6986-58-1, and BKN 6987-225 showed good kneeing ability.

PHOTOPERIOD RESPONSE OF FLOATING VARIETIES
Thai-IRRI Cooperative Deep-Water Project

Cooperative field and greenhouse studies were conducted in six different latitudes to determine the photoperiod response of 17 deep-water rices. The studies will allow prediction of the reaction of the new breeding lines when they are introduced into other latitudes.

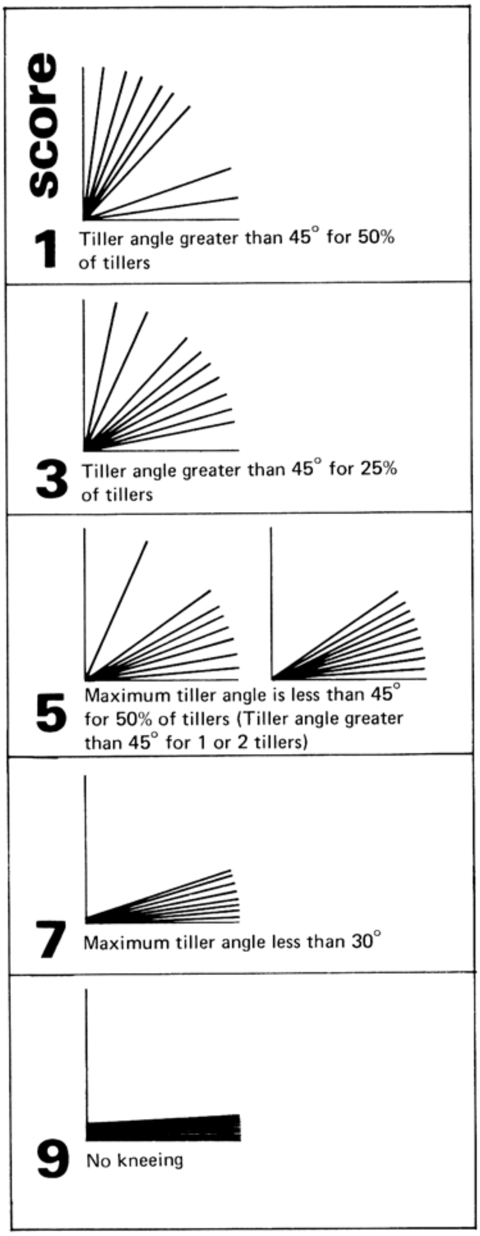
The results indicated that critical day length (day length at the panicle initiation stage) is not a good criterion to use in predicting the possible flowering date of a photoperiod-sensitive variety (Table 4); the range obtained was too wide to be useful in predicting the month of flowering for a particular variety at a given latitude.

The best method to date for determining the flowering behavior of a variety in a specific site is to grow the variety at that site. However, plant breeders can narrow down the number of lines to be introduced into another country by planting a deep-water rice variety from that country and selecting the lines that flowered more or less at the same time as that variety.

Table 4. Estimated day lengths at panicle initiation of selected deep-water rice varieties from the 1975 DeepWater Rice Flowering Date Survey planted in six locations.[a]

Variety	Estimated day length (h)					
	Kalimantan Banjarmasin 3°20′S	Colombia Palmira 4°00′N	Thailand Bangkhen 14°00′N	West Bengal Chinsurah 22°52′N	Bangladesh Dacca 24°00′N	U. Pradesh Ghograghat 27°00′N
Leb Mue Nahng 111	11 56	12 09	11 54	n.a.	11 36	11 19
Habiganj A 1	11 56	12 16	12 32	12 28	12 42	12 20
Habiganj A 2	11 56	12 14	12 25	12 14	12 34	12 18
Kekoa Bao	n.a.	12 11	12 26	12 12	12 57	12 16
Kalar Harsall	n.a.	12 06	12 03	11 51	11 47	11 37
Laki 192	11 56	12 14	12 31	12 21	12 21	12 07
Gowai 84	11 58	12 06	12 19	12 07	12 11	12 04
ARC 5955	11 57	12 18	12 57	13 12	13 37	13 13
Baisbish	11 56	12 16	12 23	11 53	12 15	11 17
Saran Kraham	n.a.	12 07	12 00	n.a.	11 44	11 34

[a]n.a. = Data not available.



3. Score system for kneeing ability in rice.

BASIC STUDIES

Plant Physiology Department

Drought stress and elongation ability. Deep-water rice is generally broadcast under upland conditions early enough to get the plants well established before the rapid rise in water level. Early planting, however, may result in young plants' dying or suffering because of stress from drought. Varietal improvement, therefore, involves both the ability to elongate at an early stage and drought tolerance at the seedling stage.

The ability of floating rices to elongate under deep-water conditions may be affected by drought stress. An experiment was conducted to study the effect of drought on the subsequent ability of floating rice to elongate when submerged.

Seeds of Leb Mue Nahng 111 (LMN 111)—a typical floating variety from Thailand—and of IR442-2-58—a line with some ability to elongate —were sown in pots. The soil was kept at field capacity until 26, 30, and 34 days after seeding, and then water was withheld for 4, 8, and 12 days, respectively. The plants were submerged in water 2 days after rewatering, and the water level was increased at the rate of 30 cm/day. A 100-cm depth (third day) was maintained for 5 days.

Drought stress definitely inhibited the capacity of LMN 111 and IR442-2-58 to elongate (Table 5). Plant height after submergence was inversely proportional to the length of time that water was withheld before submergence. The shorter plant height was reflected in the shorter internodes. Plants subjected to drought for 12 days did not produce any elongated internodes and showed no significant increase in plant height.

LMN 111 had a greater capacity for internode elongation than IR442-2-58, and the reduction in internode elongation as a result of drought stress was less for LMN 111 than for IR442-2-58.

Table 5. Effect of moisture stress on the elongation ability of Leb Mue Nahng 111 and IR442-2-58 submerged for 8 days.

Stress period (days)	Plant ht (cm)		Internode length (cm)	
	Before submergence	After submergence	Before submergence	After submergence
	Leb Mue Nahng 111			
12	65	69	0	0
8	72	114	0	3.6
4	87	143	0	24.0
0	101	155	0.6	30.0
	IR442-2-58			
12	52	49	0	0
8	58	64	0	1.0
4	65	80	0	7.3
0	66	93	0.2	11.9

However, drought inhibited the plant height of LMN 111 more than it did the height of IR442-2-58 before submergence.

Studies on the Rayadas. The Rayadas are unique floating rice varieties from Bangladesh. They are planted in November or December and harvested the following November or December. They are grown in areas where water depths vary from 370 to 600 cm. They tolerate submergence and possess good elongation ability.

The Rayada lines may have plant characters that can be used in the breeding program for deep-water rice.

- *Early internode elongation.* Deep-water rice varieties must be at least 4 to 6 weeks old by the time the fields become flooded. Three of the 13 Rayada lines tested showed internode elongation at 3 weeks of age. Those lines—R16-08, R16-09, and R16-10—are possible parents in breeding for varieties with ability to elongate at an early stage of growth. R16-09 showed internode elongation at 2 weeks of age; it also showed the most internode elongation at 3 and 4 weeks.

All the Rayada lines showed rapid elongation after only 2 weeks of growth, but it was mainly elongation from the leaf blade and the leaf sheath. Such elongation is temporarily useful so that leaves can emerge above the water level. For better survival—leaves held straight above the water level—internode elongation is needed.

- *Photoperiod response.* Rayada lines planted in November or December flower in October or November the following year. Studies show that they flower at a 12-hour photoperiod. Although they have a long basic vegetative phase (36–64 days), the Rayadas should flower in February or March if planted in November or December. However, that is not the case under field conditions. It was noted that at different photoperiods the Rayada lines produced flowers on the primary tillers, and that the many thin tillers do not produce any flowers. Those irregularities observed under short-day conditions are unusual in rice varieties.

- *Flowering response to temperature regimes.* Because November to March in Bangladesh is generally cool, it might affect the flowering response of the Rayada lines and explain their nonflowering during the short days of February or March. Three representative Rayada lines were grown in the IRRI phytotron at day temperatures of 20, 26, 29, and 32°C, and at a night temperature of 21°C from 1700 to 0700 hours. The different temperature regimes, specifically day temperatures, had little effect on the growth duration of the lines. The maximum delay obtained with low temperature (20°C) was 13 days.

The photoperiod and temperature responses of the Rayadas in the greenhouse and in the phytotron did not explain their long growth duration in the field. The Rayadas could be perennials that become dormant during the dry season.

Nodal rooting ability. Work is in progress to develop a rapid method for testing the rooting ability of deep-water rice. Several factors, i.e. temperature and light intensity, greatly affect the rooting ability. The control of those factors is being studied in detail in the rooting tests.

INTERNATIONAL COOPERATION

Thai-IRRI Cooperative Deep-Water Project and the IRRI

In November 1976, a deep-water rice workshop sponsored by IRRI in cooperation with the Rice Division, Ministry of Agriculture and Cooperatives of Thailand, was held in Bangkok. Forty scientists and more than 40 observers attended the 3-day workshop. The participants reviewed 2 years of deep-water research and toured deep-water rice areas and the deep-water rice experiment station.

The workshop covered basic studies on and screening methods for deep-water rice, and progress on deep-water rice research in different countries. The participants approved a deep-water rice terminology and recommended a standard scoring system for measuring the elongation ability of deep-water rice.

The first International Rice Deep Water Observational Nursery (IRDWON) started in 1976. Ten countries, excluding those cooperating with WARDA, participated in the project. The 50 entries of the nursery were screened for various desirable plant characters, and several were selected for further larger scale testing.

Genetic evaluation and utilization (GEU) program

Temperature tolerance

Plant Physiology, Statistics, and Plant Breeding Departments

LOW TEMPERATURE
Plant Physiology and Statistics Departments

Research to date shows great possibility for yield improvement in areas where low temperatures persist. The shorter growth duration of improved lines makes two crops a year possible for some areas instead of the traditional one crop a year. It has further encouraged breeders to make new crosses and to evaluate the progeny lines in 1976. More countries participated in the trials of the new lines.

Germ plasm evaluation (*Plant Physiology*). During the year, 3,572 entries were screened for tolerance of low temperature by techniques developed at IRRI (1975 Annual Report). Twelve indica varieties were rated tolerant. The criteria used were optimum growth duration, proper plant height at maturity, low spikelet sterility at harvest, and green leaves at the seedling stage. The 12 varieties plus 6 others previously identified as cold tolerant were further evaluated for cold tolerance (21°C) at flowering. Table 1 shows the six best varieties.

Temperature and growth duration (*Plant Physiology and Statistics*). Flowering is delayed at temperatures ranging from 32° down to 15°C. The delay at low temperatures is especially marked in the modern rice varieties when they are introduced into the temperate zones or into high-elevation areas.

An experiment using naturally lighted growth cabinets and several temperature regimes in the IRRI phytotron showed that minimum temperature alone does not account for the variations in growth duration (Table 2). Fujisaka 5 growing at the same minimum temperature (24°/18°C, 20°/18°C) greatly differed in growth duration (79 vs. 102 days). Similarly, growth duration varied greatly (from 59 days to 77 days) among plants growing at the same average temperature (24°C) but at different diurnal temperatures. Because heat summations varied with temperature regimes, they had little use in predicting growth duration.

The following relationship was obtained from the growth duration data (Table 2):

$$\frac{1}{D} = A[aT_{day} + (1-a)T_{night} - T_o]$$

where A is a constant, D = days to flower, T_{day} = average temperature during the day, T_{night} = average temperature during the night, T_o = base temperature, and a indicates the relative weight between T_{day} and T_{night}.

The "effective daily temperature" is therefore defined as the weighted average of day and night temperature with a as the weight, or

$$[aT_{day} + (1-a)T_{night}].$$

For IR8 the relationship was

$$\frac{1}{D} = 0.00069\ [-0.032T_{day} + 1.032T_{night} - 8.1]$$

and the multiple correlation coefficient is

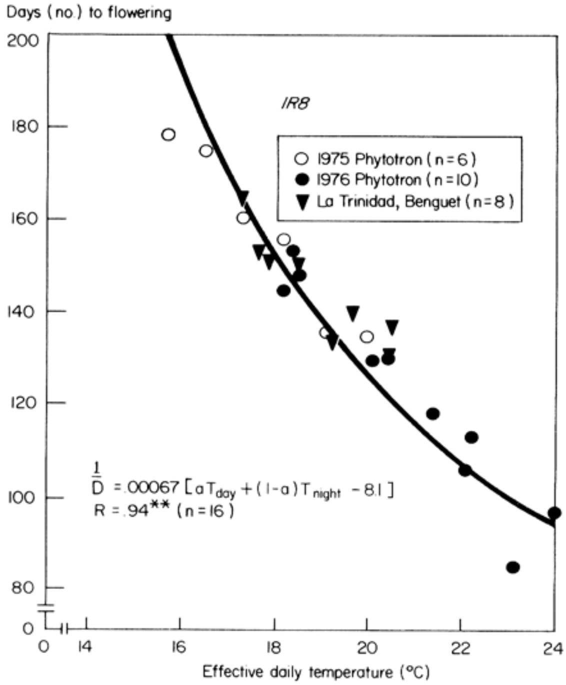
Table 1. Varieties tolerant of low temperature on the basis of growth duration, plant height, spikelet sterility, leaf color, and anthesis, selected from 12,200 entries of the germ plasm bank. IRRI, 1976.

Cultivar	Country of origin	Spikelet sterility (%)	Anthesis at 21°C (%)
Pratao	Brazil	8	100
C21	Philippines	25	100
Leng Kwang	China	27	70
Silewah	Indonesia	13	100
Thangone	Laos	9	80
Dourado Agulha	Brazil	11	80

Table 2. Effect of various temperature regimes on the number of days to flowering of Fujisaka 5 and IR8. IRRI phytotron, 1976.

Day/night temp. regime (°C)	Av. temp. (°C)	Days to flowering (no.)	
		Fujisaka 5	IR8
Same night temperature, different day temperature			
36/18	24.0	77	[a]
32/18	22.7	74	148
28/18	21.3	78	153
24/18	20.0	79	145
20/18	18.7	102	[a]
Same average temperature, different day and night temperature			
24/24	24.0	62	98
26/23	24.0	59	84
28/22	24.0	61	112
30/21	24.0	63	118
32/20	24.0	69	130
36/18	24.0	77	[a]
Same day temperature, different night temperature			
24/24	24.0	62	98
24/22	22.7	63	106
24/20	21.3	77	129
24/18	20.0	79	145

[a]No flowering at experiment's termination 155 days from seeding.



1. Regression line and actual values obtained for IR8. The a value was changed from 0.033 to 0.454 for field data with T_{night} less than 17 C.

0.958**. Data from 1975 phytotron studies were included in the 1976 data. Figure 1 shows the slightly modified regression curve and the fit of data.

Some data obtained from the low-temperature area of La Trinidad, Mountain Province, Philippines, do not fit the regression curve. Some minimum temperatures were below the base temperature, as computed from the phytotron experiments. The day and night phytotron temperatures were constant. Under field conditions, an average of 12°C for the minimum temperature during growth could mean several days with temperatures lower than T_o (8.1°C) and certainly below the lowest T_{night} used in the phytotron. However, changing the relative weight of T_{day} and T_{night} from $a = 0.033$ to $a = 0.454$ for field data with T_{night} of less than 17°C fitted the La Trinidad data into the regression curve.

Hence, the equation for determining the growth duration of IR8 at a certain site, when temperature data are available, is

$$\frac{1}{D} = 0.00067\,[aT_{day} + (1-a)T_{night} - 8.1]$$

with $a = 0.454$ when T_{night} is less than 17°C, and $a = 0.033$ otherwise.

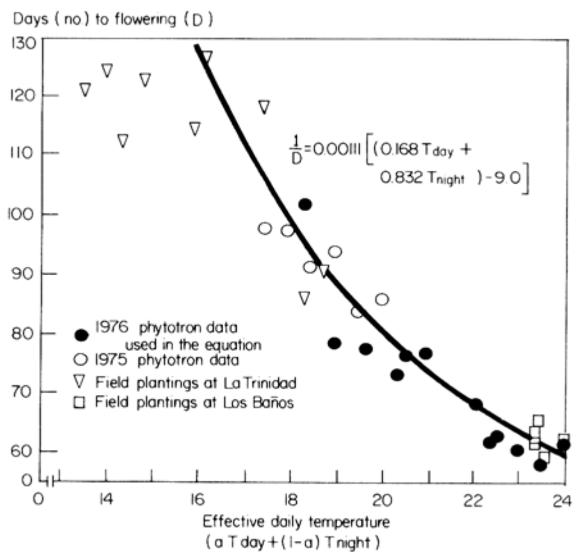
For Fujisaka 5 the relationship was

$$\frac{1}{D} = 0.00111\,[0.168T_{day} + T_{night} - 9.0].$$

The multiple correlation coefficient is 0.91**, indicating that the combination of day and night temperature accounted for 83% of the variation in the growth duration.

Figure 2 shows the regression curve and the fit of data obtained from the present and previous experiments conducted in the phytotron, and the field data from Los Baños and La Trinidad for Fujisaka 5. Some data from the low-temperature area of La Trinidad do not fit. The regression curve needs to be modified further.

In both varieties night temperature influenced growth duration more than did day temperature. That relative effect was greater in IR8 than in Fujisaka 5.



2. Regression line computed from 1976 phytotron data and the actual values obtained from the phytotron and field plantings of variety Fujisaka 5, at Los Baños and La Trinidad, Philippines.

LEAF ANGLE AND TEMPERATURE

Plant Physiology Department

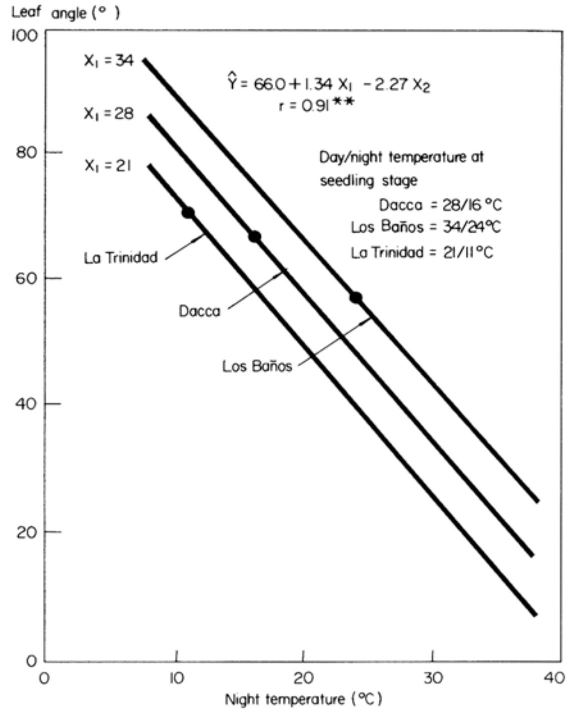
While IR8 and Fujisaka 5 were growing in the phytotron, the leaf angle varied markedly among some temperature regimes. The leaf angle of the second and third fully mature leaves was measured, and data were analyzed. The difference in day and night temperature had the best correlation with leaf angle. Day temperature had positive correlation with leaf angle of both varieties, but minimum temperature showed a significant negative correlation with the leaf angle of only IR8. The average daily temperature showed no correlation with leaf angle. In areas with a wide range of diurnal temperatures, or with high day temperatures, the leaves of IR8 and Fujisaka 5 are more open than erect.

To find out how widespread that response is, 50 varieties from different countries were grown at day/night temperatures of 20°/20°C and 26°/18°C. Forty-two had droopier second leaves at the higher diurnal temperature difference (Table 3). The varieties in the two temperature treatments did not significantly differ in the length of the leaf blade and sheath.

In Dacca, Bangladesh, and in Los Baños and La Trinidad, Philippines, differences between the maximum and minimum temperatures in the field are about the same. The average maximum and average minimum temperatures are therefore the determining factors. The day temperatures during the seedling stage in Los Baños were higher than those in Dacca and La Trinidad, and the seedlings were expected to have droopier leaves. But the lower minimum temperatures at Dacca and La Trinidad resulted in droopier leaves (Fig. 3). Plant breeders have considered the change in plant type (plant height, tillering, growth duration) caused by temperature. They should also consider the changes in leaf angle caused by temperature.

Table 3. Angle of the second leaf of 50 cultivars at 20°/20°C and 26°/18°C day/night temperatures. IRRI phytotron, 1976.

Temperature regime (day/night)	Varieties (no.)	Average leaf angle (degrees)	Range (degrees)
Increased leaf angle with larger diurnal temperature difference			
20°/20°C	42	40.3	20.4–60.9
26°/18°C	42	50.5	25.1–91.0
Difference		10.2	4.7–30.1
Decreased leaf angle with larger diurnal temperature difference			
20°/20°C	8	47.2	39.5–59.5
26°/18°C	8	43.6	38.7–51.7
Difference		3.6	0.8– 7.8



3. Effect of night temperature on leaf angle of the second mature leaf of IR8 at different day temperatures. 1976.

PROGRESS IN BREEDING FOR COLD TOLERANCE

Plant Breeding Department

The breeding program for cold tolerance expanded considerably with the additional entries to the pedigree nursery, the increase in F_2 populations, and the introduction of an observational yield trial (OYT) at Banaue, Philippines. Among the test materials were 278 entries from the second International Rice Cold Tolerance Nursery (IRCTN). Cooperative work with the Philippines Bureau of Plant Industry on this project continued.

Table 4. Characteristics of selected improved lines grown at Banaue, Philippines, 1976 wet season.

Designation and cross	Maturity (days)	Plant ht (cm)	Reaction to[a]		Grain quality	
			Blast	Bacterial blight	Gel consistency	Amylose (%)
IR30 (reselection), IR1541-102-6-3/IR2147	123	68	R	R	Medium	23
IR2061-214-3-3-17-2, IR833-6-2-1-1//IR1561-149-1/IR1737	143	—	R	R	Hard	24
IR2637-39-2-2-1, JP5/IR1529-680-3	133	86	R	R	Soft	13
IR3249-19-1-2, YR6-100-9/IR1514A-E666	151	—	R	—	Medium	24
IR3487-11-3-2-2, JP5/IR1529-382-4//IR1561-228-3-3	147	87	MR	MS	Soft	13
IR3941-14-2-2-3, CR126-42-5/IR2061-213	129	72	MR	R	Soft	0
IR5865-62-2-3, IR747B2-6/Kn-1b-213-14-3//IR747/Kn-1b-361-1-8-6-10	153	—	R	—	Hard	25
IR5896-10-2, IR747B2-6/Bagsan Daykat//IR2061-213-2-16	149	101	R	R	Soft	22
IR5908-15-1, IR747B2-6/Kn-1h-361-1-8-6-10//IR2053-522-2-3	149	90	R	R	Soft	23
IR5908-125-1, IR747B2-6/Kn-1h-361-1-8-6-10//IR2053-522-2-3	133	86	R	R	Soft	24
IR7167-3-1, China 1039/Kn-1b-361-1-8-6-10	155	—	MR	—	Medium	23
Kn-1b-361-8-6-9-2-2-2 (reselection), IR8/Jerak	131	84	R	R	Soft	25

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

A total of 3,000 pedigree rows, including check rows, were grown in two seasons. The pedigree ranged from F_3 lines to the more advanced lines (F_6 to F_8). Generally, three plants per row were selected; in some cases, bulk samples were harvested and used to supply seeds to cooperators in other countries participating in the IRCTN.

Sixty-four promising lines, which were breeding true to type, were harvested during the dry season and advanced to the wet-season OYT. Despite serious rat damage to the crop, outstanding experimental lines from the crosses of IR3941, IR5856, IR5896, IR5908, and IR7167 were identified (Table 4). Some selections from these crosses will receive more comprehensive evaluation in high-elevation areas of the Philippines during 1977.

In addition, 28 bulk hybrid populations of crosses between newly identified cold-tolerant parents and elite GEU breeding lines were planted. A population of 2,000 to 3,000 plants/cross combination were grown. Plant selections for growing in the pedigree rows were made from promising populations. The program continues to combine cold tolerance with other desirable agronomic traits, such as earliness in maturity, disease and insect resistance, fertility, intermediate plant height, and good panicle exsertion.

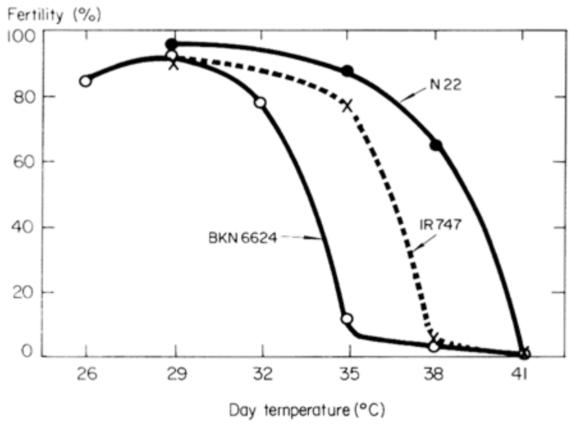
HIGH TEMPERATURE

Plant Physiology Department

In previous IRRI studies several varieties were identified as tolerant of high temperature. In 1976 the mechanism of sterility induced by high temperature was investigated. N22 was used as tolerant variety, IR747B2-6 as moderately tolerant, and BKN 6624-46-2 as susceptible.

Varietal differences in response to high temperature at flowering time. To examine varietal differences in sterility induced by high temperature at flowering time, the three varieties were subjected to varying temperatures (26 to 41°C) for 8 hours a day at flowering time. The critical temperature for inducing more than 20% unfertilized spikelets was 36.5°C for N22, 35°C for IR747, and 32°C for BKN 6624. At 41°C fertilization was zero for all varieties (Fig. 4).

In a subsequent experiment, the three varieties were subjected to 35, 38, and 41°C for durations varying from 2 to 8 hours (Fig. 5). At 35°C, the fertility percentage of BKN 6624 decreased sharply with increasing duration, while that of N22 and of IR747 remained high and stable. At 38°C, only N22 maintained a high and stable fertility percentage. The data suggest that 35° and 38°C may be used as screening temperatures to discriminate varieties susceptible to and tolerant of high temperature.



4. Relation between day temperature at flowering time and fertility percentage. Night temperature was fixed at 21°C. IRRI, 1976.

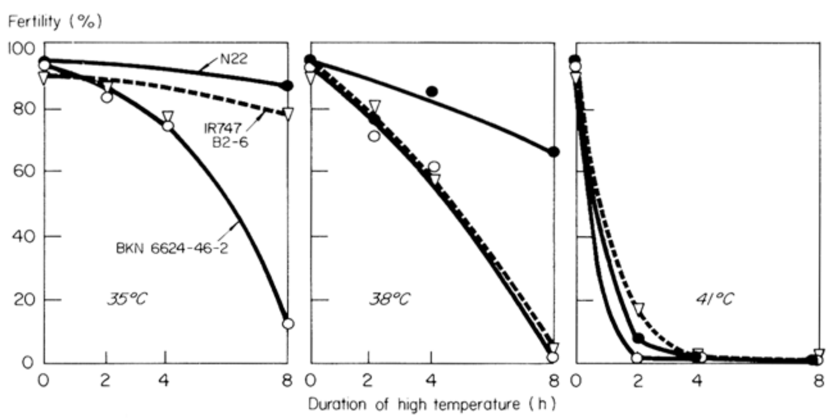
Mechanism of sterility induced by high temperature. Plants subjected to high temperatures were artificially pollinated to determine whether high temperature disturbs the pistil or the pollen. Anthers were taken from the plants growing at 29°/21°C and their pollens were freed on the stigmata of the plants subjected to high temperatures.

Artificial pollination increased the fertility percentage of BKN 6624 subjected to 35°C for 8 hours from about 35 to about 85%. It increased the fertility percentage of IR747 subjected to 38°C for 4 hours from about 3 to 65%. The data indicate that high temperature affects the process of pollination or the viability of pollen, but does not affect the pistil's ability to be fertilized. At the 41°C-for-4-hours treatment, however, the fertility percentage of IR747, which was zero, was not improved by artificial pollination.

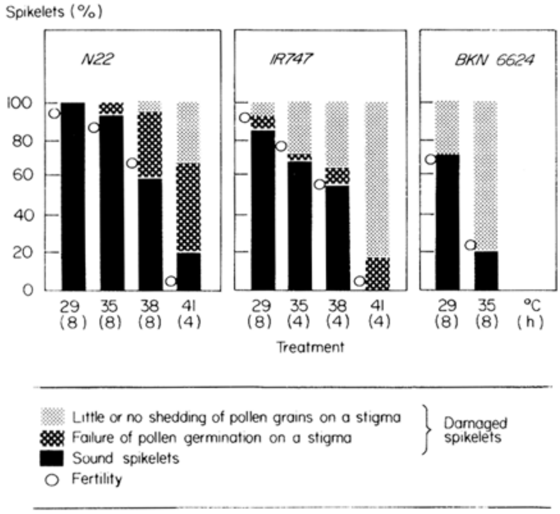
Examination with a microscope showed that the pollen of IR747 failed to germinate at the 41°C-for-4-hours treatment. On the day after termination of the high-temperature treatment, the plants were allowed to flower at 29°C. Spikelet fertility was about 10%, but it increased to more than 80% after artificial pollination. The observation confirms that the pistil's ability to be fertilized remains unaffected by high-temperature treatment.

Pollen shedding. At 29°C, varieties differed clearly in number of pollen grains on a stigma. The proportion of stigmas with more than 20 pollen grains was 100% for N22, 96% for IR747, and 68% for BKN 6624. As temperature was increased, the number of pollen grains on a stigma decreased. Varietal differences in shedding of pollen grains were greater at high temperature.

Pollen germination. It has been reported that more than 10 germinated pollen grains are required for successful fertilization of rice. Spikelets to be observed were classified into 3 groups: no germinated pollen grain, 1 to 9 germinated pollen grains, and more than 10 germinated pollen grains. Again varieties clearly differed in number of germinated pollen grains



5. Relation between duration of high temperature and fertility percentage. IRRI, 1976.

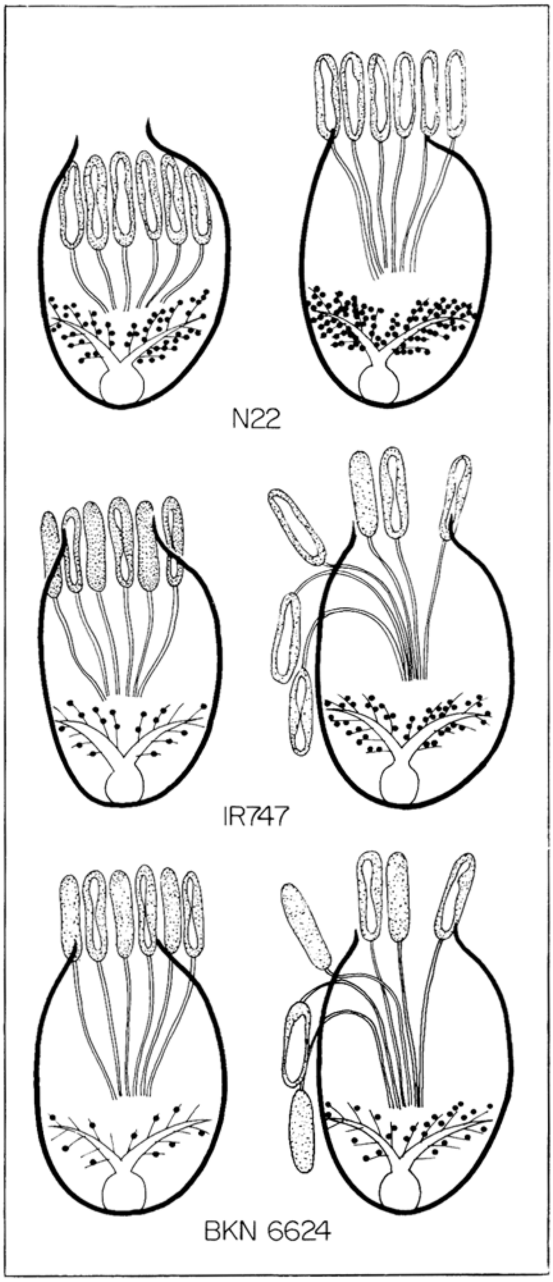


6. Causes of sterility induced by high temperature. IRRI, 1976.

at all the temperatures tested. N22 had consistently higher percentages of pollen germination at all temperatures than did IR747, which had higher germination than BKN 6624. At 41°C for 4 hours about 20% of N22 spikelets had satisfactory pollen germination; no IR747 pollen grains germinated at the same temperature.

In Figure 6, sound spikelets refer to those with more than 10 germinated pollen grains on a stigma. The percentage of sound spikelets is closely correlated with fertility percentage. Unsound spikelets are those with less than 9 germinated pollen grains. Either poor shedding of pollen grains on a stigma or failure of germination on a stigma could cause unsound spikelets. The major cause of unsound spikelets in N22 at high temperatures was poor germination. The spikelets of IR747 and BKN 6624 were unsound because no pollen grains were shed on the stigmas.

Varietal differences in sterility induced by high temperatures. Previous observations indicated that varietal difference in sterility induced by high temperature is largely related to the dehiscence characteristic of the anther. In N22, the anther starts to dehisce when glumes open, and six anthers completely dehisce while they are still within a glume. Thus, the shedding of pollen grains on a stigma at high temperature is excellent. In IR747 and BKN 6624, the anthers dehisce when the filaments elongate, and so the anthers are positioned above or outside the glumes (Fig. 7) and there is less chance of the pollen grains falling onto the stigma. In addition, BKN 6624 tends to have incomplete



7. Varietal differences in anther dehiscence of N22, IR747, and BKN 6624. IRRI, 1976.

Genetic evaluation and utilization (GEU) program

International Rice Testing Program

INTERNATIONAL NURSERIES

The International Rice Testing Network became a decisive, viable program in 1976. The greatest concentration of nurseries remains in Asia where most of the world's rice grows. Breeding materials generated by national programs and by IRRI were the source of the network's entries. Forty-nine percent originated from national programs (an increase of 14% over the 1975 entries), 39% from IRRI's breeding program, and 12% from the IRRI germ plasm bank (Table 1).

The program distributed 573 sets of 14 nurseries to 40 countries. Most nurseries were sent to Asia, some to Africa and Latin America, and a few to Oceania, North America, and Europe (Table 2). The yield and observational nurseries were widely dispersed to assure testing in diverse agroclimatic regions.

The increased volume of requests in 1976 and the difficulties encountered with quarantine regulations slowed the dispatch of seeds to some collaborators. Advisory Committee meetings were held in February and in early April to develop policies and details relative to the 1976 IRTP. Two new nurseries were added—one for stem borer resistance and another for deep-water rice. Nurseries were received by most of the participating programs in time for the monsoon planting.

A special joint IRRI-CIAT conference was held at the CIAT in August to discuss international testing with rice scientists from 17 Latin American countries. The conference participants asked for 121 sets of 10 nurseries. In addition, three special nurseries were designed specifically for Latin America.

Discussions to develop a collaborative, and more comprehensive, international rice testing program for Africa were held during the research review meetings of the West Africa Rice Development Association (WARDA). Subsequent meetings will explore how such a testing program can best meet the needs of the African rice research workers, particularly in the Sub-Saharan Africa.

REGIONAL MONITORING PROGRAM

The success of the 1975 monitoring tours prompted the IRTP Advisory Committee to recommend a substantial increase in their number. In seven monitoring tours during 1976,

Table 1. Number and sources of almost 99,000 seed packets of varieties and lines distributed through the International Rice Testing Program nurseries in 1976.

Nursery[a]	Sets (no.) Prepared	Sets (no.) Dispatched	Entries (no./nursery)	Entries (no.) from National programs[b]	Entries (no.) from IRRI Improved lines or varieties	Entries (no.) from IRRI Germ plasm bank	Packets (no.) from National programs	Packets (no.) from IRRI Improved lines or varieties	Packets (no.) from IRRI Germ plasm bank
IRYN-E[c]	75	72	19	11	8	—	792	576	—
IRYN-M[c]	75	60	31	23	8	—	1,380	480	—
IURYN[c]	50	44	24	12	12	—	528	528	—
IRON	150	96	330	195	135	—	18,720	12,960	—
IURON[d]	63	63	185	78	87	20	4,914	5,418	1,260
IRBN	51	51	478	156	234	88	7,956	11,934	4,488
IRSHBN	25	23	196	49	86	61	1,127	1,978	1,403
IRTN	25	23	219	145	43	31	3,335	989	713
IRBPHN	30	23	97	65	4	28	1,495	92	644
IRGMN	30	24	106	61	44	1	1,464	1,056	24
IRSBN	21	21	68	36	30	2	756	630	42
IRSATON	50	41	71	28	39	4	1,148	1,599	164
IRCTN	56	53	135	72	50	13	3,816	2,650	689
IRDWON	20	20	50	47	1	2	940	20	40
Total	721	614	2,009	978 (49%)	781 (39%)	250 (12%)	48,371	40,910	9,467

[a]IRYN-E = International Rice Yield Nursery-Early; IRYN-M = International Rice Yield Nursery-Medium; IURYN = International Upland Rice Yield Nursery; IRON = International Rice Observational Nursery; IURON = International Upland Rice Observational Nursery; IRBN = International Rice Blast Nursery; IRSHBN = International Rice Sheath Blight Nursery; IRTN = International Rice Tungro Nursery; IRBPHN = International Rice Brown Planthopper Nursery; IRGMN = International Rice Gall Midge Nursery; IRSBN = International Rice Stem Borer Nursery; IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery; IRCTN = International Rice Cold Tolerance Nursery; IRDWON = International Rice Deep Water Observational Nursery. [b]Entries were mostly improved lines. [c]In three replications. [d]48 sets with two replications.

Table 2. Regional distribution of nurseries of the International Rice Testing Program, 1976.

Region	IRTP nurseries[a] (no.) Yield			Observational		Diseases			Insects			Environmental stress			Total	
	IRYN-E	IRYN-M	IURYN	IRON	IURON	IRBN	IRSHBN	IRTN	IRBPHN	IRGMN	IRSBN	IRSATON	IRCTN	IRDWON	No.	(%)
East Asia	2	—	—	2	1	2	3	1	3	—	1	—	3	—	18	3
Southeast Asia	13	13	13	10	16	10	7	6	9	8	8	8	10	7	138	24
South Asia	30	25	14	56	23	11	7	9	8	15	9	16	18	9	250	44
W. Asia & N. Africa	5	4	1	4	2	4	—	—	—	—	3	5	2	—	30	5
Sub-Sahara Africa	4	2	3	13	10	8	3	—	—	—	—	7	12	—	62	11
Latin America	9	7	12	6	10	14	2	2	—	—	—	3	4	2	71	12
Europe	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	—
Oceania	1	1	—	—	—	—	—	—	—	—	—	—	1	—	3	1
Total	64	52	43	91	62[b]	49	22	18	20	23	21	39	51	18	573	100

[a]IRYN-E = International Rice Yield Nursery—Early; IRYN-M = International Rice Yield Nursery—Medium; IURYN = International Upland Rice Yield Nursery; IRON = International Rice Observational Nursery; IURON = International Upland Rice Observational Nursery; IRBN = International Rice Blast Nursery; IRSHBN = International Rice Sheath Blight Nursery; IRTN = International Rice Tungro Nursery; IRBPHN = International Rice Brown Planthopper Nursery; IRGMN = International Rice Gall Midge Nursery; IRSBN = International Rice Stem Borer Nursery; IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery; IRCTN = International Rice Cold Tolerance Nursery; IRDWON = International Rice Deep Water Observational Nursery. [b]A set of IURON contains two replications for two separate seeding dates. The last 15 of 63 sets contain only one replication for one seeding.

50 national scientists traveled to 9 different countries in Asia. They recommended policies, logistics, and details that will need attention in future years. The 1976 tours provided IRTP with valuable guidance in organizing the 1977 program.

Two IRTP scientists participated in the annual All-India Coordinated Rice Improvement Project workshop in April. Workshop participants cited the increasing threat of the brown planthopper (BPH) as one of the most serious problems facing rice production in tropical Asia. As a result, IRTP organized a monitoring tour which ended with a 1-day conference at Hyderabad, India, attended by key Indian scientists. One result of the conference was the plan for a symposium on strategies for BPH control to be held during IRRI's 1977 International Rice Research Conference.

The monitoring tours on problem soils and deep-water rice were followed by special conferences. Table 3 presents the particulars and significant results of the 1976 monitoring tours.

TRAINING PROGRAM

The GEU training program offers selected teams of rice scientists from national programs an opportunity to work closely with IRRI scientists. It provides an invaluable link in the movement of knowledge and breeding material for the benefit of national programs.

Twenty-seven rice scientists from nine countries participated in the 4-month 1976 GEU training program at IRRI. The trainees studied nine problem areas that are an integral part of the IRRI-GEU program. They acquired competence in the methodology of rice improvement through a wide spectrum of screening techniques, and developed an appreciation of the need for and the benefits to be derived from an interdisciplinary approach to varietal improvement. They conducted individual special projects, presented seminars on rice research and farming situations in their respective countries, and made crosses between lines to provide seed for studying progenies of key breeding donors at their home stations.

The alumni of this program will be an

Table 4. Utilization of entries from 1975 trials in 1976 national programs.

Nursery[a]	Countries (no.)	Entries (no.) used in crosses	Entries (no.) promoted to Station trials	State trials	National trials
Yield					
IRYN-E	6	43	35	12	3
IRYN-M	6	14	42	15	30
IURYN	4	5	12	4	12
Observational					
IRON	8	34	528	268	285
IURON	2	2	21	21	10
Screening:					
Diseases					
IRBN	5	55	23	6	10
IRSHBN	4	14	—	—	—
IRTN	4	14	47	—	—
Insects					
IRBPHN	3	19	25	—	10
IRGMN	1	—	5	—	—
Other stresses					
IRSATON	1	—	16	—	—
IRCTN	4	30	30	—	17
IRDWON	1	—	13	—	13

[a]IRYN-E = International Rice Yield Nursery-Early; IRYN-M = International Rice Yield Nursery = Medium; IURYN = International Upland Rice Yield Nursery; IRON = International Rice Observational Nursery; IURON = International Upland Rice Observational Nursery; IRBN = International Rice Blast Nursery; IRSHBN = International Rice Sheath Blight Nursery; IRTN-International Rice Tungro Nursery; IRBPHN = International Rice Brown Planthopper Nursery; IRGMN = International Rice Gall Midge Nursery; IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery; IRCTN = International Rice Cold Tolerance Nursery; IRDWON = International Rice Deep Water Observational Nursery.

IRTP Planning Session to provide guidelines for evaluating the various traits in the nurseries on a uniform scale of 0–9. Copies of the brochure were distributed to all collaborators. Several institutes and organizations outside the IRTP network requested copies.

Early in 1976, it became evident that a more complete inventory of "stock" seed of the entries being used for the various IRTP nurseries should be made. All national collaborators were asked to submit small quantities of seed of the entries in their national nurseries. The seed stocks were increased at IRRI to make available an adequate inventory of seed for the entries nominated for 1977. Seed increase is an IRTP activity that promises to be a valuable feature. Eleven countries sent 769 varieties or lines for inclusion in various 1977 nurseries after seed increase.

A survey of national collaborators in 1976 indicated that a high percentage of IRTP entries evaluated in 1975 were being used by the collaborating scientists in national programs for either crossing or further testing (Table 4).

1975 IRTP NURSERIES

The IRYN was broadly divided into early and medium maturity groups. In the early group (9 countries, 27 trials), RP6-1899-25-4, IR2061-465-1-5-5, IR2061-628-1-6-4, and IR2071-625-1-252 performed well at most sites. In the medium duration group (8 countries, 21 trials), Biplab, BR52-87-1, BR51-91-6, and BG90-2 performed well.

Results from the IRON indicate the resistance of some entries to some major diseases at most sites (Table 5).

Table 5. Entries that were found resistant to three major diseases in the 1975 International Rice Testing Program nurseries, IRRI, 1975.

Blast[a]	Bacterial blight	Tungro
IRON[a]	IRON	IRON
IR1544-181-1-1	BR51-49-6	IR2071-542-3-1
IR1820-210-2	BR51-67-1/C1	IR2863-31-3
IR2588-60-1	IR2053-362-1-4-4	IR2863-38-1
IR2588-132-1-2	IR2053-375-1-1-5	IRTN[c]
IR2793-80-1	IR2055-481-2-6-2	Ptb 8
IR2798-88-3	IR2793-80-1	ARC 13820
IR2811-24-3	IR2863-22-3	ARC 13901
IR2851-41-3	IR2863-31-3	ARC 13959
IRBN[b]	IR2863-48-2	ARC 10342
CICA 4//IR665-23-3-1/Tetep	IR2071-636-5-5	Habiganj DW8
	IR2070-423-2-5-6	ARC 7125
IR665-23-3-1//IR841-65/C46-15	IR32	ARC 13677
		Kataribhog (India)
IR665-23-3-1//IR665-33/Tetep		DWA 8
		ARC 7318
IR29		ARC 10531
IR1520-52-2-4-1		ARC 7110
IR2035-255-2-3-2		Kataribhog (26683)
IR2058-435-3-2-2-2		SLO 12
IR2588-2-3-3		ARC 7140
IR2793-10-2		IRTN
IR2793-38-3		ARC 13560
IRBN		Ambemohar 159
IR2793-80-1		
Washabo (SML 56/7)		
Raminad Strain 3		
IR1416-128-5-8		
CA 435-b-5-1		
CA 902-b-3-3		
Carreon		
PI 184675-2		
Ta-poo-choo-z		
Tetep		

[a]Varieties listed as resistant to blast under IRON (International Rice Observational Nursery) showed resistance to both leaf and neck blast. [b]IRBN = International Rice Blast Nursery (tested only for leaf blast). [c]IRTN = International Rice Tungro Nursery.

Genetic evaluation and utilization (GEU) program

Integrated GEU program

Plant Breeding and All GEU Departments

EXCHANGE OF GERM PLASM
Plant Breeding Department

In response to special requests, 10,365 seed packets of improved breeding lines and varieties were distributed. The International Rice Testing Program (IRTP) provided an additional 42,867 packets of GEU's best lines and varieties to participating national programs. Distribution of F_2 seed began on a relatively large scale with more than 400 packets distributed to national programs. Breeders in major upland rice-growing areas continued to be supplied with F_2 bulks and improved breeding lines from the upland nurseries. Twelve F_2 populations were produced and distributed on the request of breeders in four countries.

Two hundred ninety-two IRRI upland breeding lines went to 12 breeders or agronomists in 7 countries. Twenty lines were entered in the International Upland Rice Yield Nursery and the International Upland Rice Observational Nursery, and six in the Cooperative Upland Rice Performance Tests of the Philippines.

IRRI LINES NAMED IN NATIONAL PROGRAMS
Plant Breeding Department

Seven IRRI lines were named as varieties in national programs in 1976 (Table 1). That brought the number of IRRI lines named in national programs to 49 and together with varieties named directly by IRRI (11 in total) makes a grand total of 60.

The seven lines are described below:

- *Bilo* (IR1539-156) is a semidwarf, high yielding variety with resistance to brown planthoppers (BPH). It is the first BPH-resistant variety released in Fiji, where the insect pest is widespread. It is rapidly replacing Ajral (IR480-5-9-3), which had been the predominant variety there.
- *BR 6* (IR2061-214-8-3-2) is synonymous with IR28, which IRRI named in 1974. It has now been officially named and recommended in Bangladesh.
- *BR 7* (IR2053-87-3-1) is an early maturing variety with intermediate stature, long, slender grains, and excellent seedling vigor. It is recommended for boro and aus seasons in Bangladesh.

Table 1. IRRI lines named in national programs in 1976.

Variety name	Designation and cross	Country
BILO	IR1539-156, IR24//Mudgo/IR8	Fiji
BR 6	IR2061-214-8-3-2, IR833-6//IR1561-149/IR1737	Bangladesh
BR 7	IR2053-87-3-1, IR1416-131-5/IR22//C4-63	Bangladesh
FARO 22	IR627-1-31-4-3-7, IR8/Wagwag	Nigeria
IR36	IR2071-625-1-252, IR1561-228/IR1737//CR94-13	Philippines
IR38	IR2070-423-2-5-6, $IR20^2$/*O.nivara*//CR94-13	Philippines
PR 106	IR665-79-2-4, IR8//$Peta^5$/Belle Patna	India

- *Faro 22* (IR627-31-4-3-7) is an improved-plant type variety with high yield potential. It is recommended for lowland conditions in Nigeria.
- *IR36* (IR2071-625-1-252) is an early maturing (110-day), short-statured variety of high-yield potential named by the Philippine Seed Board in 1976. It has medium-long and slender grain that appears translucent. The grain has high (25%) amylose content, hard gel consistency, and intermediate gelatinization temperature.

In the Philippines, IR36 is moderately resistant to blast, and resistant to tungro and grassy stunt. It is resistant to the predominant strain of bacterial leaf blight, but susceptible to strains that prevail in the Palawan, Davao, and Isabela regions; moderately susceptible to bacterial streak; resistant to BPH biotypes 1 and 2, and to green leafhoppers (GLH); and moderately resistant to stem borers. In some countries, IR36 is resistant to gall midge (not a problem in the Philippines).

IR36 is resistant to iron deficiency, and is moderately resistant to iron toxicity, zinc deficiency, phosphorus deficiency, and salinity, and is not resistant to alkalinity.

IR36 has some degree of drought resistance and is rated "intermediate" with "fast" recovery. It is well suited to irrigated conditions and may be utilized in certain rainfed areas.

- *IR38* (IR2070-423-2-5-6) is a high yielding, short statured variety named by the Philippine Seed Board in 1976. It matures in about 120 days. It has long, slender, translucent grains of high amylose content (28%), soft gel consistency, and intermediate gelatinization temperature. It is expected to have good cooking quality.

In the Philippines, IR38 is moderately susceptible to blast and has an intermediate reaction to sheath blight. It is resistant to tungro and grassy stunt and, like IR36, is resistant to the predominant strain of bacterial blight. It is resistant to bacterial streak, resistant to BPH biotypes 1 and 2, resistant to GLH, and moderately resistant to stem borers. It is also resistant to gall midge in certain countries. It is resistant to zinc deficiency, moderately resistant to iron toxicity and salinity, but not resistant to alkalinity. It is relatively resistant to drought.

• *PR106* (IR665-79-2-4) is a high yielding, improved-plant type variety with excellent, long, slender grains. It is recommended for irrigated lowland conditions in Punjab (India) where it outyields the popular IR8 by 10%.

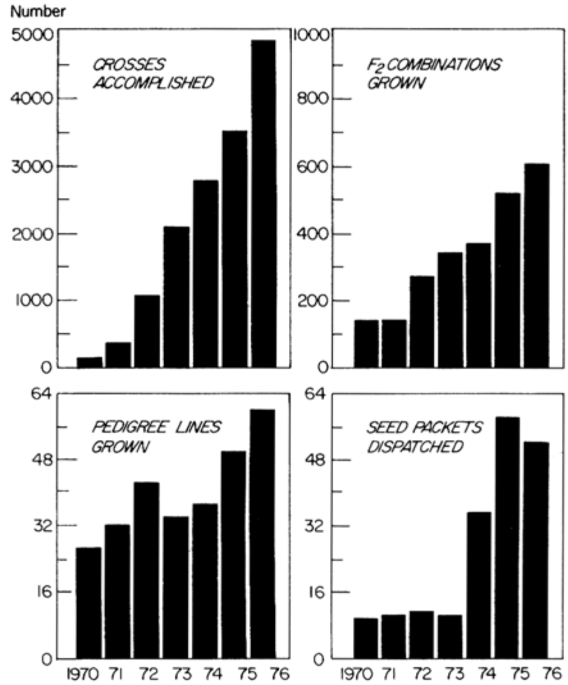
BREEDING OPERATIONS
Plant Breeding Department

The volume of breeding operations was further expanded during 1976 (Fig. 1), and the crossing program continued to expand to meet the demand of national programs for assistance. For instance, more than 450 crosses were accomplished at IRRI for the deep-water breeding program in Bangladesh. Although no real growth in IRRI's crossing work occurred, other aspects of the program continued to expand as a delayed reaction to the rapid growth in crossing of previous years.

Most segregating material was grown without chemical protection against insects, but the protected nurseries expanded considerably as more emphasis was placed on earliness, or on resistance to salinity-alkalinity for areas where pests and diseases are not of major or primary importance.

In the IRRI unprotected nurseries, the tungro virus was maintained at epidemic intensity. As a result, screening efficiency was excellent. Screening for other diseases and pests relied largely on artificial methods. The BPH, for example, was not present in numbers adequate for effective field screening.

The coordination and efficiency of screening work increased. A procedure was perfected whereby a limited number of elite lines are exhaustively evaluated each season. For the voluminous early-generation material (more than 60,000 lines), the establishment of screening requirements and timetables that take into account the capacity of each facility resulted in the timely availability of data for selection purposes. During the year, less than 5% of the lines grown lacked some data at the time of selection. For the more than 60,000 lines grown, more than 500,000 units of data were needed for selection purposes.



1. Growth of the IRRI GEU program.

Rapid Generation Advance. A new breeding procedure for photoperiod-sensitive material, called Rapid Generation Advance, was tried. It reduces generation time to about 100 days. The procedure involves growing the F_2 and F_3 between May and October, under artificial short days, with reduced nutrition and dense spacing; growing the F_4 in the field, under natural short days, between November and April; and then testing selected F_5 lines against specific problems in the field, beginning with the monsoon in May or June.

Screening facilities. The operation of the cold-tolerance project at Banaue improved during 1976. The Philippine Bureau of Plant Industry added two technicians to the staff and provided other support, which greatly improved the effectiveness of the project. An effective blast screening facility was established in Leyte, and a salinity screening project was initiated in Luzon.

NEW LINES WITH MULTIPLE ATTRIBUTES
All GEU Departments

During the past several years the proportion of IRRI breeding materials that carry resistance to most major diseases and insect pests in the Philippines dramatically increased. At present, more than 50% of the advanced lines are resistant to six major pest problems and nearly 90% are resistant to at least five. Accumulated information on the races, strains, and biotypes of the pests is discussed in detail in other sections of this report. Several genetic sources of resistance to BPH and bacterial blight have been differentiated and are now being incorporated into the breeding program.

There is only one verified major gene (from *O. nivara*) for resistance to the grassy stunt virus. A second source has been tentatively identified, but it is not yet known whether it is genetically discrete. The *O. nivara* gene has not been utilized in all IRRI material for fear of possible deleterious effects. Resistance to grassy stunt is of secondary importance compared with vector (BPH) resistance. Furthermore, a number of IRRI lines that do not carry the *O. nivara* gene appear to have a good level of field resistance to grassy stunt.

Precise genetic information on two other diseases, tungro virus and blast, is lacking because of the nature of the diseases and the currently available evaluation techniques. Different rice varieties have been used as sources of resistance, with attention to the diversity of their origin and with the expectation that they will differ in the genetic factors conditioning resistance.

In the past several years, there has been concern that a high proportion of IRRI's improved breeding material is derived from the cytoplasm of the variety Peta. The 60 varieties that have been released and named by IRRI or in national programs carry Peta cytoplasm. That situation resulted because it is more convenient to use dwarf plants in making crosses.

Since 1972, IRRI has made a concerted effort to overcome that problem, and a steadily increasing proportion of the advanced breeding lines has cytoplasm other than that of Peta. The change was accomplished through almost exclusive use of tall varieties as female parents. In topcrosses, the F_1 hybrids have been used exclusively as females. The procedure presents some difficulties and makes it difficult to detect selfs.

Table 2 shows a few representative lines of several hundred promising advanced GEU lines. Only IR2070-414-3-9 is resistant to whorl maggot. IR2071-586-5-6-3 has shown outstanding yield potential at low levels of applied nitrogen in 2 consecutive years. Both lines will be named as varieties in the Philippines. IR2823-399-5-6 does well under saline conditions. IR2863-35-3-3 appears to have high protein content. The sister line IR2863-38-1-2 was the top yielding line in the Philippine cooperative trials in 1976, and received the top average phenotypic rating in the International Rice Observational Nursery.

According to Philippine consumers, IR3351-38-3-1 has excellent grain quality. IR3464-75-1-1 represents IRRI's best rainfed prototype with waxy endosperm. IR3880-10, a selection from the upland nurseries, has moderate resistance to drought, and a soft gel consistency. IR3941-25-1 is extremely early and tolerant of low temperatures. IR4215-4-3-1-1 is one of the newer lines with intermediate-amylose content. IR4219-35-3-3 is 130 cm tall and is so sturdy that it did not lodge during the wet season even with 90 kg N/ha added. It is considered ideal for rainfed conditions.

IR4417-179-1-5-2 derives its tungro resistance from PK 203, which may prove different from the sources of tungro resistance used in the past. IR4432-52-6-4 combines two varietal sources of tungro resistance that are probably genetically discrete. IR4442-207-2-3 is one of several lines with improved resistance to the yellow stem borer.

Table 2. Important characteristics of selected promising lines. IRRI, 1976.

Designation	Cross	Ht (cm)	Growth duration (days)	Amylose content (%)	Reaction[a] to								Special traits
					Blast	Bacterial blight	Tungro	Grassy stunt	Green leaf-hopper	Brown planthopper Biotype 1	Brown planthopper Biotype 2	Stem borer	
IR2070-414-3-9	IR20^2/*O. nivara*//CR94-13	100	115	25	R	R	MR	R	R	R	R	MR	Resistant to whorl maggot
IR2071-586-5-6-3	IR1561-228//IR24^4/*O. nivara*/3/CR94-13	100	130	29	R	R	R	R	R	R	R	MR	High yield potential at low levels of nitrogen
IR2307-217-2-3	CR94-13/IR1561-228	85	105	27	S	R	R	MR	R	R	R	MR	Early
IR2823-399-5-6	CR94-13/IR1529-680/3/IR24^3/*O. nivara*//IR1416-131-5	100	125	27	R	R	MS	R	R	R	R	MR	Resistant to salinity
IR2863-35-3-3	IR1529-680/CR94-13//IR480	95	130	27	MR	R	MR	MR	R	R	R	MR	High protein content
IR2863-38-1-2	"	95	130	27	MR	R	R	MR	R	R	R	MR	High and stable yield Resistant to gall midge
IR3351-38-3-1	IR841-85//IR20^3/*O. nivara*/3/CR94-13	110	125	15	MR	R	R	R	R	R	R	MR	Excellent grain quality
IR3464-75-1-1	IR1628-68-3/IR841-67//IR2061-213	120	140	Waxy	MR	R	R	R	R	R	R	MR	Rainfed type
IR3880-10	IR841-67/C22-51//Pelita 1-2/IR1541-76	130	130	16	R	S	—	—	R	R	S	—	Upland type; drought resistance; soft gel consistency
IR3941-25-1	CR 126-42-5/IR2061-213	95	100	27	MR	R	R	R	R	R	S	MR	Cold tolerant, Very early
IR4215-4-3-1-1	IR2061-213/C4-63	120	125	23	MR	R	MR	R	R	R	S	MR	Intermediate amylose
IR4219-35-3-3	IR2061-213/IR480	130	135	27	MR	R	R	R	R	R	S	MR	Excellent rainfed type
IR4417-179-1-5-2	IR2042-101-2/IR825-11-2	110	125	27	R	R	R	R	R	R	S	MR	PK 203 tungro resistance
IR4432-52-6-4	IR2061-125-37/CR94-13	100	125	27	MR	R	R	R	R	R	R	MR	Two varietal sources of tungro resistance; resistant to gall midge
IR4442-207-2-3	IR2061-464-2/IR1820-52-2	105	120	27	R	R	R	R	R	R	S	R	Resistant to *Tryporyza*
IR4683-54-2	IR1545-339/IR1721-11//IR2035-290	120	125	27	MR	R	R	R	R	R	S	MR	xa5 BB resistance
IR5853-118-5	Nam Sagui/IR2071-88//IR2061-214	100	110	27	R	R	R	R	R	R	S	MR	Excellent vegetative vigor
IR26 (standard)	IR24/TKM 6	95	125	27	MS	R	MS	MS	R	R	S	MR	High yield potential

[a]R = resistant; MR = moderately resistant; S = susceptible; MS = moderately susceptible. Rated in the Philippines.

IR4683-54-2 is one of several lines that carry a new source of resistance to bacterial blight. IR5853-118-5 is an outstanding line with excellent vegetative vigor; it represents an increasing proportion of IRRI improved germ plasm that is not derived from Peta cytoplasm.

All the lines mentioned were evaluated for diseases and insect pests, except gall midge, in the Philippines.

Genetic evaluation and utilization (GEU) program

Computerized data management

Statistics Department

BACKGROUND

The GEU program is characterized by the efforts of several scientists who simultaneously screen and evaluate a large number of genotypes which either come from the germ plasm bank or are newly generated breeding material. Because the plant characters of interest vary from one screening process to another, the program generates a large, diverse volume of data. Such data must be stored for easy access by all scientists.

IRTP, which cooperatively tests a large number of genotypes in various countries, also generates data that need to be quickly summarized and returned to scientists, both at IRRI and in the country programs.

In 1976, a computer-based data management system was developed to handle and integrate data from three primary sources: germ plasm bank, breeding program, and IRTP. The system can print field books for systematic data collection, accept data for inclusion in the GEU data bank, analyze and summarize experimental results, and retrieve information from one or more data files.

Table 1. Basic morphoagronomic characteristics maintained on accessions in the IRRI germ plasm bank.

Number	Characteristic	Number	Characteristic
1	Variety group	20	Panicle type
2	Seedling height	21	Panicle exsertion
3	Blade length	22	Panicle threshability
4	Grain width	23	Grain length
5	Blade pubescence	24	Grain width
6	Blade flag angle	25	Sterile lemma length
7	Blade color	26	Sterile lemma color
8	Leaf sheath color	27	Lemma color
9	Ligule length	28	Apiculus color
10	Ligule color	29	Awn presence
11	Collar color	30	Awn color
12	Auricle color	31	Stigma color
13	Culm length	32	Seed coat color
14	Culm number	33	Embryo size
15	Culm angle	34	Endosperm type
16	Culm diameter	35	Spikelet fertility
17	Culm strength	36	1000-grain weight
18	Internode color	37	Senescence
19	Panicle length	38	Maturity

GERM PLASM BANK

The IRRI germ plasm bank has 34,229 registered accessions of *O. sativa*, 17,689 of which have been completely characterized for 38 basic morphoagronomic characteristics (Table 1). Many of the accessions are subjected to systematic screening for various traits (Table 2). Data management for germ plasm involved the creation of a computer data bank containing all existing data on each accession, and the ability to retrieve desired accessions that combine specified traits. The germ plasm data bank consists of:

- 33,946 accessions with complete information on varietal origin, seed source, and variety name;
- 17,869 accessions with complete information on the 38 basic morphoagronomic characteristics;
- 32,556 accessions with existing information on 37 GEU traits.

Computer programs validate and update the germ plasm data bank so that additional data can be easily entered into the system. The bank is linked to the data files of both the breeding program and IRTP.

A generalized retrieval program can search for cultivars that combine specified traits. To avail of the service, the interested scientist specifies the criterion characters, their acceptable ranges, and other desired information on the selected accessions. Figure 1 shows a sample response to a query on accessions of indica type with culm length greater than 95 cm, culm number greater than 10, grain length greater than 7 mm, grain width less than 3.5 mm, maturity from 95 to 120 days, and blast and bacterial blight reaction of less than 4.

BREEDING OPERATIONS

Since 1962, IRRI breeders have made more than 17,000 crosses. Current work adds about 5,000

Table 2. Traits screened by GEU scientists on cultivars in the germ plasm bank and on breeding material generated by the breeding program.

Problem area	Traits (no.)
Insect resistance	11
Drought tolerance	10
Disease resistance	5
Tolerance to injurious soil	4
Deep-water and flood tolerance	3
Protein content	2
Temperature tolerance	2
Total	37

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THESE ARE ACCESSIONS OF GROUP INDICA, CULM LENGTH > 95 CM.,
CULM-NO. > 10, GRAIN LENGTH > 7.0 MM., GRAIN WIDTH < 3.5 MM.,
MATURITY FROM 95 TO 120 DAYS, BLAST AND BACTERIAL BLIGHT REACTION < 4

ACCN. NO.	VARIETY NAME	VARIETY GROUP	CULM LENGTH	CULM NUMBER	GRAIN LENGTH	GRAIN WIDTH	MATURITY	BACT. BLIGHT	BLAST
03711	BJ 1	1	98	30	7.9	3.1	110	1	2
07534	DARADUNI SARDA	1	121	20	9.1	2.7	118	3	2
08351	PASHPAI	1	104	20	9.2	3.2	119	3	1
08366	DNJ 95	1	102	20	8.2	3.1	120	2	3
08378	DNJ 52	1	104	15	8.7	3.4	120	1	1
08394	DNJ 24	1	100	20	7.8	3.1	120	1	3
08399	DNJ 14	1	100	20	8.2	3.2	120	3	1
08407	DNJ 179	1	100	20	9.2	3.4	120	3	3
08418	DNJ 157	1	104	20	8.0	3.4	120	1	3
08427	DNJ 141	1	100	20	8.1	2.9	120	3	2
08428	DNJ 140	1	100	20	7.9	2.8	120	3	2
08429	DNJ 139	1	105	20	8.2	3.4	120	3	2
08441	DNJ 122	1	103	20	7.9	2.9	120	3	1
08453	DNJ 101	1	100	20	8.7	3.4	120	3	1
08456	DJ 118	1	110	20	8.6	3.2	120	3	3
08457	DJ 117	1	102	20	9.6	2.5	120	2	1
08467	DJ 93	1	99	20	8.6	3.0	120	3	3
08478	DJ 88	1	107	20	7.6	3.4	120	3	1
08480	DJ 73	1	99	20	8.2	3.2	120	3	1
08484	DJ 66	1	96	20	8.6	3.4	120	3	1
08506	DJ 24	1	119	20	10.1	2.8	120	3	1
08520	DZ 179	1	96	20	8.4	3.1	120	3	1
08543	DZ 119	1	98	20	8.0	3.0	120	3	1
08549	DZ 101	1	99	20	7.6	3.2	120	3	2
08556	DZ 74	1	114	15	9.8	2.8	120	3	1
08564	DZ 39	1	112	15	8.6	2.8	120	3	1
08597	DL 10	1	97	15	7.8	3.3	120	3	1
08620	DD 48	1	100	15	8.9	3.0	120	3	1
08639	DD 82	1	113	15	7.5	3.2	120	2	1
08687	CTG 890	1	105	20	9.1	2.8	120	3	3
12427	ARC 10311	1	98	16	7.9	3.3	99	3	2
15134	TOMBO 8	1	120	12	9.7	3.3	118	3	3
15599	HALSUDU HEENATI	1	98	17	7.7	3.2	110	3	3
15681	PATCHAIPERUMAL	1	105	17	8.2	3.2	110	3	3
16121	LAL AHU	1	104	20	9.1	2.7	103	3	3
20288	ARC 5955	1	122	28	7.9	2.8	107	1	3

END OF RETRIEVAL

1. Sample response to query on accessions of group indica, with culm length greater than 95 cm, culm number greater than 10, grain length greater than 7 mm, grain width less than 3.5 mm, maturity from 95 to 120 days, and blast and bacterial blight reaction less than 4.

crosses a year. More than 60,000 F_3–F_6 lines are evaluated annually for various traits by respective problem-area scientists.

Data management for those operations consists of a computer tape file on the history of the crosses, a data bank recording the performance of each line on all tests, and the capability to generate field books for the various tests. The computer generated field books contain the list of entries, their plot layouts, their performance in previous trials, information on the parentage of each entry, and space for recording current data.

INTERNATIONAL RICE TESTING PROGRAM

The major objectives of the IRTP data management system are to provide accurate and speedy analysis and summarization of data, efficient storage and retrieval of data and supplemental information, and meaningful integration with the two other GEU components—the germ plasm bank and the breeding operations.

The IRTP computer files consist of a master file for test locations, a master file for all entries ever tested in any IRTP nursery, and separate data files for each nursery. The system is capable of editing and performing statistical analysis and data summarization for each nursery at each test site, as well as of combining results for all test sites. Those capabilities have helped in reducing mechanical errors and delays in data processing, and, consequently, in rapidly providing summary reports to all IRTP cooperators.

Genetic evaluation and utilization (GEU) program

Genetic, professional, and sociological aspects of rice breeding in Asia

Office of Information Services

ENVIRONMENTAL AND PEST PROBLEMS

In a survey of 35 rice breeders at 28 research centers in 10 Asian countries, each breeder ranked, in order of severity, the four most serious environmental or biological problems that limit farmers' rice yields within the area he served. The breeders also ranked, in order of severity, specific insect and disease pests.

Environmental and biological stresses. Every breeder surveyed rated diseases and insects as one of the four major environmental or biological problems in his area (Table 1). In all regions, pests received the highest mean severity rating—3.2 on a 1–4 scale where 4 represented the category "most serious."

Drought, rated second in importance, was considered a major problem in 82% of the areas. Injurious soils (salinity, alkalinity, zinc deficiency, and others) were rated as a major constraint in 57% of the areas. Excessive monsoon cloudiness was considered a serious constraint in 51% of the areas.

Other major environmental problems listed were floods (38%), cold temperature (29%), and deep water—defined as water that reaches about 50 cm during the monsoon season (15%). Excessively hot temperatures were considered a major problem in 9% of the areas.

Table 1. Rice breeders' perceptions of the biological and environmental stresses that most seriously limit rice production on farmers' fields within the areas served by their research centers. Thirty-five rice breeders at 28 agricultural experiment stations and universities in 10 Asian nations, 1975.

Biological, environmental factor	Area (%) where stress was rated as one of 4 major constraints	Area (%) where stress was rated as one of 2 major constraints
Diseases and insects	100	74
Drought	82	51
Injurious soils[a]	57	17
Excessive monsoon cloudiness	51	26
Floods	38	9
Cold temperature	29	12
Deep water	15	9
Hot temperature	9	0
Waterlogged soils[b]	6	3
Other[c]	6	0

[a]Salinity, alkalinity, zinc deficiency, etc. [b]Not included among factors which breeders rated, but listed under "other" by two respondents. [c]Typhoons and weeds.

Interestingly, waterlogged soils, which were not in the list of environmental stresses, were mentioned by two breeders in India (6%) as a serious constraint under the category "other stresses." One breeder considered waterlogged soils as the most serious constraint in his region.

Diseases and insect pests. When the 35 rice breeders ranked 14 major insects and diseases, they cited six among the four most serious pests in about 30% of the areas. The six pests cited were three diseases (bacterial blight, blast, and tungro virus) and three insects (the rice stem borer, brown planthopper, and gall midge) (Table 2).

The rice stem borer was most widely considered a serious pest (60% of the areas). Its severity rating was 1.6, one of the highest calculated for all regions in 10 countries. But when calculated only for the stations where the stem borer was one of the four most serious problems, its severity rating was fifth highest. That may indicate that the stem borer limits yields across many regions, but that other local pests are usually more serious in individual areas.

Bacterial blight disease was rated second in severity. It was considered a major problem in 57% of the areas.

The brown planthopper was not a serious problem a few years ago, but the survey found it generally considered one of the most rapidly spreading pests in Asian rice fields. It is the vector of grassy stunt virus disease and was considered a major pest in 46% of the areas.

Blast disease, generally recognized as one of the most widespread problems in Asia, was rated fourth most common of the serious pests. Blast received an overall severity rating of 1.4, but in those stations where it was considered a major problem among all pests, it received the highest rating, 3.2.

The gall midge, a localized pest found mostly on the Indian subcontinent, was the fifth most cited pest. Tungro was cited as a major problem in 29% of the areas, while its vector, the green leafhopper, was cited as a serious problem in only 9%. Grassy stunt virus disease was considered a major problem in 6% of the areas, but its vector, the brown planthopper, was cited

Table 2. Rice breeders' perceptions of the specific insect and disease pests that most seriously limit rice production on farmers' fields within the areas served by their research centers. Thirty-five breeders at 28 agricultural experiment stations and universities in 10 Asian nations, 1975.

Pest	Nature	Mean severity rating[a] All stations	Mean severity rating[a] Stations where pest is a problem	Area (%) where stress was rated as major constraint
Stem borer	Insect	1.6	2.7	60
Bacterial blight	Disease	1.6	2.8	57
Brown planthopper	Insect	1.1	2.5	46
Blast disease	Disease	1.4	3.2	43
Gall midge	Insect	1.1	3.0	37
Tungro virus	Disease	0.7	2.3	29
Sheath blight	Disease	0.3	2.0	17
Green leafhopper	Insect	0.2	2.0	9
Helminthosporium	Disease	0.1	1.4	9
Striped virus[b]	Disease	0.3	3.0	9
Grassy stunt virus	Disease	0.1	1.0	6
Sheath rot	Disease	0.1	2.0	6
Other insects[c]	Insect	0.7	2.1	34
Other diseases[d]	Disease	0.4	2.1	20

[a]On a scale of 1–4: 4 = most serious insect or disease pest; 1 = fourth most serious. Calculated for all 35 areas for only those stations in which each factor was considered one of four major pests. [b]Only in Korea. [c]Includes one rating each for whitebacked planthopper, leaf roller, paddy bug, seedling fly, stink bug, armyworm, gandhi bug, and two unspecified insects. [d]Includes one rating each for bacterial leaf streak, black smut, sheath virus, glume blotch, stem rot, and two unspecified diseases.

in 46%. That may indicate that grassy stunt could become widespread and serious in the future.

COMPARISON OF FIELD CONDITIONS, SCIENTISTS' BREEDING EFFORTS, AND LATEST VARIETIES

To obtain a measure of the relevance of scientists' research efforts in providing the types of varieties that farmers need, 23 breeders at 22 experiment stations and universities in 8 countries were asked 3 questions:

• What percentage of the rice grown on farmers' fields within the area served by your experiment station is irrigated, rainfed lowland, upland, and deep-water or floating?

• What percentage of your professional time is spent in improvement of irrigated, rainfed lowland, upland, and deep-water or floating rice?

• What percentage of all varieties released by your station during the past 5 years was suited for each of the four rice-growing conditions?

A mean of 43% of the rice grown on farmers' fields was perceived as irrigated; 60% of the breeders' time was spent on the improvement of irrigated rice; and 57% of all varieties released at their stations during the previous 5 years were suited to irrigation (Table 3).

The breeders spent 22% of their time on the 40% farmers' rice cited as rainfed lowland. They considered 32% of the recently released varieties suited to rainfed conditions.

International Rice Testing Program (IRTP). Scientists in the rice-producing nations can interlock their rice improvement efforts through participation in the IRTP. To determine the extent of such participation, rice breeders at 27 research centers in 9 countries were surveyed.

Ninety-three percent of the stations participated in IRTP. Breeders at these stations were asked which of IRTP's 12 nursery sets they were growing. The 26 stations grew a total of 119 IRTP nursery sets, or an average of 4.6 international nurseries per station (Table 4).

NEW VARIETIES

To determine the types of new rice varieties going to farmers in Asia, breeders at 29 research centers in 10 countries were asked about the varieties released by their stations during the past 5 years.

Table 3. Rice breeders' perceptions of the rice grown in farmers' fields, and of the percentages of research efforts devoted to the same categories of rices, and the varieties released over the past years in the regions served by experiment stations. Twenty-three rice breeders for 23 regions served by 22 experiment stations and agricultural universities in eight Asian nations, 1976.

Rice-growing condition	Breeders perception of: Rice (%) in farmers' fields	Breeders perception of: Time (%) spent on rice improvement research	New varieties (%) released since 1970
Irrigated	43	60	57
Rainfed lowland	40	22	32
Upland	12	14	10
Deep-water	5	4	2

Table 4. Nursery sets grown at experiment stations that participated in the International Rice Testing Program (IRTP). One hundred and nineteen trials of 12 nursery sets grown at 26 agricultural experiment stations and universities in 9 Asian countries, 1976.

International nursery set	Stations where grown	
	No.	%
International Rice Yield Nursery—early maturing	19	73
International Rice Observational Nursery	19	73
International Rice Blast Nursery	15	58
International Rice Cold Tolerance Nursery	12	46
International Upland Rice Yield Nursery	10	38
International Rice Brown Planthopper Nursery	9	35
International Upland Rice Observational Nursery	7	27
International Rice Sheath Blight Nursery	7	27
International Rice Tungro Nursery	7	27
International Rice Gall Midge Nursery	7	27
International Rice Salinity Tolerance Observational Nursery	4	16
International Rice Yield Nursery—medium maturing	3	12
Total	119	
Av. no. per station	4.6	

Number of varieties. A total of 165 new varieties were released by 27 of the experiment stations in 5 years. Two stations had not released any varieties. For all stations surveyed, the average number of released varieties was 5.7 or a little more than one per year. For the stations that released varieties during the 5-year period, the average number was 6.1.

Locally bred and IRRI varieties. Each breeder was asked how many of his newest varieties had been bred in his country and how many had come from IRRI. The breeders were also asked to identify the parents of all locally bred varieties.

Seventy-eight percent of the 165 varieties had been bred in the countries where they were released; 22% had been developed at IRRI (Fig. 1). Fifty-four percent of the 129 varieties that were developed locally were the progeny of crosses involving an IRRI variety or line.

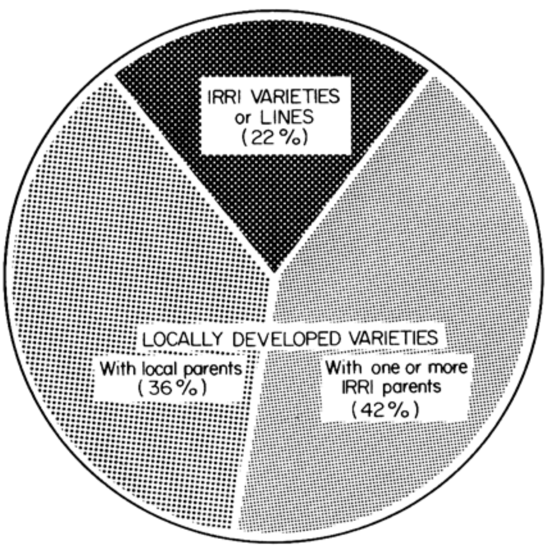
Sixty-four percent of the 165 newest varieties in 10 countries were either progeny of IRRI rices or had been developed at IRRI.

Breeding methods. The breeding methods that 31 rice breeders used in their hybridization (crossbreeding) programs were surveyed at 24 research centers in 10 Asian countries. Sixty-eight percent of the breeders depended primarily on the pedigree method of breeding. Two of the 31 breeders depended mostly on the backcross method, and one breeder depended mainly on the bulk method. Six breeders indicated that they depended on a combination of breeding techniques.

None of the breeders depended primarily on mutation breeding (chemical, radiation, or natural), but 39% used mutation in combination with other breeding methods. Of all the breeders surveyed, 94% primarily used the pedigree system (in combination with other methods); 60%, the backcross method; and 48%, the bulk system.

Sources of introduced lines. The origin of 1,406 of the introduced breeding lines in 17 advanced yield trials in 8 countries was traced.

Sixty percent of the introduced genetic material came from crosses made at other research centers in the country in which the surveyed experiment station was located. Thirty-nine



1. Of 165 new rice varieties released to farmers in Asia during 1970–75, 64% were either progeny of IRRI rices, or IRRI varieties or experimental lines. Twenty-two percent of the rices were developed at IRRI and 42% were progeny of local crosses involving an IRRI parent. Twenty-nine agricultural experiment stations and universities in 10 Asian nations, 1975.

percent came from IRRI, and about 1% came from breeding programs in other Asian nations.

Number of locally developed lines per cross. To get a further measure of the diversity of the genetic background of improved local lines, the breeders were asked to indicate the number of crosses from which they selected their locally developed advanced lines. Data on 3,791 locally developed lines in 22 advanced trials at 20 research centers in 8 countries were collected. The 3,791 breeding lines had been selected from 443 crosses—an average of 8.6 advanced lines per cross.

ADVANCED BREEDING LINES

Plant breeders enter their best experimental rices—fixed lines being evaluated for possible release as new farmer varieties—in advanced yield trials.

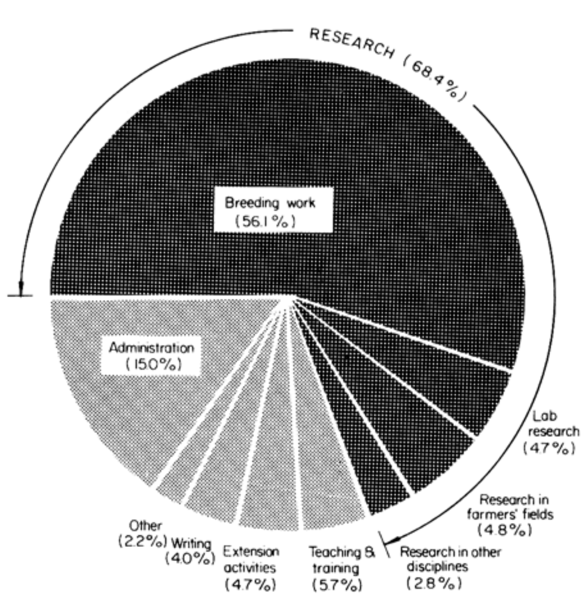
Because most of Asia's future rice varieties will come from such advanced trials, information was collected on the types of plant material that were included in them.

Number and sources of lines. Rice breeders at 28 research centers in 10 countries reported that 4,163 advanced lines were being tested in 29 advanced yield trials. A mean of 144 lines per trial was found, with a range of 12 to 630 lines per trial.

For most trials, the responsible breeder indicated the number of advanced lines developed at his station and the number from outside sources. Data on 4,021 of the breeding lines in 27 advanced yield trials in 9 countries were collected. Fifty-nine percent of the genetic material originated from local crosses made at the breeder's station, and 41% originated outside the stations.

Opinion of IRRI's varietal release policy. Since its beginning IRRI has sent advanced breeding lines to scientists in the national programs, who then test and use them as parents in crosses, or name the best lines as local varieties with local names. IRRI has also named certain elite lines as varieties.

Thirty-five rice breeders at 27 research centers in 10 Asian nations were asked whether IRRI should continue or discontinue naming and releasing varieties under the IR designation.



2. How rice breeders allocate their professional time among different types of work. Thirty-eight scientists at 27 experiment stations and universities in 10 Asian nations, 1975.

Fifty-four percent felt that IRRI should stop its official release of varieties and only send out genetic materials or advanced breeding lines for local scientists to test or use in crosses. (In late 1975, IRRI stopped naming its best experimental lines as official IRRI varieties.)

SOCIOLOGICAL AND PROFESSIONAL ASPECTS OF RICE BREEDERS IN ASIA

In a wide-ranging survey during 1975–76, IRRI asked rice breeders at 28 research centers in 10 Asian countries to give data on the sociological and professional aspects of rice breeding.

Sociological and professional aspects. The mean age of 41 rice breeders at 28 research centers in 10 Asian nations was 42 years. Fifty-three percent of the scientists had agricultural backgrounds and of those, 95% came from families that owned the land. Eighty-five percent of the breeders worked exclusively with rice. A mean of 68% of professional work time was spent in research—56% of the total in breeding activities—and 15% in administrative work (Fig 2). An aspiration of 91% of the scientists interviewed was to continue doing rice breeding work in the next 10 years.

Table 5. Cosmopolitism of Asian rice breeders as determined by their international travel. Thirty-eight rice breeders at 27 agricultural experiment stations and universities in 10 Asian countries, 1975.

International trips	Trips abroad	
	No.	%
Travel abroad[a]	29	76
Trips (av. no./scientist)	2.76[b]	
Destination on last trip		
IRRI	26	90
Other	3	10
Purpose of last trip abroad[a]		
Professional conference	14	48
Education or training	8	28
Consultation with professional colleagues	5	17
Acquisition of new genetic materials	2	7
Basis of selection[c]		
Selection by administrator	11	42
Direct invitation from international research center	8	31
Direct invitation from professional conference	6	23
Other	1	4

[a]During the past 5 years. [b]Average number of trips computed for the 27 breeders who had traveled abroad over the past 5 years. [c]Twenty-six respondents.

Seventy-six percent of the breeders had traveled outside their countries during the previous 5 years (Table 5). Those who had traveled averaged about three trips each. Ninety percent of the most recent trips abroad were to IRRI. The purpose of 48% of the latest trips was attendance at a professional conference, and that of 28% was further education or training.

Half of the breeders held the Ph.D. degree; 32% the MS; and 19% the engineer's or bachelor's degree. Ninety-three percent of the total BS degrees were earned locally and 65% of the awarded Ph.D.'s were from highly developed nations.

Sixty-two percent of the breeders had participated in the IRRI nondegree training program. About 10% had received academic degrees at the University of the Philippines in Los Baños (UPLB), through the IRRI degree training program.

Scientific publications. When the breeders were asked to name the scientific publication in which they would most like to publish an article on their research, about half indicated journals in the highly developed nations. Thirty-eight of the breeders had authored or co-authored 183 published scientific papers during the past 2 years, an average of about 5 papers/scientist. Fifty-three percent of the published articles appeared in national publications, 23% in institutional publications, 18% in journals from highly developed nations, and 6% in international publications.

Thirty-eight breeders had prepared or helped prepare 106 papers for presentation to peer scientists at professional conferences during the last 2 years; 68% of these papers were presented at national or local meetings, 26% at IRRI, and 6% in other Asian nations. The breeders had also prepared 344 newspaper or magazine articles, radio broadcasts, extension publications, and teaching materials—an average of about 9 each.

Literature use and ratings. Ninety-two percent of the total scientific literature read by 37

Table 6. Mean ratings of importance and percentages of use of various nonpersonal and personal sources of scientific information used by at least one-third of a sample of Asian rice scientists. The criterion was usefulness to the scientist in his rice breeding program. Survey of 77 information sources used by 37 rice breeders at 26 agricultural experiment stations and universities in 10 Asian nations, 1976.

Publication or information source	Scientists (%) who use source	Rating of use[a]
IRRI Annual Report	95	6.46
Local problem-area scientists	46	5.06
Communication with IRRI outreach scientists	46	5.05
Plant Breeding Abstracts (UK)	89	4.85
IRRI Reporter	97	4.83
Indian Journal of Genetic and Plant Breeding	73	4.81
Communication with IRRI "core" scientists	86	4.81
Crop Science (USA)	81	4.77
Japanese Journal of Plant Breeding	54	4.75
Professional conferences	59	4.64
IRRI Research Highlights	84	4.58
SABRAO Newsletter	59	4.45
Local plant breeders	68	4.36
International Rice Commission Newsletter (FAO)	81	4.27
Oryza (Italy)	59	4.23
Rice Journal (USA)	65	4.17
Scientific books	81	4.01
IRRI Rice Pathology Newsletter	70	3.96
Japanese Agricultural Research Quarterly	71	3.93
Indian Journal of Agricultural Science	68	3.84
Proceedings of the Crop Society of Japan	38	3.57
Current Science (India)	62	3.43
IRRI Rice Entomology Newsletter	54	3.35
Agronomy Journal (USA)	78	3.28

[a]7 = most important source; 1 = least important.

Table 7. Ratings of adequacy and importance of resources that influence the work of rice breeders. Thirty-eight rice breeders at 24 agricultural experiment stations and universities in 10 Asian nations, 1976.

Resource	Mean rating of adequacy[a]	Importance[b]
Opportunities for specialized training or advanced education for people who work under me (the breeder)	3.08	49
Availability of genetic materials with specific genetic characteristics	2.03	46
Personal freedom to incorporate new breeding materials, techniques, and ideas into the rice improvement program	1.63	45
Opportunity to have breeding lines thoroughly tested under diverse pest and environmental conditions	2.91	38
Financial support	3.00	37
Scientific information resources —journals, books, and contact with other scientists—to use in the breeding program	2.83	32
Availability and quality of trained technical help	2.75	32
Opportunities for specialized training or advanced education	3.27	17
Opportunity to gain scientific recognition	3.13	15
Equipment and tools to use in experiments and breeding work	3.08	12
Opportunities for professional advancement	3.07	11
Experimental land	2.11	7
Transportation	3.25	5
Availability and quality of labor	2.26	2
Other (specify)	3.43	10
Av.	2.99	23.87

[a]On a scale of from 1 to 5: 1 = very adequate at this station; 2 = adequate; 3 = intermediate; 4 = inadequate; 5 = very inadequate. [b]Calculated by assigning a weight of 4 to each factor rated as first in importance by each breeder, 3 to each factor rated second, 2 to each rated third, and 1 to each factor rated fourth. Totals for each factor were then summed to get an index. Maximum possible weight per factor was 96 (if all 24 respondents had rated one factor as first in importance).

breeders was in English. The breeders rated the importance and percentage of use of 77 publications or personal information sources (Table 6). The *IRRI Annual Report* received the highest mean rating—6.46 on a scale where 7 was "most important source of information." It also received the highest percentage of use. The second most important source of information was "local problem-area scientists such as agronomists, entomologists, and pathologists," followed by "correspondence or consultation with IRRI outreach scientists"; *Plant Breeding Abstracts*; the *IRRI Reporter*; and the *Indian Journal of Genetics and Plant Breeding.*

Use of resources. When the scientists rated the adequacy or inadequacy of resource factors in their breeding programs, "personal freedom" was found to be most adequate, followed by "availability of experimental land" and "availability and quality of field labor" (Table 7). Rated as least adequate were "opportunities for specialized training or advanced education" and "transportation." Noted as the most important to the success of a breeding program was "opportunities for specialized training or education for the people who work under me," followed by "the availability of suited genetic materials" and "personal freedom."

Control and management of rice pests

Summary

DISEASES

Five systemic fungicides were used as seed treatment to control blast in upland rice. In preliminary trials seed treatment reduced blast infection but did not sufficiently control the disease. Soil moisture seemed to influence the fungicide's effectiveness. Frequency of spraying appears important in blast control. Experiments on blast control by spraying showed that more frequent spraying at a reduced dosage increased the level of control and rice yield.

Dew is important to blast development. It greatly affects spore release and infection, two vital processes of the disease cycle. The longer the dew duration, the more spores were released and the more severe was blast infection.

In studies to forecast the development of blast disease by dew period and number of airborne spores, the simple correlation obtained between number of lesions and dew period was high ($r = 0.88$), while that between number of lesions and spore number was low ($r = 0.55$). With the use of both dew period and spore number in two levels, the correlation was higher ($r = 0.91$), especially when a high level of spore concentration was used.

In a continuing study of the epidemiology of tungro, farmers' fields were surveyed during the last 4 years. The number of tungro vectors and percentage of infective insects during the period between April and June, and the average tungro incidence during the period between June and October seemed correlated. The information can be used in forecasting the disease in the study area.

The dispersal of viruliferous insects affects the spread of tungro disease. The dispersal of *N. virescens* is affected by such factors as duration for dispersal, plant height, and rice variety, but not by number of insects at the point of release, time of release of insects, and tungro-diseased plants.

INSECTS

Several new insecticides effectively controlled the green leafhopper (GLH) and brown planthopper (BPH) in laboratory tests. As a foliar spray, NRDC 161, a synthetic pyrethrin or "pyrethroid," controlled GLH in field experiments but caused BPH resurgences in both irrigated and upland field experiments.

Foliar applications of carbofuran controlled BPH at low rates of 80 g a.i./ha and GLH at 4 g a.i./ha in greenhouse experiments. Many insecticides were tested as paddy-water and root-zone applications, but none were more effective than carbofuran.

A study of the rate and frequency of insecticide application indicated the necessity of protection, shortly after transplanting, for maximum yields. During the wet season, rates of broadcast application were important, but rates of 0.5 and 2.0 kg a.i./ha in the root-zone treatments showed little difference. Root-zone treatments provided more profit than any other application method.

Carbofuran provided effective control as a root-zone application when mixed and applied simultaneously with urea and 2,4-D. Coating the roots before transplanting, by dipping them into a mixture of gelatin, water, and carbofuran, provided excellent control of the whorl maggot and GLH and resulted in yields equal to those from four broadcast applications.

In greenhouse tests, field-collected BPH were more resistant to insecticides than were the greenhouse-cultured BPH. Close plant spacing increased BPH populations but had no apparent effect on GLH. Egg parasitism and predation of the GLH and BPH were important population-regulating mechanisms.

The economic loss threshold for the rice bug was established at 2–4 rice bugs/sq m.

The predaceous bug *Cyrtorhinus lividipennis* was found to be much more sensitive to insecticide applications than the spider *Lycosa pseudoannulata*. Varying the method of application did not appear to benefit the conservation of the bug.

WEEDS

Efforts were intensified to identify herbicides that perform well on rainfed rice. Of the chemicals tested for the first time the promising ones are NTN 5810/2,4-D, EXP 3316, and Prodotto D75 for transplanted rice; X-52/2,4-D, MT 101, and NTN 5810/2,4-D for direct-seeded, flooded rice, and SL-55, NTN 6867, and EXP 3316 for upland rice. Terbuchlor appeared outstanding for all types of rice culture. The search continues for herbicides that will minimize hand weeding in dry-seeded, rainfed, bunded rice without causing stand losses due to toxicity.

Integrated weed management studies included cultural practices that evaluate the effects of varietal type, water depth, and degree and interval between tillage operations in transplanted rice, as well as the effects of variety, tillage, and water depth in direct-seeded, flooded rice. In both types of rice culture IR36, with its spreading foliage, competed better with weeds than did IR34 with its erect leaves.

Zero and minimum tillage studies indicated that minimum tillage is a dependable alternative to conventional tillage where difficult-to-control weeds are absent or were previously controlled.

Control and management of rice pests

Diseases

Plant Pathology Department

Chemical control in upland rice. Several chemicals were tested for controlling blast in upland rice at both seedling and later stages.

Seed treatment. Blast infection during the first 30 to 40 days of growth is critical for upland rice. Five systemic fungicides were used as a seed treatment to protect seedlings against blast. In a preliminary experiment in the blast nursery, the seed treatment greatly reduced leaf infection. In a field trial, infection was also reduced but grain yields did not differ significantly (Table 1). Fluctuations in yield between replications, caused by soil heterogeneity and soil water content, may have affected the results.

Frequency of spraying. Two experiments were conducted on the effect of frequency of spraying on blast control. In one experiment, fungicides at 1.0 kg/ha were sprayed every week, every 2 weeks, and every 3 weeks starting at about 30 days after seeding (DS). In the other, they were sprayed at 0.25 kg/ha once a week, at 0.50 kg/ha every 2 weeks, and at 1.0 kg/ha every 4 weeks starting at 30 DS. More frequent spraying increased the level of control (Table 2). Split application and increased frequency improved efficiency (Table 3). However, chemical control appears to have little practical value for a blast-susceptible variety in upland culture.

Epidemiological studies. Because blast is incited by airborne spores, spore release is a vital

Table 1. Chemical seed treatment for control of rice blast.[a] IRRI, 1976.

Treatment	Rate (g/kg seed)	Grain yield[b] (kg/ha)	Lesions[c] (no./10 seedlings)	Neck blast[b] infection (%)
PP 389	40	1145.6 a	11 a	44 a
PP 389	10	1082.5 a	16 b	52 a
Benlate	40	1094.5 a	20 bc	45 a
Benlate	10	1061.9 a	26 cd	56 ab
NF-44	40	1078.9 a	16 bc	36 a
NF-44	10	986.1 a	19 bc	56 ab
NF-48	40	1148.9 a	9 a	41 a
NF-48	10	1121.7 a	23 bc	51 a
HOE 22843	40	1079.5 a	15 b	45 a
HOE 22843	10	1052.5 a	25 bcd	54 ab
Control	—	879.2 a	36 d	75 b

[a]Means followed by the same letter are not significantly different at the 5% level. [b]Average of 4 replications. [c]Counted 4 weeks after seeding.

Table 2. Effect of frequency of fungicide spraying on blast control.[a] IRRI, 1976.

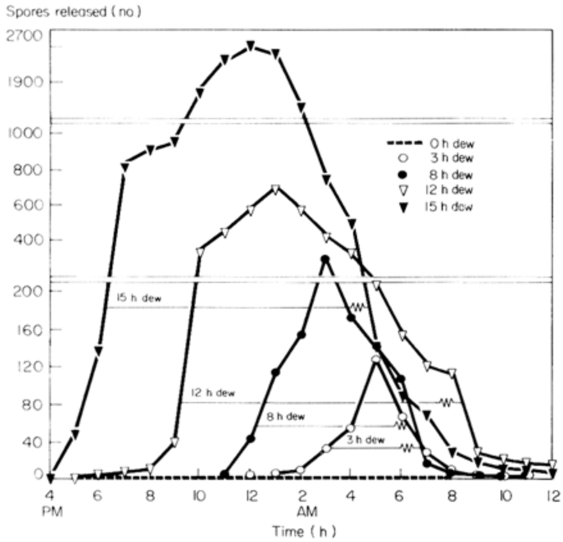
Treatment	Frequency of application	Rate (kg/ha)	Grain yield[b] (kg/ha)	Neck blast[b] infection (%)
NF-44	Once a week	1.0	2179.1 a	25.0 ab
NF-44	Every 2 weeks	1.0	1854.3 abc	28.3 ab
NF-44	Every 3 weeks	1.0	1807.6 abc	56.8 c
Benlate	Once a week	1.0	2189.1 a	18.0 a
Benlate	Every 2 weeks	1.0	1959.5 abc	27.5 ab
Benlate	Every 3 weeks	1.0	1616.2 cd	55.3 c
NF-48	Once a week	1.0	2153.8 ab	26.0 ab
NF-48	Every 2 weeks	1.0	2045.3 abc	30.0 ab
NF-48	Every 3 weeks	1.0	1823.8 abc	52.5 c
PP 389	Once a week	1.0	2103.4 ab	26.3 ab
PP 389	Every 2 weeks	1.0	2043.8 abc	41.8 bc
PP 389	Every 3 weeks	1.0	1692.9 bcd	57.5 c
Control	—	—	1325.2 d	60.3 c

[a]Means followed by the same letter are not significantly different at the 5% level. [b]Average of 4 replications.

Table 3. Effect of split application of fungicide sprays on control of rice blast.[a] IRRI, 1976.

Treatment	Frequency of application	Rate (kg/ha)	Grain yield[b] (kg/ha)	Neck blast[b] infection (%)
HOE 17411	Every 4 weeks	1.00	1845.4 abc	59.5 bcd
HOE 17411	Every 2 weeks	0.50	2103.3 a	49.5 ab
HOE 17411	Once a week	0.25	2089.2 a	48.0 a
NF-44	Every 4 weeks	1.00	1820.8 abc	54.8 abc
NF-44	Every 2 weeks	0.50	1750.4 abcd	53.3 abc
NF-44	Once a week	0.25	2024.2 ab	53.8 abc
Benlate	Every 4 weeks	1.00	1664.4 abcd	56.5 abc
Benlate	Every 2 weeks	0.50	1822.5 abc	52.0 abc
Benlate	Once a week	0.25	1842.5 abc	51.3 abc
PP 389	Every 4 weeks	1.00	1593.3 bcd	61.8 cd
PP 389	Every 2 weeks	0.50	1564.2 bcd	55.8 abc
PP 389	Once a week	0.25	1676.7 abcd	47.8 a
Control	—	—	1332.0 d	67.5 d

[a]Means followed by the same letter are not significantly different at the 5% level. [b]Average of 4 replications.



1. Effect of dew period on spore release from blast lesions on rice leaves in blast nursery. IRRI, 1976 dry season.

process in the disease cycle. Earlier IRRI studies showed that spores of the blast fungus are released from lesions in the presence of dew or light rain.

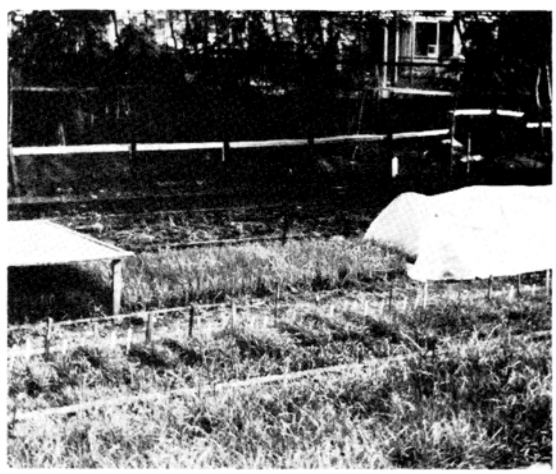
Dew period and spore release. The relationship between duration of dew period and amount of spores released was studied in the IRRI blast nursery where infected leaves were always abundant. The dew period, temperature, and relative humidity were recorded nightly (from 1700 to 0800 hours). Spore samples were collected by the Kremer-Colin spore sampler, and counted. The dew period had a dramatic effect on spore release; a longer dew period caused earlier release of spores and a larger number of released spores (Fig. 1).

In the blast nursery the dew period was extended by covering the plants with a plastic sheet. The period was reduced by hanging a bamboo mat over the seedlings (Fig. 2). Temperature, relative humidity, and dew period were recorded. The development of blast was estimated from the number of lesions on 100 seedlings on each plot every other day.

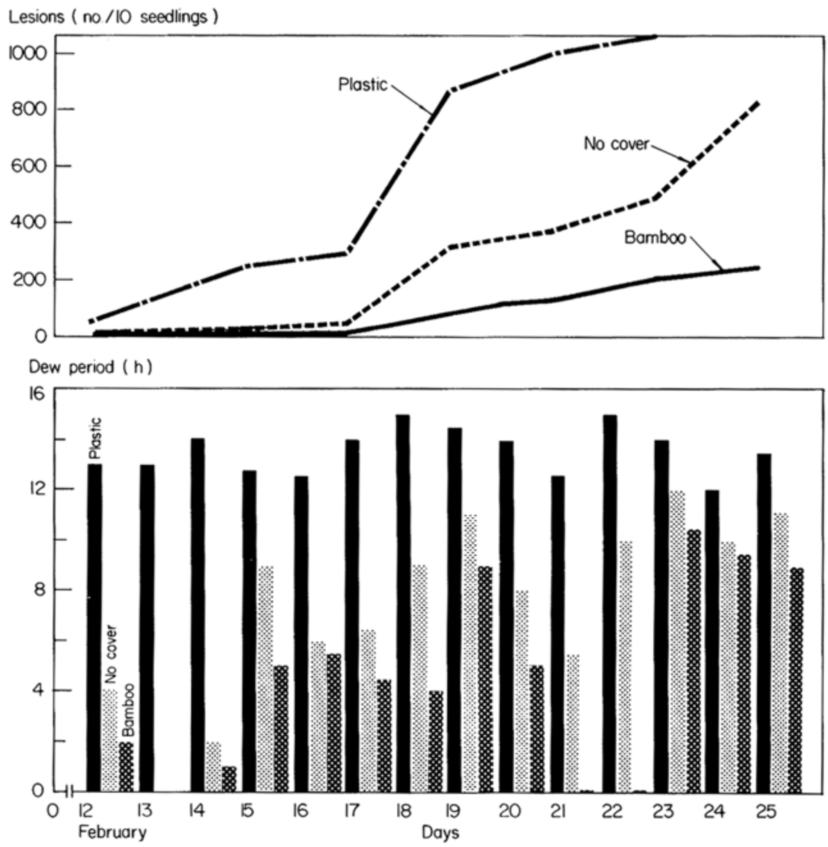
Blast developed earlier and was most severe under the plastic sheet. The plants under the bamboo mat had little blast. Under natural (no treatment) conditions, blast development was moderate (Fig. 3). Temperature and relative humidity at night did not differ significantly. Under the bamboo mat, guttation may have induced leaf infection by blast spores.

Leaf wetness and infection. Another vital process of the blast disease cycle is infection after the spores have lodged on leaves or other plant parts. A study examined the effect of duration of leaf wetness on rate of infection. After spray with spore suspension rice seedlings were placed in dew chambers in the IRRI phytotron for periods from 4 to 26 hours. Then they were moved to a room at about 25°C and 70% relative humidity to permit lesions to develop. The longer the period of wetness (up to about 23 hours), the greater the number of lesions (Fig. 4). The lesions were fewer on moderately resistant varieties (Peta) than on the susceptible Khao-teh-haeng 17. In the field, dew is the major factor that causes leaf wetness. Rain also wets the leaves, but it usually washes the spores off them.

Correlation between dew period and airborne spores. To forecast blast development by dew period and airborne spores, potted, blast-free seedlings from the greenhouse were exposed overnight in an upland field with a high incidence of blast. Temperature, relative humidity, and dew period were recorded, and airborne



2. Manipulation of dew periods in blast nursery. Plastic covering extends dew period; bamboo mat hung over the plot reduces it.



3. Effect of bamboo mat and plastic sheet covering on blast disease development in blast nursery. IRRI, 1976.

spores were sampled. After the exposure, the pots were returned to the greenhouse. A week later, the lesions were counted. Sixty-two sets of such data were accumulated.

Dew period and number of lesions were highly correlated (Fig. 5). The correlation was even higher when spore concentration was considered (Fig. 6). The correlation between spore number and lesion number was relatively low (Fig. 7); the correlation was closer with longer dew periods (Fig. 8). Correlations between temperature and relative humidity were insignificant.

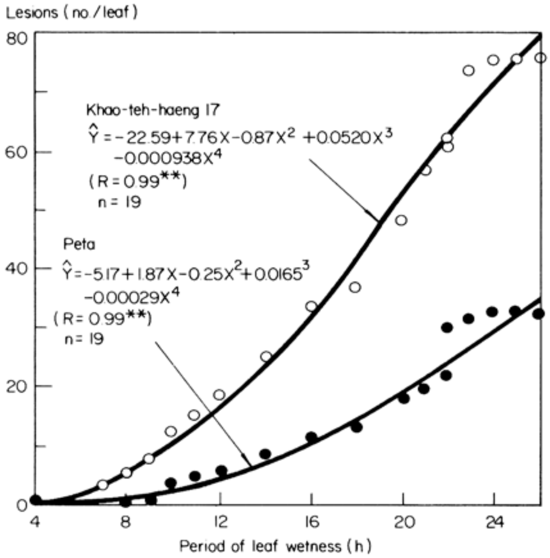
TUNGRO

The epidemiological study of rice tungro disease in farmers' fields in five provinces of Luzon, Philippines, was continued. The disease incidence was observed, insect vectors were collected, and the vectors' infectivity was determined every 2 weeks from November 1975 to October 1976 (Table 4).

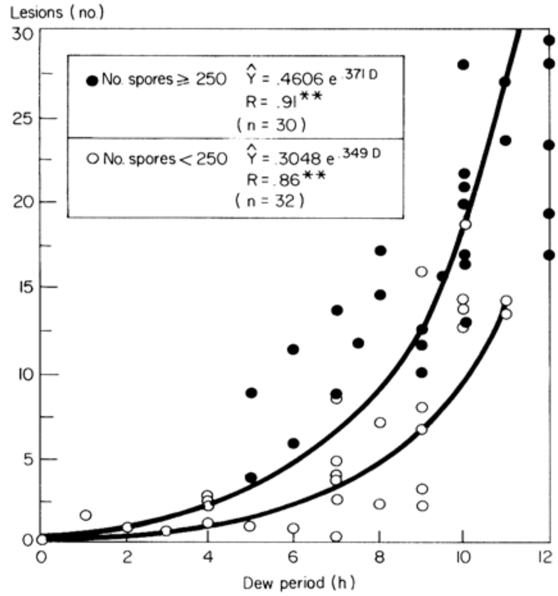
Incidence. The incidence of tungro in the study fields was low. The overall average incidence was 0.68% in 584 observations. About 44% of the fields, however, had plants with tungro. The disease appeared in the fields throughout the study period. The high incidence (2.79%) occurred in November 1975 and low incidence (0.03%) in July 1976.

No tungro infection was observed on rice varieties Bencer, IR32, IR34, Santa Maria, and Wagwag. The other 15 varieties and lines were infected to various degrees. IR1561, which had the highest disease incidence (Table 4), also had the highest disease incidence in 1975 (1975 Annual Report).

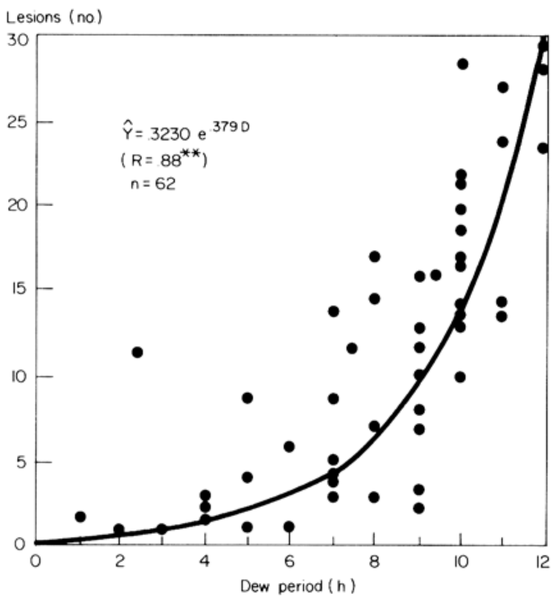
Insect vectors. A total of 3,379 insect vectors



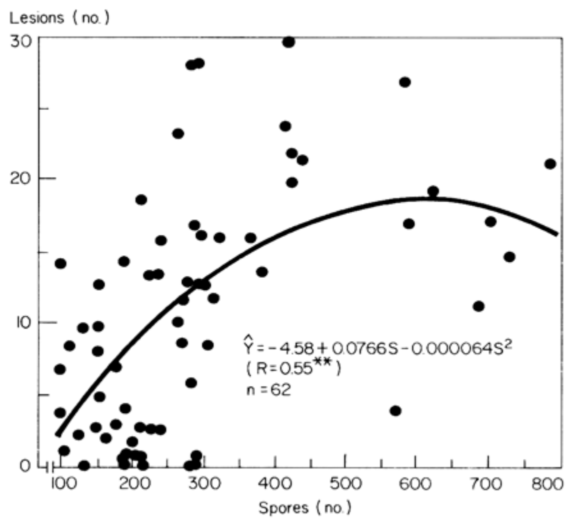
4. Relation of duration of period of leaf wetness in dew chamber to *P. oryzae* infection (number of lesions developed in greenhouse) on variety Peta and Khao-teh-haeng 17. IRRI phytotron, 1976.



6. Relation of dew period to number of lesions per seedling at two levels of spore concentration. IRRI greenhouse, 1976.



5. Relation of dew period to number of blast lesions per seedling. IRRI greenhouse, 1976.

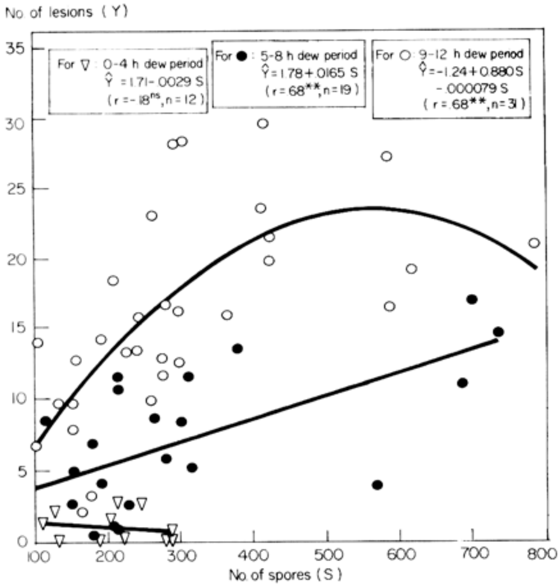


7. Relation of number of airborne spores to number of blast lesions per seedling. IRRI greenhouse, 1976.

were collected from the study fields. Of the number, 24% were nymphs and 76% were adults; 56, 39, and 5% were *Nephotettix virescens*, *N. nigropictus*, and *Recilia dorsalis*, respectively.

The number of insect vectors was generally low in the study period, particularly in December and January; the average was 5.8 insects/10 sweeps. The highest number of insects was collected in October. Data classified by province, field, and variety are in Table 4.

The highest number of *N. virescens*, *N. nigropictus*, and *R. dorsalis* was collected in October



8. Relation of number of spores to number of lesions in three dew periods. IRRI greenhouse, 1976.

(1975), March, and October (1976), respectively. The ratio of *N. virescens* to *N. nigropictus* to *R. dorsalis* was 53 : 41 : 6 in seedbeds, 74 : 23 : 3 in paddy fields, and 48 : 47 : 5 in stubble fields.

The number of insect vectors was generally higher in fields that had tungro than in the fields that had none (Table 5). But the difference in number of insect vectors between fields with and without tungro was greater in the paddy fields than in the stubble fields. Furthermore, the ratio of the three species of insect vectors differed in the fields with tungro. For instance, more *N. virescens* were found in paddy fields with tungro, but there were more *N. nigropictus* in stubble fields with tungro. The kinds of host plants present in a field may be a more important determinant of the ratio of the insects than is the presence of the disease.

Infective insects. During the study period, 8,992 insect vectors were collected from the study fields and tested for their infectivity. Of the insects tested, 55, 39, and 6% were *N. virescens*, *N. nigropictus*, and *R. dorsalis*, respectively. The percentage of infective insects was low throughout the study period, particularly in April, May, and June; the overall average was 0.75%. The highest percentage occurred in October. *N. virescens* had 1.18% infective insects, *N. nigropictus* had 0.17%, and *R. dorsalis* had 0.51%.

The percentage of infective insects varied among the provinces, the fields, and the rice varieties and lines (Table 4). Regardless of paddy or stubble fields, the percentages of infective insects were often higher in the infected fields (Table 5).

Table 4. Tungro incidence and insect vectors in Luzon, Philippines, classified by province, field, and variety. November 1975–October 1976.

Province, field type, variety	Observations (no.)	Tungro		Insect vectors			
		Fields (%)	Incidence (%)	Collections (no.)	Av. no. per 10 sweeps	Tested (no.)	Infective (%)
Bulacan	250	53	0.76	162	9.7	2998	0.90
Laguna	208	31	0.60	121	4.1	1534	0.59
Nueva Ecija	125	58	0.32	87	4.0	1372	0.29
Pampanga	155	43	0.82	88	3.4	1212	1.07
Tarlac	208	36	0.76	124	5.4	1947	0.72
Seedbed	70	0	0	70	7.0	1524	0.07
Paddy	519	38	0.43	268	3.5	2838	0.56
Stubble	211	73	1.52	210	9.3	4630	1.08
Idle	146	0	0	34	0.2	71	0
C4-63G	37	59	0.36	26	5.8	433	0.69
IR20	30	70	0.49	22	4.5	445	0.22
IR26	210	45	0.76	138	3.0	2531	1.03
IR28	77	47	0.19	51	2.5	1018	0.29
IR29	44	66	0.34	34	2.0	638	0.31
IR30	118	36	0.39	74	5.6	1131	0.44
IR1561-228-3	93	68	2.33	68	10.4	1041	2.11
Jumbo	34	59	0.46	24	0.4	422	0.47
Others	157	15	0.29	111	3.0	1333	0.23

Table 5. Insect vectors in rice fields with and without tungro disease in Luzon, Philippines, between November 1975 and October 1976.

Province	No tungro					With tungro				
	Collections (no.)	Vectors (no./10 sweeps)	Vectors ratio[a]	Vectors tested (no.)	Infective insects (%)	Collections (no.)	Vectors (no./10 sweeps)	Vectors ratio[a]	Vectors tested (no.)	Infective insects (%)
					Paddy fields					
Bulacan	38	4.1	80:16:4	403	0	24	9.3	90: 9:1	356	1.40
Laguna	60	1.6	41:56:3	392	0	11	2.7	67:33:0	174	0.57
Nueva Ecija	21	1.4	80:20:0	142	0.70	10	1.3	79:14:7	69	2.90
Pampanga	29	2.4	63:29:8	309	0.32	18	4.7	80:15:5	268	0
Tarlac	41	1.9	52:44:4	475	0.63	16	9.3	80:19:1	250	1.20
Total	189	2.3	63:33:4	1721	0.29	79	6.3	84:15:1	1117	0.98
					Stubble fields					
Bulacan	13	19.8	78:21:1	134	0	52	13.6	60:37:3	1345	1.64
Laguna	12	8.4	28:59:13	230	0.43	29	8.9	37:60:3	704	0.99
Nueva Ecija	6	13.8	69:20:11	147	0	35	4.8	35:51:14	831	0.12
Pampanga	6	1.2	57:29:14	59	0	14	4.9	57:38:5	285	4.21
Tarlac	19	2.5	21:71:8	227	0.44	24	10.7	11:86:3	668	0.90
Total	56	8.9	61:33:6	797	0.25	154	9.4	45:51:4	3833	1.25

[a]*Nephotettix virescens: N. nigropictus: Recilia dorsalis* in %.

Insect vectors and tungro. Tungro virus is transmitted only by insect vectors, and disease incidence is undoubtedly determined by the population of insect vectors and the percentage of infective insects when other factors remain unchanged.

In the study fields during the last 4 years, the average number of insect vectors and the percentage of infective insects between April and June, and the average tungro incidence between June and October seemed related (Table 6). Hence, reducing the insect vectors and the percentage of infective insects in April, May, and June may reduce the incidence of the disease on the rice crop in the study fields in the rainy season. The number of insect vectors and the percentage of infective insects in the period between April and June that could cause a tungro outbreak in the study fields remain under investigation.

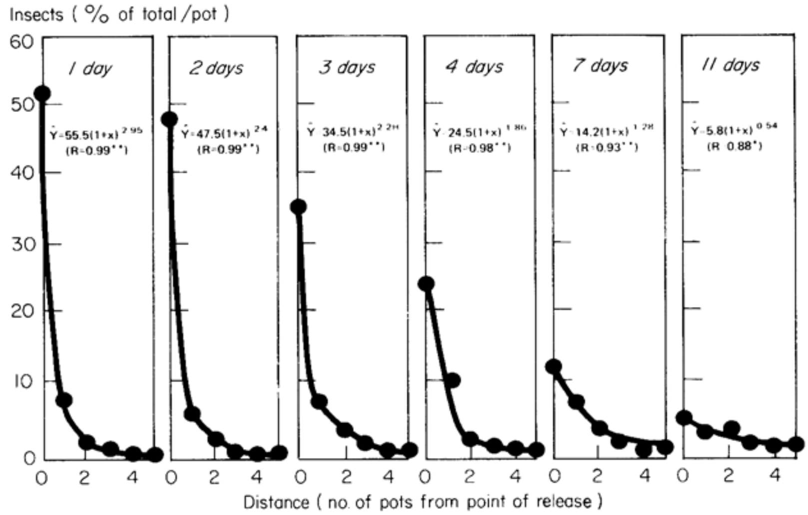
Experimental epidemiology. A factorial experiment using the cage method was conducted to determine the effect of number of adult insects of *N. virescens*, duration of caging, and amount of virus sources (number of pots containing tungro-diseased plants in a cage) on the incidence of tungro, as expressed by percentage of infected seedlings of Taichung Native 1. The test involved 137,670 insects, 2,696 pots of diseased plants, and 213,400 test seedlings in 8,536 pots.

The data are being statistically analyzed, but the overall averages indicate that 26, 35, 43, 57, 62, 67, 70, 73, and 78% seedlings were infected in cages each containing 15, 30, 60, 120, 180, 240, 300, 450, and 600 insects, respectively. The cages in which insects were confined for 1, 2, 4, 7, 11, 16, and 22 days had 15, 25, 49, 66, 77, 78, and 88% infected seedlings, respectively. In cages that each contained 1, 2, 4, and 8 pots of

Table 6. Insect vectors in study fields in April, May, and June and incidence of rice tungro disease in paddy fields between June and October, Luzon, Philippines, 1976.

Year	Insect vectors				Tungro disease		
	Collected (no.)	No./10 sweeps	Tested (no.)	Infective (%)	Observations (no.)	Fields (%)	Incidence (%)
1973	68	5.8	1028	0	151	1[a]	0.60
1974	166	11.0	2425	1.77	244	45[b]	2.38[b]
1975	181	9.8	3319	0.69	234	72	3.32
1976	149	3.9	2244	0.18	267	25	0.33

[a]Rice fields with only a few tungro-diseased plants were excluded. [b]The Philippine Government launched a green leafhopper control program in the area in July and August.



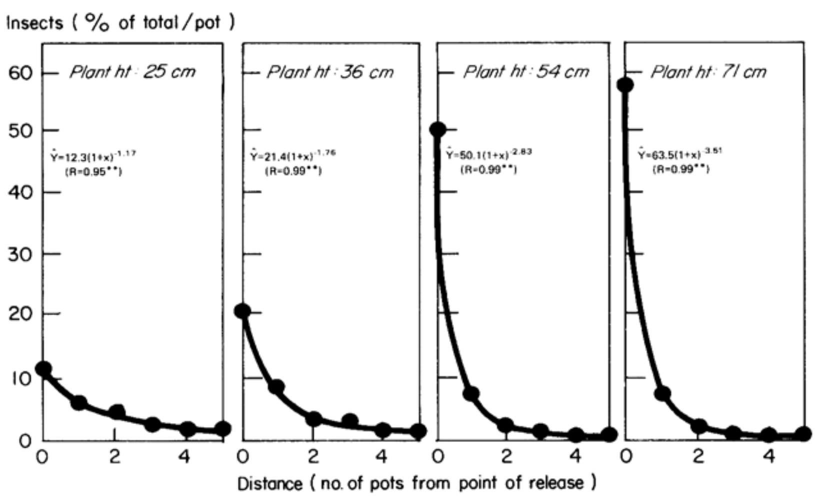
9. Dispersal of *Nephotettix virescens* adults on 36 pots of TN1 rice plants in screened cages at different days after the introduction of 100 insects/cage.

tungro-diseased plants as virus sources, 49, 54, 57, and 65% of the seedlings became infected.

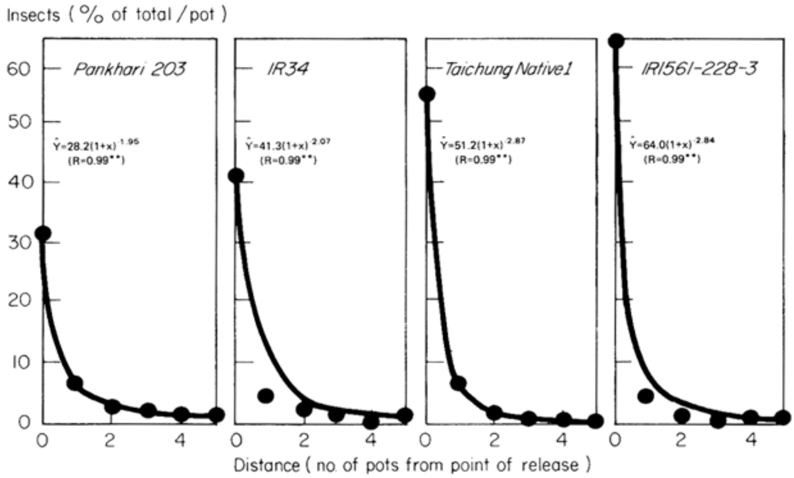
Light trap. Trapping of insect vectors of rice tungro and grassy stunt at IRRI was continued. Weekly trapping by light took place between 1700 hours and 2 hours after sunset. Some trapped insects were tested for infectivity.

The average number of tungro vectors (*N. virescens*, *N. nigropictus*, and *R. dorsalis*) was 235, 30, 143, 48, 194, 79, 135, 269, 1,883, 3,806, 3,199, and 687 per trap for each consecutive month from November 1975 through October 1976. The ratio of *N. virescens* to *N. nigropictus* to *R. dorsalis* was 68 : 22 : 10. Of 4,511 trapped insects tested, only 0.67% were infective. The infective insects were trapped in November and December 1975, and in September and October 1976.

The number of grassy stunt vector *Nilaparvata lugens* averaged 127, 15, 34, 15, 55, 21, 14, 74, 257,325, 2,935, and 1,001 per trap for each consecutive month from November 1975 to October 1976. Of 1,679 trapped brown planthoppers tested for infectivity from November 1975 to



10. Dispersal of *Nephotettix virescens* adults on 36 pots of TN1 rice plants of different heights in screened cages the morning after the introduction of 100 insects/cage.



11. Dispersal of *Nephotettix virescens* adults on 36 pots of rice plants of different varieties in screened cages the morning after the introduction of 100 insects/cage.

October 1976, none were infective. No grassy stunt was observed at IRRI during the period.

Dispersal of N. virescens. Because the spread of tungro results from the movement, dispersal, or migration of the tungro-viruliferous insects, the dispersal of *N. virescens* as affected by several factors was studied.

N. virescens reached rice plants even at a distance of 750 cm. More insects reached the plants in a given period of time when the distance was 200 cm or less.

Insect dispersal was not significantly affected by the number of insects at the point of release. Neither was it affected by the time of release as long as the duration for dispersal remained the same. The longer the time for dispersal, the more even was the distribution of insects on the rice plants in an area (Fig. 9).

The actual time required for *N. virescens* to spread tungro disease in a rice field is determined by the number of insects, the size of the field, and the site where the insects start to disperse into the field. In the present study, insect dispersal as a function of time and distance was expressed by:

$$\hat{y} = 69.8^{-0.23d}\,(1 + \chi)^{-3.6e^{-0.17d}} \quad (R = 0.99^{**})$$

where $\hat{y}$ = percentage of total insects per rice hill; $e = 2.718$; χ = distance, ranging between 0 and 5 rice hills; and d = duration, ranging between 1 and 11 days.

Plant height and insect dispersal. The size of rice plants, as expressed by plant height, affected insect dispersal (Fig. 10). The smaller the rice plants, the more even was the distribution of the insects among rice hills in the experimental area. The finding suggests that tungro would spread much more evenly and perhaps faster in a field with young rice plants than in a field with older rice plants. Furthermore, the younger the rice plant, the more susceptible it would be to tungro.

Rice variety and dispersal. Insect dispersal varied among rice varieties (Fig. 11). The difference in dispersal could be explained by the difference in plant height of the rice varieties as well as by the differences in insect preference of rice varieties. The insects moved more on a nonpreferred variety than on a preferred variety (1975 Annual Report).

Insect dispersal was not affected by tungro-diseased rice plants. No statistical significance was observed in insect dispersal when the insects were placed in separate cages of diseased and healthy plants, or in one cage with both diseased and healthy plants.

Insect dispersal in uncovered area. When adult insects were released at the center of an uncovered area with 168 pots of rice plants, the pattern of insect dispersal did not differ much from that in a cage.

Control and management of rice pests

Insects

Entomology Department

INSECTICIDES

Entomology Department

Although rice varieties with resistance to some insects are available, there are several pests to which varieties have little or no resistance. Even with resistance, the possibility of the development of a biotype that can destroy resistant varieties points out the continued need for testing pesticides to control certain rice pests.

The objectives of IRRI's insecticide program are to identify insecticides that effectively control an insect but are less harmful to beneficial insects, and to develop methods of insecticide application that decrease the amount of insecticide applied to a crop.

Contact toxicity. The contact toxicity of 26 insecticides was determined. Of the chemicals commerically available in the Philippines, none were highly active as contact poisons. The synthetic pyrethroids NRDC 149, NRDC 161, and WL 41706, and two analogues of carbofuran, FMC 31768 and FMC 27289, were most effective against both the brown planthopper (BPH) and green leafhopper (GLH) (Table 1). Compounds found ineffective as a contact spray against both BPH and GLH were carbaryl + methyl parathion, Padan + MIPC, RH 218, RH 6337, SAN 1971, Padan, carbaryl, dimethoate, BPMC, UBI R677, vamidothion, Lethox + BPMC, and Sumithion. BPMC and acephate, which are effective as foliar spray against BPH and widely recommended for BPH control, are not effective contact insecticides.

Foliar sprays. Compounds applied as foliar sprays in greenhouse tests were generally more effective than they were in the contact toxicity tests (Table 2, 3). Insecticides currently recommended for BPH control in the Philippines, such as carbofuran, chlorpyrifos + BPMC, Perthane, acephate, azinphos-ethyl, and carbophenothion, provided effective control. Of the new compounds, the synthetic pyrethroid NRDC 149 was most effective. NRDC 149 and another new compound, WL 41706, as well as carbofuran 36F (flowable formulation with molasses as carrier), all caused greater than 90% mortality at 14 days after treatment (DAT). Insecticides that were ineffective against both BPH and GLH were JF 2130, SAN 1971, EPN 300, Padan, methomyl, RH 6337, Padan + carbaryl, UBI R677, fenitrothion, and SAN 155.

Four field experiments during 1976 evaluated insecticides as foliar spray. One dry-season evaluation tested 12 insecticides against whorl maggot and against GLH as a virus vector (Table 4). Foliar sprays at 20-day intervals provided poor control of the whorl maggot. However, eleven compounds brought about significantly less damage than the control at 38 DT. Among them, NRDC 161 was the most

Table 1. Contact toxicity of insecticides applied against brown planthopper (BPH) and green leafhopper (GLH) at 0.04% concentration in a Potter's spray tower. IRRI laboratory, 1976.

Insecticide	Formulation[a]	Mortality[b] (%)							
		BPH				GLH			
		1 HT[c]	4 HT	24 HT	48 HT	1 HT	4 HT	24 HT	48 HT
NRDC 149	10 EC	80	100	100	100	86	100	100	100
NRDC 161 (Decis)	2.5 EC	53	78	80	87	80	100	100	100
WL 41706	30 EC	53	86	86	86	67	100	100	100
FMC 31768	24 EC	37	93	98	98	47	100	100	100
FMC 27289	48 EC	33	93	94	95	59	100	100	100
Methomyl	20 EC	22	40	46	46	—	—	—	—
WL 43775	30 EC	18	53	64	72	68	92	100	100
S-5602	20 EC	16	46	58	61	53	92	100	100
FMC 35001	48 EC	9	50	82	84	49	100	100	100
FMC 35023	24 EC	6	63	85	91	25	100	100	100
JF 2130	50 DP	1	4	22	23	0	2	36	69
Acephate	75 SP	0	4	9	9	0	2	32	76
NI-15	50 WP	0	5	17	26	0	0	65	90

[a]EC = emulsifiable concentrate; WP = wettable powder; DP = dispersible powder; SP = soluble powder. [b]Average of 4 replications, each consisting of 25 insects treated and caged on plants; adjusted using Abbott's formula. [c]HT = hours after treatment when insect mortality was determined.

Table 2. Knockdown and residual effects of insecticides applied against brown planthopper (BPH) and green leafhopper (GLH) as 0.04% foliar spray at 12.5 ml solution/potted plant (variety TN1). IRRI greenhouse, 1976.

Insecticide	Formulation[a]	Mortality[b] (%)					
		BPH			GLH		
		1 DAT	7 DAT	14 DAT	1 DAT	7 DAT	14 DAT
NRDC 149	10 EC	100	89	94	100	100	100
Chlorpyrifos + BPMC	21 + 10.5 EC	100	12	4	100	20	0
WL 41706	30 EC	100	78	96	100	100	100
Carbofuran	20 F	100	92	39	100	100	100
Perthane	45 EC	100	8	12	100	7	0
Carbofuran	36 F	100	100	100	100	100	100
Vamidothion	40 EC	100	68	43	100	100	100
Acephate	75 SP	100	18	7	100	44	42
BPMC	50 EC	93	19	9	100	46	17
Isoxathion	50 EC	91	55	15	100	97	46
Azinphos methyl	40 EC	90	18	14	100	89	97
NRDC 161 (Decis)	2.5 EC	88	22	21	100	94	97
AC 64475	25 EC	76	24	19	100	80	57
Fenitrothion + BPMC	75 EC	66	14	8	100	5	0
Sumithion (encapsulated)	20 EC	57	26	10	94	72	5
Dicrotophos	20 EC	42	24	10	100	68	26
Methamidophos	50 EC	45	9	8	100	76	55
WL 43775	30 EC	43	7	25	100	84	100
Carbaryl + methyl parathion	40 + 10 EC	30	15	6	70	17	0
Phosphamidon	50 EC	27	23	7	100	0	6
Carbaryl	85 WP	24	20	18	67	29	12

[a] EC = emulsifiable concentrate; WP = wettable powder; F = flowable; SP = soluble powder; Carbofuran 36 F = flowable formulation with molasses as carrier. Carbofuran 20 F has water as carrier. [b] Average of 4 replications each consisting of 15 insects caged on a potted plant; adjusted using Abbott's formula. DAT = days after treatment at which insects were caged on treated plants. Mortality was determined at 48 h after caging.

effective. Even though the incidence of virus during the dry season was low—GLH populations were low—significant differences were attributed to seven compounds. Despite excellent control of the whorl maggot and GLH by NRDC 161, a resurgence of BPH lowered the yields.

Nine insecticides were field tested during the wet season (Table 5). NRDC 161, which provided good protection in the dry season gave poor protection in the wet season. Virus infection was extremely high. Only NRDC 161,

Table 3. Knockdown and residual effects of insecticides applied against brown planthopper (BPH) and green leafhopper (GLH) as 0.04% foliar spray at 12.5 ml solution/potted plant (variety TN1). IRRI greenhouse, 1976.

Insecticide	Formulation	Mortality[a] (%)					
		BPH			GLH		
		1 DAT	6 DAT	13 DAT	1 DAT	6 DAT	13 DAT
WL 43467	40 EC	100 a	100 a	42 a	100 a	100 a	100 a
Carbophenothion	40 EC	100 a	59 b	16 bc	100 a	97 a	37 cde
Perthane	45 EC	95 a	43 bcd	10 bcd	92 ab	42 de	2 g
Endosulfan	35 EC	93 ab	18 e	18 bc	85 abc	13 fg	4 fg
Lethox + BPMC	(30 + 10) EC	92 ab	33 cde	9 bcd	97 ab	55 d	16 ef
Chlorfenvinphos	20 EC	83 bc	34 cde	16 bc	100 a	85 ab	26 de
Pyridaphenthion	40 EC	70 cd	51 bc	17 bc	88 ab	77 bc	52 bc
A47171	24 EC	67 cde	37 cde	18 bc	95 ab	25 ef	5 fg
Methyl parathion	50 EC	60 de	26 de	7 bcd	81 bcd	14 fg	2 g
Diazinon	20 EC	45 ef	32 cde	24 abc	100 a	16 efg	5 g
DS 15647	23 EC	35 fg	34 cde	14 bc	100 a	60 c	23 e
UC 51762	75 WP	33 fg	34 cde	10 bcd	100 a	96 a	49 bcd
Cytrolane	25 EC	20 gh	20 de	7 bcd	62 cd	17 efg	6 fg

[a] In a column, all means followed by the same letter are not significantly different at the 5% level. Insect mortality was determined at 48 h after caging. Average of 4 replications, each consisting of 15 insects caged on a potted plant; adjusted using Abbott's formula. DAT = days after treatment at which insects were caged on treated plants.

Table 4. Field screening of insecticides applied as foliar sprays to control rice pests on IR22.[a] IRRI, 1976 dry season.

Insecticide[b]	Whorl maggot damage[c] 24 DT[d]	Whorl maggot damage[c] 38 DT	Tungro virus (%) 95 DT	Yield (t/ha)
Monocrotophos	6 bc	5 ab	2.71 ab	3.616 a
S-3206	6 bc	5 ab	1.88 a	3.581 ab
WL 41706	6 bc	5 ab	3.55 ab	3.422 abc
NRDC 143 (Permethrin)	5 b	5 ab	3.33 ab	3.389 abc
Carbophenothion	8 cd	6 bc	2.08 a	3.360 abc
Vamidothion	8 cd	4 a	5.63 abc	3.320 abcd
Acephate	8 cd	4 a	3.33 ab	3.303 abcd
Perthane	9 d	7 cd	6.28 abc	3.125 abcd
FMC 35001	7 bc	5 ab	3.54 ab	3.079 bcd
Ofunack	6 bc	5 ab	10.83 bc	3.039 cd
Chlorpyrifos + trichlorfon	6 bc	4 a	12.29 c	2.913 cd
NRDC 161 (Decis)	3 a	4 a	0.85 a	2.227 e[e]
Control	8 c	8 d	12.29 c	2.846 d

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]Insecticides were applied three times at 20-day intervals at 0.75 kg a.i./ha. [c]Based on a scale of 0–9: 0 = no damage; 9 = more than 50% leaves damaged. [d]DT = days after transplanting. [e]Resurgence of brown planthopper lowered yields.

FMC 35001, and FMC 31768 provided protection against the GLH vector. The resurgence of BPH due to insecticide applications was a common phenomenon. Counts were taken before and after the fourth application to determine whether any significant reduction in BPH number occurred. Only three insecticides, FMC 35001, FMC 31768, and A 47171, significantly reduced the BPH population. Recommended insecticides, such as monocrotophos and acephate, were ineffective. In some treatments BPH increased after insecticide application because nymphs hatched after the treatment. Control was poor probably because the BPH fed low on the stems and were not reached by the insecticide that was applied on the canopy.

Poor BPH control was further investigated in another experiment in which recommended insecticides for BPH control in the Philippines were tested (Table 6). Before the test, NRDC 161 as foliar spray was applied over the area several times to induce a high, uniformly distributed BPH population. At about 70 days after transplanting (DT), insecticides were applied directly to the base of the plants. Monocrotophos. carbofuran, and metalkamate all gave more than 70% control 4 days after the first application.

Outbreaks of BPH are not common in local varieties of upland rice, but foliar sprays were tested on Kinanda (Table 7). After three applications, BPH resurgences and hopperburn occurred. Resurgence was highest in the NRDC 161 plots, followed by the methyl parathion and the diazinon plots. Of the other insecticides, only azinphos ethyl plots had a BPH population higher than that of the control. Only methomyl

Table 5. Field evaluation of insecticides applied as foliar sprays against rice pests and their effect on brown planthopper (BPH) resurgence on IR22.[a] IRRI, 1976 wet season.

Insecticide[b]	Whorl maggot damage[c] 27 DT	Tungro virus (%) 27 DT	Tungro virus (%) 66 DT	BPH[d] (no.) 72 DT Before 4th application	BPH[d] (no.) 72 DT After 4th application	BPH[d] (no.) 72 DT Significant reduction[e]	BPH resurgence ratio[f]	Hopperburn (%) 79 DT	Hopperburn (%) 91 DT
NRDC 161 (Decis)	7 a	4 a	28 a	47,544 d	33,322 d	n.s.	56.1	100 c	—
FMC 35001	7 a	3 a	15 a	23,877 cd	11,127 cd	*	28.2	13 ab	79 bc
FMC 31768	8 b	6 ab	20 a	15,133 cd	9,922 bc	**	17.9	18 ab	46 ab
AC 64475	9 b	22 bcde	81 bc	10,234 bc	12,328 bc	n.s.	12.1	16 ab	29 ab
DS 15647	9 b	12 abc	73 b	7,404 bc	5,623 bc	n.s.	8.7	29 b	85 bc
Monocrotophos	8 b	23 cde	87 bc	4,479 bc	3,655 bc	n.s.	5.3	4 ab	41 ab
Vamidothion	9 b	14 abcd	77 bc	2,782 ab	3,521 abc	n.s.	3.3	1 a	14 a
A47171	9 b	32 de	96 c	2,170 ab	996 a	**	2.6	3 ab	16 a
Acephate	8 b	15 abcd	76 b	2,168 ab	1,590 ab	n.s.	2.6	0 a	0 a
Control	9 b	42 e	92 bc	848 a	654 a	n.s.	—	10 ab	23 a

[a]In a column, means followed by the same letter are not significantly different at the 5% level. DT = days after transplanting. [b]All insecticides were applied at 0.75 kg a.i./ha, except NRDC 161, which was applied at 0.1 kg a.i./ha. They were applied four times at 20-day intervals on the canopy. [c]Based on a scale of 0–9: 0 = no damage; 9 = more than 50% damaged leaves. [d]BPH collected with a D-vac suction machine covering 6.5-linear meter row. [e]n.s. = no significant reduction in BPH due to spraying; * = significant reduction at 5% level of confidence; ** = significant reduction at the 1% level. [f]Resurgence ratio = number of BPH in insecticide-treated plots divided by number in control before the 4th application.

Table 6. Evaluation of Philippine recommended insecticides to control brown planthopper (BPH) on IR841. IRRI, 1976 wet season.

Insecticide[a]	BPH[b] (no.)				
	1st insecticide application			2nd insecticide application[c]	
	Before	4 days after	Control (%)	2 days after	Control (%)
Metalkamate	2678	304	89	67	78
Monocrotophos	3502	659	81	192	70
Carbofuran	2914	835	71	431	48
Acephate	3091	1414	54	588	58
MIPC	2318	1124	52	571	49
BPMC	3182	1644	48	353	79
Carbophenothion	2892	1785	38	375	79
Endosulfan	2903	1935	33	1059	45
Methyl parathion	2991	2153	28	737	66
No insecticide	2481	6183	—	5129	—

[a]All insecticides were applied at 0.7 kg a.i./ha, except carbofuran which was applied at 0.25 kg. A total volume of 1022 liters of solution was sprayed per hectare. A knapsack sprayer equipped with a twin cone nozzle at 180° was used with the spray nozzle held 2–3 inches above the water surface. [b]BPH collected with a D-Vac suction machine per 7-linear meter row. [c]Five days after first application. Percent control was based on population count 4 days after the first insecticide application.

and endosulfan significantly reduced whitehead damage by stem borers.

Low rates of highly active synthetic pyrethroids and three other insecticides were tested as foliar sprays in the greenhouse (Table 8). Most insecticides caused high BPH mortality at 1 DAT, but only carbofuran remained toxic at 14 DAT. Even at a concentration of 0.004%, which is equivalent to 80 g a.i./ha, carbofuran caused 100% mortality at 1 DAT. GLH had higher mortality than BPH except in the Perthane-treated plots. Carbofuran at rates equivalent to 4 g a.i./ha (0.0002%) caused 100% GLH mortality at 1 DAT. Additional field research is needed to determine minimum effective rates of various insecticides under field conditions.

Paddy-water application. Only eight insecticides applied to paddy water caused more than 80% BPH mortality at 1 DAT (Table 9). Mortality decreased at 7 DAT, and only carbofuran provided adequate BPH control. No insecticide had sufficient residual activity at 14 DAT. Of the new insecticides tested only the FMC carbofuran analogues and AC 64475 provided sufficient control.

The mortality of GLH was generally higher than that of BPH. Two new compounds, DS 15647 and AC 64475, were effective against GLH at 14 DAT. Insecticides ineffective against both BPH and GLH in paddy-water application were BPMC, Dyfonate, Hoe Pf 1812, MTMC + carbaryl, chlorfenvinphos, triazophos, SAN 155, chlordimeform, Perthane, NI 15, JF 5599, and RH 812.

Table 7. Effect of foliar spray on brown planthopper (BPH) population and stem borer damage in a local upland rice (variety Kinanda).[a] IRRI, 1976 wet season.

Insecticide[b]	BPH		Hopperburn (%) 109 DS	Whiteheads (%) 117 DS
	Number at 94 DS[c]	Resurgence ratio[d]		
NRDC 161 (Decis)	6733 ef	16.40	100 d	—
Methyl parathion	2468 ef	6.00	75 c	—
Diazinon	1919 def	4.67	55 b	—
Azinphos ethyl	718 cde	1.75	4 a	4.64 ab
Monocrotophos	374 bcd	.91	1 a	4.58 ab
Carbaryl	366 bc	.82	3 a	5.08 ab
BPMC	178 bc	.43	0 a	5.84 bc
FMC 35001	175 abc	.43	1 a	4.61 ab
Methomyl	164 abc	.40	1 a	2.95 a
Endosulfan	157 abc	.38	0 a	2.66 a
Acephate	156 abc	.38	1 a	4.23 ab
DS 15647	139 bc	.34	1 a	5.84 bc
MIPC	133 abc	.32	0 a	6.30 bc
Vamidothion	55 ab	.13	3 a	5.58 abc
Perthane	29 a	.07	0 a	9.80 c
Control	411 bcd	—	4 a	7.72 bc

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]All insecticides were sprayed at 18–20 psi pressure at 0.75 kg a.i./ha. Plots received one application each at 49, 77, and 94 days after seeding (DS). [c]Number per 11 linear meters, collected with a D-vac suction machine. [d]Resurgence ratio = number of BPH after two insecticide applications divided by number in untreated control.

Table 8. Knockdown and residual effects on variety TN1 of insecticides applied as foliar sprays at low rates against the brown planthopper (BPH) and green leafhopper (GLH). IRRI greenhouse, 1976.

Insecticide[a]	Concn (%)	Mortality[c] (%)					
		BPH			GLH		
		1 DAT	7 DAT	14 DAT	1 DAT	7 DAT	14 DAT
Carbofuran 20 F	0.02	100 a	100 a	100 a	100 a	100 a	100a
	0.004	100 a	82 b	21 b	100 a	100 a	67 bc
	0.0002	47 b	6 def	18 bc	100 a	3 f	15 fg
NRDC 149 10 EC	0.02	100 a	26 cd	18 bc	100 a	100 a	87 ab
	0.004	30 bcd	11 cdef	13 bcd	95 ab	50 cd	62 cd
	0.0002	9 ef	11 cdef	5 cde	37 c	0 f	3 gh
WL 41706 30 EC	0.02	97 a	30 c	13 bcd	100 a	100 a	83 ab
	0.004	20 cde	9 cdef	3 de	100 a	92 a	22 ef
	0.0002	15 def	9 def	7 bcd	100 a	35 de	10 fgh
NRDC 161 (Decis) 2.5 EC	0.02	92 a	14 cde	16 bc	100 a	100 a	100 a
	0.004	12 def	11 cdef	20 b	100 a	100 a	100 a
	0.0002	5 fg	8 def	14 bcd	93 ab	22 e	5 fgh
WL 43775 30 EC	0.02	48 b	14 cde	11 bcd	100 a	100 a	100 a
	0.004	10 ef	8 def	7 bcd	100 a	58 c	40 de
	0.0002	12 def	0 f	12 bcd	89 ab	7 f	9 fgh
Perthane 45 EC	0.02	38 bc	7 def	5 cde	43 c	2 f	5 fgh
	0.004	12 def	5 def	5 cde	5 de	2 f	2 gh
	0.0002	10 ef	5 def	8 cde	8 d	2 f	2 gh
Azinphos ethyl 40 EC	0.02	48 b	14 cde	11 bcd	100 a	100 a	89 ab
	0.004	25 cde	4 ef	11 bcd	100 a	92 a	45 de
	0.0002	14 def	5 def	10 bcd	82 b	77 b	17 fg

[a]F = flowable; EC = emulsifiable concentrate. Insecticides were applied at the rate of 12.5 ml solution per 45-day-old plant. [b]0.02 = 0.4 kg a.i./ha; 0.004 = 0.08 kg a.i./ha; 0.002 = 0.004 kg a.i./ha. [c]Average of 4 replications, each consisting of 15 insects caged on plants. Insect mortality was determined at 48 h after insects were caged on plants, and adjusted using Abbott's formula. Means followed by the same letter are not significantly different at the 5% level. DAT = days after treatment at which insects were placed on plants.

Table 9. Control of the brown planthopper (BPH) and green leafhopper (GLH) by insecticides applied to paddy water at 1.0 kg a.i./ha. IRRI greenhouse, 1976.

Insecticide	Formulation	Mortality[a] (%)					
		BPH			GLH		
		1 DAT	7 DAT	14 DAT	1 DAT	7 DAT	14 DAT
Carbofuran	3 G	100 a	92 b	26 b	100 a	100 a	100 a
FMC 27289	5 G	100 a	5 d	19 b	100 a	51 bcde	2 b
AC 64475	5 G	100 a	65 b	56 a	100 a	100 a	100 a
Disulfoton	5 G	100 a	31 c	—	100 a	23 ef	—
Metalkamate	3 G	100 a	48 c	26 b	100 a	92 ab	0 b
FMC 35020	5 G	100 a	13 cd	6 cd	100 a	80 abc	5 b
FMC 31768	5 G	100 a	4 d	29 b	100 a	92 ab	0 b
FMC 35001	5 G	82 ab	0 d	18 b	100 a	74 abcd	0 b
Diazinon	10 G	66 bc	13 cd	8 c	100 a	51 bcde	0 b
Aldicarb	10 G	59 bcd	0 d	17 b	48 bcd	4 f	0 b
MTMC	5 G	59 bcd	13 cd	0 d	82 ab	8 f	0 b
Padan	10 G	56 cde	0 d	—	76 ab	80 ab	—
Chlordimeform + carbaryl	3 + 6 G	45 cdef	0 d	6 cd	100 a	8 f	0 b
DS 15647	5 G	42 cdef	42 c	37 b	100 a	100 a	90 a
JF 5600	5 G	35 cdefg	0 d	—	66 abc	16 ef	—
Imidan + carbaryl	5 + 4 G	25 defgh	0 d	6 cd	100 a	0 f	0 b
N 2596	10 G	18 defgh	0 d	11 c	66 abc	8 f	0 b

[a]In a column, means followed by the same letter are not significantly different at the 5% level. Mean averages of three replications, each consisting of 10 insects caged on a treated TN1 plant; adjusted using Abbott's formula. DAT = days after treatment, at which insects were caged on treated plants. Mortality was determined at 48 h after caging. — = Hopperburned plants.

Table 10. Control of rice pests on IR22 by granular insecticides broadcast on paddy water at 1.0 kg a.i./ha.[a] IRRI, 1976 dry season.

Insecticide[b]	Whorl maggot damage[c]		GLH (no./10 sweeps)		Tungro virus incidence (%)		Yield (t/ha)
	25 DT[d]	35 DT	35 DT	47 DT	45 DT	68 DT	
Carbofuran	8.0 c	8.3 b	12 a	13 a	0.5 a	2.2 a	3.238 a
Mephosfolan	3.0 a	1.3 a	17 abc	21 a	1.4 abc	9.7 b	3.295 a
Triazophos	6.0 b	8.5 b	16 abc	25 ab	3.1 bc	15.9 bc	2.554 b
Chlordimeform + carbaryl	8.8 c	8.3 b	15 ab	26 ab	1.6 abc	2.5 bc	2.541 b
Fonofos	6.8 b	8.5 b	19 bc	29 abc	0.9 ab	12.3 bc	2.490 bc
RU 19053	9.0 c	9.0 a	23 c	58 bc	2.3 bc	21.1 bc	2.237 bcd
SAN 197	9.0 c	9.0 a	24 c	47 bc	4.5 cd	24.4 c	1.880 cd
Control	9.0 c	9.0 a	22 bc	58 bc	8.1 d	42.5 d	1.716 d

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]Applied twice at 5 and at 55 days after transplanting (DT). [c]Based on a scale of 0–9: 0 = no damage; 9 = more than 50% damaged leaves. [d]GLH = green leafhopper.

Two field experiments determined the effectiveness of granular insecticides broadcast on paddy water at transplanting. Mephosfolan was the most effective against the whorl maggot in the dry-season experiment (Table 10). Carbofuran best controlled GLH and tungro virus. Treatments with mephosfolan and carbofuran produced the highest yields—1,500 kg/ha more than the yield of the control.

In the wet-season experiment, only three insecticides, AC 64475, carbofuran, and chlorpyrifos, reduced whorl maggot damage (Table 11). Due to extremely high GLH populations, tungro virus was severe. Only AC 64475 and carbofuran had sufficient residual activity to provide protection against GLH at 28 DT. Yields in the other treatments were almost nil.

Screening of root-zone insecticides. In the search for additional insecticides for root-zone application, greenhouse screening of compounds continued (Table 12). Except for the FMC carbofuran analogues, no insecticide equaled carbofuran in effectiveness as a root-zone application. The liquid formulation of carbofuran (20 F) provided more immediate control at 1 DAT and had residual activity equal to that of the granular formulation.

Ten insecticides were field evaluated as emulsifiable concentrates to determine their potential as root-zone insecticides. Carbofuran, FMC 31768, FMC 35001, and FMC 27289 were effective against the whorl maggot and GLH. BPMC, which was not effective as a granular formulation in greenhouse tests, effectively controlled GLH as an emulsifiable concentrate in the field (Table 13).

Liquid root-zone applicator. Root-zone application of insecticides was first reported in the 1972 Annual Report. Capsules provided effective and long-lasting insect control. To facilitate

Table 11. Control of rice pests on IR22 by granular insecticides broadcast on paddy water at 1.0 kg a.i./ha.[a] IRRI, 1976 wet season.

Insecticide[b]	Whorl maggot damage[c] 28 DT	GLH (no./10 sweeps)			Tungro virus (%)			Yield (t/ha)
		28 DT	38 DT	48 DT	38 DT	67 DT	98 DT	
Carbofuran	4 a	27a	3 a	31 a	1 a	3 a	12 a	3.279 a
AC 64475	4 a	134 b	35 b	426 b	6 b	26 ab	47 a	1.567 b
DS 15647	9 b	318 c	57 bc	1014 c	10 b	58 bc	80 a	0.428 c
Metalkamate	9 b	267 c	119 c	1197 c	12 b	73 c	75 a	0.411 c
Pyridaphenthion + lindane	9 b	354 c	150 c	1768 c	11 b	77 c	81 ab	0.356 c
Isoprothiolane	9 b	239 c	96 c	1579 c	13 abc	81 c	84 ab	0.314 c
Chlorpyrifos	4 a	330 c	175 c	2182 c	21 cd	82 c	83 ab	0.285 c
Isoprothiolane + MTMC	9 b	303 c	161 c	2327 c	23 cd	80 c	87 ab	0.248 c
Control	9 b	229 c	171 c	1859 c	25 d	92 c	94 b	0.094 c

[a]In a column, means followed by the same letter are not significantly different at the 5% level. GLH = green leafhopper; DT = days after transplanting. [b]Isoprothiolane is a fungicide. Treatments applied once at 3 DT. [c]Based on a scale of 0–9: 0 = no damage; 9 = more than 50% damaged leaves.

Table 12. Control of the brown planthopper (BPH) and green leafhopper (GLH) by insecticides applied to the root zone at 1.0 kg a.i./ha.[a] IRRI greenhouse, 1976.

Insecticide	Formulation[b]	Mortality[c] (%)							
		BPH				GLH			
		1 DAT	12 DAT	26 DAT	32 DAT	1 DAT	12 DAT	26 DAT	32 DAT
Carbofuran	20 F	100 a	73 a	16 a	24 a	100 a	85 b	100 a	100 a
FMC 27289	48 EC	100 a	60 a	27 a	24 a	100 a	100 a	75 bc	43 c
FMC 31768	24 EC	100 a	53 a	18 a	21 a	100 a	100 a	75 bc	23 cd
FMC 35001	48 EC	90 a	65 a	24 a	19 a	100 a	100 a	95 ab	70 b
Methamidophos	50 EC	50 b	13 bcd	29 a	—	100 a	5 d	15 d	—
AC 64475	5 G	43 bc	60 a	13 a	15 a	68 b	75 bc	63 c	33 cd
AC 64475	24 EC	23 cd	23 b	18 a	5 ab	70 b	8 d	5 d	0 e
Methomyl	20 EC	23 cd	20 bc	13 a	—	100 a	10 d	5 d	—
Carbofuran	3 G	13 d	60 a	29 a	32 a	18 de	80 bc	100 a	80 b
Acephate	75 SP	10 de	8 bcd	22 a	—	48 bc	63 c	5 d	—
DS 15647	10 G	10 de	18 bc	16 a	—	38 cd	0 d	5 d	—
Methomyl	50 DP	5 de	5 cd	15 a	13 ab	35 cd	5 d	10 d	13 de
Metalkamate	3 G	0 e	12 b	11 a	8 ab	3 e	0 d	3 d	3 e

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]F = flowable; EC = emulsifiable concentrates; G = granules; DP = dispersible powder. Flowable and emulsifiable concentrates were injected into the root zone with a syringe, while granules were placed in gelatin capsules. [c]Average of four replications, each consisting of 10 insects caged on a treated TN1 plant. Observations were made at 48 h after caging. Figures were adjusted using Abbott's formula. DAT = days after treatment. — = plants died from hopperburn.

root-zone application, IRRI engineers developed a liquid applicator (1975 Annual Report). In 1976, application by a liquid applicator was compared with application in capsules (Table 14). The two methods showed little difference in insect control. At lower rates, however, the capsule treatment was slightly better for whorl maggot control. Both the capsule and liquid root-zone treatments at high rates gave excellent BPH control at 45 DT; both were less effective at the low rate.

Rates and frequency of root-zone applications. A dry-season experiment conducted in Laguna province indicated little difference in yields among rates and number of treatments when insecticides were applied shortly after transplanting (Table 15). However, a 20-day delay in application exposed the plants to more whorl maggot damage, which contributed to the lower yield. A late attack of stem borers or BPH could have produced significant differences in yields between the one- and two-application treatments.

Results of a similar experiment conducted during the wet season indicated that only one application at a low rate (0.5 kg a.i./ha) effectively controlled the leaf folder at 71 DT (Table 16). However, the two-application treatment at 1 kg a.i./ha had significantly less BPH than the one-application treatment at 0.5 kg.

Table 13. Effectiveness of insecticides applied with a liquid applicator to the root zone of IR22.[a] IRRI, 1976 wet season.

Insecticide[b]	Formulation	Whorl maggot damage[c] 37 DT	GLH (no./10 sweeps)			Tungro virus (%)		Yield (t/ha)
			27 DT	37 DT	48 DT	67 DT	97 DT	
FMC 35001	48 EC	2.8 a	6 a	2 a	8 a	5 a	10 ab	3.272 a
Carbofuran	20 F	2.3 a	4 a	1 a	13 ab	1 a	4 a	3.157 a
FMC 27289	48 EC	2.8 a	5 a	1 a	9 a	4 a	8 a	3.029 a
FMC 31768	24 EC	2.3 a	14 a	14 a	11 a	20 ab	2 a	2.994 a
BPMC	50 EC	8.0 b	54 ab	54 b	35 a	8 ab	24 b	2.491 a
Acephate	75 SP	8.5 bc	381 c	431 c	1175 c	37 bc	67 c	1.293 b
Monocrotophos	17 EC	8.8 c	44 ab	806 c	804 c	37 bc	64 c	1.144 b
Dimethoate	38 EC	9.0 c	656 c	589 c	1060 c	32 bc	64 c	1.174 b
AC 64475	24 EC	8.8 c	596 c	667 c	1304 c	4 a	73 c	0.719 b
Vamidothion	40 EC	9.0 c	897 c	683 c	1658 c	63 c	76 c	0.361 b
Control		9.0 c	355 c	548 c	1259 c	42 c	65 c	0.984 b

[a]In a column, means followed by the same letter are not significantly different at the 5% level. DT = days after transplanting. [b]All insecticides were applied with a liquid band applicator at 3 DT. [c]Based on a scale of 0–9: 0 = no damage; 9 = more than 50% damaged leaves.

Table 14. Insect control with carbofuran applied to the root zone of IR20 in a gelatin capsule and with a liquid band injector.[a] IRRI, 1976 wet season.

Treatment[b]	Rate (kg a.i/ha)	Whorl maggot damage[c] 27 DT	Insects[d] (no./10 sweeps) BPH 36 DT	BPH 45 DT	GLH 36 DT	GLH 45 DT	Tungro virus (%) 99 DT	Dead-hearts (%) 67 DT	Yield (t/ha)
In capsules	2	0 a	9 a	1 a	0 a	0 a	4 a	0.3 a	3.012 a
By liquid injector	2	0 a	8 a	6 a	1 a	0 a	7 a	0.7 ab	2.567 b
In capsules	0.5	0 a	13 ab	34 b	1 a	1 a	5 a	1.3 bc	2.494 bc
By liquid injector	0.5	3 b	32 b	71 b	7 b	1 a	15 b	1.1 bc	2.225 c
Control		9 c	59 c	302 c	80 c	43 b	38 c	2.1 c	1.269 d

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]3% granules used in the capsule treatment and 20% flowable in the liquid injector. Insecticide was applied once at 5 days after transplanting (DT). [c]Based on a scale of 0–9: 0 = no damage; 9 = more than 50% damaged leaves. [d]BPH = brown planthopper; GLH = green leafhopper.

Table 15. Effect of rate and frequency of carbofuran application in the root zone of IR1561 rice plants on control of pests.[a] Farmer's field, Laguna province, 1976 dry season.

Treatment (a.i./ha)[b]	Whorl maggot damage[c] 30 DT	Whorl maggot damage 41 DT	Deadhearts (%) 30 DT	Deadhearts (%) 61 DT	GLH[d] (no./10 sweeps) 30 DT	GLH 61 DT	Yield (t/ha)	Increased income[e] (US$)
2.0 kg at 10 DT	2 a	2 a	0.31 a	0.64 a	0.25 a	0.50 a	6.156 ab	70.92
1.0 kg at 10 DT	2 ab	3 ab	0.56 a	1.38 a	0.25 a	2.00 a	5.628 ab	50.56
0.5 kg at 10 and at 30 DT	4 b	2 a	1.14 a	0.41 a	1.50 a	0.75 a	6.270 a	137.91
1.0 kg at 30 DT	9 c	4 b	7.21 b	1.10 a	11.00 b	0.25 a	5.240 ab	–2.23
Untreated control	8 c	6 c	8.14 b	8.68 b	6.50 b	15.00 b	4.878 b	—

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]Carbofuran 20% applied with a liquid band injector at indicated days after transplanting. [c]Based on a scale of 0–9: 0 = no damage; 9 = more than 50% damaged leaves. GLH = green leafhoppers. [d]Increased income due to insect control.

Weeding method and root-zone applications. An experiment was conducted to determine whether the rotary weeder altered the efficiency of root-zone applications by bringing the insecticide to the surface. Rotary weeding did not adversely affect the effectiveness with which root-zone application controlled the whorl maggot and stem borer (Table 17). Gas chromatographic analysis of the plants indicated no statistical differences in carbofuran residues in plants from plots weeded by hand or with the rotary weeder. Higher yields in the hand-weeded plots were attributed to more effective weed control than that provided by the rotary weeder.

Root-zone application of insecticides + fertilizer + herbicide. The simultaneous root-zone application of fertilizer, insecticide, and herbicide was studied. Because like most insecticides, carbofuran is unstable when mixed in an alkaline medium, an experiment was conducted to determine how stable it was in a solution with urea and 2,4-D, applied with the liquid applicator.

Neither urea nor 2,4-D had sufficient deleterious effect on carbofuran to reduce insect control. All treatments with carbofuran provided equally good control of whorl maggot and GLH. Yields were equal in all treatments (Table 18).

Analysis of leaves from the various treatments indicated that the carbofuran levels in plants treated simultaneously with carbofuran and

Table 16. Effect of rate and frequency of carbofuran application in the root zone of IR29 on control of pests.[a] Farmer's field, Laguna province, 1976 wet season.

Treatment[b]	Whorl maggot damage[c] 29 DT	BPH[d] (no.) 53 DT	Leaf folder damage[e] (%) 71 DT
0.5 kg at 10 DT	3 ab	878 b	6 b
0.5 kg at 10 and at 30 DT	4 b	580 ab	1 a
1.0 kg at 10 DT	2 a	740 ab	4 ab
1.0 kg at 10 and at 30 DT	2 a	125 a	0 a
Control	9 c	5291 c	65 c

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]Carbofuran 20.3% flowable applied with a liquid band injector at indicated days after transplanting (DT). [c]Based on scale of 0–9: 0 = no damage; 9 = more than 50% damaged leaves. [d]BPH = brown planthopper. Based on 47 sweeps, each 1.0 m wide, with a D-vac suction machine. [e]Percentage of damaged leaves.

Table 17. Effect of hand and rotary weeding on the effectiveness of two rates of carbofuran applied in the root zone of rice plants.[a] IRRI, April 1976.

Treatments[b] (kg a.i. carbofuran/ha)	Whorl maggot damage[c] 27 DT	Deadhearts (%) 46 DT	Grain yield (kg/ha)
1.0 kg + 1 hand weeding	4 a	0.52 a	3773 a
1.0 kg + 1 rotary weeding	4 a	0.67 a	3547 ab
1.0 kg + 2 rotary weedings	5 a	0.72 ab	3496 ab
No insecticide + 1 hand weeding	9 b	1.75 c	3363 abc
No insecticide + 2 rotary weedings	9 b	1.63 c	2907 c

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]Insecticide applied with a liquid band injector at 5 days after transplanting (DT). [c]Based on a scale of 0–9: 0 = no damage; 9 = more than 50% damaged leaves.

fertilizers in the root zone were equal to the levels in plants with root-zone carbofuran and broadcast fertilizer.

Root-zone application and fish culture. The Philippine Government has done extensive research on fish raising in rice paddies. A major obstacle is the incompatibility of chemical pest control and fish culture. A cooperative project was conducted with the Freshwater Aquaculture Center, Central Luzon State University, to determine the compatibility of root-zone application of insecticides and fish culture. Carbofuran granules at 1 kg a.i./ha, broadcast after fish were placed in the ponds, caused 100% fish mortality. Neither broadcast nor root-zone application, however, had any adverse effect when fish were placed in the paddies 7 days after insecticide application (Table 19). The 1.0-kg root-zone application provided $113.00 more income than did the 1.0-kg broadcast treatment, primarily because of more effective control of the whorl maggot. Analysis of the fish indicated no measurable residues (in excess of 0.05 ppm) of carbofuran or 3-hydroxycarbofuran.

Application methods. Nine experiments were conducted to determine the extent and economics of insect control with different methods of application. A dry-season trial at IRRI compared four foliar sprayings with one broadcast application of diazinon and one root-zone application of carbofuran. Insect control was more effective and yields were highest in the root-zone treatments. Five methods of insecticide application were compared in the wet season in farmers' fields. Applying to the root zone, incorporating into the soil, and three foliar sprayings gave similar results and produced highest yields in the disease- and insect-resistant variety IR30. Root-zone and soil-incorporation treatments produced the highest yields in a local variety.

Frequency and rate of broadcast and root-zone applications of carbofuran were compared with a combination of seedling soak and either broadcast or root-zone application (Table 20).

Table 18. Insects controlled by carbofuran 20 F applied simultaneously with nitrogen fertilizer and herbicide through a liquid applicator.[a] IRRI, 1976 dry season.

Treatments[b]	Whorl maggot damage[c] 20 DT	Green leafhoppers (no./10 sweeps) 41 DT	Tungro virus (%) 113 DT	Weeds[d] (no./sq m) 30 DT	Yield (t/ha)	Carbofuran residues in leaf		
						10 DAT	20 DAT	40 DAT
C (RZ) + *urea* *(RZ)* + HW	4.3 ab	2 a	8 a	10 cde	4.006 a	0.506	0.200	0.084
C (RZ) + *AS* *(RZ)* + HW	4.3 ab	2 a	8 a	7 bcd	3.942 a	0.178	0.706	0.145
C (RZ) + *urea* *(B)* + HW	4.5 ab	2 a	6 a	22 de	3.865 a	0.522	0.289	0.241
C (RZ) + *AS* *(B)* + HW	4.5 ab	2 a	6 a	40 e	3.972 a	0.613	0.979	0.352
C (RZ) + *urea* *(RZ)* + 2, 4-D (RZ)	3.8 ab	0 a	7 a	4 bcd	4.112 a	0.494	0.583	0.269
C (RZ) + *AS* *(RZ)* + 2, 4-D (RZ)	4.8 b	1 a	5 a	8 cde	4.085 a	0.556	1.141	0.369
C (RZ) + *urea* *(RZ)* + 2, 4-D (B)	3.5 a	1 a	6 a	0 a	4.058 a	0.662	0.417	0.107
C (RZ) + *AS* *(RZ)* + 2, 4-D (B)	3.8 ab	0 a	7 a	1 ab	4.025 a	0.343	1.234	0.292
Urea *(RZ)* + *HW*	8.8 c	35 b	62 b	9 bcde	0.569 b	0.555	0.136	0.068
Urea *(B)* + 2, 4-D (B)	9.0 c	65 b	65 b	1 ab	0.792 b	0.096	0.028	0.052

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]All treatments were applied 3 days after transplanting (DT). C = carbofuran applied at 1 kg a.i./ha; RZ = root-zone application; B = broadcast application; AS = ammonium sulfate; HW = hand weeding twice at 31 days after insecticide was applied (DAT) and 50 DAT. Urea and ammonium sulfate were incorporated into the soil at 60 kg N/ha before transplanting in the broadcast treatment, and with the liquid applicator in the root-zone treatment. Italicized items are variable within each group of two treatments. [c]Based on a scale of 0–9: 0 = no damage; 9 = more than 50% damaged leaves. [d]Weeds were counted at 30 DAT before the first hand weeding.

Table 19. Yields of rice (IR34) and fish (*Tilapia mosambica*) in plots with carbofuran root-zone and broadcast applications.[a] Central Luzon State University, March 1976.

Treatment	Rice yield (kg/ha)	Fish[b]		Value of fish + rice (US$)	Income[c] (US$)
		Yield (kg/ha)	Value (US$/ha)		
1 kg broadcast once	4319 bc	141	115	703	673
1 kg broadcast 4 times	4935 abc	0	0	671	552
1 kg to root zone once	5116 ab	166	136	832	786
2 kg to root zone once	5613 a	150	123	886	794
No insecticide	4113 c	155	127	691	686

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]Fish seeded at 3000/ha 7 days after first application of insecticide. [c]Income = value of rice and fish minus cost of insecticide and its application, based on local market prices.

Root-zone treatments were superior to the broadcast treatments. The root-zone treatments at 1 kg provided better insect control and yields equal to those of four broadcast applications. The efficiency of a seedling soak followed by a root-zone application was not significantly different from that of a single root-zone application. One broadcast application at 1 kg or two applications at 0.5 kg each were inadequate, as indicated by virus incidence and yields. One root-zone application at 1 kg was equal to two 0.5-kg applications. The treatment seedling soak plus 0.5-kg broadcast carbofuran yielded twice as much as the single broadcast application at 1 kg. However, the seedling soak had no distinct advantage when followed by the root-zone treatment.

An experiment conducted during the dry season included root coating as an additional treatment. Coating seedling roots with a mixture of gelatin and carbofuran before transplanting was tested in 1975 (1975 Annual Report). The control of whorl maggots in the root-coat treatment again was superior to that in all other treatments at 20 DT. All treatments effectively controlled virus vectors.

The effects of four methods of application on the carbofuran residues in the leaves of IR22 were compared (Table 21). The highest content was recorded at 10 DAT for the root-coat and the overnight seedling-soak + broadcast treatments. Of the two, the root-coat treatment had the longest residual activity, which matched field observations of longer whorl maggot control. Apparently the gelatin root coating retains some insecticide even after transplanting.

The carbofuran contents of the leaves and stems of five rice varieties—TN1, IR28, IR30, IR32, and IR34—were compared after the insecticide was applied in the root zone at 1 kg

Table 20. Comparative efficiency of insecticide application techniques.[a] IRRI, 1976 wet season.

Carbofuran treatment[b]	Whorl maggot damage[c] 35 DT	Green leafhoppers (no./10 sweeps)		Tungro virus (%)		Yield (t/ha)	Increased income[d] (US$)
		29 DT	47 DT	65 DT	97 DT		
1 kg broadcast 4 times	4.0 cd	12 bc	9 ab	15 bc	33 a	2.516 a	221
1 kg broadcast once	4.5 de	26 c	25 c	21 cd	68 b	1.302 b	147
0.5 kg broadcast twice	6.0 e	22 c	21 bc	29 d	68 b	1.166 b	128
1 kg to root zone once	0.3 a	5 ab	3 a	3 a	20 a	3.092 a	369
0.5 kg to root zone twice	1.5 ab	2 a	4 a	6 ab	21 a	2.989 a	357
0.25 kg to root zone twice	2.5 bc	4 ab	2 a	14 bc	30 a	2.596 a	326
1000 ppm seedling soak + 0.5 kg broadcast	4.8 de	20 c	11 bc	15 bc	39 a	2.373 b	300
1000 ppm seedling soak + 0.5 kg to root zone	0.8 ab	4 ab	3 a	5 a	18 a	3.114 a	393
Control	9.0 f	123 d	212 d	78 e	100 c	0 c	

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]Carbofuran 3% granules were used in the broadcast treatment, 20% flowable in all other treatments. Seedling soak = overnight soaking of seedlings (IR22) in water containing insecticide at 1000 ppm. All broadcast and root-zone treatments were applied at 3 days after transplanting (DT). [c]Based on a scale of 0–9: 0 = no damage; 9 = more than 50% damaged leaves. [d]Increased income due to insect control.

Table 21. Carbofuran residues in leaves of IR22 from four application methods. IRRI, 1976 dry season.

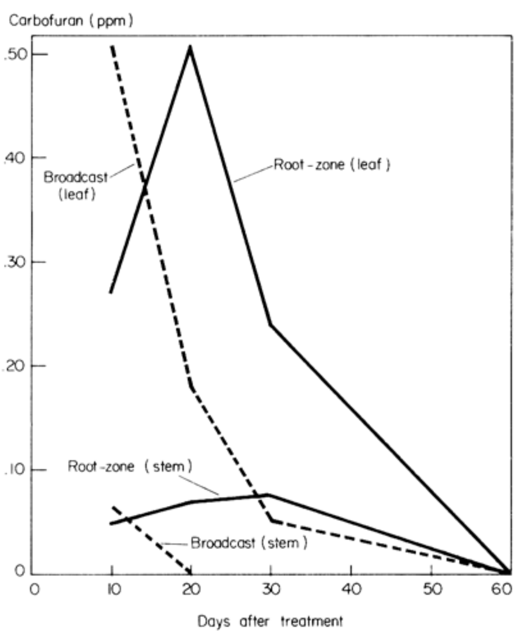
Treatment[a]	Rate (kg a.i./ha)	Carbofuran residues[b] (ppm)			
		10 DAT	20 DAT	40 DAT	60 DAT
Broadcast at 5 DT[c]	1	0.61	0.03	0.02	trace[d]
Seedling soak + broadcast at 20 DT	0.15 + 0.50	33.79	0.16	0.02	trace
Root coat	1	73.17	1.01	0.02	trace
Root zone at 5 DT	1	0.99	0.23	0.04	trace
Control		0.18	trace	trace	trace

[a]Carbofuran 3G used for the broadcast and 20% flowable for all other treatments. Seedling soak = soaking seedlings overnight in water containing insecticide. Root coat = dipping the roots into a mixture of 12 parts insecticide, 83 parts water, and 5 parts gelatin. Root-zone treatment applied with a liquid band injector. [b]DAT = days after treatment. [c]DT = days after transplanting. [d]Less than 0.005 ppm.

a.i./ha with a granule applicator, or broadcast on paddy water. The residue levels, or dissipation rates, among the five varieties did not statistically differ.

Broadcasting carbofuran on paddy water resulted in the highest plant content 10 DAT, but the root-zone treatment persisted longer, through at least 30 DAT (Fig. 1). The results agree with field observations that the broadcast treatment controls whorl maggots most effectively at 10 DAT, but that at 30 DAT the root-zone treatment provides better control.

The results in Table 21 and Fig. 1 indicate that an effective and long-lasting control of leaf feeders would result from a two-treatment sequence of a seedling root-coat for early whorl maggot control, followed by a root-zone treatment at about 30 DAT.



1. Carbofuran residues in rice leaves and stems as influenced by root-zone and broadcast methods of application. Based on the mean of five varieties. IRRI, 1975 wet season.

In two dry-season experiments the root-zone and broadcast treatments were compared in varieties resistant to some major pests and diseases. No significant differences were found among the five varieties in the first experiment. Root-zone application best controlled whorl maggot, GLH, whitebacked planthopper, and leaf folder. Grain yield was significantly higher with root-zone application than with broadcast application.

In the second experiment, one broadcast application of carbofuran, diazinon, and lindane was compared with root-zone application of carbofuran (Table 22). Carbofuran applied at 0.5 kg a.i./ha to the root zone of IR26 provided yields and control of whorl maggot, green leafhopper, and whitebacked planthopper equal or superior to those provided by carbofuran, diazinon, or lindane broadcast at 1.5 kg. Increased income due to insect control was also highest in the 0.5 kg carbofuran root-zone treatment.

During the dry and wet seasons, frequency and rates of broadcast and root-zone treatments on a variety that is susceptible to insect and tungro virus were compared (Table 23). Increased benefits due to insect control were much more evident during the wet season primarily because of higher virus incidence. Root-zone treatments controlled insects significantly better than did broadcast treatments. Yields in the dry season, however, did not show any significant difference between the two application methods. The various rates produced

Table 22. Effectiveness and economics of pest control on IR26 as influenced by type of insecticide and method of application.[a] IRRI, 1976 dry season.

Treatment[b] (kg a.i./ha)	Whorl maggot damage[c] 21 DT	Insects[d] (no.) Green leafhopper 58 DT	Insects[d] (no.) Whitebacked planthopper 40 DT	Yield (t/ha)	Increased income[e] (US$)
0.75 carbofuran broadcast	5 b	74 b	1146 bc	6.01 cde	28
1.0 carbofuran broadcast	4 ab	77 b	664 bc	6.58 bc	98
1.5 carbofuran broadcast	3 a	9 a	484 b	7.05 ab	147
0.75 diazinon broadcast	5 b	133 b	1343 bc	6.37 bcd	90
1.0 diazinon broadcast	4 ab	158 b	822 bc	5.97 cde	32
1.5 diazinon broadcast	3 a	122 b	1601 c	6.42 bc	88
0.75 lindane broadcast	8 cd	239 b	1126 bc	5.63 e	–9
1.0 lindane broadcast	8 cd	176 b	983 bc	5.90 cde	26
1.5 lindane broadcast	7 c	132 b	1389 c	6.19 cde	60
0.5 carbofuran to root zone	4 ab	6 a	61 a	7.31 a	202
0.75 carbofuran to root zone	3 a	12 a	43 a	6.97 ab	144
Untreated control	9 d	147 b	1345 c	5.64 de	—

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]All treatments applied once at 3 days after transplanting (DT). Carbofuran was applied to the root zone with a liquid band applicator. [c]Based on a scale of 0–9: 0 = no damage; 9 = more than 50% damaged leaves. [d]Insects were collected with a D-vac suction machine (43 sweeps, each 1.0 m wide). [e]Increased income due to insect control.

little difference in insect control. In the wet season, however, the two methods produced significant differences in insect control and in yields. Yields from root-zone application were superior to those from the broadcast application. The various rates of root-zone application resulted in similar yields; but the broadcast treatments gave significantly different yields.

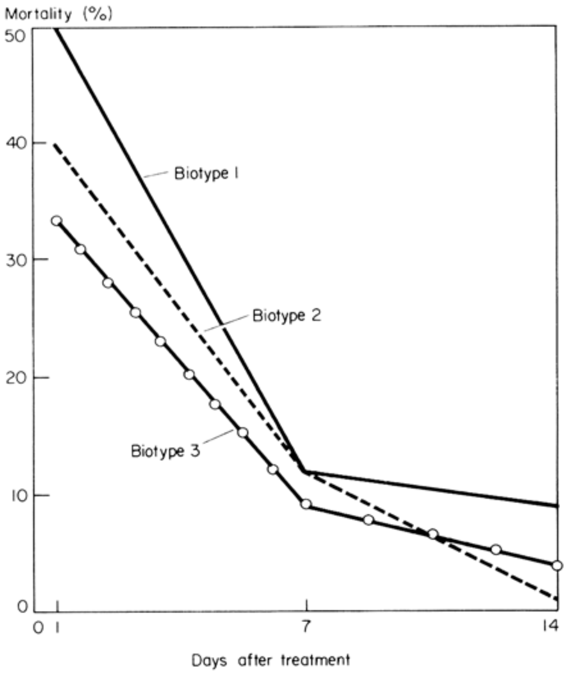
The results of the experiments lead to these conclusions:

- When the major pest problems, such as whorl maggots and tungro virus, are severe early in the crop season and it is important that adequate control be provided shortly after transplanting, one application at a high rate is superior to split applications at low rates.

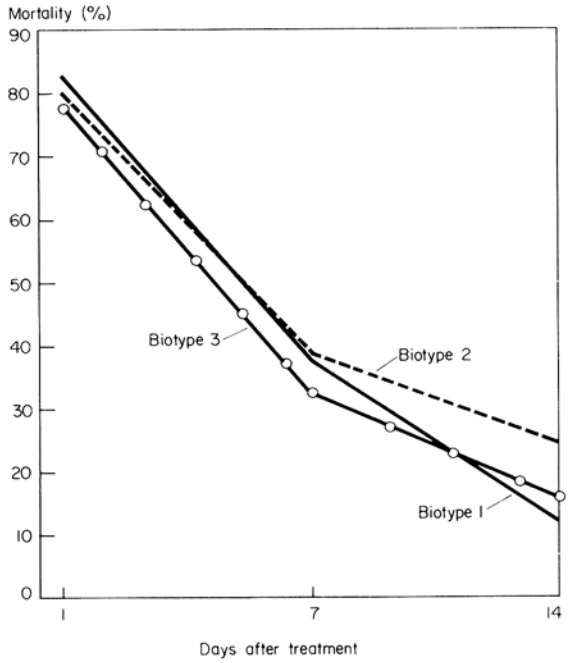
Table 23. Frequency and rates of broadcast and root-zone applications of carbofuran for effective pest control in IR22.[a] IRRI, 1976 dry and wet seasons.

Treatment[b]	Whorl maggot damage[c] 35 DT		Green leafhoppers (no./10 sweeps) 47 DT		Tungro virus (%) 98 DT		Yield (t/ha)		Increased income (US$)	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry[d]	Wet	Dry	Wet
0.5 kg broadcast once	9 d	8 b	10 b	82 b	15 cd	89 c	2.067 c	0.612 a	77	68
1 kg broadcast once	7 d	5 c	10 b	34 b	19 d	60 b	2.128 bc	1.301 b	70	147
2 kg broadcast once	8 d	4 d	6 ab	7 a	4 ab	6 a	2.277 abc	2.411 c	60	268
0.5 kg broadcast 4 times	8 d	6 e	2 a	19 ab	6 bc	64 b	2.449 abc	1.627 b	82	160
0.5 kg to root zone once	5 c	3 cd	4 ab	11 a	1 a	17 a	2.705 a	2.563 c	156	323
1 kg to root zone once	4 b	1 ab	2 a	7 a	1 a	18 a	2.229 abc	3.013 c	66	362
2 kg to root zone once	2 a	0 a	2 a	9 a	2 ab	11 a	2.431 abc	2.970 c	45	310
0.5 kg to root zone 4 times	4 b	2 bc	1 a	7 a	2 ab	18 a	2.571 ab	2.832 c	60	354
Control	9 d	9 g	19 c	156 c	43 e	99 d	1.392 d	0.000 a	—	—

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]Carbofuran 3% granules for the broadcast and 20% flowable for the root-zone treatments. Carbofuran was applied to the root zone with a liquid band injector. First insecticide application was made at 3 days after transplanting (DT), subsequent applications were at 20-day intervals. [c]Based on a scale of 0–9: 0 = no damage; 9 = more than 50% damaged leaves. [d]Dry-season crop hit by typhoon during flowering.



2. Mortality of three brown planthopper *Nilaparvata lugens* biotypes on plants treated with carbofuran (1.0 kg a.i./ha) applied to paddy water. Mean of 19 insecticides. IRRI greenhouse, 1976.



3. Mortality of three brown planthopper *Nilaparvata lugens* biotypes placed on plants treated with carbofuran as 0.04% foliar spray. Mean of 20 insecticides. IRRI greenhouse, 1976.

- During the wet season, root-zone application is distinctly more effective than broadcasting. The primary advantages of root-zone application are longer period of activity because of a slower rate of decomposition, and protection from being diluted and washed out of the paddies by rain.
- Rates at which granules are broadcast are important during the wet season, but there is no distinct difference between rates of 0.5 kg and 2 kg for the root-zone treatments.

Brown planthopper biotypes. Biotypes of the BPH, characterized by differences in their ability to destroy BPH-resistant varieties, are a severe problem in the Philippines (1975 Annual Report). Greenhouse studies were conducted to determine whether the three biotypes at IRRI differ in response to insecticides. The pooled results (Fig. 2, 3) show no distinct differences in mortality among the three biotypes in either the paddy water or the foliar spray treatments, except that biotype 1 was most susceptible in the paddy-water test (Fig. 2). The biotypes exhibited different reactions to the insecticides (Table 24). In the paddy water experiment, the three biotypes had significantly different responses to the three insecticides commonly used to control BPH. In all cases, biotype 3 had the lowest mortality. Results of the foliar spray experiment were essentially similar. All results are preliminary and further experiments will be conducted.

Brown planthopper resistance to insecticides. Field control of BPH was often poor during 1976, even with insecticides that were generally considered highly effective. Numerous factors, including resistance to an insecticide, can influence the effectiveness of field-applied insecticides. Two preliminary experiments were conducted in the greenhouse to determine whether BPH collected from IRRI fields were actually more difficult to kill than BPH cultured in the greenhouse.

In the first experiment, acephate at three rates was used as a foliar spray. The mortality of the field-collected BPH was generally one-half that of the greenhouse culture.

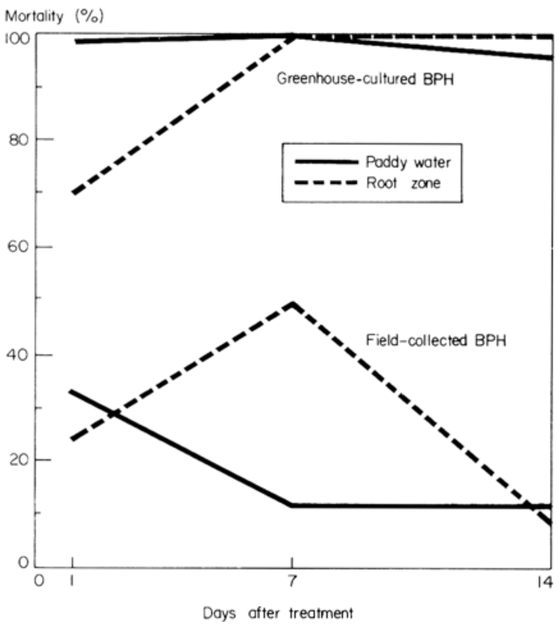
In the second experiment, the two BPH

Table 24. Effects of paddy-water and foliar-spray applications of insecticides against three brown planthopper biotypes.[a] IRRI greenhouse, 1976.

Insecticide[b]	Formulation[c]	Mortality[d] (%) 1 DAT Biotype 1	1 DAT Biotype 2	1 DAT Biotype 3	7 DAT Biotype 1	7 DAT Biotype 2	7 DAT Biotype 3
				Paddy water[e]			
Carbofuran	3 G	100 a	100 a	100 a	92 a	78 ab	54 b
Metalkamate	10 G	69 b	73 b	40 c	26 a	22 ab	3 b
Diazinon	10 G	66 b	70 b	3 c	13 b	4 bc	0 c
				Foliar spray[f]			
Carbofuran	20 F	100 a	100 a	100 a	100 a	100 a	98 a
Permethrin	10 EC	100 a	98 a	70 b	10 ab	22 a	5 b
Metalkamate	30 EC	95 a	98 a	85 a	8 a	10 a	2 a
MIPC	50 WP	95 a	72 b	68 b	2 a	5 a	2 a
Diazinon	20 EC	42 a	35 a	15 b	2 a	8 a	5 a

[a]In a row and for each DAT (days after treatment), means followed by the same letter are not significantly different at the 5% level. [b]Granules were applied to paddy water at the rate of 1 kg a.i./ha, and foliar application made as a 0.04% spray, except for Permethrin and carbofuran 20 F (0.02%). [c]G = granules; F = flowable; EC = emulsifiable concentrate. [d]Mortality was determined at 48 h after insects were caged on treated TN1 plants. [e]Average of three replications consisting of 10 insects each. [f]Average of four replications consisting of 10 insects each.

populations were tested against carbofuran in paddy water and in the root zone (Fig. 4). In both application methods, the field-collected BPH had lower mortality than the greenhouse culture. The difference in mortality was especially distinct at 14 DAT when the root-zone treatment caused 100% mortality in the greenhouse BPH and 8% in the field-collected BPH.



4. Mortality of greenhouse cultures and field-collected brown planthopper *Nilaparvata lugens* as affected by carbofuran (1 kg a.i./ha) in paddy water and in root zone. IRRI greenhouse, 1976.

A culture of field-collected BPH will be used to determine whether the resistance is genetic or field induced.

Insect control in upland rice. An experiment was conducted in IRRI's new upland area to determine the growth stage of upland rice at which insecticide control is necessary. Heavy rains caused lodging and yield data could not be taken. However, data on insect control by treating seeds with carbofuran and by foliar sprays of monocrotophos at 20-day intervals were recorded.

Stem borers, the leaf folder *Cnaphalocrosis medinalis*, and GLH were particularly abundant. Seed treatment was not effective late in the crop season, but it provided some early control of insects, especially GLH. The foliar spray effectively controlled the leaf folder, GLH, and whitebacked planthopper. Stem borer control was poor.

PLANT INJURY BY INSECTS AND ITS ECONOMIC THRESHOLDS
Entomology Department

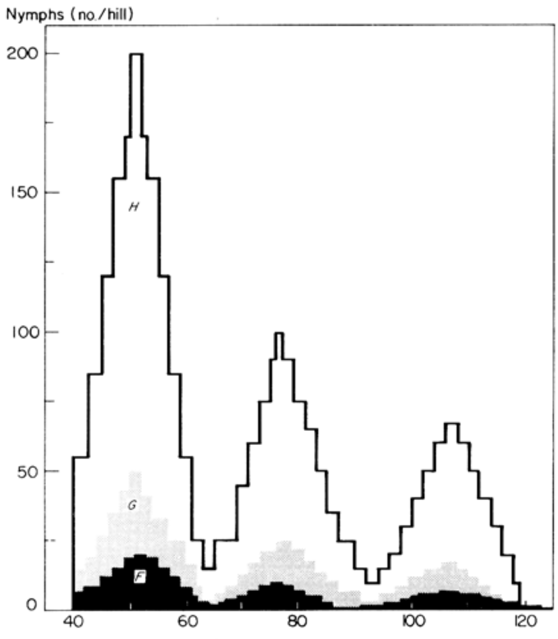
The economic importance of insects is measured by the plant injury and yield losses that they cause. Knowing the extent of damage and the growth stage when it occurs permits maximum efficiency of pest control.

Table 25. Effect of fluctuating nymphal density of green leafhopper *Nephotettix virescens* on grain weight of IR22.[a] IRRI greenhouse, 1976.

Treatment	Max nymphal density (no./hill)			Panicles[b] (no./hill)	Unfilled grains (%)	Grain wt (g/hill)	Grain wt reduction (%)
	First generation	Second generation	Third generation				
A (control)	0	0	0	16 a	25 a	26.9 a	—
B	2	1	1	14 ab	27 a	23.2 ab	14
C	3	2	1	14 ab	26 a	22.0 ab	18
D	6	3	2	11 bc	37 b	16.6 bc	38
E	12	6	4	11 bc	41 b	15.6 c	42
F	20	10	7	10 c	41 b	14.8 c	45
G	50	25	17	6 d	48 c	6.5 d	76
H	200	100	67	2 e	62 c	2.5 e	91

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]Measured at 90 days after seeding.

Rice whorl maggot. As a preliminary step toward correlating rice whorl maggot infestation with plant injury and yield loss, female flies were caged on potted seedlings in the greenhouse and a range of egg densities was obtained. It was not possible to accurately predict plant damage on the basis of number of flies or eggs per hill because damage and insect density were not related linearly. Development of an economic threshold for the whorl maggot does not appear to be promising.



5. Nymphal density of green leafhopper *Nephotettix virescens* caged on rice variety IR22 in treatments F, G, and H. IRRI greenhouse, 1976.

Green leafhopper. Studies in 1973 showed that 2-week infestations of the green leafhopper *Nephotettix virescens* at the usual field densities did not cause economic grain reduction (1973 Annual Report). However, the effect of cumulative damage for the crop period was not evaluated. That effect was measured in 1976 by a new approach (Table 25, Fig. 5). As before, leafhopper nymphs were caged on potted plants; however, field population changes were simulated. For three generations insect density was artificially regulated according to a stylized pattern based on previous field observations. The tiller number of all treatment hills was not significantly different from that of the control at the time of caging, about 40 days after seeding.

Many of the plants with the highest pest density (treatment H) were killed, and those that survived produced low yields. The leaves of plants having moderate infestation turned yellow and developed few panicles. The percentage of unfilled grains increased as the pest density increased. On the basis of percentage of grain weight reduction, even plants with relatively low pest density appeared to suffer. However, reductions of 14 and 18% were not significant, probably because grain production in potted plants is inherently variable, even with 22 replications. Because a grain loss of 14% is already greater than the probable level of economic damage, the experiment cannot be said to have clearly defined an economic threshold for field purposes. Nevertheless, it indicated that GLH inflicts much more damage to rice than was earlier thought possible.

Rice leaf folder. Observations in 1975 showed that leaf folder larvae can cause significant yield loss, and that the economic threshold could be at less than 4 damaged leaves/hill at flowering (1975 Annual Report). The number would be higher if infestation occurs earlier. An extensive greenhouse experiment was conducted in 1976 to quantify the economic injury level.

Plants that did not differ significantly in panicle number were used. Some were infested with field-collected larvae (mostly first and second instar) at the beginning of the flowering period; others were infested 1 week later.

The results indicated that plants could tolerate some leaf folder damage, but that an increasing insect density caused increasing leaf damage and grain weight reduction (Table 26). The estimated economic injury level is between 5 and 15 damaged leaves/hill when damage occurs at about the flowering period. It would be caused by 1 larva/4–8 tillers.

Rice bugs. To determine the approximate economic threshold for rice bugs, *Leptocorisa spp.*, adult bugs were placed in a 1-sq m nylon cloth field cage on IR30 plants (20 replications) that were starting to flower. The cages were checked daily and various bug densities were maintained until harvest. Panicle number per cage at harvest did not significantly differ.

Table 26. Leaf damage and grain weight of IR26 as affected by density of various instars of larvae of the rice leaf folder *Cnaphalocrosis medinalis*.[a] IRRI greenhouse, 1976.

Larval density (tillers/larva)	Damaged leaves[b]		Unfilled grains (%)	Grain wt[c] (g/hill)	Grain wt reduction (%)
	(no./hill)	(%)			
	Infested at 77 DS				
No infestation	0 a	0	43	28.5 a	—
10	6 b	7	48	29.4 a	–3
8	7 b	8	48	29.6 a	–4
6	11 c	13	51	25.4 ab	11
4	15 d	15	54	24.0 bc	16
2	19 e	23	50	20.4 c	28
	Infested at 84 DS				
No infestation	0 a	0	39	32.3 ab	—
10	3 b	5	41	32.2 ab	0
8	5 c	7	40	33.7 a	–4
6	6 d	9	43	29.7 ab	8
4	8 e	12	48	29.3 b	9
2	13 f	18	44	24.2 c	25

[a]Within the same infestation time, means followed by the same letter are not significantly different at the 5% level. [b]Measured at 91 days after seeding (DS) in the first infestation and at 99 DS in the second infestation. [c]Harvested at 130 DS.

Table 27. Effect of density of adult rice bugs *Leptocorisa spp.* on grain yield of IR30[a]. IRRI, 1976 dry season.

Bug density (no./sq m)	Unfilled grains (%)	Yield (g/sq m)	Yield loss (%)
0	28 a	453 a	—
1	30 a	438 ab	3
2	36 b	440 ab	3
4	37 b	411 b	9
8	43 c	360 c	21

[a]Means followed by the same letter are not significantly different at the 5% level.

As the rice bug density increased, the percentage of unfilled grains also increased, confirming the logical assumption that bug damage is reflected by unfilled grains. An infestation of 2 bugs/sq m caused a yield loss of only 3%, but a density of 4 bugs/sq m resulted in a significant grain loss of 9% (Table 27). The economic damage level was about 5%; that puts the economic threshold between 2 and 4 bugs/sq m.

PEST MANAGEMENT (INTEGRATION OF CONTROL MEASURES)

Entomology Department

Insecticides and predators. One component of pest management is conservation of natural enemies that may act as population-regulating mechanisms on rice pests. Recent greenhouse studies at IRRI (1975 Annual Report) showed that two predators, the spider *Lycosa pseudoannulata* and the bug *Cyrtorhinus lividipennis*, have potential for natural control of rice pests.

Insecticides differ in toxicity to predators (1974 Annual Report). A wide-spectrum chemical such as methyl parathion is toxic to *C. lividipennis*.

In 1976, greenhouse and field experiments were conducted to find insecticides and methods of insecticide application that were less toxic to natural enemies.

Several experiments were conducted to determine the insecticides that were toxic to predators under field conditions. In the first two experiments, 26 chemicals were applied twice at Philippine recommended rates. Adult *L. pseudoannulata* and *C. lividipennis* predators were separately placed in cloth cages at 1 and at 8 DAT. Two spiders and five bugs were caged in each plot.

Table 28. Mortality of adult predatory spiders *Lycosa pseudoannulata* and bugs *Cyrtorhinus lividipennis* caged on plants of rice selection IR1917-3-17 treated with insecticides. IRRI, 1976 wet season.

Insecticide[a]	Formulation[b]	Mortality[c] (%)			
		C. lividipennis		*L. pseudoannulata*	
		1 DAT	8 DAT	1 DAT	8 DAT
	Test 1				
Carbofuran	G	100 a	100 a	83 a	16 ab
Carbofuran	F	100 a	100 a	33 ab	0 b
Carbophenothion	EC	100 a	75 ab	50 ab	0 b
Fenthion	EC	100 a	73 ab	50 ab	16 ab
Phosphamidon	EC	100 a	73 ab	16 b	33 ab
Carbaryl	WP	100 a	60 bc	16 b	16 ab
Diazinon	G	100 a	60 bc	16 b	0 b
Azinphos ethyl	EC	87 ab	47 bc	50 ab	0 b
Methyl parathion	EC	87 ab	47 bc	16 b	16 ab
Endosulfan	EC	67 bc	53 bc	50 ab	16 ab
Fenitrothion	EC	67 bc	53 bc	16 b	16 ab
BPMC	EC	67 bc	53 bc	16 b	16 ab
Gamma-BHC	G	53 c	33 c	16 b	50 a
Control		13 d	27 c	0 b	0 b
	Test 2				
Pyrethrum		100 a	93 a	33 a	16 a
Diazinon	EC	100 a	80 ab	33 a	16 a
Propoxur	WP	100 a	80 ab	16 a	16 a
Monocrotophos	EC	100 a	60 ab	16 a	33 a
Methomyl	EC	100 a	60 ab	16 a	16 a
MIPC	WP	93 a	93 a	0 a	33 a
Chlordimeform	SP	87 ab	73 ab	33 a	33 a
Metalkamate (Bux)	EC	87 ab	67 ab	0 a	0 a
Perthane	EC	80 abc	80 ab	16 a	16 a
Gamma-BHC	EC	80 abc	73 ab	33 a	33 a
Malathion	EC	80 abc	73 ab	0 a	33 a
Triazophos	EC	53 bc	47 bc	16 a	50 a
Acephate	SP	47 c	60 ab	0 a	33 a
Control		33 d	33 c	16 a	16 a

[a]Carbaryl was applied at 1.5 kg a.i./ha, malathion at 1.0 kg a.i./ha, and pyrethrum at 0.5 kg a.i./ha. Other sprays were applied at 0.75 kg a.i./ha and granules at 1 kg a.i./ha. Insecticides were applied 9 wk after transplanting in test 1, and 11 wk in test 2. [b]G = granules; F = flowable; EC = emulsifiable concentrate; WP = wettable powder; SP = soluble powder. [c]Mortality was determined 5 days after caging. DAT = days after insecticide treatment. In a column, means followed by the same letter are not significantly different at the 5% level. The predator received no food.

The mortality of *L. pseudoannulata* caused by any one of the insecticides tested, including carbofuran granules, was insignificant at the 5% level (Table 28). The experiments suggest that when applied as recommended, the insecticides are not likely to be toxic to *L. pseudoannulata*.

In contrast with the spiders, *C. lividipennis* bugs suffered mortality from all the insecticides. Several compounds caused 100% mortality at 1 DAT. Carbofuran killed 100% of the bugs at 1 and at 8 DAT, and the toxicity of a few insecticides remained significant at 8 DAT (Table 28).

A few insecticides (granular gamma-BHC, sprayable endosulfan, chlordimeform, metalkamate (Bux), Perthane, gamma-BHC, and malathion) were only moderately toxic to *C. lividipennis*, causing an adjusted mortality of about 50% or less.

In another field experiment, population counts of *C. lividipennis* were taken before and after foliar sprays with three coded and three commercially available compounds (Table 29). NRDC 161, which had caused BPH increases in experiments at IRRI, reduced the *C. lividipennis* population by 96% when applied at 0.1 kg a.i./ha.

When naturally occurring field populations are used to determine the effect of insecticides on predators, as in the cited experiment, this question arises: Is the decrease in predator population due to a lack of prey, a condition that causes predators to move to other fields, or is it due to the insecticide?

To gain some information on prey abundance

Table 29. Reduction of the predaceous bug *Cyrtorhinus lividipennis* population by foliar sprays. IRRI, 1976 wet season.

Insecticide[a]	Population reduction (%) after spraying[b]
Monocrotophos	97
NRDC 161 (Decis)	96
FMC 35001	96
Vamidothion	85
A 47171	74
Acephate	71
Control	4

[a]All insecticides applied at 0.75 kg a.i./ha, except NRDC 161 which was applied at 0.10 kg. [b]Reduction based on number 1 day before and 5 days after spraying was statistically significant at the 1% level for all treatments except the control.

and predator populations before and after insecticidal treatment, acephate was applied as a foliar spray to a field heavily infested with BPH, a prey for *C. lividipennis*. Acephate reduced the *C. lividipennis* population by 90% and reduced the BPH population by 54% (Table 30). The abundance of BPH after spraying indicates that the toxic effect of the insecticides, and not lack of prey, is primarily responsible for the decrease in *C. lividipennis*.

Several experiments were conducted to determine the effects of various methods of insecticide application on predators. In earlier studies, carbofuran, an insecticide that is lethal to some predators in contact toxicity trials, was relatively nontoxic to spiders when applied as granules to paddy water or to the root zone with a granule applicator (1975 Annual Report).

Further greenhouse and field studies were conducted to confirm the results. In greenhouse trials paddy-water (broadcast) and root-zone applications of carbofuran were compared for effectiveness against *L. pseudoannulata* and *C. lividipennis* (Table 31). *C. lividipennis* was more susceptible. Carbofuran applied by either method caused 96% mortality of *C. lividipennis* at 21 DAT.

Field studies were conducted to compare the relative toxicity to *C. lividipennis* of carbofuran as a broadcast or as a root-zone treatment. At 26 DAT, *C. lividipennis* populations were low and about equal in each treatment. They decreased at 35 DAT in both treatments. At 48 DAT, the predator population in the root-zone treatment was about 20% of that in the control.

Another field experiment compared the toxicity to adult *L. pseudoannulata* and *C. lividipennis* of carbofuran applied by five different methods —seedling root coat, broadcast, soil-incorporated, applied to root zone, and foliar spray (Table

Table 30. Controlling brown planthopper (BPH) with a foliar spray of acephate and effect on the predaceous bug *Cyrtorhinus lividipennis* and spiders.[a] IRRI, 1976 wet season.

Treatment	Insects[b] (no.)			Reduction (%)			BPH: predator ratio
	BPH	*C. lividipennis*	Spiders	BPH	*C. lividipennis*	Spiders	
Before acephate spray	3092 a	283 a	24 a	—	—	—	11:1
After acephate spray	1415 b	28 b	39 a	54	90	0	51:1

[a]In a column, means followed by the same letter are not significantly different at the 5% level. Acephate applied on the lower portion of the plants at the rate of 0.50 kg a.i./ha in 1000 liters water/ha. [b]Based on samples taken with a D-vac suction machine covering a 7-linear meter row. Spider species not determined. Average of four replicates.

Table 31. Effect of carbofuran 3G at 2 kg a.i./ha in the root zone and in paddy water against beneficial arthropods. IRRI greenhouse, 1976.

Treatment	Mortality[a] (%)					
	Lycosa pseudoannulata			*Cyrtorhinus lividipennis*		
	1 DAT	7 DAT	21 DAT	1 DAT	7 DAT	21 DAT
Paddy-water application	10	60	22	99	100	96
Root-zone application	10	22	11	62	79	96
Control	0	0	12	0	0	2

[a]Average of 10 replications, 10 *C. lividipennis* adults, and 1 late-instar spider caged per replication. Observed at 48 h after caging. DAT = days after treatment.

Table 32. Mortality of the predatory bug *Cyrtorhinus lividipennis* caged on plants of rice selection IR1917-3-17 treated with carbofuran insecticide, 1-11 weeks after transplanting. IRRI, 1976 dry season.

Method of application	Mortality[a] (%) of *C. lividipennis*										
	1 wk[b]	2 wk	3 wk	4 wk[b]	5 wk	6 wk[b]	7 wk	8 wk	9 wk[b]	10 wk	11 wk
Root coat at transplanting		88 ab			65 ab		50 bc			25 a	
Granules broadcast at transplanting		58 bc			18 d			35 a			33 a
Incorporation into soil before transplanting		93 a			35 bcd		35 bc				13 a
Root-zone (capsules)			95 a		78 a		90 a			20 a	
Root-zone (granule applicator)			70 a		28 d			25 a			18 a
Root-zone (liquid applicator)			95 a		60 abc			38 a			20 a
Granules broadcast every 2 wk				53 b		90 a	70 ab		75 a	65 a	33 a
Foliar spray every 2 wk[c]				85 a		100 a	20 c		78 a	40 a	28 a
Control		38 c	30 b	25 c	30 cd	27 b	20 c	20 a	30 b	20 a	13 a

[a]Mortality measured 3 days after caging. Bugs were not fed. In a column, means followed by the same letter are not significantly different at the 5% level. [b]Insecticide applied within the week. [c]Foliar spray applied at 0.5 kg a.i./ha; all other insecticide treatments applied at 1 kg a.i./ha.

32). Predators were placed in cloth cages over individual hills at various intervals after insecticide treatment. Applying carbofuran as a seedling root coat, or to the root zone by a granule applicator or a liquid applicator in the field near transplanting time resulted in negligible toxicity to *L. pseudoannulata*. Toxicity to spiders was moderate to low when carbofuran was applied in capsule form to the root zone by hand, incorporated into the soil before transplanting, broadcast on paddy water, or sprayed on the plants. The effect of the two latter treatments was of short duration.

Carbofuran toxicity to *C. lividipennis* in the same experiment was rather high for several methods of application, and residual effects of a few treatments were noted (Table 32).

Some differences from application methods were seen on the predators, and thus certain application methods may benefit conservation of the predators.

Sex pheromone. In cooperation with the Tropical Products Institute, London, study continued on the sex pheromone and attractant inhibitor of *C. suppressalis* (1975 Annual Report).

A preliminary experiment included waterpan traps with a vial containing 100 μg of the synthetic sex pheromone to simulate a female moth (attractant). That vial was surrounded either by vials containing high (1 mg) concentrations of the attractant to prevent or confuse male moths from locating the 100-μg attractant source in the center of the trap, or by an attractant inhibitor to repel male moths from the attractant source.

In the inhibition test, the waterpan traps having only the attractant source caught 205 moths, while the trap surrounded by eight vials of the high concentration attractant inhibitor caught only two moths (Table 33).

In the confusion test, male moths did not locate the attractant source in the tray. The results of a larger scale field experiment indicated results similar to those obtained in the preliminary trial. Further field testing will be conducted in 1977.

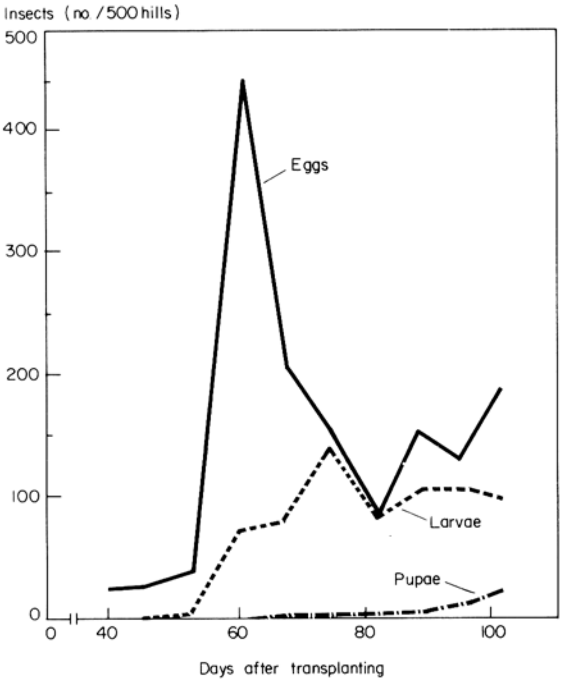
ECOLOGY OF RICE INSECTS
Entomology Department

Stem borers. It was difficult to evaluate egg mortality of *Chilo suppressalis* in the field because the sampling procedure used apparently

Table 33. *C. suppressalis* **male moths caught in water pan traps containing its sex attractant and surrounded by either an inhibitor or a confusion agent.**[a] **IRRI, 1976.**

Treatment	Moths collected (no.)
Inhibition experiment[b]	
Pheromone attractant	205
Pheromone attractant + 4 attractant inhibitor sources	80
Pheromone attractant + 8 attractant inhibitor sources	2
Confusion experiment[c]	
Pheromone attractant	15
Pheromone attractant + 4 confusion sources	0
Pheromone attractant + 8 confusion sources	1

[a]Attractant source was a polyethylene vial containing 100 μg of pheromone. Confusion and inhibitor vials contained 1 mg of the pheromone and synthetic inhibitor, respectively. They were placed on stakes around the tray at 0.5 m from the attractant source. [b]36 trap nights. [c]24 trap nights.



6. Density of the stem borer *Chilo suppressalis* per 500 hills (20 sq m) on the rice selection IR127-80-1. IRRI, 1976 dry season.

underestimated egg density (1975 Annual Report). Inasmuch as the duration of the egg stage is much shorter than that of the larval stage, the frequency of egg sampling in 1976 was increased to three times a week, but larval and pupal sampling frequencies were kept at once a week. In contrast with earlier findings, the maximum egg density exceeded maximum larval density (Fig. 6). Egg mortality, caused partly by sucking, predaceous insects, may be high, but because the mortality of small larvae may also be high, the efficiency of sampling them requires study.

Brown planthoppers and green leafhoppers. To construct life tables for a BPH population, insect eggs, nymphs, and adults were sampled three times a week throughout a crop period. There were two major peaks of oviposition—at about 6 and 11 weeks after transplanting. Each egg peak was followed by a peak of nymphs. Egg parasitism went up to 55% by the end of the first oviposition period, and then dropped to about 20% for the remainder of the crop period. A maximum 10% of the eggs were attacked by predators. The low survival percentage of the second batch of eggs could not be explained. Nymphal survival was poor.

Similar data for life table studies were collected for GLH from the same crop. Again there were two major oviposition peaks, but they came earlier in the crop period: about 4 and 9 weeks after transplanting. The maximum egg densities were much the same as for BPH, but nymphal densities were low, possibly because of egg parasitism, which ranged from 25 to 70%. Nymphal survival appeared to be moderate but higher than that for BPH.

Earlier studies showed that close spacing of hills transplanted in a square pattern could increase the density of BPH on a tiller and area basis. The inference was that high tillering varieties may magnify a BPH problem (1972 Annual Report). That inference was tested in 1976 in both field and greenhouse conditions.

Table 34. Density of brown planthopper *Nilaparvata lugens* nymphs and adults at peaks of first two generations per crop on rice varieties and selections. IRRI field study, 1976 wet season.

Variety or selection	Field population[a] (no./hill)	
	35 DT	63 DT
Low tillering		
H4	31 ef	108 bc
IR480	17 bcde	46 b
High tillering		
Peta	23 cde	66 bc
IR8	22 cde	73 bc
Tiller number artificially adjusted		
IR1917-3-17 low number	7 a	32 b
IR1917-3-17 moderate number	19 cde	43 b
IR1917-3-17 high number	28 ef	89 bc
IR1917-3-17 low number[b]	11 ab	116 bc
IR1917-3-17 moderate number[b]	28 def	139 c
IR1917-3-17 high number[b]	48 f	123 c[c]
Old varieties		
BPI-76 (NS)	18 bcde	79 bc
Sigadis	24 de	111 bc
GEB 24	27 def	54 b
New varieties		
IR20	16 bcde	85 bc
IR26	13 abcd	28 b
IR36	11 abc	4 a
C4-63G	23 de	76 bc
Pelita I-2	33 ef	76 bc
Mahsuri	19 cde	63 bc

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]To increase brown planthopper density, diazinon granules at 1 kg a.i./ha were applied at 1 and 20 days after transplanting (DT), and methyl parathion was sprayed (0.75 kg a.i./ha) biweekly beginning at 35 DT. [c]Hopperburned plots.

A uniform spacing was used for all varieties or selections, but a range of tiller numbers per hill was created by selecting certain varieties and artificially adjusting the tiller number of some plants. The field infestation was fairly high, especially at the peak of the second generation. There was some evidence that for IR1917, an increase in the tiller number per hill was associated with an increase in insect density, but it could not be shown that high tillering and new varieties had heavier infestations than low tillering and old varieties (Table 34). Other factors inherent in a variety, such as insect resistance, may play a role, as probably was the case with IR26 and IR36.

Control and management of rice pests

Weeds

Agronomy and Statistics Departments

WEED CONTROL IN RICE
Agronomy Department

IRRI weed research focuses on direct control of weeds by hand, and by mechanical and chemical methods. Experiments to identify suitable herbicides were continued at IRRI, at the Maligaya, Bicol, and Visayas Rice Research Stations of the Philippine Bureau of Plant Industry (BPI), and in a farmer's field.

Transplanted rice. The differences in yield between herbicide-treated and untreated plots ranged from 1 t/ha at Maligaya to 2.1 t/ha at IRRI and Visayas. At all sites, the yield differences between the treated and untreated plots were highly significant.

During the dry season *Echinochloa crus-galli*, *E. crus-pavonis*, *Monochoria vaginalis*, and *Cyperus difformis* were common at all experimental sites. *Scirpus maritimus* was present at IRRI, and *C. imbricatus* and *Sphenoclea zeylanica* were present in Bicol.

The only herbicide combination that consistently gave yields statistically similar to those of the hand-weeded controls at all sites was piperophos/dimethametryn (Table 1). The other herbicides gave yields comparable with those of the hand-weeded control at IRRI, Maligaya, and Bicol but not at Visayas.

During the wet season, dinitramine +2,4-D appeared best for transplanted rice at all sites (Table 2). WL 29226 gave yields significantly lower than those of the hand-weeded controls at IRRI and Bicol, and the lowest mean yield of 3.8 t/ha.

A dry-season, field experiment at IRRI evaluated herbicides that had been screened during the 1975 wet season. The principal weeds in transplanted rice were *E. crus-galli*, *E. crus-pavonis*, *M. vaginalis*, *C. difformis*, and *Paspalum* sp. All treatments gave a significantly higher grain yield than the untreated control (Table 3).

The experimental herbicide terbuchlor looked promising in many other experiments. Butachlor and benthiocarb, identified as good herbicides for tropical rice, are still being evaluated in combinations that will increase their effectiveness. The two, however, cost three to four times more than 2,4-D, which also adequately controlled weeds. None of the herbicide treatments exhibited prolonged toxicity on transplanted IR26.

All treatments effectively controlled the grassy weeds such as *E. crus-galli* and *E. crus-pavonis*, sedges, and the broad-leaved weeds. M 3432 failed to control the broad-leaved weeds, among them *M. vaginalis*, but gave a grain yield of

Table 1. Effects of granular herbicides applied before weed emergence (4 days after transplanting) on yield of transplanted IR26 rice at IRRI and three Bureau of Plant Industry stations in the Philippines. 1976 dry season.

Treatment[a]	Rate[b] (kg a.i./ha)	Yield[c] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Piperophos/dimethametryn	0.5	4.3	5.8	6.1	4.7
Terbuchlor	0.3	5.1	5.4	5.9	4.5*
Piperophos/2,4-D IPE	0.5	4.9	5.4	6.0	4.2**
Butachlor + 2,4-D IPE	0.75 + 0.5	4.4	5.5	5.8	4.4**
2,4-D IPE	0.8	4.8	5.6	5.7	4.1**
WL 29226	1.0	4.3	5.2	5.8	4.3**
Dinitramine + 2,4-D IPE	0.5 + 0.5	4.1	5.3	5.7	3.7**
Perfluidone/2,4-D IPE	1.0/0.25	4.2	5.2	5.4	3.1**
MT-B-3015	1.0/0.7	4.8	—	—	—
WL 29226	0.5	4.6	—	—	—
M 3432 5% + 2,4-D IPE	4.0 + 0.5	4.4	—	—	—
M 3432 7.5% + 2,4-D IPE	4.0 + 0.5	4.4	—	—	—
Prefar/MCPA	0.6/0.2	4.4	—	—	—
Molinate + 2,4-D IPE	2.0 + 0.5	4.1	—	—	—
Hand-weeded control[d]		4.7	5.4	5.9	5.3
Untreated control[e]		2.5	4.4	4.0	2.6

[a]A slant bar (/) between two herbicides indicates that they were formulated on the same carrier or mixed together and applied as a single treatment. A plus sign (+) between two herbicide names means that the chemicals were applied separately at about the same time. IPE = isopropyl ester. [b]a.i. = active ingredient. [c]— = not tested. [d]At 20 and at 40 days after transplanting. [e]All herbicide treatments gave significantly higher yields than the untreated control.

Table 2. Effects of granular herbicides applied before weed emergence (4 days after transplanting) on yield of transplanted IR26 rice at IRRI and three Bureau of Plant Industry stations in the Philippines. 1976 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Yield[c] (t/ha)			
		IRRI[d]	Maligaya	Bicol[d]	Visayas
Dinitramine + 2,4-D IPE	0.5 + 0.5	3.9	5.1	5.1	4.7*
Butachlor + 2,4-D IPE	0.75 + 0.5	3.7	4.8	4.7	4.8
Piperophos/2,4-D IPE	0.5	3.7	5.0	4.3	4.4*
Perfluidone/2,4-D IPE	1.0/0.25	3.7	4.8	4.5	4.4*
Piperophos/dimethametryn	0.5	3.3	4.8	4.8	4.6*
Terbuchlor	0.3	3.7	5.0	4.4	4.6*
2,4-D IPE	0.8	2.8**	5.2	4.5	4.6*
WL 29226	0.5	1.8**	4.7	4.0**	4.6*
M 3432 7.5% + 2,4-D IPE	3.0 + 0.5	3.9	—	—	—
NTN 5810/Clearcide	0.75/0.25	3.7	—	—	—
M 3432 5% + 2,4-D IPE	3.0 + 0.5	3.5	—	—	—
MT-B-3015	1.0/0.7	3.1	—	—	—
Prefar/MCPA	0.6/0.2	2.9*	—	—	—
AC 92553	0.5	3.0*	—	—	—
Hand-weeded control[e]		3.8	4.9	5.0	5.4
Untreated control		0.6	4.2	2.3	4.3

[a]A slant bar (/) between two herbicides indicates they were formulated on the same carrier or mixed together and applied as a single treatment. A plus sign (+) between two herbicide names means that the chemicals were applied separately at about the same time. IPE = isopropyl ester. [b]a.i. = active ingredient. [c]— = note tested. All herbicide treatments gave significantly higher yields than did the untreated control. [e]Weeded at 20 and at 40 days after transplanting.

8 t/ha, indicating that the yield response was primarily from control of grassy weeds. All plots were infested with *Paspalum* sp. Even though the weed population was not heavy, each hand weeding required 105 man-hours/ha. The correlation coefficient between total dry matter production of the weeds and the grain yield was significant ($r = -0.92^{**}$).

Direct-seeded flooded rice. During the dry season, most herbicide treatments on direct-seeded, flooded plots gave significantly higher yields than the untreated controls at all sites. Perfluidone/2,4-D gave the highest grain yields at IRRI and in Bicol. Yields were comparatively high with terbuchlor, piperophos/dimethametryn and with dinitramine + 2,4-D at three of four sites (Table 4). In Bicol, the yields from piperophos/2,4-D, butachlor + 2,4-D, and trifluralin/2,4-D were not significantly higher than those of the untreated controls.

An experiment at IRRI compared the effects of several granular herbicides broadcast on levelled plots (Table 5). The plots were kept saturated for 6 days after seeding (DS) and then flooded to 2.5 cm; herbicides were applied at 7 DS. The water depth was increased progressively to 5 cm and maintained at that level until crop maturity. Weed samples were taken and their dry weight was obtained.

Terbuchlor, molinate, and piperophos/dimethametryn controlled weeds adequately and produced good yields. NTN 5810 at 0.75 kg/ha and benthiocarb at 1.0 kg/ha performed well when combined with Clearcide. The additional tillers of IR26 compensated for the herbicide toxicity observed in plots treated with AC 92553

Table 3. Effects of promising herbicides applied before weed emergence (4 days after transplanting) on the grain yield of IR26. IRRI, 1976 dry season.

Treatment[a]	Rate[b] (kg a.i./ha)	Grain yield[c] (t/ha)
NTN 5810/Clearcide	0.75/0.25	8.3 a
Molinate	2.5	8.3 a
Terbuchlor	0.3	8.2 a
Benthiocarb + Clearcide	1.0 + 0.5	8.1 a
M 3432 7.5%	4.0	8.0 a
Butachlor + Clearcide	1.0 + 0.5	7.9 a
NTN 5810/Clearcide	1.5/0.5	7.8 a
WL 29226	1.0	7.8 a
WL 29226	2.0	7.6 a
Bensulide/MCPA	1.20/0.45	7.6 a
AC 92553	2.0	7.5 a
2,4-D IPE	0.8	7.1 a
Hand weeded (control)[d]	—	7.5 a
Untreated control	—	3.5 b

[a]A slant bar (/) between two herbicides indicates that they were formulated on the same carrier or mixed together and applied as a single treatment. A plus sign (+) between two herbicide names means that the chemicals were applied separately at about the same time. IPE = isopropyl ester. [b]a.i. = active ingredient. [c]Means followed by the same letter are not significantly different at the 5% level. [d]Weeded at 20 and at 40 days after transplanting.

Table 4. Effects of granular herbicides applied at early postemergence of weeds (6 days after seeding) on yield of direct-seeded, flooded IR26 rice at IRRI and three Bureau of Plant Industry stations in the Philippines. 1976 dry season.

Treatment[a]	Rates[b] (kg a.i./ha)	Yield[c] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Perfluidone/2,4-D IPE	1.0/0.25	6.0 a	3.5 de	5.4 a	3.4 cd
Piperophos/dimethametryn	0.5	3.6 c	4.9 ab	4.8 ab	4.9 a
Terbuchlor	0.3	4.3 bc	4.9 ab	4.5 ab	4.9 a
Benthiocarb/2,4-D IPE	1.0/0.5	4.1 c	4.5 abc	4.8 ab	4.6 a
Dinitramine + 2,4-D IPE	0.5 + 0.5	4.8 abc	5.2 a	4.9 ab	3.2 d
WL 29226	1.0	4.3 bc	4.3 bcd	4.4 ab	4.3 ab
Butachlor + 2,4-D IPE	0.75 + 0.5	5.1 abc	3.8 cd	3.8 bc	4.0 bc
Piperophos/2,4-D IPE	0.5	5.8 ab	4.0 cd	3.6 bcd	3.6 cd
Trifluralin/2,4-D IPE	0.4/0.54	4.3 bc	2.9 e	2.3 d	3.4 cd
Molinate + 2,4-D IPE	2.0 + 0.5	5.1 abc	—	—	—
M 3432 5% + 2,4-D IPE	4.0 + 0.5	4.9 abc	—	—	—
M 3432 7.5% + 2,4-D IPE	4.0 + 0.5	4.3 bc	—	—	—
Prefar/MCPA	0.6/0.2	4.2 bc	—	—	—
WL 29226	0.5	4.2 bc	—	—	—
Untreated control		1.1 d	2.0 f	2.4 cd	1.5 e

[a]A slant bar (/) between two herbicides means they were formulated on the same carrier or mixed together and applied as a single treatment. A plus sign (+) between two herbicide names indicates that they were applied separately at about the same time. IPE = isopropyl ester. [b]a.i. = active ingredient. [c]Av. of four replications per site. In each column, means followed by the same letter are not significantly different at the 5% level.

at 1.0 kg/ha. Severe toxicity persisted in the plots treated with benthiocarb/2,4-D.

Selectivity was best with NTN 5810/Clearcide, terbuchlor, molinate, and piperophos/dimethametryn, each of which controlled all weeds without causing damage to the crop. M 3432 5% controlled all *Echinochloa* sp. but failed to control broad-leaved weeds. None of the herbicides controlled perennial *Paspalum* sp.

No relationship was seen between the dry weight of broad-leaved weeds and sedges and grain yield. However, both the total weed weight and the weight of grassy weeds affected the yields. Total weed weight and grain yield were significantly correlated (r = −0.93*); the total weight of *Echinochloa* sp. and grain yield also were significantly correlated (r = −0.97*). The significant correlation is understandable because grassy weed seeds (2 kg/ha) had earlier been broadcast to ensure uniform weed stand. The importance of controlling grassy weeds in flooded rice was confirmed.

Table 5. Effects of granular herbicides applied at the 1- to 2-leaf stage of grasses 7 days after seeding (DS) on weed control, crop tolerance, and grain yield of direct-seeded, flooded IR26. IRRI, 1976 dry season.

Treatment[a]	Rate[b] (kg a.i./ha)	Visual rating[c]				Yield[d] (t/ha)
		Control			Toxicity 56 DS	
		Grasses	Broad-leaved weeds	Sedges		
Terbuchlor	0.3	8.6	8.6	9	1	8.1 a
Molinate	3.0	9	9	8.9	1.3	7.9 ab
Piperophos/dimethametryn	0.4/0.1	8.3	8.6	9	1	7.4 ab
WL 29226	1.0	6.3	9	9	2	6.5 ab
Benthiocarb + Clearcide	1.0 + 0.5	9	9	8.6	1.3	6.3 abc
NTN 5810/Clearcide	0.75/0.25	8.6	9	8.6	1	6.2 abc
M 3432 5%	4.0	8.3	2	7.3	1.3	6.0 abc
AC 92553	1.0	2.6	8.3	8.3	1.3	5.8 bc
Benthiocarb/2,4-D IPE	1.0/0.5	8.6	8.6	8.6	4.3	4.2 c
Untreated control	—	1.0	1.0	1.0	1.0	2.1 d

[a]A plus sign (+) between two herbicide names means that the chemicals were applied separately at about the same time. A slant bar (/) between two herbicides indicates that they were formulated on the same carrier or mixed together and applied as a single treatment. IPE + isopropyl ester. [b]a.i. = active ingredient. [c]Weed control rating scale: 0 = no control, 10 = complete control. Toxicity rating scale: 0 = no toxicity, 10 = complete kill. [d]Av. of three replications. Means followed by the same letter are not significantly different at the 5% level.

Table 6. Effects of liquid herbicides applied before crop and weed emergence (2 days after seeding) on weed control and yield of IR9575 (BPI 76⁹/Dawn) rice under upland conditions. IRRI, 1976 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Weed wt[c] (g/sq m)			Yield[d] (t/ha)
		Grasses	Sedges	Broad-leaved weeds	
AC 92553	2.0	8	64	4	2.7 a
Antor	2.0	74	17	4	1.3 e
Butachlor	2.0	86	36	4	1.3 e
Butralin	2.0	22	46	2	2.3 ab
Piperophos/dimethametryn	1.6/0.4	120	7	21	1.7 de
Dinitramine	2.0	17	49	4	2.5 ab
Terbuchlor	1.0	24	40	4	1.8 cd
Oxadiazon	1.0	73	11	1	2.2 bc
RH 2915	1.0	37	16	1	2.4 ab
Propanil[e]	3.0	195	29	0	0.0 f
Hand-weeded control[f]	—	76	20	2	2.5 ab
Untreated control	—	254	36	0.5	0.0 f

[a]A slant bar (/) between two herbicide names indicates that the chemicals were formulated on the same carrier or mixed together and applied as a single treatment. [b]a.i. = active ingredient. [c]Taken at heading stage of grasses. [d]Av. of four replications. Means followed by the same letter are not significantly different at the 5% level. [e]Applied 15 days after rice emergence (DRE). [f]Weeded at 15 and 30 DRE.

Upland rice. Weed infestation is one of the most important factors limiting upland rice yields. At IRRI the untreated control of an experimental line of upland rice (IR9575) was completely taken over by grassy weeds such as *E. colona*, *Eleusine indica*, *Digitaria sanguinalis*, *Panicum repens*, the annual sedge *Cyperus iria*, the perennial sedge *Cyperus rotundus*, and the broad-leaved weed *Commelina diffusa*. Plots treated with propanil produced no grain (Table 6). AC 92553, butralin, dinitramine, and RH 2915 gave yields statistically similar to the 2.5 t/ha obtained with two hand weedings. Antor, butachlor, and piperophos/dimethametryn did not adequately control grasses. Yields were generally low because the rice suffered from bacterial leaf streak at about the maximum tillering stage.

In a farmer's field experiment in Batangas province, the predominant weed species were *E. colona*, *Celosia argentea*, *Commelina benghalensis*, *C. diffusa*, *Ageratum conyzoides*, *Bidens pilosa*, *C. iria*, *C. rotundus*, *and E. indica*. Most herbicides gave yields similar to that of the hand-weeded control; AC 92553 and RH 2915 gave lower yields (Table 7). AC 92553 controlled grasses and broad-leaved weeds. RH 2915 reduced the rice stand by 50%.

Propanil had poor weed control and zero yield at IRRI, but controlled weeds and gave high yields in Batangas. In unpredictable monsoon weather, it provides inconsistent weed control in upland rice.

Dry-seeded rainfed bunded rice. Multiple cropping of rice in rainfed areas where previously one transplanted crop was grown requires that the first crop be planted in a dry soil. Water accumulates in the bunded field as the crop grows. The crop is thus planted as an upland crop and is harvested as a lowland crop. With those conditions, weeds generally occur in large numbers and with greater diversity of species than with rice grown in puddled soil.

Weed control trials in 1976 included herbicides that may be useful for such dry-seeded, rainfed, bunded rice.

At IRRI, all herbicides, except propanil, were applied before rice emergence. Propanil was applied 15 DS. Because of profuse weed growth, all plots were weeded 40 DS to prevent complete yield loss. Weeding time ranged from 58 man-hours/ha for the dinitramine-treated plots to 400 man-hours/ha for the untreated control (Table 8). Yield reductions were primarily caused by the weeds that were present before the weeding. Few weeds grew after 40 DS because of the presence of water and the competition offered by rice. Most of the herbicides used reduced rice stand. The reduction was particularly noticeable in the dinitramine, USB 3153, and RH 2915 treatments. Despite the stand reduction, plots treated with dinitramine had the highest yield.

Table 7. Effects of liquid herbicides applied before crop and weed emergence (2 days after seeding) on weed control and yield of IR9575 rice under upland conditions in a farmer's field. Batangas province, Philippines, 1975 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Weed wt[c] (g/sq m)			Yield[d] (t/ha)
		Grasses	Sedges	Broad-leaved weeds	
AC 92553	2.0	62	11	56	2.2 b
Antor	2.0	29	9	28	2.9 ab
Butachlor	2.0	21	12	33	3.2 a
Butralin	2.0	39	10	43	3.0 ab
Piperophos/dimethametryn (C-288)	1.6/0.4	24	5	36	3.6 a
Dinitramine	2.0	22	16	42	3.0 ab
Terbuchlor	2.0	48	14	36	2.9 ab
Oxadiazon	1.0	54	13	27	3.1 a
RH 2915	1.0	5	1	10	1.2 c
Propanil[e]	3.0	38	10	38	2.8 ab
Hand-weeded control[f]	—	12	2	14	3.2 a
Untreated control	—	215	5	22	0.0 d

[a]A slant bar (/) between two herbicide names means that the chemicals were formulated on the same carrier or mixed together and applied as a single treatment. [b]a.i. = active ingredient. [c]Taken at heading stage of grasses. [d]Av. of two replications. Any two means followed by a common letter are not significantly different at the 5% level. [e]Applied at 15 days after rice emergence (DRE). [f]Weeded at 15 and 30 DRE.

A high seeding rate (80 kg/ha) and superior weed control in the plots compensated for the loss in stand caused by the herbicides.

In another trial, weed weights 14 DS averaged 842 kg/ha in plots treated with butachlor and 1,768 kg/ha in the untreated plots. At that stage of crop growth, it took 356 man-hours/ha to weed the untreated plots, and only 79 man-hours/ha to weed the butachlor-treated plots. In the herbicide-treated plots, the weeds were smaller and were easier to distinguish from the rice.

Results at Iloilo supported the finding at IRRI that dinitramine-treated plots could yield as well as the manually weeded plots of dry-seeded rice (Table 9). AC 92553 did not perform as well in Iloilo as it did at IRRI.

A situation similar to that in Iloilo occurred in Pangasinan with a short, high yielding variety. The dry weight of weeds that grew in the untreated plots was only 1,946 kg/ha. Despite a 37% reduction in stand, benthiocarb-treated plots yielded as well as the manually weeded plots.

Applying the herbicides after seed germination rather than immediately after seeding

Table 8. Effects of herbicides on weed weight, weeding time, and yield of dry-seeded rice. IRRI, 1976.

Treatment[a]	Rate[b] (kg a.i./ha)	Weed wt 20 DS[c] (kg/ha)	Weeding time 40 DS (man-h/ha)	Weed wt at harvest (kg/ha)	Yield[d] (t/ha)
Dinitramine	1.5	354	58	178	3.9 a
Weed-free	—	—	—	—	3.8 a
AC 92553	2.0	1394	175	238	3.5 a
Butachlor	2.0	1990	184	236	3.4 a
USB 3153	1.5	1306	166	186	3.3 a
Oxadiazon	1.0	3146	224	180	3.2 ab
Terbuchlor	1.0	684	200	230	2.9 abc
Butralin	2.0	2116	192	222	2.9 abc
RH 2915	1.0	2114	184	342	2.8 abc
Piperophos/dimethametryn	1.6/0.4	2174	192	240	2.5 abc
Isoproturon	1.0	3190	317	360	2.5 abc
Propanil	3.0	2238	250	342	2.5 abc
Untreated	—	5548	400	318	1.7 bc
Fluorodifen	2.0	5184	392	224	1.5 c

[a]A slant bar (/) between herbicide names indicates that the chemicals were formulated on the same carrier or mixed together and applied as a single treatment. All plots were hand weeded 40 DS. [b]a.i. = active ingredient. [c]DS = days after seeding. [d]Means followed by the same letter are not significantly different at the 5% level.

Table 9. Effect of herbicides on weed weight and yield of dry-seeded rice. Iloilo, Philippines, 1976.

Treatment[a]	Rate[b] (kg a.i./ha)	Time of application[c]	Weed wt 65 DS[d] (kg/ha)	Yield[e] (t/ha)
Dinitramine	2.0	PE	1772	2.8 a
Manual weeding	—	15 + 30 DRE	0	2.8 a
Butachlor	2.0	PE	1568	2.5 ab
Antor	1.0	PE	1448	2.4 ab
Butralin	2.0	PE	1468	2.4 bc
AC 92553	2.0	PE	1512	2.3 bc
Piperophos/dimethametryn	1.6/0.4	PE	1536	2.0 c
Untreated	—	—	2960	1.5 d
Propanil	3.0	15 DRE	1984	1.5 d

[a]A slant bar (/) between two herbicide names indicates that the chemicals were formulated on the same carrier or mixed together and applied as a single treatment. [b]a.i. = active ingredient. [c]PE = preemergence of crop and weeds, DRE = days after rice emergence. [d]DS = days after seeding. [e]Means followed by the same letter are not significantly different at the 5% level.

slightly reduced the toxicity of herbicides to rice as reflected by stand loss (Table 10). No reduction in effectiveness of weed control accompanied the reduction in stand. However, weed growth was so severe that manual weeding was necessary in all plots. In all cases, weeding required more than 500 man-hours/ha. Such labor input in addition to preemergence herbicides appears excessive and may be unacceptable to rice farmers.

SCREENING NEW HERBICIDES
Agronomy Department

Herbicides are screened under rainfed conditions to identify those that are safe and effective for transplanted, direct-seeded, and upland rice.

Transplanted rice. During the wet season, several new herbicides showed promise for transplanted rainfed rice. Yields from 2 to 4 t/ha were obtained. The untreated plots had no yield. Of the herbicides tested for the first time, NTN 5810/2,4-D, EXP 3316, and Prodotto D75, applied before weed emergence, gave yields similar to those of the hand-weeded control (Table 11). Prodotto and X-150 also adequately controlled weeds at the three- to four-leaf stage.

Because there was no standing water in the plots for 20 days after transplanting, granular 2,4-D did not control the grasses.

The important weed species in the test plots were the annuals *E. crus-galli*, *E. crus-pavonis*, *Leptochloa chinensis*, *Fimbristylis littoralis*, *C. difformis*, *C. iria* and the perennials *Paspalum distichum* and *S. maritimus*. Infestations of the broad-leaved weeds *M. vaginalis* and *S. zeylanica* were minor.

Direct-seeded rice. Most new herbicides adequately controlled predominant weeds in a direct-seeded rice experiment that had *E. crus-*

Table 10. Effects of applying herbicides at different times on stand reduction, weed weight, weeding time, and yield of dry-seeded rice. Pangasinan, Philippines, 1976.

Treatment[a]	Rate[b] (kg a.i./ha)	Stand reduction (%)	Weed wt[c] (35 DS)	Weeding time (man-h/ha)	Yield[d] (t/ha)
		Herbicide applied after seeding			
Butachlor	2.0	13	242	793	6.1 a
Manual weeding	—	0	0	—	6.0 a
Dinitramine	1.5	28	364	768	5.8 a
Terbuchlor	1.0	8	462	672	5.2 a
AC 92553	2.0	26	514	792	5.1 a
		Herbicide applied after seed germination			
Butachlor	2.0	2	422	698	5.5 a
Manual weeding	—	0	0	—	6.0 a
Dinitramine	1.5	14	490	945	5.7 a
Terbuchlor	1.0	10	234	746	5.7 a
AC 92553	2.0	20	450	571	5.7 a

[a]All plots were handweeded 40 DS. [b]a.i. = active ingredient. [c]DS = days after seeding. [d]Means followed by the same letter are not significantly different at the 5% level.

Table 11. Effects of promising new herbicides on weed control and yield of transplanted IR26 rice under rainfed conditions. IRRI, 1976 wet season.

Treatment[a]	Application		Weed wt[d] (g/sq m)			Yield[e] (t/ha)
	Rate[b] (kg a.i./ha)	Time[c] (DT)	Grasses	Sedges	Broad-leaved weeds	
NTN 5810/2, 4-D IPE(G)	1.4/0.3	4	41	20	0	4.0 a
EXP 3316 (C)	0.5	4	22	42	0	3.5 ab
Prodotto D75 (EC)	4.0	4	97	32	0	3.2 abc
NTN 6867 (WP)	2.0	4	71	48	0	3.1 bcd
X-150 (G)	3.0	10	180	26	1	2.4 cd
EXP 3391 (G)	0.25	4	44	28	0	2.4 cd
IWD #3051 (EC)	2.0	4	117	9	0	2.3 cd
Oxadiazon (G)	1.0	4	77	30	0	2.3 cd
X-150/2, 4-D IPE (G)	1.4/0.5	4	64	40	0	2.1 e
X-150 (G)	3.0	4	128	18	1	2.0 e
NTN 6867/2, 4-D IPE (G)	1.4/0.3	4	176	10	0	2.0 e
Benthiocarb/2, 4-D IPE[f] (G)	1.0/0.5	4	126	32	0	1.9 e
2, 4-D IPE[f] (G)	0.8	4	253	6	0	0.0 f
Hand-weeded control	—	20 & 40	9	2	0	3.7 ab
Untreated control	—	—	248	39	0	0.0 f

[a]A slant bar (/) between two herbicide names indicates that the chemicals were formulated on the same carrier or mixed together and applied as a single treatment. G = granule, C = cream, EC = emulsifiable concentrate, WP = wettable powder, IPE = isopropyl ester. [b]a.i. = active ingredient. [c]DT = days after transplanting. [d]Taken at heading stage of grasses. [e]Av. of two replications. Means followed by the same letter are not significantly different at the 5% level. [f]Standard chemical controls.

galli, *E. crus-pavonis*, *M. vaginalis*, *and C. difformis*. Herbicides X-52/2,4-D, MT 101, and NTN 5810/2,4-D gave yields comparable with those of the standard controls (Table 12). Prodotto D75, which performed well in transplanted rice, showed promise for application at late post-emergence of weeds in direct-seeded rice.

Because of much rainfall, the plots were almost continuously flooded. Most herbicides were toxic to 7-day-old rice seedlings.

Upland rice. The weeds that heavily infested upland rice included *E. colona*, *C. iria*, *C. rotundus*, *Portulaca oleracea*, *Ipomea triloba*, and *C. benghalensis*. Oxadiazon, SL-55, NTN 6867, and EXP 3316 were promising; they gave yields comparable with those of the hand-weeded control (Table 13). EXP 3316 was moderately toxic to rice.

Table 12. Effects of promising new herbicides on weed control, crop tolerance, and yield of direct-seeded IR26 rice under rainfed conditions. IRRI, 1976 wet season.

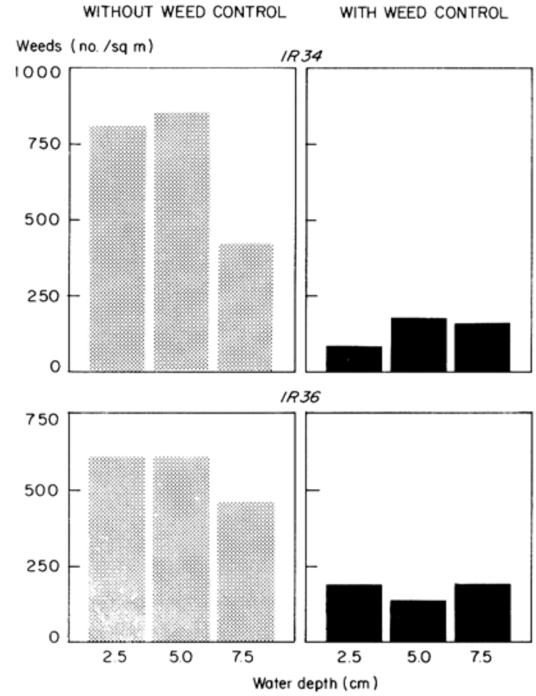
Treatment[a]	Application		Weed wt[d](g/sq m)			Visual toxicity rating[e]	Yield[f] (t/ha)
	Rate[b] (kg a.i./ha)	Time[c] (DS)	Grasses	Sedges	Broad-leaved weeds		
Benthiocarb/2, 4-D IPE[g] (G)	1.0/0.5	7	27	0	3	5	4.4 a
WL 29226[g] (G)	0.75	7	5	0	3	4	4.2 a
X-52/2, 4-D IPE (G)	1.4/0.5	7	64	0	0	4	4.1 ab
MT-101 (WP)	2.0	7	68	0	12	4	3.9 abc
NTN 5810/2, 4-D IPE (G)	1.4/0.3	7	26	4	22	5	3.9 abc
NTN 6867/2, 4-D IPE (G)	1.4/0.3	7	22	2	3	7	3.6 bc
NTN 5810 (G)	2.0	7	16	1	65	6	3.5 c
MCPA/TBA (G)	0.6/0.2	7	31	0	25	6	3.4 c
Prodotto D75 (EC)	2.0	11	44	0	1	6	3.4 c
Oxadiazon (G)	1.0	7	70	0	2	8	2.5 d
Untreated control	—	—	646	26	124	0	0.0 e

[a]A slant bar (/) between two herbicide names indicates that the chemicals used were formulated on the same carrier or mixed together and applied as a single treatment. IPE = isopropyl ester, G = granule, WP = wettable powder, EC = emulsifiable concentrate. [b]a.i. = active ingredient. [c]DS = days after seeding. [d]Taken at heading stage of grasses. [e]Taken at 19 DS. Scale: 1 = no toxicity, 10 = complete kill. [f]Av. of two replications. Any two means followed by the same letter are not significantly different at the 5% level. [g]Standard chemical controls.

Table 13. Effects of promising new herbicides applied before crop and weed emergence (2 days after seeding) on weed control and yield of IR9575 rice under upland conditions. IRRI, 1976 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Weed wt[c] (g/sq m)			Yield[d] (t/ha)
		Grasses	Sedges	Broad-leaved weeds	
Oxadiazon (EC)	1.0	18	7	2	3.5 a
SL 55 (WP)	1.0	25	26	17	3.1 ab
NTN 6867 (WP)	2.0	132	16	2	2.6 b
EXP 3316 (C)	0.5	6	28	2	2.4 b
X-150 (EC)	2.0	226	1	0	1.5 c
Butachlor[e] (EC)	2.0	93	22	6	3.3 a
Hand-weeded control[f]	—	16	3	0	3.2 ab
Untreated control	—	394	4	1	0.0 d

[a]EC = emulsifiable concentrate; WP = wettable powder; C= cream [b]a.i. = active ingredient. [c]Taken at heading stage of grasses. [d]Av. of two replications. Any two means followed by the same letter are not significantly different at the 5% level. [e]Standard chemical control. [f]Weeded at 15 and 30 days after rice emergence.



1. Effects of water depths and variety on weed growth in lowland transplanted rice at 50 days after transplanting.

INTEGRATED WEED MANAGEMENT IN FLOODED RICE

Agronomy Department

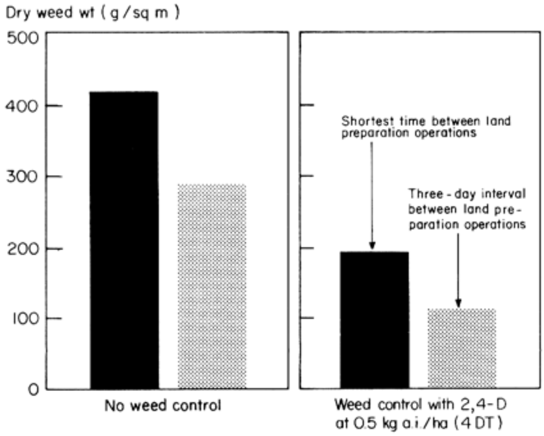
The choice between a nonchemical cultural practice and the use of a chemical depends on many factors. A combination of cultural and chemical methods may be desirable from the agronomic, economic, and biological points of view.

Dry-season field experiments at IRRI studied the effectiveness of variety, water depth, and degree and timing of tillage to control weeds.

Transplanted rice. The effects of varietal type and water depth on transplanted rice were studied in a split-split plot design that had water depth in the main plots, weed control in the subplots, and variety in the sub-subplots. Nineteen-day-old seedlings of IR34 (a tall, 120- to 130-day variety) and IR36 (a semidwarf, high-tillering, 105- to 110-day variety) were transplanted 20 cm apart. Granular 2,4-D was applied at 0.5 kg a.i./ha at 4 days after transplanting (DT). Water-level markers were installed in each plot to facilitate continuous flooding of the main plots to depths of 2.5 cm, 5.0 cm, and 7.5 cm from 4 DT until crop maturity.

At the low rate of 0.5 kg a.i./ha, 2,4-D did not affect the performance of the rice varieties. But grain yields significantly differed between varieties at the 5-cm water depth with weed control; IR36 gave higher yields than all other treatments with herbicide. At all the water depths compared, the herbicide significantly minimized weed growth (Fig. 1). Even without weed control, IR36, with its spreading canopy, was able to compete more effectively against weeds (particularly at the 2.5-cm and 5-cm water depths) than IR34 with its erect leaves. With weed control, no varietal differences showed at any water depth.

The effects of degree and timing of tillage were examined in another experiment. The split-split-plot design used had the time between tillage in the main plots, weed control in the subplots, and degree of tillage in the sub-subplots. Twenty-three-day-old seedlings of IR26 were transplanted in levelled plots. Times between the tillage operations were set at 3 days and the shortest time possible. The plots were saturated 4 DT and then flooded to 2.5



2. Effects of time interval between land preparation operations on weed weights 52 days after transplanting (DT), with and without weed control in rice. IRRI, 1976 dry season.

cm; then 2,4-D at 0.5 kg a.i./ha was broadcast. Figure 2 summarizes the results.

Direct-seeded flooded rice. The effect of variety, tillage, and water depth was studied in a strip-split-plot design with two varieties and two water depths in the main plot, three tillage treatments as strips across the main plots, and weed control treatments in the subplots. The varieties were intermediate-height IR34 and short-statured IR36; water depths were 2.5 cm and 7.5 cm; tillage treatments were three degrees of harrowing done on the same day. Terbuchlor at 0.3 kg a.i./ha was applied at the one- to two-leaf stages of the grassy weeds. The weeds present were *E. crus-galli*, *E. crus-pavonis*, *M. vaginalis*, *S. maritimus*, and *C. difformis*.

The grain yield of IR36 was significantly higher than that of IR34. The reduced yield of IR34 may be attributed to a typhoon that occurred 12 to 5 days before harvest.

At the 2.5-cm water depth, the grain yields of the two varieties did not differ significantly. At the 7.5-cm water depth, the grain yield of IR36 was significantly higher than that of IR34 (Table 14). Grain yields were not significantly affected by water depth and tillage treatments, but showed highly significant effects with weed control (Table 15). One plowing and two harrowings significantly reduced dry matter production and number of grassy weeds, compared with one plowing and three harrowings.

Table 14. Mean grain yield of broadcast-seeded IR34 and IR36 rice as affected by water depth (2.5 and 7.5 cm) and weed control (av. of all tillage treatments). IRRI, 1976 dry season.

Variety	Grain yield (t/ha)				
	Weed control		No weed control		Mean
	2.5 cm	7.5 cm	2.5 cm	7.5 cm	
IR34	3.48	3.02	2.78	2.65	3.98
IR36	4.96	4.96	3.31	3.97	5.74
Difference	1.48	1.95	0.53	1.32	1.76*

Harrowing decreased neither weed weight nor number.

The combinations of variety and water depth did not significantly differ in reducing the total dry matter production of the grassy weeds and number of weeds per square meter. The result indicated that grassy weeds were highly competitive with rice. The dry weight of the broadleaved weeds in the IR34 plots was significantly higher at the 7.5-cm water depth than at the 2.5-cm depth; no difference was observed in IR36 plots at such water depths. The result is explained by the difference in number of tillers between the two varieties at the 7.5-cm water depth—545 for IR36, and 324 for IR34.

In this experiment, the main significant differences were obtained in the weed-control treatments (Table 16). Terbuchlor at 0.3 kg a.i./ha, applied at the one- to two-leaf stage of grassy weeds, significantly reduced weeds.

Contrary to expectation, the 7.5-cm water depth did not significantly reduce the grassy weeds as did the 2.5-cm depth. One plowing and two harrowings gave better control of *Echinochloa* sp. even though those operations were not reflected in significantly higher yields. Further harrowing of the land is not necessary for higher grain yield.

Table 15. Grain yield of broadcast-seeded flooded rice as affected by weed control treatments. IRRI, 1976 dry season.

Treatment	Mean grain yield (t/ha)
Terbuchlor, 0.3 kg a.i./ha	4.10
No weed control	3.18
Difference	0.92**

Table 16. Effect of weed control treatments on number of weeds in broadcast-seeded flooded rice. IRRI, 1976 dry season.

Treatment	*Echinochloa* sp.	*Monochoria vaginalis*	Total
Terbuchlor, 0.3 kg a.i./ha	64	132	244
No weed control	116	298	462
Difference	52**	166**	218**

The highly significant results from the weed-control treatments indicate that even with good management practices, herbicides are often necessary for high yields in direct-seeded, flooded rice.

STUDIES ON *SCIRPUS MARITIMUS* L.
Agronomy Department

Field experiments begun in 1974 (1974 Annual Report) were continued through 1976 at IRRI in an area of naturally heavy *S. maritimus* infestation.

In a dry-season experiment with continuous lowland rice, the highest grain yield of 4 t/ha came from rotary-weeded plots. Bentazon-treated plots yielded only 0.4 t/ha because of the high population of grasses, annual sedges, and some *S. maritimus*. Bentazon apparently did not control annual grasses and sedges. Unweeded plots yielded only 0.2 t/ha because of a high population of *S. maritimus* and a buildup of broad-leaved weeds (Table 17).

In corn as a sole crop, the highest yield was from the plots that were hand weeded twice. That yield was not significantly higher than that from the plots treated with butachlor followed by bentazon. Butachlor did not efficiently control annual grasses. Yields from corn intercropped with mung beans did not significantly differ among the three treatments.

In a wet-season experiment, where rice was continuously grown, the highest yield was 3.3 t/ha from rotary-weeded plots. This yield was significantly higher than the 1.8 t/ha from the bentazon-treated plots (Table 18). Bentazon failed to control grasses, annual sedges, and some *S. maritimus*. Unweeded plots yielded nothing because of the high population of *S. maritimus*, annual sedges, and broad-leaved weeds.

In the lowland plots that had been previously planted to a corn-mung bean intercrop, rotary weeding significantly increased yields. The unweeded plots yielded 1.3 t/ha higher than did the unweeded treatment in the continuous lowland rice plots because weed density in the previous corn-mung bean rotation (191 plants/sq m) was lower than that (300 plants/sq m) in the continuous lowland rice plots.

In the dry-seeded, rainfed, bunded rice, the grain yields of hand-weeded plots were significantly higher than those of the oxadiazon-treated and the unweeded plots, which yielded zero.

Table 17. Effects of weeding methods on rice yield and population density of *Scirpus maritimus* L. and other weeds on three irrigation patterns. IRRI, 1976 dry season.

Cropping pattern, treatment	Weeds[a] (no./sq m)					Yield[b] (1 ha)	
	G	B	AS	*S. maritimus*	*C. rotundus*		
Continuous lowland rice						(*tons*)	
Bentazon	190	30	320	35	0	0.4	
Rotary weeding twice	10	0	25	30	0	4.0	
No weeding	85	850	55	205	0	0.2	
Corn						(*marketable ears*)	
Butachlor fb bentazon[c]	860	0	0	5	205	10,500	
Hand weeding twice	0	0	0	0	0	37,000	
No weeding	2790	0	35	15	75	0	
Corn + mung beans						*Corn* (*ears*)	*Mung beans* (*kg*)
Butachlor fb bentazon	1205	10	0	0	15	0	84 a
Hand weeding twice	0	0	0	0	0	17,000	260 a
No weeding	1410	10	0	60	30	0	151 a

[a]G = grasses, B = broad-leaved weeds, AS = annual sedges. [b]Av. of two replications. Means followed by the same letter are not significantly different at the 5% level. [c]fb = followed by.

Table 18. Effects of weeding methods and population density of *Scirpus maritimus* L. on the yield of lowland and dry-sown rainfed bunded rice. IRRI, 1976 wet season.

Cropping pattern, treatment	Weeds[a] (no./sq m)					Yield[b] (t/ha)
	G	B	AS	*Scirpus maritimus*	*Cyperus rotundus*	
Continuous lowland rice						
Bentazon	288	41	470	171	0	1.8 b
Rotary weeding twice	32	35	205	108	0	3.3 a
No weeding	161	362	645	300	0	0.0 c
Lowland rice[c]						
Bentazon	268	62	210	52	0	2.4 b
Rotary weeding twice	124	102	199	54	6	4.5 a
No weeding	88	192	359	191	0	1.3 c
Dry-sown rainfed bunded rice[d]						
Oxadiazon	444	10	17	79	296	0.0 b
Hand weeding twice	194	16	36	22	17	2.9 a
No weeding	1341	39	42	78	115	0.0 b

[a]G = grasses; B = broad-leaved weeds; AS = annual sedges. [b]Av. of two replications. Within each cropping pattern, any two means followed by the same letter are not significantly different at the 5% level. [c]Previously planted to corn + mung beans. [d]Previously planted to corn.

The data indicate that shifting from lowland to dryland preparation changes the density and composition of weeds. In the absence of adequate weed control, the risk of crop failure can be minimized by year-round cropping systems involving more than one kind of crop.

ZERO AND MINIMUM TILLAGE

Agronomy Department

Field experiments were conducted at IRRI to develop minimum- and zero-tillage techniques for transplanted and direct-seeded flooded rice.

Transplanted rice. Among the tillage methods used during the dry season, zero tillage had the highest percentage of missing hills (2.2%) in transplanted IR26. There were no differences in the number nor in the percentage of missing hills between the conventional and minimum-tillage treatments. The plots were flooded 3 days before transplanting (DBT) but the hard soil made the transplanting particularly difficult in the zero-tillage plots. The results indicate that flooding the paddy 3 DBT does not soften the soil enough for transplanting on zero-tillage plots.

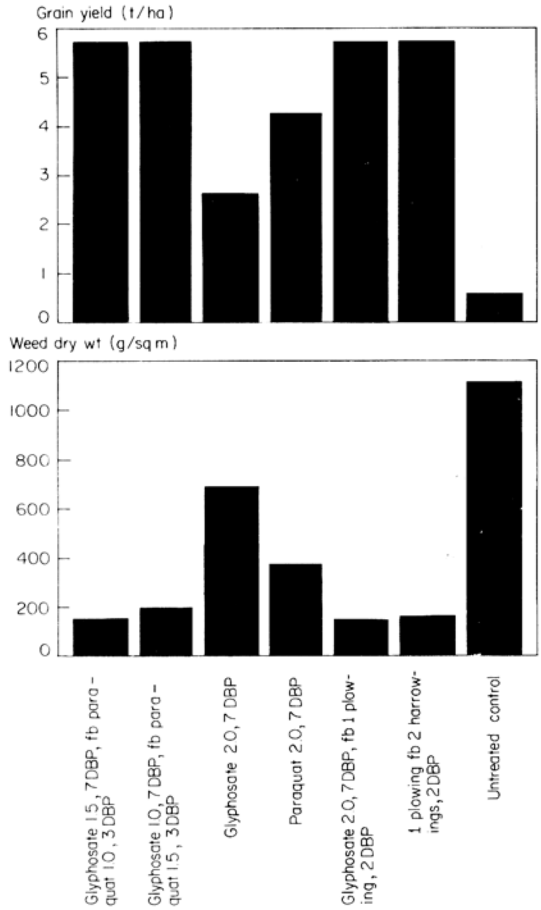
Glyphosate alone at 2.0 kg a.i./ha applied 7 DBT eliminated *P. distichum* but did not control the annual sedge *F. littoralis*. Paraquat alone at 2.0 kg a.i./ha applied 7 DBT effectively controlled annual grasses, sedges, broad-leaved weeds, and *P. distichum*, but these weeds grew faster than those in the glyphosate treatments. A mixture of glyphosate and paraquat applied 7 DBT failed to control *P. distichum*.

Glyphosate followed by paraquat showed a much broader spectrum of weed control and lower dry weight of weeds than a single mixed application. Treatments with high rates of glyphosate followed by a lower rate of paraquat effectively controlled *P. distichum*, but were inferior in controlling *F. littoralis*. *P. distichum* was controlled in plots sprayed with 2.0 kg a.i./ha glyphosate 7 DBT followed by one plowing 2 DBT.

The combination glyphosate (1.5 kg a.i./ha) 7 DBT and paraquat (1.0 kg a.i./ha) 3 DBT, or glyphosate (1.0 kg a.i./ha) 7 DBT and paraquat (1.5 kg a.i./ha) 3 DBT may serve as an alternative to conventional land preparation (Fig. 3).

In a second experiment, three components of reduced tillage were tested: preplant herbicide application (H), tillage operations (T), and flooding period (F). Each component requires different resources—the preplant herbicides require mainly capital, the flooding period requires irrigation water, and the tillage operations require mainly power and labor. To identify combinations for satisfactory weed control, crop growth, and yield, all permutations of the three components were compared with conventional tillage in a transplanted rice crop.

The treatments with preplant herbicides alone



3. Effect of chemicals and chemical combinations as alternatives to conventional land preparation on grain yield of transplanted IR26 rice and dry weight of weeds (at heading stage). DBP = days before planting; fb = followed by. IRRI, 1976 dry season.

(3.0 kg a.i. dalapon/ha followed by 0.6 kg a.i. paraquat/ha) failed to satisfactorily control *P. distichum*, *F. littoralis*, and *S. maritimus*. But when the preplant herbicide treatment was followed by a tillage operation, control of those weeds improved and rice yields were the same as those in conventional tillage plots. Five treatments (HT, HTF, HFT, FHT, and TF) gave weed control and yield results similar to those of conventional tillage. Because the TF treatment did not have a preplant herbicide, the results suggest that the preplant herbicide gave no advantage in the other treatments.

A third experiment indicated how weed populations develop with minimum and zero tillage in a continuously cropped rice system. With zero tillage the dry weight of weeds at harvest of the first crop was highest with the low-tillering, short-statured IR30, followed by that with the high-tillering semidwarf IR1632-93-2-2. The intermediate-statured IR34 was moderately competitive with weeds. After two crops with zero tillage, the perennial weeds *P. distichum* and *S. maritimus* became dominant because of ineffective control by the preplant herbicides.

The results confirmed earlier observations that continuous zero tillage may increase the incidence of perennial weeds.

After two crops with minimum tillage, the dry weights of weeds were similar to those with conventional tillage. There was also a shift to *S. maritimus* but weed growth was generally low. With the minimum tillage treatments it was possible to eliminate the preplant herbicide applications after the first crop and to resume the period of flooding before establishing the second crop. Therefore, the treatment was reduced to a single-tillage operation.

Control of *P. distichum* by minimum and zero tillage confirms findings at IRRI and elsewhere that thorough tillage is the most effective and practical means of controlling that perennial grass.

Even when using zero tillage and herbicides to control weeds and establish a good stand of rice appears to be advantageous, the practice may significantly reduce fertilizer efficiency in rice. An experiment studied the use of nitrogen with conventional, minimum, and zero tillage. Nitrogen efficiency was lower under zero tillage than under conventional tillage (Table 19). Deep placement of nitrogen, as either supergranules or liquid, raised nitrogen efficiency with zero tillage. Until deep placement of fertilizer becomes widely accepted, the question of nitrogen efficiency may limit acceptance of zero tillage.

Dry-seeded rice. A wet-season experiment was conducted under rainfed conditions to compare the effectiveness of dalapon and glyphosate against difficult weeds, under both zero and minimum tillage systems with a dry-seeded rice crop. The herbicide rates were 1, 2, and 3 kg a.i./ha for glyphosate, and 5, 10, and 15 kg a.i./ha for dalapon, with and without a follow-up

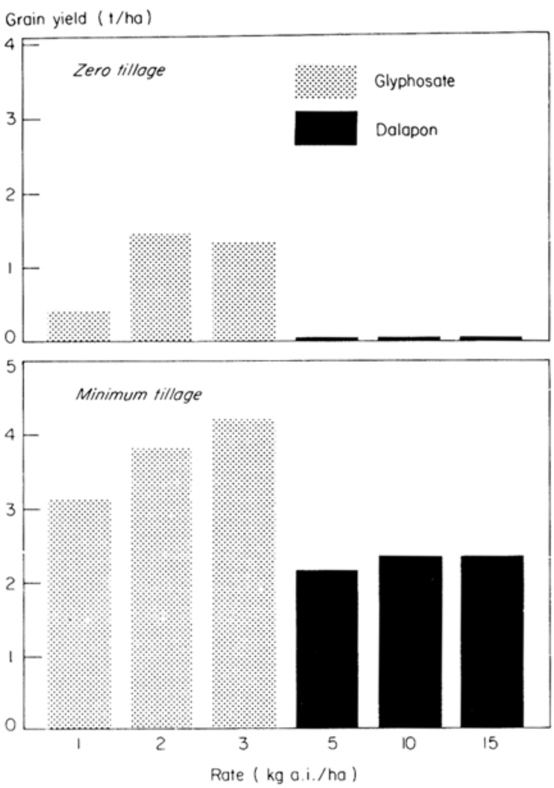
Table 19. **Apparent efficiency of nitrogen fertilizer with 56 kg N/ha, as influenced by method of land preparation and fertilizer application. IRRI, 1976 wet season.**

Method of application	Nitrogen fertilizer efficiency (kg rice/kg N)[a]			
	Conventional tillage	Minimum tillage	Zero tillage	Mean[b]
Split application	17	9	–6	7 a
Supergranule placement	58	55	31	47 b
Liquid band placement	44	47	18	34 b
Mean	40 b	37 ab	13 a	

[a]Based on comparison between mean yield of each treatment with 56 kg N/ha and mean yield of conventional tillage x split application treatment with 28 kg N/ha. [b]Two means followed by the same letter are not significantly different at the 5% level.

application of 0.4 kg a.i. paraquat/ha.

When *P. distichum* was the dominant weed species, weed control in the rainfed crop was inadequate even at the highest herbicide rates. Control of *P. distichum* and other weeds was achieved under minimum tillage with glyphosate at 2 kg a.i./ha, without a follow-up paraquat application. Similarly, yields following the application of 2 and 3 kg a.i. glyphosate/ha under minimum tillage were significantly higher than yields in any other treatments (Fig. 4).



4. Effects of preplant herbicides, glyphosate and dalapon, on grain yield of IR36 under minimum and zero tillage with a dry-seeded, rainfed rice crop. IRRI, 1976 wet season.

The results from the dry- and wet-season experiments indicate that minimum tillage is a dependable alternative to conventional tillage that requires few modifications in present management practices, at least where difficult-to-control weeds are absent or have been previously controlled. Zero tillage needs to be treated with more caution.

WEED SAMPLING IN RICE STUDIES
Statistics Department

Experiments were conducted at IRRI from 1973 to 1974 to develop a weed sampling technique that provides a reasonably accurate estimate of the weed population in rice with minimum sampling frequency and sample size.

Two sampling devices, a quadrat and a wire frame (1972 Annual Report), were tested. The wire frame was placed in the plots 2 weeks after transplanting and left there for successive samplings. The quadrat was placed in the plot at each time of sampling.

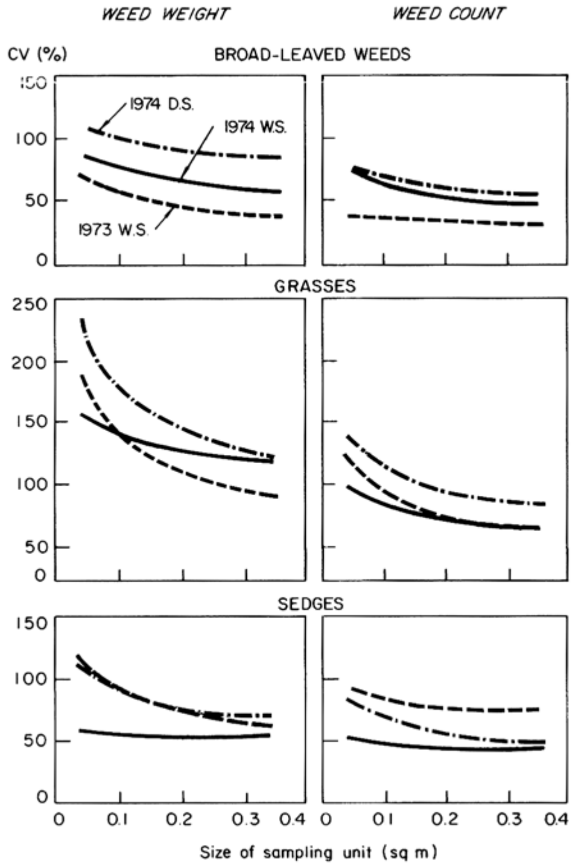
Both devices slightly overestimated the weed weights, but they did not differ from each other in magnitude of sampling variance (Table 20). The less costly quadrat is therefore recommended.

As expected, the sampling variance, expressed as the coefficient of variation (cv), decreased as the size of the sampling unit increased (Fig. 5).

Table 20. Comparison between estimates of weed weight and sampling variance with two sampling tools[a] (wire frame and quadrat) by weed type. IRRI, 1973 wet season.

Weed type	Actual weed wt (g/sq m)	Wire frame: Estimated weed wt (g/sq m)	Wire frame: cv (%)	Quadrat: Estimated weed wt (g/sq m)	Quadrat: cv (%)
Broad-leaved weeds	40.0	43.2*	39	46.8**	44
Grasses	30.4	35.6*	89	29.3	89
Sedges	10.6	11.7*	74	11.3	62

[a]Both 0.36 sq m in size. Data are averages of 12 plots and 9 sampling stages.



5. Relationships between sampling variance and size of sampling unit (quadrat) in estimating weed weight and weed count. IRRI, 1973–74.

The decrease was exponential in nature, i.e. the decrease was rapid when the sampling unit was small and became gradual when the sampling unit was large. Of the three weed types, grasses showed the highest sampling variance, which also decreased the fastest as the sampling unit size increased. The 1973 wet-season data showed that the increase in sampling unit size from 0.04 sq m to 0.36 sq m reduced the cv of grass weights from 190 to 92%, broad-leaved weed weights from 70 to 39%, and sedge weights from 120 to 63%. For all weed types, and especially for grasses, sampling variance was smaller for weed count than for weed weight. A similar trend was observed in 1974.

Considering the relationship between sampling variance (averaged over three seasons) and sampling unit size, a sampling unit size of between 0.16 and 0.20 sq m seems appropriate. With a 0.16-sq m quadrat, a sample size of 3 units/plot gave plot values with standard errors (expressed as cv) of 41, 80, and 42% for weight of broad-leaved weeds, grasses, and sedges, respectively; and of 30, 49, and 36% for weed count.

RESIDUAL EFFECTS OF WEEDING

Statistics Department

Experiments from 1973 to 1974 attempted to determine whether weed control in the previous seasons affected weed population and grain yield in a subsequent crop. Results showed less broad-leaved weeds and more grasses in the previously weeded plots than in the previously unweeded ones (Table 21). The differences were significant only in plots planted the previous season to IR127-80-1, a low-tillering line. Weeding appeared to have no appreciable residual effects on the population of sedges. Plots that received proper weed control in the previous season gave higher grain yield than those that were not weeded.

Table 21. Residual effects of weed control practices in the immediately preceding rice crop reflected in grain yields (unfertilized), weed weights, and weed counts.[a] IRRI, 1974 dry season.

Practice in preceding rice crop	Weed wt (g/sq m)			Weed count (no./sq m)			Grain yield (t/ha)
	B	G	S	B	G	S	
			IR127-80-1				
No weeding	0.3	76.2	1.1	17	96	52	2.5
Weeding	3.4	58.8	1.4	129	50	42	4.1
Difference	3.1**	–17.4	0.3	112**	–46*	–10	1.6**
			IR1514A-E597				
No weeding	1.1	30.8	2.5	39	33	87	3.2
Weeding	1.5	18.2	2.0	72	14	68	3.7
Difference	0.4	–12.6	–0.5	33	–19	–19	0.5*

[a]B = broad-leaved weeds, G = grasses, S = sedges.

Irrigation and water management

Irrigation and Water Management and Agricultural Economics Departments

SUMMARY

Case studies on the rehabilitation of two small-scale village irrigation systems in Indonesia and one in the Philippines showed that farmers contributed substantially to the projects. For both Indonesian cases, local contributions were more than three times the value of government support. The benefit: cost ratios for all three projects averaged 3.0 with locally contributed labor valued at the agricultural wage rate, or 12.7 with labor assumed available for free. The return to village labor for all three projects averaged about US$1.50/man-day, which was about twice the nominal value of agricultural labor in the village studied. The benefits in the Philippine case were shared nearly equally among landowners, farm operators, and hired labor, but unlike the other two groups, landowners received their benefits at essentially no cost to themselves.

A production function analysis to estimate the yield benefit attributable to irrigation at optimum rates of nitrogen resulted in a series of six nitrogen response equations reflecting different conditions of irrigation, seasons, and variety groups (traditional and modern). Modern varieties grown in farmers' fields with irrigation in the wet season produced about 2.8 t/ha, more than 1 t/ha higher than comparable rainfed yields. Indicated dry-season yields were almost 3 t/ha, but because the limited water available permitted dry-season planting on only one-third of the command area, the total yield benefit for both seasons was about 2 t/ha per year. For traditional varieties, the total yield benefit was about 1.5 t/ha per year. These results were compared with those from a water balance model, which considered expected variability in rainfall, irrigation flows, rates of water seepage and percolation, and the resulting adequacy of irrigation throughout the season. It was found that average irrigation of modern varieties in the wet and dry seasons combined would result in yields about 1.8 t/ha more than those expected with no irrigation, assuming optimum use of nitrogen. An additional 0.75 t/ha could, however, be achieved if the level of irrigation performance were improved from average to fully adequate. The yield benefit of irrigation in the wet season resulted in only half of that indicated by the production function analysis because rainfed land has seepage and percolation rates significantly greater than those of the lower-lying land already receiving irrigation.

Farms that grew two crops of rice in the 1976 wet season without irrigation in Bulacan, Philippines, had lower yields than comparable one-crop farms, but the combined production from both their crops was greater than that from one-crop farms. Where the farms were located on the high terraces of a watershed, the combined production from two crops was about 1 t/ha (33%) greater than that from one crop, but the net farm income was the same. For farms on low terraces that received substantial water from the higher parts of the watershed, production from two crops was 2.6 t/ha (77%) greater than that from one crop, and net income was US$179/ha (60%) greater. A long-term analysis based on 7 years of rainfall data predicted similar mean results, but showed that the second crop is likely to fail completely in about 1 year in 3 because of insufficient rainfall late in the season.

Studies of management practices to improve the productivity of subsoils exposed during land leveling showed that nitrogen and a combination of six microelements are important in achieving high yields. Mulching with weeds pulled from small plots significantly increased the proportion of productive tillers and straw and grain yield relative to unmulched control plots on the exposed subsoils. Yields were higher and water retention was greater when organic matter was applied to exposed subsoils than when soils received no additives, but differences among the sources of organic matter and an inorganic fertilizer treatment were not significant.

CASE STUDIES OF VILLAGE IRRIGATION IMPROVEMENT

Agricultural Economics Department

Large-scale, government-organized irrigation systems have increased rapidly in Asia in recent years. They have tended to obscure the importance of village or communal irrigation, which still accounts for about half of the total irrigated area of countries such as the Philippines. Little is known about village systems except that farmers usually participate more directly in their operation than they do in large-scale national systems. Village systems are comparatively inexpensive to build and usually command 50 to 200 ha, whereas national systems may command many thousand hectares.

One of the most important aspects of village irrigation is the extent to which it involves village labor in operations and maintenance (O&M) and even in the construction of the system. Three case studies were therefore made of the economic and social conditions under which local resources, primarily labor, were effectively used for village irrigation development during 1971–74. The cases were analyzed in terms of the amounts of locally mobilized resources relative to government assistance, and the rates of return on total investment.

The projects studied were the Saebah Irrigation System in West Java and the Takkapala Irrigation System in South Sulawesi, Indonesia, and the Cavite Communal Irrigation System in Zambales province, Philippines. The Saebah System is in an area of high population density where off-farm jobs are relatively plentiful; the Takkapala System is located on an island with low population density, and the Cavite System is on the edge of Central Luzon, northwest of Manila, with a population density similar to that in the Takkapala System.

The three cases were not intended to be representative of the bulk of village systems. They were relatively successful cases selected to provide insights into labor mobilization and economic returns under favorable conditions. Each involved the rehabilitation of portions of an older system, rather than the construction of an altogether new one.

The rehabilitation of the Saebah System involved renovating the rock and gravel diversion structure into a higher concrete dam in 1971, and lining critical canal stretches with concrete in 1972. The work was done during the annual slack period of agricultural production when the maximum number of villagers could participate. Thirty people contributed 45 work days each the first year, and 30 days each

Table 1. Costs[a] of rehabilitating three village irrigation systems in Indonesia and the Philippines, 1971–74.

	Saebah		Takkapala		Cavite	
	US$	%	US$	%	US$	%
Outside assistance						
Administration	82	4	12	1	98	3
Materials	369	18	89	7	483	17
Hired labor	31	1	140	10	907	32
Miscellaneous	0	0	0	0	437	15
Total	482	23	241	18	1925	67
Locally mobilized resources						
Materials	0	0	91	7	354	12
Village labor[b]	1357	65	976	75	600	21
Hired labor	255	12	0	0	0	0
Total	1612	77	1067	82	954	33
Grand total	2094	100	1308	100	2879	100
Investment inducement coefficient[c]	4.3		5.4		1.5	

[a] In US dollars. US$1 = Indonesian Rp 415 and Philippine P7.4.
[b] Valued at existing farm wage rates in the respective villages.
[c] Total costs ÷ cost of outside assistance.

the second year. Rehabilitation of the system expanded the irrigated rice area from 70 to 100 ha in the wet season, and from 50 to 90 ha in the dry season. Government assistance to the project totalled US$482 from a national program designed to stimulate community and economic development through the use of excess village labor.

Rehabilitation of the Takkapala System in 1971 involved renovating the diversion dam and rebuilding some canal structures. Forty people contributed 40 days of labor each. Wet-season irrigation increased from 60 to 80 ha, and dry-season irrigation from 0 to 70 ha. The Takkapala project received a US$241 government subsidy.

Rehabilitation of the Cavite System in 1974 involved the construction of a new concrete dam and improvements to the trunk canals and structures in the primary canal network. Eighty-eight of the 96 farmers within the system's command area contributed labor to the project. Their number was augmented by 12 outsiders who expected increased opportunities to rent farmland or to hire out their services as agricultural laborers. Each participant contributed an average of 10 days of work. The village work force was divided into seven teams, with each team working a different day of the week. Project support of about US$1,925 came from civic, government, and church-related sources. The rehabilitation increased the dry-season irrigated area from 36 to 74 ha. The area irrigated in the wet season was not significantly changed and was not included in the analysis.

Local resource mobilization. The first criterion for assessing the projects is the extent of locally mobilized resources. Government assistance for the two Indonesian systems amounted to about 20% of total project costs, with local labor (valued at the prevailing farm wage rate of US$0.54 to 0.60/day) the largest item of local support (Table 1). Local support for the Cavite System was about the same as that for the Indonesian systems; however, outside support was much greater (about two-thirds of the total project cost) because the project involved the construction of a new dam, which required more materials and the hiring of supervisory labor.

From the governments' points of view, all three projects were attractive investments. If rural labor is plentiful and not fully employed, its contribution is a net addition to the development effort that permits government assistance to be spread much further. The inducement coefficient (total cost divided by the outside support) of the projects, a measure of local relative to outside support, ranged from 1.5 to 5.4 for the three cases, indicating strong inducement to government investment, especially for the two Indonesian cases (Table 1).

Profitability of the project. The economic profitability of the rehabilitation projects was analyzed by estimated benefit: cost (B:C) ratios and internal rates of return. Benefits from the projects consist of both yield increases per hectare and expansion in irrigated area. In this analysis, however, only benefits stemming from increased area were included, to provide conservative estimates. The annual flows of benefits were computed by multiplying the increased irrigated area by the value of the rice yield and subtracting current production expenses for the newly irrigated area. The value of secondary crops grown before rehabilitation was deducted from the benefits, and possible increases from cropping intensity were excluded. Other assumptions in the calculations were a gestation period of 1 year, periods of usable life of 9 years for the two Indonesian systems and 10 years for the Cavite system, a 12% external rate of interest, and annual O&M requirements of 120, 320, and 466 man-days for the Saebah, Takkapala, and Cavite systems, respectively. Two analyses were conducted, one assuming zero opportunity cost for locally mobilized labor (Case A), and the other assuming the prevailing agricultural wage rate for that labor (Case B).

The benefits associated with rehabilitation far outweighed the costs for all three projects, resulting in B:C ratios higher than 2.5 even when the cost of village labor was conservatively set equal to the agricultural wage rate. Inasmuch as the real opportunity cost of village labor in the dry season is probably lower than that rate, but not nil, the real profitability of the rehabilitation projects is somewhere between the estimates for Case A and Case B (Table 2). From the standpoint of government investment criteria, assistance to communal work projects

Table 2. Benefits and costs[a] associated with the rehabilitation of three village irrigation systems based on two alternative wage rates.[b] Indonesia and Philippines, 1971–74.

Benefit or cost	Saebah System		Takkapala System		Cavite System	
	Case A	Case B	Case A	Case B	Case A	Case B
Capitalized construction costs[c] (US$) (A)	648[d]	2005[d]	332	1308	2279	2879
Capitalized value[c] (US$) of O&M[e] cost (B)	0	320	0	923	0	1567
Capitalized value[c] (US$) of benefit (C)	5841	5841	7704	7704	13289	13289
Benefit : cost ratio = $\frac{C}{A + B}$	9.0	2.5	23.2	3.5	5.8	3.0
Internal rate of return (%)	209	58	589	89	102	72

[a]In US dollars US$1 = Indonesian Rp 415, Philippine P7.4. [b]Case A assumes zero opportunity cost of village labor; Case B assumes that village labor earns the farm wage rate. [c]Using 12% discount rate and 9-year lifetimes for Saebah and Takkapala Systems, 10 years for Cavite System. [d]Differs from entry in Table 1 because of the effect of capitalization over the 2-year construction period. Other projects were completed in 1 year. [e]O&M = operations and maintenance.

Table 3. Estimated returns in US$[a] to village labor mobilized for rehabilitating three village irrigation systems, Indonesia and Philippines, 1971–74.

	Saebah System	Takkapala System	Cavite System
		US$	
Capitalized[b] value of benefits (A)	5841	7704	13289
Capitalized[b] costs excluding value of village labor (B)	648	332	2279
Capitalized[b] value of O&M costs (C)	320	923	1567
Total return to village labor:			
For construction only (A)–(B)	5193	7372	11010
For construction and O&M (A)–(B)–(C)	4873	6449	9443
		Man-days	
Total village labor contributed (D)	3210	4680	5673
For construction only (E)	2250	1800	1010
For operations & maintenance	960	2880	4663
Returns to village labor		US$/man-day	
For construction only $\frac{(A)-(B)}{(E)}$	2.3	4.1	10.9
For construction and O&M $\frac{(A)-(B)-(C)}{(D)}$	1.5	1.4	1.7

[a]Using Indonesian Rp 415 and Philippine P7.4 per US$1. [b]Using 12% discount rate and 9-year lifetimes for Saebah and Takkapala Systems; 10 years for Cavite System.

like these represent extremely lucrative investment opportunities, especially where rural labor is not fully employed.

From the standpoint of the villagers who contributed labor, the relevant criterion is their labor's benefit to the community. The average returns per man-day of labor was therefore estimated by subtracting all costs other than village labor from total benefits, and dividing the remainder by the total man-days of that labor. Village labor for the two Indonesian systems was thus worth between US$1.50 and 4.00/man-day depending on whether or not O&M costs were included in the calculations (Table 3). These values are 2.6 to 7 times the agricultural wage rate, and indicate that locally contributed labor was highly rewarding for the communities. Similar benefits were recorded for the Cavite system.

Distribution of benefits. The high productivity of local labor in the projects implies a strong incentive for the communities to carry out such projects. However, the high return to the community as a whole does not guarantee that the returns to individuals and classes within the village are sufficient to ensure their participation in future work. Shares of gross value added per farm were therefore estimated before and after the rehabilitation of the Cavite System to show the changes in income associated with its rehabilitation.

The distribution of these benefits among different groups was calculated by determining net agricultural income per farm and apportioning that income among landowners, farm operators, and hired laborers according to the transfer payments found for a subsample of 30 respondents from the Cavite study interviewed for this purpose.

Analysis of the Cavite System revealed that landowners as a group increased their shares by 133%, farm operators by 142%, and hired laborers by 180% (Table 4). The benefits from the rehabilitation are widely distributed, with all three groups receiving substantial increases in income. Unlike the other two groups, however, landowners received their benefits without having contributed significantly to the project. It is quite likely that Philippine landowners, confronted recently by a land reform program, have little incentive to invest in further land improvement. But if this is the case, they should be obliged to forego their gains in favor of those who did contribute their resources to the project.

COMPLEMENTARY EFFECTS OF IRRIGATION AND NITROGEN ON RICE YIELDS

Irrigation and Water Management and Agricultural Economics Departments

The importance of assured water supply on yield response to nitrogen and on farmers' willingness to use high levels of nitrogen was reported in 1975 (1975 Annual Report). This analysis was extended to estimate yield response to nitrogen under conditions of variable water supply in the Philippines, and to estimate the production gains attributable to increased nitrogen use, and to the improvement and expansion of irrigation. Differences in yield response between the traditional and modern rice varieties were also examined.

The supply of irrigation water varies greatly among years, locations, and even successive days in the same area. Benefits associated with

Table 4. Output per farm[a], input costs, and gross value added for different rural groups before and after rehabilitation of the Cavite System, Philippines, 1972 and 1974.

Factor	1972 (US$[b])	1974 (US$[b])	Change from 1972 to 1974 (%)
Output[c] per farm	100	257	157
Payment for current inputs per farm	11	38	245
Gross value added per farm	89	219	146
Distribution of added gross value among:			
Landowners	43	100	133
Farm operators	26	63	142
Hired labor	20	56	180

[a]Mean of 30 sample farms. [b]US$1 = P7.4. [c]Valued at a constant price of US$0.122/kg rough rice.

irrigation are therefore small where irrigation contributes little assurance of water beyond that provided by rainfall. The benefits are much greater, however, in areas where irrigation supplies the full crop requirement throughout the season. Data were taken from a number of sources and corrections were made where necessary to estimate nitrogen response equations for rainfed and for this range of irrigated conditions, and for traditional and modern varieties.

Yield response equations. Preliminary comparisons of the production functions of modern varieties (MV) and traditional varieties (TV) showed considerable variability caused by sources of data, years the studies were made, and many other factors outside the scope of this analysis. Two assumptions were therefore adopted in estimating the response equations. The first is the conservative assumption that yields with no nitrogen are essentially the same under field conditions for MV and TV. Experimental data (1973 Annual Report) have indicated somewhat higher yields for MV at zero nitrogen, but this result is less likely under field conditions, which are often less favorable to MV.

The second assumption is that with typical irrigation, mean yields of either variety group are about the same in the wet and the dry season because the impact on yield of water shortage differs between the two seasons. With good water supply, dry-season yields tend to be higher than wet-season yields, but at current levels of irrigation performance, the potential yield advantage of the dry season is offset by the increased susceptibility of the crop to drought during that season (1973 Annual Report).

Modern varieties with irrigation: dry season. MV with irrigation in the dry season were studied in two similar sets of experiments in farmers' fields during the 1972–73 and 1973–74 crop years (1973, 1974 annual reports). Many variables, including nitrogen, phosphorus, days of drought stress, solar radiation, weed growth, soil texture, and grain yield, were monitored or controlled. Their combined effects and interactions explained more than 70% of yield variation in the two sets of data.

For this analysis the values for some variables, such as solar radiation, were substituted at their mean levels of occurrence in the dry season, and the equation is simplified to

$$Y = 2485 + 20.6\,N - 0.06\,N^2 - 91.6\,S - 0.39\,NS \qquad (1)$$

where S is days of drought stress (days in excess of the first 3 for which the paddy is without standing water) during the critical 30-day growth period beginning with panicle initiation (1972 Annual Report), N is nitrogen (kg/ha), and Y is grain yield (kg/ha).

To further simplify this equation to a representative nitrogen response function, the expected value of S under average irrigated conditions is needed. That value is difficult to estimate because of the wide range in irrigation performance, but previous studies showed an average of 6 to 7 stress days during the 30-day period to be representative of Philippine systems. Using this value of S in equation 1 gives

$$Y = 1900 + 18\,N - 0.06\,N^2 \qquad (2)$$

the formula used for the dry-season MV response.

Modern varieties with irrigation: wet season. MV with irrigation in the wet season were also studied in the research cited above, with the resulting equation

$$Y = 2197 + 16.2\,N - 0.06\,N^2 - 47.8\,S - 0.39\,NS. \qquad (3)$$

Few stress days, S, for irrigated crops in the wet season can be assumed, giving a simplified equation with intercept, first-order N and second-order N coefficients of about 2200, 16.2, and 0.06, respectively. The second-order N term is the same as that for the dry season (equation 2), which is not consistent with other findings. The reduced solar radiation in the wet season diminishes the responses of yield to N. The second-order N term was therefore increased to 0.10, and was compensated for by increasing the first-order N coefficient to 18 (the same as that for the dry season) to give

$$Y = 2200 + 18\,N - 0.10\,N^2. \quad (4)$$

This response is close to that computed by the Philippine Bureau of Agricultural Economics from interviews of 320 farmers throughout the country in 1973–74. A comparison of the dry-season (equation 2) and the wet-season (equation 4) responses of MV showed a lower intercept but a higher nitrogen response for the dry season. Together the two produce about equal yields for the two seasons at optimum N (Table 5).

Modern varieties: rainfed. Rainfed MV in the wet season can be represented by adapting equation 4 to the less favorable rainfed environment. In the Central Luzon experiments, rainfed MV grown in farmers' fields had 36% lower intercept (zero N) yields and, because of less favorable moisture status, 17% lower nitrogen response than irrigated MV. Applying these adjustments to equation 4 gives

$$Y = 1400 + 15\,N - 0.11\,N^2. \quad (5)$$

Table 5. Equations for yield response to nitrogen for rice under different combinations of varieties, seasons, and irrigation, with corresponding optimum nitrogen-use rates[a] and yields of rough rice. Philippines, 1969–75.

Condition	Equation[b]	Optimum nitrogen (kg/ha)	Grain yield (t/ha)
	Modern varieties		
Irrigated dry season	$Y = 1900 + 18\,N - 0.06\,N^2$	75	2.91
Irrigated wet season	$Y = 2200 + 18\,N - 0.10\,N^2$	45	2.81
Rainfed wet season	$Y = 1400 + 15\,N - 0.11\,N^2$	27	1.73
	Traditional varieties		
Irrigated dry season	$Y = 1900 + 11\,N - 0.13\,N^2$	8	1.98
Irrigated wet season	$Y = 2200 + 11\,N - 0.13\,N^2$	8	2.28
Rainfed wet season	$Y = 1400 + 9\,N - 0.16\,N^2$	0	1.40

[a]Assuming nitrogen: rice shadow price ratio of 9:1. [b]Where Y is in kilograms of rough rice per hectare, and N is in kilograms nitrogen per hectare.

Traditional varieties with irrigation: wet season. TV irrigated in the wet season have not been carefully studied. Their nitrogen response is highly variable because of genetic heterogeneity among varieties, their susceptibility to lodging, and the wide range of climatic conditions during the wet season. Analysis of 195 experiments from the 1966–72 wet seasons at IRRI (1973 Annual Report) resulted in one equation for MV and one for TV.

Discounting the intercept and slope coefficients of the MV equation by 45% gave the response function reflecting farm-level conditions for MV (equation 4). To derive a farm-level TV function, the slope coefficients of the experimental TV response were also discounted by 45%, but the intercept was set equal to the MV intercept, as explained earlier. This procedure gave

$$Y = 2200 + 11\,N - 0.13\,N^2. \quad (6)$$

As expected, the nitrogen response was lower than that for MV (equation 4).

Traditional varieties with irrigation: dry season. TV irrigated in the dry season are now rare in most of the Philippines, so the wet-season TV response (equation 6) was arbitrarily modified to reflect dry-season conditions. As in the case of MV, the intercept of the wet-season equation was reduced by 300 kg/ha to give equal intercepts for the two variety groups in the same season. The N terms for the dry season were assumed to be the same as those for the wet-season TV response (equation 6) because the corresponding terms for MV were the same for both seasons. The resulting function is

$$Y = 1900 + 11\,N - 0.13\,N^2. \quad (7)$$

Traditional varieties: rainfed. Rainfed TV can be treated the same way as rainfed MV (equation 5), whose intercept and nitrogen response terms were 36 and 17% lower, respectively, than those of irrigated wet-season MV. Applying the same downward adjustments to TV (equation 6) gives

$$Y = 1400 + 9N - 0.16N^2. \quad (8)$$

These functions are compared in Table 5.

Production attributable to irrigation and nitrogen. Yield differences among the six response conditions summarized in Table 5 stem from differences in the shape of the functions and in the optimum level of *N* selected for each function. The theoretical optimum level of *N* is that amount of nitrogen at which its marginal cost is equal to the value of the additional rice produced by the nitrogen. It can be calculated once the price ratio of nitrogen to rice—currently about 4.5:1—is specified. But that ratio does not account for interest costs, costs of transporting and applying the nitrogen, the possibility of its not being available when needed, and the uncertainty of response due to factors beyond the farmers' control. Thus, more realistic estimates of optimum *N* can be found at levels lower than the theoretical optima. Therefore an optimum rate of nitrogen use defined by the point at which the marginal value of rice is two times the marginal cost of nitrogen (computed as the theoretical optimum with a price ratio of nitrogen to rice of 9:1) was calculated for each function. Optimum rates of *N* and corresponding yields were calculated for each function (Table 5).

In estimating the benefits of irrigation at optimum *N*, the difference in yields between irrigated and rainfed crops in the wet season was added to the full yield in the dry season. Yield increments attributable to irrigation and optimum *N* were thus 0.88 and 1.98 t/ha for TV in the wet and dry seasons, respectively, and 1.08 and 2.91 t/ha for MV (Table 6). To compute the yearly gain in production, it was assumed that those benefits can be achieved over the whole irrigated area in the wet season, but on only one-third of that area during the dry season due to limited water availability then.

The total yearly production increase attributable to irrigation and optimum *N* is thus 1.54 t/ha of irrigated land for TV, and 2.05 t/ha for MV (Table 6). The shift from the TV to MV group, when accompanied by optimum *N*, increases productivity by about 0.5 t/ha per year, or about 30%, which explains some of the renewed interest in irrigation development since MV have become widely planted.

Table 6. Yields attributable to irrigation and optimum nitrogen rates by variety group and season. Philippines, 1969–75.

Season, water status	Traditional varieties: Optimum nitrogen (kg/ha)	Traditional varieties: Grain yield (t/ha)	Modern varieties: Optimum nitrogen (kg/ha)	Modern varieties: Grain yield (t/ha)
Wet season				
Irrigated	8	2.28	45	2.81
Rainfed	0	1.40	27	1.73
Difference	8	0.88	18	1.08
Dry season				
Irrigated	8	1.98	75	2.91
Total per year[a]	11	1.54	43	2.05

[a] Assuming benefits to 100% of the irrigated area in the wet season and 33% in the dry season.

Although this analysis has emphasized production increments attributable to irrigation, the key role of nitrogen should be noted. If farmers who shift from TV to MV do not apply nitrogen at rates greater than the optimum for TV, their yield increase in either season would be less than 0.1 t/ha (5%).

Water-balance model and variable irrigation performance. The yield effects of irrigation discussed in the previous section are limited to comparisons of production with no irrigation and average irrigation. This section treats the adequacy of irrigation as an explicit variable, and estimates yields for conditions of poor irrigation, average irrigation, and good irrigation. In addition, analysis of ideal irrigation reflecting full water adequacy throughout crop growth is included. This procedure considers the full range of variable irrigation instead of representing all irrigation by a mean value, and can be used with rainfall and irrigation data from many years to derive long-term expected outcomes.

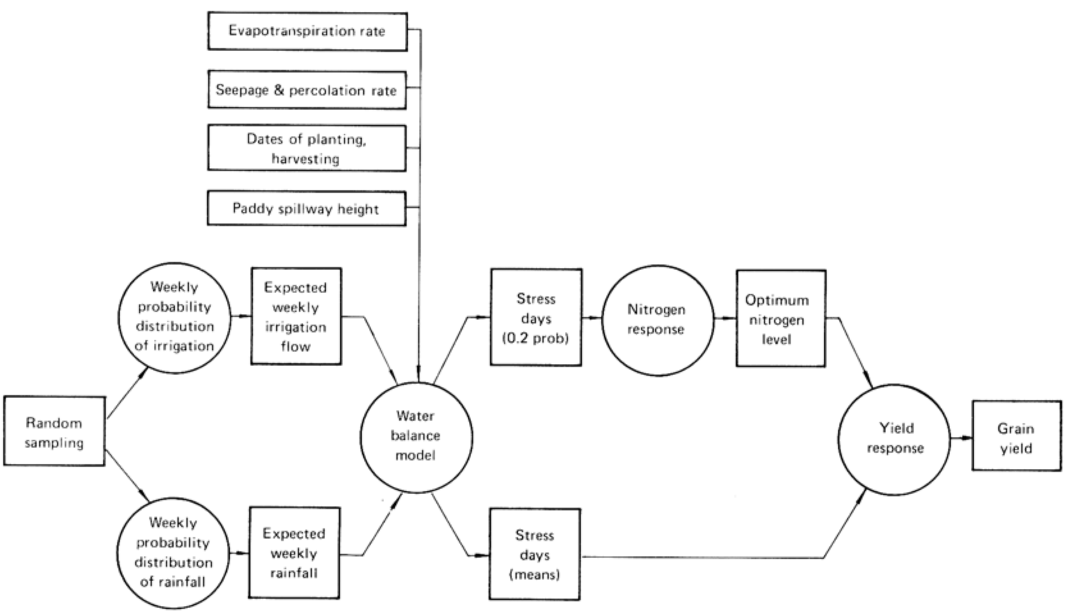
The model is adapted from earlier work (1972 Annual Report) in which the daily water status in the field was computed by the balance of the water sources (irrigation and rainfall) less water sinks (evapotranspiration, seepage and percolation, and surface drainage). During periods of low supply and high demand, a water deficit develops and stress days—days when the rice fields are continuously without standing water—accumulate.

The model in this analysis was modified to work on a weekly rather than a daily basis after preliminary testing. Thus, stress days were computed from weekly data on irrigation, rainfall, and soil and crop-water use. Then, the number of stress days was used together with the computed optimum rates of nitrogen to calculate expected yields (Fig. 1). Results representing a wide range of physical environments and many years can then be simulated by using different estimates of rainfall and irrigation.

Specification of the model's parameters. To quantify conditions of poor, average, and good irrigation, we obtained the mean weekly irrigation flow rates and their variance for 11 sites studied in 1969–70 and the four larger ones in the Peñaranda River Irrigation System, for which flows were measured in 1973. Wet- and dry-season flow rates were not significantly different because limited water availability usually offsets the greater water requirements of the dry season. The mean flow rate for all sites and weeks was 79 mm, with a standard deviation of 70 mm. Those parameters were used to describe average irrigation flows.

Good irrigation performance was determined by pooling observations from all sites that had mean weekly flows in excess of the 79-mm average. The new distribution had a weekly mean of 119 mm and a standard deviation of 85 mm. The distribution defining poor irrigation performance came from pooled observations from all sites with weekly flows less than 79 mm; it had a mean and a standard deviation of 53 and 42 mm/week, respectively. Random sampling from each distribution generated a series of variable flows corresponding to poor, average, or good irrigation service.

Other parameters were also specified to enable the water-balance model to generate stress days and yields (Fig. 1). A probability distribution of weekly rainfall was computed based on 26 years of data from the Cabanatuan City weather station in Central Luzon. Four planting dates in each season were selected to assess variation caused by planting early or late in the season. To simulate the weekly water status, weekly expected irrigation flows were randomly generated for each of the three levels of irrigation performance by sampling from the corresponding probability distribution. The first week of data generation began with one of the four specified planting dates. Simulated rainfall for the same week was generated by sampling from the rainfall distribution. The water-balance model was then operated for 16 consecutive weeks of simulated data by adding expected weekly irrigation and rainfall, and



1. Flow diagram of water-balance model used for simulating stress days and yields of irrigated lowland rice.

subtracting estimates of evapotranspiration, seepage and percolation, and surface drainage.

Evapotranspiration (ET) rates over large field areas are about equal to open-pan evaporation, which for Central Luzon averages about 28 and 40 mm/week for the wet and dry seasons, respectively. Because ET does not vary widely within seasons or among years, those constant estimates were used for each week of the season.

Seepage and percolation rates (S&P) are strongly affected by soils and topographic conditions. Thus, the model incorporated minimum, moderate, and high S&P estimates. Representative S&P data are not available, but previous studies (1972, 1975 annual reports) have shown from 0 to more than 20 mm/day of water loss into the soil. For this analysis 0 mm/week was used as the minimum S&P rate for both seasons, and 105 mm/week was used as the high rate, above which commercial rice production in the Philippines is marginal, even with irrigation. A moderate rate of 14 mm/week for the wet season and 32 mm/wk for the dry season was selected to represent conditions of substantial but not excessive losses. Most irrigated rice land in South and Southeast Asia has S&P rates between these minimum and moderate values.

Surface drainage flow rates are computed by the model as residuals for weeks when the computed depth of water on the field exceeds 40 mm, which is assumed to be the effective height of the paddy bunds.

One hundred simulated outcomes for the same set of input conditions proved sufficient for computing stable estimates of stress days. Mean stress days for each season were computed by averaging those for each of the four planting dates. Only the number of stress days computed for the 8th through the 12th week of the crop is used in the analysis, however, because that is the critical period of crop growth during which stress most markedly affects yield (1972 Annual Report). Moreover, including stress days from the earlier or later periods of crop growth in the model did not add significantly to its precision.

When the number of stress days is known, the optimum nitrogen level and grain yield are calculated (Fig. 1) with the use of the procedures and yield relationships for MV described in the first part of this section.

Dry-season simulations. Dry-season simulation gave mean stress days ranging from 2.6 for the most favored combinations of circumstances to 18.8 for the least favorable combinations of poor irrigation and high S&P (Table 7). The year-to-year variation in stress days computed by random sampling from the rainfall and irrigation distributions also permitted estimation of stress days for relatively wet or dry years. Thus, the tabulation includes the number of stress days for each set of conditions that could be expected in 20% of years having the least rainfall and irrigation. Stress days expected with 0.2 probability ranged from 3.5 for the most favorable water status to 21.4 for the least favorable, substantially greater than the values reflecting mean irrigation and rainfall (Table 7).

The equation relating stress days and N to yield in the dry season is

$$Y = 2485 + 20.6\,N - 0.06\,N^2 - 91.6\,S - 0.39\,NS \qquad (1)$$

where N refers to optimum N use. In the previous analysis optimum N was defined by equating its marginal cost with the marginal value of rice production, but the resulting N level was discounted for risk by assuming that the ratio of the price of nitrogen to that of rice was double its current value (4.5 to 1).

In this analysis, however, there is a direct measure of risk in stress days occurring with 0.2 probability. It is assumed that farmers would prefer to risk using too little nitrogen than too much, and that optimum nitrogen use should therefore be consistent with stress days expected in years of 0.2 probability water adequacy. That accounts for risk caused by variable water status, but there still exist risks of insect and disease attack, marketing problems, and other factors. Because of that, the shadow price ratio of nitrogen to rice was increased only to 6.5 to 1. Optimum nitrogen can then be computed for each combination of conditions (Table 7).

In estimating yield effects, the optimum rate of N use and mean stress days, S, were substituted in equation 1, and resulting yields ranged

Table 7. Mean stress days, at probability levels and corresponding optimum rates of N use and grain yield, simulated[a] for four levels of irrigation performance and three rates of seepage and percolation[b], with modern varieties and 24 years of rainfall data from Cabanatuan City, Philippines, 1976.

Irrigation performance[c]	Minimum seepage and percolation rate				Moderate seepage and percolation rate				High seepage and percolation rate			
	Stress days (no.)		Optimum N use (kg/ha)	Grain yield (t/ha)	Stress days (no.)		Optimum N use (kg/ha)	Grain yield (t/ha)	Stress days (no.)		Optimum N use (kg/ha)	Grain yield (t/ha)
	0.2 probability	Mean			0.2 probability	Mean			0.2 probability	Mean		
					Dry season							
Ideal[d]	0.0	0.0	118	4.08	0.0	0.0	118	4.08	0.0	0.0	118	4.08
Good	3.5	2.6	106	3.65	8.2	4.9	91	3.24	13.6	9.6	73	2.52
Average	8.7	5.2	89	3.19	14.7	9.7	70	2.48	19.4	15.1	54	1.72
Poor	15.8	9.0	66	2.53	21.1	15.0	49	1.69	21.4	18.8	48	1.26
					Wet season							
Ideal[d]	0.0	0.0	81	3.12	0.0	0.0	81	3.12	0.0	0.0	81	3.12
Irrigated	2.4	1.6	73	2.94	3.1	2.1	71	2.89	11.3	7.9	44	2.28
Rainfed	8.1	5.1	54	2.55	11.6	7.5	43	2.30	20.4	16.8	14	1.52

[a]Means of 100 trials each for 4 planting dates. Stress days include means and expected values for the second year out of 10 (0.2% probability level), and are computed only during the 8th through 12th week of crop growth. Optimum N is computed using 0.2% probability level stress days and shadow price ratio of 6.5:1 of nitrogen to rice with the equations $Y = 2485 + 20.6\,N - 0.06\,N^2 - 91.6\,S - 0.39\,NS$ (dry season) and $Y = 2197 + 16.2\,N - 0.06\,N^2 - 47.8\,S - 0.39\,NS$ (wet season). Yield calculations use mean stress days and optimum N. [b]Minimum, moderate, and high rates of S&P are, respectively, 0, 32, and 105 mm/week in the dry season and 0, 14, and 105 mm/week in the wet season. [c]Sampled from three distributions made up of above-average, average, and below-average (good, average, and poor) discharges measured from several canal systems, 1969–1974. [d]Ideal irrigation eliminates all stress days, regardless of the amount of water required. Corresponding yields are computed directly without simulation.

from 3.65 t/ha for good irrigation and minimum S&P, to 1.26 t/ha for poor irrigation and high S&P. Ideal irrigation, or that amount required to reduce stress days to 0, regardless of the S&P rate, gave yields of 4.08 t/ha (Table 7). For conditions of minimum S&P, the poorest and ideal irrigation performance gave yields of 2.53 and 4.08 t/ha, or a difference of about 0.5 t/ha for each irrigation performance level. Improvements in irrigation performance can result in greater yield increments for land with moderate and high S&P rates. If irrigation in the Philippines can be characterized by average irrigation performance and minimum to moderate S&P rates, the expected yield in the dry season would be about 2.84 t/ha, which is similar to that estimated directly from the production functions (Table 5).

Wet-season simulations. Wet-season simulations were carried out in the same way as those for the dry season except that the yield response used was

$$Y = 2197 + 16.2\,N - 0.06\,N^2 - 47.8\,S - 0.39\,NS. \quad (2)$$

The different levels of irrigation performance had little effect on stress days or yield; thus, only the outcomes for average irrigation performance and for rainfed conditions in combination with the three S&P rates were included. Rainfed simulations were computed with all irrigation inputs to the model deleted. As in the case of the dry season, yields derived from ideal irrigation are also tabulated to show the potential yields with existing farm-level technology where water is not limiting.

For maximum S&P rates, yields are about 2.55 t/ha under rainfed conditions, 2.94 t/ha with average irrigation, and 3.12 t/ha with ideal irrigation (Table 7). For moderate S&P rates, rainfed and irrigated yields are 2.30 and 2.89 t/ha, respectively, and for high S&P rates they are 1.52 and 2.28 t/ha, respectively. With a national estimate of S&P intermediate between the minimum and moderate rates, the yield benefit from irrigation and optimum N in the wet season averages about 0.5 t/ha, with another 0.2 t/ha attainable if irrigation eliminates all stress days.

The yield benefit attributable to wet-season irrigation by this model is only half that found through the production function approach (Table 6). The difference can be explained by the different soils and topography normally found in irrigated and rainfed land. Irrigated soils are low-lying and usually have S&P rates between the minimum and moderate levels assumed in the model. Rainfed land is higher and usually lighter in soil texture, with S&P rates between the moderate and high figures used in the analysis. This can be reflected in the results from the model, however. Irrigated yields with S&P between the minimum and moderate rates are 2.9 t/ha, compared with 1.9 t/ha for rainfed yields with moderate to high S&P (Table 8). The 1-t/ha difference is the same as that found in the production function analysis.

It is concluded that current wet-season production using optimum amounts of nitrogen produces about 1 t/ha more yield on irrigated than on rainfed land, but that the construction of new irrigation facilities on existing rainfed land will result in yield increments of only 0.5 to 0.6 t/ha in the wet season.

Implications for irrigation management. Calculations in the previous sections show an MV yield increase of 1.0 t/ha in the wet season attributable to irrigation at optimum nitrogen use, and a further yield increase of 0.2 t/ha if enough irrigation water were provided consistently throughout the season. Irrigation systems functioning in the dry season at average performance levels can support yields of 2.5 t/ha, which is about 1.6 t/ha less than yields associated with a fully adequate water supply (Table 8).

Providing the basic irrigation infrastructure is generally sufficient to achieve the first yield increment associated with basic irrigation service. This increment totals about 1.8 t/ha per year (Table 8), assuming that only one-third of the irrigated area is planted during the dry season, and has been achieved in many irrigation projects in Asia.

Table 8. Simulated mean yields and yield differences due to different levels of irrigation performance with optimum rates of nitrogen used on modern varieties. Philippines, 1976.

Irrigation performance	Yield (t/ha)		
	Dry season	Wet season	Combined seasons[a]
Rainfed[b]	0.00	1.91	1.91
Basic irrigation[c]	2.47	2.92	3.74
Yield increment I[d]	2.47	1.01	1.83
Ideal irrigation[e]	4.08	3.12	4.48
Yield increment II[f]	1.61	0.20	0.74

[a]Assuming 100% of the command area benefited in the wet season and 33% in the dry season. [b]Mean yield for moderate and high S&P rates, average irrigation. [c]Mean yield computed for conditions of minimum and moderate S&P rates and poor and average irrigation. [d]Yields with average irrigation minus rainfed yields. [e]Yields with no stress days. [f]Yields with ideal irrigation minus those with average irrigation.

Much less attention has been paid to achieving the second yield increment, which is the difference between yields with basic irrigation and those associated with ideal irrigation. This increment is estimated at 0.2 and 1.6 t/ha in the wet and dry seasons, respectively, or 0.74 t/ha per year, after discounting the benefited area in the dry season.

Much remains to be learned about how to provide full water adequacy throughout irrigated areas, but some general comments can be made.

- In most cases high-performance irrigation is not precluded by insufficient water at the source. Instead, the problem appears to be overuse of water along upstream sections of canals, resulting in excessive wastage, and consequently, in insufficient supply to the tail end of those canals (1973 Annual Report). There is usually enough total water if it were equitably distributed along the canals.
- Achieving the second yield increment is largely a problem of management or control of water, and not one of infrastructure. Some rehabilitation of debilitated systems is often necessary, however, before effective water control can be realized.
- Improved irrigation service requires greater emphasis on the manpower requirements of systems, especially their field staff.
- The indirect benefits of more intensive irrigation management include greater rural employment opportunities through increased field staff, more reliance on local rather than foreign resources, and reduced risk in crop production. Thus, farmers can quickly adopt better cultural practices and attain still higher crop yields.

EVALUATION OF TWO CROPS OF RAINFED RICE

Irrigation and Water Management Department

It has become possible to grow two rice crops a year without irrigation provided the rainfall pattern is favorable. The key technological factors making this possible are the short growth duration (less than 100 days) of some modern varieties, and direct seeding of at least one of the crops to avoid the delay associated with land preparation and puddling for transplanting.

Preliminary observations indicate that the two-crop technology is successful in some places but not in others because of variation in soil and rainfall. A pilot study of the feasibility of growing two rainfed rice crops was therefore made in Bulacan, Philippines, where a government program encouraging farmers to adopt the practice was begun in 1974. The objectives of the study were to determine the effects of selected physical and biological factors on the production of two rainfed crops, to compare crop growth and yield of rainfed farms planted to a single crop with those growing two crops a year, and to assess some socioeconomic factors affecting the performance and adoption of the two-crop technology.

Methodology. Eight farmers who planned to grow two rainfed crops in 1976 were selected from two villages, with fields from each farm classified as relatively high or relatively low in elevation. High elevations are associated with steep terraces, little surface runoff from the watershed, and substantial depths to the water table, while low elevations are associated with flatter areas that receive considerable water draining from higher elevation. A total of 7 paddies from high-elevation fields and 7 from low-elevation were observed. In most cases both the high- and low-elevation samples were found within the same farms. For comparison, a one-crop sample paddy was selected adjacent to and at essentially the same elevation as each of the 14 two-crop paddies. The total sample was thus composed of 14 pairs of observation paddies, each pair composed of a two-crop and a one-crop paddy.

The rate of water seepage and percolation (S&P) into the soil was measured by a technique based on water subsidence in the field (1975 Annual Report), and the occurrence of stress days was recorded for each sample paddy throughout the season. Stress days were computed as days in excess of two for which there was no standing water in the paddy (1972 Annual Report). Stress days occurring between the date of planting (emergence for direct-seeded rice) and 60 days before harvest (DBH) were considered early stress days (S_1), while those between 60 and 26 DBH were considered late stress days (S_2). Yields were estimated by two crop-cut samples of 4 sq m/paddy.

Data on fertilizer use and management practices were obtained by interview. Socioeconomic information and farmers' judgments of one- or two-crop rainfed rice were also collected during the interview.

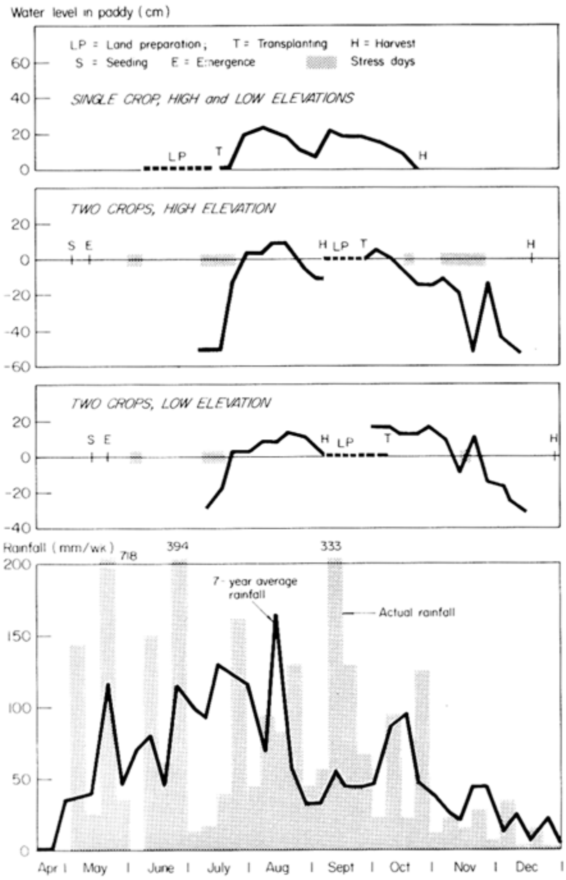
Rain gauges were installed in both villages, evaporation data were collected, and soil samples and piezometric readings were taken. Weekly rainfall records for the last 7 years were collected from a nearby weather station at San Ildefonso, Bulacan, which is in a similar rainfall regime as the two test villages.

The farmers' practices were not intentionally influenced by the study. IR1561 was planted on all two-crop farms. Either IR1561 or a local variety, Tjeremas, was planted in the one-crop paddies.

Results. *Land preparation.* The two-crop farms were disc-plowed with large tractors shortly after the harvest of the last crop in 1975. The fields remained fallow until the first heavy rainfall in May. The soil was then harrowed several times and prepared for direct seeding on dry soil.

Shortly before harvesting the direct-seeded first crop, the farmers drained their fields; after harvest, they puddled the soil for transplanting with power tillers or animal power. The mean time period between harvesting the first crop and transplanting the second crop was 22 days for the low-elevation paddies and 16 days for those at high elevation, but this difference was not significant. Heavy rainfall during September expedited land preparation for the second crop. The September 1976 rainfall was, however, considerably higher than expected from long-term averages (Fig. 2). Thus, land preparation in other years could take longer than it did in 1976 if farmers have to wait for adequate water to work their fields.

Dates of planting. The two-crop farms at low elevation were direct seeded somewhat later than those at high elevation (Fig. 2) because of



2. Average weekly rainfall for 1970–76 at San Ildefonso, Bulacan; weekly rainfall for 1976, cropping pattern for two crops and one crop of rainfed rice; depth of water in the paddy and stress days on farms located at high and low elevations. Average of two barrios, Bulacan, Philippines, 1976.

sustained flooding of the lower fields after a strong typhoon in May. Some of the lowest farms were eventually puddled and direct seeding was done on wet soils.

The second crops were transplanted late in September and harvested in December or early January. The mean date of transplanting the one-crop farms was 52 days after seeding of the first crop; their mean date of harvest was also 52 DBH of the second crop on two-crop farms (Fig. 2). Seedlings for the one-crop farms were 30 days old at transplanting, whereas those for the two-crop farms were 38 days old because of unexpected delays in harvesting the first crop and preparing for the second. Elevation did not affect planting dates or age of seedlings significantly.

Cultural practices. Nitrogen was applied at mean rates close to 50 kg N/ha per crop for all crops studied. Mean nitrogen use did not differ significantly between the two elevations, but the lower farms tended to use more nitrogen. Most two-crop farmers applied organic manure from neighboring pig and poultry farms while preparing land for the first crop.

Weed control was cited by all two-crop farmers as their chief problem in the direct-seeded first crop. Weed competition was negligible on all transplanted paddies whether on one- or two-crop farms. Chemical control was not used and hand weeding was rarely necessary.

Two-crop farmers cited insect and pest control as the most important problem of the second crop. Rats, brown planthoppers, and green leafhoppers concentrated on the second-crop plantings after the harvest of the surrounding one-crop farms.

Seepage and percolation rates. Seepage and percolation (S&P) was consistently less for the low-elevation paddies than for those at high elevation, as expected (Table 9). It was slightly less for the unpuddled soils of the first crop than for the same paddies when puddled for the second crop. This is unexpected in view of experimental findings of excessive S&P in unpuddled rice soils (1972 Annual Report), but the low rate can be explained by subsurface water movement. The soil of both villages is underlain by semipermeable limestone at depths of up to 1 m, which restricts vertical water movement. Piezometric observations confirmed positive hydrostatic pressure after heavy rains. Because the rainfall was much greater during the first crop than during the second (Table 9), S&P was less for the first crop even though the soil was more porous then.

Stress days. Stress days were numerous during the early growth stage (S_1) of the first crop and during the later growth stage (S_2) of the second crop (Table 9). The effect of relative elevation on S_2 was significant for both crops, with more than twice as many stress days for high-elevation farms as for low ones. Stress days were slightly more numerous for the first crop than for the

Table 9. Mean rates of seepage and percolation, rainfall, and stress days for two-crop and one-crop rainfed farms at different elevations, Bulacan, Philippines. 1976 wet season.[a]

Crop, elevation	Seepage and percolation		Mean rainfall (mm/wk)	Stress days (no.)	
	Observations (no.)	Rate (mm/day)		Early[b]	Late[c]
			TWO-CROP FARMS		
First crop (direct seeded)					
High elevation	70	3.8 ab	127 a	12.7 a	14.3 b
Low elevation	50	3.0 b	121 a	16.1 a	6.9 c
Second crop (transplanted)					
High elevation	56	5.6 a	54 c	2.9 b	22.1 a
Low elevation	121	3.3 ab	44 c	0.4 b	9.6 bc
			ONE-CROP FARMS		
High elevation	150	4.0 ab	94 b	1.4 b	0.0 d
Low elevation	122	3.0 b	89 b	2.3 b	0.0 d

[a]Means in the same column followed by the same letter are not significantly different at the 5% level. Testing based on differences between crops at both elevations. [b]From date of emergence or transplanting to 60 days before harvest (DBH). [c]From 60 to 26 DBH.

second, despite the greater rainfall for the first —the rainfall distribution was uneven during the first crop, with 3 consecutive weeks of rainfall less than 45 mm/week in July (Fig. 2). In addition, the direct-seeded first crop was exposed to early stress over a longer period.

One-crop farms at either elevation experienced only a few days of early stress and no late stress (Table 9).

Grain yield and net farm income. Yields and net farm income for the direct-seeded first crop were significantly greater on the low-elevation farms than on the high-elevation farms (Table 10). The effect of elevation was small for the second crop, however, and negligible for the one-crop plantings. When data from the two elevations were averaged, the yield of the direct-seeded first crop was about 0.4 t/ha less than that of the second and 1 t/ha less than that of the transplanted single crop. The yield advantage of the single crop is 0.5 t/ha greater, however, if data for the local varieties are not included. Total production per year was thus 4.44 t/ha for high-elevation two-crop farms, and 3.34 t/ha for high-elevation one-crop farms (3.82 t/ha for single crops of IR1561). At low elevations, two crops produced 5.92 t/ha, and the corresponding one-crop farms produced 3.35 t/ha.

In the computation of net farm income, the

Table 10. Grain yield, gross income, total costs, and net income[a] for two-crop and single-crop rainfed farms at different elevations, Bulacan, Philippines. Wet season 1976.

Crop, elevation	Observations (no.)	Grain yield (t/ha)	Total cost[b] (US$/ha)	Income (US$/ha)		
				Gross	Net farm	Net family
		TWO-CROP FARMS				
First crop (direct-seeded)						
High elevation[c]	7	1.82**	162	271	115**	157**
Low elevation	7	3.01	195	447	252	296
Second crop (transplanted)						
High elevation	7	2.62	209	389	181	220
Low elevation	7	2.91	203	433	225	260
		ONE-CROP FARMS				
All varieties (transplanted)						
High elevation	7	3.34	195	496	301	345
Low elevation	7	3.35	199	498	298	340
IR1561 only[d]	4	3.82	211	568	294	327

[a]Philippine P7.4/US$. [b]Including family labor costs at US$1.35/man-day. [c]Asterisks denote significant difference at the 1% level between one-crop and the indicated two-crop farms at the same elevation. Only grain yield and net income are tested. Differences between elevations are significant only for the direct-seeded first crop. Single crops planted to IR1561 only are not included in significance testing. [d]Two observations at high and two at low elevations.

farmer and landowner were assumed as partners to avoid problems in distributing income and cash expenses. Gross income was estimated by valuing production at US$149/t. Family labor was valued at US$1.35/man-day, which was higher than the official minimum wage for agriculture, but the lowest rate for attracting agricultural labor for the study. The higher rate seemed justified in the study area where cottage industries employed many people. The measures of net income included net farm income, for which the value of family labor has been subtracted. But because imputed family labor costs are credited to the farmer's family, a net family income criterion that does not reflect expenses for family labor was also included.

Net farm income from the direct-seeded, high-elevation crop was about US$115/ha; that on low-elevation farms was US$252/ha (Table 10). Net farm income for the second crop was US$181/ha and US$225/ha for high- and low-elevation farms, respectively. Total yearly income from the two-crop farms was thus US$296/ha for high-elevation, and US$477/ha for low-elevation farms. The net yearly income from high-elevation one-crop farms (US$301/ha) was about the same as that from high-elevation two-crop farms. For farms at low elevation, the net yearly income was US$298/ha for one crop and US$477/ha for two crops (Table 10).

Comparisons using net family income, which excludes the cost of family labor, present a somewhat more favorable picture of the two-crop technology because of the greater labor requirements of two crops, but the conclusions are essentially the same as those for net farm income.

The combined data for both elevations result in annual net farm income of US$300/ha for one-crop farms and US$386/ha, 29% greater, for two-crop farms.

Two-crop performance with different rainfall patterns. The distribution of rainfall is a major factor affecting the performance of two rainfed crops. This section relates grain yield to rainfall patterns of different years to determine the long-term feasibility of two crops of rainfed rice.

Yield response model. A multiple-regression model based on stress days was used to estimate the effects on yield of water shortage in combination with other factors. The model used for the direct-seeded first crop was different from that used for the transplanted crops because of differences in the technology for the two crops. No equation was computed from the one-crop data because stress days for those farms were negligible. Instead, the two-crop equation was also used for one-crop farms because both crops were transplanted on puddled soils.

The equation computed for the direct-seeded first crops is

$$Y = 4140 + 36.6\,N - 0.4\,N^2 - 63\,S_1 - 36\,S_2 - 1365\,W + 0.4\,S_1 N + 2.3\,NW$$
$$(R^2 = 0.89;\ \text{no. obs.} = 15)$$

where Y is grain yield (kg/ha), N is nitrogen (kg/ha), S_1 and S_2 are stress days in the vegetative and reproductive growth stages, respectively, and W is a measure of weed growth estimated by visual observation but spot checked to conform to the scale: $W = 0$ for negligible weed growth, $W = 1$ for weed growth whose dry weight (not including roots) is less than 200 g/sq m, and $W = 2$ for weed growth in excess of 200 g/sq m of dry weight.

The terms of the model are highly significant and consistent with other equations. The coefficient of S_1 is greater than that of S_2, but the difference is offset by the strong positive interaction term $S_1 N$, which reduces the overall effect of S_1 in the model to about the same level as that of S_2 at mean N rates. Strong yield reduction due to S_1 can be expected for IR1561, however, because it is a short-seasoned variety with fewer days of vegetative growth than most other varieties. Early stress, by interfering with crop establishment and by stimulating weed growth, is also likely to affect direct-seeded crops more seriously than it does transplanted crops.

The equation estimated from the transplanted second-crop data is

$$Y = 1240 + 42.3\,N - 14\,S_2 - 6.4\,A$$
$$(R^2 = 0.80;\ \text{no. obs.} = 11)$$

where A is age (days) of seedlings at transplanting. S_1 was not used in the model because there were so few days of early stress for the second crop. The intercept is lower than expected, which is partly the result of insect and pest damage that was not directly incorporated in the model. The effect of S_2 is weaker than that for the direct-seeded first crop.

Each input factor times its mean level of field occurrence gives the contribution of that factor to grain yield. For the direct-seeded first crop, weed growth accounted for more than 2 t/ha yield loss, and stress (S_1 and S_2) for about 1.2 t/ha loss. Nitrogen accounted for 1.1 t/ha gain. For the transplanted second crop, N accounted for almost 2 t/ha yield gain, and S_2 and A each contributed 0.3 t/ha loss.

Prediction of stress days. A water-deficit model was developed to predict stress days based on daily rainfall. Mean daily rainfall for the villages was tabulated and compared with the demand for water, which was taken as 4 mm/day due to S&P (Table 9) and 4 mm/day (the mean rate of open-pan evaporation) for evapotranspiration. For each week the number of days of water deficit when the rainfall supply was less than the 8-mm demand was counted. To avoid residual lag effects, deficit days were precluded for the first day after rainfall in excess of 10 mm, and for 2 days after a day of 20 mm or more rainfall. This procedure provided a weekly series of deficit days, n, which were then related to the mean number of stress days, S, found during the corresponding week in the 1976 study. The results are:

For the first crop: $S = 0.7 + 0.41\ n$ ($R^2 = 0.76$; no. obs. = 10)

For the second crop: $S = 0.3 + 0.23\ n$ ($R^2 = 0.81$; no. obs. = 9),

where S is the number of stress days per week, and n is the number of deficit days for the same week. Both equations are highly significant.

Yield protection. Using the water-deficit model, expected stress days for 1976 and for the past 7 years were computed from rainfall data. Calculations began with the 20th week of the year (mid-May). The analysis spanned 15 weeks for the first crop and 12 for the second, with 3 weeks of land preparation between crops. Days of stress were distributed as S_1 or S_2 and used to compute yields in the regression equations. Nitrogen use was set at 45 kg N/ha and weed growth, W, for the direct-seeded crop was assumed equal to the mean value recorded in 1976 ($W = 1.21$). Seedlings for the transplanted crops were assumed to be 38 days old for the second crop and 30 days old for the single crop. Stress days and yields predicted by this procedure approximate closely the measured values for 1976 (Table 11).

Table 11. Computed stress days[a] and yields based on weekly rainfall in San Ildefonso, Bulacan, for two crops of rainfed rice on high and low elevations. 1970–76 wet seasons.

Year	First crop			Second crop		
	Stress days (no.)		Yield (t/ha)	Stress days (no.)		Yield (t/ha)
	S_1	S_2		S_1	S_2	
			Measured			
1976	14.4	10.6	2.4	1.4	15.9	2.8
			Computed			
1976	13.5	9.0	2.8	2.5	15.0	2.6
1975	4.0	4.0	3.1	7.5	36	0[b]
1974	10.5	5.0	2.8	[c]	[c]	0[c]
1973	7.5	15.5	2.5	10.5	17.5	2.5
1972	7.0	0.0	3.1	[c]	[c]	0[c]
1971	4.0	4.0	3.1	3.5	8.5	2.7
1970	13.0	13.0	2.3	2.0	18.5	2.4
Mean	8.5	7.2	2.8			1.4

[a] S_1 = stress at early stage of crop growth. S_2 = stress at late stage. [b] Because the entire second growth period would be composed of stress days, zero yield was assumed. [c] Total rainfall during the first 5 weeks after harvest of the first crop was less than 40 mm; thus the second crop would have been delayed and harvested well beyond the period of late-season rainfall; zero yield was therefore assumed.

The long-term analysis shows less variability in yield than is normally expected. Yields of the first crop are relatively stable over the years despite important variations in S_1 and S_2. Part of the reason is the lack of interaction effects in the yield model. For example, if weed growth in the first crop were greater in years of high S_1, which is likely, the yield for those years would be lower than the levels computed by the model.

The analysis brings out the vulnerability of the second crop to water shortage (Table 11). In 3 of the 7 years, essentially complete failure of the second crop was predicted due to inadequate rainfall. For 2 of those years, inadequate rains during the land preparation period would have delayed transplanting of the second crop and caused severe stress later in crop growth. Mean yields over the 7 years were 2.8 t/ha for the first crop and 1.4 t/ha for the second crop. The former is 0.4 t/ha greater than that measured from the 1976 first crop, and the latter is 1.4 t/ha less than that found for the 1976 second crop.

To bring out the effects of different elevations, the equation predicting S from deficit days n was recomputed independently for the two topographic regimes. The results based on the 1976 data combined for both crops are:

For high elevations: $S = 0.00 + 0.37\ n$ ($R^2 = 0.71$; no. obs. = 16)

For low elevations: $S = -0.80 + 0.29\ n$ ($R^2 = 0.66$; no. obs. = 16),

with the same assumptions described earlier. These relationships were then used with the 7-year set of daily rainfall records to compute S_1 and S_2, which can be used to predict expected yields, as shown above. The same rate of nitrogen use (45 kg N/ha) was assumed for both crops, and the 1976 mean weed index of 1.57 for high-elevation farms and 0.86 for low-elevation farms were used in these responses. The simulated yields for all 7 years were then averaged to find the mean effect of relative elevation for that period.

For high-elevation farms, the mean expected yield is 2.1 t/ha from the first and 1.5 t/ha from the second crop, for a total of 3.6 t/ha for both crops (Table 12). This total production is only 29% greater than the 2.8 t/ha mean for the single transplanted crop, and results in slightly less net farm income with the two-crop than with the one-crop technology.

For low-elevation farms, two crops combined produced 5.1 t/ha, about 76% greater than the single crop yield of 2.9 t/ha. These mean yields are lower than those measured in the 1976 field study (Table 10), which indicated that 1976 was a year of better-than-average rainfall. The relative production advantage of two crops over one crop was, however, about the same for the 1976 field study and the 7-year means.

Table 12. Mean stress days and yields computed for farms at two relative elevations. Means for 7 seasons with two crops and single crops of rainfed rice, 1970–76.[a]

Crop	Stress days (no.) Early	Stress days (no.) Late	Grain yield[b] (t/ha)
High elevation[c]			
First crop (direct seeded)	10	8	2.1
Second crop (transplanted)	6	22.7	1.5
Combined first & second crops			3.6
Single crop (transplanted)	8.0	12.4	2.8
Low elevation[d]			
First crop (direct seeded)	6.0	3.0	3.5
Second crop (transplanted)	2.2	15.3	1.6
Combined first & second crops			5.1
Single crop (transplanted)	3.2	5.6	2.9

[a]Based on daily rainfall records from San Ildefonso, Bulacan, 1970–76. [b]Assuming optimum levels of N use. [c]Stress days computed from $S = 0.0 + 0.37\ n$. [d]Stress days computed from $S = -0.8 + 0.29\ n$.

It can be concluded that the costs of producing two crops of rainfed rice require a substantial production advantage to justify the two-crop technology. For high-elevation farms, total production from two crops was about 29% greater than that from one crop, but this advantage did not result in additional net income to the farm because of the increased production costs for two crops.

For low-elevation farms, total production for two crops was about 76% greater than that for a single crop, and resulted in about 60% more net farm income. This analysis, however, is based on means and does not reflect the substantial year-to-year variation that should be expected for the second crop. For about 1 out of every 3 years, farmers should expect essentially total failure of the second crop, and thus serious problems in refinancing for the following year.

The two-crop technology would be more attractive if weeds, insects, and rats could be controlled better, and if high yielding rice varieties with 75- to 90-day growth durations were available. Either would greatly improve the prospects for two-crop rice production in areas of marginal rainfall such as Bulacan province.

IMPROVING THE PRODUCTIVITY OF SUBSOILS EXPOSED DURING IRRIGATION CONSTRUCTION

Irrigation and Water Management Department

The construction of irrigation canals, drains, and access roads in irrigated areas of the Philippines is associated with extensive topsoil removal. Where land is also leveled, subsoils at 30 cm or deeper are sometimes exposed. Some properties of exposed subsoils and their response to fertilizer treatments were previously reported for the Pilot Land Consolidation Project in Talavera, Nueva Ecija province (1974 Annual Report). Those studies were continued to examine the effects of selected microelement and organic matter treatments on restoring the deeply cut soils to high levels of productivity The research also included studies on mulching and the water status of the soils.

Effects of selected microelements. In the Pilot Land Consolidated Project area, an experiment was conducted on soils that had been cut to depths of 30 cm or deeper to confirm earlier findings that microelements are important constituents of fertility treatments for these soils, and to find which of five microelements are most important. The study was conducted during the May-August 1975 cropping season, the second season since topsoil removal. Treatments included different combinations of nitrogen, phosphorus, and potassium; compounds containing microelements; and topsoil and organic matter in the form of fresh leaves from nearby acacia trees.

One-third of the 120 kg N/ha and the full amounts of the other fertilizers (60 kg P_2O_5/ha and 30 kg K_2O/ha) were basal applications. One-third of the nitrogen was applied 30 days after transplanting (DT), and the remaining one-third 60 DT. The microelement compounds of iron sulfate, copper sulfate, calcium silicate, sodium borate, and manganese sulfate were broadcast at 5 kg/ha each and mixed with the surface soil. One microelement treatment had nitrogen, phosphorus, and potassium plus all five compounds. The five other treatments were identical to it, except that each was without a different microelement compound. Acacia leaves and topsoil were incorporated to depths of 8 to 10 cm, without added fertilizer.

Twenty-one-day-old seedlings of IR28 were used in 4- × 5-m plots. Standard experimental practices were observed except that the plots suffered from drought from 25 to 35 DT and from 75 to 80 DT because of a general water shortage in the area.

The results (Table 13) indicated that nitrogen and selected microelements are important to the achievement of high yields on exposed subsoils. All microelements combined were required to achieve yields significantly greater than those achieved with nitrogen and phosphorus only. Microelement treatments that included silicon and boron compounds had the greatest yield response of the five microelements, but the individual effects of the microelements may have been affected by the presence of unintended microelements in the commercial preparations of the compounds tested.

Table 13. Mean[a] plant height, tiller count, dry matter production, and grain yield of IR28 with different microelement treatments on deeply cut (30 cm) soils. Land Consolidation Project, Talavera, Nueva Ecija province. May-August 1975.

Treatment[b]	Plant ht (cm)	Tillers (no./hill)	Dry matter production[c] (g/3 plants)	Grain yield[d] (t/ha)
Control	64 e	7 c	7 f	0.58 e
N	87 bcd	30 a	126 abcd	(3.03) cd
N+P	97 a	34 a	151 abc	(3.37) bc
N+P+K	91 bc	32 a	140 abc	(3.17) cd
N+P+K+ME (−Fe)	86 cd	36 a	107 cd	(2.76) d
N+P+K+ME (−Cu)	86 bcd	33 a	127 abcd	(3.76) ab
N+P+K+ME (−Si)	83 d	29 a	158 ab	3.08 bcd
N+P+K+ME (−B)	92 ab	32 a	113 bcd	3.04 cd
N+P+K+ME (−Mn)	89 bcd	32 a	91 d	3.26 bcd
N+P+K+ME	91 abc	35 a	159 a	4.05 a
Acacia leaves	67 e	13 bc	26 ef	0.96 e
Topsoil	69 e	14 b	50 e	0.92 e
CV (%)	3.7	14.2		11.2

[a]Means of 3 replicates. Means in each column followed by the same letter are not significantly different at the 5% level. [b]N = 120 kg N/ha; P = 60 kg P_2O_5/ha; K = 30 kg K_2O/ha; ME = 5 kg/ha each of Fe, Cu, Si, B, and Mn compounds applied together. Treatments 5–9 have ME treatments in which successive constituents of the mix are dropped. Acacia leaves (fresh) = 5 t/ha; topsoil (wet) = 50 t/ha. [c]At 72 days after transplanting. [d]Values in parentheses indicate some yield loss due to lodging.

Topsoil and acacia leaves did not increase yields significantly, possibly because the drought condition reduced the effectiveness of the organic matter by slowing its rate of decomposition.

Effects of mulching. Weed control was a problem in the microelement experiment because of the difficulty of tillage, even when the soils were saturated with water, and the difficulty of keeping the soils flooded. Both problems were related to the physical characteristics of the subsoil.

Some of the weeds were used in an experiment to find out if mulching with weed growth would improve the performance of the rice crop. In one replicate of each treatment of the microelement study, two small areas, each encompassing four rice hills, were delineated. One area in each treatment was mulched with weeds that were pulled from the same sample area.

Table 14. Mean effects[a] of mulching on tillering, straw yield, and grain yield of IR28 grown on deeply cut (30 cm) soils. Land Consolidation Project, Talavera, Nueva Ecija. May-August 1975.

Treatment	Productive tillers[b] (%)	Straw yield (g dry matter/ 4 plants)	Grain yield (g/4 plants)
Control	59	54	91
Mulched[c]	84	78	127

[a]Means of 12 paired comparisons. Mulched values are significantly greater than values for the control for all three parameters at 5% level. [b]Productive tillers ÷ total tillers. [c]Mulched with weeds picked from same plots.

Mulching was done about 4 weeks after transplanting, at the rate of about 100 g of dry matter/plot (0.16 sq m). Control plots were not mulched, but were otherwise treated the same as the mulched plots.

Mulching had a significant effect on the proportion of productive tillers at harvest (Table 14). The percentage production of tillers, rather than tiller number, was examined to avoid possible bias resulting from different initial tiller counts on the small plots.

Straw and grain production were also significantly greater on mulched than on unmulched plots, partly because more water was conserved in the mulched areas during the two periods of drought. The study indicates that mulching may be an important means of rehabilitating exposed subsoils and achieving high yields, particularly in areas where water supply is unpredictable.

Effects of organic fertilizers on rice growth. Earlier studies on the exposed subsoils of the Land Consolidation Project showed that carabao manure or acacia leaves applied together with 60 kg N/ha produced significantly greater yields than nitrogen applied alone (1974 Annual Report). In an experiment from October 1975 to January 1976, five different sources of organic fertilizers and topsoils were tested for their effects on rice growth and yield. Treatments were a control with no fertilizer, and seven treatments with 60 kg N/ha plus 60 kg P_2O_5/ha. Six of those treatments also received acacia leaves, green mungo, carabao manure, hog manure, or poultry manure at the rate of 5 t/ha (fresh weight). Earlier studies showed no response to potassium, so it was not included.

The nitrogen rate was set at 60 kg/ha, about the maximum used by farmers in that area. Nitrogen was applied in three equal applications 1 month apart. The first nitrogen application and all other fertilizers were incorporated just before transplanting. Three-week-old IR28 seedlings were transplanted on thrice-replicated plots in an area where topsoil had been removed to a 30-cm depth. The experiment was conducted during the third season after excavation.

Grain yields of all treatments with organic fertilizers were greater than those of the control, but not significantly greater than those of the N + P treatment (Table 15). Topsoil resulted in yields significantly greater than those of the inorganic fertilizer treatment and the organic treatments. There is thus little basis for recommending the use of any of the organic fertilizers readily available near the area to restore the productivity of deeply cut soils. But if the deeply cut areas are backfilled with topsoil saved from the surface layer, farmers could achieve normal yields with only moderate use of nitrogen and phosphorus.

Effects of organic fertilizers on soil water status. All experiments on the exposed subsoils of the Land Consolidation Project indicated that the land could be tilled only to shallow depths, and that puddling did not result in the fine slurry produced from undisturbed topsoils. Tilled land settled firmly at the soil surface, strongly resisted penetration, and made transplanting and weeding difficult. Because water tended to percolate into the soil quickly, the water requirements for rice production were high. Standing water on the surface of the fields was clear and hotter than water in fields with undisturbed topsoil. Water temperatures in the deeply cut plots during November and December frequently exceeded 40°C for several hours a day.

It was hypothesized that the organic fertilizers used in the experiment might improve the water status of the soil. The daily rate of water seepage and percolation (S&P) into the soil and soil moisture content at two stages of growth for all plots of that experiment were therefore measured. S&P rate was measured with the in situ water subsidence method (1975 Annual Report), and moisture content was de-

Table 15. Mean effects[a] of organic matter addition on plant height, tiller number, grain yield, seepage and percolation rate, and soil moisture content at harvest of IR28 on deeply cut (30 cm) soils. Land Consolidation Project, Talavera, Nueva Ecija province. October 1975–January 1976.

Treatment	Plant ht (cm)	Tillers (no./hill)	Grain yield[b] (t/ha)	Seepage and percolation rate (mm/day)	Soil moisture content[c] (%) at harvest
0 N + 0 P	66 a	12.9 a	1.83 a	(n.a.[d])	25.5 a
60 N + 60 P	80 b	19.4 b	2.67 b	7.7 a	27.9 ab
60 N + 60 P + AL[e]	81 b	16.9 b	(2.89) bc	6.3 a	36.2 c
60 N + 60 P + GM[e]	78 b	17.1 b	2.53 b	6.7 a	29.6 b
60 N + 60 P + CM[e]	80 b	17.4 b	2.51 b	7.4 a	27.4 ab
60 N + 60 P + HM[e]	82 b	18.8 bc	(2.82) b	7.4 a	25.5 a
60 N + 60 P + PM[e]	82 b	18.8 bc	2.90 bc	7.4 a	28.3 ab
60 N + 60 P + TS[f]	88 c	20.5 c	(3.43) c	6.0 a	36.2 c
CV (%)	4.1	7.7	11.8	13.1	6.8

[a]Means of 3 replicates. Values in each column followed by the same letter are not significantly different at the 5% level. [b]Values in parentheses indicate yield loss due to rat damage. [c]Moisture content by weight, wet basis, at 8-cm depth. All samples were fully saturated by standing water at time of sampling. [d]n.a. = data not available. [e]5 t/ha AL (acacia leaves), GM (green mungo), CM (carabao manure), HM (hog manure), or PM (poultry manure) applied. [f]50 t/ha wet topsoil (TS) applied.

termined from soil sampled at 8-cm depths 15 DT and just before harvest. Saturated conditions were produced by keeping standing water on the surface of each plot at the time of sampling.

Organic matter had no significant effects on S&P rates (Table 15). The mean S&P rate was 7.0 mm/day, much higher than that for undisturbed soils in the same area. The topsoil treatment had a mean S&P rate about 1 mm/day less than the others, and this difference probably would have been significant, had the test plots been full-sized paddies with reduced edge effects. Major changes in S&P as a result of surface applications are not likely, however, because S&P is strongly influenced by soil texture and the hydrostatic head in the area.

The plots with acacia leaves and those with topsoil contained significantly more moisture at harvest than all other treatments tested (Table 15).

Soil and crop management

Summary

SOIL CHARACTERIZATION

In South and Southeast Asia more than 100 million ha of land potentially suited to rice production are not cultivated because of salinity, alkalinity, strong acidity, or histosol problems. Toxicities of iron, aluminum, and manganese, or deficiencies of iron, zinc, and phosphorus limit rice yields on another 50 million ha.

Soil and plant analyses and plant observations in the Philippines revealed the presence of zinc deficiency in 26 areas, copper deficiency in 6 organic soils, molybdenum deficiency in 1 organic soil, iron toxicity in 3 strongly acid soils, and boron toxicity in a hydrothermal soil.

Studies of the chemical kinetics of the solutions of flooded soils showed that flooding depresses the concentration of copper and zinc, increases that of molybdenum in acid soils and depresses it in alkaline soils, and does not noticeably affect that of boron. Chemical kinetics of 12 organic soils indicated that poor rice growth on such soils is associated with deficiencies of nitrogen, phosphorus, and zinc, as well as with toxicities of carbon dioxide and unknown organic substances.

Long-term experiments revealed that flood fallow increased soil nitrogen; compost increased organic matter, nitrogen, and available phosphorus; and straw left in the field markedly increased soil nitrogen.

Incorporation of straw did not depress the nitrogen supply in submerged soils. Drying between crops of soils receiving no fertilizer did not cause significant denitrification losses. Loss of nitrogen due to alternate wetting and drying was least in plots receiving no nitrogen but was considerable in fertilized plots of Maahas clay.

Loss of fertilizer nitrogen, presumably by volatilization as ammonia, was highest in a sodic soil and lowest in an acid Ultisol.

The proportion of fertilizer nitrogen fixed by soil minerals ranged from 3.6 to 27.7% in 10 Philippine rice soils.

Direct distillation of anaerobic soils with magnesium oxide gave higher exchangeable NH_4^+ values than did distillation of potassium chloride soil extracts.

SOIL FERTILITY MANAGEMENT: MICROBIOLOGICAL STUDIES

Nitrogen fixing activity was higher in nonfertilized plots than in plots fertilized with nitrogen, phosphorus, and potassium. The highest nitrogen fixing activity appeared at a later stage of rice growth and coincided with the highest in vitro photo-dependent, nitrogen fixing activity and the highest algal mass. The contribution of nitrogen fixation in the rice root zone was relatively smaller than algal contribution.

A study showed that phosphorus addition in the field was necessary for better growth of *Azolla* and that incorporation of *Azolla* was beneficial to rice growth.

SOIL FERTILITY AND FERTILIZER MANAGEMENT

Soil fertility studies on the effects of 60 kg N/ha indicated that between 1200 and 1600 hours, floodwater temperature could rise to 32°C and pH to 8.5, and dissolved carbon dioxide could go down to 0 ppm. The rise in pH of floodwater was less in an acid Ultisol (Luisiana clay) than in a neutral Vertisol (Maahas clay). The magnitude of ammonia losses from the Vertisol varied with the method of measurement, time of measurement, and soil type. However, losses were least if nitrogen fertilizer was applied by deep placement.

A year-round study indicated that a grain yield increase of more than 1.0 t/ha could be obtained from proper timing of nitrogen application. However, the increase would vary with solar energy, nitrogen level, and the rice variety used.

SOIL AND CROP CULTURE

Soil and crop culture studies for 1 year indicated that by preparing the land at the end of the previous wet season to develop a dry soil mulch, soil moisture was conserved and the crop was seeded 20 days earlier than the crop for which land was prepared at the beginning of the wet season.

Soil and crop management

Soil characterization

Soil Chemistry Department

SURVEY OF PROBLEM SOILS

Two surveys of the problem rice soils of the tropics and subtropics were made during the year. One survey covered rice-growing soils from the standpoints of landform, hydrology, genesis, taxonomy, and suitability. Publication of the result of that survey is in progress.

The other survey emphasized chemical problems of current and potential rice-growing soils. It included correlation of soil properties with nutritional problems. Survey data were gathered by visits to rice-growing countries to check the correlations and inspect problem soils, by consultations with soil scientists, agronomists, and extension workers in rice-growing countries, and by collection of soil survey reports, maps, and amelioration data.

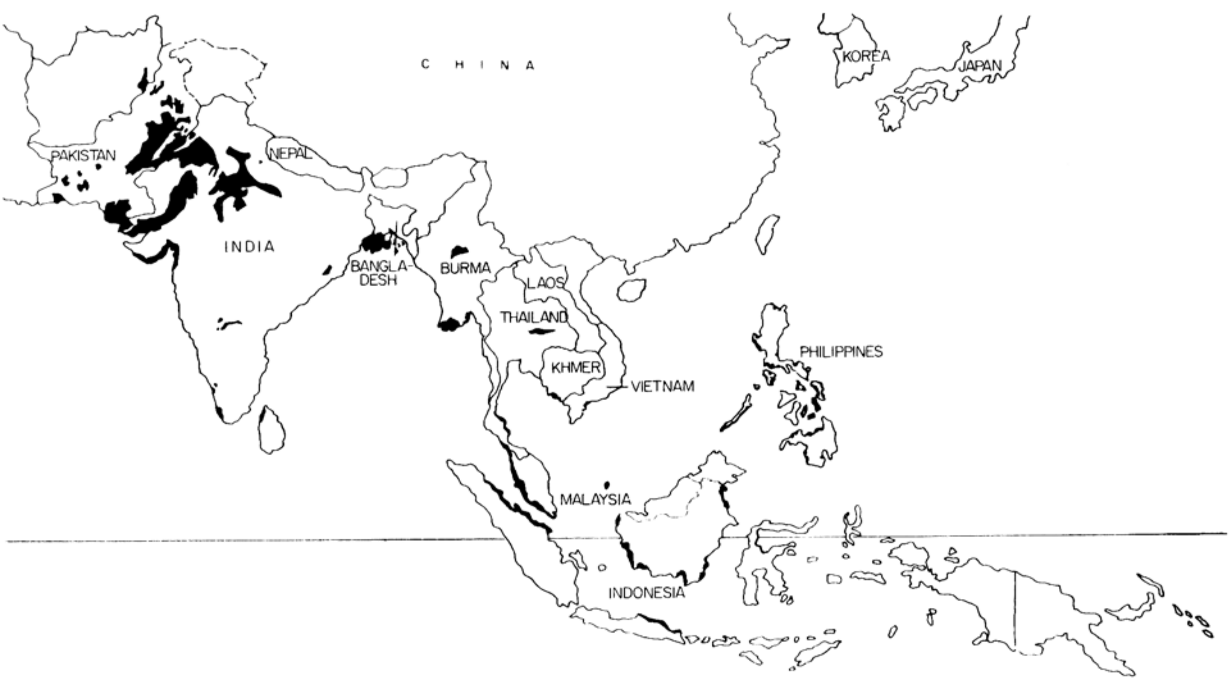
The chemical problem survey material is being analyzed. The survey revealed that in South and Southeast Asia about 100 million ha of land physiographically and climatically suited to rice production lie uncultivated largely because of soil problems such as salinity, alkalinity, strong acidity, or excess organic matter (Table 1). It also showed that iron toxicity on strongly acid soils; phosphorus deficiency on Oxisols, Ultisols, and Vertisols; and zinc deficiency on alkaline soils, organic soils, and wet soils currently limit rice yields on another 50 million ha.

Table 1. Problem rice soils (current and potential) of South and Southeast Asia.

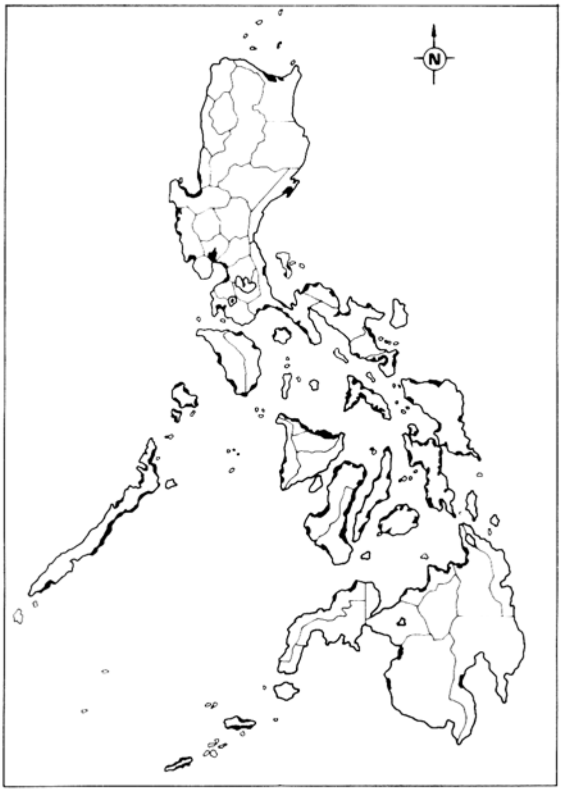
Kind of soil	Extent (million ha)
Saline soils	62.5
Alkali soils	2.2
Acid sulfate soils	9.8
Organic soils	29.0

Table 2. Distribution of saline soils in South and Southeast Asia.

Country	Extent (million ha)
Bangladesh	2.5
Burma	0.6
India	23.2
Indonesia	13.2
Khmer Republic	2.4
Malaysia	4.6
Pakistan	9.4
Philippines	0.3
Sri Lanka	0.2
Thailand	1.8
Vietnam	4.6
Total	62.8



1. Saline soils of South and Southeast Asia.



2. Coastal saline soils of the Philippines.

Saline soils. Saline soils cover 62.5 million ha in South and Southeast Asia (Table 2). The largest saline area is in India (23.2 million ha), much of it in the densely populated states of Uttar Pradesh, West Bengal, and Gujarat (Fig. 1). Other saline soil areas also lie close to thickly populated Asian urban areas—Bombay, Karachi, Bangkok, Surabaja, Ho Chi Minh City, and Hanoi. About 27 million ha of saline soils in South and Southeast Asia are on coastal plains of the humid tropics. The Philippines has 280,000 ha of coastal saline soils (Fig. 2).

Many of the saline soil areas currently grow rice, but the salt-tolerant varieties grown have low yield because of poor plant type and susceptibility to diseases and insects. Many of Asia's less saline soils could be planted to rice without high capital inputs if modern salt-tolerant rice varieties are developed.

Alkali soils. In the tropics and subtropics, there are more than 370 million ha of alkali soils; the bulk of that area is in Australia. The largest area of alkali soils in Asia is on the Indo-Gangetic plain (Table 3).

Table 3. Distribution of alkali or sodic soils in the tropics and subtropics.

Region	Extent (million ha)
Africa	26.9
Asia	2.2
Australia	340.0
South America	3.0

Alkali soils can be reclaimed by applying gypsum and by leaching the soil. But during the reclamation process, rice will grow because it is adapted to the waterlogging that is unavoidable in the reclamation process. Waterlogging brings down the pH of the alkali soils and increases the availability of nutrients. Where available, alkali-tolerant rices with high yield potential can be grown on moderately alkali areas throughout the reclamation period (about 5 years).

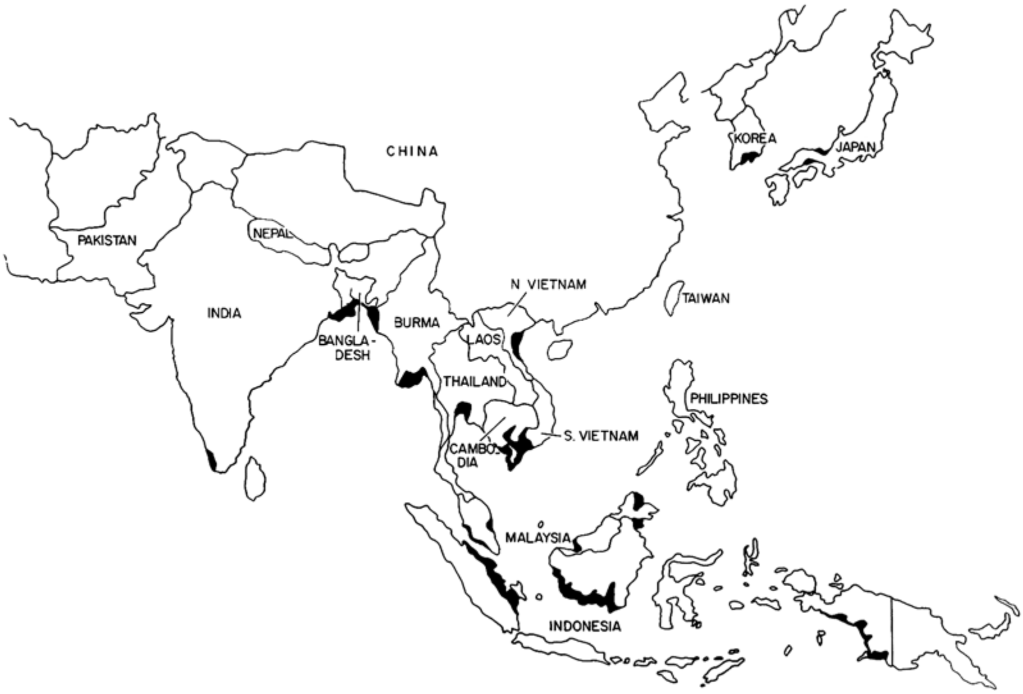
Acid sulfate soils. In the tropics and subtropics, acid sulfate soils cover more than 15 million ha of land that is physiographically and climatically suited to rice production (Fig. 3). South and Southeast Asia have nearly 10 million ha of such soils (Table 4).

When submerged, an acid sulfate soil is nearly neutral but when drained and dried, it becomes acid and lethal to plants. Rice can be grown on undrained acid sulfate soils, but it may suffer from aluminum toxicity in the early stages of soil submergence as well as from iron toxicity and phosphorus deficiency. Development of rice varieties tolerant of those soil conditions can make the less strongly acid soils fit for rice production without recurrent liming, which is the common method of amendment.

The acid sulfate soils vary widely in their chemical and hydrological properties, a fact

Table 4. Distribution of acid sulfate soils in South and Southeast Asia.

Country	Extent (million ha)
Bangladesh	0.66
Burma	0.81
India	0.63
Indonesia	2.00
Khmer Republic	1.50
Malaysia	0.85
Thailand	1.30
Vietnam	2.05
Total	9.80



3. Acid sulfate soils of Asia.

which suggests that research is best done in the areas where such soils exist. IRRI has arrangements for such research in the Philippines and in Malaysia.

Organic soils (Histosols). Organic soils (Histosols) cover more than 300 million ha of land in Southeast Asia. More than 27 million ha of those Histosols are in Indonesia. To grow dryland crops the organic soils must be drained. Draining causes rapid oxidation and a subsidence in soil level. The drop in soil level makes further drainage difficult. With the right combination of management and adapted varieties, rice will grow on the Histosols without drainage.

Iron toxicity. Iron toxicity is a widespread nutritional disorder of rice. It occurs in strongly acid Oxisols, Ultisols, Histosols, and acid sulfate soils, and has been identified in several countries in South and Southeast Asia, in West Africa, and in South America. The damage it causes to a rice crop depends on soil, weather, and the variety, age, and general nutritional status of the plant. Where iron toxicity is severe, the rice yield may be low despite good vegetative growth. Severe toxicity also kills the rice plant.

Iron toxicity can be corrected by liming and by water management, both of which involve capital outlay and recurrent inputs. Varietal tolerance for iron toxicity could provide a less expensive answer to the problem.

CHEMICAL ANALYSIS OF SOILS

Nearly 1,000 samples from experimental plots, greenhouse experiments, and problem areas were analyzed. Methods were developed for measuring the partial pressure of carbon dioxide and the concentration of silica, molybdenum, and boron in submerged soils.

Partial pressure of carbon dioxide. The partial pressure of carbon dioxide (P_{CO_2}) is important chemically because it controls the pH values of submerged soils and the solubility of several divalent cations. P_{CO_2} is also important physiologically because in excess it retards water and nutrient uptake and poisons plants.

Work resumed on a method of P_{CO_2} measurement based on total CO_2 and pH, which was proposed earlier but not tested adequately (1967, 1968 annual reports). Total CO_2 was measured by gas chromatography and P_{CO_2} was derived from the equation

$$\text{Total } CO_2 = KP_{CO_2} \frac{1 + K_1 \times 10^{pH}}{\gamma_{HCO_3}}$$

where $K = 10^{-1.47}$, $K_1 = 10^{-6.38}$, and γ_{HCO_3} is the activity coefficient of HCO_3^-.

The validity of the equation was confirmed with pure sodium carbonate solutions (Table 5) and with reduced soils (Table 6) equilibrated with CO_2 at different partial pressures. Previously it was shown that the P_{CO_2} calculated from total CO_2, and pH should be less than that derived by alkalinity and pH because gas chromatography eliminates the organic acid error. Table 7 shows that except in two cases, P_{CO_2} values obtained by the new method were slightly less than those obtained by titration.

The measurement of total CO_2 by gas chromatography is rapid and reliable. About 60 soil solutions (100-μl samples) can be analyzed daily. About 30 samples can be run without replacing the CO_2 vaporizer, the desiccant, or the silica gel column.

Assay of boron, molybdenum, and silicon. Nutritional disorders of rice associated with deficiencies or excesses of micronutrients have assumed increasing importance. That has created interest in measuring iron, manganese, zinc, copper, and boron content, and their kinetics in submerged soils. Although neither a micronutrient nor an essential element, silicon influences the solubility of some micronutrients and rice yield.

Table 5. Comparison of observed P_{CO_2} values with the actual values of 0.001 N Na_2CO_3. IRRI, Philippines, 1976.

P_{CO_2} (atm)	
Actual	From total CO_2 and pH
0.966	0.960
0.207	0.202
0.0096	0.0095

Table 6. Observed P_{CO_2}'s of the suspensions of three reduced soils equilibrated with CO_2 at three partial pressures. IRRI, Philippines, 1976.

Soil	Actual P_{CO_2} (atm)		
	0.967	0.255	0.0096
	Observed P_{CO_2} (atm)		
Luisiana clay (pH: 4.6; O.M.: 3.2%)	0.999	0.299	0.0094
Maahas clay (pH: 6.6; O.M.: 1.9%)	0.965	0.264	0.0109
Pila clay loam (pH: 7.5; O.M.: 3.6%)	0.936	0.289	not determined

Table 7. Comparison of P_{CO_2} of solutions of three submerged soils by two methods of four intervals.

Method	P_{CO_2} (atm) in soils submerged for				
	0 wk	2 wk	4 wk	6 wk	8 wk
			Luisiana clay		
Titration	0.000	0.58	0.63	0.50	0.41
Gas chrom.	0.018	0.42	0.62	0.45	0.38
			Maahas clay		
Titration	0.001	0.12	0.11	0.14	0.13
Gas chrom.	0.004	0.12	0.10	0.17	0.16
			Pila clay loam		
Titration	0.001	0.48	0.45	0.48	0.39
Gas chrom.	0.004	0.44	0.45	0.38	0.31

The assay of micronutrients (except iron, manganese, zinc, and copper) by atomic absorption spectrophotometry encounters interferences from the large quantities of iron, manganese, and organic reducing substances present in anaerobic soils.

The curcumin method gave satisfactory recovery of added boron from anaerobic soil solutions containing 0.5 to 1.9 ppm boron. Apparently the method can be used without modification for the assay of boron in anaerobic soil solutions.

The phenylhydrazine method for determining molybdenum was unsatisfactory because of a strong negative error. The dithiol method, although superior, gave a positive error of 6 to 26% with anaerobic soil solutions.

The silico-molybdenum blue method was subject to less interference from iron and phosphate than the silico-molybdate methods in the assay of silicon in solutions of submerged soils.

MICRONUTRIENTS

Nutritional problems. Soil and plant analyses, coupled with plant responses, revealed nutritional problems in Philippine rice soils—zinc deficiency at 26 sites, copper deficiency in 6

Table 8. Some properties of soils from Philippine areas where zinc deficiency was observed. 1976.

Location	pH	Organic matter (%)	Available Zn[a] (ppm)
San Isidro, Santa Ana, Leyte	5.2	38.9	0.48
Banaue, Ifugao	5.3	3.6	0.32
Lam-aw, Pila, Laguna	5.6	30.7	0.44
Kalayaan, Laguna	5.7	21.9	0.50
Butuan, Agusan del Norte	6.2	5.0	0.60
Barrio Lalakay, Los Baños, Laguna	6.6	21.8	0.77
Ampayon, Agusan del Norte	6.7	5.5	0.68
Butuan, Agusan del Norte	6.9	5.7	0.56
Tiniwisan, Agusan del Norte	6.9	5.5	0.68
IRRI, Los Baños, Laguna	6.9	3.7	0.71
Calauan, Laguna	7.1	6.2	0.67
Sariaya, Quezon	7.1	15.3	0.20
Candelaria, Quezon	7.1	7.0	1.20
Opol, Cagayan de Oro	7.2	13.0	0.44
Cabadbaran, Agusan del Norte	7.2	2.6	0.44
Ampagan, Agusan del Norte	7.2	2.6	0.50
Tiniwisan, Agusan del Norte	7.3	7.0	0.64
Butuan, Agusan del Norte	7.3	7.0	0.48
Abilan, Agusan del Norte	7.4	7.6	0.72
San Pablo, Laguna	7.4	5.1	0.48
Tiniwisan, Agusan del Norte	7.7	3.1	0.12
Buenavista, Agusan del Norte	7.7	5.1	0.68
Capudlosan, Agusan del Norte	7.7	3.1	0.12
Caaringayan, Pangasinan	7.9	2.4	0.18
Lipit, Pangasinan	8.0	1.9	0.10
Tiaong, Quezon	8.2	12.8	0.04

[a]By the method of Katyal and Ponnamperuma.

organic soils, molybdenum deficiency in 1 organic soil, iron toxicity in 3 strongly acid soils, and boron toxicity in a soil from a hydrothermal area. All but one of the zinc-deficient soils contained <1 ppm available zinc and had a pH > 7 or high organic matter content. The only acid soil with low organic matter that was deficient in zinc was the continuously wet Banaue soil (Table 8).

Chemical kinetics. A study of the chemical kinetics of the solutions of 10 soils showed that flooding depressed the concentrations of copper and zinc, increased the concentration of molybdenum in the acid soil and depressed it in the alkaline soil, and did not noticeably affect the concentration of boron.

Chemical kinetics of 12 organic soils revealed that

- On submergence pH did not change by more than 0.3;
- The fairly stable redox potential (Eh) values reached after 6 weeks' submergence ranged from +35 mV for a soil from Longos to +204 mV for the soil from Leyte;
- Electrical conductivity (EC) values were <1 mmho/cm. P_{CO_2} reached peak values of 0.30 to 0.46 atm 6 weeks after submergence and declined slowly thereafter;
- Peak Fe^{2+} concentrations ranged from 10 to 190 ppm;
- Mn^{2+} concentrations reached plateaus at levels between 0.1 and 5.4 ppm;
- Concentrations of reducing substances decreased from 3.0 meq/l at the start to 1.4–7.8 meq/l 6 weeks later;
- Zinc concentrations ranged from 0.02 to 0.07 ppm 6 weeks after submergence;
- NH_4^+ concentrations were less than 0.5 ppm 6 weeks after submergence;
- Phosphorus concentrations, with one exception, were less than 0.1 ppm 4 weeks after submergence;
- Potassium concentrations ranged from 1.8 to 4.2 ppm 6 weeks after submergence.

The poor rice yield (Table 9) on those organic soils was associated with deficiencies of nitrogen, phosphorus, and zinc; excess CO_2; and the presence of unknown organic toxins.

LONG-TERM EXPERIMENTS

Water regime and soil nitrogen. A study of the influence of four water regimes on the properties of three soils and the growth of rice was

Table 9. Rice yield[a] on 12 submerged organic soils. IRRI, Philippines, 1976.

Soil source	Yield (g/pot)	
	Straw	Grain
Kalayaan		
1	18.7 g	6.2 e
2	41.8 bc	25.0 ab
3	26.8 efg	18.0 bcd
4	28.5 def	13.1 cde
5	45.1 ab	25.1 ab
6	51.6 a	31.8 a
Lamau		
1	34.6 cde	20.3 bcd
2	26.1 efg	11.4 de
3	33.2 cde	19.9 bc
4	37.8 bc	22.4 b
Longos	37.4 bcd	21.7 b
Alang Alang	21.8 fg	9.8 de

[a]In a column, means followed by the same letter are not significantly different at the 5% level.

started 10 years ago (1967 Annual Report). The water regimes were flood fallow between crops, flood fallow plus midseason soil drying, dry fallow between crops, and dry fallow plus midseason soil drying. Samples of Luisiana clay, Maahas clay, and Pila clay loam were placed in 200-liter drums. At the beginning of each season the first 20 cm of the soil was mixed with the stubble, and fertilizer nitrogen, phosphorus, and potassium at the rate of 100 ppm each were worked into the puddled soil. Analysis of the soils in 1970 revealed that the nitrogen content was more markedly increased by flood fallowing (continuous soil submergence) than by dry fallowing (1970 Annual Report). Soil analysis and plant responses showed that the accumulated nitrogen benefited the rice plants (1973 Annual Report). The experiment was continued without the addition of nitrogen, phosphorus, and potassium fertilizers. Despite the absence of fertilizer nitrogen and the removal of nitrogen by five crops, the soil nitrogen was higher in the flood fallow soils than in the dry fallow (Table 10). Rice benefited from the accumulation of nitrogen (Table 11).

The findings indicate that flood fallowing increases a soil's natural supply of nitrogen and that midseason soil drying releases some of the nitrogen for plant use.

Compost application and nutrient status. In a field experiment to ascertain the long-term effects of ammonium sulfate and urea, with

Table 10. Influence of four water regimes on changes in total nitrogen, averaged for three Philippine soils. 1974–76.

Water regime[a]	Total N content of soil (%)			
	1974 wet	1974 dry	1975 wet	1975 dry
Flood fallow	0.168	0.187	0.178	0.183
Flood fallow with MSD	0.161	0.177	0.173	0.182
Dry fallow	0.121	0.129	0.126	0.135
Dry fallow with MSD	0.110	0.124	0.125	0.130

[a]MSD = midseason soil drying.

Table 11. Influence of four water regimes on the yield of IR26, and nitrogen uptake, averaged for three Philippine soils and four seasons, 1974–76, in the absence of nitrogen fertilizer.

Water regime[a]	Straw (g/drum)	Grain (g/drum)	N uptake (mg/drum)
Flood fallow with MSD	137	133	467
Flood fallow	129	119	450
Dry fallow with MSD	98	104	274
Dry fallow	100	103	302

[a]MSD = midseason soil drying.

and without compost, on soil properties and rice yield, compost at 10 t/ha significantly increased contents of organic matter, nitrogen, and available phosphorus (Table 12).

Straw application and nutrient status. Rice straw left in the fields will supply, per hectare, about 30 kg nitrogen, 5 kg phosphorus, and 150 kg potassium. To ascertain the long-term effects of different straw management practices on the nutrient status of soils, an experiment was started 4 years ago (1973 Annual Report).

Leaving the major nutrients of straw in the field as long straw, compost, or ash increased the nutrient status of Maahas clay on which wetland rice was grown with 150 kg fertilizer

Table 12. Cumulative effect of compost on the nutrient status of Maahas clay for nine seasons.[a] IRRI, Philippines, 1976.

Compost (t/ha)	Organic matter (%)	N (%)	Available P (Olsen) (ppm)
0	4.05 b	0.207 b	22 b
10	5.43 a	0.252 a	35 a

[a]In a column, means followed by the same letter are not significantly different at the 5% level.

Table 13. Influence of four straw treatments on the nutrient status of Maahas clay at the beginning of the ninth season. IRRI, Philippines, 1976.

Treatment	Organic matter (%)	N (%)	Available P (Olsen) (ppm)
Straw removed	3.58 b	0.187 c	23 b
Straw burned in situ	3.74 b	0.206 b	34 a
Straw composted and applied	4.19 a	0.217 b	40 a
Straw plowed in	4.46 a	0.232 a	33 a

Table 14. Influence of straw incorporation on the content of organic matter and nitrogen[a] averaged for three water regimes in 9 seasons. IRRI, Philippines, 1976.

Treatment	Organic matter (%)	N (%)
No straw	3.34 b	0.191 b
Straw (10 t/ha)	4.02 a	0.209 a

[a]In a column, means followed by the same letter are not significantly different at the 5% level.

N/ha per season (Table 13). The relative effects of the straw treatments were apparent after the fourth season and were constant during the past five seasons.

In another long-term field experiment on the influence of three water regimes on the nutrient status of the soil, straw incorporated into the soil at 10 t/ha increased the content of nitrogen and organic matter (Table 14).

The effect of straw at 5 t/ha on the nutrient status of three soils was studied in 200-liter drums. A 17-cm layer of soil in each drum was loosened and mixed with 0.125% (5 t/ha) of chopped straw and 25 ppm nitrogen (50 kg N/ha as urea). Soil analyses revealed higher contents of nitrogen, phosphorus, potassium, and organic matter in the straw-treated soils than in the untreated soils (Table 15). The higher nutrient status was reflected in the rice yield, which was 177 g/drum with the 5 t/ha straw and 158 g/drum with no straw incorporated.

NITROGEN TRANSFORMATIONS

Less than half of the nitrogen applied to rice as fertilizer is used by the crop. Laboratory, greenhouse, and field experiments investigated the

Table 15. Effects of straw incorporation on the nutrient status of three flooded soils after the third cropping season. IRRI, Philippines, 1976.

Straw (t/ha)	Organic matter (%)	N (%)	K (meq/100 g)	Available P (Olsen) (ppm)
		Luisiana clay		
0	2.88	0.145	0.15	1.7
5	3.07	0.173	0.19	5.6
		Maahas clay		
0	2.84	0.150	0.34	23
5	2.90	0.160	0.52	29
		Pila clay loam		
0	2.33	0.116	0.18	14
5	2.45	0.143	0.37	20

causes of the low efficiency of nitrogen utilization.

Nitrogen-supplying power. An incubation study revealed that during 6 weeks' anaerobic incubation, Luisiana clay (pH: 4.8; O.M.: 3.2%) released 64 ppm NH_4^+, while Maahas clay (pH : 6.6; O.M. : 2.0%) released 25 ppm. Straw added at 0.15% by weight did not retard the rate of ammonification.

In a second experiment the nitrogen-supplying power of eight soils that were subjected to continuous submergence and to soil drying between crops was measured by determining nitrogen uptake by IR32 on those soils during four cropping cycles in the greenhouse. The highest nitrogen uptake was from Paete clay loam, the lowest was from Maahas clay. Drying the soil between crops resulted in iron toxicity that killed the plants in Calalahan sandy soil. Drying between crops, however, did not significantly depress the uptake of nitrogen by IR32 in the seven other soils (Table 16). Apparently soil drying between crops on the soils without nitrogen fertilizer did not cause nitrogen loss by denitrification.

Water regime and nitrogen losses. A field experiment was conducted on Maahas clay in the dry season to study the effects of three water regimes at three nitrogen fertilizer levels on rice yield and nitrogen uptake. The experiment was spoiled by typhoon damage, but both yield and nitrogen uptake figures suggest that alternate wetting and drying significantly reduced yield and nitrogen uptake only in the fertilized treatments. Furthermore, nitrogen

Table 16. Influence of soil properties and water regime on nitrogen uptake of four crops of IR32 in the greenhouse. IRRI, Philippines, 1976.

Soil	pH	Organic matter (%)	N (%)	N uptake (mg/kg of soil)	
				Continuously submerged	Dried between crops
Paete clay loam	5.3	10.4	0.35	340	368
Lipa loam	7.0	4.3	0.19	185	154
Pila clay	7.5	3.9	0.19	219	230
Luisiana clay	4.8	2.6	0.18	163	167
Maahas clay	6.5	1.6	0.12	63	58
Quinqua silty loam	6.5	2.2	0.12	139	150
Calalahan sandy loam	3.4	2.7	0.11	115	0
Buenavista clay loam	6.3	1.1	0.07	110	124

Table 17. Exchangeable NH_4^+-N in flooded soils by two methods. IRRI, Philippines, 1976 dry season.

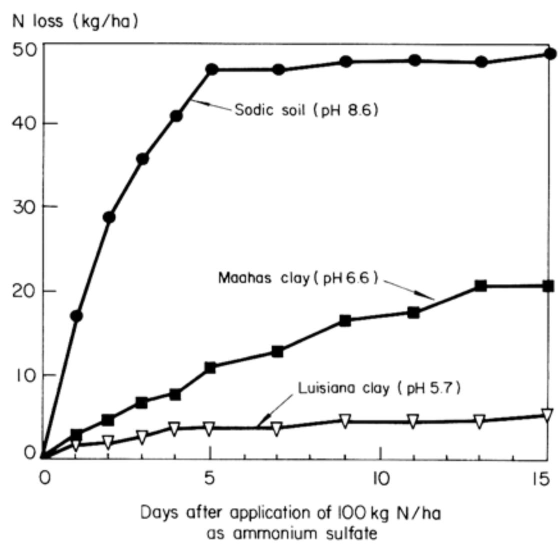
Soil	pH	Organic matter (%)	Exchangeable NH_4^+-N (ppm)		
			Distilling KCL extract with MgO	Distilling soil with MgO	Diff.
Aggaie clay	7.4	1.0	26.7	35.3	8.6**
Buenavista loam	6.3	1.1	66.5	71.5	5.0**
Calalahan sandy loam	3.4	2.7	65.6	76.4	10.8**
Paete clay loam	5.3	10.4	428.9	485.0	56.1**
Luisiana clay	4.8	2.6	68.0	74.0	6.0**
Maahas clay	6.5	1.6	26.2	29.1	2.9*
Pila clay	7.5	3.9	93.5	113.3	19.8**
Quinqua silty loam	6.5	2.2	71.2	77.5	6.3**
Lipa loam	7.0	4.3	56.7	67.3	10.6**
Bani clay	6.1	2.4	21.6	44.3	22.7**
Castañas clay	3.5	3.8	433.5	522.8	89.3**
Cotabato silt clay loam	8.7	1.7	28.9	30.4	1.5
Keelung silt loam	5.4	2.9	85.5	113.1	27.6**
Lam-au A_1 peat	5.3	26.8	362.5	404.1	41.6**
Lam-au A_2 peat	5.5	38.2	435.2	506.9	71.7**
Silo silt loam	7.7	2.0	17.1	21.5	4.4**
Lipa clay loam	7.1	3.9	192.9	227.6	34.7**

CV (among samples with treatment) = 1.2%

losses due to midseason soil drying were apparently less than those on soils that were alternately flooded and dried.

Determination of NH_4^+ in reduced soils. Exchangeable NH_4^+ in dry soils used to be measured by distilling a potassium chloride extract of the soil with magnesium oxide. It has been suggested that the procedure could be simplified by omitting the potassium chloride extraction. Because the latter procedure had not been tested critically with flooded soils, the two methods were compared. Table 17 shows that direct distillation gave inflated values for exchangeable NH_4^+ in each of 17 soils. The increases were highly correlated ($r = 0.96^{**}$) with the organic matter content of the soils.

Fixation of NH_4^+ in soils. Chemical fixation by soil materials can temporarily immobilize



4. Influence of soil properties on cumulative loss of N as NH_3 gas. IRRI, 1976.

NH_4^+ in soils. In 10 Philippine soils the amounts fixed ranged from 3.6% to 27.7% of the added NH_4^+, with 15.5% for Maahas clay.

Losses of nitrogen as ammonia gas. Ammonium or NH_4^+-producing fertilizers broadcast on the surface of flooded soils may lose some of their nitrogen as ammonia gas. Theoretically the loss should increase with increase in pH, temperature, and wind velocity. The pH of any soil containing HCO_3^- will increase sharply as the concentration of CO_2 decreases. That happens when conditions are favorable for algal growth. A study of ammonia losses from three flooded soils (a sodic soil, pH 8.6; Maahas clay, pH 6.6; and Luisiana clay, pH 5.7) confirmed the hypothesis. Both magnitude and rate of loss were highest in the sodic soil and lowest in the acid soil (Fig. 4).

Soil and crop management

Soil fertility management: microbiological studies

Soil Microbiology and Multiple Cropping Departments

BIOLOGICAL NITROGEN FIXATION IN RICE FIELDS
Soil Microbiology Department

Nitrogen fixation in IRRI's long-term fertilizer plots. Assay of the nitrogen fixing (NF) activity in long-term fertilizer plots that received no fertilizer and in plots that received complete (NPK) fertilizer continued during the dry season (24th crop.) Figure la shows the results of in situ assays during the 1975 wet season and 1976 dry season.

Figure 1b shows the weight of algae collected from floodwater. The sum of photo-dependent in vitro NF activity assayed for floodwater, for algal mass collected from water, and for weeds to which algae firmly adhered is shown in Figure 1c. NF activity by photo-dependent microorganisms was higher in the dry season than in the wet season. The photo-dependent NF activity (Fig. 1c) and algal biomass (Fig. 1b) showed peaks at the later stage of rice growth in both seasons, and coincided with the stage when in situ NF activity was highest in each season.

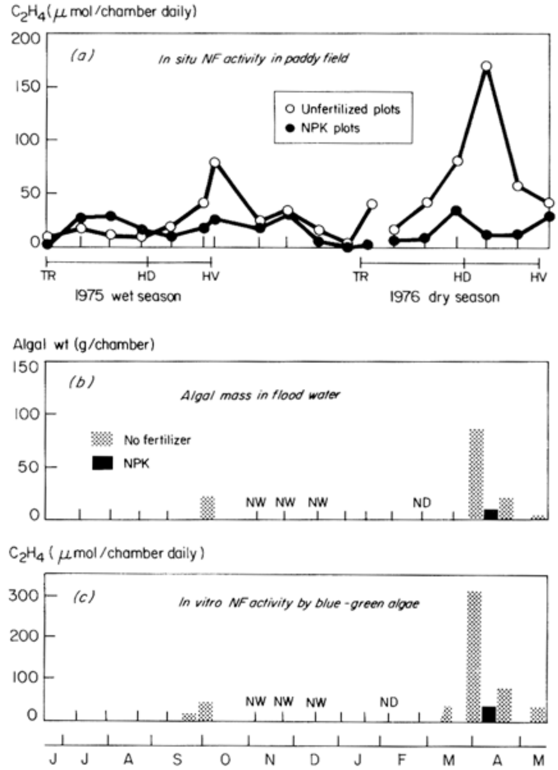
Endogenous ethylene (C_2H_4) formation from soil and plants was negligible in the assayed plots. Close correlation ($r = 0.86$, $n = 49$) between in situ NF activity and in vitro photo-dependent NF activity was found in samples from unfertilized plots, indicating that photo-dependent NF activity in floodwater mainly controls in situ activity around rice plants.

When algal mass was high late in the dry season, a water-replacement experiment was conducted to eliminate the bulk of algal NF activity. Without water replacement, NF activity gave 5,700 μmol C_2H_4/sq m daily. With the elimination of the bulk of blue-green algae, NF activity gave 660 μmol C_2H_4/sq m daily, an amount attributed to NF activity near the roots of the rice plants.

Photo-dependent nitrogen fixation by deep-water rice roots. Nodal roots emerging into water may be a major factor in deep-water rice nutrition. Nodal roots of a deep-water rice (RD6255) grown in a water tank were collected, and their NF activity was assayed under aerobic light and aerobic dark conditions for 3 hours. The roots were classified according to root diameter (thick, medium, and thin) and their activities were assayed separately. NF activity, in nanomoles of C_2H_4 per hour per gram fresh weight, was 260 (light) and 21 (dark) for thick roots; 220 (light) and 70 (dark) for medium roots; and 37 (light) and 7.3 (dark) for thin roots.

Colonies of blue-green algae were found only around the axils of the emerging lateral roots. The colonies were composed of 10 to 20 filamentous cells, and the incidence of heterocyst cells was high. The observation suggests an association between blue-green algae and the nodal roots of deep-water rice.

Nitrogen fixation by *Azolla-Anabaena* association. The nutritional requirements of *Azolla* (species not identified) associated with *Anabaena azollae* were studied by removing iron, calcium, magnesium, phosphorus, or potassium from a



1. Nitrogen fixing (NF) activity and algal mass in long-term fertilizer experiments at IRRI. 1975–76. NW = no water; ND = no determination; TR = transplanting; HD = heading; HV = harvest.

water-culture solution. The deficiency of iron, phosphorus, and calcium affected *Azolla* most and caused low fresh weight, low number of algal cells in the frond cavities, and low rate of nitrogen fixation. Potassium deficiency had less effect, and magnesium deficiency had the least effect.

In a study of the effect of daily average temperatures of 22, 25, 28, and 31°C, with an 8°C difference between day and night, an *Azolla* strain from Bicol, Philippines, was found sensitive to temperature. Daily average temperatures above 22°C affected the color and frond size of *Azolla*, and 31°C caused increased discoloration and lower fresh weight.

The release of ammonia from dried *Azolla* (4.97% N) was studied in a submerged soil (100 mg dried *Azolla*/10 g dry soil) at 30°C. The ammonia formed from the total nitrogen of dried *Azolla*, measured weekly, was 13% up to 1 week incubation, 19% at 2 weeks, 22% at 3 weeks, 46% at 4 weeks, and 75% at 6 weeks. It appears that nitrogen in *Azolla* is of the slow-release type.

The availability of *Azolla* nitrogen was tested in pot experiments, with nitrogen added either as ammonium sulfate or as dried *Azolla* at rates of 0.5 and 1.0 g N/pot. Nitrogen in *Azolla* was slightly less available to rice than was ammonium nitrogen. Nitrogen in the straw and in the grain (relative to nitrogen applied) was 57 and 69%, respectively, for 0.5 and 1.0 g *Azolla* nitrogen, and 88 and 78%, respectively, for 0.5 and 1.0 g of ammonium nitrogen.

Field inoculation experiments with *Azolla* began at IRRI in the dry season. The experiments included *Azolla* inoculation, phosphorus addition, and midseason puddling to assist incorporation of surface-grown *Azolla*. About 1.25 kg (fresh weight) of *Azolla* inoculum prepared in the field was added to a 25-sq-m experimental plot immediately after transplanting (IR30).

Addition of 30 kg P/ha as superphosphate stimulated *Azolla* growth. In phosphorus-treated plots, the surface coverage of *Azolla* 22 and 40 days after incubation was 85 and 96%, respectively. In the plots without phosphorus, it was 62 and 76%, respectively. The plots were drained and *Azolla* was incorporated by a hand weeder 41 days after transplanting.

Table 1. Straw and grain yield[a] of IR30 following three treatments of *Azolla* inoculation. IRRI, 1976 dry season.

Treatment	Straw wt[b] (t/ha)	Grain yield[b] (t/ha)
None	1.01 d	1.48 d
W	1.36 bc	2.36 ab
A	1.54 ab	1.85 c
WA	1.31 bc	2.15 abc
P	1.24 cd	1.86 c
PW	1.30 bc	2.24 bc
PA	1.38 bc	2.02 bc
PWA	1.64 a	2.35 a

[a]P = phosphorus addition; W = midseason puddling; A = *Azolla* inoculation. [b]In each column, means followed by the same letter are not significantly different at the 5% level.

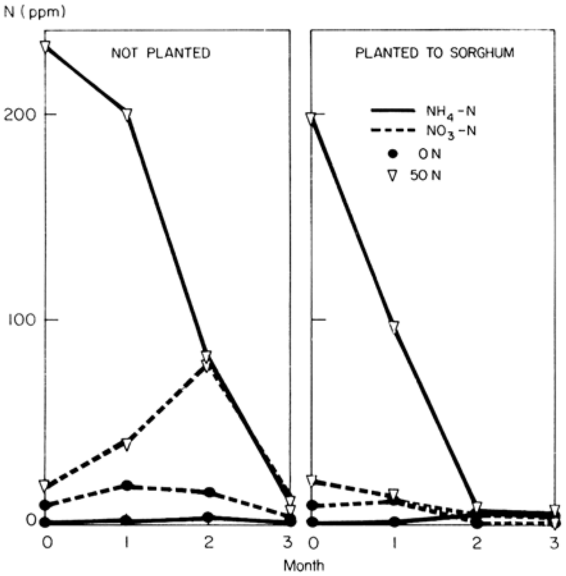
Table 1 shows the yield data. Grain and straw yields were higher in plots with *Azolla* inoculation, added phosphorus, and midseason puddling to incorporate *Azolla* than in the treatment without the three factors. *Azolla* inoculation significantly affected straw yield.

Azolla *inoculum production. Azolla* inoculum was produced by incorporating 2–3 kg (fresh weight) of *Azolla* in half of a 25-sq-m plot. Superphosphate (7.5 kg P_2O_5/ha) and carbofuran (5 kg a.i./ha) were mixed with the *Azolla* immediately before inoculation. In the second week, when the surface of half the plot was almost covered by *Azolla*, about half of the *Azolla* was collected, mixed with phosphorus and carbofuran, and inoculated into the adjacent half-plot. The fresh weight of *Azolla* was 15 t/ha in about 25 days and its nitrogen content was estimated at 30–40 kg N/ha. From April to December (230 days), nine crops of *Azolla* produced about 270–360 kg N/ha. That suggests the potential of growing *Azolla* as an organic fertilizer in an open swamp or canal near a paddy.

NITROGEN TRANSFORMATION IN RICE SOILS

Soil Microbiology and Multiple Cropping Departments

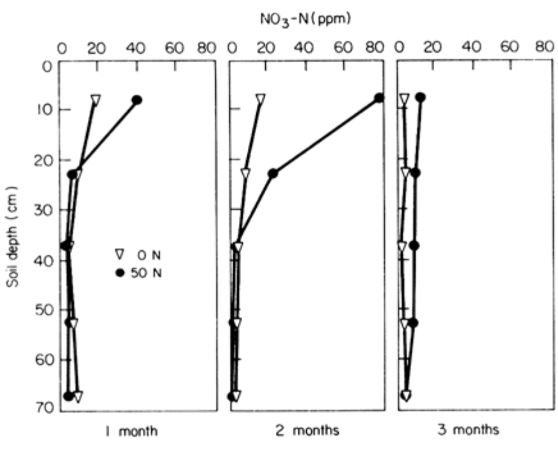
Nitrogen transformation in rainfed and upland rice soils (*Soil Microbiology, Multiple Cropping*). Experiments begun in the 1975 wet season were continued to examine nitrate formation and its vertical distribution and loss during the 1976 dry season at two sites—IRRI, with poor soil



2. Changes in amount of ammonium nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) in the surface soil layer (0–15 cm). IRRI, 1976 dry season.

drainage, and a farmer's field (Cale, Batangas) with good soil drainage.

IRRI field study. Ammonium sulfate was applied at 50 kg N/ha. Changes in the amounts of ammonium nitrogen and nitrate nitrogen in the surface soil (0–15 cm) in both planted (sorghum) and unplanted plots are shown in Figures 2 and 3. The nitrification rate was slower than in the first month of the 1975 wet season (1975 Annual Report) because of low rainfall (28.7 mm).



3. Vertical distribution of nitrate nitrogen (NO_3-N) in the soil profile of unplanted plots 1, 2, and 3 months after application of fertilizer. IRRI, 1976 dry season.

During the second month, with 71.6 mm of rainfall, ammonium nitrogen decreased more rapidly. The remaining ammonia, however, was still higher than that found 2 months after fertilizer application during the wet season. During the third month, with 872 mm of rainfall, the amount of ammonia decreased sharply. Measurement of vertical distribution of nitrate nitrogen showed that the nitrate formed accumulated at the soil surface until 2 months after application and then was lost from the whole layer (down to 75 cm). That sudden disappearance of nitrate may have been related to increased rainfall.

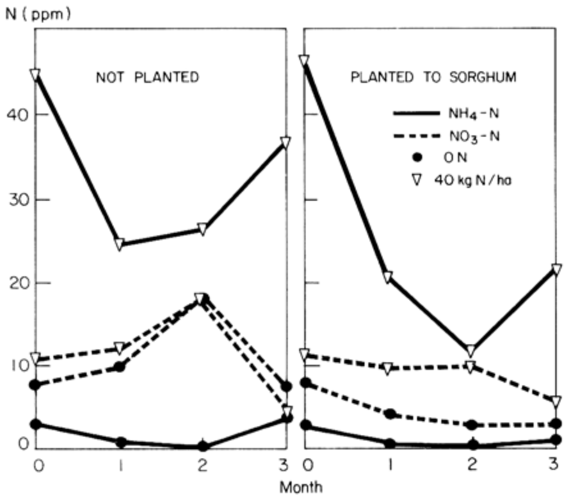
Cale field study. The Cale site was on a slight slope with soil of volcanic origin, which was permeable to water. Forty kg N/ha was uniformly broadcast on both the unplanted and planted (second crop sorghum) plots.

The ammonium nitrogen content at the surface (0–15 cm) layer is shown in Figure 4, and the vertical distribution of nitrate nitrogen down to 75 cm is in Figure 5.

Within 1 month after nitrogen fertilizer application, 45% of the applied ammonium disappeared, but there was no nitrate formation to account for the decrease of ammonium nitrogen. From 2 months to 3 months after fertilizer application, ammonium content increased while nitrate content decreased. The vertical distribution of nitrate shows that nitrate moved upward during the second month after fertilizer application.

Because the nitrate contents of plots with nitrogen fertilizer and without nitrogen fertilizer did not differ greatly, it is likely that nitrification of the applied nitrogen was limited. That was supported by the population of ammonium oxidizers. At the start of the experiment, the most probable number (MPN) of ammonium oxidizers at the surface of the fertilizer plots was 5.5×10^3/g dry soil. Within 1 month after fertilizer application, the MPN decreased to 1.1×10^3. During the second month, it decreased sharply to 1.5×10^2.

The rainfall in Batangas (near Cale) was 25.9 mm, 20.3 mm, and 11.4 mm during the first, second, and third month of the experiment, respectively. Because the soil was almost dry throughout the experiment, nitrification was



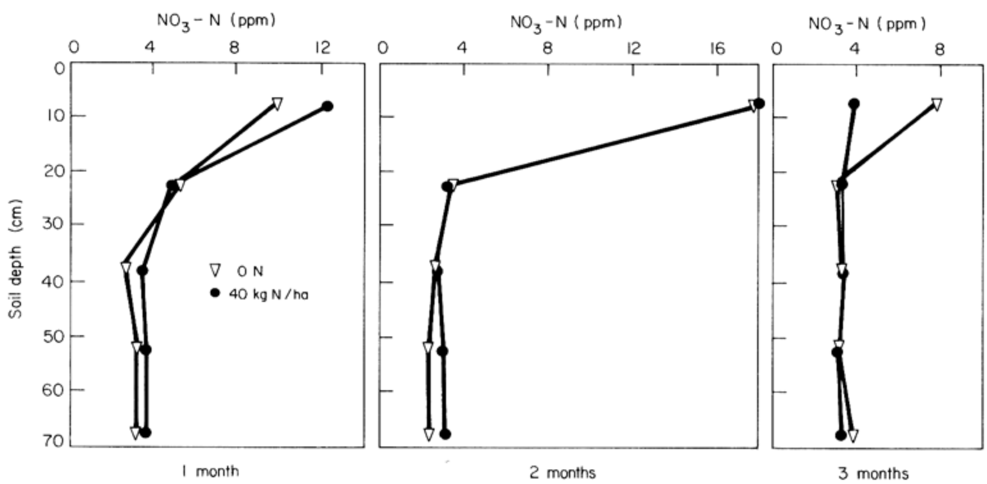
4. Changes in the amount of ammonium nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) in the surface soil layer (0–15 cm). Cale, Batangas, Philippines, 1976 dry season.

only slight, and the nitrifiers were killed. The decrease in nitrate during the third month could not be explained.

Soil condition during dry season and availability of soil nitrogen during wet season (*Soil Microbiology*). Most of tropical Asia's rice fields are rainfed and the soil water condition is unstable. To determine how soil conditions —particularly soil nitrogen availability—during the dry season may affect rice growth, soils in pots were treated to simulate conditions that may occur during the dry season. To label the easily decomposable fraction of soil nitrogen, half of the pots were treated with 15-N labeled ammonium sulfate (17.05 atm % excess) during the 1975 wet season. The other half of the pots were similarly treated with nonlabeled nitrogen.

After harvest of the wet-season crop, these soil conditions were set: 1) flooded planted, 2) flooded unplanted, 3) upland planted, 4) upland unplanted, 5) kept air dried, and 6) kept outdoors. The pots kept outdoors received moisture from occasional rain during the dry season, and all other pots were kept in the greenhouse. To simulate the gradual wetting process in rainfed rice fields after harvest of the dry-season crop, half of the pots kept outdoors were immediately water saturated, puddled, and kept unwatered until cracks appeared in the soil surface. The procedure was repeated once, and then the soil was kept entirely submerged until transplanting. The period between initial watering and transplanting was 20 days. Pots that did not receive N-15 labeled fertilizer in the previous wet-season crop had 100 ppm N, and received N-15 labeled ammonium sulfate and pots that received N-15 labeled fertilizer in the wet season received no ammonium sulfate. The soil in all pots was puddled and remained flooded for 10 days before transplanting.

The changes in tiller number and dry weight at harvest are shown in Table 2. At the early growth stage, rice growth on the continuously



5. Vertical distribution of nitrate nitrogen (NO_3-N) in the soil profile of unplanted plots 1, 2, and 3 months after fertilizer application. Cale, Batangas, Philippines, 1976 dry season.

Table 2. Tillers (no.) and yield[a] of lowland IR28 as affected by different soil conditions in the previous dry season. IRRI greenhouse, 1976 wet season.

Previous dry-season soil treatment[b]	Tillers (no.)				Panicles (no./pot)	Straw wt (g/pot)	Grain wt (g/pot)
	20 DT	40 DT	60 DT	85 DT			
Flooded planted	6 a	28 a	27 a	18 b	18 b	23.6 b	24.0 b
Flooded unplanted	6 a	28 a	27 a	27 a	20 a	27.1 a	26.6 ab
Upland planted	2 b	7 de	10 d	10 f	10 e	13.4 d	16.4 c
Upland unplanted	2 b	10 c	15 c	14 c	12 d	17.2 c	18.7 c
Kept air dried	2 b	15 b	21 b	20 a	19 ab	22.5 b	28.6 a
Kept outdoors	2 b	6 e	11 d	12 e	12 d	14.6 d	18.2 c
Kept outdoors (soil preparation with alternate wet-dry)	2 b	9 cd	15 c	16 c	15 c	18.2 c	23.8 b

[a]In a column, means followed by the same letter are not significantly different at the 5% level. DT = days after transplanting. [b]Average of 2 sets of 4 replications per set.

flooded soil was far better than that in other treatments.

Soil in the pots kept outdoors (almost dry, with cracks during the dry season) had lower soil-nitrogen release, which occurred at a later stage of rice growth during the wet season, than soil that was completely air dried. Scattered wetting by rain probably caused loss of available soil nitrogen. The results gave clues to the management of soil fertility in rainfed rice fields.

Ammonia volatilization following broadcast nitrogen (*Soil Microbiology*). Broadcast applications of ammonium nitrogen in flooded fields just before or soon after transplanting are relatively ineffective in increasing yields. Two mechanisms, a nitrification-denitrification sequence on one hand and ammonia volatilization on the other hand, have been hypothesized. Because of algae consumption of photosynthetic carbon dioxide during daytime, the floodwater pH in IRRI fields is often above 8 and sometimes as high as 10. Such high pH values are conducive to rapid loss of ammonia through volatilization. Four treatments that are likely to influence algal growth were applied to the surface of a 400-sq-cm paddy field enclosed by metal squares. The fertilizer was applied at 1300 hours and water samples were taken at 1300 hours for the first 3 days to determine changes in pH and ammonium nitrogen. After 6 days, the entire amount of soil in each square (to a depth of about 7 cm) was removed and analyzed for ammonium nitrogen. The results are summarized in Table 3. The smaller increase in pH in the area treated with Diuron (inhibiting algae) illustrates the key role of algae. Added ammonium sulfate increased floodwater pH, probably by stimulating algal bloom. The addition of phosphorus stimulated additional algal growth conducive to drastic increase of pH, and, hence, ammonia loss. In Diuron-treated plots, higher amounts of ammonia were found in the floodwater after 3 days.

The results agreed with the expectation that algal activity may be a major factor in stimulat-

Table 3. The influence of various treatments on pH and ammonium nitrogen content of paddy water and soil. IRRI, 1976.

Treatment[a]	pH of water after				NH_4-N (mg/l) in water after			NH_4-N in soil[b] (kg N/ha)
	1 day	2 days	3 days	6 days	1 day	2 days	3 days	After 6 days
AS	8.2	8.6	9.0	9.0	34	15	6	18
Urea	8.8	8.7	9.0	9.5	6	8	8	18
AS + DAP	8.2	8.7	9.7	9.3	45	18	2	15
AS + DIU	7.8	7.8	8.0	8.1	46	28	18	41
None[c]	8.4	8.0	8.3	8.5	0	0	0	—

[a]AS = ammonium sulfate; DAP = diammonium phosphate; DIU = Diuron. [b]Calculated to a depth of 7 cm. The ammonium nitrogen (NH_4-N) content of bulk paddy was 17 kg N/ha on April 20 and 5 kg N/ha on May 9. [c]Bulk paddy that was not treated with nitrogen; less than 0.5 ppm NH_4-N in bulk paddy water at all times.

Table 4. Summary of results of open cans-closed bottles experiments.[a] IRRI, 1976.

Treatment	Nitrogen (kg/ha)		Recovery (%) of added N	Nitrogen estimated lost by volatilization	
	Added	Found		kg/ha	%
– N closed	0	22	—	—	—
+ N closed	40	55	82	—	—
+ N open	40	30	23	25	59
– N closed	0	14	—	—	—
+ N closed	42	50	86 (± 5)	—	—
+ N open	40	27	32 (± 11)	23	54 (± 12)
– N closed	0	15	—	—	—
+ N closed	42	43	70 (± 9)	—	—
+ N open	40	20	12 (± 9)	23	58 (+ 22)
– N closed	0	14	—	—	—
+ N closed	61	67	87 (± 16)	—	—
+ N open	59	53	64 (± 18)	14	23 (± 21)
– N closed	0	10	—	—	—
+ N closed	61	46	59 (± 21)	—	—
+ N open	59	27	28 (± 14)	19	31 (± 20)
– N closed	0	5	—	—	—
+ N closed	60	48	80 (± 5)	—	—
+ N open	60	16	23 (± 15)	31	57 (± 15)

[a]Numbers in parentheses are 1% confidence intervals of means.

ing ammonia loss of the broadcast nitrogen fertilizer.

To estimate the loss of broadcast ammonia, bottomless open cans and bottomless closed bottles were set in the paddy field. At the end of the experiments, water and soil samples were taken and analyzed for inorganic nitrogen.

The results of the experiments (Table 4) indicate the large and rapid loss of nitrogen—as high as 50% for 5 days—that occurs in the open system relative to the closed system. Presumably the loss results largely from volatilization of ammonia. Such rapid loss is unlikely to be a consequence of nitrification-denitrification. The incomplete recovery of added ammonium nitrogen in closed bottles is likely the result of reaction of ammonium nitrogen with the clay into forms not extractable with potassium chloride, a common phenomenon in soils at IRRI. That reaction complicates interpretation of the experiments.

To estimate rate of loss over periods of a few hours, dish experiments were conducted. After application of ammonium nitrogen, paddy water was removed periodically and transferred to flat glass dishes placed in the paddy field. The aliquots in the dishes were analyzed for total volume of water, pH, and ammonium nitrogen. Losses as high as 1 kg N/ha per hour were observed. Losses during the day were usually 1/2 that rate or less; at night they were 1/10 that rate or less. The sum of losses during 2 to 3 days following application was usually less than the losses given in Table 4.

Ammonium loss was also estimated with an aerodynamic method. Ammonia and water vapor concentration in the atmosphere at four heights above the paddy water were measured and the flux of ammonia in the atmosphere was calculated with the equation:

$$\frac{FH_2O}{\triangle V} = \frac{FNH_3}{\triangle N}$$

where FH_2O = flux of water per unit surface area per unit time,
$\triangle V$ = difference in water vapor concentration in air at height Z_1 and Z_2 above water surface,
FNH_3 = flux of ammonium nitrogen, and $\triangle N$ = difference in ammonium nitrogen gas concentration in air at height Z_1 and Z_2 above water surface.

The results of the measurements generally agreed with the observations made through the two previous procedures.

Table 7. Average levels of farmers' inputs and levels of four input management packages, project areas in three provinces, Philippines. 1976 wet season.

Province	Sites (no.)	Package level[a]	Fertilizer (kg/ha)			Insect control[b] (av. no. of applications)				Weed control[c] (av. no. of treatments)	
						Seedbed		Field			
			N	P_2O_5	K_2O	F	G	F	G	M	C
Nueva Ecija	1	M1	23	29	0	1	0	2	1	0	0
Camarines Sur	1	M1	71	17	17	1	0	4	0	3	0
Iloilo	2	M1	54	14	7	0	0	1.5	0	1	0
All three	4	M2	40	10	0	0	0	2	0	1	0
All three	4	M3	60	20	20	0	1	1[d]	0	0	1
All three	4	M4	80	30	30	2	0	1[d]	1	1	1
All three	4	M5	100	40	40	0	2	1	4	1	1

[a] M1 = average of farmers' levels of application of the three inputs by site, insect control, and weed control listed in this table. [b]F = foliar, G = granular. [c]M = mechanical weeding either by hand or rotary weeder; C = chemical weedicide. [d]Root-zone placement of liquid carbofuran.

probably due to the low level of farmers' fertilizer for a dry-season crop (Table 1). Yield at the second intermediate level of fertilizer was 0.8 t/ha above that at the farmers' level (Table 3). A 0.5-t/ha further increase in yield was obtained by applying fertilizer at the high level.

In the management-package experiments on two farms, the test variety gave about 1.0 t/ha yield increase across the five management packages (Table 5). At the farmers' level of inputs, the average test variety yield was 0.4 t/ha higher than that of the farmers' variety. The difference increased to 1.5 t/ha at the M5 level of inputs.

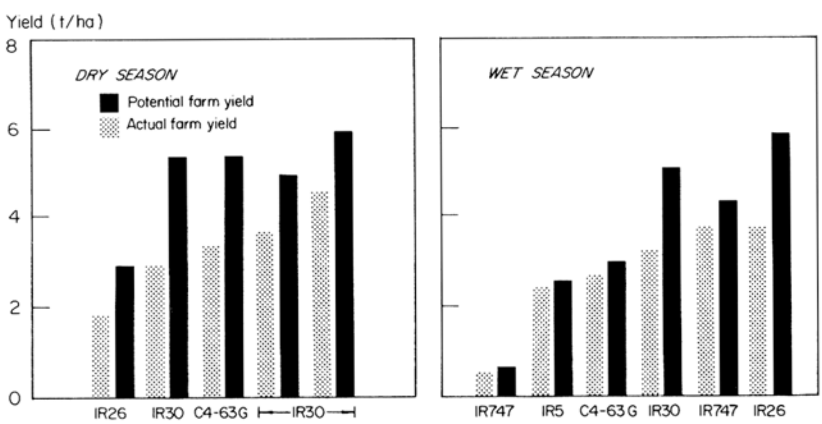
Wet season. The wet-season experiments were on five irrigated farms and one rainfed farm. Farmers' fertilizer levels were lower than those in other sites (Table 1). No fertilizer was applied on one irrigated farm and on the rainfed farm.

Table 8. Average grain yield of farmers' varieties and test varieties compared at five levels of input management packages[a] and grown under high levels of cultural practices, project areas in three provinces, Philippines, 1976 wet season.

Province	Sites (no.)	Variety[b]	Yield (t/ha)					
			M1[c]	M2	M3	M4	M5	Av.
Nueva Ecija	1	F	3.8	3.1	4.8	4.8	4.8	4.3
		T	5.0	5.2	4.5	4.4	4.9	4.8
Camarines Sur	1	F	2.7	2.9	3.2	2.2	1.9	2.6
		T	2.7	2.7	1.9	2.8	2.4	2.5
Iloilo	2	F	4.4	4.4	5.1	5.5	5.8	5.0
		T	4.2	4.2	5.0	5.1	5.4	4.8

[a] Management packages (M1, M2, M3, M4, and M5) contain varying levels of fertilizer, insect control, and weed control as shown in Table 7. [b]Farmers' (F) varieties: IR30, IR1529, and IR26. Test (T) variety: IR36. [c]Farmers' level.

Yields with the farmers' input varied from 0.5 t/ha on the rainfed farm, which had irregular rainfall, to 5 t/ha, averaging 2.7 t/ha (Table 2).



Soil and crop management

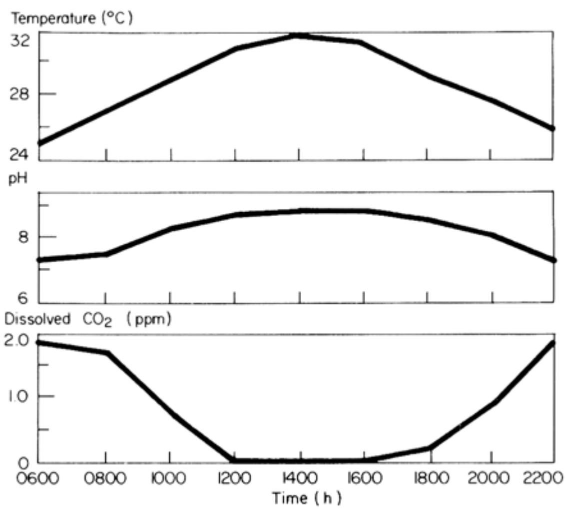
Soil fertility and fertilizer management

Agronomy and Soil Chemistry Departments

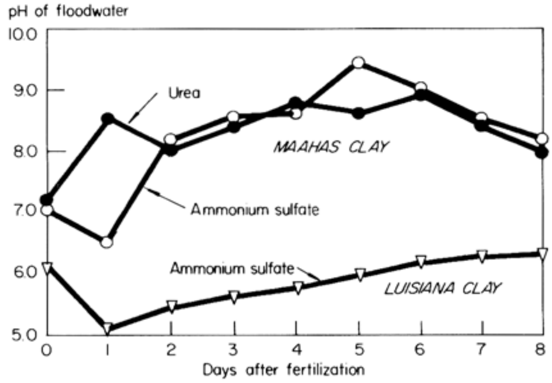
Seldom does the rice crop recover more than 30–40% of the nitrogen fertilizer applied to it. During 1976, studies included some of the basic issues on nitrogen fertility of soils, and management practices that affect nitrogen fertilizer efficiency on lowland and upland rice.

Diel fluctuations of pH, temperature, and dissolved carbon dioxide in floodwater. In aquatic plant systems such as those that occur with rice, factors affecting photosynthesis and respiration directly influence the carbonate equilibrium of the floodwater and indirectly alters pH. During the daylight hours the high photosynthetic carbon requirement stimulates rapid removal of carbon dioxide from the aquatic system. A net carbon dioxide release to the system is typical of conditions during the night when respiratory processes enrich the supply. Typical diel fluctuations of pH, temperature, and dissolved carbon dioxide in floodwater are shown in Figure 1.

Effects of nitrogen sources on floodwater pH. The effects of aquatic biota on water pH are great, but the application of nitrogen fertilizers may also temporarily alter the pH of the water regime. Ammonium sulfate may temporarily decrease water pH, while urea may increase it. After the initial effect of the dissociation and hydrolysis of fertilizer salts, the aquatic biota then assumes a prominent role in regulating the pH of paddy water. Figure 2 shows the effect on pH of ammonium sulfate and urea broadcast on the paddy water on Maahas clay and Luisiana clay during the wet season.



1. Diel fluctuations of temperature, water pH, and dissolved CO_2 in Maahas clay, 3 days after fertilization with 60 kg N/ha. IRRI, 1976.

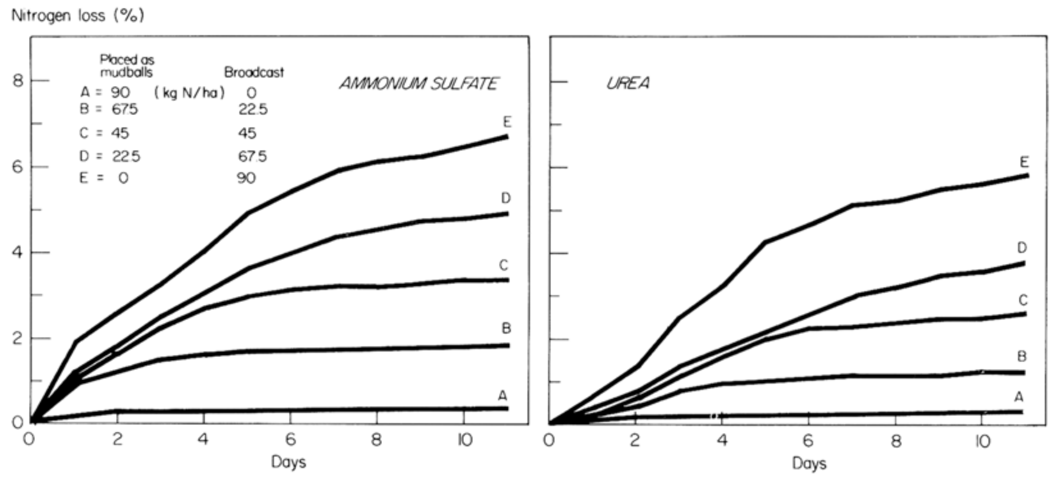


2. Effect on pH of paddy water of broadcast nitrogen at 60 kg N/ha applied as ammonium sulfate and urea. Maahas and Luisiana soils, IRRI 1976 wet season.

Under the influence of aquatic biota, the measurement and proper quantification of ammonia volatilization losses in the field meet considerable technical problems. Several techniques for evaluating ammonia volatilization were tried with no consistent results.

Placement effects on minimizing nitrogen losses. To determine the effect of fertilizer placement on ammonia volatilization losses in newly transplanted paddy, variable proportions of ammonium sulfate and urea were either broadcast or applied in mudballs. The broadcast treatments were made into about 5 to 8 cm of standing water, and the mudballs were placed 10 to 12 cm deep in the soil between alternate hills. The losses of ammonia nitrogen measured by trapping in acid are shown in Figure 3.

Slightly more nitrogen was lost from broadcast ammonium sulfate than from urea during the 11-day period immediately after application. Ammonia losses from ammonium sulfate occurred somewhat earlier and at a higher rate than losses from urea, which showed a definite time lag in volatilization. Because direct



3. Ammonia volatilization loss (% of total application) on Maahas clay as affected by source and placement. IRRI, 1976 wet season.

volatilization from water depends on the quantity of ammonium present in the water, presumably the hydrolysis of urea to ammonium was inhibited by low urease activity in the floodwater.

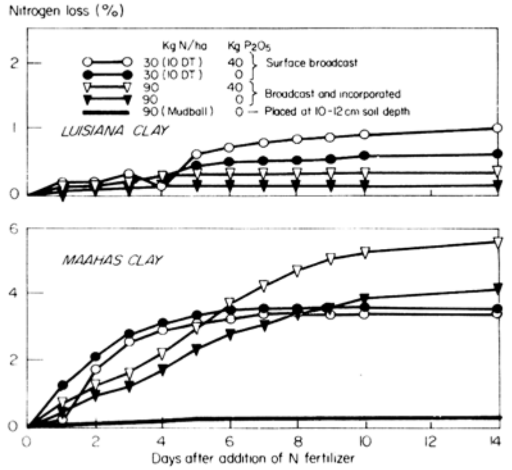
The ammonia volatilization losses from broadcast ammonium sulfate during the overcast wet season amounted to about 6.8% of the total nitrogen applied. The losses were proportionally less with increasing levels of fertilizer applied by deep placement. Ammonia volatilization losses from the 90 kg N/ha in mudballs were about 0.25% of the amount applied.

Similar trends in ammonia volatilization losses were observed in urea, except that the total percentage loss from the all-broadcast treatment reached a maximum of 5.8% during the first 11 days after treatment. Losses from placement of mudballs reduced the ammonia volatilization losses to about 0.25% of the amount applied, as in similar ammonium sulfate treatments. The results suggest that proper fertilizer placement techniques minimize ammonia volatilization losses and increase nitrogen-use efficiency.

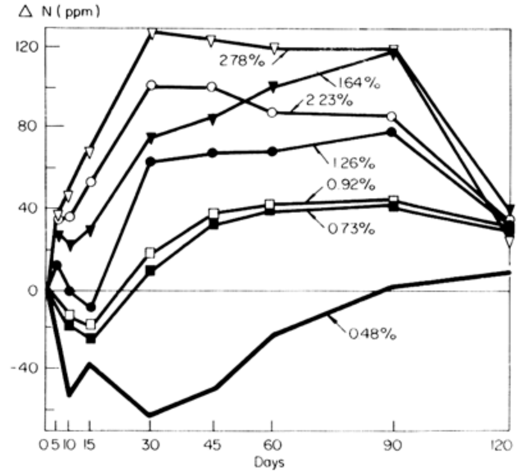
Nitrogen losses as affected by pH, and time and method of application. Rice growers in Southeast Asia use a wide variety of practices to apply nitrogen to lowland rice. In many instances, the deep placement of nitrogen (mudball or similar techniques) significantly improved the efficiency of plant nitrogen uptake. Broadcasting ammonium nitrogen onto the surface of alkaline soils, or into water made alkaline as a consequence of carbon dioxide assimilation by photosynthesizing aquatic species can result in significant losses of fertilizer nitrogen.

Ammonia losses by direct volatilization were evaluated with ammonium sulfate applied by various methods on neutral Maahas clay (Tropudalf) and acid Luisiana clay (Tropaquept) soils. With the use of a 0.1 N sulfuric acid entrapment system, where a constant flow of air replaces the atmosphere hourly, direct ammonia volatilization losses during a 14-day period were measured. Treatments compared were 30 kg N broadcast 10 days after transplanting, 90 kg N broadcast and incorporated in a basal application, and 90 kg N in mudballs 10 to 12 cm deep between the hills of transplanted rice. Nitrogen was broadcast alone and, in some treatments, with phosphorus as superphosphate. The cumulative nitrogen losses from the soil (volatile ammonia), as the percentage of the quantity applied, are shown in Figure 4.

On the acid Luisiana soil, ammonia volatilization was favored by the broadcast phosphate, which stimulated the growth of algae and produced a slightly higher water pH than that in the nitrogen broadcast treatments without phosphorus. Ammonia volatilization losses from broadcast and incorporated ammonium sulfate



4. Cumulative loss thru volatilization of nitrogen added to flooded soil in a greenhouse experiment. IRRI, 1976 wet season.



5. Effect of N content (0.48–2.78%) of rice straw on the changes in extractable mineral nitrogen in Maahas clay at 32°C. IRRI, 1976.

(90 kg N/ha) were about 0.25% of the total applied, or about 2.3 kg N/ha. Phosphorus additions also enhanced volatilization losses, but to only a small extent. Where nitrogen was applied by mudball placement, no volatile ammonia was detected above the natural background level.

On Maahas soil, phosphorus applied to the field stimulated algal growth and produced a higher floodwater pH that enhanced volatilization losses. Mudball placement at 90 kg N/ha showed about 0.25% loss, which was just measurable above the natural ammonia background level. Results suggest that deep placement of nitrogen, or broadcasting and thorough incorporation—depending on soil type—greatly minimizes the volatile ammonia losses on flooded, nitrogen-fertilized rice fields.

Effects of straw nitrogen composition and temperature on the mineralization and immobilization of nitrogen. Incorporating crop residues, especially rice straw, into the soil is receiving increased attention as a means of maintaining the fertility of flooded rice soils.

Temperature is a major factor affecting the activity of microorganisms and the decomposition rate of rice straw. Within the favorable range, the growth and metabolism of specific organisms will increase twofold to threefold for each 10°C temperature increase.

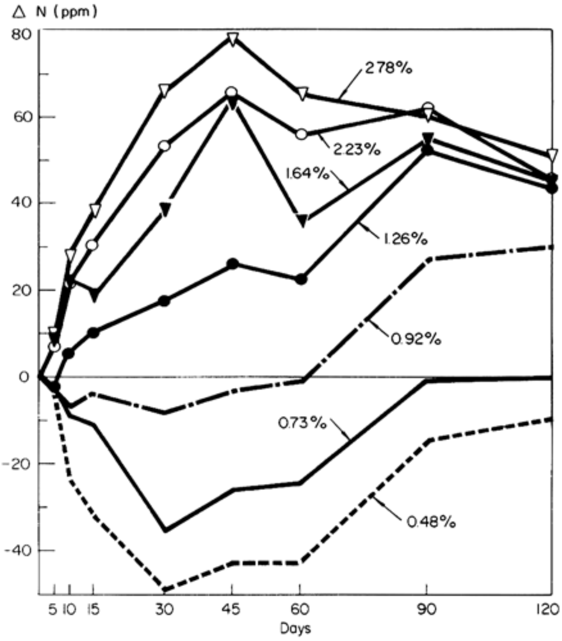
The amounts of mineral nitrogen (exchangeable NH_4^+ extractable NO_3^- N) produced by incubating rice straw containing 100 ppm N (from rice straw of different nitrogen compositions) at temperatures of 12, 22, and 32°C are shown in Figures 5 to 10. The figures give the changes in nitrogen immobilized or mineralized over a period of 120 days on Maahas clay and Luisiana clay incubated in the laboratory.

On Maahas clay at 32°C, rice straw with greater than 1.26% N released nitrogen soon after it was incorporated into the soil (Fig. 5). The magnitude of mineralized nitrogen was roughly proportional to the original nitrogen content of the rice straw.

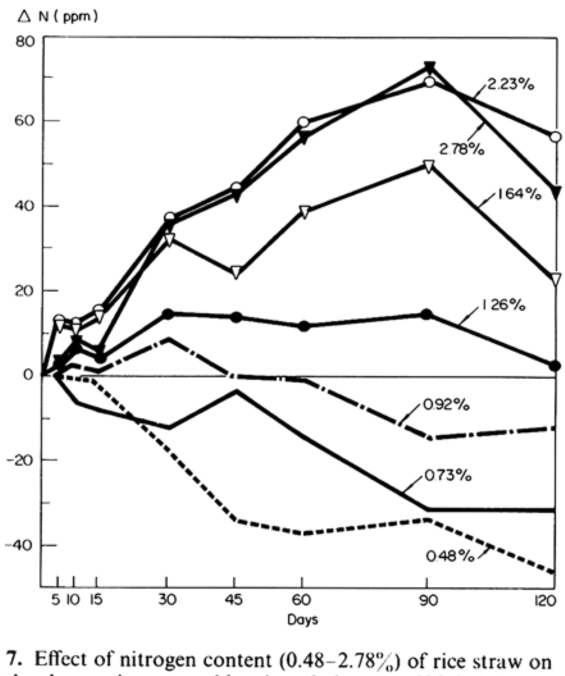
On Maahas clay at 22°C, nitrogen was released almost immediately from rice straw with greater than 1.26% N, but the extent of mineralization (Fig. 6) was much more reduced than at 32°C.

At 12°C on Maahas clay, straw with more than 1.26% N released mineral nitrogen to the soil system, but at a considerably lower rate and intensity (Fig. 7) than at 22°C and 32°C.

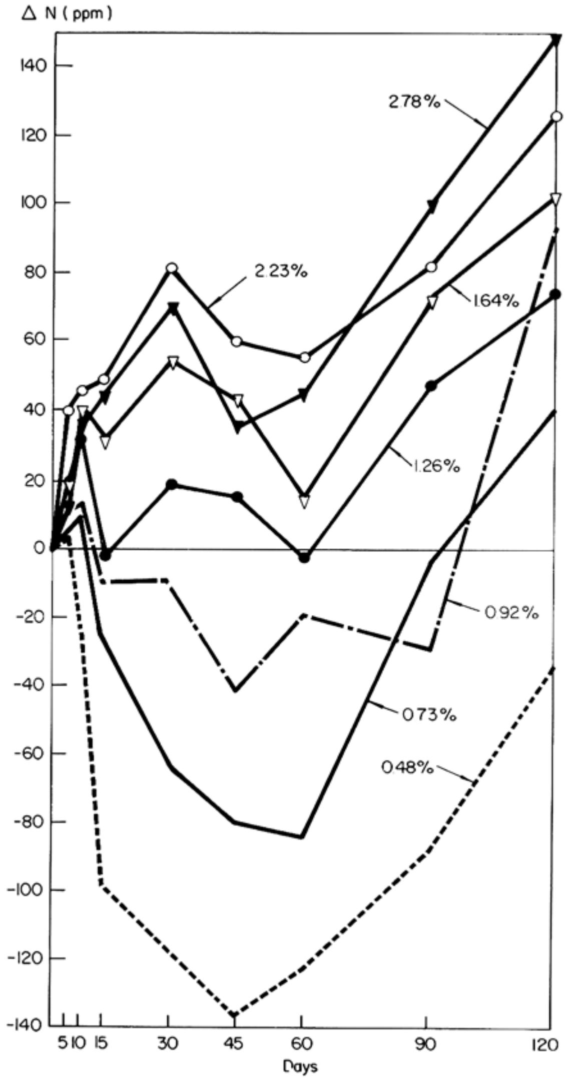
Luisiana soil, with added straw containing 100 ppm N (from rice straw of different nitrogen compositions), was incubated in flooded soil and sampled at various times up to 120 days.



6. Effect of nitrogen content (0.48–2.78%) of rice straw on changes in extractable mineral nitrogen (ΔN) in Maahas clay at 22 C. IRRI, 1976.



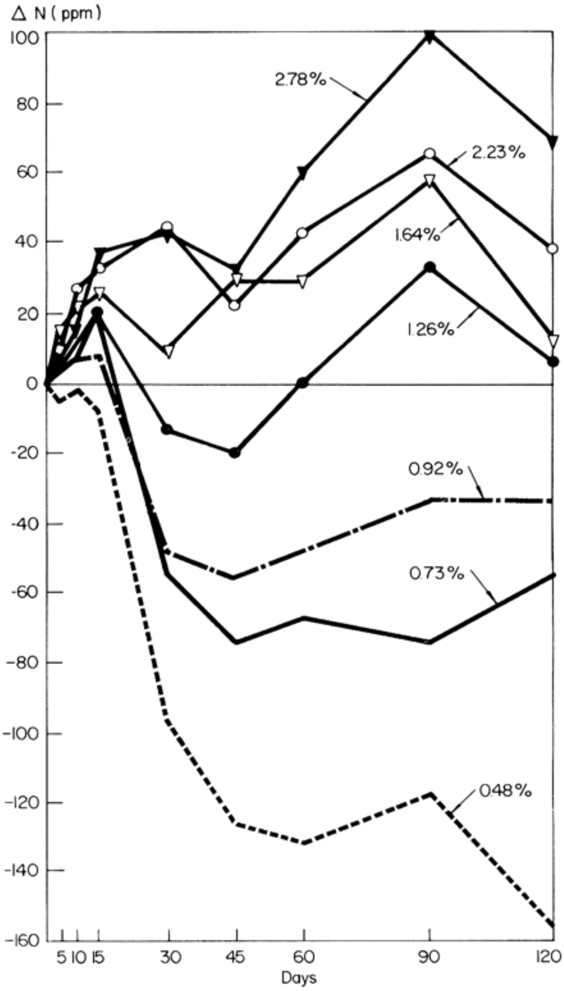
7. Effect of nitrogen content (0.48–2.78%) of rice straw on the changes in extractable mineral nitrogen (ΔN) in Maahas clay at 12 C. IRRI, 1976.



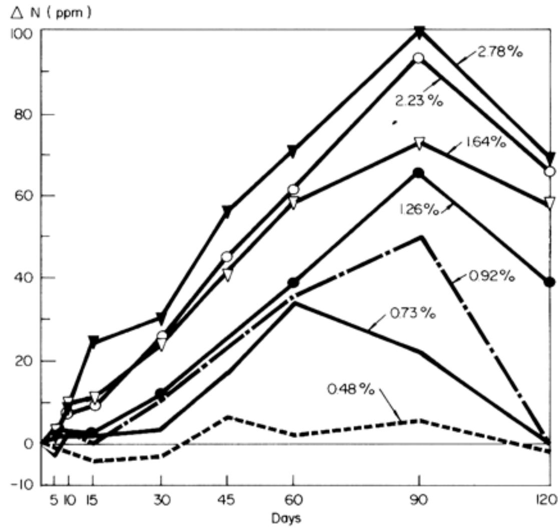
8. Effect of nitrogen content (0.48–2.78%) of rice straw on the changes in extractable mineral nitrogen (ΔN) in Luisiana clay at 32 C. IRRI, 1976.

At 32°C (Fig. 8) the straw with greater than 1.26% N released nitrogen, but in a pattern different from that in Maahas soil. After an initial increase in mineralized nitrogen, a temporary lag occurred, followed at 60 days of incubation by a near-linear release pattern that persisted until the incubations terminated at 120 days.

Incubated at 22°C (Fig. 9) Luisiana clay was marked by both retarded mineralization and



9. Effect of nitrogen content (0.48–2.78%) of rice straw on the changes in extractable mineral nitrogen (ΔN) in Luisiana clay at 22°C. IRRI, 1976.



10. Effect of nitrogen content (0.48–2.78%) of rice straw on the changes in extractable mineral nitrogen (ΔN) in Luisiana clay at 12°C. IRRI, 1976.

immobilization of straw nitrogen. Note that straw decomposition related to nitrogen mobilization-immobilization in Luisiana clay at 12°C showed virtually no net nitrogen immobilization, except for a 30-day duration with straw containing 0.48% N (Fig. 10).

The results of the experiments on Maahas and Luisiana soils indicate that the amount and rate of release of nitrogen increased with increasing temperature levels and, generally, in proportion to the nitrogen composition of the straw. The higher the temperature, the greater the amount and the faster the rate of nitrogen release. Temperature levels affected nitrogen immobilization, but to a lesser degree than they did nitrogen mineralization.

Luisiana soil, with a pH of 5.1 (1:1 water-to-soil ratio) and 3.14% organic matter behaved differently in some respects of mobilization-immobilization from Maahas clay with a pH of 6.0 (1:1) and 1.99% organic matter.

PLACEMENT OF FERTILIZER NITROGEN
Agronomy Department

Irrigated rice. A field experiment at IRRI during the dry season evaluated the effect of placement of urea in mudballs and as supergranules on fertilizer nitrogen efficiency. Another treatment consisted of sulfur-coated urea (SCU) broadcast and incorporated during land preparation. The test varieties were early maturing IR36 and the medium maturing IR26. Average data for the two varieties showed that urea in mudballs and as supergranules, and SCU applied basally at 56 kg N/ha gave yields comparable with those with urea at 150 kg N/ha applied in split doses (Table 1). At 56 kg N/ha the difference between supergranules and urea applied in split doses was not significant.

During the wet season, nitrogen efficiency

Table 1. Effects of methods of nitrogen application on grain yield of irrigated IR26 and IR36 rices. IRRI, 1976 dry season.

Method of nitrogen application, and sources	Grain yield (t/ha)		
	IR26	IR36	Mean[a]
No nitrogen fertilizer	3.2	3.3	3.3 c
56 kg N/ha			
Split application, urea[b]	4.5	4.4	4.5 b
Placement as supergranule	5.1	4.9	5.0 ab
Sulfur-coated urea, broadcast and incorporated	5.7	5.0	5.3 a
Placement of mudballs	6.1	5.3	5.7 a
150 kg N/ha			
Split application, urea[b]	5.4	5.7	5.5 a

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]2/3 basal+1/3 5 to 7 days before panicle initiation.

trials were formalized under the International Network on Fertilizer Efficiency in Rice (INFER) program. Eleven fertilizer treatments developed jointly by rice scientists of South and Southeast Asia during the 1976 International Rice Research Conference were evaluated at IRRI and in three Philippine farmers' fields. IR26 and IR36 were the test varieties.

The interaction between fertilizer and variety was not significant, and the data for the two varieties were averaged (Table 2). The mean grain yield at 28 kg N/ha was significantly higher than the grain yield without fertilizer nitrogen. The grain yield at 56 kg N/ha was except for the treatments with SCU and mudballs. At 56 kg N/ha, the SCU treatment gave significantly higher yields than those with supergranules or urea as split application or as liquid band placement, but it gave yields comparable with those at 80 kg N/ha as urea applied in split doses.

Efficiency of fertilizer nitrogen on different soil types. During the dry season, experiments were conducted in two farmers' fields in Nueva Ecija (Muñoz and San Jose) on a Vertisol and in one farmer's field in Rizal on an Ultisol. Blanket application of 30 kg P_2O_5/ha and 10 kg K_2O/ha was made on both sites. Intermediate maturing IR26 was the test variety.

Fertilized plots gave significantly higher grain yields than the unfertilized ones except in San Jose, where the yields from the unfertilized plots were comparable with those from plots with 56 kg N/ha applied as SCU, urea supergranules, and urea placed in a band (Table 3). In the San Jose trial, water shortage during the reproductive and ripening stages of the crop caused poor crop and poor fertilizer response.

Table 2. Effects of methods of nitrogen application on grain yield of irrigated IR26 and IR36 rices. IRRI, 1976 wet season.

Method of nitrogen application	Grain yield (t/ha)		
	IR26	IR36	*T*-mean[a]
No fertilizer nitrogen	3.5	3.8	3.7 d
28 kg N/ha			
Split application of urea[b]	4.5	4.9	4.7 c
Band placement (urea solution)	4.7	4.9	4.8 c
Mudball	4.2	5.1	4.6 c
Supergranule	4.4	4.8	4.6 c
Sulfur-coated urea, broadcast and incorporated	4.7	5.4	5.0 bc
56 kg N/ha			
Split application of urea[b]	5.0	4.9	4.9 bc
Band placement (urea solution)	4.9	5.2	5.0 bc
Mudball	5.4	5.3	5.3 ab
Supergranule	5.0	5.1	5.0 bc
Sulfur-coated urea, broadcast and incorporated	5.6	5.4	5.5 a
80 kg N/ha			
Split application of urea[b]	5.3	5.2	5.2 ab

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]2/3 basal+1/3 5 to 7 days before panicle initiation.

Table 3. Effects of methods of nitrogen application on the grain yield of IR26 rice. Farmers' fields in Nueva Ecija and Rizal provinces, Philippines, 1976 dry season.

Method of nitrogen application	Grain yield[a] (t/ha)		
	Nueva Ecija		Rizal (Teresa)
	San Jose	Muñoz	
No nitrogen	2.9 cd	2.7 c	3.1 c
56 kg N/ha			
Split application of urea[b]	3.0 b	3.7 b	4.4 b
Placement as supergranule	2.9 cd	3.9 b	4.6 b
Sulfur-coated urea, broadcast and incorporated	3.0 bc	4.0 ab	4.1 b
Band placement (urea solution)	2.8 d	3.7 b	4.8 b
Granular band placement of urea	2.8 d	3.8 b	4.6 b
112 kg N/ha			
Split application of urea[b]	3.1 b	4.1 ab	4.8 b
150 kg N/ha			
Split application of urea[b]	4.0 a	4.7 a	5.7 d

[a]In a column, means followed by the same letter are not significantly different from each other. [b]2/3 basal+1/3 5 to 7 days before panicle initiation.

Table 4. Effects of different methods of nitrogen application on the grain yield of IR26 and IR36 rices. Tanay, Rizal province, Philippines, 1976 wet season.

Method of nitrogen application	Grain yield (t/ha)		
	IR26	IR36	Mean[a]
No fertilizer nitrogen	3.6	3.0	3.3 e
28 kg N/ha			
Split application of urea[b]	4.6	3.9	4.2 d
Band placement (urea solution)	4.8	4.1	4.4 d
Mudball placement	4.9	4.1	4.5 cd
Supergranule placement	4.5	4.2	4.4 d
Sulfur-coated urea, broadcast and incorporated	4.4	4.0	4.2 d
56 kg N/ha			
Split application of urea[b]	5.0	4.6	4.8 bc
Band placement (urea solution)	5.5	4.7	5.1 ab
Mudball placement	5.4	4.5	4.9 ab
Supergranule placement	5.3	4.6	5.0 ab
Sulfur-coated urea, broadcast and incorporated	5.5	4.6	5.0 ab
80 kg N/ha			
Split application of ammonium sulfate	5.6	4.8	5.2 a
Mean	4.9	4.2	

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]2/3 basal+1/3 5 to 7 days before panicle initiation.

Table 5. Effects of different methods of nitrogen application on the grain yield of IR36 rice. Farmers' fields in Teresa, Rizal province, and Luisiana, Laguna province, Philippines. 1976 wet season.

Method of nitrogen application	Grain yield[a] (t/ha)	
	Teresa (Rizal)	Luisiana (Laguna)
No nitrogen	2.8 e	3.1 c
28 kg N/ha		
Split application of urea[b]	3.8 d	3.8 bc
Liquid band placement	3.9 d	3.7 bc
Mudball placement	4.2 cd	3.9 abc
Placement as supergranule	3.9 d	3.8 bc
Sulfur-coated urea, broadcast and incorporated	4.0 d	4.0 ab
56 kg N/ha		
Split application of urea	4.4 bc	4.3 ab
Liquid band placement	4.6 ab	4.4 ab
Mudball placement	4.6 ab	4.8 a
Supergranule placement	4.5 bc	4.5 ab
Sulfur-coated urea, broadcast and incorporated	4.8 ab	4.5 ab
80 kg N/ha		
Split application of ammonium sulfate	4.8 a	4.8 a

[a]In same column, means followed by the same letter are not significantly different from each other. [b]2/3 basal + 1/3 5 to 7 days before panicle initiation.

During the wet season, the trials became part of the INFER program. Two farmers' fields in Rizal (Tanay and Teresa) and one in Laguna (Luisiana) were chosen to represent an acid ultisol. In Tanay, varieties IR36 and IR26 were used, and in Teresa and Luisiana only IR36 was the test variety. The blanket application of phosphorus and potassium was raised to 40 kg/ha each of P_2O_5 and K_2O.

In the Tanay trial, average data for IR36 and IR26 rices showed no significant grain yield differences among treatments at a given fertilizer level (Table 4). However, 80 kg N/ha as ammonium sulfate in split application gave significantly higher grain yields than 56 kg N/ha as urea, also in split application.

IR36 without fertilizer nitrogen gave significantly lower grain yields than fertilized IR36, except at Luisiana where it gave yields comparable with those from plots with 28 kg N/ha applied in split doses, or placed in mudballs or as supergranules. At Luisiana, 28 kg N/ha as mudballs or as SCU gave yields similar to those from plots with 80 kg N/ha as ammonium sulfate in split doses (Table 5).

Nitrogen efficiency in rainfed rice. During the wet season, a nitrogen efficiency trial used IR26 and IR36 in rainfed plots.

In general, grain yields under different methods of application were similar. However, at 28 kg N/ha, band placement of urea solution gave significantly higher grain yield (average of two varieties) than split application and supergranule placement at the same rate (Table 6).

EFFECTS OF PLANTING DATE AND TIME OF NITROGEN APPLICATION ON RICE YIELD RESPONSE

Agronomy Department

Field experiments at IRRI during the dry and wet seasons of 1975 (first planting was in January 1975, last harvest was in April 1976) examined the optimum time of planting and time of nitrogen application to get maximum rice yield.

A split-split plot design with three replications was used, with time of planting in the main plots, variety in the subplots, and the combination of nitrogen levels and times of application in the sub-subplots. The early maturing rice IR28 and the intermediate maturing rice IR26 were the test varieties. Ammonium

Table 6. Effects of methods of nitrogen application on the grain yield of IR26 and IR36 rices. IRRI, 1976 wet season (rainfed).

Method of nitrogen application	Grain yield[a] (t/ha)			
	IR26	IR36	Mean	
No nitrogen	2.9	1.9	2.4	g
28 kg N/ha				
Split application of urea[b]	4.6	3.4	4.0	ef
Band placement (urea solution)	4.8	4.5	4.7	bcd
Mudball placement	4.9	4.1	4.5	cde
Supergranule placement	4.3	3.6	3.9	f
Sulfur-coated urea, broadcast and incorporated	4.9	3.6	4.3	def
56 kg N/ha				
Split application of urea[b]	5.3	4.6	5.0	bc
Band placement (urea solution)	5.2	4.9	5.0	b
Mudball placement	4.3	5.3	4.9	bc
Supergranule placement	5.0	4.9	5.0	b
Sulfur-coated urea, broadcast and incorporated	5.2	5.0	5.2	b
80 kg N/ha				
Split application of urea	5.9	5.3	5.6	a

[a]In a column, means followed by the same letter are not significantly different at the 5% level. [b]2/3 basal + 1/3 5 to 7 days before panicle initiation.

sulfate was applied to both varieties at rates of 30, 60, and 120 kg N/ha in the dry-season plantings (January to June), and 30, 60, and 90 kg N/ha in the wet-season plantings (July to December). Superphosphate and muriate of potash as basal applications were applied at 30 kg P_2O_5 and 30 kg K_2O/ha. The basal application was broadcast and incorporated, and nitrogen was topdressed on paddy water.

Nitrogen was applied at the following growth stages: 1 day before transplanting, 10 days after transplanting, 20 days after transplanting in IR28 and 30 days after transplanting in IR26, 5 to 7 days before panicle initiation, and panicle initiation.

The results suggest that with favorable solar energy levels of the dry season, the optimum time of nitrogen application depended upon nitrogen levels; with the low solar energy levels of the wet season (each variety responded differently to the environment and had lower responses to nitrogen levels), the effects of time of nitrogen application were governed by planting time and variety.

The effects of time of nitrogen application on grain yield and yield components for the dry season are summarized in Table 7. During the dry season, nitrogen at low levels could be applied once or in split doses. At a low nitrogen level increased grain yields were determined by four yield components: panicle number per hill, number of spikelets per panicle, percentage of unfilled grains, and weight of 100 grains. At high nitrogen level, however, increasing grain yields were determined by three yield components: panicle number per hill, spikelet number per panicle, and percentage of unfilled grains. It seems that in the wet season, split application increased fertilizer efficiency in both varieties (Table 8). Nitrogen applied at 5 to 7 days before panicle initiation frequently gave the highest grain yields (Table 7, 8).

The results suggest that environmental conditions severely limited the growth and yields of both IR28 and IR26. The plant stress they caused could not be overcome by increasing nitrogen levels, unless the varieties used were adapted to such conditions. The experiments suggest that yield can be increased by more than 1.0 t/ha when nitrogen is applied at the appropriate time based on level of solar energy. In a given harvest month and at a given solar

Table 7. The highest and the lowest grain yields obtained with a particular time of nitrogen application in the dry-season plantings. IRRI, 1975–76.

Nitrogen level	Grain yield[a] (t/ha)			Determining component			
	Highest	Lowest	Difference	Panicles per hill	Spikelets per panicle	Unfilled-grain percentage	100-grain wt
30 kg/ha	4.0(4,8,1)	3.7(3)	0.3	+	+	+	+
60 kg/ha	4.7(4,6)	4.2(2)	0.5	+	+	–	–
120 kg/ha	5.5(8)	5.0(2)	0.5	+	+	+	–

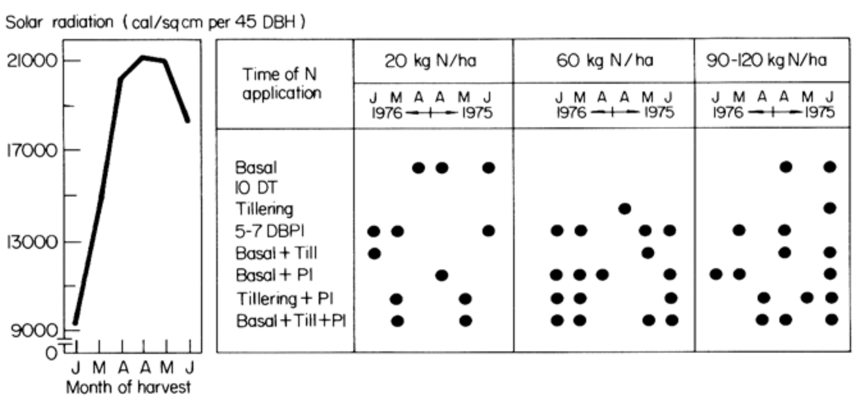
LSD (0.05) = 0.2 t/ha.
[a]Numbers in parentheses refer to time of N application: (1) basal, (2) 10 days after transplanting, (3) tillering, (4) 5–7 days before panicle initiation, (6) basal + panicle initiation, (8) basal + tillering + panicle initiation.

Table 8. The highest and the lowest grain yields obtained with a particular time of nitrogen application as affected by planting times in the wet season. IRRI, 1975–76.

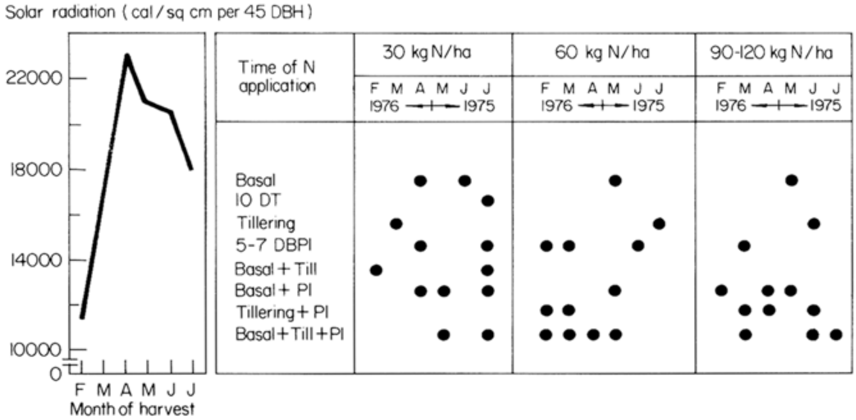
Planting time	Grain yield[a] (t/ha)			Determining component			
	Highest	Lowest	Difference	Panicles per hill	Spikelets per panicle	Unfilled-grain percentage	100-grain wt
			IR28				
July	3.9(4)	2.5(2)	1.4	+	–	+	–
August	3.4(8)	3.1(2)	0.3	+	–	–	–
September	3.4(3)	3.0(6)	0.4	+	+	–	–
October	3.3(6)	2.7(2)	0.6	+	–	–	–
November	3.5(4)	2.8(1)	0.7	+	+	–	–
December	4.3(6)	3.6(3)	0.7	+	–	–	+
			IR26				
July	3.6(5,8)	2.8(2)	0.8	+	+	–	–
August	3.6(8)	3.2(2)	0.4	+	–	–	+
September	2.8(8)	2.4(4)	0.4	–	+	+	–
October	3.8(4,7)	3.1(2)	0.7	+	–	+	–
November	3.9(8)	3.4(2)	0.5	+	+	–	–
December	4.8(8)	3.8(2)	1.0	+	–	–	+

LSD (0.05) = 0.4 t/ha.
[a] Numbers in parentheses refer to time of N application: (1) basal, (2) 10 days after transplanting, (3) tillering, (4) 5–7 days before panicle initiation, (5) basal + tillering, (6) basal + panicle initiation, (7) tillering + panicle initiation, (8) basal + tillering + panicle initiation.

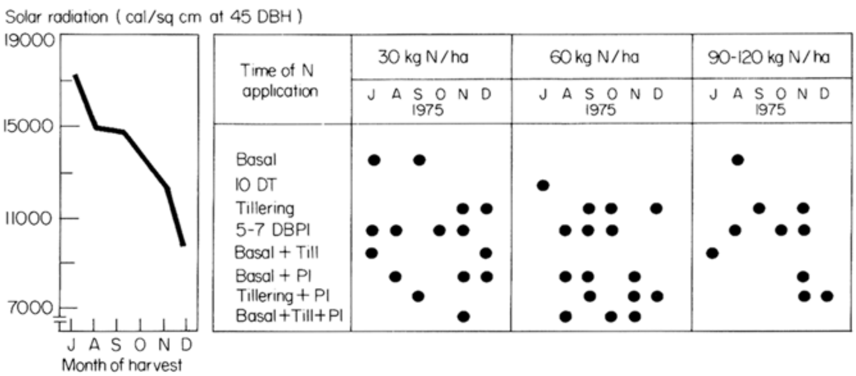
energy total for 45 days before harvest, similar grain yields can be obtained with several alternative times of nitrogen application (Fig. 11 to 14). Results indicate that with the high solar radiation that prevailed in the dry season, basal application at low and high levels was as effective as split application in obtaining maximum nitrogen efficiency in both varieties (Fig. 11, 12). With the low solar radiation that prevailed in the wet season, split application of low, medium, and high nitrogen levels was effective for IR28 (Fig. 13). In IR28 nitrogen efficiency was high when nitrogen at low, medium, or high levels was applied once at growth stages close to the reproductive growth phase—at tillering or at 5 to 7 days before panicle initiation (DBPI). With low solar radiation, split application had no advantage over single application in IR26, because it produced few tillers (Fig. 14). The single application of nitrogen increased



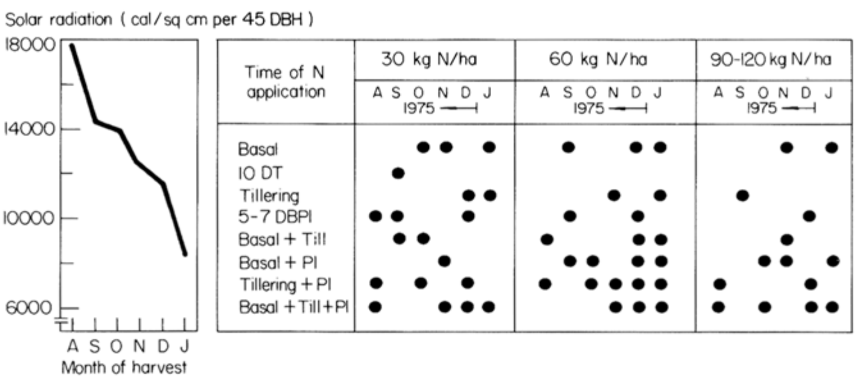
11. At a given solar energy level, with increasing solar energy totals for 45 days before harvest (DBH) with a particular month of harvest, similarly high grain yields of IR26 and IR28 rice were obtained (•) with various times of N applications. DT = days after transplanting; DBPI = days before panicle initiation; Till = tillering; PI = panicle initiation. IRRI, 1975–76.



12. At a given solar energy level, with increasing solar energy totals for 45 days before harvest (DBH), with a particular month of harvest, similarly high grain yields of IR26 and IR28 rice were obtained (•) with various times of N applications. DT = days after transplanting; DBPI = days before panicle initiation; Till = tillering; PI = panicle initiation. IRRI, 1975–76.



13. At a given solar energy level, with decreasing solar energy totals for 45 days before harvest (DBH), with a particular month of harvest, similarly high grain yields of IR28 rice were obtained (•) with various times of N applications. DT = days after transplanting; DBPI = days before panicle initiation; Till = tillering; PI = panicle initiation. IRRI, 1975–76.



14. At a given solar energy level, with decreasing solar energy totals for 45 days before harvest (DBH), with a particular month of harvest, similarly high grain yields of IR26 were obtained (•) with various times of N applications. DT = days after transplanting; DBPI = days before panicle initiation; Till = tillering; PI = panicle initiation. IRRI, 1975–76.

the panicle number per hill of IR26 to compensate for the high percentage of unfilled grains. Under farmers' conditions and with poor control of water and weeds, split application is advisable to minimize nitrogen losses.

The final choice of any one time of nitrogen application, however, will largely depend on the rate of application, the farmers' resources, their judgment of soil type and water conditions, and the rice variety grown.

The following trends were observed: IR28 had a low number of spikelets per panicle. To increase panicle number per hill, the single application of nitrogen at tillering or at 5 to 7 DBPI is desirable when a low nitrogen level is used with either high or low solar radiation. With higher levels with low solar radiation, topdressing of nitrogen just before panicle initiation is desirable for maximum benefit from fertilizer nitrogen.

For IR26, the number of spikelets did not appear limiting. Because the percentage of unfilled grains appeared more critical, split application of nitrogen is desirable to reduce that percentage. The single application of low nitrogen level is also effective with high or low solar radiation, when nitrogen application is basal or at 5 to 7 DBPI.

The results are summarized in a suggested schedule of nitrogen fertilizer application for soils similar to Maahas clay.

With high solar radiation

Early maturing variety

- Low N level —single application basal.
- Medium N level—single application at tillering stage or at 5 to 7 DBPI, or split application basal + tillering stage.
- High N level —single application basal or at 5 to 7 DBPI, or split application basal + tillering stage + panicle initiation stage.

Medium maturing variety

- Low N level —single application basal.
- Medium N level—single application basal or at 5 to 7 DBPI, or split application basal + panicle initiation stage.
- High N level —single application basal, or split twice, basal + panicle initiation stage, or thrice basal + tillering stage + panicle initiation stage.

With low solar radiation

Early maturing variety

- Low N level —single application at 5 to 7 DBPI, or at tillering stage.
- Medium N level—single application at tillering or at 5 to 7 DBPI, or split application between basal + panicle initiation, tillering stage + panicle initiation stage.

Medium maturing variety

- Low N level —single application basal or at tillering stage, or split application between basal + panicle initiation stage.
- Medium N level—single application basal or at tillering stage or 5 to 7 DBPI, or split application between tillering stage + panicle initiation stage, basal + tillering stage + panicle initiation stage.

METHODS, SOURCES, AND TIME OF NITROGEN APPLICATION FOR UPLAND RICE

Agronomy Department

In the wet season, the early maturing, intermediate-statured IR9575 and the medium maturing semidwarf IR2035-117-3 were used to determine the effects of method, source, rate, and time of nitrogen application on grain yield under upland culture. The three methods of application were broadcast and incorporated, band placement, and split application. Sources of fertilizers were urea, sulfur-coated urea (SCU), and ammonium sulfate. Rates of nitrogen application were 60 and 90 kg/ha. There was also a basal application of 30 kg P_2O_5/ha and 30 kg K_2O/ha.

There were no significant interactions between variety and the treatment combinations of sources, time, and methods of nitrogen application. The data are averages for IR9575 and IR2035-117-3. Mean grain yield was highest when ammonium sulfate at 60 or 90 kg N/ha was applied in three equal split doses at planting, 30 days after rice emergence, and at panicle initiation (Table 9). That yield was significantly higher than that of the SCU treatment at 60 kg N/ha applied all at planting in a band, or broadcast and incorporated. The incorporation or band placement of 90 kg N/ha as SCU at planting did not prove superior to any treat-

Table 9. Effect of different methods, sources, and time of nitrogen application on yield of IR9575 and IR2035–117–3. IRRI, 1976 wet season.

Method[a]	Source[b]	Rate of application (kg/ha) of nitrogen applied at[c]				Yield (t/ha)		Mean[d]
		Planting	10 DRE	30 DRE	PI	IR9575	IR2035–117–3	
—	—	0	0	0	0	2.2	2.1	2.1 c
BI	SCU	60	0	0	0	3.5	2.9	3.2 b
BP	SCU	60	0	0	0	3.5	2.8	3.1 b
BI	U	60	0	0	0	3.2	3.3	3.2 ab
BP	U	60	0	0	0	3.3	3.2	3.3 ab
S	U	20	0	20	20	3.7	3.1	3.4 ab
S	U	0	20	20	20	3.5	3.3	3.4 ab
BI	AS	60	0	0	0	3.7	3.3	3.5 ab
BP	AS	60	0	0	0	3.6	3.0	3.3 ab
S	AS	20	0	20	20	3.9	3.5	3.7 a
S	AS	0	20	20	20	3.7	2.9	3.3 ab
BI	SCU	90	0	0	0	3.8	3.3	3.6 ab
BP	SCU	90	0	0	0	3.8	3.2	3.5 ab
BI	U	90	0	0	0	3.4	3.4	3.4 ab
BP	U	90	0	0	0	3.4	3.6	3.5 ab
S	U	30	0	30	30	3.9	3.3	3.6 ab
S	U	0	30	30	30	3.8	3.2	3.5 ab
S	AS	30	0	30	30	4.0	3.3	3.7 a

[a]BI = broadcast and incorporated; BP = band placement; S = split; [b]SCU = sulfur-coated urea; U = urea; AS = ammonium sulfate. [c]DRE = days after rice emergence; PI = panicle initiation. [d]Means followed by the same letter are not significantly different at the 5% level.

ment combination of urea or ammonium sulfate. However, the yield obtained with the added 60 or 90 kg N/ha as SCU, urea, or ammonium sulfate was significantly higher than the 2.1 t/ha of the control treatment (0 fertilizer nitrogen).

The results suggest that SCU is not a better source of nitrogen for upland rice on Maahas clay soil. Urea and ammonium sulfate, which are relatively cheaper than SCU, are equally good sources of nitrogen fertilizer if applied at the proper time.

LONG-TERM FERTILITY EXPERIMENTS
Agronomy Department

IRRI. In the 24th and 25th crops of a long-term fertility experiment at IRRI, the dry-season results showed a highly significant nitrogen response (Table 10). That response, however, varied with varieties. The yield increase from fertilizer was 3.0 t/ha for IR36 and 4.0 t/ha for the two other varieties. During the wet season, a modest but significant response to nitrogen was recorded (Table 10). In either season, the application of 30 kg P_2O_5/ha or 30 kg K_2O/ha did not give significant response in the presence or absence of fertilizer nitrogen.

Bureau of Plant Industry (BPI) stations. In 1968 a series of long-term fertility experiments was started at three BPI stations with the same

Table 10. Effects of NPK fertilization on the grain yields of IR8, IR26, and IR36 in the 24th (dry season) and 25th (wet season) consecutive crops. IRRI, 1976.

Fertilizer treatment (kg/ha)			Yield[a] (t/ha)			
N	P_2O_5	K_2O	IR8	IR26	IR36	Mean
			Dry season			
0	0	0	3.5	3.2	3.7	3.5 c
140[b]	0	0	7.6	7.8	6.8	7.4 b
0	30	0	3.8	3.6	3.7	3.7 c
0	0	30	3.5	3.9	3.4	3.6 c
140[b]	30	0	7.7	7.1	7.0	7.3 b
140[b]	0	30	7.8	7.8	6.9	7.5 ab
140[b]	30	30	8.2	7.7	7.1	7.7 ab
140[bc]	30	30	8.8	7.5	7.3	7.9 a
			Wet season			
0	0	0	2.8	3.9	3.9	3.6 b
60[b]	0	0	3.3	4.7	4.8	4.3 a
0	30	0	3.2	3.8	3.8	3.6 b
0	0	30	2.9	3.6	3.7	3.4 b
60[b]	30	0	3.2	4.6	4.8	4.2 a
60[b]	0	30	3.6	4.8	4.8	4.4 a
60[b]	30	30	3.7	4.5	5.1	4.4 a
60[bc]	30	30	3.5	5.1	5.0	4.5 a

[a]Average of four replications. In a column means followed by the same letter are not significantly different at the 5% level. [b]Includes topdressing of 40 kg N/ha at panicle initiation in the dry season and 20 kg N/ha in the wet season. [c]Compost (10 t/ha) plus inorganic (24 kg N/ha) compost + 116 kg N/ha organic, for dry season; 24 kg N/ha + 36 kg N/ha inorganic, for wet season.

Table. 11. Effects of NPK fertilization on the grain yield of IR8, IR26, and IR36 rices in the 17th (dry season) and 18th (wet season) crop in the long-term fertility experiments at three locations (av. of three replications). Maligaya Rice Research and Training Center, Bicol Rice and Corn Experiment Station, and Visayas Rice Experiment Station, Philippines. IRRI-BPI cooperative experiments, 1976.

Fertilizer (kg/ha)			Yield[b] (t/ha)					
			Maligaya		Bicol		Visayas	
N[a]	P_2O_5	K_2O	Dry	Wet	Dry	Wet	Dry[c]	Wet
0	0	0	3.7 d	3.2 d	2.6 b	2.7 d	—	4.6 c
140/70	0	0	4.5 c	3.4 cd	2.8 b	3.8 c	—	5.2 b
140/70	60	0	5.3 b	4.1 b	3.1 b	4.9 b	—	6.2 a
140/70	0	60	4.8 c	3.9 bc	3.1 b	4.3 c	—	5.1 b
140/70	60	60	6.8 a	4.9 a	4.5 a	5.9 a	—	6.6 a
140/70	60	60+30[d]	6.9 a	5.0 a	4.7 a	5.9 a	—	6.4 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]Av. of three varieties. Means followed by the same letter are not significantly different at the 5% level. [c]Experiment was discontinued because of severe water shortage. [d]Applied in split doses, basal and panicle initiation.

objectives as the experiments at IRRI. The BPI stations are on Vertisols similar to the IRRI soil. The 1976 data averaged for the rice varieties IR8, IR26, and IR36 showed a marked response to complete fertilizer (NPK), compared with that to nitrogen alone or to nitrogen and phosphorus (NP) in both Maligaya and Bicol stations (Table 11). Because of a severe water shortage, the experiment at the Visayas station was discontinued.

The 1976 wet-season results were consistent with those of the dry season for both Maligaya and Bicol stations. The yield response to NPK was greater than that to NP in both dry and wet seasons at Maligaya and Bicol (about 1.5 t/ha). As in the previous 2 years (1974, 1975 annual reports), nitrogen and phosphorus applications improved the grain yield by 1 t/ha over that of the nitrogen treatment at the Visayas station. Unlike in the previous year, complete fertilizer did not give a significantly higher grain yield than the nitrogen and phosphorus treatments. It gave, however, a significantly higher grain yield response than did the nitrogen and potassium treatment (Table 11).

Long-term fertility experiments on acid Ultisols. During the 1976 wet season, a third series of long-term fertility experiments was initiated on the acid Ultisols of Tanay (Rizal) and Luisiana (Laguna) in the Philippines. This series is part of the first International Network on Fertilizer Efficiency in Rice program to monitor fertility changes with intensive cropping and modern varieties. The test varieties were IR26 and IR36.

In Tanay, variety and fertilizer treatments interacted significantly. The grain yield response to phosphorus of IR36 treated with 60 kg N/ha was significant; that of IR26 was not (Table 12). In both varieties, however, complete fertilizer (NPK) gave significantly higher grain yield than did nitrogen fertilizer alone.

On Luisiana soils, variety and fertilizer treatments did not interact significantly. There was no significant difference in yield response to phosphorus or to potassium among treatments with nitrogen nor among those without nitrogen (Table 13). Because the trial was the first in a series, no grain yield responses to phosphorus or potassium (or both) were expected, although growth differences were apparent during the tillering stage of the crop.

Phosphorus response on acid Ultisol. A field experiment conducted during the dry season

Table 12. Grain yields of IR36 and IR26. Long-term fertility trial (first crop) in farmer's field, Tanay, Rizal. 1976 wet season.

Fertilizer treatment (kg/ha)			Grain yield[a] (t/ha)		
N	P_2O_5	K_2O	IR36	IR26	Mean
0	0	0	2.94 d	3.17 c	3.05
60	0	0	4.17 b	4.70 b	4.44
0	40	0	3.36 c	3.38 c	3.37
0	0	40	3.01 cd	3.35 c	3.18
60	40	0	4.70 a	4.80 b	4.75
0	40	40	3.30 cd	3.52 c	3.41
60	0	40	4.08 b	5.08 ab	4.58
60	40	40	4.87 a	5.31 a	5.09

[a]In a column, means followed by the same letter are not significantly different at the 5% level. CV = 6.6%.

Table 13. Grain yield of IR36 and IR26. Long-term fertility trial (first crop) in farmer's field, Luisiana, Laguna. 1976 wet season.

Fertilizer treatment (kg/ha)			Grain yield[a] (t/ha)		
N	P_2O_5	K_2O	IR36	IR26	Mean[a]
0	0	0	3.05	2.91	2.98 c
60	0	0	4.55	5.49	5.02 a
0	40	0	3.54	3.99	3.76 b
0	0	40	2.79	3.06	2.93 c
60	40	0	4.27	5.62	4.95 a
0	40	40	3.19	3.73	3.46 bc
60	0	40	4.24	5.70	4.97 a
60	40	40	4.49	5.82	5.15 a

[a]Means followed by the same letter are not significantly different at the 5% level. CV = 14.4%.

Table 14. Response of IR8, IR26, and IR36 to phosphorus on an ultisol in Teresa, Rizal, Philippines.[a] 1976 dry season.

Fertilizer treatment (kg/ha)			Yield (t/ha)			Treatment mean
N	P_2O_5	K_2O	IR8	IR26	IR36	
0	0	0	2.4	2.4	2.6	2.4 c
100+40	0	0	3.5	3.2	2.9	3.2 b
100+40	60	0	4.2	3.6	4.1	4.0 a
100+40	0	60	3.6	2.7	2.8	3.1 b
100+40	60	60	4.3	3.7	4.1	4.0 a
100+40	60	60+30	4.3	3.7	4.1	4.0 a
Variety mean[a]			3.7 a	3.2 b	3.4 b	

[a]In a row or column, means followed by the same letter are not significantly different at the 5% level.

on an Ultisol in a farmer's field at Teresa, Rizal, Philippines, had the same fertilizer treatments as the long-term fertility experiments at the BPI stations (Table 11). The test varieties were IR8, IR26, and IR36.

Variety and fertilizer treatments showed no significant interaction. IR8 gave the highest mean yield of 3.7 t/ha, which was significantly higher than the yield of IR36 (3.4 t/ha) and that of IR26 (3.2 t/ha). The yields of IR36 and IR26 did not significantly differ. No treatment showed significant response to potassium application. There was, however, a highly significant response to nitrogen and phosphorus. The average response of the three varieties to 140 kg N/ha was 0.77 t/ha. The average yield response to 60 kg P_2O_5/ha was also 0.77 t/ha (Table 14).

The site should be useful to evaluate phosphorus sources for flooded rice.

ZINC RESPONSE OF LOWLAND RICE ON CALCAREOUS SOIL

Agronomy Department

Zinc deficiency is the third most important nutritional factor that limits the grain yield of lowland rice. It is common on calcareous soils with high pH and high organic matter.

During the wet season, a field experiment in Tiaong, Quezon, Philippines, evaluated the effect of different zinc sources applied at different rates to transplanted and to direct-seeded flooded rice.

Chemical analysis showed that the soil has a high pH and a relatively high organic matter content (Table 15). Table 16 shows the grain yield data from the transplanted-rice experiment. The seedling dip of 2% ZnO plus foliar spray of 0.5% $ZnSO_4$ at 5 to 7 DBPI produced the highest grain yield of 3.5 t/ha. It was followed by seedling dip in 2% ZnO alone, which produced 3.3 t/ha. A satisfactory yield of 3.2 t/ha was obtained when 50 kg $ZnSO_4$/ha was broadcast and incorporated in the soil during the final land preparation.

Drought during the late vegetative and early reproductive stages of the crop apparently caused the generally lower yield in the direct-seeded experiment (Table 17). During that period, the experiment was generally nonflooded, a condition that somewhat alleviated the zinc deficiency problem. The highest grain yield (3.2 t/ha) was obtained with zinc oxide-coated pregerminated seeds plus foliar spray of 0.5% $ZnSO_4$ 5 to 7 DBPI. However, that yield did not significantly differ from the yields of

Table 15. Chemical properties of Tiaong (Quezon, Philippines) soil. 1976.

Property	Value
pH	8.38
Organic matter (%)	9.62
Nitrogen (%)	0.47
Available P (ppm)	23.00
Exchangeable K (meq/100 g)	0.90
Available zinc (ppm)	0.04
CEC (meq/100 g)	38.10
Exchangeable bases:	
Potassium (meq/100 g)	1.09
Sodium (meq/100 g)	1.56
Magnesium (meq/100 g)	5.60
Calcium (meq/100 g)	10.85

Table 16. Zinc response on a calcareous soil as affected by various zinc management practices in transplanted IR28 rice. Tiaong, Quezon, Philippines, 1976 wet season.

Zinc treatment	Application		Grain yield[b] (t/ha)
	Rate	Time[a]	
No zinc	—	—	0.1 g
Seedling dip—ZnO	2%	Before transplanting	3.3 a
Seedling dip—ZnO + $ZnSO_4$ foliar spray	2% + 0.5%	Before transplanting + 5–7 DBPI	3.5 a
Seedbed application—$ZnSO_4$	50 kg/ha	5 days after sowing	0.2 g
$ZnSO_4$ broadcast and incorporated	50 kg/ha	Basal	3.2 ab
Foliar spray of $ZnSO_4$, three times	0.5%	Seedbed, tillering and 5–7 DBPI	1.4 de
Zn-Ke-Min (14% Zn) broadcast and incorporated	2 kg Zn/ha	Basal incorporated	1.2 def
Zn-Ke-Min (14% Zn) broadcast and incorporated	4 kg Zn/ha	Basal incorporated	2.4 bc
Zn-coated urea (U) – ammonium sulfate (AS)	2 kg Zn/ha	Basal incorporated	0.6 efg
Zn-coated urea	2 kg Zn/ha	Basal incorporated	0.4 fg
Zn-coated ammonium sulfate	2 kg Zn/ha	Basal incorporated	0.7 efg
Zn-coated ammonium sulfate	4 kg Zn/ha	Basal incorporated	2.0 cd

[a]DBPI = days before panicle initiation. [b]Means followed by the same letter are not significantly different at the 5% level.

Table 17. Zinc response on a calcareous soil as affected by various zinc management practices in direct-seeded rainfed IR28 rice. Tiaong, Quezon, Philippines, 1976 wet season.

Zinc treatment	Application		Grain yield[b] (t/ha)
	Rate	Time[a]	
No zinc	—	—	0.0 b
Seed coating with ZnO on pregerminated rice	2 kg/ha	—	2.2 a
Foliar spray—$ZnSO_4$ three times	0.5%	15 DRE + 45 DRE + 5–7 DBPI	1.9 a
Zn-Ke-Min (14% Zn)	2 kg Zn/ha	Applied on surface before rice seeding	2.6 a
Zn-Ke-Min	4 kg Zn/ha	"	2.5 a
Seed coating with ZnO + foliar spray of $ZnSO_4$	2 kg Zn/ha + 0.5%	Before seeding pregerminated rice	3.2 a
Zn-coated urea—ammonium sulfate	2 kg Zn/ha	Applied on surface before rice seeding	1.9 a
Zn-coated urea	2 kg Zn/ha	"	2.0 a
Zn-coated ammonium sulfate	2 kg Zn/ha	"	2.1 a
Zn-coated ammonium sulfate	4 kg Zn/ha	"	2.2 a

[a]DRE = days after rice emergence. DBPI = days before panicle initiation. [b]Means followed by the same letter are not significantly different at the 5% level.

the other zinc treatments. When no zinc was applied, no grain was produced.

The results tend to confirm reports of other studies that dipping seedlings in zinc oxide before planting is a practical and economical means of correcting zinc deficiency in transplanted rice. In direct-seeded rice, coating the pregerminated seeds with zinc oxide is most promising.

NITROGEN EFFICIENCY
Soil Chemistry Department

To ascertain whether rice varieties differ in their innate capacity to extract and use soil fertilizer nitrogen, eight varieties were grown in a replicated pot experiment on submerged Maahas clay. Treatments consisted of 0, 50, 100, and 150 ppm N as ammonium sulfate over a basal dressing of 25 ppm P and 50 ppm K.

Peta and H4, both tall indicas, apparently extracted and used soil and fertilizer nitrogen more efficiently than the other varieties (Table 18). The tall indicas Pokkali, Peta, and H4 produced more dry matter than Pelita I/1, IR5, IR26, and IR20 in all treatments.

Mathematical treatment of the responses of grain yield, dry matter yield, and nitrogen uptake revealed varietal characteristics with important practical implications.

The regression of grain yield (y) on level of N (x) is usually described by the equation

$$y = a + bx + cx^2$$

Table 18. Total grain yields of seven rice varieties on Maahas clay in the greenhouse (total of 5 crops). IRRI, 1976.

Variety	Grain yield[a] (g/pot) with				
	0 ppm N	50 ppm N	100 ppm N	150 ppm N	Variety mean
Peta	189 a	326 a	397 ab	440 a	338 a
Pokkali	94 c	139 c	172 d	138 d	136 d
H4	185 a	323 a	423 a	429 a	339 a
Pelita I/1	156 ab	301 a	338 bc	416 a	302 b
IR5	159 ab	283 ab	373 b	431 a	312 b
IR20	138 b	242 b	332 c	340 ab	278 c
IR26	147 b	257 b	357 b	424 a	296 bc
Nitrogen mean	139	247	319	357	

[a]Means followed by the same letter are not significantly different at the 5% level.

Theoretically, varieties with large a's are those that exploit soil nitrogen and other growth factors efficiently; varieties with large b's are those that respond markedly to added nitrogen; and varieties with large c's are those that rapidly decline in yield as level of nitrogen goes up. The regressions of grain yield on level of nitrogen were:

Peta

$$y = 187.8 + 3.0768^{**}x - .0094^{*}x^2 \qquad R = .99900^{*}$$

Pokkali

$$y = 89.7 + 1.5308x - .0079x^2 \qquad R = .97508^{ns}$$

H4

$$y = 178.5 + 3.6704x - .0132x^2 \qquad R = .99799^{ns}$$

Pelita I/1

$$y = 160.8 + 2.652x - .0067x^2 \qquad R = .98429^{ns}$$

IR5

$$y = 156.3 + 2.8152^{**}x - .0066^{**}x^2 \qquad R = .99999^{**}$$

IR20

$$y = 131.8 + 2.8512x - .0096x^2 \qquad R = .99567^{ns}$$

IR26

$$y = 143.5 + 2.4984^{**}x - .0042^{*}x^2 \qquad R = .99977^{*}$$

Of the varieties that gave significant quadratic responses, Peta had the highest a value and the second highest b value. IR26 had the smallest c value. These values suggest that Peta responds to low rates of nitrogen and IR26 to high rates.

The regressions for total dry matter production were:

Peta

$$y = 546.7 + 9.2436^{**}x - .0223^{*}x^2 \qquad R = .9998^{*}$$

Pokkali

$$y = 598.4 + 11.588^{**}x - .0400^{**}x^2 \qquad R = .9999^{**}$$

H4

$$y = 527.9 + 9.3256^{**}x - .0208^{*}x^2 \qquad R = .9997^{**}$$

Pelita I/1

$$y = 409.3 + 7.0096x - .0168x^2 \qquad R = .9966^{ns}$$

IR5

$$y = 404.3 + 6.8064^{**}x - .0122^{*}x^2 \qquad R = .99969^{*}$$

IR20

$$y = 300.1 + 5.514^{**}x - .0105^{*}x^2 \qquad R = .99972^{*}$$

IR26

$$y = 323.8 + 7.1488x - .0204x^2 \qquad R = .9943^{ns}$$

The regressions show that Pokkali, Peta, and H4 use soil nitrogen more efficiently than the improved varieties IR5, IR20, and IR26. Also, as indicated by their high b values at low rates of nitrogen, they used nitrogen more efficiently than did the short-strawed varieties.

Differentiation of the equation

$$y = a + bx + cx^2$$

yields

$$\frac{dy}{dx} = b + 2\,cx.$$

When the yield is maximum

$$x = \frac{-b}{2c}.$$

The levels of nitrogen at which yield began to decline were 164 ppm for Peta, 213 ppm for IR5, and 298 ppm for IR26.

Soil and crop management

Soil and crop culture

EFFECT OF DRY SOIL MULCH ON MOISTURE CONSERVATION

In IRRI field trials in Bulacan, Philippines, where land was prepared at the end of the previous wet season, the following rice crop survived a period of drought. That survival may have been due to the available soil moisture conserved by the dry soil mulch. A crop seeded at the same time, but following land preparation at the beginning of the wet season, suffered considerable drought stress. It was hypothesized that land preparation at the end of the wet season generates a dry soil mulch that conserves significant amounts of soil moisture.

A field experiment at IRRI during 1976 tested that hypothesis. The experiment sought to determine whether conserved soil moisture was due to weed control or to the generation of a dry soil mulch and whether soil nitrogen was also conserved; and to ascertain the potential amount of time saved by the early planting of early seeded rice crop following the dry soil mulch.

The design was a split plot with the dry-season treatments followed by wet-season rice crop in the main plots and nitrogen level for the wet-season rice crop in the subplots. The 1976 dry-season treatments were dry soil mulch followed by (fb) dry-seeded crop, weed-free with herbicide fb dry-seeded crop, weedy fallow fb dry-seeded crop, and weedy fallow fb transplanted crop. The nitrogen levels were 20, 40, 60, and 80 kg N/ha as ammonium sulfate.

The dry soil mulch was generated during February 1976 by three rotovations at 1- to 2-week intervals as the soil surface progressively dried. The resulting dry soil mulch was 5 to 10 cm thick. The plots were harrowed 20 April, furrowed 20 cm apart and 5 to 10 cm deep with the native furrower (*lithao*), seeded, and covered by one pass with the spike-toothed harrow (*kalmot*).

Weed-free plots were maintained by two applications of 15 kg dalapon/ha and subsequent spot spraying with paraquat. This treatment was followed by minimum tillage of one rotovation 20 April, followed by a harrowing 30 April. The plots were dry seeded 30 April in the same manner as the dry-soil mulch plots.

The remaining two plots of each replicate were left fallow—up to 20 April in the case of plots for dry seeding and 30 May for the plots to be transplanted. Starting on 20 April, the plots to be dry seeded were rotovated three times over a period of 3 weeks as weed and soil moisture conditions permitted. The plots received a final harrowing on 10 May when they were seeded.

The plots for transplanting were plowed and harrowed twice, starting 1 June, and transplanted 1 July with 30-day-old seedlings.

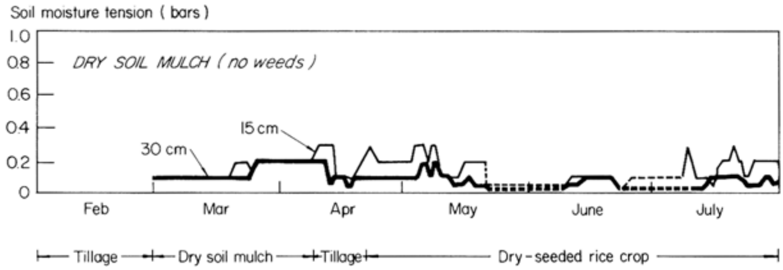
Thirty kg P_2O_5/ha and 30 kg K_2O/ha were basally incorporated at seeding. Sixty kg N/ha was topdressed in three equal applications at 20 days, 35 days, and 67 days after rice emergence in the seeded plots. In the transplanted plots, two-thirds of the nitrogen fertilizer was basally incorporated with the last harrowing and one-third topdressed at 40 days after transplanting (DT).

Soil moisture tension (SMT) was measured daily, or as weather conditions permitted, by means of a tensiometer and gypsum blocks. The water table was measured in a 1-m deep hole. Rice stand count was recorded 10 days after rice emergence. Weed dry weight was assessed at preplant and at maximum tillering stage (48 days after rice emergence or 30 DT), and recorded according to species. Grain yield, corrected to 14% moisture, was based on sampling area of 10 sq m.

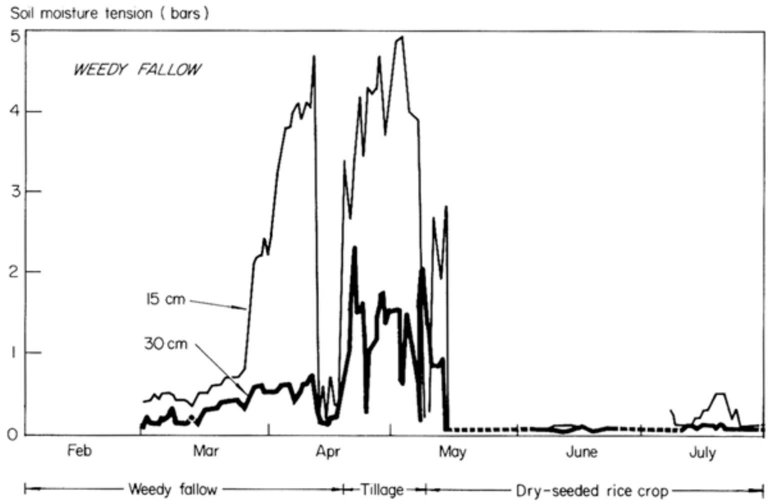
In plots where land preparation was completed at the end of the previous wet season, the SMT under the dry soil mulch did not exceed 33 centibars, even though the water table was below 1 m during the whole period (Fig. 1).

By comparison, the SMT in the weedy fallow plots at the end of the dry season rose to 5 bars at a depth of 15 cm (Fig. 2).

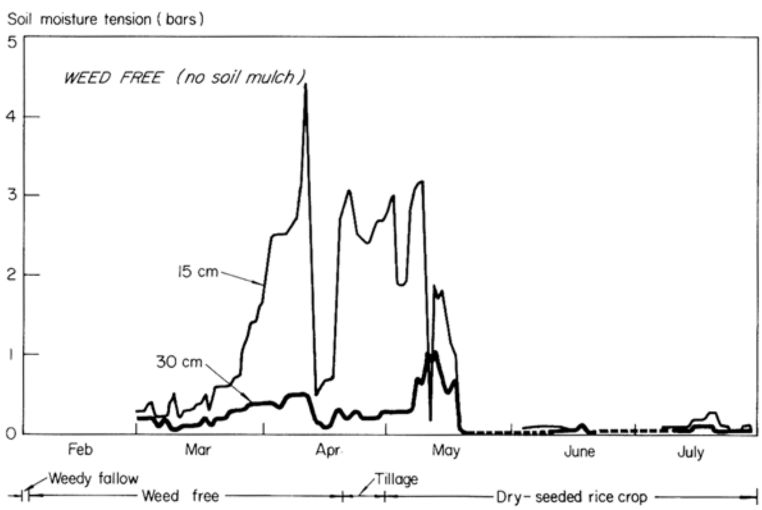
The weed-free sites gave somewhat lower values for SMT, particularly at a depth of 30 cm (Fig. 3). By the end of the dry season, the SMT at 15 cm rose to 3 bars, while that at 30 cm reached only 1 bar. Comparing these soil moisture values with the values in the weedy fallow showed a negligible conservation of soil moisture at 15 cm. At 30 cm about 5 g water/100 g



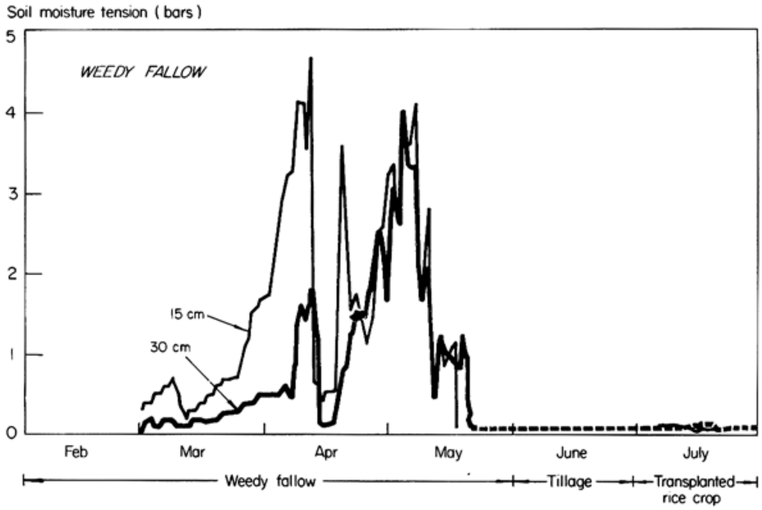
1. Effect on soil moisture tension of a dry soil mulch during the dry season followed by (fb) a dry-seeded rice crop. Tillage consisted of 3 rotovations in February fb 1 harrowing in April. Rice was dry-seeded on 20 April; it emerged on 10 May. IRRI, 1976 dry and wet seasons.



2. Effect on soil moisture tension of a dry-season weedy fallow followed by dry-seeded rice crop. Tillage consisted of 3 rotovations and 1 harrowing. IRRI, 1976 dry and wet seasons.



3. Effect on soil moisture tension of a weed-free site during the dry season followed by a dry-seeded rice crop. Tillage consisted of 1 rotovation and 1 harrowing. Rice was dry-seeded on 30 April; it emerged on 10 May. IRRI, 1976 dry and wet seasons.



4. Effect on soil moisture tension of a dry-season weedy fallow followed by a transplanted rice crop. Tillage consisted of 2 plowings and 2 harrowings. The seedbed was sown 1 June, and seedlings were transplanted 1 July. IRRI, 1976 dry and wet seasons.

soil was conserved by the control of weeds. The findings suggest that keeping the site weed free during the dry season conserved some soil moisture, but not as much as that conserved by dry-soil mulching. Land preparation time and number of tillage operations were halved, and 10 days of potential growing time was saved. This study was, however, conducted on a deeply cracking clay soil. The results on a soil type that does not crack could be different.

Rotovating the soil at the beginning of the wet season may either conserve some soil moisture or improve retention of the early rainfall of the wet season or both. That is demonstrated by the observation that in the weed-free plots and in the fallow plots that were rotovated at the onset of the first rains, the SMT did not exceed 1 and 2 bars, respectively. When tillage was delayed until June for the traditional lowland preparation of puddling the soil, moisture tension values at the end of the dry season rose to 4 bars at depths of both 15 and 30 cm (Fig. 4). Furthermore, in the transplanted crop, at least 3 weeks of growing time was lost. Yields were similar under the three systems of land preparation that were followed by a dry-seeded crop (Table 1). The yield from the transplanted rice crop was low because of poor establishment and subsequent weed competition. The only important difference may be the significantly poor response at 20 and 40 kg N/ha of the dry-seeded crop following the dry soil mulch treatment, compared with the response of the crop seeded after a weedy fallow or weed-free treatment. This fertilizer response suggests no evidence that dry soil mulch conserves soil nitrogen.

Apparently in areas with a distinct dry season, generation and maintenance of a dry soil mulch would be valuable for securing an early establishment of the dry-seeded rice crop.

Table 1. Effects of methods of land preparation and crop establishment on fertilizer response of IR36. IRRI, 1976 wet season.

Land preparation and crop establishment method[a]	Grain yield[b] 20 kg N/ha	40 kg N/ha	60 kg N/ha	80 kg N/ha	Tillage mean
3 rotovations (Feb) fb 1 harrowing (Apr); dry seeded: 20 Apr	3.0	3.3	3.7	4.2	3.5 a
3 rotovations + 1 harrowing (Apr); dry seeded: 9 May	3.3	3.6	3.7	4.1	3.7 a
1 rotovation + 1 harrowing (Apr); dry seeded: 30 Apr	3.4	3.9	4.2	4.5	4.0 a
2 plowings fb 2 harrowings (June); transplanted: 1 July	1.1	1.2	1.5	1.4	1.3 b
Fertilizer rate mean	2.7 d	3.0 c	3.3 b	3.5 a	

[a]Av. of three replicates. Any two means in a row or column followed by the same letter are not significantly different at the 5% level.

Climatic environment and its influence

Plant Physiology Department

SUMMARY

Most locations in the major rice-growing areas of the world receive about 300 cal/sq cm or higher daily during the ripening period of rice. The maximum potential yields based on effective grain-filling period and efficiency of solar energy utilization can be estimated with a simple mathematical model.

In the tropics, where high ambient temperatures shorten the grain-filling period of rice, the potential productivity *per crop* appears to be lower than in the temperate regions. The potential production *per year*, however, is higher because favorable temperatures for rice growth exist throughout the year, making it possible to grow two or more crops annually.

High temperature regimes were described for selected locations in Pakistan, India, and Iran, where high temperature is likely to constrain rice production. Heat-tolerant varieties of rice may be required for successful rice production in these areas.

The most sensitive stage of the rice plant to high temperature appears to be the day of flowering, particularly at anthesis. One hour or less of high temperature at anthesis was found to be the critical period for fertilization of a rice spikelet.

The maximum temperature, its duration, and the temperature-rise pattern have a paramount effect on the incidence of unfertilized rice grains.

SOLAR RADIATION

Solar radiation in the world's major rice-growing areas. The amount of solar radiation reported at 26 sites in 15 rice-growing countries (Fig. 1) ranged from 50 cal/sq cm daily in December in Milano, Italy, to 700 cal/sq cm daily or higher in June or July at Lisboa, Portugal, and in Davis, California, USA, and in November through January at Griffith, Australia. Most places, however, appear to receive 300 cal/sq cm or more daily during the ripening of rice.

Excessively cloudy weather conditions prevailing during the rice-growing seasons are a concern in India. Among three locations recording climatological data in India, Cuttack receives the lowest amount of solar radiation, but its minimum solar radiation is about 300 cal/sq cm daily. High solar radiation is considered an important factor contributing to the high national average yields of rice achieved in Australia, Spain, and Portugal.

Maximum potential yields. Maximum potential yields for a specified physical environment can be estimated in several ways, but they are ultimately determined by temperature and solar radiation. Temperature determines the duration of the grain-filling period (GFP). Solar radiation during the GFP determines the solar energy available for grain filling.

The dry matter production (ΔW, g/sq m) of a crop during the ripening period can be estimated by the formula:

$$\Delta W = \frac{Eu \times T \times \bar{S}}{K} \times 10^4$$

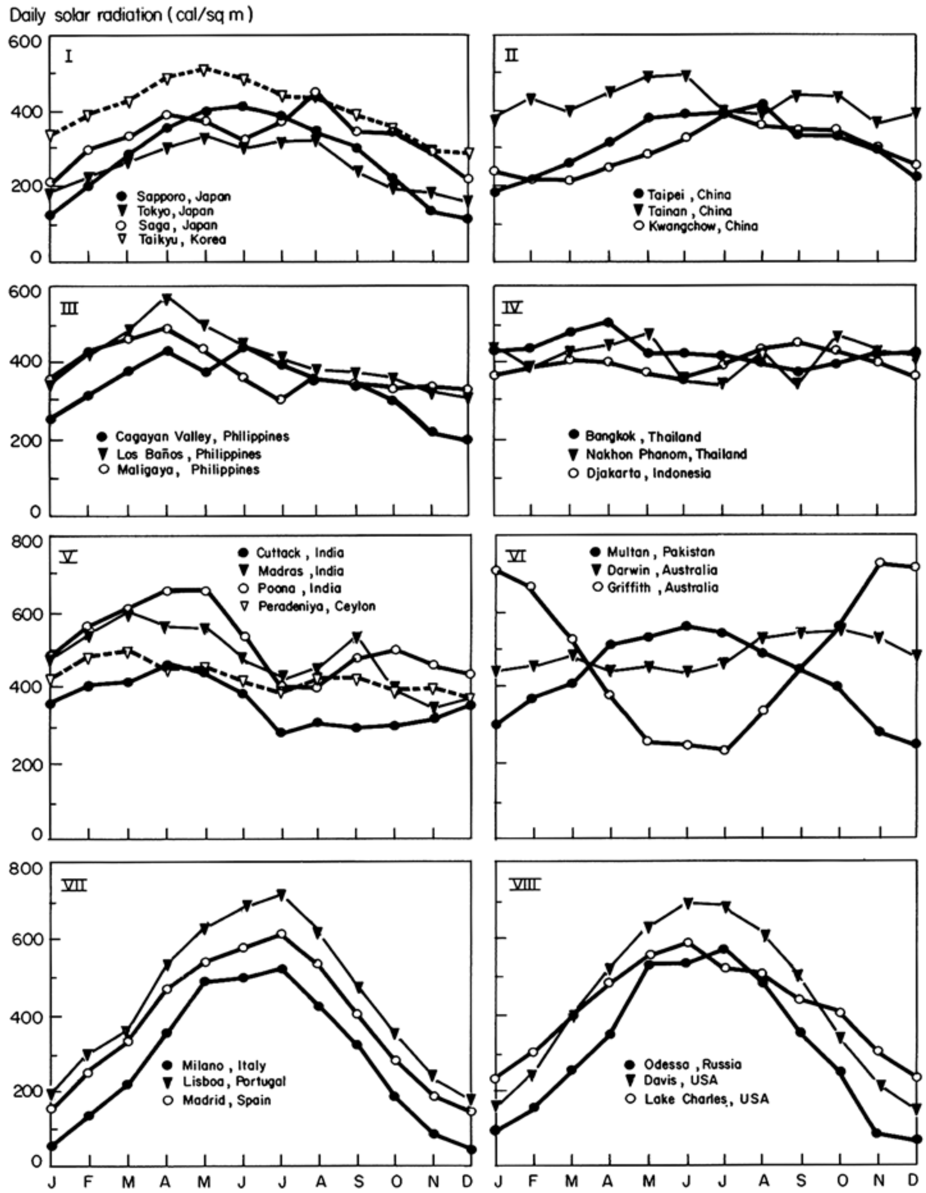
where *Eu* is efficiency of solar energy utilization (%), *T* is effective GFP (days), $\bar{S}$ is mean solar radiation (cal/sq cm daily) during the GFP, and *K* is the heat of combustion for brown rice (4,000 cal/g).

It is assumed that the dry matter produced during the ripening period is used for grain production. The maximum grain yield of rice can be estimated by using appropriate conversion factors for husk weight and moisture content.

The maximum *Eu* recorded in Japan was 3.5%; but if the formula is used, 2.5% may be a more realistic value. The effective GFP in the tropics was estimated to be 25 days and that in temperate regions 35 days. The contribution to the maximum grain yield of the carbohydrate stored before flowering was not taken into account. Hence, a realistic estimate of maximum yield may be made by using *Eu* values between 2.5 and 3.5% (Fig. 2).

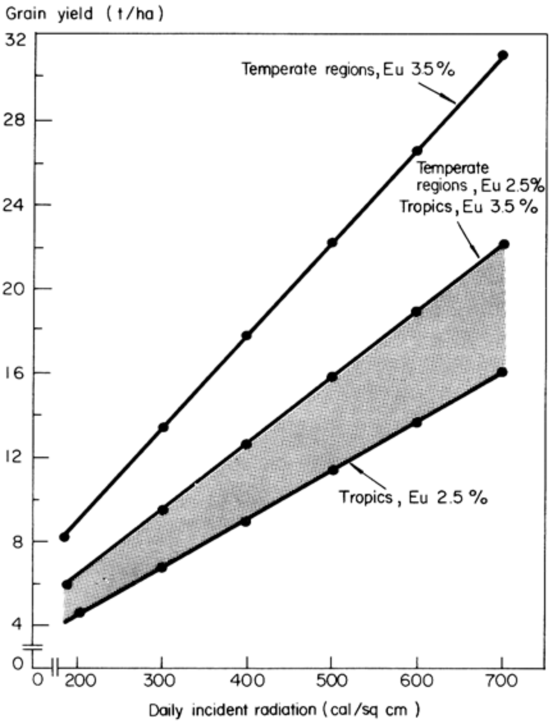
The estimated maximum yields shown in Figure 2 may be compared with recorded maximum yields: 13.2 t/ha in Japan (1960) with an estimated solar radiation of 350 cal/sq cm daily and 11.0 t/ha at IRRI (1972) with an estimated solar radiation of 550 cal/sq cm daily. The above model for estimating maximum potential yields agrees with more complicated models.

At the same *Eu* value, the temperate region, where the GFP is longer, is more productive



1. Solar radiation in some of the world's major rice-growing areas (I–VIII).

than the tropics. Previously a longer day length, higher solar radiation, or a lower rate of respiration was thought to be responsible for the higher productivity in the temperate region than in the tropics. The model, however, suggests that the duration of the GFP causes the difference. Although the potential productivity per crop is lower in the tropics than in the temperate regions, the potential production per year is higher in the tropics because the favorable



2. Relation between potential yield and incident radiation during the grain-filling period of rice.

temperature throughout the year makes two or more crops a year possible.

HIGH TEMPERATURE

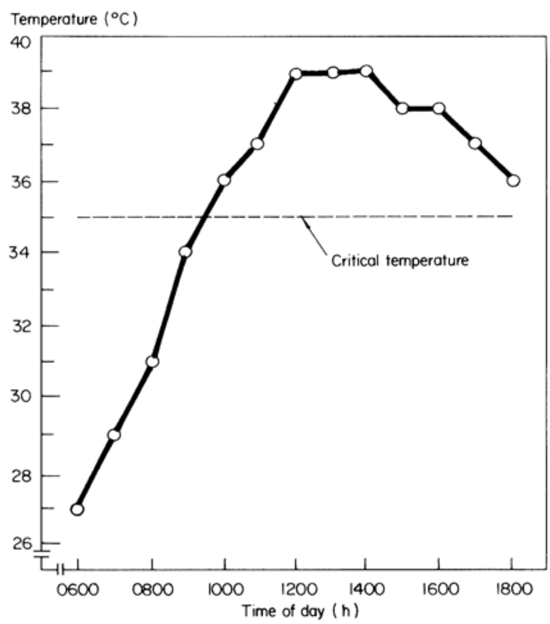
High temperature regimes. A knowledge of temperature regimes in areas where high temperature could constrain rice production is required in the development of improved techniques for screening rice lines for heat tolerance in the IRRI Genetic Evaluation and Utilization (GEU) program and in the establishment of criteria by which to predict the incidence in rice of sterility caused by high temperatures in a given environment.

In Pakistan, in experiments where two crops of rice were grown annually, 40 to 50% sterility occurred in Lyallpur, where the first crop [a radiation mutant of Basmati 370 (EF-29-1) rice] flowered in July and matured in August when the temperature was high. The monthly mean temperature was not excessive (30.3 C) for July, but the daily maximum temperature fluctuated markedly and occasionally exceeded 35 to 40°C in the first part of the month.

In Pakistan, shifting the flowering time to June or May should increase the incidence of high temperature during this growth stage, thus causing a larger percentage of high temperature-induced sterility. In that country, the ambient temperature at Dokri is higher than that at Lyallpur. The first rice crop at Dokri flowers in June when the temperature is high. Semidwarf experimental lines, such as IR1561-223-3-3, exhibit high percentages of sterility.

In the semiarid climate of Hyderabad, India, the daily maximum temperature is high (38-40°C) in April and May, when the rabi crop flowers and matures. When some rice varieties flowered in April, the percentages of sterility were high: 15% for Mahsuri, 20% for Sona, 30% for H4, and 60% for Kashmir selection 89. Apparently, the sterility was due in large part to the high temperature during flowering.

Because anthesis of rice occurs from morning to early afternoon, it is important to know when the temperature reaches the critical level for high temperature-induced sterility. At Hyderabad the temperature reaches 35°C (the critical temperature) at 0930 hours and 39°C at 1200 hours (Fig. 3). This temperature-rise pattern,



3. Diurnal changes in air temperature at Hyderabad, India, May 12, 1976.

or a similar one, may apply elsewhere in semiarid climatic regions.

Although the southern part of Iran is reported to have a great potential for rice production, high temperature and salinity could limit production. Because the maximum temperature during June through September reaches 45°C, temperature-induced sterility could constrain rice production in the area.

Most weather records available provide monthly mean temperature readings but seldom include maximum temperatures.

An empirical relation obtained from the data collected in India and Pakistan shows that the daily maximum temperature is higher than the daily mean temperature by 7 or 8°C. Thus, when the daily mean or monthly mean temperature exceeds 30°C, the maximum temperature could exceed 37–38°C, well above the critical temperature for high temperature-induced sterility. Such temperatures are common in Pakistan, Middle East countries, and tropical Africa. High temperature could be a physical constraint for rice production in these locations.

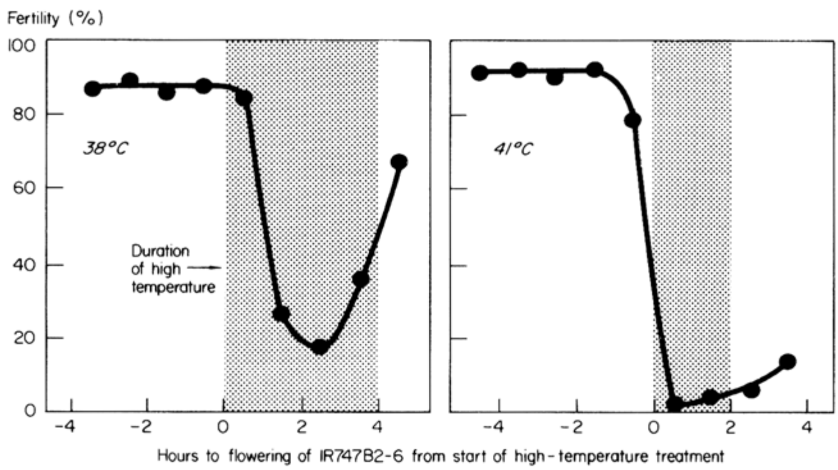
Growth stage sensitive to high temperature. A previous study identified flowering time as the growth stage when the rice plant is most sensitive to high temperature. Subsequent experiments, in which rice spikelets were subjected to 2 or 4 hours of high temperatures (35, 38, or 41°C) on each of 5 successive days after flowering showed that high temperature-induced sterility occurred only in the spikelets exposed to high temperature at flowering. The spikelets that flowered 1 day before or 1 day after the high-temperature treatments had a normal fertility percentage. The critical period during which high temperature affects rice spikelets appears to be less than 24 hours after anthesis.

The fertility percentage of the rice spikelets decreased with increasing temperature. It was about 75% for spikelets exposed to 35°C for 4 hours, about 55% for those spikelets subjected to 38°C for 4 hours, and about 15% for those exposed to 41°C for 2 hours.

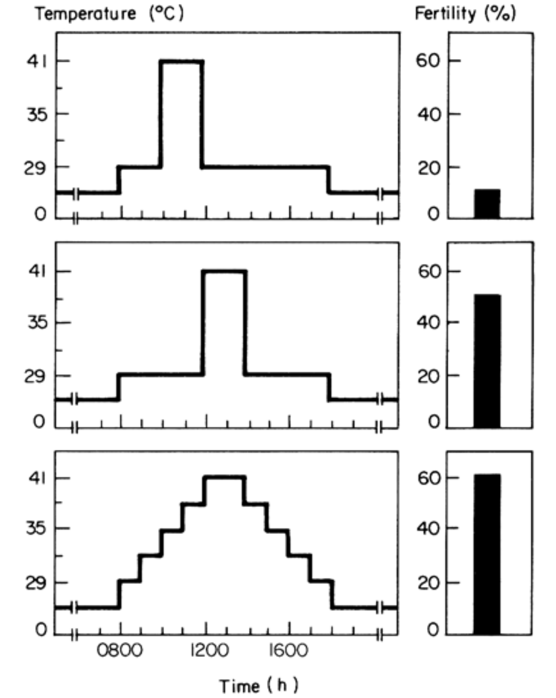
Spikelets that flowered several hours before, during, and after high temperature treatments were examined for fertility percentage (Fig. 4). The fertility percentage of spikelets that flowered during the high-temperature treatments was low, but that of spikelets that flowered 1 hour before the start of the high-temperature treatments was not affected. The fertility percentage of spikelets that flowered after the high-temperature treatments tended to rise again.

Apparently the growth stage at which rice is most sensitive to high temperature is the date of flowering, particularly during anthesis.

Effect of temperature-rise pattern on high temperature-induced sterility. Under the natural growing conditions of rice, the ambient temperature may rise sharply or gradually in a multiple-step fashion. To examine the effect of



4. Fertility of rice spikelets that flowered before, during, or after high-temperature treatments.



5. Influence of temperature-rise patterns on the fertility of IR747B2-6 rice spikelets at flowering.

the pattern of temperature increase on the incidence of sterility caused by high temperature, a one-step control was compared with a multistep control. The basic temperature regime used was 29/26°C (day/night) and the maximum temperature 41°C (Fig. 5).

The fertility percentage was lower when the spikelets were exposed to 41°C for 2 hours early in the day (morning), when most spikelets flowered. When the spikelets were exposed to the maximum temperature at the same time of the day, the fertility percentage was higher in the multistep control than in the one-step control. In the multistep control more spikelets flowered before the temperature became critical for fertilization, whereas in the one-step control more spikelets flowered during the critical high-temperature hours.

The pattern in which the temperature rises during the flowering of rice has a major effect on the incidence of unfertilized grains. Apparently, the maximum temperature, its duration, and the pattern of temperature rise affect the occurrence in rice of sterility induced by high ambient temperatures.

Postproduction technology and management

Agricultural Engineering Department

SUMMARY

Survey work, equipment testing, and pilot-area trials during 1976 further assessed paddy loss and the characteristics of a range of field and mill-level postproduction systems. Data describing labor requirements, costs, and the overall profitability associated with each system were also analyzed.

A completed study distinguished between the potential marketable surplus of paddy rice available for sale after a farmer has met household requirements, and the amount actually sold. The analysis revealed that significant quantities are sold to meet short-term financial obligations.

POSTPRODUCTION SYSTEMS

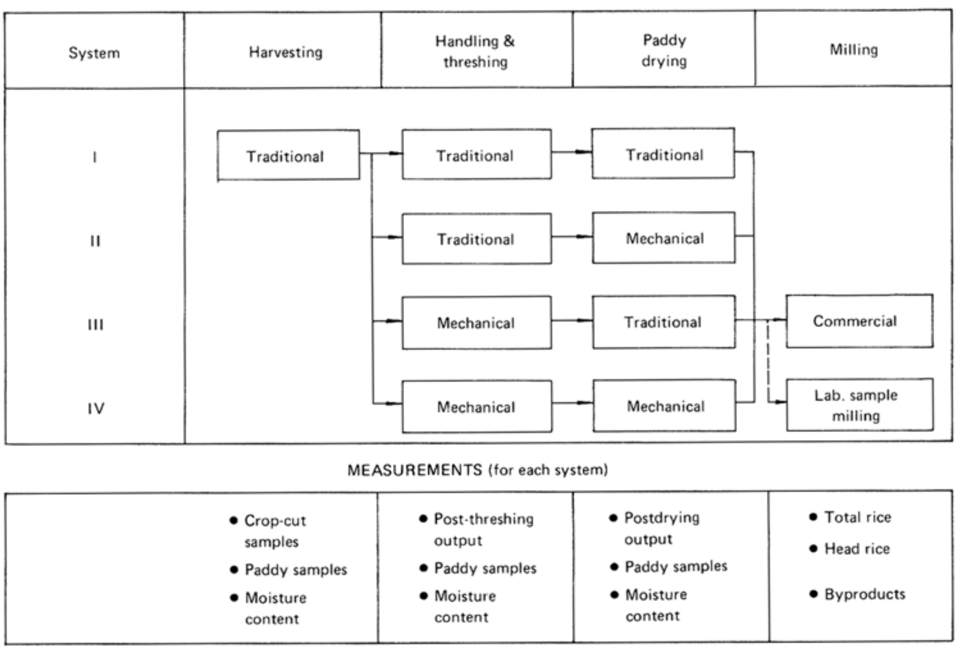
Evaluation of the nature and characteristics of farm- and processing-level systems for handling and managing paddy and milled rice continued. The research involved a combination of experiments, surveys, and pilot-area trials.

Farm-level trials. During 1975, a series of pilot trials in Central Luzon examined the effect of threshing and drying techniques on output and grain quality. The trials were completed in early 1976 and another series was initiated in four villages in the Bicol region. Figure 1 summarizes the technical alternatives under evaluation at the farm level. The Central Luzon trials were replicated at 20 farm sites and

Table 1. Grain loss incurred in harvesting and threshing operations, Central Luzon and Bicol region, 1975–76.

Item	Grain loss (%) in			
	Harvesting[a]		Threshing[b]	Total
	Harvesting	Stacking		
Central Luzon				
Traditional	3.16	0.12	6.82	10.10
Improved	2.14	0.14	2.07	4.35
Bicol[c]				
Traditional	3.75	[d]	0.93	4.68
Improved	2.03	1.85	2.18	6.06
Mean (av. of				
Traditional	3.35	0.12	5.74	9.21
Improved	2.26	0.74	2.12	5.12

[a]Based on paddy recovered in 32 fields during the interval from harvesting to stacking (immediately after harvest). [b]Based on the quantity recovered by gleaners in the traditional system. For mechanical threshing, losses included blower and straw losses. [c]Data taken from field trials in Bicol region. [d]No stacking loss was noted in the Bicol area because paddy was threshed immediately after harvest with no intermediate stacking operations.



1. Farm-level postproduction systems.

Table 2. Relationships between time lapse between harvesting and drying, and grain yield for alternative postproduction systems. Central Luzon, 1975–76.

Postproduction system	Time lapse (days)			Yield (t/ha)			Grain loss (%)
	Harvest to threshing	Threshing to drying	Harvest to drying	Harvest	Threshing	Drying	
I Manual threshing and sun drying	1	1	4	3.3	2.9	2.5	24
II Manual threshing and mechanical drying	1	0	1	4.1	3.6	3.6	12
III Mechanical threshing and sun drying	0	2	2	4.9	4.8	4.2	14
IV Mechanical threshing and drying	0	2	2	3.9	3.8	3.5	10

covered 190 paddy fields growing 8 rice varieties. The average rice yield was 3.3 t/ha. In Bicol, the trials retained the same pattern plus seven alternative milling technologies.

Quantitative grain loss. Harvesting loss was estimated from the quantity of grain recovered during the interval between harvesting and stacking. Compared with the traditional system, the improved system incurred lower losses in harvesting but higher in stacking (Table 1). The differences were partly a result of stack size. With the traditional system, paddy is placed in small bundles in the field. Paddy for mechanical threshing is hauled and placed in large stacks along the levees or roadside to make it accessible to the thresher. This practice is common especially during the wet season when soft, muddy fields make it impossible for the mechanical thresher to cross the field.

Data from the Central Luzon trials show that grain losses from manual threshing were three times greater than those from systems using the mechanical thresher. The results from Bicol were nearly the opposite because manual threshing was done on a concrete floor and all grain recovered after threshing was considered part of the threshing yield. Moreover, traditional threshing in Bicol is a combination of treading and flail, a more complete operation compared with the *hampasan* method (beating paddy against a threshing frame) in Central Luzon.

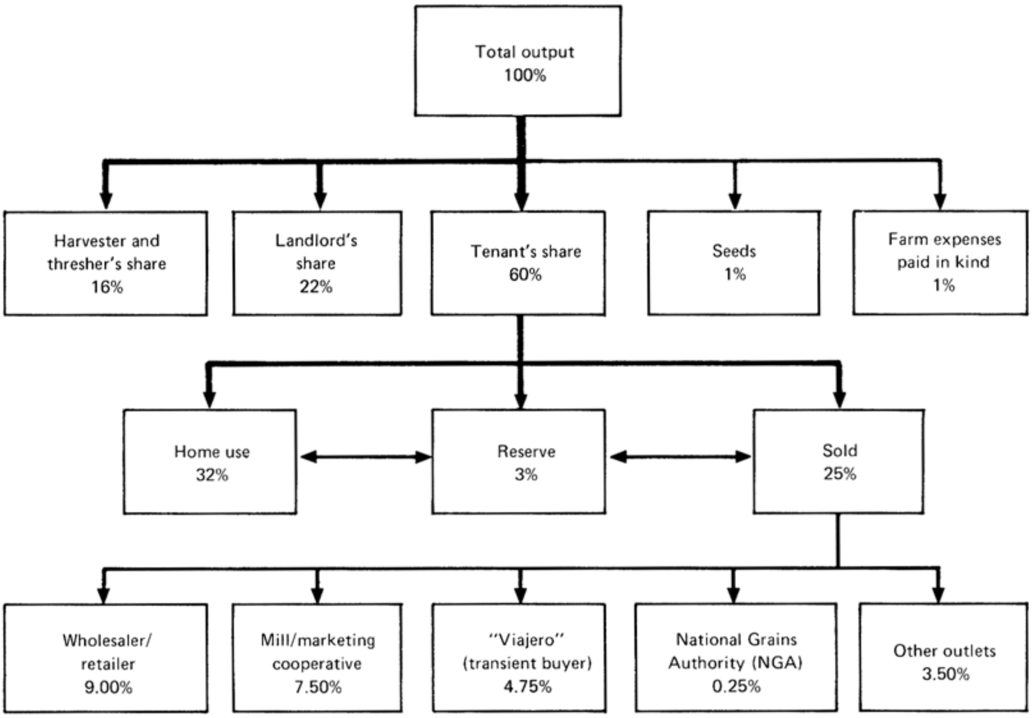
Table 2 illustrates the relationship between the time lapse between harvest and drying and the resulting grain yield. In general, grain loss increased as the interval between the harvest and drying operations increased. More significant, however, were the yield differences observed between traditional systems and those using improved methods. Use of a dryer in system II reduced grain loss to 12%, in contrast with 24% observed in system I. Use of the mechanical thresher gave similar reductions in grain loss in system III. System IV, which used both the thresher and dryer, produced the lowest grain loss.

Each system had a high degree of variability, largely because factors that affected the performance of the systems were variable. Rain after harvest but before threshing often damaged grain in the field.

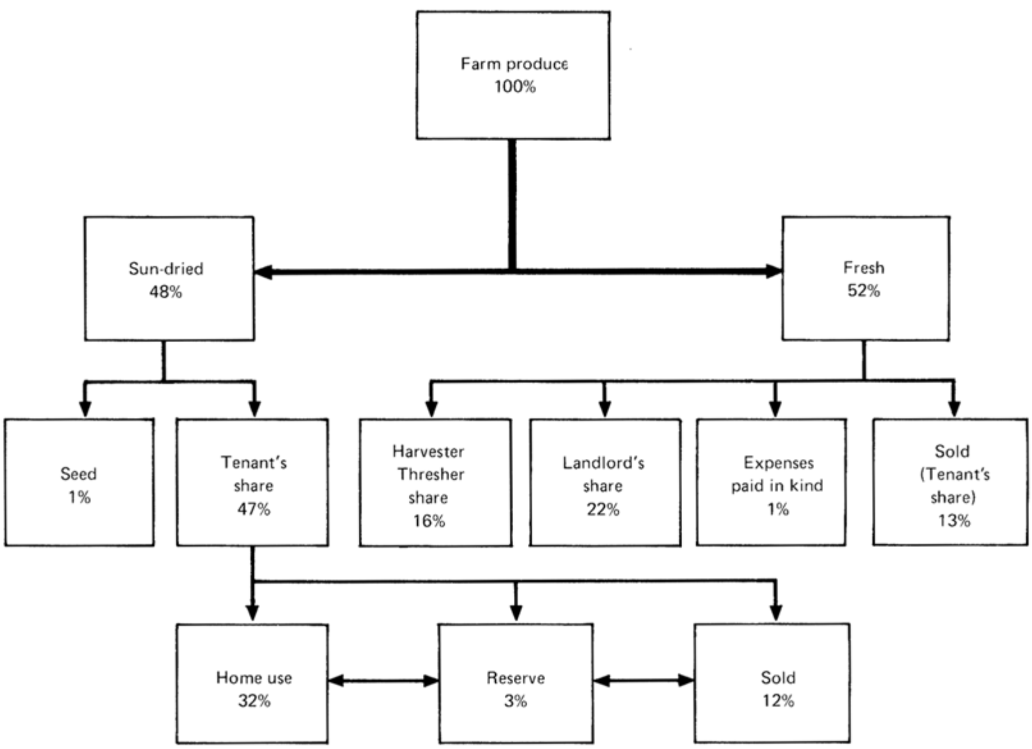
Qualitative grain loss. The differences in grain quality of milled rice from each postproduction system are shown in Table 3. Although overall milled-rice recovery increased only 4 to 6% with the improved system, the percentages of broken, fermented, discolored, and immature grains were significantly reduced, particularly in systems using the grain dryer. The time lapse between harvest and final drying, and percentage of head-rice recovery were inversely related

Table 3. Quality characteristics of milled rice from alternative postproduction systems, 51 paddy samples, 16 plots, Central Luzon, 1975.

System	Time lapse between harvesting and drying (days)	Quality characteristic (%)			
		Head rice	Broken rice	Milling recovery	
				Brown rice	Milled rice
Manual threshing and sun drying	4	77.4	20.2	63.0	59.3
Manual threshing and mechanical drying	1	84.5	14.1	67.4	63.4
Mechanical threshing and sun drying	2	90.6	8.8	70.5	65.6
Mechanical threshing and drying	2	89.9	9.2	68.4	64.4



2. Production and disposal of paddy by a tenant-operator. Central Luzon, Philippines, 1974–75.



3. Flow of tenant-operator paddy in fresh and dried form. Central Luzon, Philippines, 1973–74.

(Table 2, 3). A time lapse of 4 days between harvest and final drying resulted in 77% head-rice recovery. In contrast, systems with a total time lapse of 2 days or less gave 85 to 91% head-rice recovery.

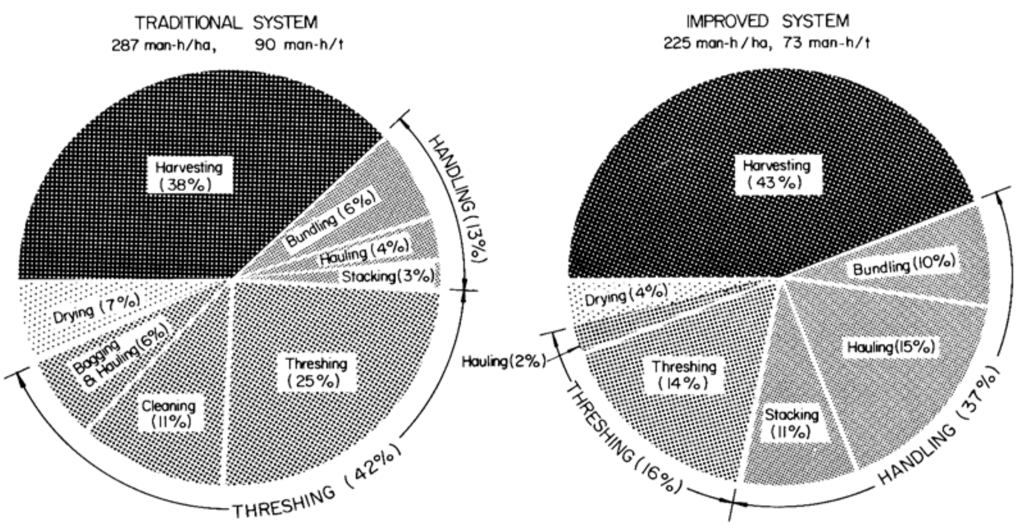
Distribution system. An examination of the paddy marketing system following the field-level, postproduction operations partially explains why mechanical dryers are not attractive to farmers. Figure 2 shows the distribution of paddy among recipients after harvest. Of the 60% retained by a tenant-operator, 25% is sold and 32% is kept for home consumption. Figure 3 pinpoints the location within the postproduction distributive system where drying takes place. The tenant-farmers dispose of 52% of the paddy without drying. The remainder is not sufficient inducement for an individual farmer to own and operate a dryer.

Labor requirements. Detailed records were kept of the number of man-hours used in each operation for each level of technology. The net time devoted to each operation is expressed in man-hours. Snack and rest periods are excluded.

Figure 4 shows the relative percentage distribution of labor between traditional and improved systems by operation. Harvesting, which includes cutting, gathering, bundling, and stacking, required the greatest manpower input and was a major contraint in the postproduction process. The study indicated that rapid harvest had little correlation with a farmer's desire to plant a subsequent crop. Generally, farmers who harvested their paddy early tended to wait and plant at the same time as their neighbors to protect their crop from rat infestation and other pest problems. Timing of harvest operations reflected the farmer's awareness of the relationship between delays and increased losses.

In handling operations, the improved system required twice as much labor as the traditional system (Table 4). The paddy had to be moved to the dikes or roadside to make it accessible to the thresher, and had to be placed in large stacks for effective use of the equipment.

In the traditional system, threshing included cleaning or winnowing. The mechanical thresher



4. Comparative labor use for traditional and improved postproduction systems. Central Luzon, Philippines, 1975–76.

Table 4. Comparative labor requirements by operation of postproduction systems,[a] Central Luzon, 1975–76.

Operation	Labor requirement: Traditional (man-h/ha)	Improved (man-h/ha)	Traditional (man-h/t)	Improved (man-h/t)
Harvesting	108	97	35	31
Handling	37	83	11	27
bundling	17	24	5	9
hauling	13	34	4	9
stacking	7	25	2	9
Threshing	122	36	39	11
threshing	72	31	23	10
cleaning	33		11	
bagging	9		3	
hauling	8	5	2	1
Drying	20	10	7	3
spreading	9		2	
stirring	1		1	
collecting/ bagging	9		3	
weighing	1		1	
loading		2		1
unloading		4		1
weighing		4		1
All operations	287	226	92	72

[a]Improved system includes mechanical thresher and dryer.

reduced overall threshing labor requirements by 70% on a per-hectare basis. The reduction is slightly greater on a per-ton basis because the thresher also tends to improve grain yields.

Farmers preferred the mechanical thresher because it allowed recovery of more grain, had a high degree of availability (timeliness), and eased monitoring of threshing and distribution of the final product. In contrast with traditional threshing methods, which offer considerable opportunity for pilferage, mechanized threshing consolidates control of the threshing operation.

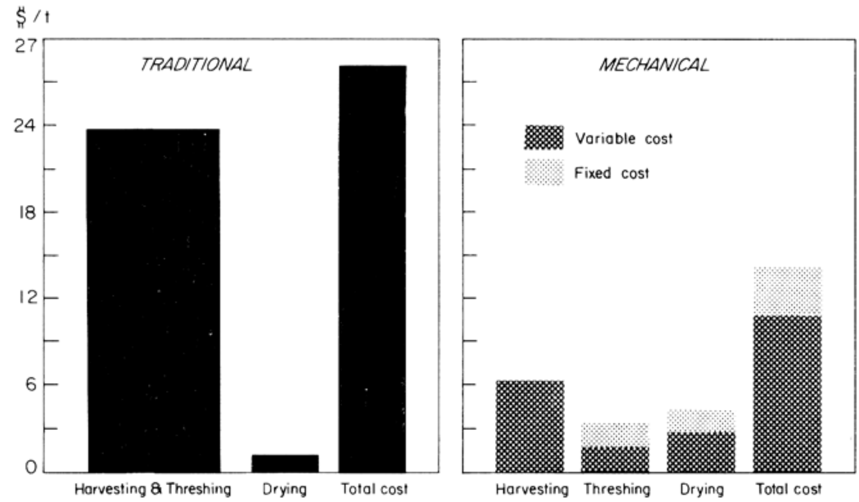
The mechanical thresher used in the trials had the technical capability to thresh high-moisture paddy, a feature found useful when combined with mechanical drying. The major limitations of the unit were its high initial cost and lack of mobility in the field during the wet-season harvest (Fig. 5). The machine did not eliminate the need for repeated intermediate handling of the unthreshed grain, a major cause of grain loss. Partly because the axial-flow thresher lacked mobility, a smaller model was introduced (Fig. 6). The smaller machine permitted in-field operation near the point of harvest, reduced paddy handling between harvesting and threshing from 5 steps to 1 step, and increased yield by 3%.

The labor required for drying includes the handling of threshed paddy in preparation for drying, management of the drying system, and collection and bagging of dried materials. Use of mechanical dryers reduced by 50% the labor required for drying on both a per-hectare and a per-ton basis. Use of the mechanical thresher resulted in higher yields. In contrast, use of the mechanical dryer did not improve the output of traditional methods, particularly when the dryer was used in combination with traditional harvesting-threshing techniques. The dryer, however, improved grain quality, as measured by head-rice recoveries. It performed best in combination with the mechanical thresher.

Comparative costs. A series of cost estimates for traditional and improved postproduction systems were computed for each village in the

5. Threshing and drying field trials in 1975–76 identified high initial cost and lack of mobility during the wet season as limitations to use of the axial-flow thresher.

6. A two-man portable axial-flow thresher was introduced in 1976 to permit in-field operator near the point of harvest.



7. Cost estimate (based on contractual harvesting and threshing fee) for alternate postproduction systems. Nueva Ecija province, Philippines, 1975–76.

Central Luzon trials. Items included in the analysis were observed labor, fuel and maintenance, and fixed-investment requirements. Although it would have accentuated the differences, increased value was not ascribed to improvements in quality that resulted from use of the mechanical systems.

Two methods of estimating costs were considered: one based on a contractual harvesting-threshing fee paid in kind and the other calculated using an imputed wage rate of US$0.14/h for actual labor.

In the Central Luzon trials, both harvesting and threshing activities used hired or exchange labor from the village or from neighboring communities. Compensation for labor was usually in kind, and harvesting and threshing were considered a joint operation. In the cost estimate, the harvester-thresher's fee was one-sixth of the gross production. For the traditional system, the harvesting-threshing fee amounted to US$23.80/t (Fig. 7). With the axial-flow thresher, costs that included the man-hour requirement for harvesting and threshing were reduced by 60% to US$9.43/t.

Farmers in the study area were willing to pay the high contractual fee for harvesting and threshing plus the added cost for the mechanical thresher. The harvester-thresher's fee covered the clearing of the field immediately after harvest, a major problem under the traditional system in which threshing is carried out in the field and straw disposal is a problem. With mechanical threshers, the straw is spread along the dike, scattered on the road, or burned immediately after threshing.

The improved drying system cost US$4.40/t, of which US$3.97 was for the operation of the batch dryer. In contrast, sun drying incurred expense only for labor. Most farmers sold their paddy immediately after threshing, without drying. Because of that, the total labor time involved in sun drying could not be accurately estimated.

Although use of the dryer achieved limited improvement in output, it clearly increased milled- and head-rice recoveries.

A major factor affecting the acceptability of drying equipment is the lack of price incentives. Surveys at the pilot-trial sites showed that farmers received little or no price differential for delivering dry paddy. A minimum price differential of US$4.40/t is required to offset the costs of using the mechanical dryer.

In addition to pricing policies, other factors conditioned acceptance of the mechanical dryer. First, the drying equipment was too expensive for individual farm ownership. Second, the absence of paddy grades and standards and the methods for administering them limited the

Table 5. Alternative milling systems evaluated in the Bicol region, 1976.

System	Precleaning	Hulling	Husk aspiration	Whitening	Refining
I One-pass system (local Engleberg)	None	Engleberg	Air trap	Engleberg	Leather polisher
II Conventional cono-type rice mill	Scalper-sieve	Stone-disc	Air trap	Cone	Leather polisher
III Japanese multipass rice mill	Scalper-sieve	Rubber roll	Aspirator	Abrasive friction	Leather polisher
IV Rubber-roll huller-Engleberg whitener rice mill	None	Rubber roll	Air trap	Engleberg	None
V Stone-disc huller-Engleberg whitener rice mill	Sieve	Stone-disc	Air trap	Engleberg	None
VI One-pass Japanese rice mill	None	Rubber roll	Aspirator	Friction	None
VII IRRI-improved Engleberg	None	Engleberg	Air trap	Engleberg	None

incentives for using the dryer. Third, the most effective output effect of the dryer was only achieved in conjunction with better field-level handling and threshing machinery.

Mill-level trials. Mill-level trials were confined to the Bicol region. As in the field-level pilot trials, a number of alternative systems were evaluated (Table 5). Except the IRRI-improved steel huller (*kiskisan*), all mills included in the trials are commercially available units operating in the Bicol region. While the study focused on the village mill, selected commercial level disc-cone and rubber roll-type mills were also assessed for comparison.

The first step involved a technical assessment of the seven milling systems. To reduce experimental error, a 35-ton homogeneous paddy sample was threshed and dried under controlled conditions and the sample was segregated into lot sizes large enough for replicated test runs through each milling system. Before each test, rice mill operators were asked to calibrate their systems to government specifications for second-class milled rice. The procedure partially eliminated bias attributable to differences in the degree of milling.

The mean performance of each mill type in the commercial milling tests showed that mills using rubber-roll hullers had the highest total milling recoveries followed by disc-cone and steel hullers. Close examination of total milling recoveries for two cone-type units showed recoveries of 71 and 70%, slightly higher than was obtained for the rubber-roll hullers (Table 6).

Table 6. Results of commercial and laboratory milling tests for six alternative milling technologies in the Bicol River Basin Area, 1976.

Milling system	Actual capacity (kg/h)	Recovery (%)							
		Commercial milling[a]				Laboratory milling			
		Milling recovery	Head rice	Broken rice	Brewer's rice	Milling recovery	Head rice	Broken rice	Brewer's rice
Rubber roll single pass	225	69.75	60.55	38.50	0.95	72.65	82.94	14.97	2.09
Rubber roll multipass	4200	69.43	77.71	21.94	0.35	71.33	80.00	17.25	2.75
Rubber roll-steel huller combination	300	68.47	59.05	40.50	0.45	71.31	86.07	11.50	2.43
Disc cone (av.)[b]	630	68.36	74.55	24.61	0.84	70.90	80.22	17.37	2.41
Libmanan RM	800	71.10	72.91	26.17	0.82	73.10	84.35	14.00	1.65
Concina RM	600	69.90	72.32	26.45	1.23	71.12	79.44	18.16	2.40
Gonzales RM	900	67.88	78.45	21.03	0.42	70.06	80.46	16.69	2.85
Nazarrea RM	225	64.56	74.52	24.78	0.70	69.33	76.62	20.63	2.75
Stone disc-steel huller combination	444	65.56	53.68	43.63	2.69	68.80	80.00	17.67	2.33
Steel huller (av.)[b]	380	64.50	29.18	68.86	2.06	72.29	81.19	16.45	2.36
Torres RM	585	66.70	26.60	67.37	2.41	72.11	83.19	14.79	2.02
Olaño RM	270	65.09	38.23	77.00	1.67	70.87	82.32	15.42	2.26
Dycoco RM	410	63.26	21.75	60.08	1.25	72.12	80.70	16.45	2.88
Ruta RM	240	62.93	30.12	70.99	2.47	74.06	78.56	19.13	2.31

[a]Tests for each milling system were replicated four times. [b]Mills selected within the pilot areas of the farm-level demonstration and applied research trials. RM = rice mill.

One steel huller had a total milling recovery of 67%, comparable with the output obtained from the cone-type mills.

Systems employing multipass milling obtained higher head-rice recoveries than systems using single-pass milling (as exemplified by the steel huller and the stone disc-steel huller combination). The differences in head-rice recovery in multipass milling are attributed to the lower pressures and temperatures during the whitening process and bran removal. In single-pass milling, the grain is under high pressure and, concurrently, under higher temperature that results in excessive breakage. Moreover, single-pass mills do not have paddy separators, and so unhulled paddy mixes with brown rice during the whitening process. The mixture of unhulled paddy and brown rice increases friction in the whitening process, causing further breakage.

Among the six milling technologies tested, the steel-huller mill gave the lowest total and head-rice recovery. However, when it was used as a whitener in combination with a rubber-roll or stone-disc huller, the total and head-rice recoveries were significantly higher.

To gauge the performance of the commercial mills included in the technical assessment stage of the trials, a series of laboratory milling tests were conducted on the same paddy samples used in the commercial milling tests. Preliminary results showed that the rubber-roll huller produced milling rates comparable with those obtained in the laboratory.

MARKETABLE SURPLUS

Associated with the question of technological choice in postproduction systems is the proportion of paddy retained in the rural sector for storage and use by rural households. This reserve will determine not only the quantity moving into marketing channels outside the farm sector but also the requirements of household storage, localized milling and logistical services, and the degree and conditions affecting trade in paddy and milled rice at the village level.

Under normal conditions, small producers sell or trade that part of the crop in excess of the amount required for household consumption, seed, and debt repayment. There are circumstances, however, when sales may not be determined solely by consumption requirements.

To assess the degree to which farmers sell paddy in excess of normal marketable supplies, 100 farmers in Laguna province were interviewed during the 1975–76 crop year. They were classified by the size of their marketed surplus expressed as a percentage of total farm production. Those who marketed 35% or less of total production were rated low in marketed surplus; those with 36 to 60%, medium; and those above 60%, high. Thirteen farmers had high, 50 had medium, and 37 had low marketed surplus.

Seven factors affected the size of the marketed surplus: farm size, household size, level of production, monthly income, monthly cash requirements, land rent, and the level of income from other sources (Table 7).

Table 7. Factors affecting the level of marketed surplus. Laguna province, 1976.

Item	Farms (no.)	Marketed surplus	
		t/farm	% of production[a]
Farm size			
1.0 ha and below	31	1.8	38 b
1.1–3.0 ha	51	6.0	42 b
3.1 ha and above	18	19.9	50 a
Household size			
4 persons or less	19	5.7	41 a
5–7 persons	48	6.3	41 a
8 persons or more	33	9.3	44 a
Production			
Less than 5 t	21	1.1	39 a
5–19 t	50	4.7	40 a
20 t and above	29	15.9	47 a
Income			
Less than $71/mo.	32	1.8	37 b
$71 – $143/mo.	35	5.0	41 ab
More than $143/mo.	33	14.7	48 a
Cash requirements			
Less than $71/mo.	33	2.2	37 b
$71 – $143/mo.	41	5.8	40 b
More than $143/mo.	26	15.7	52 a
Land rent			
15% of production and below	17	9.0	49 a
16–40%	70	7.1	41 ab
41% and above	13	5.1	36 b
Other income			
20% of total income and below	41	10.6	47 a
21–50%	39	5.4	38 b
51% and above	20	3.7	40 ab
All farms	100	7.2	42

[a] Means followed by a common letter are not significantly different at the 5% level.

Constraints on rice yields

Agronomy, Statistics, and Agricultural Economics Departments

SUMMARY

Results in 1976 tended to confirm earlier findings that the dry-season yield gap between farmers' level and a high level of inputs is about 2 t/ha. Fertilizer accounted for the major portion of the yield gap at four sites. Insect control accounted for one-third of the gap in Laguna and Nueva Ecija. For the first time, yield levels at Laguna and Nueva Ecija were comparable.

The wet-season yield gap varied from 2.6 t/ha in Laguna to 0.6 t/ha in Camarines Sur. In Laguna, the brown planthopper was the principal insect problem; in Nueva Ecija tungro and bacterial leaf blight reduced yields. The high level of insect control raised yields above the farmers' level of control by 1.6 t/ha in Laguna and by 0.9 t/ha in Nueva Ecija. Many farmers sustained yield losses due to insects and diseases even with varieties originally thought to be resistant.

Similar research in Camarines Sur and Iloilo provinces gave somewhat different results; in both the dry and wet seasons, fertilizer effects were more dominant than they were in Nueva Ecija and Laguna. High insect control contributed less to yield in Camarines Sur and Iloilo provinces than in Nueva Ecija and Laguna.

To facilitate economic evaluation of the experimental results, a set of fertilizer and insect control levels intermediate between the farmers' and the high level were tested. The added levels showed that in the dry season the high level of fertilizer generally increased profits, but the high level of insecticide reduced profits when compared to the intermediate level. In the wet season, by contrast, the high level of fertilizer generally gave lower profit than did the intermediate level.

Although about half of the Laguna farmers studied spent more on fertilizer than the cost of the experimental high level, the high level generally gave profitably higher yields than did the farmers' level. Survey results showed that large numbers of farmers did not know the best time to apply fertilizer.

Evaluation of the comparable paddy that replicated farmers' practices in the experimental plot showed no systematic yield bias among farm yields, comparable paddy yields, and farmers' treatment plot yields. An experimental design with a minimum number of treatments was developed for areas where interaction is not appreciable. In constraints studies, variance was much higher among farms than among replications within farms, indicating that resources should be used to increase the number of experimental farms, rather than the number of replications.

BIOLOGICAL CONSTRAINTS

Agronomy and Statistics Departments

Research continued in four Philippine provinces on the difference, or gap, between farmers' actual yields and the yields possible with high levels of inputs such as fertilizer, insect control, and weed control (1975 Annual Report). Farmers' inputs and experimental high inputs for both seasons at all test sites are in Table 1.

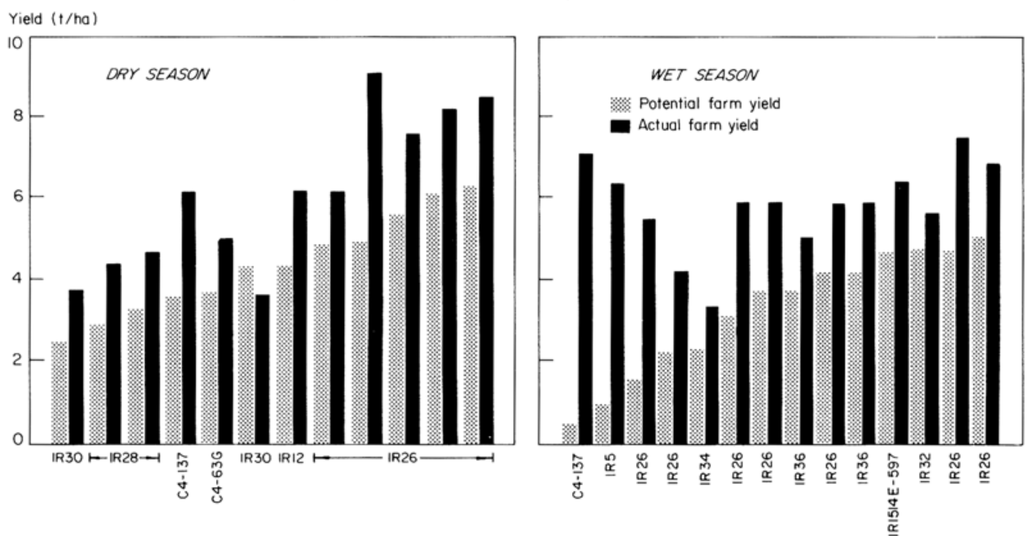
Laguna sites (*Statistics*). *Dry season.* Dry-season experiments were on 12 farms—six canal irrigated, three pump irrigated, and three irrigated by a combination of pump and canal. The average farmer-applied fertilizers—96 kg N/ha, 15 kg P_2O_5/ha, and 8 kg K_2O/ha—were split into two or three applications. Most farmers controlled weeds by one or two rotary weedings followed by hand weeding. To control insects, all farmers used foliar sprays, averaging three applications. Only one farmer supplemented spraying with granular insecticide. With those inputs, farmers' yields varied from 2.5 to 6.1 t/ha (Fig. 1), averaging 4.4 t/ha. The high levels of insect control, fertilizer, and weed control produced yields that ranged from 3.8 to 9.1 t/ha, averaging 6.1 t/ha. Yield gaps ranged from 1.3 to 4.2 t/ha, except for one farm where high inputs did not increase yields. Of the average yield gap of 1.7 t/ha, 59% (1.0 t/ha) was contributed by improved fertilizer use and 35% (0.6 t/ha) by improved insect control (Table 2). Improved weed control contributed little to the gap.

Wet season. Wet-season experiments were on 14 farms; nine had canal irrigation, four had pump irrigation, and one had the combination canal and pump irrigation. Farmers' rates of fertilizer application were only slightly lower than in the dry season. Weed control practices

Table 1. High levels and farmers' levels of inputs in yield-constraints experiments on farmers' fields at four sites in the Philippines, 1976 dry and wet seasons.

Input level	Province	Sites (no.)	Fertilizer (kg/ha)			Weed control[a]		Insect control[b]	
			N	P_2O_5	K_2O	M	C	F	G
			Dry season						
Farmers'	Laguna	12	96	15	8	3.2	0.1	3.5	0.1
High	Laguna	12	120	0	0	2.6	1.0	2.0	5.1
Farmers'	Nueva Ecija	9	76	34	1	0.9	0.4	1.5	0.4
Intermediate 1	Nueva Ecija	9	50	20	10	—	—	0.0	2.0
Intermediate 2	Nueva Ecija	9	100	30	20	—	—	—	—
High	Nueva Ecija	9	150	40	30	1.0	1.0	1.0	4.0
Farmers'	Camarines Sur	5	43	25	10	0.5	0.5	4.0	0.2
Intermediate 1	Camarines Sur	5	50	20	10	—	—	0.0	2.0
Intermediate 2	Camarines Sur	5	100	30	20	—	—	—	—
High	Camarines Sur	5	150	40	30	1.0	1.0	1.0	4.0
Farmers'	Iloilo	2	37	9	0	0.5	1.0	1.5	0.0
Intermediate 1	Iloilo	2	50	20	10	—	—	0.0	2.0
Intermediate 2	Iloilo	2	100	30	20	—	—	—	—
High	Iloilo	2	150	40	30	1.0	1.0	1.0	4.0
			Wet season						
Farmers'	Laguna	14	77	7	2	2.3	0.8	3.3	0.4
High	Laguna	14	90	0	0	2.3	0.9	2.1	4.9
Farmers'	Nueva Ecija	9	57	13	0	0.1	0.3	1.7	0.4
Intermediate 1	Nueva Ecija	9	40	20	10	—	—	0.0	2.0
Intermediate 2	Nueva Ecija	9	70	30	20	—	—	—	—
High	Nueva Ecija	9	100	40	30	1.0	1.0	1.0	3.0
Farmers'	Camarines Sur	6	36	8	6	1.4	0.5	3.0	0.2
Intermediate 1	Camarines Sur	6	40	20	10	—	—	0.0	2.0
Intermediate 2	Camarines Sur	6	70	30	20	—	—	—	—
High	Camarines Sur	6	100	40	30	1.0	1.0	1.0	3.0
Farmers'	Iloilo	7	43	11	5	0.3	0.1	1.3	0.1
Intermediate 1	Iloilo	7	40	20	10	—	—	0.0	2.0
Intermediate 2	Iloilo	7	70	30	20	—	—	—	—
High	Iloilo	7	100	40	30	1.0	1.0	1.0	3.0

[a]Data show av. no. of mechanical weeding operations (M)—either by hand or by rotary weeder—or of chemical weedicide (C) applications. [b]Data show av. no. of foliar (F) sprays—Hytox, Azodrin, Brodan, Panapest, etc.—or of granular (G) applications—lindane, Carbofuran, and diazinon—to paddy water. The main field crops were treated. In some cases, seedbeds were also treated.



1. Potential farm yield and actual farm yield from yield-constraints experiments in farmers' fields. Laguna, Philippines, 1976 dry and wet seasons. (Each set of bars represents one farm.)

Table 2. Contribution of separate inputs toward improving rice yields over farmer's levels in yield-constraints experiments in farmers' fields, project areas in four provinces, Philippines, 1976.

Province	Sites (no.)		Yield (t/ha)			Contribution[a] (t/ha) of			
	Irrigated	Rainfed	Farmers' inputs	High inputs	Difference	Fertilizer	Weed control	Insect control	Residual
			Dry season						
Laguna	12	0	4.4	6.1	1.7	1.0	0.2	0.6	–0.1
Nueva Ecija	9	0	4.0	6.5	2.5	1.4	0.3	0.8	0.0
Camarines Sur	5	0	3.3	4.8	1.5	1.3	0.1	0.2	–0.1
Iloilo	2	0	3.1	5.6	2.5	1.6	0.4	0.2	0.3
			Wet season						
Laguna	14	0	3.3	5.9	2.6	0.7	0.2	1.6	0.1
Nueva Ecija	6	3	2.8	4.4	1.6	0.6	0.0	0.9	0.1
Camarines Sur	5	1	2.7	3.3	0.6	0.4	0.1	0.2	–0.1
Iloilo	5	2	3.3	5.3	2.0	0.9	0.3	0.5	0.3

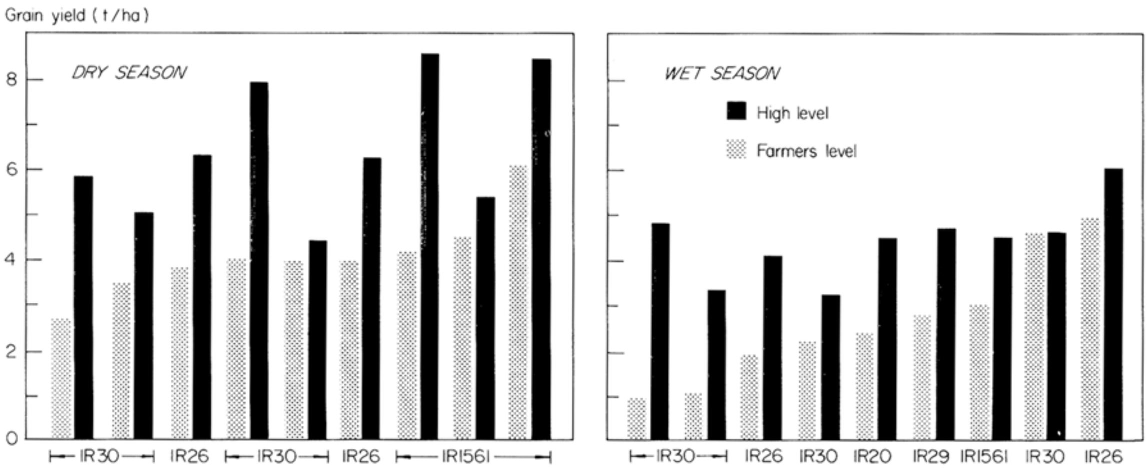
[a]Measured as the average yield increase from the high level of each input compared with yield at farmers' level of each input, averaged over all levels of other inputs.

were similar to those in the dry season. The frequency of hand weeding was slightly lower, however, and herbicide use increased. Farmers' insecticide use was similar to that in the dry season.

Farmers' yields ranged from 0.5 to 5.2 t/ha (Fig. 1), averaging 3.3 t/ha (Table 2). With high inputs, yields ranged from 3.4 to 7.6 t/ha (av. of 5.9 t/ha). Yield gaps ranged from 0.9 to 6.7 t/ha (av. of 2.6 t/ha). The major portion of the yield gap, 62% (1.6 t/ha), was from improved insect control and 27% (0.7 t/ha) was from improved fertilizer use. As in the dry season, improved weed control did not appreciably increase yield.

The larger yield gap in the wet season was primarily caused by severe brown planthopper attack on some farms. Three farms had severe hopperburn in treatments with the farmers' level of insect control, and had yield gaps of 2.2, 5.5, and 6.7 t/ha. The results suggested a much larger relative average contribution from improved insect control in the wet season.

Nueva Ecija sites (*Agronomy*). *Dry season.* Dry-season experiments were on nine pump-irrigated farms. The average level of fertilizer applied by the cooperating farmers was 76 kg N/ha, 34 kg P_2O_5/ha, and about 1 kg K_2O/ha.



2. Variations in yield gap between farmers' fields in farm yield-constraints studies in Nueva Ecija province, Philippines, 1976 dry and wet seasons. (Each set of bars represents one farm.)

Table 3. Grain yield under different levels of inputs, project areas in three provinces, Philippines. 1976 dry season.

Province	Farms (no.)	Grain yield[a] (t/ha)								
		Fertilizer				Insect control			Weed control	
		F	I-1	I-2	H	F	I	H	F	H
Nueva Ecija	9	4.5	4.6	5.5	5.8	4.8	4.9	5.6	5.0	5.3
Camarines Sur	5	3.4	3.7	4.2	4.7	3.9	4.0	4.1	3.9	4.1
Iloilo	2	3.7	4.6	5.3	5.4	4.7	4.8	4.8	4.5	5.0
Average		3.9	4.3	5.0	5.3	4.5	4.6	4.8	4.4	4.8

[a]F = farmers' level; I = intermediate; H= high.

Nearly all farmers sprayed more than once, and about half of them used granular insecticides. Most farmers hand weeded once, and half of them used herbicides.

Yields at the farmers' level of inputs ranged from 2.6 to 6.1 t/ha (Fig. 2), averaging 4.0 t/ha. One reason for low yields on some farms—in addition to low levels of inputs—was late application of fertilizer and herbicide. Application of the high level of inputs resulted in an average yield gain of 2.5 t/ha (Table 2).

Fertilizer, the most important of the three major input factors studied, contributed 56% (1.4 t/ha) of the yield gap; insect control accounted for 31% (0.8 t/ha); and weed control, for 13% (0.3 t/ha).

This year's experiment included two levels of fertilizer intermediate between the farmers' and the high level, and one intermediate level of insecticide (Table 1). The value for a specific input level (Table 3) is averaged over all other inputs. In the dry season, increasing fertilizer levels continued to increase yields up to the high input level. Average yields at intermediate (I-2) and high levels of fertilizer input were appreciably higher than those at farmers' level. Yields at the intermediate level of insect control were no higher than those at the farmers' level but yields at the high level of insect control were higher than those at the farmers' level.

Management package experiments were run on two farms in each of three provinces with two varieties. Input levels are in Table 4, and the results are in Table 5. The farmers' variety was IR30 on one site and IR1561-228-3 on the other. The test variety was IR36.

Wet season. Wet-season experiments were on three rainfed and six irrigated farms. The average levels of fertilizer and weed control used were generally lower than those in the

Table 4. Average levels of inputs used by farmers, and levels of four input management packages, project areas, three provinces, Philippines, 1976 dry season.

Province	Sites (no.)	Package level[a]	Fertilizer (kg/ha)			Insect control[b] (av. no. of applications)				Weed control[c] (av. no. of treatments)	
			N	P_2O_5	K_2O	Seedbed		Field			
						F	G	F	G	M	C
Nueva Ecija	2	M1	83	36	3.5	0.5	0	0.5	0.5	1	0.5
Camarines Sur	2	M1	42	32	5	1.5	0	4	0	0.5	0.5
Both provinces	all	M2	40	10	0	0	0	2	0	1	0
		M3	80	20	20	1	0	2	1	0	1
		M4	120	30	30	2	0	2	2	0	1
		M5	160	40	40	2	1	1	4	1	1
Iloilo	2	M1	52	21	21	0	0	2.5	1	0.5	1
		M2	25	10	0	0	0	2	0	1	0
		M3	50	20	10	1	0	2	1	0	1
		M4	75	30	20	2	0	3	2	0	1
		M5	100	40	30	2	1	5	3	1	1

[a]M1 = average of farmers' level of application of the three inputs by site. M2 through M5 have levels of fertilizer, insect control, and weed control, listed in this table. [b]F = foliar, G = granular. [c]M = mechanical weeding, either by hand or rotary weeder; C = Chemical weedicide.

Table 5. Average yield of farmers' varieties and test varieties compared at five levels of input management packages and grown under high levels of cultural practices, project areas in three provinces, Philippines, 1976 dry season.

Province	Sites (no.)	Variety[a]	Yield[b] (t/ha)					
			M1	M2	M3	M4	M5	Av.
Nueva Ecija	2	F	4.3	4.6	5.2	5.6	6.5	5.2
		T	4.8	5.0	5.6	6.0	6.7	5.6
Camarines Sur	2	F	3.2	3.3	3.6	4.3	4.8	3.8
		T	3.6	4.2	4.5	5.2	6.3	4.8
Iloilo	2	F	4.3	3.1	3.8	4.6	5.4	4.2
		T	4.9	4.1	4.4	4.8	5.4	4.7

[a]Farmers' varieties (F): IR30, IR1561, and IR26; test varieties (T): IR36 and IR34. [b]Management packages (M1, M2, M3, M4, and M5) contain varying levels of fertilizer, insect control, and weed control as shown in Table 4.

dry season, but levels of insect control were about the same for both seasons (Table 1).

Yields at the farmers' level of inputs were generally low, ranging from 0.9 t/ha to 4.8 t/ha (Fig. 2) and averaging 2.8 t/ha (Table 2). Application of high inputs gave an average gain of 1.6 t/ha. A severe outbreak of green leafhoppers that subsequently transmitted tungro prevented most farmers from getting high yields. The highest grain yield of 6.0 t/ha was obtained with high inputs on a rainfed farm where tungro was not a problem, despite severe tungro infection in surrounding farms.

High insect control contributed 61% (0.9 t/ha) of the yield gap, and fertilizer accounted for 39% (0.6 t/ha). High weed control did not increase grain yield above the farmers' weed control level (Table 6).

On most farms yield increases were obtained from the application of two intermediate fertilizer levels—with an average 0.5 t/ha yield increase from the second intermediate level (Table 6). Although the farmers' level was higher than the first intermediate level, the increase in grain yield of about 0.2 t/ha was obtained from the intermediate level, where fertilizer use apparently was more efficient. The high level of insect control produced significantly higher yields than did the farmers' level on seven out of nine farms.

In Nueva Ecija, the management package experiment was conducted on one site in the wet season with the input levels shown in Table 7. Subsoil placement of insecticides was evaluated at the M3 and M4 input levels. Average grain yield for the test variety IR36 was 0.5 t/ha higher than that for the farmers' variety, IR30 (Table 8). IR36 gave higher yields only at M1 and M2. At those levels, IR30 suffered from tungro. Although both varieties lodged during the dough stage, they produced a maximum grain yield of about 5 t/ha.

Camarines Sur sites (*Agronomy*). *Dry season.* Dry-season experiments were on three canal-irrigated and two pump-irrigated farms. The average nitrogen applied by farmers was 43 kg ha, which was substantially lower than the level in Laguna and Nueva Ecija (Table 1). Insect control inputs, by contrast, were somewhat higher than in the other areas, averaging four sprays per crop. Four farmers used mechanical methods of weed control (i.e. rotary weeders), and one farmer used both chemical and mechanical methods.

At the farmers' level of inputs, yields ranged from 1.7 to 4.5 t/ha, averaging 3.3 t/ha (Table 2). At the high level of inputs they ranged from 2.9 to 5.9 t/ha, averaging 4.9 t/ha. The average yield gap was 1.6 t/ha (Fig. 3), 78% (1.25 t/ha) of which was contributed by fertilizer. Insect control and weed control each gave about 11% (0.2 t/ha) increase in grain yield over the farmers' level.

The large yield response from fertilizer was

Table 6. Grain yield under different input levels, project areas in three provinces, Philippines, 1976 wet season.

Province	Farms (no.)	Grain yield[a] (t/ha)								
		Fertilizer				Insect control			Weed control	
		F	I-1	I-2	H	F	I	H	F	H
Nueva Ecija	9	3.3	3.5	3.8	3.9	3.1	3.7	4.0	3.6	3.6
Camarines Sur	6	2.8	3.0	3.2	3.2	3.0	3.0	3.2	3.0	3.1
Iloilo	7	3.8	4.2	4.5	4.5	4.0	4.3	4.6	4.0	4.5
Average		3.3	3.6	3.8	3.9	3.4	3.7	3.7	3.5	3.7

[a]F = farmers' level; I = intermediate; H = high.

Table 7. Average levels of farmers' inputs and levels of four input management packages, project areas in three provinces, Philippines. 1976 wet season.

Province	Sites (no.)	Package level[a]	Fertilizer (kg/ha)			Insect control[b] (av. no. of applications)				Weed control[c] (av. no. of treatments)	
						Seedbed		Field			
			N	P_2O_5	K_2O	F	G	F	G	M	C
Nueva Ecija	1	M1	23	29	0	1	0	2	1	0	0
Camarines Sur	1	M1	71	17	17	1	0	4	0	3	0
Iloilo	2	M1	54	14	7	0	0	1.5	0	1	0
All three	4	M2	40	10	0	0	0	2	0	1	0
All three	4	M3	60	20	20	0	1	1[d]	0	0	1
All three	4	M4	80	30	30	2	0	1[d]	1	1	1
All three	4	M5	100	40	40	0	2	1	4	1	1

[a] M1 = average of farmers' levels of application of the three inputs by site, insect control, and weed control listed in this table. [b]F = foliar, G = granular. [c]M = mechanical weeding either by hand or rotary weeder; C = chemical weedicide. [d]Root-zone placement of liquid carbofuran.

probably due to the low level of farmers' fertilizer for a dry-season crop (Table 1). Yield at the second intermediate level of fertilizer was 0.8 t/ha above that at the farmers' level (Table 3). A 0.5-t/ha further increase in yield was obtained by applying fertilizer at the high level.

In the management-package experiments on two farms, the test variety gave about 1.0 t/ha yield increase across the five management packages (Table 5). At the farmers' level of inputs, the average test variety yield was 0.4 t/ha higher than that of the farmers' variety. The difference increased to 1.5 t/ha at the M5 level of inputs.

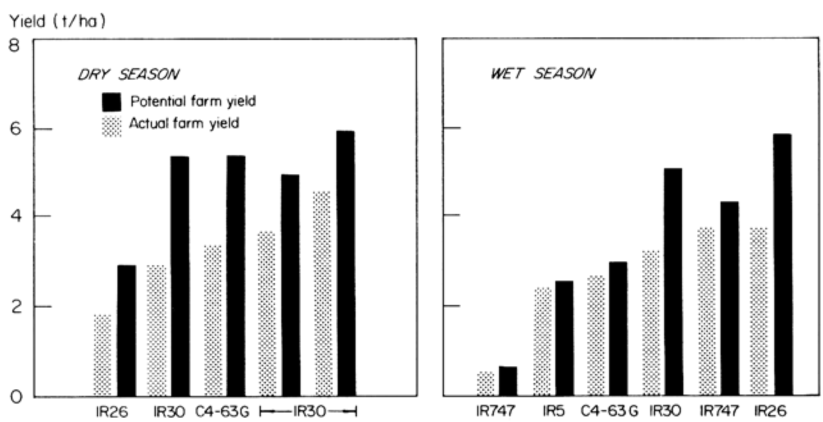
Wet season. The wet-season experiments were on five irrigated farms and one rainfed farm. Farmers' fertilizer levels were lower than those in other sites (Table 1). No fertilizer was applied on one irrigated farm and on the rainfed farm.

Table 8. Average grain yield of farmers' varieties and test varieties compared at five levels of input management packages[a] and grown under high levels of cultural practices, project areas in three provinces, Philippines, 1976 wet season.

Province	Sites (no.)	Variety[b]	Yield (t/ha)					
			M1[c]	M2	M3	M4	M5	Av.
Nueva Ecija	1	F	3.8	3.1	4.8	4.8	4.8	4.3
		T	5.0	5.2	4.5	4.4	4.9	4.8
Camarines Sur	1	F	2.7	2.9	3.2	2.2	1.9	2.6
		T	2.7	2.7	1.9	2.8	2.4	2.5
Iloilo	2	F	4.4	4.4	5.1	5.5	5.8	5.0
		T	4.2	4.2	5.0	5.1	5.4	4.8

[a] Management packages (M1, M2, M3, M4, and M5) contain varying levels of fertilizer, insect control, and weed control as shown in Table 7. [b]Farmers' (F) varieties: IR30, IR1529, and IR26. Test (T) variety: IR36. [c]Farmers' level.

Yields with the farmers' input varied from 0.5 t/ha on the rainfed farm, which had irregular rainfall, to 5 t/ha, averaging 2.7 t/ha (Table 2).



3. Potential farm yield and actual farm yield-constraints experiments in farmers' fields. Camarines Sur, Philippines, 1976 dry and wet seasons. (Each set of bars represents one farm.)

With the high level of inputs, the average yield for the six farms was 3.3 t/ha. Both the absolute level of yield and the yield gap were lower than in the other regions because of the problems encountered on the rainfed farm. High fertilizer application accounted for 59% of the gap (0.4 t/ha); high insect control, for 28% (0.2 t/ha); and weed control, for 13% (0.1 t/ha).

The intermediate level of fertilizer gave 0.2 t/ha higher grain yield than did the farmers' level, and the high and maximum levels gave a 0.4-t/ha increase. In the management-package experiment, neither the test variety nor the management levels gave yield increases above the farmers' practice (Table 8).

Iloilo sites (*Agronomy*). *Dry season*. The dry-season experiment was on only two farms. Neither farm used much fertilizer or practiced insect control, but both used herbicides for weed control (Table 1).

Farmers' yields averaged 3.1 t/ha, and yields from the high inputs averaged 5.6 t/ha (Table 2). The yield gap was 1.7 t/ha on one farm and 3.3 t/ha on the other. Fertilizer accounted for 73% (1.8 t/ha) of the yield gap and weed control for 18% (0.5 t/ha).

The yield gap of 0.4 t/ha due to weed control resulted from inadequate hand weeding practiced by one farmer and poor weed control with herbicide by the other.

Yield at the intermediate level of fertilizer was 0.9 t/ha higher than that at the farmers' level. At the high level it was 1.6 t/ha higher. Yield at the maximum level, however, was only 0.1 t/ha above that at the high fertilizer level (Table 3). All three insect control levels gave about the same yield.

Management package experiments were carried out on two farms, with IR34 as test variety. The farmers' variety was IR26 on one farm and IR30 on the other farm. The input levels are in Table 4. The difference in average yields across all inputs was 0.5 t/ha in favor of the test variety. At the farmers' level of inputs, the test variety gave 0.6 t/ha higher yield than the farmers' varieties (Table 5).

Wet season. Wet-season experiments were on five canal-irrigated and two rainfed farms. The average farmers' input levels are in Table 1. Farmers' yields varied from 2.9 t/ha to 3.8 t/ha, averaging 3.3 t/ha (Table 2). With a high level of input, the yields ranged from 4.5 to 6.0 t/ha. The average yield gap was 2.0 t/ha.

The grain yield increase with high fertilizer was significant on six out of seven farms. Fertilizer accounted for 53% (0.9 t/ha) of the gap, largely because of farmers' low rates of fertilizer application. The high level of weed control accounted for 18% (0.3 t/ha) of the gap. The high level of insect control accounted for 29% (0.5 t/ha) of the yield gap, although yield increase due to high insect control was significant on only one of seven farms.

The intermediate fertilizer level (I-1) raised yields above those of farmers by 0.4 t/ha. The intermediate (I-2) level gave an additional 0.3 t/ha, but the high level added nothing (Table 6). The intermediate insect control level raised yield by 0.3 t/ha above that at the farmers' input level.

Management-package experiments were conducted on one irrigated and one rainfed farm. One farmer grew IR26, and the other grew IR30. The test variety was IR36. The average data for two farms gave no advantage to the test variety over the farmers' variety. The grain yield response to the maximum level package (M5) was higher than that to the farmers' package (M1) by 1.4 t/ha in the farmers' variety and by 1.2 t/ha in the test variety (Table 8).

SOCIOECONOMIC CONSTRAINTS
Agricultural Economics Department

In 1976 an increase from the farmers' level to the high level fertilizer was profitable in all four locations, but nearly twice as profitable in the dry as in the wet season (Table 9). High levels of insect control, which were often less profitable than farmers' practices in past trials, were highly profitable in Laguna and Nueva Ecija during the wet season. High weed control gave only modest increases in the value of output, but the increases exceeded their cost in all but one case.

The performance of fertilizer and insect control inputs was evaluated at intermediate levels. In two of the three study areas, increasing insecticide application from the intermediate

Table 9. Increase in cost and value of output from high levels of three inputs compared with costs at farmers' levels, project sites in four Philippine provinces, 1976.

Province	Sites (no.)	Farmers' fertilizer cost (US$/ha)	Increase from high fertilizer (US$/ha)		Farmers' insect control (US$/ha)	Increase from high insect control (US$/ha)		Farmers' weed control (US$/ha)	Increase from high weed control (US$/ha)	
			Cost	Value		Cost	Value		Cost	Value
Dry season										
Laguna	12	62	3	146	11	71	87	16[a]	–1	29
Nueva Ecija	9	65	43	205	28	73	106	11	9	55
Camarines Sur	5	32	79	158	18	92	23	8	7	17
Iloilo	2	24	89	208	10	90	13	7	8	58
Wet season										
Laguna	14	45	2	90	35	130	205	18[a]	–3	26
Nueva Ecija	9	39	45	105	19	54	141	8	13	0
Camarines Sur	6	23	63	50	23	50	24	15	0	5
Iloilo	7	29	57	86	10	63	75	3	12	56

[a]Farmers in this area use contract laborers to weed and harvest their rice fields for a share of the crop. The amount shown is in addition to such weeding.

to the high level decreased profit (net returns) during the dry season (Table 10). There was no economic complementarity between fertilizer and insect control for levels above the farmers'. In the wet season, the results were generally the same, except that profit increased with high insect control at the high fertilizer level in two provinces.

Higher profits were registered by shifts from intermediate-1 to intermediate-2 levels of fertilizer than by shifts from intermediate-2 to high levels in the dry season (Table 11). There was no consistent economic complementarity between fertilizer and the two other inputs. The wet-season data show that the shift from intermediate-2 to high fertilizer is generally not profitable, even if insect and weed control are kept at a maximum.

Table 12 shows the increased profit obtained with four alternative packages of practices. In Nueva Ecija and Camarines Sur, profit substantially increased with all high packages during the dry season, but in the wet season modest profit increases were possible only from M2 input level. In Iloilo, packages higher than the farmers' were not profitable in the dry season but in the wet season, M2, M3, and M4 increased profits.

Identification of dominant constraints. A combined subjective-objective survey technique determined the relative importance of various explanations for the existing yield gap and for farmers' failure to close it. The dominant constraint that apparently prevented each farmer from obtaining the yield that experiments

Table 10. Additional net returns obtained by increasing insect control from farmers' to intermediate and high levels in experiments on farmers' fields, three Philippine provinces, 1976.

Province	Observations (no.)	Insecticide levels compared	Increased net returns (US$/ha) from insecticide	
			At farmers' fertilizer[a] level	At high fertilizer[a] level
Dry season				
Nueva Ecija	10	Farmers' and intermediate	16	15
Camarines Sur	5	Farmers' and intermediate	9	3
Iloilo	2	Farmers' and intermediate	23	4
Nueva Ecija	10	Intermediate and high	10	5
Camarines Sur	5	Intermediate and high	–72	–40
Iloilo	2	Intermediate and high	–46	–5
Wet season				
Nueva Ecija	9	Farmers' and intermediate	86	59
Camarines Sur	6	Farmers' and intermediate	–4	9
Iloilo	7	Farmers' and intermediate	23	51
Nueva Ecija	9	Intermediate and high	–4	10
Camarines Sur	6	Intermediate and high	–19	–5
Iloilo	7	Intermediate and high	–32	5

[a] With farmers' weed control levels.

Table 11. Additional net returns obtained by increasing fertilizer from farmers' to intermediate to high to maximum levels in experiments on farmers' fields, three Philippine provinces, 1976 dry and wet seasons.

Fertilizer levels compared	Province	Sites (no.)	Net returns from fertilizer (US$/ha)		
			At farmers' insect control, weed control levels	At intermediate insect control, farmers' weed control levels	At intermediate insect control, high weed control levels
		Dry season			
Farmers' and intermediate-1	Nueva Ecija	10	13	36	50
Intermediate-1 and intermediate-2	Nueva Ecija	10	102	106	73
Intermediate-2 and high	Nueva Ecija	10	27	–1	0
Farmers' and intermediate-1	Camarines Sur	5	27	19	27
Intermediate-1 and intermediate-2	Camarines Sur	5	27	39	42
Intermediate-2 and high	Camarines Sur	5	27	16	59
Farmers' and intermediate-1	Iloilo	2	228	160	79
Intermediate-1 and intermediate-2	Iloilo	2	–25	18	59
Intermediate-2 and high	Iloilo	2	–8	36	–22
		Wet season			
Farmers' and intermediate-1	Nueva Ecija	9	58	4	17
Intermediate-1 and intermediate-2	Nueva Ecija	9	–11	30	16
Intermediate-2 and high	Nueva Ecija	9	3	–11	–11
Farmers' and intermediate-1	Camarines Sur	6	28	14	14
Intermediate-1 and intermediate-2	Camarines Sur	6	–25	16	16
Intermediate-2 and high	Camarines Sur	6	–25	–39	–53
Farmers' and intermediate-1	Iloilo	7	20	75	47
Intermediate-1 and intermediate-2	Iloilo	7	70	2	–38
Intermediate-2 and high	Iloilo	7	–93	–53	16

achieved on his farm was identified for each input through cost and returns analysis of the experiments and careful examination of each farmer's situation. The dominant constraint was then assumed to account for the yield contribution (Table 2) of each input for each experimental farmer.

On a few farms, the high levels of a particular input neither gave an increase nor produced a gap. Where an input gave an increase, four distinct reasons or constraints were identified. In addition a residual sometimes existed. The distinct constraints follow:

- Inefficient use of high inputs—the farmer used more inputs or inputs costing more than the researcher's high level, but did not obtain an increase in yield.
- Farmer thought his level was adequate—the farmer thought the level of input he used was high enough, but the experiment showed that higher yields could have profitably been obtained.
- Lack of capital—the farmer said he lacked capital with which to purchase inputs, and he had either no loan or a loan of less than US$100/ha, which was adequate only for the M3 input level.
- Lack of profit—the benefit-to-cost ratio on input in excess of the farmers' level was below 2, a level chosen to include nonmeasured additional costs of interest, harvest costs, and a high return.

In Laguna, the most striking result was that

Table 12. Farmers' net returns above cost of fertilizer, weed control, and insect control; and increase in net returns obtained from four alternative input management packages[a] using test varieties. Three Philippine provinces, 1976.

Province		Farmers' net returns (US$/ha)	Increase in net return (US$/ha)			
			M2	M3	M4	M5
		Dry season				
Nueva Ecija	2	625	75	112	108	144
Camarines Sur	2	395	100	85	112	184
Iloilo	2	539	–55	–67	–80	–78
		Wet season				
Nueva Ecija	1	605	20	–114	–170	–176
Camarines Sur	1	230	53	–88	–22	–141
Iloilo	2	458	9	64	32	–1

[a]M2, M3, M4, and M5 are management packages with varying levels of fertilizer, insect control, and weed control as shown in Table 4 for the dry season and in Table 7 for the wet season.

Table 13. Proportion of yield increase from higher-than-farmer's levels of fertilizer, weed control, and insect control that is attributed to each reason. Laguna and Nueva Ecija, Philippines, 1976.

Yield gap source	Measured yield gap (t/ha)	Farms with no gap (%)	Measured yield gap (%) due to				
			Inefficient use of high inputs	Believed input level adequate	Lack of capital	Lack of profit	Others
			Laguna, dry season				
Fertilizer	1.0	11	47	8	0	0	45[a]
Insect control	0.6	10	0	52	0	48	0
Weed control	0.2	0	65[b]	16	0	18	0
			Laguna, wet season				
Fertilizer	0.7	22	50	0	3	0	46[c]
Insect control	1.6	7	0	32	0	45	23
Weed control	0.2	20	0	64	5	4	0
			Nueva Ecija, dry season				
Fertilizer	1.4	0	0	61	31	8	0
Insect control	0.8	22	0	74	0	26	0
Weed control	0.3	11	0	75	0	4	21
			Nueva Ecija, wet season				
Fertilizer	0.6	0	13	11	11	40	25
Insect control	0.9	0	0	22	11	10	57[d]
Weed control	0.0	67	0	39	0	61	0

[a]On fields of farmers who feared insect attack, lodging, or lack of water. [b]These farmers used high levels of weed control, mainly through *gama*, a system whereby workers weed and harvest for a share of the crop. In the wet season, *gama* was also used, but the researchers used more expensive herbicides. [c]Contributed mainly by one farm where a nonresistant variety was grown with inadequate level of insect protection. [d]46% thought resistant varieties did not require protection from tungro, while protection was used in the experiment.

half of the yield constraint overcome by the high fertilizer level was attributed to relatively inefficient use of fertilizers by farmers (Table 13). For about half of the farmers with experiments in Laguna, the cost of fertilizer was the same as, or more than that of the high-fertilizer treatment, but the latter gave a higher yield. The same inefficiency was noted in weed control in the wet season, but it is explained by the institutional arrangement of contracting the weeding and harvesting operation with the same laborer, giving him incentive to use large amounts of labor.

In Laguna, the most important explanations for not using high insect control were lack of profitability and the farmers' conviction that they had applied adequate levels of insecticides. In the latter case, cost and returns analysis showed that higher levels of insecticide application would have raised profits.

In Nueva Ecija, the major constraint to using the high fertilizer level in the dry season, which would have raised yields by 1.4 t/ha, was the farmers' belief that the usual levels were adequate. In addition, about one-third of the farmers cited lack of capital. No single reason for not using the high level of fertilizers was dominant in the wet season. A similar pattern was observed in reasons for not using high levels of insecticides—in the dry season most farmers thought their insecticide level was adequate, and in the wet season they had varied reasons.

Fertilizer timing. The data on fertilizers suggest that the farmers who participated in the experiments could have applied fertilizers more efficiently, especially in Laguna. In the field experiments the high fertilizer level was applied basally and just before panicle initiation, but farmers applied a significant proportion of nitrogen fertilizer between 11 and 30 days after transplanting (DT), or after 50 DT (Table 14). Nearly half of the phosphorus and potassium was applied after 10 DT (Table 15), whereas agronomists generally agree that phosphorus and potassium should be applied before transplanting.

Interview of a random sample of farmers, in addition to farmers with experiments, revealed wide variability in the time that they considered optimal for applying fertilizer. Table 16 shows the responses to the question on optimum time of urea application. A wide range of application times was considered optimal. About 40% of

Table 14. Timing of nitrogen application in constraints experiments in farmers' fields. Three Philippine provinces, 1976 wet season.

Time of application (DT[a])	Nitrogen applied (kg/ha)			Farmers applying (no.)		
	Laguna	Nueva Ecija	Camarines Sur	Laguna	Nueva Ecija	Camarines Sur
0	0	2.2	0	0	1	0
1–10	5.5	22.6	7.4	4	4	2
11–20	9.1	15.6	1.7	3	2	1
21–30	5.6	2.8	1.4	3	1	1
31–40	10.0	15.7	0.5	3	2	1
41–50	21.3	2.2	11.7	7	1	2
51–60	9.5	0	6.6	4	0	1
61–70	10.9	0	0	3	0	0

[a] Days after transplanting.

Table 15. Timing of phosphorus and potassium application in farm constraints experiments in farmers' fields. Three Philippine provinces, 1976 wet season.

Time of application (DT[a])	Nitrogen applied (kg/ha)			Farmers applying (no.)		
	Laguna	Nueva Ecija	Camarines Sur	Laguna	Nueva Ecija	Camarines Sur
0	0	1.9	0	0	1	0
1–10	5.2	10.3	8.5	3	3	2
11–20	1.8	2.4	0	2	1	0
21–30	0	0	2.8	0	0	1
31–40	3.1	2.4	0.6	2	1	1
41–50	0.6	1.8	0	1	1	0
51–60	0	0	0	0	0	0
61–70	0	0	0	0	0	0

[a]Days after transplanting.

the farmers thought a single application was optimal, the others preferred various split applications. Similar results were observed for fertilizers containing phosphorus and potassium, except that about one-fourth of the farmers replied they simply did not know the optimum time of application of those materials.

The results support the contention that without an increase in the cost of fertilizer applied, farmers can increase rice yields by applying fertilizer at the optimum time, but further investigation is needed to confirm that.

EVALUATION OF EXPERIMENTAL TECHNIQUES

Statistics Department

The experimental technique for evaluating constraints in farmers' fields is characterized by the farmer's practices as the basis of comparison and the use of simple, small experiments. Problems with the technique were reported earlier (1974, 1975 annual reports). Procedures were developed to identify the farmer's input level, arriving at a minimum number of treatments to be tested and allocating replications within and among farms to measure farmers' yields and the biological yield constraints.

Comparable paddy technique to identify farmer's input level. Because a farmer's input use and other practices can vary from one paddy to another on a given farm, the "comparable paddy technique" for identifying the farmer's level of the test inputs was tested. Before experiments are set up, the paddy where the experimental plots are located, or a nearby paddy—if the experiment occupies a major portion of the paddy—is chosen as the comparable paddy. The specific levels of practices used by the farmer in the comparable paddy are then considered as the farmer's level.

Yields from three to four 10-sq-m crop cuts

Table 16. Farmers' responses to the question on the best time to apply urea for maximum rice yield. Three Philippine provinces, 1976 wet season.

Location	Farmers' responses (no.)											Total responses (no.)
	Don't know	Prefer single application of urea at[a]					Prefer split application of urea at				Others	
		7–14 DT	20 DT	30 DT	40 DT	60 DT	(0, 45) DT	(10, 45) DT	(5, 60) DT	(15, 30) DT		
Laguna	2	2	7	2	0	2	5	7	13	6	3	49
Nueva Ecija	11	9	8	2	3	0	2	8	4	3	0	50
Camarines Sur	2	0	7	4	8	4	15	3	6	1	0	50
Three areas	15	11	22	8	11	6	22	18	23	10	3	149

[a]DT = days after transplanting.

Table 17. Comparison of yields determined from whole farm, crop cuts from comparable paddy, and experimental plots. Laguna, Philippines, 1976.

Farm no.	Variety grown	Grain yield (t/ha) from Whole farm[a]	Comparable paddy[b]	Experimental plot
		Dry season		
1	IR28	3.5	2.7	2.9
2	IR28	3.8	3.7	3.3
3	IR26	4.1	6.0	6.1
4	IR26	4.4	5.5	5.6
5	IR30	3.7	4.0	4.3
Av.		4.0 ± 0.2	4.5 ± 0.6	4.4 ± 0.6
		Wet season		
1	IR26	5.4	5.2	5.2
2	IR26	6.0	4.9	4.3
3	IR26	6.7	2.3	3.8
4	IR32	4.7	4.6	4.8
5	IR36	5.5	4.4	3.8
6	IR36	0.9	1.9	1.6
7	IR36	4.4	4.3	4.3
8	IR5	2.3	1.4	1.0
9	IR34	4.0	3.2	2.4
10	IR26	1.7	1.5	2.3
11	IR26	5.2	4.9	4.8
12	IR1514-E-597	3.7	4.7	4.7
13	IR26	4.7	2.6	3.2
Av.		4.2 ± 0.5	3.6 ± 0.4	3.5 ± 0.4

[a]Total farm production data obtained through interview and total planted area determined from actual measurement. [b]3–4 crop cuts, each 10 sq m, from the comparable paddy of each farm.

taken from the comparable paddy were compared with those from the farmer-level experimental plots and with total farm yield computed as farm production divided by the planted area. Farm production data obtained from an interview with farmers received appropriate adjustment for the harvesters' shares (1967 Annual Report). Planted area was actually measured. The average comparable paddy yield was within 0.1 t/ha of the average on the experimental plots, but differed more from the total farm yield (Table 17). The discrepancy between yields from the whole farm and from the comparable paddy did not follow any set pattern over farms, however, indicating no bias in the choice of the comparable paddy. The results apparently confirm the validity of the comparable paddy technique for determining farmers' practices in the yield-constraints experiments.

Minimum number of treatments. In the yield-constraints study, three to four factors are generally tested in each trial. Experience in Laguna indicated that among the three factors tested—fertilizer, insect control, and weed control—fertilizer and insect control showed significant interaction only in the dry season (Table 18). The interaction caused a difference in the size of the yield increase. The yield increase from high fertilizer application was greater under high insect control and that from high insect control was greater under high fertilizer rate. Interaction effects in the yield-constraints study are more straightforward and smaller than those generally found in experiment stations. The fact that the low level in the study is the farmers' input level, which is rarely zero, especially in Laguna, may contribute to that result.

For cases where interaction effects are not expected to be appreciable, the "mini-factorial" treatment arrangement seems appropriate. Its main feature is that the number of treatments to be tested is always two more than the number of test factors. For example, five treatments are used when three factors are to be tested. The five treatments involving three factors are listed in Table 19.

Number of replications and of farms. Varia-

Table 18. Effects of interaction between fertilization and insect control levels on farm yields, Laguna. 1975–76.

Year	Farms (no.)	Farmer yield (t/ha)	Yield increase (t/ha) from high fertilizer under Farmers' insect control	High insect control	Yield increase (t/ha) from high insect control under Farmers' fertilizer rate	High fertilizer rate	Interaction effect (t/ha)
				Wet season			
1975	19	3.69	0.68	0.76	0.62	0.70	0.08^{ns}
1976	14	3.34	0.76	0.72	1.65	1.61	-0.04^{ns}
				Dry season			
1975	9	4.05	0.80	1.36	0.74	1.30	0.56^{*}
1976	10	4.19	0.83	1.46	0.36	0.99	0.63^{*}

tion in the yield-constraints study is from two major sources—variation among farms and variation within farms. The use of several farms takes care of variation among farms, while replications within a farm take care of variation within farms. In the Laguna experiments, variance among farms was at least 6 times, and as much as 14 times, that among replications within farms (Table 20). Thus, in such yield-constraints experiments, emphasis should be placed in assuring that a sufficient number of farms is included rather than in having a large number of replications within a farm. The data in Table 20 suggest that more than two replications are unnecessary. An experienced researcher could use partial replication. The effect of number of farms on the standard error of the mean yield, with the number of replications per farm fixed at two, is shown in Figure 4.

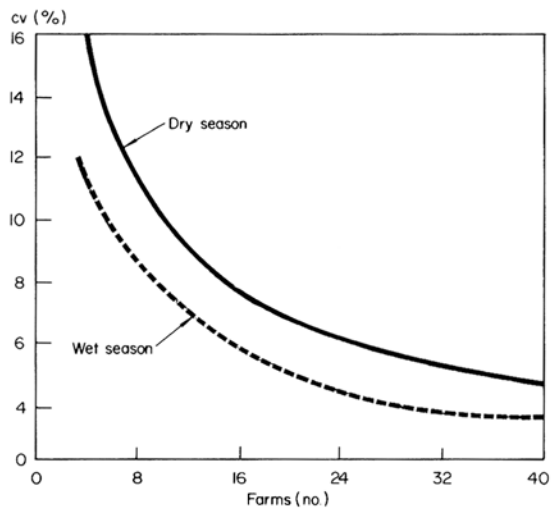
Table 19. A mini-factorial treatment arrangement for studying yield constraints in farmers' fields, with three test factors: fertilizer, insect control, and weed control.

Treatment no.	Input level[a]		
	Fertilizer	Insect control	Weed control
1	H	H	H
2	F	H	H
3	H	F	H
4	H	H	F
5	F	F	F

[a]H = high level; F = farmer's level.

Table 20. Relative magnitudes of the variance among farms ($\sigma_F{}^2$) and among replications within farms ($\sigma_R{}^2$), yield constraints experiments in Laguna farms. 1975–76.

Year, season	Farms (no.)	Treatments tested (no./farm)	Among farms		Among replications within farms		Ratio
			Variance	CV (%)	Variance	CV (%)	
1975, dry	9	18	1.0142	20.1	0.0729	5.4	14:1
1975, wet	4	16	0.5882	16.3	0.0986	6.7	6:1
1976, dry	7	8	2.0338	27.6	0.1603	7.7	13:1



4. Estimated relationship between standard error of the mean (expressed as CV) and number of farms (two replications per farm) based on data from yield constraints experiment. Laguna, Philippines, 1975–76.

Table 21. Sites of the International Agro-Economic Network studies of constraints to higher farmers' rice yields, January 1976.

Study site	Institution
BRRI Pilot Project Area, Bangladesh	Bangladesh Rice Research Institute
Baybay, Leyte, Philippines	Visayas State College of Agriculture
Kandalama, Sri Lanka	University of Sri Lanka
North Java, Indonesia	Central Research Institute for Agriculture
North Taiwan	National Chung-Hsing University
Suphanburi, Thailand	Kasetsart University and Department of Agriculture
Yogyakarta, Indonesia	Gadjah Mada University

AGROECONOMIC YIELD CONSTRAINTS NETWORK

Agricultural Economics, Agronomy, and Statistics Departments

Seven national teams of researchers, besides those at IRRI, are involved in a cooperative project studying yield constraints (Table 21). The teams at each site include an agronomist and an economist. Whenever possible, the work is done with scientists within the national organization that has responsibility for rice research.

Consequences of new technology

Agricultural Economics Department

Aggregate national statistics were used to analyze the social returns to rice research, and the policy alternatives for rice self-sufficiency. Farm surveys provided data for analyzing changes in labor use in rice production, and for studying in depth the rice village economy.

Analysis of returns to rice research in the Philippines and other tropical rice-growing areas indicates that investment in research has been highly profitable. Other alternatives for increasing rice output and achieving national self-sufficiency in rice were examined, with the Philippines as an example. Investment in irrigation gave a higher benefit-to-cost ratio than either a price support for rice or a fertilizer subsidy.

An important finding from farm survey data in Laguna, Philippines, related to the change taking place in the village structure, land tenure relationships, and the organization and use of labor in rice production.

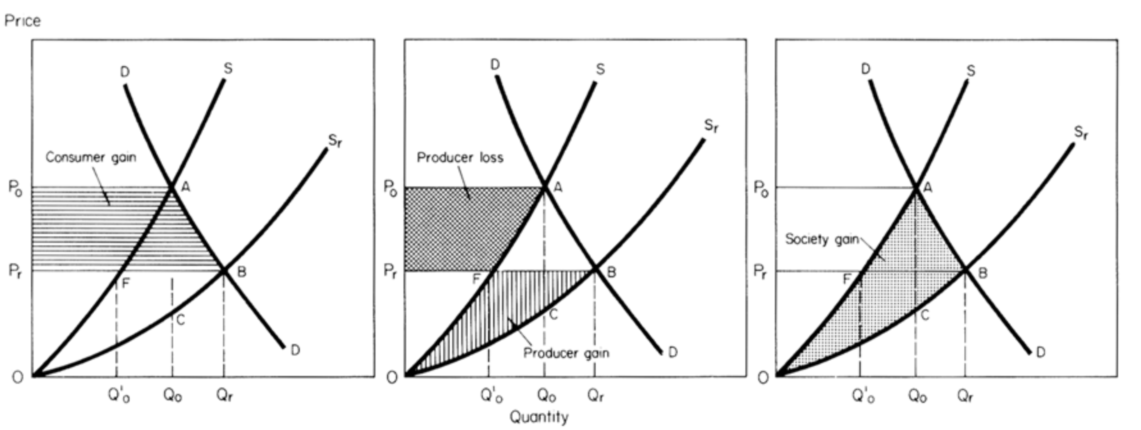
As a consequence of expanding population and technological change, the number of transactions in tenure rights (the right to cultivate the land) is increasing as is the landless labor force. Through a system called *gama*, landless laborers contract to weed rice fields in return for the right to harvest the plot and obtain a one-sixth share of the harvest as payment. This practice accounts in part for the large increase in the use of hired labor.

SOCIAL RETURNS TO RICE RESEARCH

Estimates were made of the rates of return from rice research accruing to the Philippine economy, and of the spin-off benefits of rice research in the Philippines to other rice-producing countries. IRRI and the Philippine national agencies —the Bureau of Plant Industry (BPI) and the University of the Philippines at Los Baños (UPLB)—are the major rice research institutions in the Philippines. They have been a major source of new rice technology for the tropics since 1962.

Estimating social returns. The return to rice research was measured from the changes in consumers' and producers' surpluses that resulted from the shift in the rice supply curve due to a shift in the rice production function. In the model (Fig. 1) *DD* represents total market demand for rice, *SO* is the supply curve before technological change, and S_rO is the supply curve after technological changed induced by rice research. If market equilibrium is reached and no imports are allowed (closed economy), the shift in the supply curve increases consumers' surplus by the area AP_oP_rB, and producers' surplus by (area *BFO*–area AP_oP_rF). Total economic surplus then equals area *AOB*.

If domestic rice production does not meet the demand requirement at the government's target consumer price, the gap has to be filled by imports (open economy). That may be illustrated in Figure 1 with P_r as the price that the govern-



1. Model for estimating social returns to rice research. IRRI, 1976.

ment wishes to maintain. If the domestic supply does not shift from S to S_r, the government has to import Q'_oQ_r and the producers' surplus will not increase by area BFO, the increase brought about by technological advance. This area may be defined as the producers' gain in economic welfare from rice breeding research when the government maintains price P_r. Because prices are stable, the consumers' surplus remains unchanged under these conditions, and the producers' gain equals the total social benefit produced from the rice research. Another contribution of rice research to the national economy in the open economy case is the gain in foreign exchange by area BFQ'_oQ_r, which represents the savings from not having to import rice.

The closed-economy assumption is not realistic in the Philippines, which has been a net importer of rice. However, the open-economy model with the government price stabilization policy, as developed above, is not totally realistic either. Because foreign exchange is a stringent constraint, a large gap between domestic production and the desired domestic price-consumption level may not be fully compensated for by imports. Thus, the price of rice in the Philippines may rise in the absence of rice research, but it may not rise as sharply as in the completely closed economy. Therefore, in the estimation of social benefits from rice research to the Philippine economy, the closed-economy and open-economy models are used as polar cases.

The benefit from rice research in the Philippines has not been confined to the Philippines. IRRI was established to serve all tropical rice-producing countries. Considering its relative influence on rice research in the Philippines, the rates of returns would be seriously underestimated if spin-off benefits to other countries are not included in the calculations.

The market equilibrium model in Figure 1 is readily applicable to the estimation of the spin-off social benefit from rice research in the Philippines. Rice production in tropical developing countries dominates world production, and the rice trade between those countries and developed countries in the temperate zone is negligible. Therefore, the shift in the aggregate supply of rice in the tropical zone as a whole (from S to S_r) faces a relatively inelastic downward sloping demand schedule (D). Thus, applying the same logic as in the closed-economy case, consumers' gain due to rice research may be represented by area AP_oP_rB, producers' gain by (area BFO — area AP_oP_rF), and total gain in economic welfare by area AOB.

For the quantitative estimation of the changes in consumers' and producers' surpluses, the following formula applies.

$$\text{Area } AFB \cong \frac{pq[k(1+\beta)]}{2(\beta+\eta)}$$

$$\text{Area } BFO \cong kpq$$

$$\text{Area } AP_oP_rF \cong \frac{kpq(1+\beta)}{\beta+\eta}\left[\frac{1-k(1+\beta)}{2(\beta-\eta)} - \frac{k(1+\beta)}{2}\right]$$

$$\text{Area } BFO'_oQ_r \cong (1+\beta)pq$$

where p and q are the price and output of rice, k is the rate of shift in the rice production function, β is the price elasticity of rice supply, and $(-\eta)$ is the price elasticity of rice demand.

To assess the efficiency of investment in rice research, both the benefit-to-cost ratio and the internal rate of returns are calculated.

The benefit-to-cost ratio is computed as

$$\frac{(iP+F)}{iC}$$

where i is the external rate of interest, P is the accumulation of past returns, F is future annual returns, and C is the accumulation of past research expenditures. The external rate of interest (i) is applied to the accumulation of both past returns and expenditures.

The internal rate of return (r_i) is the rate that results in

$$\sum_{t=0}^{T}\frac{R_t - C_t}{(1+r_i)^t} = 0$$

where R_t is the social benefit in year t, C_t is the research cost in year t, and T is the year that the research ceases to produce returns.

Parameters and data. Estimating the social returns from the rice research by the model discussed in the previous section requires specification of the price elasticities of demand and

Table 1. Expenditures[a] for rice research in the Philippines, 1959–75.

Year	IRRI			Natl. institutions[b]	Total	
	Headquarters	Outreach	Total		IRRI head-quarters + natl. institutions	IRRI total + natl. institutions
1959	—	—	—	406	406	406
1960	2,470	—	2,470	530	3,000	3,000
1961	9,989	—	9,989	587	10,576	10,576
1962	2,243	—	2,243	551	2,794	2,794
1963	1,895	326	2,221	500	2,395	2,721
1964	4,522	334	4,856	514	5,036	5,370
1965	3,199	448	3,647	528	3,727	4,175
1966	3,152	174	3,326	524	3,676	3,850
1967	2,642	1,028	3,670	597	3,239	4,267
1968	1,520	909	2,429	610	2,130	3,039
1969	2,282	1,365	3,647	543	2,825	4,190
1970	2,135	778	2,913	479	2,614	2,392
1971	2,313	876	3,189	480	2,793	3,669
1972	2,324	1,163	3,487	737	3,061	4,224
1973	1,944	968	2,912	1,019	2,963	3,931
1974	2,438	769	3,207	882	3,320	4,089
1975	3,462	889	4,351	944	4,406	5,295

[a]Expenditures in pesos were converted into US dollars (1970 exchange rate of P6.5/$1). Deflated by the wholesale price index of the Central Bank of the Philippines (1970 = 100). [b]National institutions include Bureau of Plant Industry, University of the Philippines at Los Baños, National Science Development Board, and Bureau of Agricultural Extension. Source: Finanical statements of respective institutions.

supply (η and β), the rate of shift in production function (k), and the value of rice output ($p\ q$). In addition, the data for research costs are needed.

The following demand and supply parameters are used.

Price elasticity of demand $\eta = 0.3$

Price elasticity of supply $\beta = 0.4$

Data on expenditures for rice research and extension were collected from the financial statements of IRRI, BPI, UPLB, the National Science Development Board (NSDB), and the Bureau of Agricultural Extension (BAE) (Table 1). The data for BPI and UPLB include expenditures for both rice and corn research, but the portion allocated to corn was a minor fraction. Extension costs incurred by BAE were included because extension conveyed the new rice technology to farmers.

IRRI's budget is divided into "headquarters" and "outreach." The latter covers the cost of the IRRI programs in various countries in Asia in collaboration with local institutions. Because the outreach programs are primarily outside the Philippines, expenditures for them are excluded in the calculation of returns accruing to the Philippines. But because those programs are highly instrumental in promoting the dissemination to other countries of new technology developed at IRRI, the outreach expenditures are included in the calculation of the rate of returns of Philippine rice research for the tropical world as a whole. Therefore, the last two columns in Table 1 are used as the data of rice research expenditures for respective cases.

In estimating the benefits from rice research, it was assumed that the shifts in the rice production function from 1965–75 resulted from research investment from 1959 to 1975. In addition, it was conservatively assumed that the research investment would generate an infinite stream of benefits after 1975 at the level of the 1973–75 average. Rice output was valued at US$100/t paddy.

The shift in the rice production function due to rice research was measured by the proportion of area planted to modern varieties (MV) and the differences in the yield per hectare between MV and the traditional varieties (TV) at the same level of inputs.

The national sample survey of the Bureau of Agricultural Economics (BAEcon) provided data on the annual average yields per hectare planted to MV and TV in 1968–75. Differences in average yields between MV and TV based on the survey overestimated the effect of technology because farmers applied more fertilizer and other inputs on MV.

The difference in input levels was adjusted by the data of the BAEcon surveys for 1970 and 1971. The average nitrogen inputs per hectare were 35.5 for MV and 32.8 kg for TV in irrigated areas, and 36.6 for MV and 30.5 kg for TV in rainfed areas. The actual MV yields were adjusted downward to the levels of nitrogen input for TV by assuming a fertilizer production elasticity of 0.1.

The rates of shift in the aggregate rice production function for the Philippines are shown in Table 2. To obtain them, the difference between the adjusted average yield of MV and the actual reported yield of TV was divided by the adjusted average yield of MV. The resulting percentage of increase due to MV was multiplied by the percentage of the area planted to MV. Calculations for irrigated and rainfed areas were made separately and a weighted average was obtained according to the percentage of the irrigated and rainfed area.

The rates of shift in aggregate rice production in the tropical world due to research in the Philippines were first estimated on the basis of a UPLB study. The estimated shift value tested on the Philippines using the UPLB analysis was somewhat higher than the shift estimated from the BAEcon survey data. The difference suggests the possibility of an upward bias in the estimating equation based on the UPLB study. Therefore, the IRRI study tried two estimates of the shifts in aggregate production function. Case A uses the rates derived from the UPLB model, and Case B adjusts the case A estimates proportionally to the differences between the estimates for the Philippines based on the BAEcon survey and the UPLB equation (Table 3).

Table 2. Estimates of the average rates of shift in rice production function in the Philippines due to rice research, 1965–75.

Year	Estimate of average rates of shift (%)		
	Irrigated areas	Rainfed areas	Average[a]
1965	4.19	0.04	1.28
1966	4.85	0.14	1.57
1967	5.50	0.24	2.51
1968	6.06	0.38	2.57
1969	5.08	0.47	2.46
1970	6.75	0.40	2.74
1971	2.55	0.35	1.35
1972	11.23	2.32	5.68
1973	6.92	5.18	5.15
1974	5.77	8.73	6.38
1975	11.52	8.27	8.51

[a]Average using irrigated and rainfed areas as weights. The absence of MV, which was assumed for the upland area, lowered the weighted average. Source: Unpublished survey data of the Bureau of Agricultural Economics.

Table 3. Estimates of the average rates of shift in rice production function in the tropical world[a], 1967–75.

Year	Estimate of average rates of shift (%)	
	Case A	Case B
1967	0.27	0.07
1968	0.81	0.11
1969	1.41	0.21
1970	2.45	0.37
1971	3.46	0.21
1972	5.49	1.37
1973	6.32	1.45
1974	7.71	1.93
1975	8.03	2.81

[a]Case A = derived from the UPLB model. Case B = case A results were adjusted proportionally to the differences between the rates of shift for the Philippines calculated from the BAEcon survey data and those calculated from the UPLB model.

Findings. Under the closed-economy assumption for the Philippines and the cases considering the tropical world, the consumers are the sole beneficiaries of the research, while the producers suffer losses (Table 4). The results are due to the low price elasticity of demand. A rightward shift in the rice supply curve in the face of inelastic demand results in a decline in rice price that is more than proportional to the increase in output, and a loss of income for rice producers.

In the open economy, producers are better off, and consumers enjoy the same level of economic welfare without causing a drain on foreign exchange. The open-economy and the closed-economy cases in this analysis represent the polar cases between which reality lies.

The estimated benefits from rice research in the Philippines to the rest of the tropical world are extremely large compared with those accruing only to the Philippines. Even in Case B, for which the estimated rates of shift in aggregate rice production function derived from the UPLB model were drastically adjusted downwards, the estimated total benefits for the tropical world

Table 4. Estimates of the average annual benefits from rice research in the Philippines[a], 1966–75.

Data source and period covered	Benefit to the Philippines (million US$)				
	Closed economy			Open economy	
	Producer's gain	Consumer's gain	Total	Producer's gain	Savings of foreign exchange
Survey data:					
1966–1970	-10.2	21.3	11.1	11.5	15.0
1971–1975	-25.0	56.1	31.1	30.5	40.0
After 1975	-35.2	81.1	45.9	44.3	58.0
	Benefit to tropical world (million US$)				
	Producer's gain	Consumer's gain	Total		
Case A[b]					
1967–1970	-185.0	383.0	197.2		
1971–1975	-842.5	1,948.9	1,106.4		
After 1975	-1,129.2	2,614.0	1,484.7		
Case B[b]					
1967–1970	-30.1	60.5	30.4		
1971–1975	-244.5	505.9	261.4		
After 1975	-444.0	931.4	487.5		

[a]Increases in rice output due to research were valued at 100 US$/m t of paddy. [b]Case A = derived from the UPLB model. Case C = Case A results were adjusted proportionally to the differences between the rates of shift for the Philippines calculated from the BAEcon survey data and those calculated from the UPLB model.

are about 10 times as large as those for the Philippines alone.

To assess the efficiency of rice research investment in the Philippines, benefit-to-cost ratios and internal rates of return were calculated (Table 5). In the computation of benefit-to-cost ratios, 12%, the standard rate of interest commonly applied to the government development loans in the Philippines, was used as the rate of discount. In the calculation of the open-economy case, a foreign exchange premium (assumed at 5% of total foreign exchange saving) was included in the total social benefit. The 5% rate was based on the difference between the official and the free market rates of exchange in recent years.

The estimated benefit-to-cost ratios based on the survey data showed that $1 invested in rice research has actually produced an average social benefit of $4 to the Philippines. The rates of return to the tropical world as a whole are extremely high. The estimates suggest the critical importance of international technology transfer in agricultural and economic development. They also suggest the importance of the role of international centers, such as IRRI, for agricultural research. It must be strongly emphasized, however, that the high rates of returns depend on investment in local research to adapt MV of Philippine origin to ecological conditions in the respective countries. Inclusion of the costs of such domestic investments in the tropical rice-producing countries will result in somewhat lower benefit-to-cost ratios and rates of return.

Table 5. Estimates of the rates of social returns to rice research in the Philippines, 1976.

Social returns	Benefit-to-cost ratio	Internal rate of return (%)
To the Philippines		
Closed economy	4	27
Open economy	4	27
To the tropical world		
Case A	106	71
Case B	30	46

POLICY ALTERNATIVES FOR RICE SELF-SUFFICIENCY

The study of policy alternatives for rice self-sufficiency continued using rice in the Philippines as a case. The study measures the benefits and costs of alternative policies for shifting the supply function by 5% to achieve self-sufficiency.

The earlier analysis is expanded to include irrigation as an alternative, to compare results because farmers applied more fertilizer and other inputs on MV.

The difference in input levels was adjusted by the data of the BAEcon surveys for 1970 and 1971. The average nitrogen inputs per hectare were 35.5 for MV and 32.8 kg for TV in irrigated areas, and 36.6 for MV and 30.5 kg for TV in rainfed areas. The actual MV yields were adjusted downward to the levels of nitrogen input for TV by assuming a fertilizer production elasticity of 0.1.

The rates of shift in the aggregate rice production function for the Philippines are shown in Table 2. To obtain them, the difference between the adjusted average yield of MV and the actual reported yield of TV was divided by the adjusted average yield of MV. The resulting percentage of increase due to MV was multiplied by the percentage of the area planted to MV. Calculations for irrigated and rainfed areas were made separately and a weighted average was obtained according to the percentage of the irrigated and rainfed area.

The rates of shift in aggregate rice production in the tropical world due to research in the Philippines were first estimated on the basis of a UPLB study. The estimated shift value tested on the Philippines using the UPLB analysis was somewhat higher than the shift estimated from the BAEcon survey data. The difference suggests the possibility of an upward bias in the estimating equation based on the UPLB study. Therefore, the IRRI study tried two estimates of the shifts in aggregate production function. Case A uses the rates derived from the UPLB model, and Case B adjusts the case A estimates proportionally to the differences between the estimates for the Philippines based on the BAEcon survey and the UPLB equation (Table 3).

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[a]Average using irrigated and rainfed areas as weights. The absence of MV, which was assumed for the upland area, lowered the weighted average. Source: Unpublished survey data of the Bureau of Agricultural Economics.

Table 3. Estimates of the average rates of shift in rice production function in the tropical world[a], 1967–75.

Year	Estimate of average rates of shift (%)	
	Case A	Case B
1967	0.27	0.07
1968	0.81	0.11
1969	1.41	0.21
1970	2.45	0.37
1971	3.46	0.21
1972	5.49	1.37
1973	6.32	1.45
1974	7.71	1.93
1975	8.03	2.81

[a]Case A = derived from the UPLB model. Case B = case A results were adjusted proportionally to the differences between the rates of shift for the Philippines calculated from the BAEcon survey data and those calculated from the UPLB model.

Findings. Under the closed-economy assumption for the Philippines and the cases considering the tropical world, the consumers are the sole beneficiaries of the research, while the producers suffer losses (Table 4). The results are due to the low price elasticity of demand. A rightward shift in the rice supply curve in the face of inelastic demand results in a decline in rice price that is more than proportional to the increase in output, and a loss of income for rice producers.

In the open economy, producers are better off, and consumers enjoy the same level of economic welfare without causing a drain on foreign exchange. The open-economy and the closed-economy cases in this analysis represent the polar cases between which reality lies.

The estimated benefits from rice research in the Philippines to the rest of the tropical world are extremely large compared with those accruing only to the Philippines. Even in Case B, for which the estimated rates of shift in aggregate rice production function derived from the UPLB model were drastically adjusted downwards, the estimated total benefits for the tropical world

Table 6. Data assumptions for evaluating policy alternatives to achieve rice self-sufficiency in the Philippines[a], 1976.

Parameters	TV regime $P_d = P_w$	MV regime $P_d = P_w$ (normal year)	MV regime $P_d > P_w$ (1970–71)	MV regime $P_d < P_w$ (1973–74)
Price elasticity of rice supply	0.3 & 0.1	0.3 & 0.1	0.3 & 0.1	0.3 & 0.1
Production elasticity of fertilizer	0.05	0.1	0.1	0.1
Price elasticity of fertilizer demand	−0.75	−0.5	−0.5	−0.5
			Price (US $/m t)	
Domestic-producer price of rice	200	200	200	200
Domestic-consumer price of rice	260	260	260	260
Import price of rice	200	200	160	360
Retail cost of imported rice	260	260	220	420
Import price of nitrogen	400	400	250	600
Farm price of nitrogen	460	460	310	660
Farm wage rate (US$/man-day)	1.2	0.8	0.8	0.8
			Quantity (thousand m t)	
Domestic rice consumption	4400	4400	4400	4400
Domestic rice output	4180	4180	4180	4180
Producers' home consumption of rice	2090	1670	1670	1670
Nitrogen input in rice production	80	80	80	80

[a]TV = traditional varieties; MV = modern varieties; P_d = domestic producer price of rice; P_w = import price of rice.

the pre-MV estimate of 0.3 to about 0.1. In this analysis 0.3 and 0.1 are used as alternative assumptions for β.

Assumptions with respect to parameters and data are summarized in Table 6. Costs and benefits associated with the construction of new irrigation systems are summarized in Table 7. The budget shown is for a typical NIA (National Irrigation Administration) diversion system. The real cost of constructing irrigation systems is assumed to have risen by 20% during the past decade because of the shift toward areas that are more difficult to irrigate.

Table 7. Data assumption on costs and benefits associated with a 1-ha increase in irrigation system command area in the Philippines[a], 1976.

	TV regime	MV regime
Capital cost: Total ($)	500	600
Foreign exchange component ($)	200	240
Irrigated area (%): Wet season	75	75
Dry season	33	33
Increase in rice output (t milled rice/yr)	1.5	1.8
Increase in nitrogen input (kg/yr)	30	45
Increase in labor input (man-days/yr)	40	50
Operation and maintenance cost (US$/yr)	20	20
Collection of water fee (US$/yr)	15	15
Period of usable life (yr)	50	50
Construction period (yr)	3	3
Discount rate (%)	15	15

[a]TV = traditional varieties; MV = modern varieties.

Benefits and costs. The estimated benefits and costs associated with three policy alternatives to achieve rice self-sufficiency in the Philippines for different technology and price regimes are presented in Tables 8 and 9.

• For all the technology and price regimes, the rice price-support program gives the highest benefits to producers, even for the lower estimates based on the assumption that the price elasticity of supply equals 0.3. In most cases price support produces the largest savings of foreign exchange. Consequently, the total social benefit produced by the price-support programs are the highest among the three policy alternatives. However, because the direct costs to the government of support are even larger, the social net benefits are negative and the social benefit-to-cost (B : C) ratios are less than one, except for such years as 1973–74 when the import cost of rice exceeded the domestic price and the government incurred a large deficit from rice import operations.

• By lowering the assumed value of β from 0.3 to 0.1, the cost of the government price-support program for self-sufficiency rises to an almost prohibitive level even though the efficiency of the program, as measured by the B : C ratios, does not decline so much.

• Producers' benefits from the fertilizer-subsidy program are the second largest among

Table 8. Estimated social benefits associated with alternative policies to achieve rice self-sufficiency in the Philippines[a], 1976.

Policy	Annual benefit flow (million US$)			
	Increase in producers' income	Change in gov. cost of rice import	Foreign exchange savings	Total[b]
	TV regime: $P_d = P_w$			
Price support: $\beta = 0.3$	82	0	37	84
$\beta = 0.1$	296	0	22	297
Fertilizer subsidy	61	0	−42	59
Irrigation development	20	0	24	21
	MV regime: $P_d = P_w$ (normal year)			
Price support: $\beta = 0.3$	97	0	40	99
$\beta = 0.1$	352	0	30	354
Fertilizer subsidy	66	0	12	67
Irrigation development	21	0	23	22
	$P_d > P_w$ (1970–71)			
Price support: $\beta = 0.3$	97	−9	33	90
$\beta = 0.1$	352	−9	27	345
Fertilizer subsidy	59	−9	15	51
Irrigation development	22	−9	18	14
	$P_d < P_w$ (1973–74)			
Price support: $\beta = 0.3$	97	35	73	136
$\beta = 0.1$	352	35	59	390
Fertilizer subsidy	76	35	31	113
Irrigation development	20	35	45	57

[a]TV = traditional varieties; MV = modern varieties; P_d = domestic producer price of rice; P_w = import price of rice. [b]Increase in producers' income + change in gov. cost of rice import + 0.05 × foreign exchange savings.

the policy alternatives. The foreign exchange savings are the smallest (negative for the TV regime) because the subsidy program can increase the consumption of imported fertilizer relative to the use of domestic factors such as labor and land.

• For the TV regime, the cost to the government of the fertilizer subsidy exceeds the total social benefit it produces; the resulting B : C ratio is smaller than one. For the MV regime, the government subsidy cost is smaller than the benefit, and the B : C ratio becomes greater than one. Such an improvement in the efficiency of the fertilizer-subsidy program is primarily due to the increase in the production elasticity of fertilizer from 0.05 to 0.1.

• The irrigation investment produces smaller annual benefit flows to producers than do the rice-support and fertilizer-subsidy programs. However, because the government costs are even smaller (in annual flow terms), the B : C ratios are usually the highest among the three alternatives. An increase in the real cost of irrigation construction due to the gradual exhaustion of accessible construction sites seems to be largely compensated for by the introduc-

Table 9. Evaluation of alternative policies to achieve rice self-sufficiency in the Philippines in terms of social benefit and cost criteria.[a]

Policy	Annual flow (million US$)		Benefit : cost ratio[c]	Internal rate of return
	Total social benefit	Gov. cost[b]		
		TV regime: $P_d = P_w$		
Price support: $\beta = 0.3$	84	85	0.99	—
$\beta = 0.1$	297	310	0.96	—
Fertilizer subsidy	59	115	0.51	—
Irrigation development	21	8.8 (56)	2.39	31
		MV regime: $P_d = P_w$ (normal year)		
Price support: $\beta = 0.3$	99	101	0.98	—
$\beta = 0.1$	354	366	0.97	—
Fertilizer subsidy	67	59	1.13	—
Irrigation development	22	8.7 (55)	2.53	32
		$P_d > P_w$ (1970–71)		
Price support: $\beta = 0.3$	90	101	0.89	—
$\beta = 0.1$	345	366	0.94	—
Fertilizer subsidy	51	40	1.28	—
Irrigation development	14	8.7 (55)	1.61	32
		$P_d < P_w$ (1973–74)		
Price support: $\beta = 0.3$	136	101	1.35	—
$\beta = 0.1$	390	366	1.07	—
Fertilizer subsidy	113	85	1.33	—
Irrigation development	57	8.7 (55)	6.55	36

[a]TV = traditional varieties; MV = modern varieties; P_d = domestic producer price of rice; P_w = import price of rice. [b]Figures in parentheses are initial capital costs. [c]Total social benefit ÷ government cost.

tion of new rice technology, resulting in a more or less constant efficiency in the government irrigation investments for the TV and the MV regimes in terms of the B : C ratio criteria.

- Changes in the relation between import price and domestic price of rice greatly affect the efficiencies of government programs to achieve rice self-sufficiency. The B : C ratios for the three policy alternatives are all low for the price relations that prevailed during 1970–71, when the world rice price declined sharply and the government could import rice with profit. The B : C ratio increased dramatically as the price relations changed to those that prevailed during 1973–74, when the government had to import to meet a large deficit during a world food shortage and high prices.

For both the TV and the MV regimes, the investment in irrigation systems has been the major means of the government for increasing rice production. It has also proved the most effective policy for raising national output and productivity. The high B : C ratios of the irrigation development program estimated in the study clearly suggest the basis of the government's choice of irrigation investment as the major means to achieve rice self-sufficiency.

Changes in the price relations seem a strong force governing the government's efforts for rice self-sufficiency. Slackening of the efforts during the period of the "green revolution euphoria" (1970–71) corresponds to the sharp decline in the B : C ratios of all the three policy alternatives. In contrast, the increases in the B : C ratios during the world food crises (1973–74) were accompanied by dramatic increases in irrigation investments and the initiation of large extension and credit programs such as the Masagana 99.

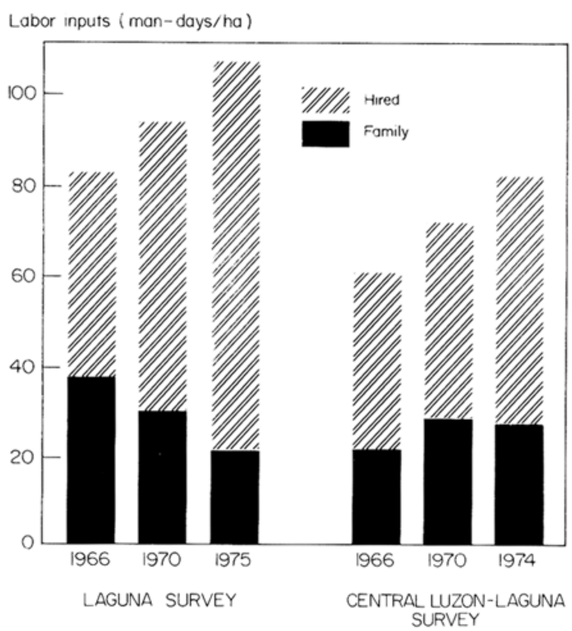
LABOR UTILIZATION

Surveys of rice production conducted periodically in Laguna and Central Luzon since 1966 provided the basis for investigating changes in labor use in rice production after the introduction of new rice technology. Data from the Laguna survey are based on a sample drawn from seven villages surveyed in 1966, 1970, and 1975. Data from the Central Luzon-Laguna survey are based on a sample of farms surveyed in 1966, 1970, and 1974. Both surveys were in progressive rice-growing areas that were undergoing rapid changes as shown in Table 10. Over that period, the principal changes that occurred were the introduction of MV and associated inputs, and the spread of the *gama* system in Laguna. *Gama* is an arrangement whereby the hired laborer contracts to weed a plot of rice in return for the right to harvest the plot and obtain a one-sixth share. *Gama* replaces the

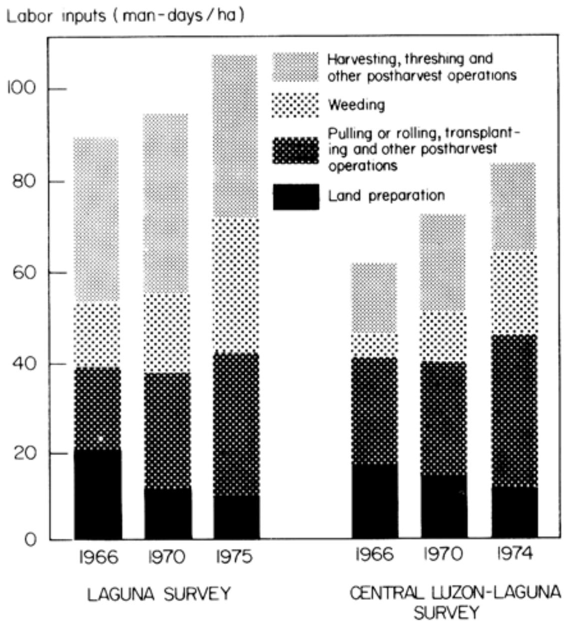
Table 10. Adoption of selected new practices since 1966, 62 Laguna and 63 Central Luzon-Laguna farms, wet season.

Practice	Adoption (%)			
	Laguna		Central Luzon-Laguna	
	1966	1975	1966	1974
Modern varieties	0	100	0	81
Tractor plowing	7	21	11	52
Tractor harrowing	38	85	18	41
Herbicides	86	92	19	61
Gama[a]	0	85	0	11

[a]*Gama* is a system of contracting to weed a paddy field in return for the right to harvest the field and obtain 1/6 share of the harvest.



2. Labor inputs by type of labor and by year, 62 Laguna farms and 63 Central Luzon-Laguna farms, Philippines, 1966–75 wet seasons.



3. Labor inputs by task and by year, 62 Laguna farms and 63 Central Luzon-Laguna farms, Philippines, 1966–75 wet seasons.

traditional system for contracting at harvest time and is spreading in Laguna as the number of landless laborers increases.

Labor input per hectare increased significantly in both study areas, with the principal increase supplied by hired labor (Fig. 2). In fact, in the Laguna villages family labor has declined. Breaking down the labor inputs by task shows that labor input for weeding increased substantially while labor input for land preparation declined (Fig. 3).

To identify the contribution of labor-saving and yield-increasing technology to the change in labor use, a model for total and for hired labor demand was developed. The factors influencing the level of hired and family labor input are in Figure 4. Regression models were estimated by pooling the data for the three survey years (Table 11).

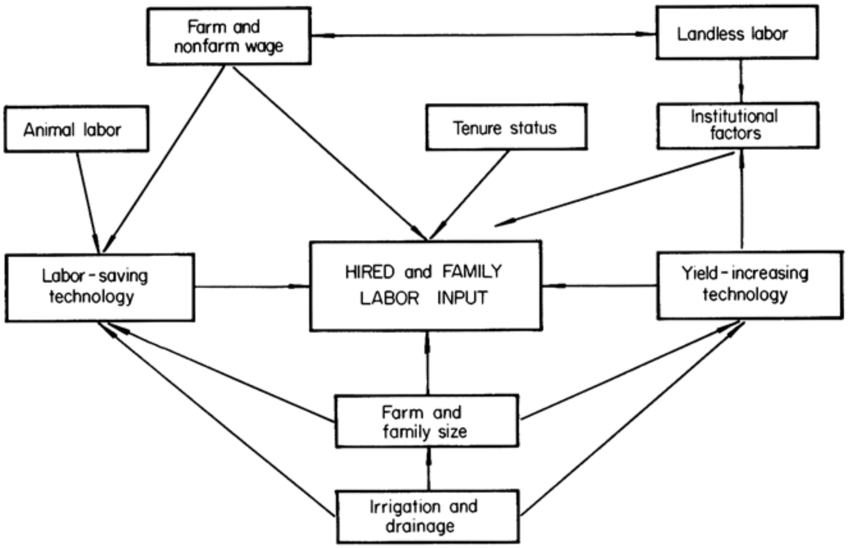
Yield-increase factors associated with the new rice technology are positive and thus associated with a higher labor input. They include fertilizer, insecticide, herbicide, and MV. Tractors used in plowing and harrowing are labor saving. But note that the signs are consistently negative and significant for total labor only. Tractors substitute for family and not for hired labor in these samples.

By substituting mean values for 1966 and for 1974 (or 1975) into each equation, the change in labor input associated with changes in technological, institutional, or other factors (Table 12) was estimated. The more rapid increase in labor input in Laguna than in Central Luzon seems to be associated almost entirely with the introduction of the *gama* system, while the reduction in family labor is associated with the adoption of the tractor for land preparation.

Table 11. Regression coefficients of log of hired labor and total input per farm as a function of specified variables. Laguna, 1966–75, and Central Luzon-Laguna, 1966–74 wet seasons.[a]

Independent variables	Laguna		Central Luzon-Laguna	
	Hired	Total	Hired	Total
Log area[b] (ha)	+1.244**	+0.957**	+1.160**	+0.795**
Log wage[c] (P/day)	−0.453**	−0.223**	−0.038	−0.222**
Log fertilizer and insecticide cost (P/farm)	+0.032	+0.011	+0.094**	+0.075**
Log herbicide cost (P/farm)	+0.112**	+0.004	−0.009	+0.006
MV adoption[d]	+0.108*	+0.068*	+0.028	+0.060*
Tractor used in plowing[e]	−0.058	−0.066**	+0.048	−0.030
Tractor used in harrowing[e]	+0.045	−0.051**	−0.091	−0.076
Cropping intensity[f]	+0.001	+0.001	+0.003	+0.001
Gama[g]	+0.240**	+0.060**	+0.253**	+0.087
Log family labor (man-days/farm)	−0.293**	—	−0.131**	—
a	1.593	1.799	1.316	1.611
R^2	0.68	0.61	0.70	0.75
Durbin-Watson Statistic	1.812	1.648	2.150	2.010

[a]Dependent variables: Hired labor and total labor in man-days per farm. [b]Area = total rice area. [c]Transplanting wage. [d]1 for MV adopter (partial or full); 0 for nonadopter. [e]1 = yes; 0 = no. [f]Cropping intensity: 1 crop = 50%; three crops in 2 years = 75%; and 2 crops = 100%. [g]*Gama* (contract weeding and harvesting): 1 = yes; 0 = no.



4. Factors influencing labor use in rice production. Laguna, 1966–75, and Central Luzon-Laguna farms, Philippines, 1966–74.

ANATOMY OF RICE VILLAGE ECONOMY

Analysis of the impacts of new rice technology on the various facets of rural economy, such as employment and income distribution, requires more than the collection of information on the input-output and the cost-return relations in rice farming. Typically, farmer households make decisions on production and consumption simultaneously. In the rural community, rice farming is dependent on factors contributed by nonfarmer households, such as landlords and landless laborers. The analysis of the full impact of rice production technology on the rural society requires data on the complex of economic activities of both farmer and nonfarmer households.

An integrated, household record-keeping project was started on a pilot scale in a rice village in Laguna, Philippines. The data are being processed, but this section presents some provisional results on the structures of asset-holdings and labor use in the village households.

Village characteristics and data collection procedures. The study village—Barrio Tubuan—is in a rice-monoculture area along Laguna de Bay where absentee landlordism is pervasive. The canal irrigation system is of high quality and double cropping of rice is commonly practiced with the use of MV. A benchmark survey conducted in November 1974 showed that the village consisted of 95 households with 549 persons—54 were households of tenant-farmers and 41 were households of landless workers. Of 54 tenants, 24 were "large farmers" who cultivated more than 2 ha of rice land, and 30 were "small farmers."

Table 12. Contribution of labor-saving and yield-increasing technology to the change in man-days of total preharvest and hired preharvest labor input per hectare. Laguna, 1966–75, and Central Luzon-Laguna, 1966–74.

Change due to	Labor (man-days/ha)			
	Laguna		Central Luzon-Laguna	
	Total	Hired	Total	Hired
Labor-saving technology	–8	1	–7	–1
Yield-increasing technology	20	13	25	10
Adoption of *gama*[a]	13	18	2	3
Others[b]	–3	6	9	2
Net change in preharvest labor	22	38	29	14

[a]*Gama* is a system of contracting to weed a paddy field in return for the right to harvest the field and obtain 1/6 share of the harvest. [b]Change in area, price, and intensity of cropping.

Four households were selected from each of three categories—"large farmer," "small farmer," and "landless worker." The 12 cooperators were assisted in keeping daily records on economic activities, including labor use, from June 1975 to May 1976. At the beginning and at the end of the period, family assets were surveyed. Thus, the data on "initial" and "terminal" asset-holdings pertain to 1 June 1975 and 31 May 1976, respectively. For inventories and financial assets, the cooperators were interviewed and quantities and values were identified at the beginning of each month.

Structure of asset-holdings. The average asset-holdings of sample households are summarized in the balance sheet (Table 13). The asset values were estimated either as the resale value (land, buildings, livestock, and plants), or as the present values by subtracting depreciation from acquisition values (machinery and consumer durables). Land assets consist of farmland and residential lots. Only one of seven farmer operators in the sample owned a small parcel of coconut land; others were only tenants. A tenancy right, however, commands a value and transfer of tenancy right was common in the area.

Table 13. Balance between assets and liabilities, average of all households in Barrio Tubuan, Laguna, Philippines, 1975–76.

Assets and liabilities	Initial (1 June 1975) US$	%	Terminal (31 May 1976) US$	%	Change (US$)
ASSETS					
Fixed assets:					
Land	1789	51	1828	53	39
Building and structures	517	15	516	15	−1
Major consumer durables	205	6	192	6	−13
Machinery and implements	469	14	412	12	−57
Livestock	90	3	62	2	−28
Perennial plants	76	2	96	3	20
Total	3146	91	3106	91	−40
Inventories:					
Farm products	86	2	204	6	118
Farm inputs	69	2	0	0	−69
Total	155	4	204	6	49
Financial assets:					
Savings	70	2	66	2	−4
Cash	111	3	47	1	−64
Total	181	5	113	3	−68
Total assets	3482	100	3423	100	−59
LIABILITIES					
Outstanding debts	556	16	489	13	−67
Net worth	2926	84	2986	87	60
Total liabilities	3482	100	3423	100	−59

The balance sheet shows that the net worth or net asset value per household was $2,926, which, divided by the average family size of 5.9, gives a per capita net worth of $496. The tentative estimate of per capita annual income was $190, making the asset-to-income ratio about 2.5.

As much as 90% of the total asset value consisted of fixed assets, of which land, primarily in the form of tenancy rights, was the dominant component. About half of the remaining 10% was the value of inventories, and the other half was financial assets. The outstanding debt was three times as large as the total of financial assets. Net liquid assets—financial assets plus inventory minus outstanding debt—were also negative (−$220).

The total assets per household declined slightly between the initial date and the terminal date of the study. But because debt decreased, net worth increased. The decline in each holding was explained partly by an increase in unsold product inventory and partly by debt repayment. Liquid assets remarkably improved, even though the net liquid assets on the terminal date were still negative. Equity ratio—net worth divided by total assets—increased from 84 to 87%.

The asset positions were vastly different among large farmers, small farmers, and landless workers (Table 14). The total assets of large farmers were more than 4 times as large as those of the small farmers and 25 times as large as those of the landless workers. The differences in net worth among the three classes were equally large. Landless workers had lower equity ratios than did farmers. The differences were quite large even when adjusted for the differences in average family size (7.5 for large farmers, 5.3 for small farmers, and 5.0 for landless workers).

The composition of assets also varied. The ratio of fixed assets to total assets was much higher for farmer households than for landless households (91% vs. 75%) because of the dominance of land in the farmers' holdings. However, if the assets, excluding land are com-

Table 14. Asset-holdings per household in Barrio Tubuan, Laguna, Philippines, 1 June 1975.

	Large farmer	Small farmer	Landless worker	Large : small farmer	Large farmer : landless worker
Total assets (US$)	7870	1853	316	4.2	24.9
Outstanding debt (US$)	1358	119	81	11.4	16.8
Net worth (US$)	6512	1734	235	3.8	27.7
Equity ratio (Net worth: total assets)	83	94	74	0.9	1.1

pared, the relative weights of the fixed assets were not so different (Table 15).

Between the initial date and the terminal date, the asset positions of large farmers, small farmers, and landless workers changed at differential rates (Table 16). The households of landless workers achieved major gains in both total assets and net worth compared with the farmers' households. Small farmers gained more than large farmers. Thus, even though the differences in asset-holdings were extreme, the direction of change was toward equalization.

Patterns of labor use. The average family size of large farmers was larger than that of small farmers and of landless workers. There was, however, little difference between large and small farmers in the labor-force ratio and in the labor-participation ratio. The ratios were higher for landless workers, especially the females. The higher participation rates of landless households might reflect their greater need to earn income from labor contributions.

On the average, each working member of the family worked 170 days/year on income-generating activities (Table 17). With the conservative assumption that the full labor utilization of a working family member is 20 days a month, the actual labor utilization rate was 70% of full capacity. The full capacity of labor utilization was approached only during the wet-

Table 15. Composition of assets, 1 June 1975. Barrio Tubuan, Laguna, Philippines.

Household	Assets					
	Total (US$)		Fixed (US$)		Ratio[a] (%)	
	Including land	Excluding land	Including land	Excluding land	Including land	Excluding land
Large farmer	7870	3842	7152	3124	91.0	81.3
Small farmer	1853	663	1685	494	91.0	74.6
Landless worker	—	316	—	236	—	75.0

[a]Fixed assets ÷ total assets.

Table 16. Changes in asset positions, 1 June 1975 to 31 May 1976. Barrio Tubuan, Laguna, Philippines.

Household	Assets					
	Initial (US$)		Terminal (US$)		Change (%)	
	Total	Net worth	Total	Net worth	Total[a]	Net worth[b]
Large farmer	7870	6512	7546	6558	−4.1	0.7
Small farmer	1853	1734	1933	1799	4.3	3.8
Landless worker	316	235	418	308	32.4	31.1

[a]Change in total assets $= \frac{\text{Terminal assets} - \text{Initial total assets}}{\text{Initial total assets}}$.

[b]Change in net worth $= \frac{\text{Initial net worth} - \text{Terminal net worth}}{\text{Initial net worth}}$.

Table 17. Average number of workdays per month per working family member. Barrio Tubuan, Laguna, Philippines, 1975–76.

Month	Workdays (no./working family member)			
	All households	Large farmers	Small farmers	Landless workers
June	16.2	19.6	19.8	10.2
July	18.6	19.3	18.8	17.9
August	15.0	19.0	14.2	11.6
September	13.7	15.2	13.4	12.2
October	19.5	15.7	22.0	21.1
November	13.6	13.7	17.1	10.7
December	14.5	15.2	16.4	12.1
January	13.4	11.4	12.3	16.5
February	10.9	7.4	13.5	12.1
March	12.3	9.4	16.8	11.8
April	13.5	8.0	16.0	17.0
May	8.5	7.7	12.2	6.4
Total	169.7	161.6	192.5	159.6

season rice planting (June–July) and harvesting (October–November). The average number of work days per working member was highest for small farmers, although the differences in the labor utilization rates among the three groups were relatively minor.

The rates of labor tend to be higher during the wet season than during the dry season. The tendency reflects in the higher labor demand for weeding and harvesting. More intensive weeding is required in the wet season, and harvesting in wet fields requires more labor.

The difference in the family labor utilization between the wet and the dry season was especially large with large farmers but was not significant with landless workers. The finding may be due to the decision of large farmers to let hired workers take care of tasks conventionally considered as tasks of hired workers. The hired workers normally handle such tasks, and the family members participate only when the tasks become more difficult, or when hired workers cannot handle them with due care or in due time.

On the average, one working family member spent about one-half of the total workdays self-employed, of which 60% was for rice farming, and the other half for outside employment as hired worker (Table 18). Labor in exchange for neighbors' was a relatively small fraction of total workdays.

The allocations of family labor differed between farmers and landless workers. About 70% of total family workdays of both large and small farmers was on self-employment. In contrast, landless workers spent more than 80% of their time as hired workers.

Total number of workdays of both family and hired workers used for rice production per hectare was substantially higher for the wet season. This observation is consistent with the observed seasonal pattern in family labor utilization (Table 17).

Family and hired workers shared the labor for all tasks in rice production more or less equally. The share of exchange labor was only about 7%. Planting and harvesting depended highly on hired labor. Hired workers supplied as much as 70% of harvesting labor. Exchange

Table 18. Allocation of family labor among different jobs (workdays per working family member per year). Barrio Tubuan, Laguna, Philippines, 1975–76.

Employment type	Large farmers		Small farmers		Landless workers		All households	
	Days (no.)	%	Days (no.)	%	Days (no.)	%	Days (no.)	%
Self-employed								
Rice farming	86.3	53	64.2	33	0	0	49.1	29
Nonrice farming	17.6	11	76.0	39	9.9	6	31.2	18
Nonagricultural enterprise	3.4	2	0	0	0	0	1.2	0.7
Capital production	0	0	0	0	2.0	1	0.7	0.3
Total	107.3	66	140.2	72	11.9	7	82.2	48
Exchange	2.0	1	19.9	10	7.5	5	9.0	5
Hired								
Village employment	49.6	31	31.8	16.7	134.1	84	75.1	44
Urban employment	2.7	2	0.6	0.3	6.0	4	3.4	2
Total	52.3	33	32.4	17.0	140.1	93	78.5	46
Grand total	161.6	100	192.5	100	159.5	100	169.7	100

labor was a significant component of planting labor, especially for small farmers during the wet season.

The share of family labor was the highest for the task categorized as "others," which includes irrigation control, and fertilizer and pesticide applications. In land preparation, family labor was a major component for large farmers. It was a relatively minor fraction for small farmers because few of them owned tractors and depended on work on hire or exchange.

Nearly one-half of weeding labor was from hired workers. In weeding, the *gama* was common. Most people who sought employment under the *gama* system were landless workers.

The inputs of weeding labor under the *gama* system represented about 50% of total weeding labor. Dependence of small farmers on *gama* labor was high—nearly 100% of hired labor for weeding. In contrast, few large farmers contracted for weeding labor.

Large farmers can afford to pay cash for weeding, but small farmers prefer to delay the payments until harvest. The *gama* payment for weeding is normally 11 to 12 kg/plot (about 0.10 ha).

Cropping systems program

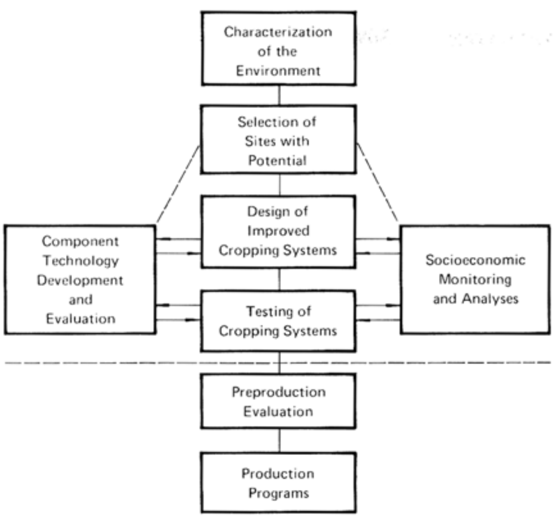
Summary

The Cropping Systems Program focused on some of the major areas shown in the figure. It continued to emphasize crop intensification in rainfed lowland rice. The separation between rainfed and partially irrigated rice is not clear-cut, however, in the farmers' fields.

ENVIRONMENTAL DESCRIPTION

In the expanded activities on the characterization of the environment, improved methods of measuring economic conditions on sites were tried and their effect on farmers' practices was studied. Ways of identifying the landscape position of the fields in relation to their production potential were evaluated. The rainfall classification system, modified in 1976, was completed for Bangladesh and the Philippines. The methods used for monitoring insect occurrence in farmers' fields provided a good assessment of the pest situation at three sites in the Philippines and indicated that substantial yield losses of mung beans could be prevented.

Key pests responsible for yield losses in cropping patterns were identified by extensive monitoring of pest species plus use of pesticides. Pest species varied in intensity by crop among the three research sites because of differences in the physical and biological environments. For example, the upland rice site in Batangas was essentially free from pests because of the prolonged dry fallow immediately preceding the well-synchronized area-wide planting, which precluded pest buildup. In lowland rainfed areas, under the traditional single-crop system, pests multiplied for 2 months on alternate weed hosts or volunteer rice that emerged with the onset of rains before rice was transplanted. In a double-crop system, the first crop escaped serious pest buildup when planted early, but the second crop had up to a 24% yield loss.



IRRI scientists work with counterparts in national programs to implement the program through the testing of cropping systems (above horizontal dotted line). Preproduction evaluation and production programs are implemented at the national level.

DESIGN OF CROPPING PATTERNS

The impact of increased labor requirements of different cropping patterns was better evaluated through improved cropping pattern design. Simulation of the effect of new cropping patterns on the variability of labor demands during the year allowed a comparison of different patterns and identification of the areas where they should be used to achieve the best distribution of labor requirements. Results of the work in environmental characterization led to the design for the 1976–77 season, of cropping patterns suited to the landscape position and soil texture of the fields to achieve improved adaptation of the double rice and rice-upland crop cropping pattern to variations in land types. Cropping patterns that were designed for 1976–77 compared with those tested in 1975–76, reduced cash inputs and labor requirements.

A comparison of the different socioeconomic factors that could influence lengthy and costly turnaround times indicated that the farmers' ability to acquire power during the critical land preparation period influences both turnaround time between crops and rate of establishment of the first crop.

TESTING OF CROPPING PATTERNS

The alternate cropping patterns tested in 1975–76 tended to increase cash requirements and reduce returns to cash invested. Labor requirements for the cropping patterns tested appeared high, and when the patterns were adopted by farmers, the labor inputs were substantially reduced.

Careful measurement of turnaround times between crops showed that with the present transplanting methods and the farmer's power resources and equipment, the minimum turnaround time was 26 days. However, the use of the wet-seeded establishment methods decreased the turnaround time to 16 days.

The slow rate of land preparation, possibly due to a lack of draft power, can cause a serious loss of crop production potential.

COMPONENT TECHNOLOGY DEVELOPMENT AND EVALUATION

Component technology studies showed that control of early season insect pests of mung beans was the only management component that increased mung bean yields in Pangasinan, Philippines. The population of the Asian corn borer *Ostrinia furnacalis* was higher in lowland fields than in upland areas, probably because of the absence of the earwig *Proreus similans*, an effective predator of the corn borer in upland areas.

Flooding during paddy rice cultivation greatly suppressed plant parasitic nematodes, creating conditions advantageous to growing grain legumes after rice. Flooding nearly doubled the mung bean yields in the Pangasinan study site.

Follow-up evaluation of the potential of dry-seeded rice in high-pH soils in Pangasinan showed that IR28 rice was highly susceptible to early iron deficiency, while IR36 rice appeared to be tolerant. The results are encouraging for the introduction of a two-crop rice system in Pangasinan.

Rice + corn intercropping produces higher total yields when later maturing varieties are used. Rice yields were only slightly reduced by the competition from corn when corn matured 45 days before the rice.

Peanuts compensated substantially for corn crop damage caused by stand and foliage reduction in a corn + peanut intercrop. The intercrop yields appeared to be less sensitive to damage than the yields of corn and peanuts as monoculture crops. This observation indicates that intercropping reduces risk. Similar trends were observed in a corn + rice intercrop, in which clipping of corn foliage resulted in increased rice yields. Detasseling corn increased both rice and corn yields.

Yield reduction caused by weeds was less for taller rice varieties. There was no correlation between yield loss, and number of tillers and leaf area index. The effectiveness of weed control measures on rice was measured by the weight of the weed *Cyperus rotundus* L., harvested 28 days after the emergence of a uniform stand of peanuts. The best weed control occurred in the plots treated with 1.2 kg butachlor/ha. The weight of *C. rotundus* was reduced about 40% by high plant density, 50% by puddling, and 70% by hand weeding following an initial mechanical weeding or herbicide application on the previous crop.

In another experiment, the number of *Scirpus maritimus* L. plants in transplanted rice in an upland crop-lowland crop rotation was reduced by 36% and the rice yield was increased by 1.3 t/ha, compared with that in transplanted rice in a continuous lowland rotation.

CROPPING SYSTEMS NETWORK

A cropping systems network was initiated in collaboration with government agencies in Asia to help national programs increase the cropping intensity of the rice-producing areas. Priority is given to rainfed and partially irrigated rice areas. A network of test sites was established. In 1976, 12 sites were operational: three in the Philippines, four in Thailand, one in Bangladesh, two in Sri Lanka, and two in Indonesia. The major activities of the network, in addition to design and testing of cropping patterns, were training of scientists from collaborating countries and sharing of research information. The network also sponsored an administration seminar on cropping systems research and development, an international symposium on cropping systems research and development for the Asian farmer, and two working group meetings. Different varieties of upland crops (corn, sorghum, soybeans, mung beans, peanut, and sweet potato) were evaluated at different test sites.

Cropping systems program

Environmental description

Multiple Cropping Department and Entomology Department, Cropping Systems Component

RAINFALL CLASSIFICATION SYSTEM OF THE PHILIPPINES

Multiple Cropping Department

Rainfall plays a major role in the timing and success of agricultural operations such as seedbed preparation, cultural practices on crop protection, planning and implementing crop protection measures, and harvest and post-harvest operations.

The rainfall classification system based on the mean monthly rainfall and developed in 1974 was reviewed and modified to include 17 climate types (Table 1). The primary number of the classification denotes the dry season (4 types)—the number of consecutive months with less than 100 mm rain (dry month). If there are less than 2 dry months per year (type 1), there is probably no rainfall limitation to continuous cropping. Where there are 2 to 4 dry months (type 2), drought-tolerant upland crops can be used during the dry season. Continuous cropping becomes difficult in rain-fed areas with 5 to 6 consecutive dry months (type 3) and with more than 6 dry months (type 4).

The second level of the classification denotes the length of the wet season (5 types)—the number of consecutive wet months (> 200 mm rain); .1 = more than 9 wet months; .2 = 7–9 wet months; .3 = 5–6 wet months; .4 = 3–4 wet months; .5 = less than 3 wet months.

In addition, a zero (0) may precede the second digit to denote a rapid transition from wet to dry, or the zero (0) may follow the second digit to denote rapid change from dry to wet. The "rapid" transition applies when a month or less separates monthly rainfall of 50 mm or less from a monthly rainfall of 200 mm or more. The number 6 at the end of a classification indicates at least 1 month with a mean rainfall exceeding 500 mm.

This climate classification was used in a joint IRRI-BRRI (Bangladesh Rice Research Institute) Agroclimatic Study of Bangladesh and in an agroclimatic classification of Java and Sulawesi, Indonesia, conducted by the Indonesian Central Research Institute for Agriculture. The four types of dry season as they occur in the Philippines are shown in Figure 1; the five wet-season types are in Figure 2.

Table 1. Rainfall classification system of the Philippines.[a] 1976.

Climate type	Dry and wet months[a]
	< 2 DM and
1.1	> 9 WM
1.2	7–9 WM
1.3	5–6 WM
1.4	3–4 WM
1.5	< 3 WM
	2–4 DM and
2.1	> 9 WM
2.2	7–9 WM
2.3	5–6 WM
2.4	3–4 WM
2.5	< 3 WM
	5–6 DM and
3.1 (not possible)	> 9 WM
3.2	7–9 WM
3.3	5–6 WM
3.4	3–4 WM
3.5	< 3 WM
	> 6 DM and
4.1 (not possible)	> 9 WM
4.2 (not possible)	7–9 WM
4.3	5–6 WM
4.4	3–4 WM
4.5	< 3 WM

[a]DM = consecutive dry months with 100 mm rain; WM = consecutive wet months with 200 mm rain.

Frequency of tropical cyclones. Tropical cyclones are more prevalent in the Philippines from July to November. February and March are practically cyclone-free months. Tropical cyclones produce rainy periods, torrential rains, and very strong winds that cause floods and crop damage. The four categories are:

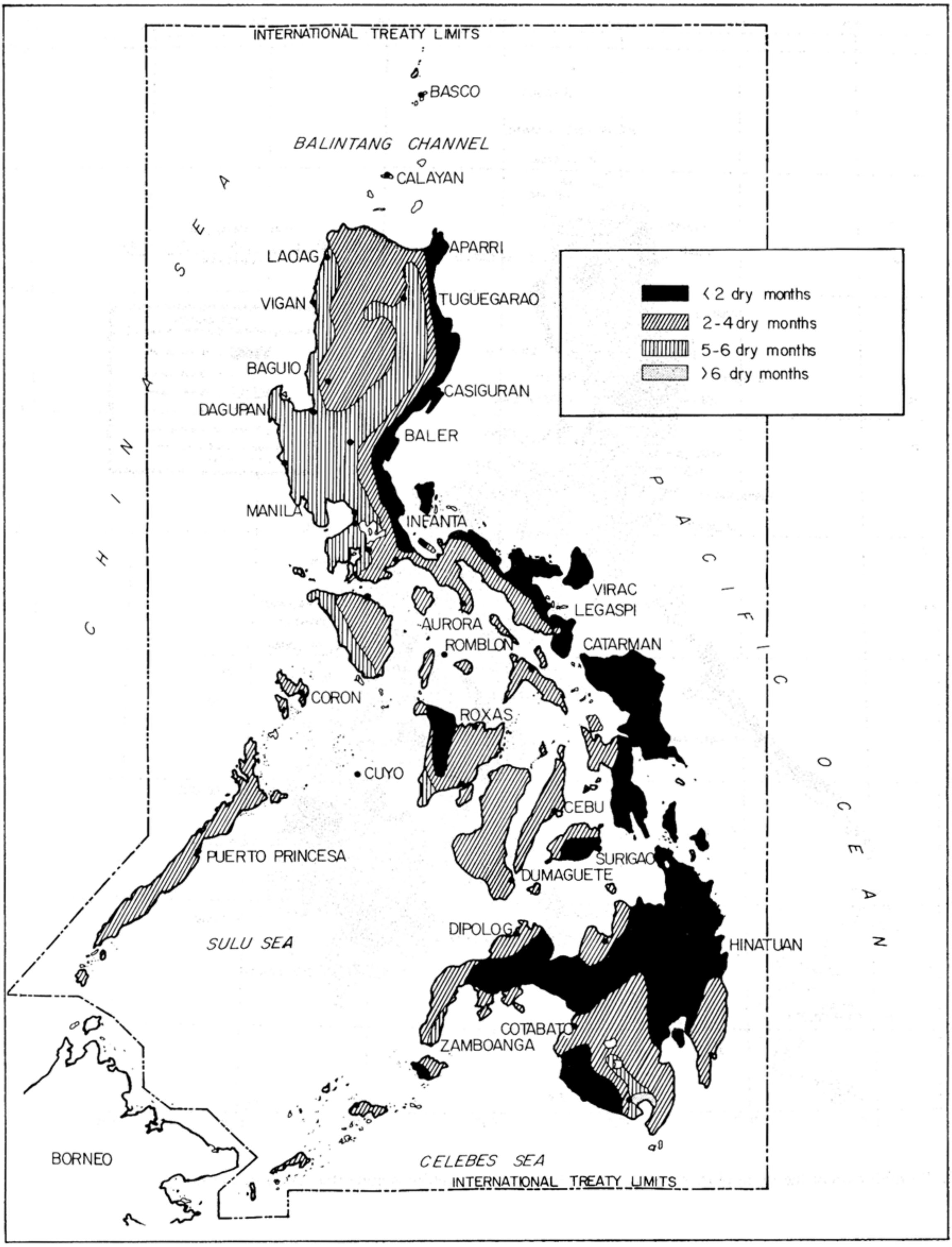
1) tropical depression—cyclones with winds 45–61 km/hour;

2) tropical storm—cyclones with winds 62–87 km/hour;

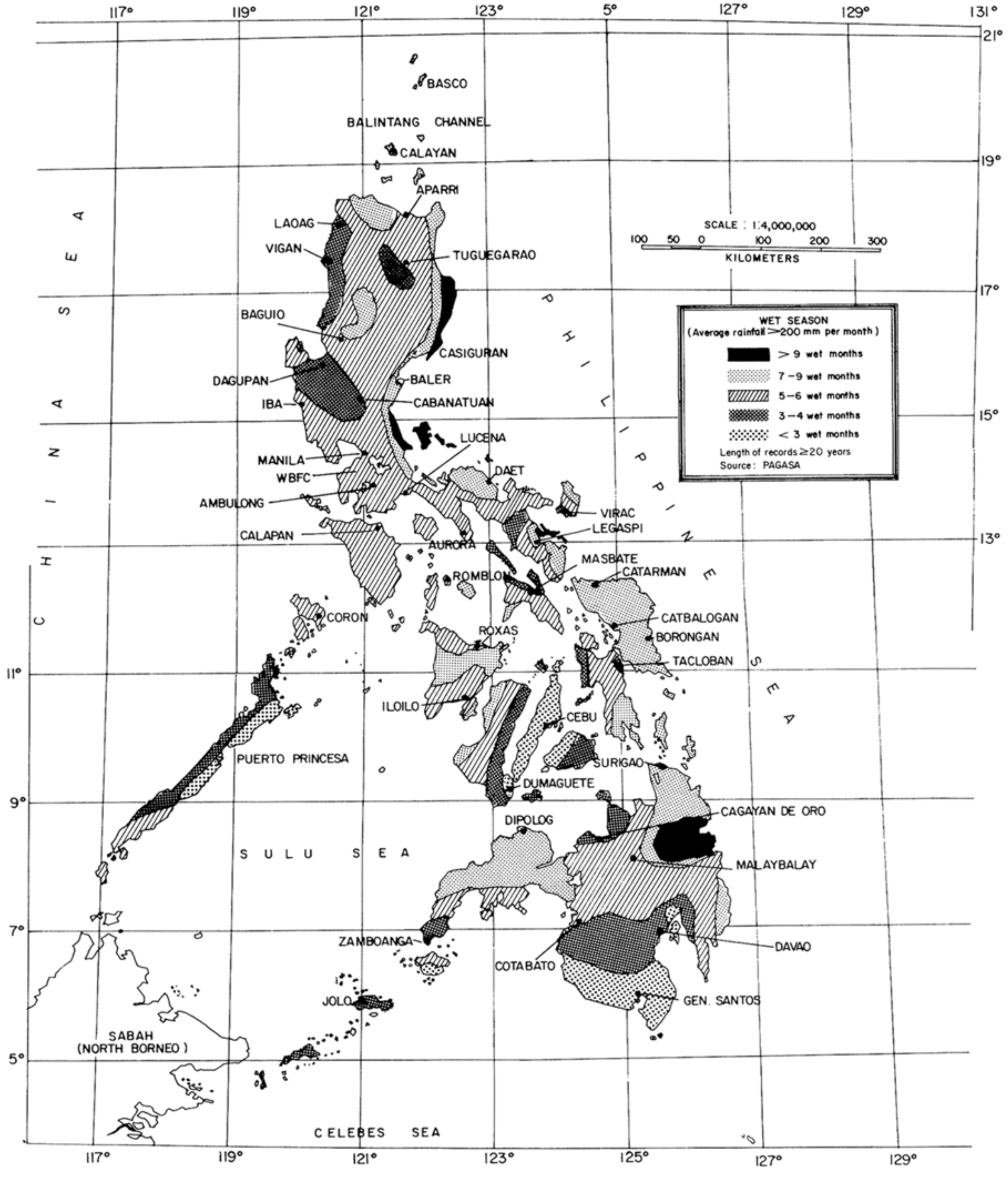
3) severe tropical storm—cyclones with winds 88–117 km/hour;

4) typhoon—cyclones with winds 118 km/hour.

The yearly frequency percentage of tropical cyclones in the Philippines was charted. The high-frequency areas are over the southern Bicol peninsula of Luzon and the northern Samar area through Masbate and the north-eastern Luzon sector. Except for its northeastern area, Mindanao has the lowest cyclone frequency. Cyclones rarely occur in regions within 5° of the equator.



1. Rainfall map of the Philippines showing areas where average rainfall is less than 100 mm/month.



2. Rainfall map of the Philippines showing areas where average rainfall is more than 200 mm/month.

LANDSCAPE CLASSIFICATION FOR CROPPING PATTERN PERFORMANCE

Multiple Cropping Department

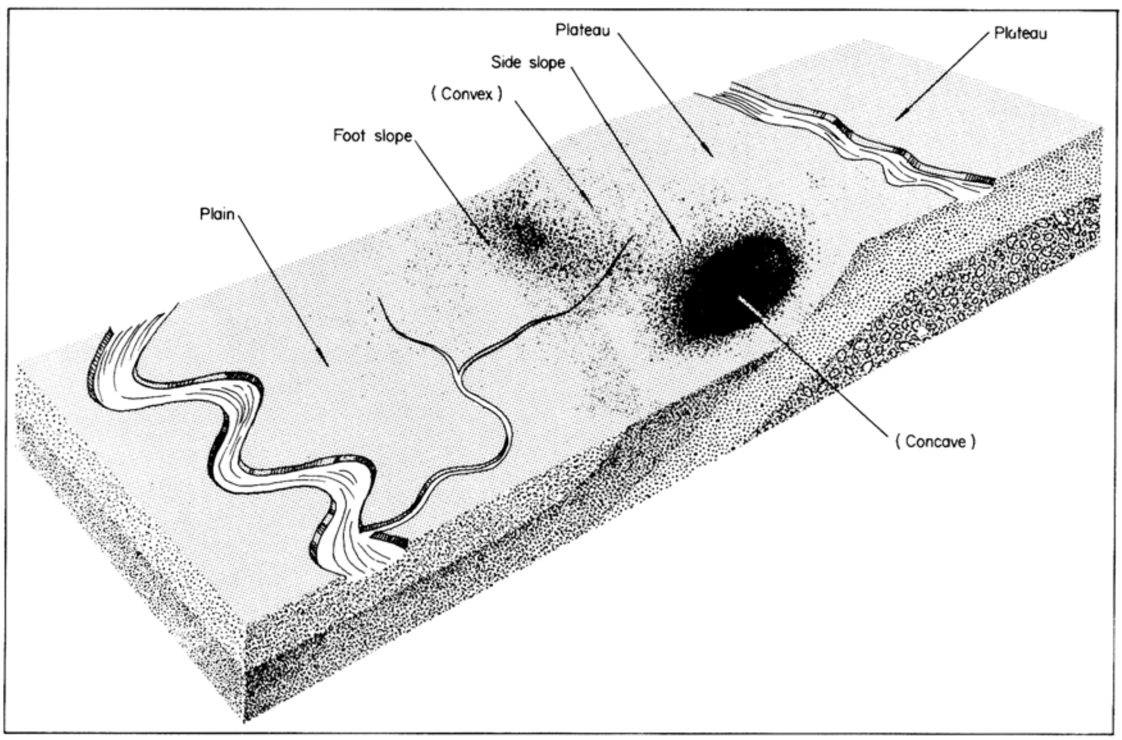
Early in 1976, the first approximation for a landscape classification was used to design cropping patterns in Iloilo (Fig. 3). Later a more complete land classification was developed. It considered topographically and pedologically related components of the microenvironment (Table 2). Farmers' fields in Iloilo and Pangasinan, Philippines, were classified according to the landscape scheme. Cropping pattern performance and paddy water relations are being analyzed to evaluate the feasibility of the classification.

Because of the importance of drainage characteristics of paddy fields, a survey was conducted to evaluate the potential of using the color of soils at a depth of 15 to 30 cm as an indicator of paddy field hydrology. Soils at the depth of 15 to 30 cm are close enough to the surface to be sensitive to water depth fluctuations during the year, but are below the frequently cultivated layer and undergo little color masking by organic matter.

The results of the survey indicated that soil color could be useful, but not to the extent expected. Most of the paddy areas studied

Table 2. Components of the microenvironment for describing and identifying land units for use in rice-based cropping systems.

Landscape classification according to				
Topographical components			Pedologic components	
Hydrology (water regime)	Landscape position	Drainage control	Soil texture	Clay mineralogy
Delugic Cumulic Fluxial	Bottom lands Plains	Normal Pan control Water table control	Clayey Loamy Sandy	Expanding Mixed Nonexpanding
Phreatic Pluvial	Side slopes Plateaus Knolls			Oxidic Allophanic



3. IRRI researchers used cropping pattern trials to develop a landscape classification and predict the cropping pattern suited to an area.

showed a completely gray matrix; even paddies in landscapes with slopes of 10% had a gray matrix. Upland fields, even as enclosures in paddy areas, lacked bright colors. Only a few bunded fields on river levees showed bright colors. However, the mottled colors in the gray matrix helped to differentiate fields and relate color differences to topographic position. Soil color continues to be used for identifying hydrologic conditions in paddy soils.

PESTS IN UPLAND RICE-BASED CROPPING SYSTEMS

Entomology Department, Cropping Systems Component

Rice. Earlier reports (1975 Annual Report) showing that upland rice in the Batangas, Philippines, site is not under intensive pressure from insect pests were further confirmed in 1976. Additionally, no major disease was recorded.

The white grub *Leucopholis irrorata* Chevrolat, which had caused severe yield reductions over a wide area of Batangas in 1974, was at a low ebb in 1976. Intensive sampling of upland rice revealed a general lack of foliar pests and no yield loss.

Sogatella furcifera (Horvath) was the most abundant insect, but its population peak was low—40.4/10 net sweeps. The level of other rice pests, typical of lowland areas, was low—*Nephotettix virescens* (Distant), *N. nigropictus* (Stal), *Nilaparvata lugens* (Stal), *Recilia dorsalis* (Motschulsky), and *Cicadella spectra* (Distant). Particularly low was the incidence of stem borers—a mixture of *Chilo suppressalis* (Walker), *Sesamia inferens* (Walker), and *Tryporyza incertulas* (Walker).

The general insignificance of foliar pests is attributed to such cultural practices as planting rice with the onset of rains after a 3-month dry fallow. Thus, many pests were not able to build up on alternate weed hosts that can occur when planting is delayed after initial rains. Also, the planting dates among fields are well synchronized; that too shortens the period for pest increase. Upland environments have a relatively low humidity, which is unfavorable to such potential rice pests as the brown planthopper. *Strepsiptera* parasitization of leafhoppers and planthoppers was 2 to 10%. Only low levels of spiders and *Cyrthorhinus* were found.

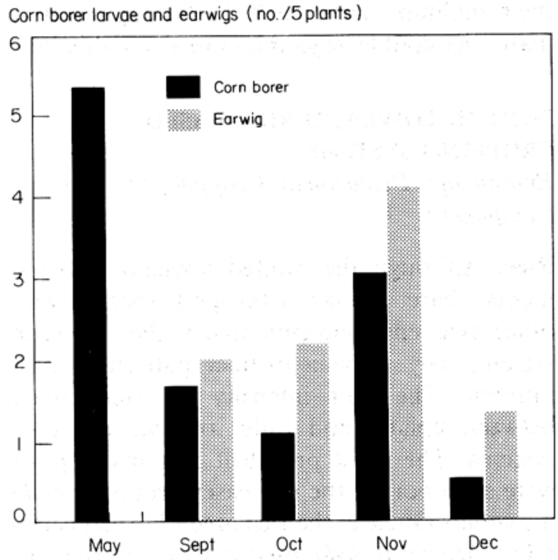
Corn. The most serious threat to corn in upland environments is the Asian corn borer *Ostrinia furnacalis* (Guenee). The largest numbers appeared during the May and November plantings and the lowest during the December planting.

Farmers at the Batangas site who planted early during the latter half of April, during the first monsoon thundershowers, avoided a high borer infestation. The majority of farmers, however, planted 1 month (one corn borer generation) later, after corn borer buildup.

Minor foliar pests, which were not considered of any economic importance, responded significantly to the month of planting: the corn leaf aphid *Rhopalosiphum maidis* (Fitch) was most abundant in the November planting; the corn seedling maggot *Atherigona oryzae* (Malloch) and corn thrips *Frankliniella williamsi* Hood were prevalent in the December planting; the corn earworm *Heliothis armigera* Hubner was abundant in the September and December plantings; and the silk beetle *Monolepta bifasciata* (Hornstedt) was prevalent in the September and October plantings. No major foliar disease was found in 1976.

Corn earworm damage is generally confined to ear tips, and actual grain loss is minimal. There is no markdown in the price of green corn due to earworm damage. The earwig *Proreus similans* Stal preyed on corn borer eggs and larvae. It is not normally found on the ground under litter but seeks shelter above ground. On the corn plant it is found behind leaf sheaths and among ear husks.

The earwig is also found in sugarcane fields and coconut crowns. Harvesting of sugarcane in the dry fallow drives the earwig away. The insect's delay in recolonizing the fields with the onset of the rainy season may explain the high corn borer population in the May corn planting. The insect, however, appears to be effective in subsequent plantings (Fig. 4). In Batangas, most corn is planted in October when over 50% of the arable land is occupied by corn (Fig. 5). A dilution effect thus reduces the impact of the



4. Relative populations of the tropical corn borer *Ostrinia furnacalis* and the earwig predator *Proreus similans* in five corn plantings, Tanauan, Batangas, Philippines, 1975-76.

corn borer. The relatively high numbers found in the November planting were a carryover from the previous month's planting; they were kept under control by the earwig.

Lady beetles responded positively to the aphid population, they were more numerous during the October and November plantings.

The average yield losses for field corn (7%) and green corn (3%) were probably underestimated because the corn borer could not be controlled effectively with insecticides.

Mung beans. Insects caused an average crop loss of 44% in mung beans in the Batangas site in 1976. Mung beans can be planted in May, September, October, November, and December in upland areas in various cropping patterns. The combined action of the same early vegetative pests found in lowland environments—bean fly *Ophiomyia phaseoli* (Tryon), leafhopper *Empoasca biguttula* (Shiraki), and flea beetle *Longitarsus manilensis* (Weise)—caused significant yield losses. Defoliation was constant (14 to 18%) in all monthly plantings, mainly because of the night-feeding flea beetle. Other defoliators included the semilooper *Chrysodeixis chalcites* (Esper); common cutworm *Spodoptera litura* (Fabricius), leaf folders *Homona coffearia* (Nietner), *Lamprosema indicata* (Linneaus), *Sylepta sabinusalis* (Walker), leaf miner *Stomopteryx subsecivella* (Zeller), Orthoptera-*Phaneroptera furcifera* Stal, and *Atractomorpha psittacina* (Haan); and corn earworm.

The populations of the black bean aphid *Aphis craccivora* Koch were slightly higher during the dry periods: the beginning (May planting) and end (December planting) of the rainy season. The many vegetables planted in upland areas served as alternate hosts for the legume pests, which spanned the dry season on hyacinth beans *Lablab niger* Medik, an 8- to 9-month crop planted in August (after corn or relay intercropped with eggplants) and harvested as green pods for the local market in Batangas from February through May. The relatively high bean fly population in May undoubtedly transferred from hyacinth beans. The September and October mung beans with low levels of *Empoasca* leafhoppers coincided with the eggplant and okra crops. *Empoasca* showed a preference for the two crops.

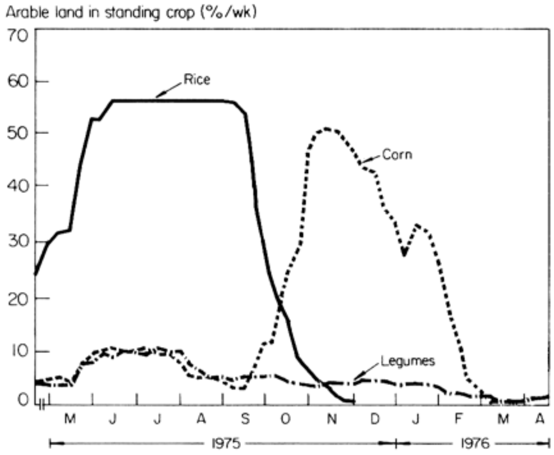
Yield losses of mung beans from pod borers *Catochrysops cnejus* Fabricius, *Maruca testulalis* (Geyer), and *H. armigera* were less than 5%.

The main seed pests in mung beans, *Nezara viridula* L. and the bruchid weevil *Callosobruchus* spp. (which infests mung beans in the field), were numerically low.

Yield losses due to insects were greater in the dry season than in the wet season. Losses in the May (35%), September (25%), and October (39%) plantings were similar. The highest crop losses occurred in the November (55%) and December (68%) plantings.

Powdery mildew *Erysiphe polygoni* DC and *Cercospora* leaf spot were not significant diseases. The low incidence of diseases is probably related to the low level of inoculum; at any one time, less than 10% of the arable land was planted to legumes in Batangas (Fig. 5).

Cowpeas. Pest damage to the cowpea crops caused a 66% yield loss in 1976 at the Batangas site. The same insect-pest complex that affected mung beans affected cowpeas. Cowpeas are more susceptible to bean fly, leafhopper, and leaf miner. Yield loss was greatest (80%) in the October planting probably because of the high



5. Percentage of arable land in rice, corn, and legumes determined from daily records of 37 farmers. Tanauan, Batangas, Philippines, 1975–76.

bean fly infestation (8.6 larvae + pupae/5 plants). The crop losses were 57% in May and 62% in December. Diseases caused negligible crop loss. An aphid-vectored mosaic virus, *Cercospora* leaf spot, and rust *Phakospora pachyrhizi* (Sydow) were of minor importance. Bacterial wilt *Pseudomonas solanacearum* E. F. Smith, present in upland environments, affected less than 5% of the cowpea plants and was not noticed in lowland fields that had been flooded.

Soybeans. In the Batangas site, soybeans established in May, September, and November were under less pressure from the insect complex than were mung beans or cowpeas. Pest damage reduced yields by an average of 22%. The main pest appeared to be the bean fly, and its high population effected a 45% yield loss during the May planting. The September and November plantings were under the least stress from insects. The seed-feeding Hemiptera—*Riptortus linearis* (Fabricius) and *N. viridula*—were observed only in the May planting. Two *Aphis* species, *A. craccivora* and *A. glycines* (Matsumura), were present.

Rust, bacterial pustule *Xanthomonas phaseoli* var *soyense* (Hedges) Starr and Burk, and *Cercospora* leaf spot were negligible. The legumes were susceptible to plant-parasitic nematodes of the genera *Meloidogyne* and *Rotylenchulus*. The actual yield loss caused by nematodes is unknown. Upland soils are most favorable for their buildup, particularly in Batangas where many susceptible vegetables are also cultivated.

PESTS IN LOWLAND RICE-BASED CROPPING SYSTEMS

Entomology Department, Cropping Systems Component

Rice. Although the rainfed lowland environments share similar arthropod species with other rice environments under the one-crop system, they show a distinct pattern in pest ranking. The pest intensity is intermediate between upland and fully irrigated agroecosystems. The most prevalent rice insect pests were stem borers, the rice caseworm *Nymphula depuntalis* Guenee, the rice green-horned caterpillar *Melanitis leda ismene* Cramer, the rice leaf folder *Cnaphalocrosis medinalis* (Guenee), the rice green leafhopper *Nephotettix* spp., and the rice bug *Leptocorisa* spp. (Table 3). Armyworms and several species of *Orthoptera* were also present. Grassy weeds served as alternate hosts to all the pests. As the areas shift from one to two crops a year, the pest pattern may become more similar to that occurring in fully irrigated areas.

Rainfed lowland environments in the Philippines were traditionally one-crop systems where weeds and volunteer rice proliferated in the fields with the first rains and allowed pests to build up and subsequently transfer to rice. The brown planthopper was present at low levels on susceptible varieties.

Iloilo in the Visayas, Philippines, represents the more typical rainfed lowland condition because of its isolation by mountains and the sea from the influence of nearby irrigated areas. In Iloilo, five stem borer species were evident. The most dominant was the white rice borer *T. innotata* (Walker) (60%), followed by the striped rice borer *C. suppressalis* (20%), yellow rice borer *T. incertulas* (7%), dark-headed rice borer *Chilo polychrysus* (Meyrick) (7%), and the pink borer *Sesamia inferens* (Walker) (5%).

Pangasinan, Philippines, is located in the Central Luzon "rice bowl," much of which is irrigated during the dry season, permitting continuous rice cropping. There, the yellow rice borer, whose only known host is rice,

Table 3. Rice arthropod complexes in rainfed paddy environments, with different varieties as first and second crops under different methods of establishment. Iloilo and Pangasinan, 1976.

Variety	Crop establishment method	Month of planting	Fields (no.)	Whorl maggots		Stem borers		Arthropods[b] (no./10 hills)					Defoliation[d] (%)
				Grade[a]	Tillers (%)	Deadhearts (%)	Whiteheads (%)	*Nilaparvata*[c]	*Cyrtorhinus*	Spiders	*Melanitis*	*Rivula*	
						Iloilo, first crop							
IR28	Wet seeded	May	6	1.7	—	2.6	2.3	22.5	0.8	6.8	0	0	4.3
Kapopoy	Wet seeded	May	4	1	—	1.9	1.7	63.3	0.3	6.5	0.2	0	21
						Iloilo, second crop							
IR28	Transplanted	October	6	—	19	5.4	7.4	14.8	4.2	21.7	2.2	0.2	21.8
BE3	Transplanted	October	4	—	18.1	3.9	16.2	40.8	1.9	28.9	2.5	0.8	16.4
						Pangasinan, first crop							
IR28	Wet seeded	May	4	—	45.4	5.5	0	4	—	1.9	0.1	0	—
IR28	Transplanted	July	5	3.6	—	11.3	2.8	5	1.8	3.6	0	0	—
Wagwagaga	Transplanted	July	3	2.6	—	4.3	13.2	3.3	4.3	7.5	0	0	—
Inano	Transplanted	July	3	2.3	—	6.2	2.4	6.6	0	4.8	0	0	—
						Pangasinan, second crop							
IR28	Transplanted	October	5	—	48.1	3	5.1	1.6	19.8	10.2	0	3	—

Variety	Crop establishment method	Month of planting	Fields (no.)	Arthropods[b] (no./10 net sweeps)						Leaf folders (% damaged leaves)	Rice bugs (no./sq m)	Yield[f] (t/ha)
				Leafhoppers			Planthoppers					
				Nephotettix[e]	*Recilia*	*Sogatella*	*Cicadella*	*Orthoptera*	Lady beetles			
					Iloilo, first crop							
IR28	Wet seeded	May	6	7.6	0.7	1	1.2	2.3	4.8	2.3	1.2	5.1
Kapopoy	Wet seeded	May	4	158	10.6	11.6	16.4	22.4	29.5	2.2	2	3.8
					Iloilo, second crop							
IR28	Transplanted	Oktober	6	17.3	3.7	0.2	8.5	14.2	10	1.7	4.7	3.9
BE3	Transplanted	October	4	106.9	11.8	1	34.1	17.5	6.3	2	3.5	2.8
					Pangasinan, first crop							
IR28	Wet seeded	May	4	28	1.3	3.3	1.3	4.6	0.8	21.4	3.3	3.9
IR28	Transplanted	July	5	11	0.4	5.8	0.8	0	0.4	0	1.4	3.8
Wagwagaga	Transplanted	July	3	72	1	6.1	3	0.1	2.3	0	1.1	1.1
Inano	Transplanted	July	3	157	0.4	7.5	0.3	1.8	3.2	0	3.3	3.3
					Pangasinan, second crop							
IR28	Transplanted	October	5	12.8	0.3	0.4	13.4	7	4.6	0	2.6	2.6

[a] On 1–5 scale: 0 = clean plants, 1 = light infestation, 5 = severe infestation. [b] Arthropod counts represent the peaks of infestation per crop. [c] One 5-sq-m sample area/plot. [d] Per-plot visual estimate. [e] Adults and nymphs. [f] Untreated plots.

accounts for 99% of the stem borer population. The pest probably comes from the surrounding irrigated rice areas.

While the rice whorl maggot *Hydrellia philippina* Ferino was a major pest in Pangasinan and not in Iloilo, a pyralid defoliator of rice, *Rivula atimeta* Swinhoe, previously unknown to the Philippines, was prominent in both places.

In the introduced double-cropped rice patterns for Iloilo and Pangasinan, the first crop was wet seeded in May at the beginning of the rainy season. The occurrence of the rice crop coincided with weed buildup and volunteer rice in adjacent fallow fields. Insects caused no yield loss at either site; however, a 30% yield loss occurred in the July-transplanted single rice crop in Pangasinan. This crop and the second planted (October) rice crop occurred after a substantial pest buildup. The yield losses for the October-planted crop were 20% in Iloilo and 24% in Pangasinan.

Stem borer damage and defoliation by several pests were more prevalent in the July and October plantings (Table 3). Except in the May planting in Iloilo, the rice bug population did not appear to increase with time. The rice whorl maggot population was high in Pangasinan throughout the growing season.

Differences between rice varieties resistant and susceptible to the green leafhopper showed up. The traditional susceptible varieties—Kapopoy and BE3 in Iloilo, and Wagwagaga and Inano in Pangasinan—had much higher green leafhopper counts than IR28, which is resistant to the insect (Table 3). Tungro disease, which was absent in Iloilo, caused severe crop losses on susceptible varieties in Pangasinan, and reduced yields of Wagwagaga crops (1.1 t/ha). IR28 showed no disease problems.

Brown planthopper populations were generally low, but were higher on the traditional varieties than on resistant IR28 in Iloilo (Table 3). The lack of pest buildup on IR28 may also be attributed to the plant's early maturity (80–85 days) compared with the maturation length of traditional varieties. The differences also showed up with respect to the zigzag leafhopper *R. dorsalis*, the whitebacked planthopper *S. furcifera*, and the white planthopper *C. spectra* (Table 3).

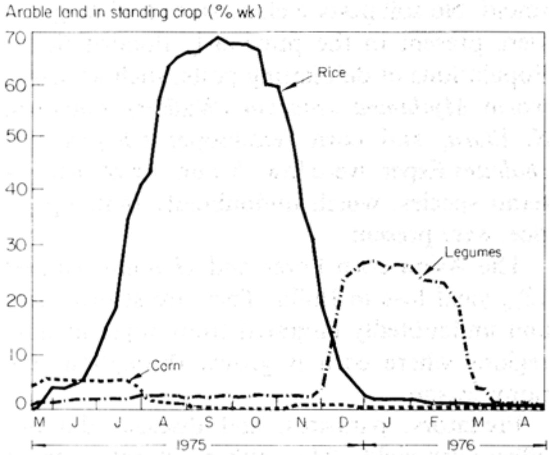
The occurrence of parasites of rice pests was erratic in 1976. In Pangasinan the yellow rice borer was 60% parasitized, but still achieved populations above economic thresholds. Some pests experienced no recorded parasites. In Iloilo, *Cercospora* or brown spot occurred sporadically on many varieties.

Legumes. Mung beans, cowpeas, and soybeans share a similar insect pest complex. After rice in lowland areas, three early season pests are important: bean fly, flea beetle, and leafhopper (Table 4). These pests, not found on

Table 4. The insect complexes of mung beans, cowpeas, and soybeans planted after rice in two rainfed lowland environments. Pangasinan and Iloilo, 1975.[a]

Location	Defoliation[b] (%)	Aphid infestation[c]	Insects (no.)							Pod borer-damaged pods[e] (%)	Bruchid weevil emergence (no./100 seeds)
			Per 5 plants				Per 10 net sweeps				
			Bean fly[d]	Leaf hopper nymphs	Leaf folder tunnels	Leaf miner tunnels	Flea beetles	Hemiptera	Orthoptera		
			Mung beans								
Iloilo[fh]	5	3.3	2.2	0	3.9	4.5	7.5	8	36.5	8	0.5
Pangasinan[gh]	29	1.3	2.7	3.3	1	1	86	0	1	28	0.2
			Cowpeas EG2								
Iloilo[h]	18	2.4	25.1	0	0	12.6	—	—	—	28	0
Pangasinan[i]	27	5.3	8.7	218	0.7	15	18	12	3	44	0
			Soybeans TK5								
Iloilo[h]	14	1.1	4.7	0	2.3	3.8	—	—	—	57	0
Pangasinan[i]	20	1	5.1	2	4.7	1.6	—	—	—	—	0

[a]Data presented are peak counts per arthropod or arthropod infestation from one sampling date. Biweekly sampling from unreplicated untreated fields. [b]Visual estimate. [c]On 1–9 scale: 1 = no aphids, 3 = small colonies, 5 = several colonies, 7 = many distinct colonies, 9 = many indistinct colonies. [d]Larvae and pupae. [e]Green pods. [f]CES 55. [g]CES 14. [h]Av. of 2 fields. [i]One field.



6. Percentage of arable land in rice, corn, and legumes determined from daily records of 49 farmers. Manaoag, Pangasinan, Philippines, 1975–76.

rice, are carried over in the rainy season from small upland fields planted to legumes (Fig. 6).

The flea beetle is particularly abundant in Pangasinan. The most serious damage occurs during the first 3 weeks of the crop even though flea beetles are found during all growth stages. The bean fly, another quick colonizer of legume fields, lays eggs in the leaves beginning with the young cotyledons. Infested plants become stunted and have fewer pods and lower yields.

The leafhopper attacks relatively later than the bean fly and flea beetle, but can cause stunting before flowering, which results in fewer pods per plant.

Pod borers are the next most important group, but in 1975 their populations were relatively low, as was their effect on yield. The principal pod borers of mung beans and cowpeas in lowland areas are *Heliothis* and *M. testulalis*.

Soybeans are attacked by two other pod borers in Iloilo—*Catochrysops* and *Etiella zinkenella* (Treitsche). The latter became a serious pest only in Iloilo, where it infested 57% of pods in 1975. Its main host is pigeon peas *Cajanus cajan* (Milsp.), present around homesteads or along wide rice bunds.

Legume yield losses due to insect pests in Iloilo and Pangasinan were 100% and 98% for cowpeas, 32% and 78% for mung beans, 47% and 41% for soybeans, and 0% and 26% for peanuts, respectively. Factors contributing to the low yields from untreated plots include drought stress, which reduces the plants' vigor and capacity to tolerate insect damage; low management (no weeding), which stunts plants and prevents them from competing effectively with the more hardy weeds; and sparse stands, caused by low seedling emergence in poorly prepared seedbeds of previously puddled soil.

There was a general lack of effective entomophagous arthropods on legumes. Aphid predators, such as lady beetles and syrphid fly larvae, were the most abundant, but few aphids were found. Even though farmers used low amounts of insecticide, parasite emergence from legume pests was generally low in 1975. The highest incidence was recorded for the leaf folders *H. coffearia* (23%) and *L. indicata* (12%) in Iloilo.

Mung beans planted after rice are generally heavily infested with powdery mildew. In two fields, symptoms appeared during the early vegetative stages and no harvest was possible. *Cercospora* leaf spot and rust occurred on mung beans, but were not important. Although they were readily available locally, fungicides were not used in controlling diseases.

The cowpea aphid-borne mosaic virus attacked less than 1% of plants in 1975. Rust and leaf spot were also detected on cowpeas. Soybean rust and several virus diseases, a mosaic and a rosette, were detected on soybeans but were not important.

A virus rosette disease of peanuts affected 12% of the crop in Iloilo. It was absent in a corn intercrop probably because the aphid vector had been excluded by the barrier of tall corn plants in rows. Both soybeans and peanut seeds were infested by soil fungal pathogens, which survived the flooded conditions during the rice crop. They reduced peanut seed emergence by 15% in Iloilo. Cowpeas and mung beans in four rice-growing environments in and near the Pangasinan site were surveyed for populations of two major nematode pests, *Rotylenchulus* and *Meloidogyne*. Flooding was associated with the differences in nematode counts (Table 5). More nematodes were detected in the nonflooded upland fields. Isolated paddy fields in drainage ways among upland fields

Table 5. Plant parasitic nematode populations in susceptible legume crops (cowpeas and mung beans) following rice in four environments. Pangasinan, Philippines, 1976.

Environment	Nematodes (no./250 cc soil and 1 g roots)		
	Rotylenchulus	*Meloidogyne*	Total of 6 genera
Upland fields	56	431	551
Isolated paddies in drainageways among upland fields	2	0	17
Highly intermittently flooded fields	2	5	35
Normal rainfed paddies	1	0	3

harbored only low populations, even though reinfestation was common. In paddies where rice was cultivated with 2 to 3 months of flooding even intermittently, the following legume crop was almost nematode free.

Corn after lowland rice. Corn is not grown extensively after rice in lowland environments, and that is reflected by the few pest species found. No soil pests such as ants or white grubs were present in the previously flooded fields. Populations of defoliating pests, such as armyworm *Mythimna separata* (Walker), cutworm *S. litura*, and corn semilooper *Chrysodeixis chalcites* Esper, were low. A number of orthopteran species, which undoubtedly built up on rice, were present.

The Asian corn borer and *Heliothis* caused 12% yield loss in Iloilo. They are strong fliers and undoubtedly migrated from adjacent hilly regions where corn is grown throughout the rainy season.

Predators, parasites, and diseases did not affect corn yields. They either did not occur or occurred at ineffectually low levels. The few lady beetles detected on corn showed that factors other than predators caused low corn leaf aphid incidence. Notably absent was the earwig *P. similans*, which is important in upland fields. The flooded rice fields excluded that soil-inhabiting insect.

Cropping systems program

Design of cropping patterns

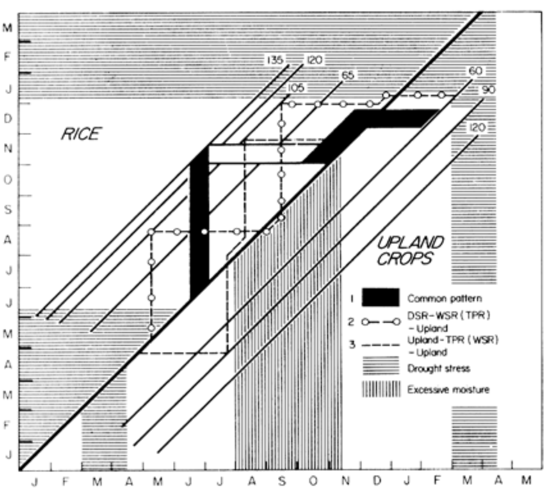
Multiple Cropping Department and Agricultural Economics Department, Cropping Systems Component

CROPPING PATTERNS DETERMINANTS

Climate. The design of experimental cropping patterns is based upon environmental description and available technology. In designing multicrop sequences, the relationship between the moisture environment (drought and flooding) and the crop (upland and lowland) is taken into consideration (Fig. 1).

A traditional cropping pattern of transplanted, late-maturing rice followed by mung beans (used in Pangasinan, Philippines) largely avoids adverse weather. A 1-month turnaround period between rice and the upland crop appears inconsequential for the upland crop since it grows under suitable moisture conditions.

Short-duration rice varieties and short turnaround periods make possible the experimental rice-rice-upland crop pattern (Fig. 1). This alternate pattern is likely to be subjected to more adverse moisture conditions than is the common pattern. It requires early seeding of the first crop and short turnaround periods, a technique that has been successfully applied in the Iloilo site. Trial plots of direct-seeded rice–transplanted rice–mung beans sequence performed poorly in 1975–76 at the Pangasinan site because of iron deficiences that led to poor establishment of the direct-seeding rice crop, and weed problems caused by a lack of water accumulation early in the growing season reduced yields severely in most plots.



1. Partially irrigated areas offer great opportunities for crop intensification and (or) more efficient use of water by careful crop sequencing. Pattern 2 replaces pattern 1 in areas with low seepage and percolation. Pattern 3 should be assigned to high seepage areas of irrigation districts.

Lines parallel to the diagonal and labeled 65, 105, and so on show length of growing periods of crops. A horizontal line segment connecting the diagonal and a parallel line in the bottom half of the chart represents the growing period of a hypothetical upland crop read from the bottom scale. A line segment rising vertically from the diagonal represents the growing period of a lowland rice crop, read from the lefthand scale. The wide black band traces the usual pattern of farmers in Manaoag, Pangasinan, Philippines: transplanted, late-maturing rice, followed by mung beans.

Landscape, topography, and soil texture. The cropping patterns evaluated during the 1976–77 season were designed according to climate type, landscape (knolls, plateaus, side slopes, plains, and waterways), the topographic position in the landscape (high, medium, and low), and the predominant soil textural classes in the area (Table 1). At the design stage, the management of the patterns was specified as to crop varieties, dates and methods of planting, fertilizer rates and methods of application, and pest management on the basis of specifications developed by the relevant research groups in the cropping systems program (Fig. 2). After the patterns are tested, their economic and biological performance are evaluated. The effects of landscape on cropping pattern performance and measured paddy water conditions are also studied to better understand how landscape affects the potential for crop intensification.

Computerization of a sequential cropping pattern design routine in 1976 will allow fuller elaboration of the climatic and economic determinants. The routine allows consideration of a maximum 20 crops and 10 environmental conditions. However, crop moisture requirements are the only environmental condition that has been entered into the routine to date. They permitted the design of 25 double-crop sequences considered feasible in Cale, Batangas, Philippines.

Labor. Stability of labor requirements on a farm means less cost to the farm household in seeking and releasing laborers on the market. The rudimentary technique developed in 1975 for measuring the tendency of experimental patterns to more evenly distribute labor in a

Table 1. Cropping patterns designed for the Iloilo site for the 1976–77 crop year considered the effects of landscape type, topographic position in the landscape, and soil texture.

Landscape and soil type	Cropping pattern[a] High elevation	Medium elevation	Low elevation
Knolls			
Loam	Corn–soybeans–sweet potatoes		
Plateaus			
Loam	DSR–WSR–cowpeas Corn–rice–cowpeas DSR–TPR–TPR	TPR–peanuts TPR–sweet potatoes DSR–WSR–cowpeas	WSR–rice–mung beans DSR–TPR–TPR
Clay	DSR–WSR–cowpeas Corn–rice–sorghum	TPR–sorghum DSR–TPR–TPR	WSR–rice–mung beans
Heavy clay	DSR–TPR–TPR TPR–mung beans TPR–cowpeas	WSR–rice–mung beans DSR–TPR–TPR TPR–honeydew	WSR–rice–mung beans DSR–TPR–TPR
Side slopes			
Loam	Corn–rice–cowpeas	TPR–soybeans TPR–peanuts TPR–sweet potatoes	WSR–rice–mung beans
Clay	Corn–rice–cowpeas	TPR–soybeans TPR–mung beans TPR–cowpeas	WSR–rice–mung beans
Heavy clay	TPR–mung beans TPR–cowpeas	TPR–soybeans TPR–melon	WSR–rice–mung beans
Plains			
Loam	DSR–WSR–cowpeas	TPR–corn TPR–corn + peanuts TPR–corn + mung beans	DSR–rice–mung beans Corn + rice–soybeans–sweet potatoes
Clay	DSR–WSR–cowpeas	TPR–corn	WSR–rice–mung beans
Heavy clay	DSR–WSR–cowpeas	TPR–sorghum TPR–melon WSR–rice–mung beans	WSR–rice–mung beans WSR–rice–rice WSR–TPR–melon
Waterways			
Intermittent			TPR–TPR–sorghum
Continuous			TPR–TPR–TPR

[a]In a cropping pattern, – = followed by; + = intercrop. DSR = dry-seeded rice; WSR = wet-seeded rice; TPR = transplanted rice.

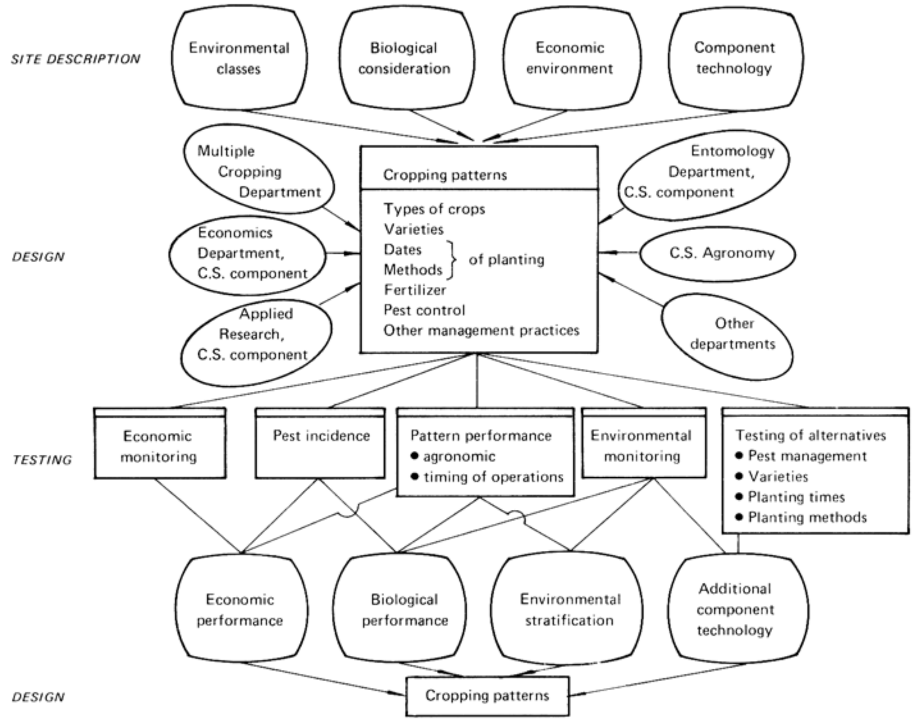
cropping system was improved. The improved method shows the rate at which weekly labor variance in a system changes as a new cropping pattern replaces an old one, and the level of introduction of a new pattern that can minimize the labor variance in the system (Table 2). A rice-sweet potato pattern (rice followed by sweet potato) was found to have the most rapid initial impact on labor variance, but a rice-mung bean pattern would eventually (at 30% replacement) reduce variance in the system the most.

The technique for routine design of new cropping patterns has been computerized. Low labor-variance patterns can be assembled for a chosen base crop or low labor-variance systems can be designed for a chosen base pattern. Low labor variance does not guarantee profitability;

Table 2. Change in labor variance as labor used for an existing rice-corn pattern is shifted to new patterns. IRRI, 1976.

% of total system labor allocated to new system	Change (%) in labor variance for cropping pattern[a] Rice–mung beans[a]	Rice–cowpeas[a]	Rice–sorghum[a]	Rice–sweet potatoes + corn[a]	Rice–sweet potatoes[a]
0	0	0	0	0	0
10	–17	–16	–16	–13	–23
20	–28	–24	–24	–21	–32
30	–33	–23	–24	–23	–28
40	–32	–14	–16	–21	– 9
50	–26	+ 3	0	–12	+22
60	–14			+ 2	
70	+ 4				

[a]In the cropping pattern, – = followed by; + = intercrop.



2. Contribution of program areas to site description, design, and testing of cropping patterns and component technology generation. CS = cropping systems. IRRI, 1976.

therefore, other costs of production must also be considered at subsequent stages. Subsequent profitability analysis must be conducted with labor seasonal prices.

ANALYSIS OF TESTING RESULTS

Farmers' practices were studied to investigate low-level management, rapid adoption of rice-rice patterns, and long turnaround times.

Competitive activities. Haphazard bunding, low water impoundment, and excessive weed infestation showed low levels of management of rice by farmers in barrios Pao and Lipit, Pangasinan, Philippines. Zinc-deficient or iron-deficient soils, or both, were suspected as the cause of low yields. To verify if that was indeed the case, other possible explanations were explored. One possibility was that Pao-Lipit farmers were poor crop managers.

To quantify management and associated crop production, labor use, fertilizer, and rice yields in Pao-Lipit were compared with those of the nearby barrio of Caaringayan where management was superior. The possible causes of inefficiency in the management and performance criteria (as alternatives to the soil-related hypothesis) were identified by comparing farm operators' ages, experience, and education; family labor force; farm power base; and management of crops not likely to be affected by the soil problem. Labor inputs on rice for nonharvest operations, mainly plowing and weeding, differed between the two areas, and lower yields were verified in the Pao-Lipit area.

The indicators of farmer management capacity—age, education, number of family workers, and number of carabaos—were not similar. However, lower incomes from rice in Pao-Lipit were entirely offset by larger incomes of farmers from upland crops elsewhere on their farms. Thus, inefficient farm management was eliminated as an adverse determinant of lowland rice cropping potential in Pao-Lipit.

Subsequent agronomic studies showed that treatments for zinc deficiency can raise rice yields in Pao-Lipit to levels comparable with those in Caaringayan. Component technology studies also showed that dry-seeded IR36 rice was tolerant of iron deficiency and would produce acceptable yields. Rice-rice patterns with zinc treatment of seedlings have been recommended in Pao-Lipit.

Low management techniques for certain cropping patterns may be appropriate even where higher labor or material inputs can profitably achieve higher yields, if there are more profitable alternate uses on the farm for those resources.

The alleviation of the constraint of iron deficiency on rice production in Pao-Lipit may lead to the reallocation of labor and power resources to rice production. In certain situations where more profitable nonrice alternatives exist, the key to maintaining or increasing rice production may be the more efficient utilization of residual resources after first-choice alternatives.

Small technological changes. Rice-rice patterns in Iloilo did well. The technique of wet seeding of early maturing varieties, followed by an additional rice crop, was widely adopted. Timely tillage, seeding, water control, and weeding practices by farmers without the benefit of extension services suggested that farmers already had some familiarity with the practices. Although farmers in the rainfed areas were unfamiliar with double-cropping, they had occasionally used direct-seeding techniques early in the season to allow themselves more time to work on other farms for additional income. The short-season IR28, IR30, and IR36 rice varieties provided an incentive for double-cropping; 47% of all wet seeding performed by 36 farmers during their life on their farm occurred in 1975–76 with the use of those rices.

An important element of farmers' capacity to manage more intensive cropping patterns is their familiarity with techniques; small steps in technology are likely to be more successfully adopted by farmers than are large ones.

While two rice crops plus a third upland crop have also been shown to be possible in previously single-cropped areas, small technological changes have greater possibility of success. Farmers' technical experience may be a determinant of cropping pattern potential and should be assessed at an early stage of research.

Labor as determinant of turnaround time. Upland rice can be harvested early through rapid planting techniques and use of early maturing varieties. Existing systems were studied to determine the length of turnaround times in farmers' present patterns, the factors affecting length of turnaround, and the benefit to be gained from a short turnaround time.

A first step to learning why farmers use a long turnaround time is to determine the magnitude of gains that would be realized from rapid replanting. One approach is to determine whether crops can be grown during the turnaround and, if so, what levels of returns are lost when land is idle at various times of the year. Such gains must then be compared with the costs of accelerating the rate of land preparation and replanting. Expected costs should include the costs of rented draft power and, perhaps, additional field losses on the first crop resulting from less supervision of harvesting and threshing by the operator.

The sum of US$2,300 is taken as the gross value of biological potential under the present technology. The most productive experimental patterns have achieved about a third of the potential. In Cale, Batangas, Philippines, the dominant crop pattern, upland rice-corn, achieves about one third, while the most intensive pattern, rice-garlic, achieves 85% of potential production. The potential may not be realized on a wide scale because actual patterns cover the land preparation periods. Also it is unlikely that any combination of crops can be grown end to end under environmental conditions optimum for the growth of each. Furthermore, resources are not sufficiently homogenous to permit a combination of crops to be grown on a given plot under conditions optimum for each.

Nevertheless, the economic benefit of some increase in crop intensity seems clear. Surveys of farmers' field corn over three seasons from 1973 through 1976 in Cale showed an average 1-ton drop in yield between the October and November plantings. During the typical turnaround period from 13 September to 10 Octo-

Table 3. Average lag between harvest of first crops and planting of second crops in present cropping systems. Batangas, 1975–76, and Iloilo, Philippines, 1976–77.

Pattern group[a]	Plots (no.)	Turnaround time (days)		
		Range		Average
		36 farms, Batangas		
Upland rice–corn	60	7–56		35
Upland rice–mung beans	17	7–42		35
Upland rice–vegetable	14	14–77		46
		45 farms, Iloilo		
		Harvest week[b]	Planting week[b]	
Rice–rice	111	43	46	24
Rice–upland crop	12	51	3	10
Rice–upland crop relay	46	49	49	–6
Corn–upland crop	9	29	44	58
Upland crop–upland crop	7	35	52	81

[a]In a cropping pattern, – = followed by. [b]Calendar week, January 1–7 = week 1.

ber, farmers relinquished US$140 worth of potential food production per hectare at the present rates of crop yield. Evaluation of a triple-crop sequence in Batangas indicated the possibility of substantial returns from an additional crop if the turnaround time could be reduced.

Despite this apparent potential, long turnaround times predominate in present systems. Extended lag times between the harvest of first crops and planting of second crops prevailed at all three cropping systems research sites in the Philippines during 1975–76. It took 7 weeks to replant three-fourths of second crops in Batangas and Pangasinan, and 6 weeks in Iloilo. Furthermore, long replanting lags affect all types of patterns (Table 3).

A labor constraint was suggested. In the weeks following rice maturity, all available labor was probably allocated to harvesting and threshing rice on various parts of the farm, leaving none to land preparation and replanting.

The farms where plots were most rapidly replanted were those still heavily engaged in rice harvest on other plots (Table 4) and were generally the busiest farms. During the initial weeks of the lag, farmers who were slow to replant spent as much time harvesting and threshing as the replanting farmers did; however, farm size and rate of replanting were not related. Harvesting and threshing activities did not appear to be related to length of turnaround.

During turnaround, lowland farmers were occupied in harvesting as well as in land preparation (Table 4), but upland farmers were predominantly occupied with harvesting operations. The reason is that upland rice establishment is simultaneous over large areas (first rains), whereas planting of the first lowland rice is staggered.

The relatively constant rates of land preparation and planting, across lag groups within sites suggested a power constraint. Each plot is replanted in turn so that on the same farm some plots are replanted quickly and others later. The land preparation rates of 34 and 31 hours/week in Iloilo (Table 4) approach the maximum work capacity for one carabao. Interviews in Cale tended to confirm the power constraint and a staggered replanting schedule. The fact that many Cale farmers borrow draft animals from each other perhaps explains the lower average rates of land preparation per farm.

Table 4. Total labor use on the farm, and distribution by activity during the turnaround period between first and second crops. Batangas, 1975–76, and Iloilo, Philippines, 1976–77.

Lag (wk) until plot is 100% replanted	Plots observed (no.)	Av. labor (h/wk) during an av. turnaround period[a]					
		Land preparation	Planting, nursery	Crop tending	Harvesting	Threshing and other postharvest operations	Total
		36 upland farms, Batangas					
1–2	7	9	2	10	103	32	156
3–4	12	8	6	12	65	19	110
5–6	23	10	4	10	53	17	94
7–8	15	9	4	11	44	15	74
		45 lowland farms, Iloilo					
1–2	10	34	25	5	18	28	110
3–4	11	31	15	5	26	18	95
5+	11	13	18	5	12	22	70

[a]By type of activity on whole-farm basis.

Cropping systems program

Testing of cropping patterns

Multiple Cropping Department and Agricultural Economics Department, Cropping Systems Component

PANGASINAN TESTS

The IRRI-BPI (Philippines Bureau of Plant Industry) Cropping Systems Outreach Program research area in Pangasinan has 5 to 6 dry months and 3 to 4 wet months. In at least one of the wet months, rainfall exceeds 500 mm. The pH of the dominant calcareous clay loams ranged from 6.7 to 7.9. The high pH became a great concern, with iron and zinc unavailability interacting with water management and soil redox conditions. The soil problems related to high pH severely impaired crop performance. In the rice-mung pattern (rice followed by mung), the dominant farmer's cropping pattern in the area, the rice is planted in July and is followed by a low-management broadcast mung in December. Irrigation extended the cropping season through February in some locations.

Fourteen rice-based cropping patterns were tested by 54 farmer cooperators during the crop year 1975–76 (Table 1). They included single and double rice crops followed by either mung beans, soybeans, cowpeas, peanuts, sorghum, sweet potato, and mung beans, or peanuts with corn intercrop. Rice was grown at the peak of the rains, while the upland crops were grown toward the end of the rainy season to use residual soil moisture.

Table 1. Grain yields[a] of 14 cropping patterns tested in Manaoag, Pangasinan. May 1975–March 1976.

Cropping pattern[b]	Fields tested (no.)	Grain yield[c] of component crops of each pattern (t/ha)
TPR	2	(2.15)
TPR–TPR	4	(4.70) + (3.1)
TPR–sorghum	8	(2.90) + (2.31)
TPR–sweet potato	11	(2.89) + (4.57)
TPR–soybeans	9	(3.54) + (0.11)
TPR–cowpeas	8	(2.98) + (0.32)
TPR–mung beans	26	(3.33) + (0.68)
TPR–mung beans + corn	11	(3.20) + (0.21/0.64)
TPR–peanuts + corn	5	(3.12) + (0.59/1.16)
TPR–TPR–sweet potato	1	(4.6) + (2.8) + (11.84)
DSR–TPR–cowpeas	1	(2.0) + (4.2) + (3.8)
DSR–TPR–mung beans	7	(2.01) + (2.7) + (0.36)
DSR–TPR–mung beans + corn	5	(2.02) + (3.4) + (0.48/0.28)
DSR–TPR–peanuts + corn	2	(3.35) + (4.1) + (0.25/1.53)

[a]Av. yields of fields in each pattern. [b]TPR = transplanted rice; DSR = dry-seeded rice. In a cropping pattern, – = followed by; + = intercrop. [c]Arranged according to crop sequence of each pattern.

The cropping patterns design used the available rainfall data for the area. In 1975, the rains started slightly earlier, but stopped about a month sooner than usual. The sharp cessation of the rains had an unfavorable effect on the general stand and performance of the upland crops following rice.

The yields of transplanted rice (TPR) were generally higher (average, 3.2 t/ha) than the yields of dry-seeded rice (DSR) (average, 2.2 t/ha). Zinc deficiency in TPR was corrected by dipping seedlings in a 2% solution of zinc oxide. DSR yields were low because of iron deficiency and weeds. DSR appeared to be an economic risk in Pangasinan because of problem soils plus the varieties and technology used.

Of the two-crop-per-year patterns, those with either mung beans or peanuts performed best. The traditional TPR-mung beans patterns responded to high management and improved varieties. TPR-TPR and TPR-sorghum patterns gave reasonably high yields, but the lower prices of cereals and sweet potatoes required high yields for the patterns to match the profitability of legumes, which commanded a much higher price.

The TPR-cowpea and TPR-soybean patterns gave low total yields and net returns. Because of varietal photosensitivity and difficulty in getting good stands, the soybean plants were short, flowered early, and competed poorly with weeds. Cowpea yields were low because of inadequate soil moisture at the reproductive stage. The corn intercrop contributed little to overall productivity because of zinc deficiency during early growth, downy mildew infection, and moisture stress.

With the three-crop patterns, one farmer achieved exceptionally high yields and net returns with TPR-TPR-sweet potato because his field had access to supplemental irrigation water in a drainage canal. In general, the yields of the legume components in the three-crop patterns were low because the preceding two rice crops caused the legumes to be grown during the dry season. A normal rainfall would have been favorable to the legumes. Reduced turnaround times between crops would also improve the productivity of those patterns.

The 1975–76 cropping pattern trials in Pan-

Table 2. Cost and returns of experimental cropping patterns and farmers' present patterns. Manaoag, Pangasinan, Philippines, 1975–76.

Cropping pattern[a]	Input requirements				Returns				
	Plots (no.)	Cash[b] (US$/ha)	Labor (d/ha)	TVC[c] (US$/ha)	Gross (US$/ha)	Net of TVC[c] (US$/ha)	To cash[d] (US$/1$)	To labor[e] (US$/d)	Farm resources[f] (US$/ha)
					Low management patterns				
Farmers' patterns									
TPR–no tillage mung beans	12	43	138	165	471	306	12	3.1	365
TPR–low tillage mung beans	27	56	175	221	497	276	10	2.4	355
Experimental pattern									
TPR–no tillage mung beans	9	238	299	500	703	203	3	1.5	329
TPR–low tillage mung beans	12	235	276	497	611	114	3	1.4	340
TPR–low tillage soybeans–cowpeas	5	299	234	556	750	194	3	1.9	355
TPR–low tillage sorghum	3	273	274	535	830	295	3	2.0	421
TPR–low tillage corn–legume	7	236	356	556	559	3	2	.9	157
					Intermediate management patterns				
Farmers' patterns									
Corn–TPR	3	103	208	294	624	330	6	2.5	422
Experimental patterns									
DSR–TPR	16	343	524	918	748	–170	2	.8	106
TPR–legumes	30	225	288	498	632	134	3	1.5	265
TPR–corn + legumes	19	343	309	644	704	60	2	1.2	204
TPR–sorghum	8	223	276	493	694	201	3	1.7	331
					High management patterns				
Farmers' patterns									
Rice–tomato	15	61	292	332	739	406	12	2.3	537
Experimental patterns									
TPR–TPR	5	301	472	719	1041	322	3	1.6	523
DSR–TPR–mung beans	7	444	701	1009	891	–118	2	.6	153
DSR–TPR–corn + legumes	6	479	551	959	974	15	2	.9	245

[a]In cropping patterns, – = followed by, + = intercrop, TPR = transplanted rice; DSR = direct-seeded rice. [b]Cash requirements are computed as the value of material inputs, or seed, fertilizer, and pesticides. [c]Total variable costs (TVC) include the value of material inputs and labor, where labor for land preparation including draft power is valued at US$1.63/day and other labor is valued at US$0.82/day. One workday is assumed to be 8 hours. Labor was originally recorded in man-hours. [d]Return to cash = gross return ÷ cash requirements. [e]Return to labor = $\frac{\text{gross return} - \text{cash costs}}{\text{total labor requirements}}$. [f]Return to farm resources = gross return – value of material inputs (footnote[b]) and 52% of labor costs, which represent amount of labor usually hired.

gasinan showed that rice-upland crop sequences that used minimum tillage for the upland crops required low management (Table 2). At low management, a single furrowing required 20 hours/ha; at intermediate management, complete plowing required 100 hours/ha. Ultimately, however, the labor saving was more than offset by larger labor requirements for subsequent operations of harrowing, seeding, and fertilizer and pesticide applications. Thus, the total variable costs and gross returns of both the low- and intermediate-management systems were similar.

High-management systems absorbed more inputs and showed higher gross returns (Table 2). Among them, double-cropping of transplanted, early maturing rice varieties yielded the highest gross returns. The next highest gross returns from an experimental pattern occurred with rice-sorghum under low management and with rice followed by legumes.

None of the experimental patterns performed as well as the crop patterns used by farmers in the respective management classes. Furthermore, while the high-management DSR-TPR pattern appeared competitive with patterns in lower management classes on the basis of net returns, the average rates of return to cash and labor resources in that pattern are below the rates achieved with farmers' patterns.

The use of larger amounts of labor in the experimental patterns than in the farmers' patterns contributed in part to the high costs of the new patterns. Improved designs for the subsequent year aimed to reduce the labor input with no reduction in yield. However, not all of the labor in excess of that which farmers usually apply can be removed without impairing yield. This observation tends to modify the possible conclusion that the experimental patterns, with present technology, are not competitive in those cases where family labor to perform all of the operations is sufficient and has no alternate employment. In Manaoag, 52% of the farm labor is hired. Farm family members commonly hold nonfarm jobs that contribute 33% to the farm cash inflow and represent additional income for the household. In this case, patterns can be reevaluated on the basis of total return to farm resources. The total return to farm resources (Table 2) shows that the high-management TPR-TPR pattern and several of the low-management patterns would be competitive within their respective classes if household labor were not marketable.

Patterns were redesigned for the 1976–77 trials. The results of the first rice crop show that labor requirements for weeding dry-seeded rice were reduced by more effective chemical weed control. Wet-seeding further reduced the weed problem. Improved weed control reduced costs, increased yields, and improved net returns. A change in rice variety from IR28 to IR36 also improved yields.

The crop yields and gross returns shown in Table 2 are estimated as the mean of sample crop-cut yields and production as reported by farmers who own the 0.1-ha experimental plots. In keeping with the method of on-farm research, farmers manage the experimental patterns according to instructions from researchers. They harvest and report all produce outside the sample 0.1-ha experimental plots.

ILOILO TESTS

The Iloilo test site has rainfall type 2.3, which has 2 to 4 dry months (< 100 mm/month) and 5 to 6 wet months (> 200 mm/month). Soils are generally slightly acid clay or clay loam.

The results of the 1975–76 cropping pattern trials showed good yields and substantial profit advantages for the rice-rice patterns over the patterns now being grown by farmers (1975 Annual Report). The double-rice crop technology was widely used by farmers in 1976–77; 40% of the cropland of 45 farms in Oton and Tigbauan, Iloilo, was used for rice-rice and 54% for rice-fallow. The performance of the new pattern in farmers' fields was compared with its

Table 3. Comparison of cost and returns of experimental and farmers' rice plots. Iloilo, Philippines, 1976–77.

Crop, cropping pattern[a]	Plots reported (no.)	Yield (t/ha)	Costs (US$/ha)			Returns (US$/ha)			
			Labor	Material	TVC[b]	Gross	Net of TVC[c]	To labor[d]	To cash[e]
				Experimental plots					
First crop									
WSR	89	5.3	176	98	274	782	508	0.36	1.10
TPR	8	4.6	184	108	292	688	397	0.31	0.87
Second crop									
WSR	10	4.6	153	93	246	644	398	0.39	0.94
TPR	10	4.1	171	102	272	582	309	0.30	0.78
				Farmers' plots					
First crop									
WSR	24	2.3	68	67	135	316	181	0.39	0.64
TPR	14	3.1	74	108	182	457	275	0.52	0.57
Second crop									
WSR	13	3.1	81	100	181	446	265	0.46	0.61
TPR	12	3.6	47	152	199	523	324	0.86	0.46

[a]WSR = wet-seeded rice, TPR = transplanted rice. [b]Total variable cost = labor cost + material cost. [c]Net return of TVC = gross return − TVC. [d]Return to labor = $\frac{\text{gross return} - \text{material cost}}{\text{labor hours}}$. [e]Return to cash = gross return ÷ material cost.

performance in the experimental plots (Table 3).

The two-crop technology was adjusted when it was adopted by farmers. For example, lower rates of labor were used. That resulted in higher average rates of return to labor and suggests that farmers value their labor more highly than was estimated. Consequently, the design of new patterns should use labor-saving techniques, whenever possible.

The application of fertilizers and pesticides (material costs) on farmers' plots matched that on research plots, except in the first-season wet-seeded rice (WSR), to which only 6% of the farmers applied herbicides.

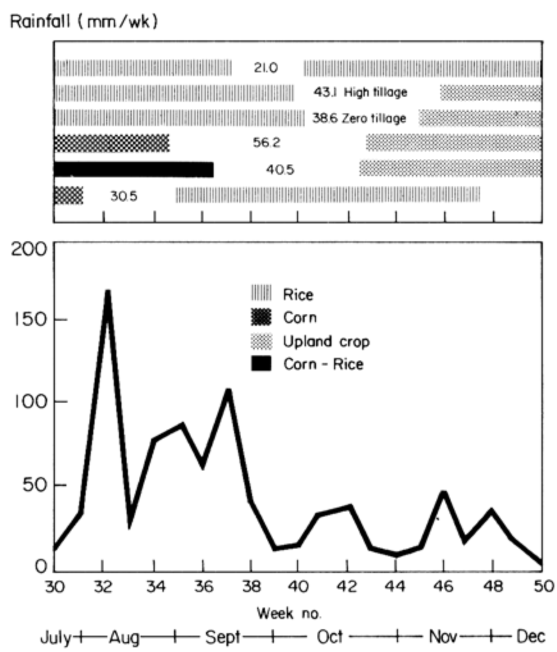
All double-cropped rice throughout the project area in 1975–76 and 1976–77 was established by the wet-seeding technique, which requires sufficient rainfall for puddling the land. The area seeded before week 26 (30 June) was closely related to the rainfall received from week 16 to week 24 for the 3 years studied. The area seeded before week 26 is potentially available for double-rice cropping. Lack of early rains may reduce the potential for double-rice cropping unless the first rice crop is established by the dry-seeding method.

Analysis of the rate of land preparation as a function of rainfall indicated that farmers are unable to take sufficient advantage of early rains because between 10 and 15 days is required to prepare 1 ha of land. By the time farmers have planted part of their land, water is lost from the remaining areas and they have to wait for the next surge of the monsoon rains. Thus, some farmers never manage to establish rice in all their fields, and the percentage of fallow land can be high in low-rainfall years.

The rate of early rice crop establishment was not strictly associated with landscape units in 1975–76. Farmers on the higher, better drained plateaus established early WSR at the same time as farmers in the low-lying, more poorly drained plains. The potential for increasing the rate of land preparation and the extent to which farmers will shift to dry seeding of rice for an early rice crop in drier years continue to be studied.

Long turnaround times between crops account for another important loss of cropping potential (see the figure). The 1976 cropping pattern trials showed that only 21 days of turnaround occurred between the first and second rice crops, while 43.1 days occurred between the first rice crop and second upland crop. The delay in upland crop establishment appears to be related to excess moisture in the fields, which prevents land preparation for upland crops. The use of zero tillage reduced the turnaround time only slightly. Among the rice-rice cropping patterns, the turnaround time was 16 days when the second crop was wet seeded. It was significantly lower than the 28-day turnaround time when the second crop was transplanted.

Several upland crops grown after rice in lowland paddies showed promise. Sorghum after rice did well where tillage was good. Corn followed rice successfully only in floodplains where the soil could be worked early, where supplemental water was available, and where the plants were protected from the high dry-season wind. Corn that was widely spaced in intercrop combinations with peanuts or soybeans had lower infestations of corn borer, the most serious insect pest of corn in Asia.



Average turnaround periods of different groups of introduced cropping patterns graphed against weekly rainfall. Iloilo, Philippines, 1976.

Because of their low plant habit (profile), peanuts seemed well suited to the postpaddy climate. The paddy bunds protected the crop from the hot winds. Peanuts exhibited good drought tolerance. Sweet potatoes did best in low beds or ridges built in the paddy fields. The loose soil helped in tuber formation and made harvesting easier. Melons grew well—except when infected with downy mildew—but their perishability limited their market value. Soybeans, grown after rice, were the least stable of the crops, primarily because of the combination of short day lengths and high temperatures.

BATANGAS TESTS

In Cale, Batangas, the performance of single upland crops (field corn, mung beans, soybeans, and peanuts) following upland rice in 1974–75 was compared with that in 1975–76 cropping pattern trials (Table 4). The 1975–76 trials were formulated to evaluate potential production and received much higher inputs than did the 1974–75 trials.

Yields were substantially higher for the 1975–76 patterns (Table 4), particularly those of rice and field corn, partly because of the better rainfall during the early rainy season of 1975. High-input management produced improved yields for peanuts, green corn, and sorghum. Sorghum ratoon yields in 1975–76 were not improved over those in 1974–75 because of an early drought in the 1975–76 season. Soybean and mung bean yields were low in both periods because of powdery mildew on mung beans. The late seeding dates of soybeans entered the crop into short day length conditions, which probably reduced yields. Earlier seeding of soybeans with closer row spacing may be needed to increase soybean yields.

The most promising cropping patterns appeared to be those involving rice, field corn, peanuts, and sorghum.

Testing through pattern simulation. A simulation model of a typical Cale farm was constructed with data from daily records of crop activities of a 50-farmer sample in Cale. It is a tool for synthetically testing the performance of new cropping patterns with respect to rainfall and various crop management practices.

Rainfall options are random selection of a past year of rainfall, simulation of a typical rainfall pattern for Cale based on a gamma statistical distribution fitted to past rainfall data, selection of a specific year of rainfall or of average rainfall, or random selection of a past high- or low-rainfall year. Crop management practices include choices of fertilizer rates, pesticide levels, and weeding labor.

Farmers commonly grow rice-corn in Batangas. Simulation of two crops of corn indicated high risk of negative net returns on the second corn crop. That may explain the observed behavior of farmers who grow the rice-corn pattern.

Cale farmers "traditionally" plant rice in the third week of May. The practice was projected as a constraint to potential cropping patterns. However, when 9 years of rice planting was simulated under the condition that 0.5 inch of rainfall in a week was necessary for plowing and another 0.5 inch was necessary for planting, the average planting date fell on 10 May, near the

Table 4. Yields of cropping patterns evaluated in Cale, Batangas, Philippines, with low inputs in 1974–75 and high inputs in 1975–76 growing seasons.

Cropping pattern[a]	Yield (t/ha)					
	1974–75			1975–76		
	Crop 1	Crop 2	Crop 3	Crop 1	Crop 2	Crop 3
Rice–soybeans	1.40	0.95	—	3.28	0.67	—
Rice–peanuts	1.40	0.80	—	2.96	1.75	—
Rice–field corn	1.40	1.53	—	3.09	4.10	—
Rice–mung beans	1.40	0.35	—	3.15	0.60	—
Rice–sorghum–sorghum (ratoon)	1.40	2.46	0.98	3.00	3.87	0.64
Rice–green corn–mung beans	—	—	—	3.02	38.7[b]	0.77
Green corn–field corn–mung beans	—	—	—	34.9[b]	3.86	0.59

[a]In a cropping pattern, – = followed by. [b]In thousand marketable ears per ha.

"traditional" date. When planting was further projected to the earliest suitable time after 1 May, the average planting date was 19 May, the precise "traditional" time. A slightly higher rice yield was obtained with the second strategy. The traditional planting dates reflected sound crop management.

Parameters representing crop response to environment are being improved so that the simulation testing of new patterns can be applied more widely and with more confidence.

Introduction of rice-sorghum pattern. The crop sequence of upland rice-sorghum-ratoon showed highest net returns in the 1974–75 trials in Cale, and farmers' interest in the new pattern seemed to confirm its potential. The Philippines Bureau of Plant Industry (BPI) and University of the Philippines at Los Baños (UPLB) Multiple Cropping Extension Pilot Project, with IRRI technical support, introduced the pattern on 61 farms on 15 ha. Farmers paid all costs for their crops and were given technical advice and assistance in contacting sorghum buyers.

About 40% of the cropland was planted to coconut, and the average yield was 1.0 t/ha. In open fields the sorghum yield averaged 1.9 t/ha, and ranged from 0.2 to 4.2 t/ha because of differential nitrogen rates (0 to 250 kg/ha) and plant populations (150,000 to 600,000 plants/ha). Thirteen farmers profitably applied an average 125 kg N/ha on sorghum fields in the open, and got yields of 2.7 t/ha. The yield was 1.8 t/ha on 11 farms where 75 kg N/ha was applied, and 1.2 t/ha on 15 farms where 25 kg N/ha was applied. Under coconut, 125 kg N/ha gave 1.4 t/ha sorghum, 75 kg N/ha gave 1.2 t/ha, and 25 kg N/ha gave 0.7 t/ha. The recommended rate was 80 kg N/ha.

Differential plant stands resulted from seeding too deeply. In open fields 450,000 sorghum plants/ha gave the highest yield of 2.5 t/ha, under coconut 550,000 plants/ha gave the highest yield of 1.4 t/ha. A stand of 350,000 plants/ha, achieved by drilling 20 seeds/m in 60-cm rows, was recommended.

Net returns above variable costs for the main sorghum crop plus ratoon in open fields were US$100/ha—about 60% of that realized in experimental trials—and US$80/ha in fields under coconut. They are still competitive with net returns from farmers' dominant second field crop—about US$90/ha in 1975–76. Additionally, the sorghum-ratoon crop provides employment in a period of slack farm labor use.

Cropping systems program

Component technology development and evaluation

Multiple Cropping Department, Cropping Systems Component of Agronomy, Entomology, and Soil Microbiology Departments, and Rice Production Training and Research Office

Dry-seeded rice potential in high-pH soils. During 1976, five rice varieties (IR28, IR30, IR36, experimental line 1561, and Wagwagaga) were tested in Manaoag, Pangasinan, Philippines. On the 19 sites the high soil pH and the prevalence of free calcium carbonate in the soil caused iron deficiency in IR28 rice during the 1975 trials. The rice was seeded 4–9 June and weeds were controlled with herbicides (butachlor and azodrin) plus hand weeding. The soil pH ranged from 6.85 to 7.36.

Paddy position (high or low) did not greatly influence the number of stress days, but proximity to the canal increased the stress days. There were more early stress days (40–42) when the paddy was located close to the canal than when it was far (34–46 days). The presence or absence of standing water proved to be a poor measure of the moisture condition of the rooting zone.

Distance from the canal was the most important determinant of rice yields. The influence of paddy position on rice yields depended on proximity to the canal—the yield difference between the high and low paddies was much larger for the paddies far from the canal than for those close to it. There was considerable variation within each of the four production complexes: high paddy close to the canal (HC), low paddy close to the canal (LC), high paddy far from the canal (HF), and low paddy far from the canal (LF).

Yield differences were related to the number of productive tillers, which were greatly affected by the production complex as well as by the variety. The number of productive tillers (131/0.5 sq m) was largest in low paddies far from the canal. The tiller number of the local Wagwagaga rice variety was not affected by different field characteristics, but that of IR28 was. The tillers of IR28 rice in the HC complex were only 64% of those in the HF complex. The plant tops of IR36 rice contained more iron (324 ppm) than did those of the local Wagwagaga variety (229 ppm). The promising performance of dry-seeded IR36 (5.2 t/ha) in the high-pH soils of Manaoag, suggests that further evaluation of the dry-seeding methodology is warranted for the area. IR28, whose yields ranged from 2.23 to 2.73 t/ha, does not appear suitable for dry-seeded rice establishment.

Management of mung beans after lowland rice. Mung beans after lowland rice is the traditional cropping pattern in Manaoag, but poor management reduces yields. Powdery mildew, an important pathogen prevalent in the area at the start of the dry season, is never controlled although fungicides are available.

In a study to evaluate the effects of different levels of management inputs on the productivity of CES 55 mung beans, a benomyl fungicide was used to control powdery mildew. Grain yields significantly increased when the plants were adequately protected from insect pests from the vegetative stage to maturity. Control of insects increased the yields more than did weed control (hand weeding at 14 and 21 days from seeding), seed inoculation, or 30 kg N/ha applied at planting time. The most economic management practice appeared to be to concentrate on good stand establishment and insect control without fertilization and inoculation, and to weed only when badly needed.

The mean yield across all treatments receiving insect control was 1.59 t/ha, compared with 0.46 t/ha achieved by 15 farmers. The farmers' fields were generally weedy with poor plant stand, and the plants were stunted and infected with powdery mildew.

Reduced tillage for upland crops. Low tillage (furrow planting with no land preparation but supplemented with a paraquat spray before seeding), medium tillage (one plowing and one harrowing), and high tillage (with hand tractor rotovator) were compared for the establishment of upland crops following rainfed lowland rice in Pangasinan.

Yields for all the crops used were highest under low tillage (Table 1), probably because of the better soil moisture condition during the early growth stages in the early part of November. In most cases, establishment of the medium- and high-tillage plots was about a month late, when primary cultivation was possible without puddling the soil. During the 1-month delay, the soil dried up considerably and there was little residual moisture to give high yields. The longer

Table 1. Yields of upland crops, at three tillage levels, following rainfed lowland rice. Manaoag, Pangasinan, Philippines. November 1975–February 1976.

Crop	Yield[a] (t/ha)		
	Low tillage	Medium tillage	High tillage
Mung beans	0.66 (6)	0.56 (9)	0.59 (9)
Corn intercropped			
with mung beans	1.1 (3)	0.50 (1)	0.06 (1)
with peanuts	2.7 (1)	1.91 (3)	2.07 (3)
Peanuts intercropped			
with corn	1.39 (1)	0.33 (5)	0.40 (3)
Mung beans intercropped			
with corn	0.73 (3)	0.40 (1)	0.10 (1)
Sorghum	2.70 (3)	2.56 (7)	2.53 (4)
Soybeans	0.04 (2)	0.16 (6)	0.17 (3)
Cowpeas	0.76 (1)	0.43 (4)	0.46 (5)
Sweet potatoes	1.54 (1)	9.60 (5)	7.20 (3)

[a]Figures in parentheses are numbers of observations.

turnaround time caused the late plantings to grow under less favorable conditions. The low-tillage method shortened the time and cost of land preparation and was particularly practical during the postharvest processing period of the rice crop when labor was limited.

Tolerance for waterlogged conditions. A study of the effect of duration (1 to 5 days) of waterlogged conditions on mung beans, sorghum, soybeans, cowpeas, peanuts, and field corn revealed that in general, sorghum, followed by peanuts, appeared tolerant of flooding during germination. After 5 days of submergence, the germination of sorghum was 47% and that of peanuts was 31%.

In terms of reduction of seedling dry weight, sorghum proved less sensitive to flooding than peanuts, which were again less sensitive than corn, cowpeas, mung beans, and soybeans.

Management studies for upland rice-based cropping patterns in Batangas. Several management aspects were tested in 1975–76 in Batangas by means of superimposed trials on farmers' fields.

Upland rice. Planting date of upland rice had only a slight effect on yields of Dagge rice—3.2 t/ha for the April planting and 2.9 t/ha for the May planting. The yield difference was not statistically significant. Dagge rice gave an optimal response to 75 kg N/ha. Butachlor at 1.5 kg active ingredient (a.i.)/ha effectively reduced weed incidence and did not impair rice yields. At 2.5 kg a.i./ha, it caused some loss of stand at the seedling stage and reduced rice yields slightly.

Field corn. The local corn variety Tinumbaga yielded about the same as the improved UPCA Var. 1 in October plantings (4.1 and 4.0 t/ha, respectively). Most farmers in Batangas do not plant corn until November, because of long turnaround times between rice and the upland crop (see Environmental description). The lower yield (2.45 t/ha) of Tinumbaga corn planted with a 2-month delay suggested the advantage of reduced turnaround times.

Nitrogen fertilization of upland rice had no residual effect on corn grown after rice. Damage by rats and wind could reduce green corn production by at least 10%.

Sorghum. The optimal nitrogen rate for sorghum appeared to be 90 kg N/ha. When seeds were broadcast on furrows and covered with one harrowing, three seeding rates (30, 50, and 70 kg/ha) gave similar yields (3.8 t/ha). The yields were slightly superior to those obtained when the seeds were row drilled.

Upland rice, 1976–77 season. Compared with the local check Dagge, C166-135 and C171-136 rices on farmers' fields under farmers' management were tolerant of the weed-control method of crossways harrowing, which damages the stand of most other improved varieties. The stand and vigor of both varieties appeared superior to those of Dagge, but their yield was more affected by the eruption of Taal Volcano in September than was that of the slightly earlier Dagge. C171-136 was severely affected because the eruption coincided with its pollination stage.

Both lines had more tillers at harvest time, but the yield and the number of filled grains per panicle were similar to those of Dagge.

WEED SCIENCE

Agronomy Department, Cropping Systems Component

Crop competition as an aid to weed control. The 1975 observation that decreased spacing between hills of transplanted rice reduced weed growth and increased yields in unweeded plots was confirmed in 1976. At spacings of 20 × 20 and 25 × 25 cm, the hand-weeding treatments were generally superior to the herbicide treat-

Table 2. Effect of plant spacing and weed control treatments on yield of transplanted rice. IRRI, 1976.

Treatment[a]	Rate of application (kg/ha)	Yield[b] (t/ha) 15 × 15 cm	20 × 20 cm	25 × 25 cm
Two hand weedings	—	3.7 a	3.7 a	3.2 a
Weed free[c]	—	3.4 ab	3.7 a	3.2 a
One hand weeding	—	3.6 a	3.6 a	2.9 ab
2,4-D fb rotary weeding	0.8	3.5 ab	3.4 ab	3.1 a
Benthiocarb/2,4-D fb rotary weeding	0.5/0.25	3.4 ab	3.4 ab	2.9 ab
Benthiocarb/2,4-D	1.0/0.5	3.5 ab	3.3 ab	2.5 b
Benthiocarb/2,4-D	0.5/0.25	3.5 ab	2.9 bc	2.6 b
Two rotary weedings	—	3.4 ab	2.9 bc	2.6 b
2,4-D	0.8	3.1 b	3.1 bc	2.5 b
Untreated	—	2.5 c	1.5 d	1.3 c

[a]fb = followed by. A slant bar (/) between two herbicide names indicates that the chemicals were formulated on the same carrier or mixed together and applied as a single treatment. [b]In a column, means followed by the same letter are not significantly different at the 5% level. [c]During first 30 days after transplanting.

ments and the rotary weedings or their combinations. In all instances, one hand weeding controlled most of the weeds, while 2,4-D was the poorest of the posttransplanting treatments for weed control.

At all spacings the best grain yields were obtained from the plots that were hand weeded, while the lowest were harvested from the untreated check and the 2,4-D-treated plots (Table 2). However, weed weights among treatments at the 15- × 15-cm spacing did not differ.

Yield losses caused by weeds in the untreated check plots were higher than those in the plot that was weed free during the first 30 days after transplanting. They averaged 26, 29, and 59% for the 15- × 15-cm, 20- × 20-cm, and 25- × 25-cm spacings, respectively.

Closer row spacing is better for fields where there is little or no weeding and also where there is good weed control. It takes less time to remove the weeds that are present at close than at wide row spacing.

The effects of different seeding rates and weed control treatments on weed suppression in and grain yield of wet-seeded rice were studied at IRRI and Iloilo. At IRRI, yields in plots treated with herbicides (terbuchlor, benthiocarb/2,4-D, or butachlor) were significantly higher than those in untreated plots, but there was no significant difference among herbicide treatments. Increasing the seeding rate progressively from 50 kg to 250 kg/ha had no effect on the yields of IR28 and IR30, but the yields of IR26 were significantly lower at the seeding rate of 50 kg/ha than at the higher rates (100, 150, 200, and 250 kg/ha).

Within each weed control treatment, the increased seeding rate did not affect grain yield, but the average dry weight of broadleaf weeds and grasses decreased significantly as the seeding rate increased. The sedges were unaffected. In the no-weeding plots, increased seeding rates were associated with increased grain yield, whereas in the herbicide-treated plots, yield was relatively uniform across seeding rates. Terbuchlor and benthiocarb/2,4-D were superior to butachlor in controlling weeds.

In a similar trial in Iloilo, where the weed population was less dense, 2 kg butachlor/ha had no significant effect on rice yield and weed weight. Seeding rates did not affect grain yield, but weed weight decreased significantly as the seeding rate increased.

When 10 rice cultivars were subjected to two weeding regimes—weed-free (weeded weekly during the first 5 weeks after transplanting) and unweeded—yields in both regimes were highest for BG 90-2 rice cultivar and lowest for Peta (Table 3). The yield reduction due to weeds was greatest with IR1561-228-3-3 and least with Peta. IR1561-228-3-3 had more tillers than Peta, but was considerably shorter and had a lower leaf area index 10 weeks after transplanting. The lowest yield was from the unweeded Peta plots. The results suggest that although a cultivar may be more competitive, its lower yield potential may preclude a better yield. The relationship between yield reduction because of weeds and weed weight can be expressed by the equation, $Y = 4427.7 - 25.2X$, $r = -0.76^{**}$ The correlation between yield reduction due to weeds and number of tillers, and that between yield reduction and leaf area index were not significant.

The weight of weeds 10 weeks after transplanting varied from 0.7 t/ha for IR1632-93-2-2 to 2.9 t/ha for both IR1561-228-3-3 and IR28. The weight of weeds competing with Binato was 1.7 t/ha; Binato had the lowest yield reduction caused by weeds.

Generally the greater the amount of weeds

Table 3. Yield reduction due to weeds, plant heights, and weed weights of various rice cultivars grown under different weeding regimes.[a] IRRI, 1976.

Cultivar	Yield (t/ha)		Yield reduction due to weeds[b] (t/ha)	Av. plant ht 10 WT (cm)	Av. tiller count 10 WT	LAI[c] of unweeded plots 10 WT	Dry weed wt (t/ha) 10 WT
	Weed-free plot	Unweeded plot					
BG 90-2	6.2	4.1	2.1 abc	84.3 de	16.2 bc	2.0 b	1.9 ab
IR34	6.1	3.7	2.4 abc	95.1 c	17.4 abc	4.1 ab	1.3 ab
IR1561-228-3-3	5.7	2.8	2.9 a	79.7 e	19.8 ab	2.3 b	2.9 b
IR26	5.4	2.6	2.8 ab	77.2 e	19.4 ab	5.0 a	2.0 ab
IR4816-70-1	5.3	3.5	1.8 abc	91.8 cd	14.5 c	2.4 b	1.0 ab
IR28	5.2	2.5	2.7 ab	83.5 de	16.4 bc	3.2 ab	2.9 b
IR1632-93-2-2	5.0	3.7	1.3 bc	92.4 cd	13.9 c	3.8 ab	0.7 a
Binato	4.7	3.5	1.2 c	143.1 a	18.6 ab	2.7 b	1.7 ab
IR36	4.7	2.4	2.3 abc	79.9 e	20.3 a	2.5 b	2.1 ab
Peta	2.9	1.8	1.1 c	113.9 b	18.4 ab	3.0 ab	1.0 ab

[a]Within a column, means followed by the same letter are not significantly different at the 5% level. WT = weeks after transplanting. [b]Yield differences greater than 1.1 t/ha between weed-free and unweeded treatments are significant at the 5% level. [c]Leaf area index.

in competition with the crop, the greater were the yield losses. There was a tendency for fewer weeds to be growing in association with the taller rice cultivars. Taller rice cultivars appear to be needed for lower yield reductions due to weeds, and the few weeds that compete with the taller rice crop are controlled by less labor.

Advanced screening of herbicides for upland crops. Two experiments were conducted during the 1976 wet season at IRRI and in a farmers' field in Batangas. Ten herbicides found promising for weed control in upland rice were compared with hand-weeded and untreated checks for weed control and phytotoxicity in rice, corn, sorghum, soybeans, mung beans, and peanuts.

The weed species at IRRI were *Eleusine indica*, *Rottboellia exaltata*, *Digitaria sanguinalis*, *Amaranthus spinosus*, *Portulaca oleracea*, *Centrosema pubescens*, *Ipomoea triloba*, and *Cyperus rotundus*. The experimental area was recently graded and weed density was only moderate. However, the stand of *A. spinosus* appeared heavier than that of other weeds.

The experimental site in Batangas was heavily infested with *Echinochloa colona*, *Celosia argentea*, *Commelina benghalensis*, *C. diffusa*, *Ageratum conyzoides*, *Bidens pilosa*, *Euphorbia hirta*, *Cyperus iria*, *E. indica*, *I. triloba*, and *C. rotundus*.

RH 2915 gave excellent control of annual weeds, while the other herbicides adequately controlled most of these weeds at both sites. Infestation of *A. spinosus* at IRRI and *C. argentea* in Batangas was heavy in all plots except those treated with RH 2915 at both sites and those with propanil at IRRI.

In both locations, butachlor was the most promising herbicide for controlling weeds without causing crop damage. The yield of the butachlor-treated plots was similar to that of the hand-weeded check (Table 4). Butachlor, piperophos/dimethametryn, and Antor were selective in all crops. AC 92553, butralin, terbuchlor, and oxadiazon were selective in five crops but moderately toxic to sorghum. Propanil and RH 2915 were the most toxic herbicides. Both caused leaf scorch in some crops and complete kill in others. Propanil reduced the stand of leguminous crops by 80 to 100%.

RH 2915 was highly toxic to sorghum and mung beans and moderately toxic to rice. Dinitramine was slightly toxic to rice and mung beans, and moderately toxic to sorghum. The crops were ranked according to tolerance for herbicides as follows: peanuts > rice > corn > soybeans > mung beans > sorghum.

Because propanil applied postemergence controlled *A. spinosus*, the rice yield of propanil-treated plots was similar to that of the hand-weeded check plots. RH 2915 also controlled *A. spinosus* but damaged the rice plant. Thus, the yield of RH 2915-treated plots was lower than that of the hand-weeded check. The untreated plots in Batangas failed to yield because of the heavy infestation of *E. colona* and *C. argentea*. All herbicides provided adequate initial control of weeds, and yields from all

Table 4. Yields of upland crops as affected by preemergence herbicides at IRRI and Batangas. 1976 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Yield[c] (t/ha) IRRI[d]						Batangas[e]					
		Rice	Corn	Sorghum	Soybeans	Mung beans	Peanuts	Rice	Corn	Sorghum	Soybeans	Mung beans	Peanuts
Hand weeded twice[f]	—	4.7 a	2.8 a	3.0 a	1.3 abc	1.2 a	1.4 bc	3.2 a	2.8 a	4.2 a	0.8 a	0.6 a	0.4 cde
Butachlor	2.0	3.3 bc	2.1 ab	2.9 a	1.2 abc	1.2 a	1.4 bc	3.2 a	2.4 ab	4.4 a	0.7 ab	0.5 ab	0.3 ef
Piperophos/ dimethametryn	1.6/0.4	3.4 bc	1.8 ab	2.3 abc	1.1 abc	0.6 b	1.4 bc	3.6 a	2.2 abc	4.0 a	0.5 b	0.5 ab	0.3 def
Antor	2.0	3.0 c	1.8 ab	2.6 a	1.2 abc	1.2 a	1.2 c	2.9 ab	1.2 d	4.2 a	0.7 ab	0.5 ab	0.5 bcde
Butralin	2.0	3.6 bc	2.1 ab	2.2 abc	0.9 cd	1.1 a	1.2 c	3.0 ab	2.7 ab	3.6 ab	0.6 ab	0.4 bc	0.4 cde
Oxadiazon	1.0	3.5 bc	2.5 a	1.4 de	1.3 abc	1.0 a	1.3 bc	3.1 a	2.5 ab	3.6 ab	0.6 ab	0.6 a	0.6 bc
Dinitramine	2.0	3.0 c	2.6 a	2.4 ab	0.9 cd	0.6 b	1.2 c	3.0 ab	1.8 bcd	3.4 ab	0.6 ab	0.4 bc	0.6 bc
Terbuchlor	1.0	3.3 bc	2.2 ab	0.9 e	1.4 ab	1.2 a	1.6 ab	2.9 ab	2.1 abcd	3.2 abc	0.5 b	0.5 ab	0.6 bc
AC 92553	2.0	3.1 bc	1.9 ab	1.7 bcd	0.9 bcd	0.3 c	1.2 c	2.2 b	2.2 abc	1.8 cd	0.2 cd	0.4 bc	0.7 ab
Propanil[g]	3.0	4.2 ab	1.6 ab	2.6 a	0 e	0 c	0.4 e	2.8 ab	1.8 bcd	2.3 bc	0.05 d	0 e	0.1 f
RH 2915	1.0	3.2 bc	2.2 ab	0 f	1.6 a	0 c	1.6 a	1.2 c	1.9 abcd	0.7 cd	0.2 cd	0 e	0.9 a
Untreated	—	2.6 c	1.2 b	1.6 cde	0.6 d	0.6 b	0.7 d	0 d	1.4 cd	1.7 cd	0.3 c	0.2 d	0.2 ef

[a]A slant bar (/) between two herbicide names indicates that the chemicals were formulated on the same carrier or mixed together and applied as a single treatment. [b]a.i. = active ingredient. [c]In a column, means followed by the same letter are not significantly different at the 5% level. [d]Means of four replications. [e]Means of two replications. [f]At 15 and 30 days after crop emergence (DE). [g]Applied 15 DE.

plots, except those treated with RH 2915 and AC 92553 were not statistically different from the yield obtained for the hand-weeded check (Table 4).

The most promising compounds for weed control in corn were oxadiazon and dinitramine at IRRI, and oxadiazon, butachlor, and butralin in Batangas.

Antor, butachlor, and butralin were the most promising herbicides for sorghum at both locations. They provided adequate initial weed control and excellent selectivity, with no deleterious effect on yields. The other herbicides caused moderate to severe injury to sorghum.

Antor, butachlor, piperophos/dimethametryn, terbuchlor, and oxadiazon looked very promising for soybeans. Antor, butachlor, terbuchlor, and oxadiazon gave the best results with mung beans.

Peanut yields from plots treated with RH 2915 were significantly higher than those from the hand-weeded plots at IRRI and Batangas (Table 4). AC 92553, dinitramine, terbuchlor, and oxadiazon also performed well at both locations.

Initial screening of herbicides for upland crops. During the 1976 wet season, 15 herbicides were screened on six crops. The herbicides, many of which had not been tested previously at IRRI, were compared with butachlor (the standard chemical treatment), a hand-weeded treatment, and an untreated check. Because of a typhoon at silking time, the corn lodged severely and failed to yield.

The experimental area was heavily infested with the following weeds: *E. colona*, *D. sanguinalis*, *E. indica*, *C. iria*, *C. rotundus*, *P. oleracea*, *Eclipta alba*, *Phaseolus lathyroides*, *I. triloba*, *A. spinosus*, and *C. diffusa*. The infestations of *E. colona* and *C. iria* were heaviest. In certain instances where herbicides controlled grasses and broadleaf weeds but not sedges, *C. iria* became the major weed problem.

The most promising compounds were oxadiazon, K-223 followed by (fb) terbuchlor, EXP 3316, NTN 6867, and SL-55. However, K-223 fb terbuchlor and NTN 6867 were toxic to sorghum; NTN 6867 provided only moderate control of grass weeds; EXP 3316, SL-55, and oxadiazon caused moderate leaf scorch on

Table 5. Yields of upland crops as affected by preemergence herbicides. IRRI, 1976 wet season.

Treatment[a]	Rate[b] (kg a.i./ha)	Yield[c] (t/ha)				
		Rice	Sorghum	Soybeans	Mung beans	Peanuts
Hand weeded twice[d]	—	3.2 abc	4.4 a	0.9 abcde	1.0 a	2.4 ab
Butachlor	2.0	3.3 ab	4.0 a	0.8 abcde	0.8 abc	2.4 ab
Oxadiazon	1.0	3.5 a	3.2 cd	1.2 ab	0.6 def	3.0 a
EXP 3316	0.5	2.4 c	2.8 cd	1.3 a	0.7 bcde	3.0 a
K-223 fb terbuchlor	6 fb 1	3.4 ab	2.1 ef	1.1 abc	0.9 ab	2.7 ab
NTN 6867	2.0	2.6 bc	2.8 cd	0.7 bcde	0.6 def	2.6 ab
SL-55	1.0	3.1 bc	1.8 fg	1.0 abcd	0.4 gh	2.8 ab
X-150	2.0	1.5 d	3.4 b	0.8 abcde	0.6 efg	2.0 bcd
K-1441 fb terbuchlor	6 fb 1	3.1 abc	0 i	0.9 abcde	0.8 abc	2.1 bcd
Diphenamid	2.0	0 e	3.4 b	0.7 bcde	0.6 def	1.6 cde
EL 171	0.1	0 e	2.7 cd	0.6 cde	0.7 bcde	2.2 abc
SL-501	1.0	0 e	0 i	1.2 ab	0.8 abc	2.5 ab
SL-502	1.0	0 e	0.5 h	1.0 abcd	0.4 gh	2.4 ab
Prodotto D75	4.0	0 e	2.3 de	0.4 ef	0.3 h	1.4 def
Untreated	—	0 e	2.8 cd	0.5 def	0.5 fg	0.6 f
Propanil/fenoprop	1.5/0.5	0 e	2.6 de	0 f	0.4 gh	1.1 ef
MT-101	2.0	0 e	1.6 g	0.4 ef	0.4 gh	1.0 ef
IWD #3051	2.0	0 e	1.5 g	0 f	0.4 gh	1.2 ef

[a]fb = followed by. A slant bar between two herbicide names indicates that the chemicals were formulated on the same carrier or mixed together and applied as a single treatment. [b]a.i. = active ingredient. [c]Means of two replications. For each crop, means followed by the same letter are not significantly different at the 5% level. [d]15 and 30 days after crop emergence.

corn and peanuts during early crop growth and stand reduction in sorghum. EXP 3316 also slightly reduced the rice stand. The other herbicides either did not control weeds adequately or were highly toxic to several crops. The crops were ranked for herbicide tolerance as follows: mung beans > soybeans > peanuts > corn > rice > sorghum.

The infestation of *E. colona* in rice was so heavy that the untreated control produced no grain yield (Table 5). The yields from plots treated with oxadiazon, SL-55, NTN 6867, and both K-223 and K-1441 fb terbuchlor were not significantly different from those obtained from plots treated with butachlor or from those that had been hand weeded.

X-150 and diphenamid showed excellent selectivity, but weed control was only moderate. The plots treated with X-150 yielded less than the butachlor-treated and the hand-weeded check plots; the diphenamid-treated plot produced no grain yield (Table 5).

Soybean yields from eight herbicide-treated plots were not significantly different from the yields from the butachlor-treated and hand-weeded plots. The best weed control was obtained with EXP 3316, oxadiazon, and K-223 fb terbuchlor.

The highest yields of mung beans, other than those from the check plots, were obtained from plots treated with SL-501 and K-223 or K-1441 fb terbuchlor. Plots treated with EXP 3316 and EL 171 also gave good yields.

The highest peanut pod yields were obtained from plots treated with EXP 3316 and oxadiazon. Other promising compounds were NTN 6867, EL 171, K-223 fb terbuchlor, and the three SL compounds.

Effect of crop rotation and weed control practices on crop yield and weed population. *Scirpus maritimus.* The study of the effect of soil and water management on weed growth and crop yield, initiated in 1974, was continued in 1976. The 1976 results confirmed those of previous years.

In the unweeded check plots, the *S. maritimus* population was slightly less in continuous lowland rice (cropping system I) than it was in 1975, probably because of increased competition from a high level of annual weeds.

When upland crops were rotated with lowland rice (cropping system II), the total number of weeds was slightly reduced. The number of *S. maritimus* plants was lower than that in plots where lowland rice was grown continuously. More *C. rotundus* was present in the upland crop-dry-seeded rainfed rice rotation (cropping system III) than in cropping system II because this weed cannot grow in continuously flooded soils.

In the 1976 wet season, weed growth was so severe that rice failed to yield in cropping systems I and III; in cropping system II, where upland and lowland crops were rotated, the rice yield was 1.3 t/ha. In the 1976 dry season the large number of annual weeds in the upland crop in cropping systems II and III resulted in no crop yield.

C. rotundus. During the seventh and eighth crops on land where 5 successive crops had been grown (rice in the wet season and continuous upland crops in the dry season), corn yields did not appear to be affected by different weed control practices. However, the treatments affected the dry weight of weeds growing in association with corn. Failure to control weeds within the row by interrow cultivation caused some yield reduction in the seventh crop in the plots that had not been puddled the previous year. This difference was not observed in the eighth crop when less weeds were present. The weeds occurring in the plots that had been puddled for rice were mostly *E. colona* and *C. rotundus* in the plots with high plant density; all other plots had a more mixed weed community. *C. rotundus* predominated in plots that had been treated with 1.2 kg butachlor/ha.

In the ninth crop, only slight differences in yield occurred in the puddled soil. A significant yield increase occurred in the unpuddled soil when the herbicide treatment was followed by one hand weeding, indicating that the use of herbicide alone is not sufficient to give adequate or sustained weed control in dry-seeded, rainfed rice.

The tenth and last crop in the experiment was peanuts planted at uniform density. No weeding was done before weed weights were taken 28 days after emergence, when the weed population was predominantly *C. rotundus*. The highest weed weight occurred in the plots that had been treated previously with butachlor at 1.2 kg/ha. The weight of *C. rotundus* was reduced by 40% by increased plant density, 50% by puddled soils, and 70% by hand weeding.

The difficult-to-control weed species are less likely to increase in a crop rotation involving both lowland and upland crops than in continuous or upland culture. With no weeding, yield losses are less when upland and lowland crops are rotated than when lowland crops are grown continuously. Continued use of the same weed control practices can markedly change the weed population. Such changes are observable even when the treatment has ceased.

Herbicide trials for dry-seeded rice in rainfed-lowland rice areas. In a study of weed control by herbicides on dry-seeded rice in three Philippine locations, weed infestations increased and yields declined with fairly continuous dry periods of 10 to 15 days throughout the growing period of the rice crop (Table 6). Generally the herbicides were applied when the soils were moist, a condition that helped to lower the weed population.

PLANT PROTECTION

Entomology Department, Cropping Systems Component

Upland rice-based cropping systems. *Insecticides to control white grub*. In continuing studies on low insecticide dosages to control the white grub soil pest of rice and corn, granules were broadcast during land preparation or placed in bands in the seed furrow at planting. The two methods were compared with banding at weed cultivation at rates from 0.5 to 0.125 kg a.i./ha. Banding in the seed furrow at 0.25 and 0.5 kg a.i./ha significantly reduced the number of larvae in the soil. This preventive method costs US$2.50/ha.

Effect of insecticide treatments on optimal rate of seeding. Farmers in Batangas use seeding rates of 100 to 125 kg/ha to achieve an optimal stand of upland rice with rainfed cultural practices. Soil insects, such as ants, may reduce the number of plants that ultimately grow in a stand of rice.

Both dieldrin and carbofuran were applied with the seed (Table 7). Seeding rates were 50, 100, 125, and 150 kg/ha; the latter two rates were untreated.

The results indicated that pests present in upland rice soils were attacking the seed. The optimal seeding rate with no insecticide was 100 kg/ha. If a farmer lacked seed he could sow at the 50-kg/ha rate and achieve optimal yield potential if insecticide was used with the seed.

Table 6. Toxicity rating and effects of promising liquid (L) and granular (G) herbicides, applied preemergence to both weeds and crop, on the yield of IR36 direct-seeded in dry soil at the start of the rainy season in three locations in the Philippines.[a] 1976 wet season.

Treatment	Rate (kg a.i./ha)	Toxicity rating[b]	Yield (t/ha)		
			Iloilo	Isabela	Bukidnon
Butachlor (L)	2.0	0.0 e	2.9 b	2.2 ab	3.7 a
Terbuchlor (L)	1.0	0.0 e	1.4 c	1.6 ab	3.0 a
Butralin (L)	2.0	0.7 de	3.7 a	1.4 b	3.3 a
Oxadiazon (L)	0.75	1.0 d	2.8 b	1.2 bc	2.8 a
AC 92553 (L)	2.0	2.2 c	2.8 b	2.5 a	3.1 a
RH 2915 (L)	1.0	6.5 a	1.6 c	0.0 d	2.8 a
Butachlor (G)	1.5	3.7 b	2.6 b	1.7 ab	2.9 a
Hand weeded rice	20 + 40 DRE[c]	0.0 e	3.9 a	2.1 ab	3.2 a
Untreated	—	0.0 e	1.0 c	0.4 cd	2.7 a

[a]Av. of 3 replications in 3 locations. Any two means followed by the same letter are not significantly different at the 5% level. [b]Based on scale of 0–10: 0 = no toxicity; 10 = complete kill of plants. [c]Days after rice emergence.

Effects of cropping pattern on nematode buildup. The well-drained soils of upland environments are most favorable to plant parasitic nematodes. In Batangas the genera *Rotylenchulus* and *Meloidogyne* predominate. Nematode injury to susceptible legumes includes reduced seedling emergence, leaf chlorosis, severe necrosis combined with galling of roots, plant stunting, early flowering, reduced pod size, and reduced yield. Rice and corn are not hosts. However, the many vegetables or grain legumes (bush sitao, mung beans, cucurbits, tomato, garlic, chinese cabbage, hyacinth beans, lima beans, eggplant) grown in small plots on the same land are susceptible hosts. Most farmers are aware of the benefits from crop rotation and practice it.

In a 1976 survey to determine if crop rotation was an effective alternative to the use of nematicides (nematode-resistant varieties are not available), farmers were asked to review the crops grown on their land over the previous 3 years. Five cropping patterns were identified based on sequences of nematode-susceptible (S) and non-susceptible hosts (N): 1) continuous S; 2) N preceding two S; 3) N alternating with one S, 4) N for 2 years preceding one S, and 5) N for 3 years preceding one S. Nematode counts were taken from the last susceptible crop.

Continuous cropping of susceptible hosts over the growing season (dry fallow from January to May) resulted in the highest nematode count (1,495 nematodes/250 cc soil and 1 g roots). Cropping pattern 2 gave little protection (1,050 nematodes). Although pattern 3 reduced nematode incidence, the nematode count of 460

Table 7. Effects of seeding rates and insecticides on plant density and yield of upland rice, variety Dagge.[a] Batangas, Philippines, 1976.

Seeding rate (kg/ha)	Insecticide	Formulation[b]	Method of application	Insecticide rate[c] (kg a.i./ha)	Plant density[d] (no./1-m row) 14–23 DE	Yield (t/ha)
50	None	—	—	—	34.9 a	2.0 a
50	Carbofuran	3 G	Basal in furrow	0.5	34.9 a	2.4 ab
50	Carbofuran	3 G	Basal in furrow	2	40.9 ab	2.5 ab
50	Carbofuran	4 F	Seed treatment	1	37.8 ab	2.3 ab
50	Dieldrin	50 WP	Seed treatment	1	41.4 ab	2.2 ab
100	None	—	—	—	45.3 bc	2.5 ab
100	Carbofuran	3 G	Basal in furrow	0.5	52.3 cd	2.5 ab
100	Carbofuran	3 G	Basal in furrow	2	50.9 cd	2.6 b
100	Carbofuran	4 F	Seed treatment	1	50.9 cd	2.3 ab
100	Dieldrin	50 WP	Seed treatment	1	52.3 cd	2.2 ab
125	None	—	—	—	59.5 d	2.4 ab
150	None	—	—	—	59 d	2.2 ab

[a]Av. of eight fields, unreplicated within fields. Means followed by the same letter are not significantly different at the 5% level. [b]G = granular; F = flowable; WP = wettable powder. [c]a.i. = active ingredient. [d]DE = days after emergence.

was considered still high. Patterns 4 and 5 gave the best protection, 16 and 75 nematodes, respectively, per 250 cc soil and 1 g roots. However, such protection lasts for only one cropping of a susceptible host because the nematodes recover quickly.

Weeds, always present in fields, also sustained nematode populations. The following common weed hosts were identified from field observation and pot confirmation tests in the greenhouse: *Amaranthus spinosus*, *Cyperus rotundus*, *Ipomoea alba*, *Portulaca oleraceae*, *Mollugo verticilia*, *Veronia cinierea*, *Commelina benghalensis*, *Digitaria sanguinalis*, and *Eclipta alba*.

Stand protection for corn. In yield loss trials, a basal application of 0.5 kg a.i. granular carbofuran/ha resulted in denser plant stands than those in untreated plots. Consistently higher plant stands were noted in the treated plots of field corn planted in May, October, and November, with the planting density in May and November being significantly higher than that of the untreated check. Further studies are needed to determine less costly methods of protecting the corn seed in upland soils.

Lowland rice-based cropping patterns. *Insect pests of the wet-seeded first rice crop.* Insecticides are the general means for controlling the principal pests of lowland rainfed rice—rice whorl maggot, stem borers, rice caseworm, rice green-horned caterpillar, rice leaf folder, and rice bug. IR28 has only moderate resistance to stem borers. Monocrotophos sprays and carbofuran granules were used in a study to determine the optimal number of insecticide applications and the correct timing to effect satisfactory control.

Insecticide treatments were tested against an unknown insect complex on IR28 rice, which proved to be earlier maturing than anticipated (80–85 days). One treatment consisted of spraying only when the economic injury level had been exceeded. The thresholds were: 2–4 brown planthoppers/tiller; 10% tillers showing leaf folder damage; 2–4 rice bugs/sq m; 10% deadhearts before maximum tillering.

Of the three pests that emerged (rice whorl maggot, rice leaf folders, and rice bug), only the rice leaf folder was controlled by the insecticide treatments (Table 8). Monocrotophos sprayed at 35 and 45 days after rice emergence (DRE) gave good control. Broadcasting 2 kg a.i. carbofuran granules/ha 1 DRE failed to reduce whorl maggot damage. The insecticide either was tied

Table 8. Effect of insecticide regimes on the arthropod complex and yield of first crop of wet-seeded IR28 rice sown in May.[a] Pangasinan, 1976.

Whorl maggot-damaged tillers[b] (%) 25 DRE	Stem borer damage[c] (%) Deadhearts 35 DRE	Stem borer damage[c] (%) Whiteheads 70 DRE	Arthropods (no./10 hills) 70 DRE *Nilaparvata*	Arthropods (no./10 hills) 70 DRE Spiders	Arthropods (no./10 net sweeps[d]) *Nephotettix*[e] 45 DRE	Arthropods (no./10 net sweeps[d]) Lady beetles 20 DRE	Leaf folder-damaged leaves[f] (%) 55 DRE	Rice bugs[g] (no./sq m) 65 DRE	Yield (t/ha)	Insecticide cost[h] (US$/ha)	Benefit: cost ratio[i]
					Four applications: granules broadcast 1 DRE, sprays at 35, 45, and 65 DRE						
40 a	4.3 a	2.6 a	3	2	18	4	2 a	2.4 a	3.7 a	129	−0.3
					Three applications: granules broadcast 1 DRE, sprays at 35 and 45 DRE						
37 a	4.2 a	1.8 a	4	2	13	1	1 a	2.2 a	3.6 a	83	−0.7
					Three applications: sprays at 35, 45, and 65 DRE						
48 a	4.3 a	1.9 a	2	2	22	1	1 a	2 a	4.1 a	106	−0.3
					Two applications: granules broadcast 1 DRE, spray at 65 DRE						
37 a	5.4 a	2.5 a	3	2	14	1	19 b	3.3 a	3.8 a	68	−0.1
					Economic threshold: sprays at 15 and 60 DRE						
38 a	4.2 a	2.9 a	3	2	10	0.5	11 b	3.2 a	3.9 a	45	0
					No insecticide						
45 a	5.5 a	2.1 a	4	2	28	1	21 b	3.3 a	3.9 a		

[a]Av. of 4 fields, unreplicated within fields. Broadcast granules: 2 kg a.i. carbofuran/ha; sprays: 0.75 kg a.i. monocrotophos/ha. Means followed by the same letter are not significantly different at the 5% level. DRE = days after rice emergence. [b]10-hill sample/plot. [c]One 5-sq-m sample area/plot. [d]10 sweeps/plot. [e]Adults and nymphs. [f]100-leaf sample/plot. [g]Ten 1-sq-m samples/plot. [h]Furadan 3G (Shell), US$0.95/kg. Azodrin 16.8 EC (Shell) US$5/946 cc. [i]US$0.18/kg rice. Change in the value of product/insecticide cost.

up in the upper layers of the soil and did not reach the root zone, or was deactivated in the high pH of the paddy water. The carbofuran broadcast treatment also failed to control stem borer deadhearts.

The monocrotophos spray at 65 DRE was probably too late to reduce rice bugs, and none of the treatments receiving the protective spray outyielded those that were not sprayed. None of the treatments yielded significantly higher than the untreated plots (3.9 t/ha).

Pests of the transplanted second rice crop. The same insecticide treatments used on wet-seeded rice were compared, with some changes, on transplanted rice. The carbofuran granules were incorporated into the soil during the last harrowing before transplanting. A treatment consisting of five spray applications was added.

The higher yields attained on this planting were probably due to better insect protection. All treatments with carbofuran incorporated into the soil adequately controlled the rice whorl maggot and stem borer deadhearts, and achieved yields ranging from 5.1 to 5.4 t/ha. The best spray treatments, which had no carbofuran, gave yields of 4.7 and 5.0 t/ha. The highest yield (5.4 t/ha) gave a low benefit-to-cost ratio of 0.5. The optimal treatment was three foliar sprays at 25, 40, and 60 days after transplanting; it cost US$69 and yielded 5.0 t/ha, giving a benefit-to-cost ratio of 2.6.

Pest control in corn after rice. Studies were designed to determine the best method of applying insecticides to control the Asian corn borer in corn (Thai Composite Early, a 90-day corn) following lowland rice. Three methods of application were tested: 1) granules in the whorl (1.0 kg a.i. carbofuran/ha), 2) foliar spray (0.75 kg a.i. monocrotophos/ha), and 3) the "soil jab" method—granules (0.5 kg a.i. carbofuran/ha) in holes made by a pointed stick at the base of the plants. None of the treatments proved effective.

The corn borer responds positively to fertilizer. Perhaps more studies are needed to examine the trade-off of the benefit from fertilizer and the cost of corn borer control.

Control of pests in mung beans grown after rice. In a Pangasinan trial to determine the proper timing and application frequency of insecticides to control pests of mung beans (bean fly, leafhopper, flea beetle, and pod borers), recommended insecticides were used at 0.25 kg a.i./ha.

Three applications of sprayable insecticides during the vegetative stage gave the largest yield, 1.5 t/ha (Table 9). The benefit-to-cost ratio was 8.9 from insecticide use; it cost US$8.10/ha. The control of the bean fly, leafhopper, and flea beetle resulted in a dense stand (232,000 plants/ha), tall plants (70 cm) and, consequently, a high number of pods per hectare (3.3 million). Other treatments produced fewer and shorter plants and fewer pods per hectare. The yield of the untreated plot was 0.4 t/ha.

Control of pests in cowpeas grown after low-

Table 9. Insect control, costs and returns, and mung bean response to preflowering insecticide treatments. Variety CES 14 planted in December after lowland rainfed rice.[a] Manaoag, Pangasinan, 1975.

Bean fly (larvae + pupae/ 15 plants) 21 DE	*Empoasca* leafhopper nymphs (no./15 plants) 35 DE	Flea beetles[b] (no./10 sweeps) 21 DE	Plants (thousands/ha)	Pods (no./ plant)	Pods (millions/ ha)	Plant ht (cm)	Yield (kg/ha)	Insecticide cost (US$/ha)	Benefit: cost ratio[c]
			Three applications: 5 DE, 15 DE, and 25 DE						
1	2	7	232	15	3.3	70	1.5	60	8.9
			Two applications: 15 DE, and 25 DE						
4	8	15	183	11	1.9	60	1.1	40	8.2
			One application: 5 DE						
4	34	18	216	14	2.9	59	1.1	20	16.5
			No insecticide						
8	25	83	175	9	1.5	52	0.4	—	—

[a]Av. of 2 fields. Two applications of benomyl to all plot. DE = days after emergence. Monocrotophos (Azodrin 16.8 EC) 0.25 kg a.i./h.a. [b]Night. [c]US$1.10/kg. Change in the value of product/insecticide cost.

land rice. In a trial in Iloilo where the soil had been puddled, dried and then tilled, carbofuran granules at 1 kg a.i./ha were applied in the seed furrow to control the early season cowpea pests. The cowpeas (EG 2 variety), which followed rice, were under drought stress, and only one treatment—carbofuran plus 0.25 kg a.i. monocrotophos/ha and 0.50 kg a.i. methomyl/ha—protected the crop in both the vegetative and reproductive stages and gave a yield of 612 kg/ha.

The treatment with granules and sprays only at the reproductive stage wilted even faster than the untreated control. Early vegetative protection is essential for grain legumes planted during drought because the insect pests stunt not only the upper portion of the plant but also the root system. It is important that the crop be able to continually send roots down into the descending moisture zone.

The failure of carbofuran, known to be effective in upland soils, can be explained by a change in the soil structure when puddled soil is tilled. Such a soil becomes aggregated into large clods that are loosely packed, precluding adequate contact of moisture, granule, and roots.

VARIETAL TESTING

Multiple Cropping Department and Rice Production Training and Research Office

The main food crops studied in the IRRI Cropping Systems research program are rice, corn, sorghum, soybeans, mung beans, cowpeas, peanuts, sweet potatoes, and cassava. In a rice-based system these crops are planted before and after rice, which is usually planted during the wet season, or intercropped with rice during the wet season or with each other in the dry season.

The elite varieties and lines of upland crops generated in the breeding and screening program of the University of the Philippines at Los Baños (UPLB) and the UPLB Institute of Plant Breeding are evaluated in replicated trials in the cropping systems network in Bangladesh, Burma, Indonesia, the Philippines, Sri Lanka, and Thailand. In the Philippines, variety trials of upland crops were carried out from October to December 1975 and harvested in January to March 1976.

Table 10. Yields and agronomic characteristics of promising rice varieties evaluated under upland conditions. IRRI, 1976 wet season.

Pedigree	Yield (t/ha)	Maturity (days)	Ht (cm)	Lodging (%)
IR2823-399-5-6	4.69	131	94	6
IR4722-36-1	4.03	131	104	15
IR1561-228-33	4.03	113	86	8
IR4442-45-2-1	3.94	125	95	12
IR2058-78-1-3-2-3	3.91	131	99	8
IR4427-119-6-1	3.83	126	95	43
IR2071-586-5-6-3-4	3.81	138	92	0
IR4227-107-1-3	3.76	131	104	13
IR4422-143-2-1	3.76	130	106	22
IR3941-25-1	3.58	111	96	61
IR4432-52-6-4	3.49	131	101	10
IR4422-164-3-6	3.46	130	108	15
IR4440-165-2-4	3.43	127	88	8
IR28	3.40	108	91	52

LSD (.01): 0.55; CV (%): 13.13.

Rice. Thirty varieties developed by IRRI were evaluated at the IRRI farm for suitability for direct-seeding dry. Because no water accumulated in the paddy at any stage of rice growth, except for a few days following very heavy rains, the trial was conducted under upland conditions. Several promising varieties gave yields superior to the yield of IR28 (3.40 t/ha); IR2823–399–5–6 rice gave the highest yield (4.69 t/ha) (Table 10). All these promising varieties matured later (125–138 days) than IR28 (108 days).

In another trial, a second rice crop was transplanted in September 1976 under rainfed conditions after the early rice crop. Five lines and varieties yielded more than 3 t/ha; IR30 and IR36, the varieties used in the cropping pattern trials, gave the highest yields—about 3.5 t/ha each (Table 11). The yield level was low because

Table 11. Yields, maturity, and lodging of the top 10 high yielding selections of early maturing lowland rice (transplanted). IRRI, 1976 late wet season.

Pedigree	Yield (t/ha)	Maturity (days)	Lodging (%)
IR30	3.52	92	70
IR36	3.50	94	100
IR2061-522-6-9	3.49	91	80
IR1561-228-3-3	3.46	94	20
IR28	3.44	86	70
IR2307-64-2-2	2.99	94	100
IR2061-465-1-5-5	2.97	90	60
Pusa 2-21	2.79	82	40
BG 94-2	2.67	95	0
IR4829-39-2	2.66	95	20

LSD (.01): 0.68; CV (%): 19.84.

Table 12. Yield and other agronomic characteristics of promising early maturing rice varieties evaluated in Pangasinan and Iloilo, Philippines, 1976 wet season.

Variety[a]	Yield (t/ha)	Yield advantage over check (%)	Maturity (days)	Ht (cm)	Whiteheads (%)
FENSART early maturing varieties					
		Manaoag, Pangasinan			
IR2061-628-1-6-4-3	4.94	5.6	109	96	17
IR1561-228-3-3	4.83	4.4	117	85	15
IR36	4.82	4.3	118	76	9
IR28 (check)	4.42	—	100	89	20
		Oton, Iloilo			
IR2061-628-1-6-4-3	4.85	27.3	112	—	7
IR2061-522-6-9	4.75	26.3	112	—	2
IR2070-414-3-9	4.74	26.2	112	—	7
IR28 (check)	2.77	—	97	—	8
FENSART medium maturing varieties					
		Manaoag, Pangasinan			
C131-129	3.90	7.6	121	97	9
MRC-46-466	3.69	4.8	130	85	3
IR2823-399-5-6	3.64	4.3	118	87	6
MRC 345	3.64	4.3	114	82	8
IR26 (check)	3.35	—	126	84	3
		Oton, Iloilo			
IR2071-105-9-1	5.94	3.6	125	—	2
IR2863-38-2	5.92	3.4	123	—	3
IR2071-588-5-45	5.87	3.0	123	—	2
IR2833-399-5-6	5.77	2.1	121	—	3
IR26 (check)	5.53	—	123	—	0

[a]FENSART = Farmers' Evaluation of New Selections Applied Research Trials.

lodging at various stages of grain filling and ripening forced early harvest. Maturity varied by 12 days, with Pusa 2–21 maturing in only 82 days.

A FENSART (Farmers' Evaluation of New Selections Applied Research Trials) transplanted yield trial, conducted in Iloilo and Pangasinan, consisted of two groups of 12 entries each. One group included early maturing varieties from IRRI and the other group included medium-maturing selections from UPLB, IRRI, and the Philippines Bureau of Plant Industry (BPI). IR2061-628-1-6-4-3 gave the highest yield in Pangasinan (4.94 t/ha) and in Iloilo (4.85 t/ha) (Table 12). IR28 had the shortest maturity time (97–100 days) at both sites. In the medium maturity group, C131–129 gave the highest yield (3.90 t/ha) in Pangasinan, and IR2071-105-9-1 (5.94 t/ha) and IR2863-38-2 (5.92 t/ha) were the most promising selections in Iloilo. C131-129 was discarded in Iloilo because it germinated poorly.

Variety trials (11 varieties or selections) using the dry-seeded rice establishment technique were conducted in six IRRI-PCARR (Philippine Council on Agriculture and Resources Research) locations in the Philippines at the beginning of the 1976 rainy season. In Iloilo and Bulacan, where the rainfall increased gradually after seeding and continued uniformly without drought, the yields were significantly higher than those in the other locations (2.8 to 5.0 t/ha in Iloilo and 1.5 to 5.8 t/ha in Bulacan). The yields were lowest (0.2 to 4.4 t/ha) in North Cotabato, Mindanao, where severe pest and disease damage (tungro and grassy stunt) occurred. However, IR36 rice yielded 4.4 t/ha.

Among the check varieties, IR36 performed best in three locations (Iloilo, Isabela, Zambales) and did not differ significantly from the highest yielding varieties in all other locations.

IR30 performed as well as IR36 in four locations except in Isabela (where severe drought occurred) and Cotabato (where disease and insect infestation was severe). Promising selections included IR2061-522-6-9, which gave yields comparable with those of IR36 in four locations and ranging from 2.1 t/ha in Isabela to 4.8 t/ha in Bulacan. IR2061-465-1-5-5 gave yields as high as those of the check variety.

Table 13. Yields and some agronomic characteristics of top two high yielding corn varieties and their check at each site. Philippines, 1975 dry season.

Site and pedigree[a]	Yield[b] (t/ha)	Yield advantage over check (%)	Days to silking	Ht (cm)	
				Plant	Ear
IRRI					
Thai Early Comp. 1	3.79	0	50	233	122
Phil. DMR Comp. 1	3.77	—	49	232	104
Batangas					
TC #1 (TC #1 Early × Phil. DMR F_3)F_3	5.53	55	56	162	79
Thai Early Comp. 1	5.46	53	55	176	93
Tinumbaga	3.56	—	51	175	82
Pangasinan (low water table)					
Thai Early Comp. 1	3.47	54	59	148	74
Early DMR Comp. 1	2.54	12	60	172	85
Phil. DMR Comp. 1	2.26	—	59	149	65
Pangasinan (high water table)					
TC #1 DMR × Medok F_3	4.17	42	54	169	88
Thai Early Comp. 1	3.85	31	57	170	75
Phil. DMR Comp. 1	2.93	—	54	178	92

[a]Comp. = Composite. [b]Mean of 4 replications.

Corn. Field corn, which is early maturing, fits into a rice-based cropping system, especially if it is planted before or after rainfed and partially irrigated rice. Trials were conducted in Batangas and Pangasinan and at IRRI. The IRRI trial was planted in the dry season under upland conditions. Thai Composite 1 Early consistently exhibited high yields at all the test sites (3.47 to 3.79 t/ha) (Table 13). However, it is susceptible to downy mildew, a major disease of corn in Southeast Asia. Yield levels in Pangasinan were higher with a high water table than with low. The promising varieties matured later than the checks.

(TC#1 DMR × Medok F_3) and TC#1 (TC#1 Thai Composite 1 Early × Phil. DMR F_3) F_3 are both promising in Sri Lanka and Thailand. Both early DMR Composite 2 and Thai Composite 1 Early were promising in Bangladesh.

Sorghum. Sorghum is the most promising crop for planting after rainfed rice in the dry season; it tolerates drought and waterlogging. In an evaluation of the most promising varieties from UPLB, several varieties yielded 3 to 21% better than Cosor 3, a recommended variety used in the IRRI cropping pattern studies. The best yields were obtained in Pangasinan at the high water table site.

In Sri Lanka CS102, IS9204, and CS103 performed well under rainfed conditions; in Bangladesh IS2940, Cosor 2, CS108, and CS100 appeared promising.

Soybeans. Clark 63 consistently gave high yields at the three sites (IRRI, Batangas, and Pangasinan). Its yields were better than those of TK5, a recommended soybean variety used in cropping pattern trials. The promising entries gave yields that were from 41 to 92% better than those of TK5. However, TK5 matured earlier (77–79 days). Clark 63 is being increased for the cropping pattern trials after rice.

Clark 63 was also promising in Thailand and Bangladesh. Warasoy gave the highest yield in Bangladesh, and Bragg gave the best yield with irrigation. SJ-1 gave the best yield under rainfed conditions in Sri Lanka and performed best in Thailand. Like Clark 63, CES 16–23 has a wide range of adaptability.

Mung beans. Mung bean varieties M350 from Korea and Dau Mo from Vietnam performed well at each of the four study sites in the Philippines—IRRI, Batangas, Pangasinan and Iloilo. Under high tillage, seven entries at IRRI, nine in Batangas, eight in Pangasinan, and nine in Iloilo were better than the check. Under low tillage, the local variety yielded as well as the improved varieties.

The yield was 100% better with good land preparation (high tillage) after the rice crop than with only one plowing and one harrowing (low tillage). The seedling vigor of M350 was better under lowland than under upland conditions.

Dau Mo and CES 14 were promising in Thailand, while CES 14 gave the highest yield in Sri Lanka with irrigation. Under rainfed conditions, CES 87 and MG 50-10A (G) looked promising both in Indonesia and in Sri Lanka.

Cowpeas. Under upland conditions, the three Philippine BPI varieties of cowpeas—EG#1, EG 32, and EG#3—were found to be best. However, Red Cowpea 6-12G and Red Cowpea 6-1 were superior to the other entries in trials after lowland rice. Ten varieties were superior to the check (EG#1) in Pangasinan

Table 14. Yields and maturity of the top two high yielding sweet potato varieties and their check at each site. Philippines, 1975 dry season.

Site and variety	Tuber yield[a] (t/ha)	Yield advantage over check (%)	Maturity (days)
IRRI			
Georgia Red	29.4	488	133
North Carolina	21.9	338	133
BNAS 51	5.0	—	130
Pangasinan (low water table)			
Kaogban	6.5	18	103
Bangued	6.0	9	104
BNAS 51	5.5	—	94
Pangasinan (high water table)			
Bangued	17.7	92	134
SP #45	11.3	23	132
BNAS 51	9.2	—	107
Iloilo			
Hsinchu 1	19.4	76	102
Jewel	19.4	76	102
Local check	11.0	—	102

[a]Mean of 4 replications.

where the water table was low, while eight were better than the checks when the water table was low. Under low tillage, six lines were better than the check in Iloilo.

EG #2 looked promising in Indonesia, Sri Lanka, and Thailand, but under rainfed conditions EG #3 gave the highest yield in Indonesia and Sri Lanka. In Thailand, the yields of EG 32 and EG #1 were more than 300% better than the local check.

Sweet potatoes. The yields of several sweet potato varieties were better than those of BNAS 51, a check variety used in the cropping pattern trials. At IRRI, the yields of Georgia Red and North Carolina varieties were more than 300% higher than the yield of BNAS 51 (Table 14). Bangued, a local variety, looked promising in Pangasinan whether the water table was high or low. The yield was 2 to 3 times greater when the water table was high than when it was low. In Iloilo, both Hsinchu and Jewel yielded 76% more than BNAS 51.

Peanuts. In trials at IRRI and in Iloilo, Gadjah, Kidang, F334-33, and CES 102 appeared to be the most promising peanut entries for both upland conditions and following rainfed rice in the dry season. Maturity varied only slightly in each location—102 to 104 days in IRRI, and 90 to 93 days in Iloilo.

INTERCROPPING
Multiple Cropping Department

Intercropping corn and rice varieties of different maturity. Recent studies on corn and rice intercrop (corn + rice) (1975 Annual Report) indicated that the benefit from intercropping compared with sole cropping could be attributed to the higher leaf area duration (LAD) that resulted from intercropping. The high LAD is achieved by partial sequencing of the canopies and their time of major assimilation. To further evaluate that observation, corn and rice varieties of different maturity were intercropped under upland rainfed conditions to measure relative changes in yields due to maturity differences. The corn varieties were Penjalinan (78 days), Thai Composite (95 days), DMR 2 (102 days), and UPCA-2 (106 days); the rice varieties were IR28 (107 days), C-22 (124 days), and IR34 (134 days).

Rice was drilled at the rate of 100 kg/ha in rows spaced 25 cm apart. The intercropped plot had six corn rows spaced 1.5 m apart, with five rice rows between each pair of corn rows. The corn population had a density of 33,333 plants/ha. Monoculture corn rows were spaced at 75 cm, with 53,333 plants/ha.

Fertilizer was applied at the rate of 20-80-80 kg NPK/ha at planting, 100 kg N/ha to corn and 50 kg N/ha to rice 28 days after seeding (DS), and 50 kg N/ha to rice 62 DS. Weeds and pests were adequately controlled.

Land equivalent ratio (LER) is the total land required for monoculture to give a total production similar to that of the same crops grown as intercrop. It is calculated by determining the ratio of the yield of an individual crop in a mixture to its yield in monoculture and adding the fractions. Because individual varieties of both corn and rice differ in yields (Table 15), a high LER value does not necessarily indicate a total production higher than a combination with a low LER value. The LER value is meaningful for individual combinations only.

The yields of rice intercropped with corn were lower than those of rice in monoculture because

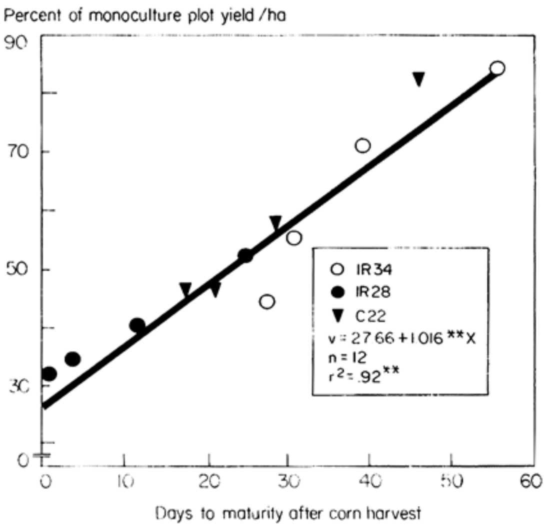
Table 15. Grain yields and land equivalent ratio (LER) for rice + corn intercrop combinations.[a] IRRI, 1976.

Corn	Grain yield[b] (t/ha) and LER									Main plot mean yield[c] (rice) (t/ha)
	IR28 (3.31)			C22 (3.25)			IR34 (2.41)			
	Corn	Rice	LER	Corn	Rice	LER	Corn	Rice	LER	
Penjalinan (3.18)	1.90	1.75	1.12	1.66	2.08	1.34	2.16	2.04	1.52	1.96 a
Thai Composite (4.73)	2.73	1.35	0.98	2.77	1.91	1.17	3.37	1.73	1.43	1.66 b
DMR 2 (5.40)	3.30	1.14	0.95	3.62	1.54	1.14	3.72	1.34	1.24	1.34 c
UPCA-2 (5.28)	3.49	1.06	0.98	3.20	1.57	1.09	4.05	1.08	1.21	1.24 c
Subplot mean yield[c] (corn)		2.86 b			2.81 b			3.33 a		

[a]Corn as main plot, rice as subplot. [b]Values in parentheses are monoculture yields (t/ha). For rice and corn varieties the days to maturity were IR28, 107; C22, 124; IR34, 134; Penjalinan, 78; Thai Composite, 95; DMR 2, 103; and UPCA-2, 106. [c]Means followed by different letters are significantly different at the 5% level.

corn competition depressed yield. The yields of intercropped C22 and IR34 rices were not reduced much when the varieties were associated with the earliest maturing corn variety Penjalinan. The difference in yield was attributed to a reduced stand because corn replaced every sixth rice row in the intercropped plot.

Part of the yield reduction in the other corn + rice combinations could also be attributed to actual yield depression. The yields of IR28 were markedly decreased in all combinations. The yield depression was greater for all rice varieties when the associated corn variety matured late. The earliest and latest maturing corn varieties caused the minimal and the maximum depressing effect, respectively. The overall yield depression in rice varieties was in the relative order of IR28 > C22 > IR34. This indicated the tolerance of rice for shading and for other competitive effects due to corn. The yields appeared to be positively correlated with the number of days during which rice could grow to maturity without competition from corn after the corn was harvested. Thus, the reduction in the intercrop rice yield was less as the difference in days to maturity (DTM) of corn and rice increased (Fig. 1) from 1 to 56 days.



1. Relationship between intercrop rice yields and days to maturity after corn harvest.

Corn yields for various intercrop treatments also differed. The yield of corn intercropped with early maturing rice IR28 was significantly lower than that of corn combined with late maturing IR34 (Table 15). The per-hectare yields of intercropped corn were lower than those of monoculture corn mainly because the corn population was lower. Individual plant yields of intercropped corn tended to be higher than monoculture yields as the DTM increased, indicating a greater competitive advantage when the corn and rice maturity period had minimum overlap. Generally, high corn yields appeared to compensate for yield depression in rice, and total production was maximized by maintaining sufficient maturity differences between the intercropped varieties. Since late maturing upland rice may, however, be subject to drought, rices that mature too late should not be intercropped in areas with a short rainy season.

Evaluation of corn + rice intercrop on farmers' fields. Three corn varieties—the local varieties Macapuno (86 DTM) and Tinumbaga (99 DTM) and the improved variety DMR 2 (107 DTM)—at two planting densities and row spacings were intercropped with a local upland rice variety (Dagge, 119 DTM) in Cale, Batangas. Increasing the corn population from 8,000 to 16,000 plants/ha increased corn yields for the 1.75-m row spacing, but not for the 2.5-m row spacing. Increased row spacing decreased corn yields at the high planting rate. Although the yield of DMR 2 was better than the yields of the two local varieties, the difference was statistically significant only at the 1.75-m row spacing.

The effects of corn variety and spacing on yields of the intercropped rice generally contrasted with their effects on corn yields. Rice yields were highest when rice was seeded with the low yielding early maturing Macapuno corn. They decreased significantly when the corn plant population was increased at the 1.75-m row spacing. Rice yields did not increase when corn row spacing was increased.

Total yields in all corn + rice intercrop treatments were similar because of the compensating behavior of the two component crops (Table 16). The total yields were higher at the 1.75-m corn row spacing and at the 16,000 plants/ha corn population. At the 1.75-m row spacing, the yield of rice intercropped with Tinumbaga corn was poorer than that of rice intercropped with Macapuno and with DMR 2.

Table 16. Effects of two corn densities, three corn varieties, and two corn row spacings on total yield of the corn + rice intercrop in farmers' fields. Batangas, 1976 wet season.[a]

Corn density (no. plants/ha)	Yield (kg/ha) of corn + rice intercrop			
	Macapuno	Tinumbaga	DMR 2	Mean[b]
	1.75-m corn row spacing			
8,000	3134	2567	2957	2886 a
16,000	2948	2678	3167	2931 a
Mean[b]	3041 a	2623 b	3062 a	
	2.50-m corn row spacing			
8,000	2440	2837	2611	2629 a
16,000	2920	2791	2771	2829 a
Mean[b]	2680 a	2814 a	2691 a	

[a] Mean of 5 replications (1 replication/farm). [b] In a row (or column), means followed by the same letter are not significantly different at the 5% level.

Intercropping sorghum and mung beans at different nitrogen levels and plant arrangements. In a sorghum (Cosor 3) + mung bean (CES 55) intercropping experiment to measure changes in total production at various nitrogen levels and row arrangements, a basal fertilizer (0-50-50 kg PK/ha) was applied to all plots. The main plots received no nitrogen (NO); N1 had 40 kg N/ha applied to the whole plot at planting; N2 had 40 kg N/ha applied to the whole plot at planting, and 40 kg N/ha applied to sorghum only (both intercrop and monoculture) at 30 DS.

Crop rows were spaced 40 cm apart for both species. Sorghum rows had 10 plants/linear meter, and mung bean rows had 12; monocultures had 250,000 and 300,000 plants/ha respectively. Crop proportion by row arrangements—1:1, 1:2, 1:3 for each of the species and monoculture plots—produced seven subplots. Weeds and pests were adequately controlled. The final priming of the mung beans occurred 72 DS; sorghum matured in 91 DS.

Monoculture sorghum responded well to nitrogen at N0 to N1, but at N2, its yield was not much higher than it was at N1. The intercrop sorghum also responded to the second application of nitrogen (N2) (Table 17). Nitrogen had no effect on the yields of monoculture mung beans, but tended to lower the yields of intercropped mung beans. The differences in yield per hectare for each crop in various treatments can be attributed both to changes in the plant number and to individual plant yields. On an individual-plant basis, the yields of intercropped mung beans were similar to monoculture yields at N0, but were slightly depressed when nitrogen was applied (N1 or N2) possibly because of increased shading from better developed sorghum rows. Compared with monoculture yields, the yields of intercropped sorghum decreased, especially when no nitrogen was applied. That result accounted for the high LER value of that treatment.

In the N0 treatment the per-hectare yields of sorghum at the row proportion of 1M:2S (one row of mung beans and two rows of sorghum) or 1M:3S (one row of mung beans and

Table 17. Grain yields of mung beans (M) and sorghum (S) at various nitrogen levels[a] and row proportions.[b] IRRI, 1976.

Culture[c]	Grain yield (t/ha) and LER[d]								
	N0			N1			N2		
	Sorghum	Mung beans	LER	Sorghum	Mung beans	LER	Sorghum	Mung beans	LER
Monoculture	2.82	1.52		4.78	1.60		4.82	1.65	
1M : 1S	2.49	0.80	1.41	3.32	0.66	1.11	3.46	0.66	1.12
2M : 1S	2.02	1.05	1.40	2.54	0.82	1.04	2.90	0.96	1.18
3M : 1S	1.46	1.05	1.21	1.55	1.11	1.01	1.89	1.16	1.09
1M : 2S	2.87	0.58	1.40	3.77	0.49	1.09	4.00	0.39	1.07
1M : 3S	3.00	0.38	1.31	3.79	0.33	1.00	4.54	0.32	1.14

[a]N0 = no nitrogen; N1 = 0 kg N/ha applied to whole plot at planting; N2 = 40 kg N/ha applied to whole plot at planting and 40 kg N/ha applied to sorghum only at 30 days after seeding. [b]All rows 40 cm apart. [c]Numbers in M : S combinations represent rows of mung beans and sorghum alternated. [d]Land equivalent ratio.

three rows of sorghum) were similar to or higher than the yield of monoculture sorghum; mung bean yields were high. Planting alternate rows of sorghum and mung (1M:1S), or 2M:1S minimizes the loss in yield of mung beans. It appears that a farmer growing sorghum alone can benefit by intercropping mung beans (or switching to mung beans alone), but a farmer that generally grows mung beans will lose by introducing sorghum as intercrop. The market price for mung beans tends to be four to five times higher than that for sorghum. The yield loss in mung beans due to intercropping and the consequent low economic return are not compensated for by the price obtained for sorghum, especially when the yields of monoculture mung beans are high. Intercropping showed little yield benefit at high nitrogen treatments, but the LER values averaged 1.35 where no nitrogen was applied.

Effect of corn canopy on yields of corn + rice intercrop. Reduced rice yields in a corn + rice intercrop can be attributed mostly to shading by corn. To measure changes in the total production of the corn + rice intercrop caused by changes in corn canopy at various corn populations, the Thai Composite corn variety was intercropped with C22 rice.

Intercrop corn rows were spaced 1.25 m apart with 4 rice rows, spaced 25 cm between the corn rows. Corn plant spacing within rows was adjusted to achieve 32,000, 40,000, and 50,000 plants/ha (main plots). One rice plot and two corn plots were also included as monoculture checks. The corn check plot had 53,333 plants/ha in rows spaced 75 cm apart. Rice was drilled in 25-cm rows at 100 kg/ha.

Ten days after silking, subplot treatments were applied to intercropped corn plants in each main plot, as follows: (a) all leaves were tied upright; (b) half of the blade of each leaf was cut; (c) the tassel above the uppermost leaf was removed; (d) a normal intercropped corn row was designated as check. The tassels were also removed in one of the monoculture corn treatments.

Intercropping at 40,000 corn plants/ha was optimum. Yields of both corn and rice declined when the population density was 50,000 plants/ha. Corn yields declined significantly when the leaves were tied or clipped; the leaf treatments probably disturbed photosynthesis and translocation to the grain. However, the yields of rice increased significantly. Removal of the tassel significantly increased corn yields and to some extent rice yields. Corn varieties with more upright leaves should be specially suited for intercropping. Total yields indicated that damage to corn foliage in a corn + rice intercrop is substantially compensated for by increased rice yields.

Effect of crop damage in corn + peanut intercrop. Because crop damage can reduce the stand and leaf area of a crop, farmers are encouraged to practice intercropping as an insurance against such damage. To provide stability of production, at least one of the crops must compensate for the yield loss caused by crop damage in the other. To evaluate the extent of compensation, the crop stand and foliage of both corn (Thai

Table 18. Yield of unshelled peanuts as affected by time and level of damage in corn + peanut intercrop.[a] IRRI, 1976.

Damage to peanuts[b]	Peanut yield (t/ha)						Yield (t/ha) of peanut monoculture[c]
	0 damage	At 33% damage to corn		At 75% damage to corn		Mean[c]	
		25 DS[b]	55 DS	25 DS	55 DS		
0 damage	1.64	1.80	1.47	2.22	2.03	1.83 a	2.93 a
33% stand, 30 DS	1.56	1.81	1.72	2.66	2.06	1.96 a	2.85 a
33% foliage, 70 DS	1.30	1.40	1.23	1.99	1.67	1.52 b	2.57 ab
75% stand, 30 DS	1.30	1.29	1.24	2.07	1.67	1.51 b	2.42 bc
75% foliage, 70 DS	1.24	1.19	1.30	1.90	1.58	1.44 b	2.17 c
Mean	1.41 c	1.50 c	1.39 c	2.17 a	1.80 b		

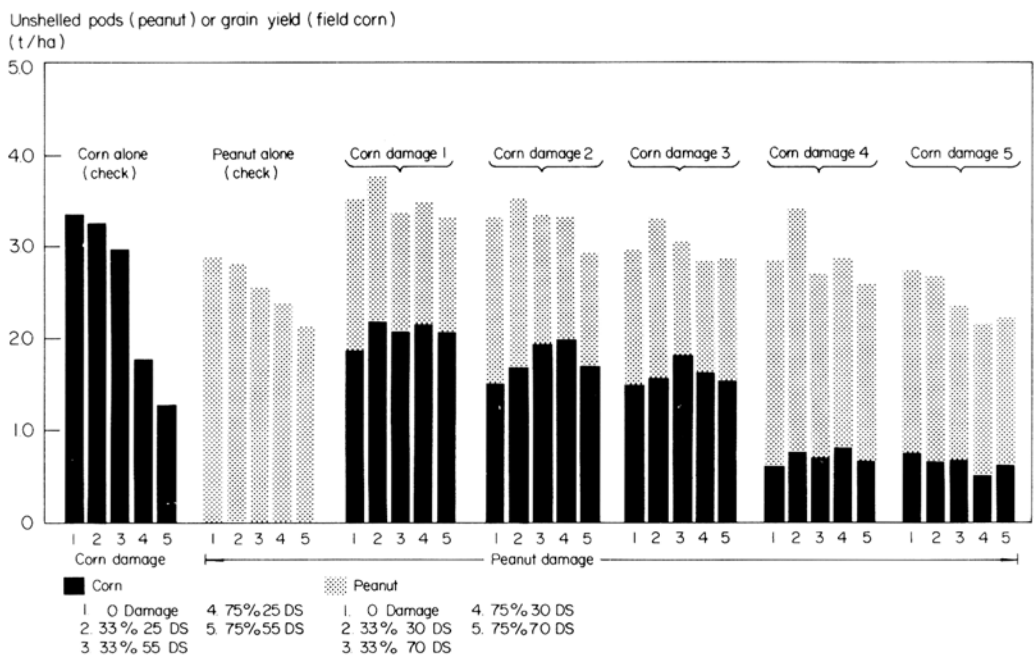
[a]Av. of 4 replications. Means followed by the same letter are not significantly different at 5% level. [b]DS = days after seeding. [c]CV (a) – 23.0%; CV (b) 13.5%.

Composite Early) and peanuts (CES 101) were reduced to 33% and 75% at 25 and 55 DS for corn and at 30 and 70 DS for peanuts. The density of the corn monoculture was 50,000 plants/ha, while that of the corn intercrop and peanuts (monoculture and intercrop) was 20,000 and 200,000, respectively.

The monoculture corn crop compensated substantially for loss of stand and foliage, particularly when the loss occurred early (25 DS) in the growing season. Because of its lower plant population, the intercropped corn did not show that ability to compensate.

The yield of peanuts was more stable than that of corn, even when the peanuts were severely damaged (Table 18). In fact, at an early growth stage under light damage—33% at 30 DS—the peanut yield even increased slightly. Undamaged plants apparently were able to compensate for the damaged plants, particularly when the damage occurred early in the season.

In the intercrop, peanuts also compensated more for damage to corn than did corn for damage to peanuts (Fig. 2), because peanuts,



2. Grain yield (t/ha) of monoculture corn and unshelled peanuts and their intercrop at different levels of damage. DS = days after seeding. IRRI, Oct. 1975–Feb. 1976.

as the lower canopy crop, benefit from less light interception by the corn canopy. Yields of intercropped corn at a low population density increased by 9% because of damage to peanuts; that indicates that peanuts competed with corn for certain growth factors, probably moisture and nutrients. The total yields of the corn + peanut intercrop were less reduced by damage to corn than were the yields of monoculture corn; also they were less reduced by damage to peanuts than were the yields of the peanut monoculture (Fig. 2).

CONTINUOUS CROPPING

Soil Microbiology Department, Cropping Systems Component; and Rice Production Training and Research Office

Continuous cropping of upland rice and other upland crops. *Harmful effects.* As indicated in the previous year (1975 Annual Report), the growing of the same crop species continuously on the same land can impair the succeeding crops because of the condition described as "soil sickness." The growth and yield of upland rice, mung beans, and cowpeas were markedly decreased because of continuous cropping. Rice, on which the inhibitory effect was most pronounced at later stages of growth, maintained a low yield of 0.5 t/ha or less.

Seed germination and seedling growth of legumes were affected. The plants usually recovered near flowering, but they did not recover when the injurious effect was severe, as in the seventh cropping. After eight continuous croppings, corn and sorghum showed no visual symptoms of soil sickness.

The growth and yield of upland rice, corn, and cowpeas improved when those crops were grown in rotation with other crops. This finding gave circumstantial evidence of soil sickness affecting those crops (Table 19). A rotation crop of cowpeas improved the yield of corn. Sorghum, however, was not affected by crop rotation.

To see if a rotation crop could eliminate soil sickness in a continuous cropping pattern, the rotation portion of the mother plot was again planted to the same continuous crop. One rotation crop of sorghum failed to eliminate soil sickness in upland rice, suggesting that the causal agent of soil sickness remains in the soil for a long time and may affect a susceptible succeeding crop, even after several rotations. One rotation crop of corn partially corrected soil sickness in cowpea. One rotation crop of cowpea eliminated all detrimental effects of continuous corn cropping.

Crops may be ranked according to response to soil sickness as follows: upland rice, most susceptible; mung and cowpeas, susceptible; corn, slightly susceptible; and sorghum, not visibly affected.

Upland rice and mung were grown under three cropping conditions: continuous cropping, 5-month fallow in the continuous cropping pattern, and rotation cropping (mung beans with sorghum, and rice with cowpeas). Keeping the soil fallow for 5 months improved the growth and yield of both rice and mung beans in the succeeding crop, but plant growth was poorer than that of mung beans and of upland rice that were grown for the first time. Soil sickness, once established, is corrected slowly by crop rotation.

Root residues as source of harmful effect. To ascertain the cause of soil sickness, upland rice (IR2061-464-2-4) and mung beans (MG50-10A) were grown in pots containing 3.5 kg of soil from a continuous-culture plot and from an adjacent field. Root residues, the amount of which was determined from the quantity present in the field, were cut into small segments and,

Table 19. Effect of one rotation crop on growth and yield in the continuous cropping pattern.[a] IRRI, 1976.

Rotation crop[b]	Previous crop treatment	Plant ht (cm)	Grain yield (t/ha)
Upland rice	5 continuous IR747	42 a	0.08 a
Rice (IR747B2-6-3)	One sorghum crop after 4 continuous IR747	43 a	0.09 a
Cowpea (EG green pod #2)	6 continuous cowpea	38 b	0.05 a
"	One corn crop after 5 continuous cowpea	61 a	0.65 a
Corn (DMR 2)	6 continuous corn	250 a	2.64 b
"	One cowpea crop after 5 continuous corn	248 a	4.45 a
Sorghum (Cosor 2)	5 continuous sorghum	168 a	6.10 a
"	One rice crop after 4 continuous sorghum	170 a	6.51 a

[a]For a crop, means followed by the same letter in a column are not significantly different at the 5% level. [b]Days to maturity = 100 for rice, 72 for cowpea, 91 for corn, and 92 for sorghum.

without being washed or dried, added to the soils in pots. Some of the soils were subjected to partial sterilization by treatment with 10% acetone or with steam for 30 minutes at 1 atm.

In all crops except sorghum, partial soil sterilization slowed the rate of autolysis, indicating that microorganisms may play a part in the appearance of soil sickness. When grown in the dark on other soils, rice and mung had slower autolysis than they had on continuously cropped soil. That suggests a possible effect of harmful organisms (fungi) on the two crops.

Conditions of dark culture differ from those of light culture and from those of the field. Inhibitive action in dark culture should therefore be considered a supplementary tool in finding the potentiality of harmful biological effects.

Partial sterilization of the cowpea soil produced no clear difference among continuous-culture, rotation, and fallow soils. Sorghum did not respond to partial soil sterilization in dark culture. The result may be related to the observation that sorghum appears unaffected by soil sickness.

The causal agent of soil sickness appeared to have specific affinity with a crop; upland rice showed no harmful effects when grown in the continuous mung bean soil, and vice versa. In mung beans, results in the field, the greenhouse, and dark culture agreed. A microorganism, most probably a fungus, could be the causal agent. No such pattern was observed with upland rice. The behavior of rice plants grown under various conditions did not suggest a particular cause.

Continuous rice production methods for irrigated areas. The continuous rice production method (CRPM) is designed for the farmer who has irrigation water available throughout the year and wants maximum production. He can make fuller use of his resources, especially his own family labor, if he divides his field into manageable areas and plants and harvests without hiring additional labor. He can thus keep all the production that is generally given to paid labor. The CRPM allows the farmer to receive income from rice sales the year round. It will also reduce his need to borrow money at high interest rates.

In this concept, rice is transplanted in 250-sq m plots (1 ha) on Monday, Wednesday, and Friday of each week and harvested Tuesday, Thursday, and Saturday. In effect, 40 plots/ha will all be planted before the first plot is harvested. With a minimum turnaround time of 1 day after harvest, the 365 days of the year are used for producing rice.

To select the rice variety with the highest yield potential for this method, an experiment evaluated the factors affecting yield calculated on a per-day basis: 1) variety, 2) fertilizer, 3) spacing, and 4) pest management. Five early maturing and five medium maturing varieties and lines were used with five different spacings and two levels of K_2O (Table 20).

A basal fertilizer of 60 kg nitrogen and phosphorus was applied. Potash, at 0 and 90 kg/ha, was applied with nitrogen and phosphorus in the root zone. Nitrogen was topdressed at the rate of 60 kg N/ha (split, applied twice at 30 kg N/ha) and broadcast 33 and 38 days after transplanting in the early maturing group, and 38 and 44 days in the medium maturing group. Maximum protection from insects was maintained.

For the first crop, Ai-nan-tsao produced the highest yields of 122 and 108 kg/ha per day at the 30- × 15-cm and 40- × 5-cm spacing, respectively (Table 20). Plants at both spacings significantly outyielded those in the 20- × 20-cm check. IR1561-228-3-3 produced the highest yield on a per-day basis among the medium-maturity group, but showed no marked response within the five spacings. IR8 produced its highest yield when spaced at 20 × 20 cm. No yield difference was noted between the plots treated with 90 kg potash/ha and those receiving no potash.

Ai-nan-tsao produced the highest number of panicles at the widest spacing between rows—40 × 5 cm—without affecting the number and weight of filled grains per panicle. At wider spacing, IR36 produced more panicles but the number and weight of filled grains were reduced. IR8 produced fewer filled grains per panicle at closer spacings within the row.

Weather, insects, and diseases, reduced the yields of the second and third crops. The same factors affected IR747B2-6-3 and Ai-nan-tsao in

Table 20. Mean production of 10 rice varieties or lines grown at 5 different plant spacings (averaged over 2 levels K_2O, each with 2 replications), first crop, January 1976.

Variety or line[a]	Mean daily production[b] (kg/ha) at spacing of					Average[c]
	30 × 5 cm	40 × 5 cm	30 × 10 cm	20 × 20 cm	30 × 15 cm	
			Early maturing (77–105 days)			
Ai-nan-tsao (77)	97	108**	95	85	122**	101 a
IR747B2-6-3 (86)	89	93	94	93	91	92 bc
IR2061-465-1 (92)	97	90	93	97	92	94 bc
IR36 (92)	102	98	91	96	97	97 ab
BG-34-8 (85)	98	95	102	101	103	100 a
			Medium maturing (100–120 days)			
IR1561 (96)	101	94	96	97	98	97 ab
IR2307 (100)	78	80	88*	74	75	79 d
IR8 (112)	87**	92	90*	99	90*	92 bc
IR2588 (114)	91	88	80	88	92	88 c
IR2145 (106)	71	65	70	63	62	66 e

[a]Figures in parentheses refer to number of days in field. [b]*, ** indicate significantly different from the 20- × 20-cm spacing of the same variety at 5% and 1% levels, respectively. [c]Means followed by the same letter are not significantly different at the 5% level.

the fourth cropping season. Only IR36 proved resistant to the major pests and diseases; however, it failed to yield well in the second and third crop, when planted adjacent to or near susceptible varieties or selections. All varieties or selections, except IR36, were discarded because of serious infestations of bacterial blight, leaf streak, virus diseases, and brown planthoppers. The trial for 1977 was revised to include varieties and selections with a broad spectrum of pest and disease resistance.

Production model. IR36 was selected for a new production model to produce maximum grain yields on a per-day basis. Starting on 4 October 1976, 250-sq m plantings were made on Monday, Wednesday, and Friday of each week. Starting on 4 January 1977, harvesting was done on Tuesday, Thursday, and Saturday.

Cropping systems program

Asian Cropping Systems Network

Multiple Cropping Department

The IRRI cropping systems program aims to increase food production in South and Southeast Asia by identifying more productive rice-based cropping systems that are acceptable to small-scale farmers. To accomplish that objective, the Cropping Systems Network (CSN) was initiated in collaboration with government agencies involved in cropping systems research and production programs in several Asian countries. The CSN was designed to help national programs increase cropping intensities through collaborative work in cropping systems in Asia (Table 1).

SELECTION OF RESEARCH SITES

Priority is given to rice areas with potentials for increased production per crop season and intensive cropping from one rice crop to two crops or from two to three crops. Such areas are rainfed lowland and partially irrigated (irrigated during the rainy season but without sufficient water to irrigate another rice crop during the dry season). Irrigated and rainfed upland rice areas are included, particularly in countries like Malaysia and Indonesia where the development priorities are on those rice lands.

The major efforts in 1976 concentrated on the design and testing of cropping patterns in the operational test sites and selection of additional sites in other countries. In 1976, 12 sites were operational compared with only 6 in 1975; most of the new sites started research in May (Thailand) and October 1976 (Sri Lanka).

Cropping pattern studies in the test sites in 1976 varied from country to country, and from site to site. In the lowland irrigated rice areas (Indonesia, Thailand, and Bangladesh), four major patterns were used: 1) rice-rice-rice, 2) rice-rice-upland crop, 3) rice-rice, and 4) rice-upland crop-upland crop.

Six cropping patterns were tested in lowland rainfed and partially irrigated rice areas (Philippines, Indonesia, Bangladesh, Thailand, and Sri Lanka): 1) rice-rice-upland crop, 2) upland crop-rice-upland crop, 3) rice-upland crop-upland crop, 4) rice-rice, 5) rice-upland crop, and 6) upland crop-rice.

In upland rice areas (Philippines and Indonesia) five cropping patterns were investigated: 1) rice-upland crop, 2) rice-upland crop-upland crop, 3) rice + upland crop intercrop, 4) rice + upland crop intercrop + upland crop relay + upland crop intercrop + upland crop intercrop, and 5) rice + upland crop intercrop + upland crop relay + upland crop intercrop.

Among the many upland crops used, the most commonly grown were corn, sorghum, soybeans, peanuts, sweet potatoes, mung beans, cowpeas, and cassava. Other upland crops used at some sites are muskmelon, cucumber, and bush sitao.

SITE-RELATED RESEARCH METHODOLOGY

Research in the CSN is carried out in farmers' fields, and the farmers participate in the development of the technology. The test site usually includes two or more villages. Research on component technology such as fertilization, varietal evaluation, tillage, insect control, and weed control is conducted in farmers' fields managed by either farmers or research workers in the Philippines, Indonesia, and Sri Lanka. The number of farmer cooperators varies from site to site, depending on the environment. The Philippines, Indonesia, and Bangladesh have two kinds of cooperators—agronomic and economic; Thailand has only agronomic cooperators. Economic cooperators are involved in keeping farm records and agronomic cooperators participate in biological research—mainly cropping pattern trials.

A research team, headed by the site coordinator, is assigned to each site. The site coordinators in Indonesia, Thailand, and Sri Lanka were trained at IRRI. The number of research personnel at each site depends on the volume of work. Each site has at least two professional staff members and several field assistants. The number of research staff in outreach sites in the Philippines and Indonesia is sufficient. More are needed in Sri Lanka and Thailand, and will be added in the next cropping season. The research team lives near or at the site, to effectively and efficiently supervise the implementation of the research projects in farmers' fields.

Table 1. Location, description, collaborators, and state of development of sites participating in the Asian Cropping Systems Network, 1976.

Location	Description[a]	Site development (years of activity)	Collaborator
Philippines			
1. Oton and Tigbauan, Iloilo	R-L, P-I	2	Bureau of Plant Industry
2. Tanauan, Batangas	U	4	"
3. Manaoag, Pangasinan	R-L, P-I	2	"
Indonesia			
4. Bandarjaya Gunung Sugih, Lampung	U, P-I	1	Central Research Institute for Agriculture
5. Jatibarang, Indramayu	I, P-I	1	"
Bangladesh			
6. Joydebpur	R-L, I	1	Bangladesh Rice Research Institute
Thailand			
7. In Buri, Singhburi	P-I, I	1	Dept. of Agriculture, Technical Division and Division of Agricultural Economics
8. Pi Mai, Nakhon Ratchasima	R-L	$\frac{1}{2}$	Dept. of Agriculture, Rice Division and Division of Agricultural Economics
9. Ubon, Ratchathani	R-L, P-I-T	$\frac{1}{2}$	"
10. Bangpae, Rajburi	R-L	$\frac{1}{2}$	Kasetsart University
Sri Lanka			
11. Walagambahuwa	P-I-T	$\frac{1}{2}$	Department of Agriculture
12. Alankara and Moragani, Katupota	R-L	$\frac{1}{2}$	"

[a]U = upland rice; I = irrigated rice; R-L = rainfed lowland (bunded); P-I = partially irrigated rice; P-I-T = partially irrigated, rice-tank fed.

CROPPING SYSTEMS SYMPOSIUM, SEMINAR, MEETINGS, AND TRAINING

Sixteen research administrators from Thailand, Indonesia, the Philippines, Nepal, Malaysia, India, South Korea, Bangladesh, and Sri Lanka attended a seminar on 26-28 January 1976 at IRRI to learn about recent developments in cropping systems research. Research methodologies, production programs, and the establishment of good working relations among key administrators in Asian countries collaborating with the cropping systems network were emphasized.

A symposium on cropping systems research and development for the Asian rice farmer was held on 21–24 September 1976 at IRRI. The 61 participants came from 17 countries; the majority (50) came from Asia. The objectives were 1) to bring together leading scientists in the region and from other parts of the world to exchange information and ideas on how to accelerate and to efficiently conduct research and development programs on rice-based cropping systems, 2) to discuss and develop approaches in implementing the different phases of cropping systems research and development programs, and 3) to identify areas for further collaboration among the programs in Asia and IRRI. The proceedings will be published.

A working group composed of program leaders from the collaborating countries, the IRRI program leader and network coordinator, and some representatives from outside the region met twice in 1976.

At the meeting held in Bangkok, Thailand, on 16–18 February 1976, the group discussed design and testing of cropping patterns, economic analysis of cropping systems, cropping systems information delivery systems, plans for a cropping systems symposium, weed control research methodologies, varietal testing, and approaches to production programs.

The working group met on 20, 24, and 25 September, before and after the symposium, to present highlights of the work and research plans of each member country. The members discussed development of an in-country training program, varietal testing, direct seeding, farmer participants' research approach, superimposed trials on cropping patterns, environmental classification, and a handbook of economic analysis.

Five major accomplishments of the working group, in addition to sharing research information by reviewing the research data and plans for the following crop season, are:

- Current awareness of research methodologies in cropping systems research
- Formulation of a conceptual framework for cropping systems research and development to be adopted by the national programs
- Development of a strategy for sharing and pooling research information
- Development of a varietal testing scheme
- Preparation of a format for monitoring cropping pattern trials and the environment.

A major activity of the IRRI cropping systems program is the training of research and extension workers involved in cropping systems research and development programs. Priority for training is given to young scientists who are directly involved in the collaborative project and in national research and production programs. In 1976, more emphasis was given to training of research personnel who are or will be involved in the cropping systems research sites. The training programs are summarized in the section of this report on IRRI's training programs.

SHARING OF RESEARCH INFORMATION

The CSN facilitates the exchange of research information among scientists in Asia working on cropping systems research. Research papers on cropping systems research are sent to the CSN office for duplication and distribution to scientists involved in cropping systems research, and extension and production programs. Workshop and symposium proceedings relevant to cropping systems are also distributed within the network.

In 1976, 24 papers, 2 reports of the cropping systems working group, and 2 proceedings (international workshop on farming systems and symposium on cropping patterns in India) were distributed. A total of 199 scientists from Indonesia, Thailand, India, South Korea, Malaysia, Nepal, the Philippines, Bangladesh, Burma, and Sri Lanka received CSN publications through the cropping systems program leaders or coordinators in each country. An additional 36 scientists from 11 countries in Europe, North America, South America, and Africa received CSN publications.

Machinery development and testing

Agricultural Engineering Department

SUMMARY

Machinery development efforts in 1976 were concentrated on the development of a new 6- to 8-hp tiller and a portable axial-flow thresher. The new power tiller design offers increased durability and versatility and will replace the present 5- to 7-hp design. It can accommodate diesel or gasoline engines and has steering clutches as an important added feature. The portable axial-flow thresher was developed to meet the demand for a low-cost thresher for rice farmers who cannot afford the more expensive axial-flow thresher. It is lightweight and can be carried into the field by two men. The thresher's capabilities for threshing sorghum and soybeans look promising.

Four other projects initiated during 1976 were a rice seedling transplanter, a multicrop upland seeder, a rice straw-or hull-fueled steam engine, and a granular-chemical injector for upland crops. Work continued on the development of a windmill-driven water pump, a liquid injector for lowland rice, and a portable grain cleaner.

The compacted soils study completed its eighth cropping season. The rate the compacted layer is deepening has decreased but has not yet stabilized. The four-wheel tractor experienced some bogging problems during the fifth cropping season, and excessive bogging during the sixth season prevented its use for land preparation.

Power tiller owners and dealers surveyed in selected areas in the Philippines indicated that farmers desire a tiller that is more durable and easier to handle. Furthermore, they prefer to purchase from dealers that provide good after-sales service and have an adequate stock of service parts.

The US Agency for International Development-funded Industrial Extension projects in Pakistan and Thailand are fully operational. They are actively promoting IRRI designs among manufacturers and farmers and have begun evaluating and adapting IRRI machines to local conditions.

With the addition of subcontracts in Bangladesh, India, and Malaysia, seven Industrial Extension subcontracts are now active. Over 30,000 machines based on IRRI designs were commercially produced in 1976.

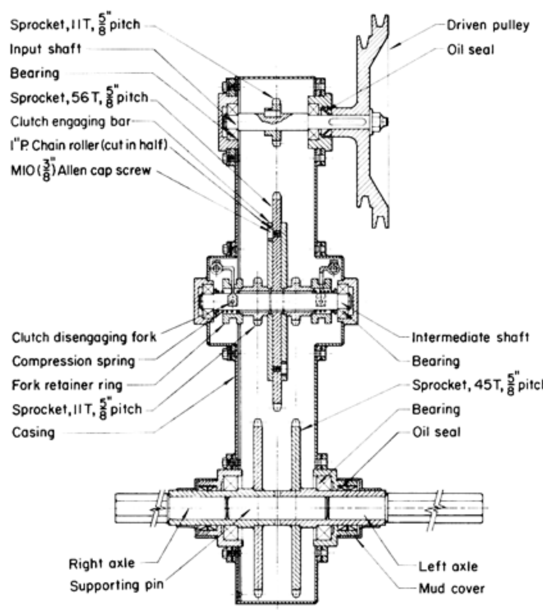
MACHINERY DESIGN

Agricultural Engineering Department

6- to 8-hp tiller with steering clutches. Feedback from farmers and manufacturers on the present 5- to 7-hp tiller indicated a preference for a diesel-powered unit with steering clutches and improved durability. Design efforts focused on keeping the product cost low and avoiding highly technical production processes.

The new design uses a single transmission casing instead of the two in the previous design (Fig. 1). One size of roller chain is used throughout and only three sizes of sprockets are required. Two bearing sizes, instead of four, are used. Although steering clutches were added to the new design, a 20% reduction in repair parts inventory items and a 14% reduction in the cost of manufacturing the transmission were achieved.

The steering clutch mechanism is located on the intermediate transmission shaft (Fig. 2). Two



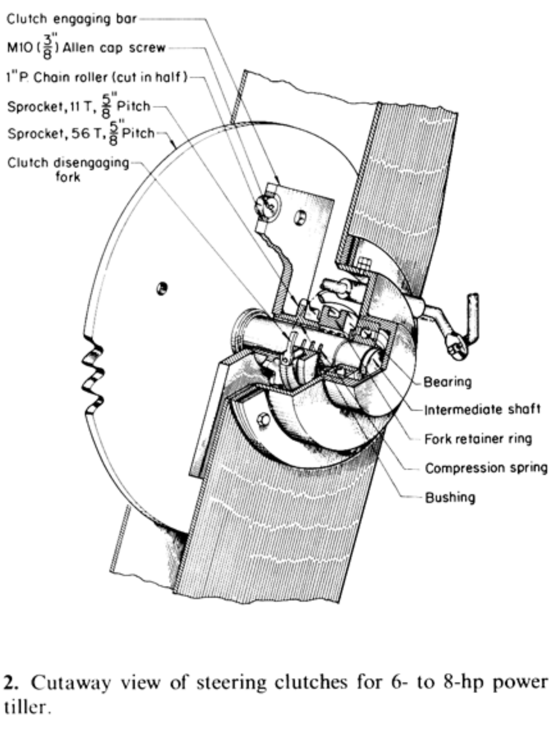
1. Cross-sectional view of IRRI 6- to 8-hp power tiller with steering clutches.

cap screws on each side of the first reduction-driven sprocket engage flat bars welded to the ends of the final reduction-driven sprockets. When the clutch lever is pressed, the disengaging fork slides the flat bar out of engagement with the cap screws to effect de-clutching.

Without an engine, the new design weighs 10% less than the previous tiller. With a diesel engine, it weighs considerably more than the previous gasoline-powered tiller, and necessitates a different cage wheel design for lowland operations. A wheel with a larger diameter and wider lugs was used.

With a gasoline engine, the new design gave satisfactory results. The reduced weight and increased flotation wheels allow negotiation of fields that are too soft for the 5- to 7-hp tiller. When fitted with a gasoline engine, the design requires no steering clutches. The transmission was subjected to accelerated life test on a dynamometer.

Steering clutches for 5- to 7-hp tiller. Development and testing work on steering clutches for the 5- to 7-hp tiller continued early in 1976,



2. Cutaway view of steering clutches for 6- to 8-hp power tiller.

but with the encouraging results with the steering clutches on the new 6- to 8-hp tiller, work on the 5- to 7-hp tiller project was suspended pending completion of tests on the new design.

Small four-wheel riding tractor. The four-wheel tractor prototype described in previous reports was tested in lowland and upland fields. It was also subjected to drawbar-pull testing by making it pull a loaded sled on hard ground. The tests uncovered weaknesses in the drive train that required some component redesign.

During field tests, the tractor prepared 1.6 ha of lowland paddy fields/8-hour day using a rotary tiller 1.37 m wide. The tractor can plow about 0.5 ha of dry land/day using a single moldboard plow with a 25-cm bottom. A 0.82-m-wide rotary tiller can be used for upland work at a forward speed of 1.4 km/hour and a depth of 10 cm.

The industrial extension teams in Pakistan and the Philippines are conducting detailed cost analysis to determine if the design is competitive, pricewise, with imported tractors of the same size.

Multicrop upland seeder. Improvements in seeding methods can raise yields by establishing more uniform crop stands. Limited water and variable climate in many areas of the tropics make planting on schedule critical to yield, and the slow pace of manual planting techniques is often a limiting factor. A project was started in 1976 to develop an economical multicrop seeder that can easily vary row spacing and seed spacing in the row.

The first prototype (Fig. 3) has individual seed hoppers and seed-metering plates for each of its five rows. The seed plates are pinned to a common oscillating frame, which is driven by a cam on one of the two ground wheels. There is a provision for disengaging the cam drive during transport and turning at the end of rows.

Row spacing can be varied from 20 cm upwards in 20-cm increments by selectively filling the hoppers. The seed plate has seven pairs of graduated holes, and seeding rate is varied by adjusting the seed plate position to expose different-size holes to the seeds in the hopper. Spacing within the row is adjusted by

3. Prototype of multicrop upland seeder being pulled by a power tiller.

selecting different cams on the ground wheel. Individual seed hoppers and seed plates for each row permit simultaneous planting of two crops. For example, a row of corn can be seeded with a row of beans on either side.

In preliminary field tests uniform seed placement was achieved in planting rice, soybeans, mung beans, and corn with small kernels. Some bridging occurred in the planting of large-kernel corn seeds and peanuts. It took 3 to 5 hours to plant 1 ha when the seeder was pulled by a power tiller. Seed plate changes and seed rate adjustments were made easily without tools.

To prevent the bridging of large seeds, the hopper bottoms will be widened and the oscillation length will be increased. Press wheels will also be added.

Rice transplanter. Transplanting 1 ha of rice requires about 100 man-hours. It is one of the most labor-consuming phases of rice production. Commercially available transplanters can reduce labor requirements below 10 man-hours/ha, but their cost is too high for small Asian farmers. The machines also often encounter difficulty in coping with the field and seedling conditions in tropical Asia.

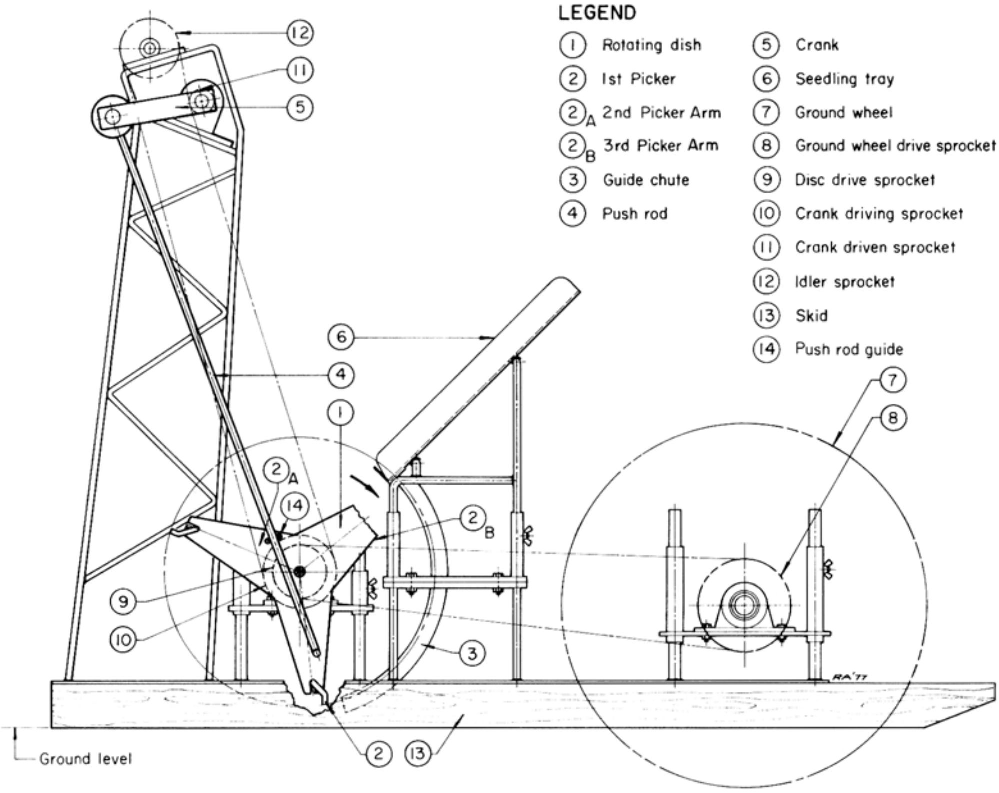
IRRI initiated a transplanter development project in 1976. The effort concentrated on development of an appropriate seedling picking and planting mechanism. One approach tried was a simple rotating disc carrying a number of "pickers" to pick seedlings from a seedling tray. The picker consists of a pair of 5-mm diameter steel rods, with one finger fixed to the disc and the other hinged sideways. The hinged finger engages a stationary cam to effect release of the seedling as it enters the soil. The mechanism was tested in a soil bin with simulated flooded field conditions. It singled out mat-type seedlings well, but the seedlings were not planted erect and often stuck to the disc because mud accumulated on the pickers.

Another design used a fork-shaped picker with three points. The disc was raised so that the pickers did not touch the soil. A guide chute was provided to prevent the seedlings from dropping off the picker as they were pulled from the seedling tray. A crank-driven pushrod pushes the seedlings off the picker fork and into the soil (Fig. 4). Initial tests indicated that this type of mechanism will accommodate a wide range of seedling lengths and water depths.

Liquid applicator for lowland rice. The two-row liquid applicator for lowland rice described previously (1975 Annual Report) was further tested. The flow of the solution could not be detected unless the nozzles were withdrawn from the mud, a shortcoming that worried operators. A flow indicator made of transparent plastic tubing was installed to make the movement of the solution visible.

A four-row applicator with a float-valve flow regulator in an auxiliary container was developed (Fig. 5). An almost constant flow rate is attained by maintaining a constant level in the auxiliary container, regardless of the liquid's level in the main tank. A hand-controlled rubber tube clamp was installed on the outlet tube of the flow regulator as a means of cutting off flow during transport or change of row. A large nylon strainer was installed inside the flow regulator to prevent granules and undissolved materials from clogging the nozzles. Four plastic tubes of equal length with 3-mm internal diameter connect the injector nozzles to the main outlet of the flow regulator, and control and equalize the flow of liquid to individual nozzles.

Limited tests indicate that the four-row applicator is about as easy to push as the two-row unit. That characteristic is attributed to the improved operator position in the four-row design. Both machines are difficult to push in



4. Experimental transplanting mechanism which uses a crank-driven pushrod to plant seedling into the soil.

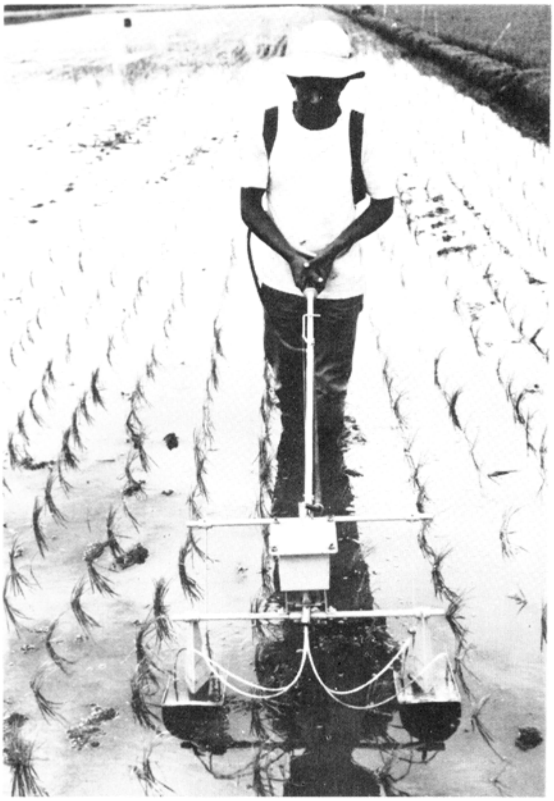
poorly prepared fields and in fields where the soil consolidates rapidly after tillage.

Granular chemical injector for upland crops. A device for applying granular chemicals by spot injection was developed (Fig. 6). It operates when a cross lever is rocked about its central pivot, causing two rods to alternately enter a tapered nozzle with an opening slightly larger than the diameter of a rod. While one rod extends through the nozzle opening, the other rod completely withdraws. When the cross lever is actuated, the extended rod withdraws from the nozzle, leaving a cavity in front of the nozzle opening. The other rod simultaneously pushes fertilizer into the soil cavity left by the retracted rod. Rate adjustment is obtained by using different-size nozzles and by varying the length of pushrod stroke. Three nozzle sizes were tested with five types of fertilizer. Initial tests indicate that the injector will apply fertilizer to a wide range of crops.

Portable axial-flow thresher. Trailer- and tractor-mounted threshers have difficulty negotiating soft paddy fields and are normally stationed on firm ground near the grain to be threshed. Previous studies indicate that 2 to 7% of the grain is lost in moving paddy from the field to the threshing area. Loss can be minimized if threshing is done in the field.

A portable thresher (Fig. 7) that can be used as a hold-on or throw-in thresher was developed. When powered by a 5-hp air-cooled gasoline engine, the thresher weighs about 100 kg. To keep weight and cost low, the thresher has no cleaning system. Threshed grain falls through a woven wire concave and collects beneath the thresher.

The threshing drum of the portable thresher is much shorter than that of the trailer-mounted axial-flow thresher, but grain separation loss is less than 2%. The loss is kept low by increasing the time the paddy stays in the thresher. That



5. Four-row liquid injector with float-valve flow regulator.

6. Spot injector for applying granular chemicals in the root zone of upland crops.

has been achieved through stripper bars installed in the concave, reduction in angle of the louvers that impart axial-flow motion, and decrease in distance between peg teeth on the cylinder.

IRRI's Rice Production Training and Research Department used the thresher to thresh rice, sorghum, and soybeans. Three operators could thresh 2,000 to 3,250 kg rice/day depending on their experience and the location of the crop being threshed. The capacity was 2,400 to 3,600 kg/day for sorghum and about 3,000 kg/day for soybeans.

Five Filipino manufacturers submitted acceptable prototypes of the portable thresher to IRRI. They have been permitted to begin production on a commercial basis. An additional 11 manufacturers are in various stages of prototype fabrication and evaluation. The new thresher design is being evaluated in India, Korea, Pakistan, Sri Lanka, and Thailand by Machinery Development Program network cooperators.

Portable grain cleaner. The portable grain cleaner (1975 Annual Report) was fabricated using an integral arrangement of the blower and eccentric drive (Fig. 8). This simple arrangement uses one V-belt to drive the cleaning mechanism from the prime mover. Eccentric journals, which impart the oscillating motion to the screen through pushrods, were machined on each end of the blower shaft. Dynamic balancing was achieved by increasing the weight of one blower blade opposite the eccentric throw.

The body of the cleaner is fabricated from 12-mm thick plywood and angle iron. The oscillating linkages are mounted with rubber bushings. The discharge chute was separated from the oscillating assembly to reduce the vibrating mass.

The cost of this portable cleaner is comparable with that of indigenous hand-operated win-

7. Portable axial-flow thresher powered by 5-hp engine.

8. Portable grain cleaner with simplified blower and eccentric drive system.

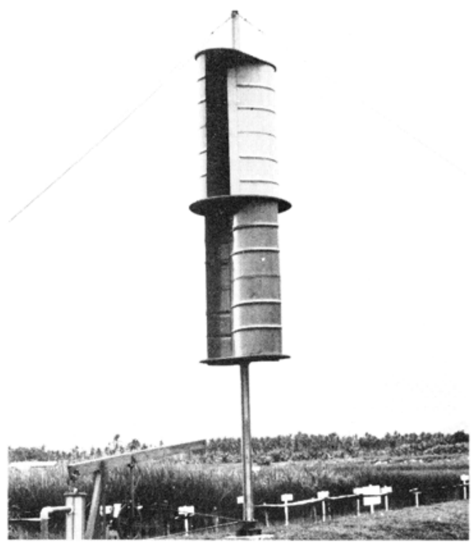
nowers used by Filipino farmers. The IRRI design offers farmers improved performance through a provision for "screening" large impurities such as short straws. The portable grain cleaner can become a companion item to the IRRI portable thresher.

Cleaning performance of the cleaner is equal to that of the 2 t/hour unit developed previously. Capacity is about 1 t/hour. The design will be given to cooperating manufacturers after the completion of durability tests.

Vertical-axis windmill pump. The limited lift capability of the tubular pump design (1975 Annual Report) prompted development of a self-priming piston pump for use with the Savonius rotor windmill. The 15-cm-diameter piston pump uses polyvinyl chloride (PVC) pipe as the cylinder. A leather cup provides a water seal between the cylinder wall and piston assembly. The center portion of the leather cup serves as the outlet flapper valve. The windmill drives the pump with a belt-driven crank. A 5- × 10-cm wooden level connects the pump's piston rod with the crank rod. The lever provides a means of manually operating the pump and balances the pump load at different lift conditions.

To increase starting torque and pumping capacity, the windmill's rotor size was increased. Four oil drums are used in pairs set on the shaft at 90° to each other. A steel tube that serves as both structural support and rotating shaft simplifies the rotor's supporting structure (Fig. 9). Bearings at each end support the rotating structure. Three guy wires are attached to the top bearing to stabilize the unit.

To evaluate the windmill-piston pump under different conditions, units were installed at eight



9. Vertical axis windmill/pump.

Table 1. Capacity of IRRI vertical axis windmill/pump at various wind and lift conditions.

Wind speed (km/h)	Capacity (l/h) at different suction lifts			
	1.5 m	3.0 m	4.6 m	6.1 m
14.5	4,010	2,005	2,340	1,000
16.1	5,530	2,760	1,820	1,380
19.3	9,535	4,770	3,180	2,385
24.1	18,700	9,350	6,210	4,655
32.2	44,290	22,145	14,760	11,053

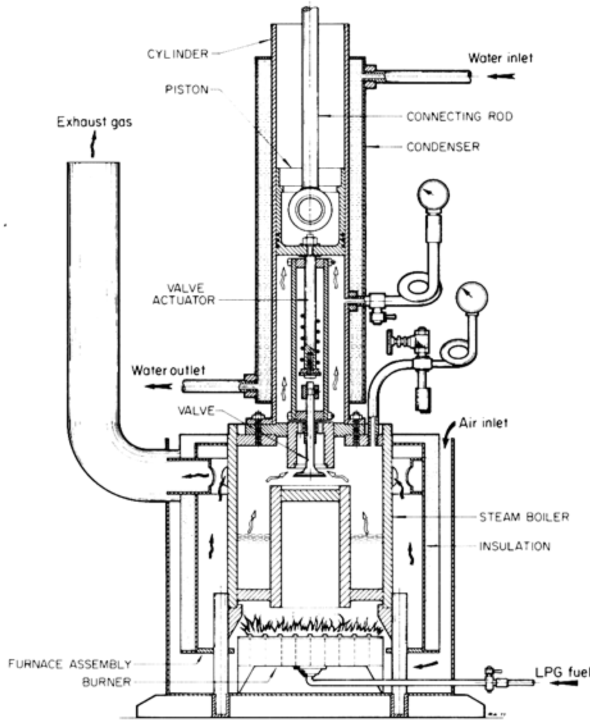
sites in the Philippines. IRRI's Cropping Systems and Rice Production Training and Research Departments are assisting in evaluating the performance of the windmill. Their studies will determine the maximum areas that can be irrigated effectively and identify the best cropping system to maximize utilization.

Pumping capacities for various wind and lift conditions are in Table 1.

Steam engine. A steam engine project was initiated for several reasons. A steam engine fired by rice straw or rice husks may provide the cheapest means of pumping water and performing other stationary engine tasks in view of the limited reserves and high costs of fossil fuel.

The combustion heat contained in rice straw and husks from a 1-ha rice field is about 5.9×10^6 Kcal. The energy required to irrigate 1 ha of rice land from a water supply 6 m below ground level is about 1.4×10^5 Kcal. If energy from rice straw and husks is used for pumping water, conversion efficiency must be at least 2%, which appears feasible with existing technology.

Two types of steam engines were evaluated as prime movers. The first is a simple condensing type (Fig. 10) with boiler, valve, and condenser as integral parts. For experimental purposes, liquefied petroleum gas was used to fire the boiler. The valve is opened by a mechanism attached directly to the piston. As the piston approaches bottom dead center, the valve admits steam to the cylinder, driving it upwards (power stroke). Steam in the cylinder is continuously condensed by the water jacket surrounding the cylinder, a process that causes the piston to travel downwards after reaching the end of its stroke. The condensate returns to the boiler while the valve is open. The valve



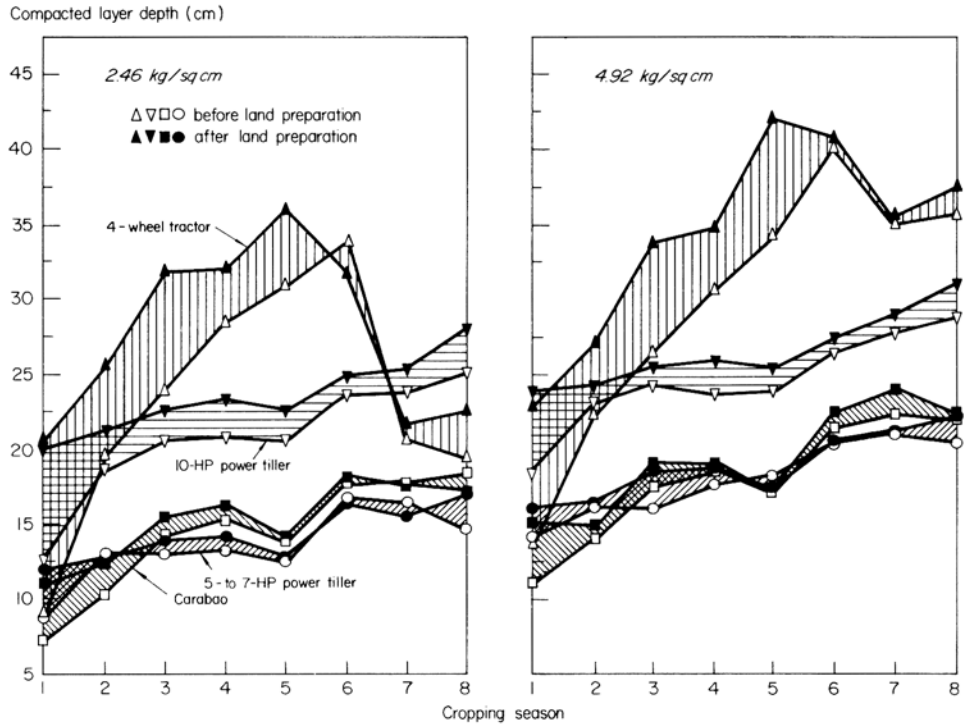
10. Schematic view of steam engine with integral boiler and condenser.

remained open too briefly, however, and waterlogging occurred after 8 to 12 cycles of operation.

The second prime mover tried was an exhausting uniflow steam engine made from a modified, vertical, single-cylinder, gasoline engine. The engine cylinder head was replaced with a steel plate to reduce clearance volume to 4%. A chain-driven rotary valve mounted on the cylinder head contains the inlet valve and an auxiliary exhaust port. Primary exhaust ports are drilled around the lower end of the cylinder wall. Tested with the condensing engine boiler, the engine produced 0.9 hp at 1,400 rpm on 4.2 kg/sq cm steam. Investigation of both engines will continue.

MECHANIZATION RESEARCH

Mechanization research involved machine utilization studies and prototype testing. Information gained from these activities aids in selecting and writing specifications for projects to develop new machinery.



11. Compacted layer depth.

Soil compaction study. A study of compacted soils initiated in 1973 is being conducted on adjacent plots at IRRI station, and is now in its eighth cropping season.

Compacted layer depth is determined by measuring the depth at which penetrometer readings of 2.46 kg/sq cm and 4.92 kg/sq cm are reached. The depth is increasing fastest in the plot where the four-wheel tractor is used (Fig. 11). During tillage for the fifth crop, the four-wheel tractor bogged down in some spots in the plot, but land preparation was completed by the four-wheel tractor with rotary tiller. Tillage for the sixth crop could not be completed with the four-wheel tractor because of repeated bogging. Completion of the tillage operation with a lightweight 5-hp tiller produced a marked change in the movement of the compacted layers. A 5- to 7-hp IRRI tiller was used for land preparation for the seventh crop in the four-wheel tractor plot, using the same tillage procedure as that in the 5- to 7-hp tiller plot. Again the depth of the compacted layer was sharply reduced.

The change in compacted layer depths before and after tillage has become less with each succeeding cropping season. Little change was observed before and after land preparation for the seventh crop.

The study will go on to determine if the compaction depths continue to stabilize.

Multihopper seeder evaluation. The IRRI-designed multihopper seeder can direct-seed rice efficiently where there is good water control. The seeder's advantage over conventional broadcast methods is that the paddy is planted in rows and at a uniform rate for easier weed control and more uniform stand establishment.

A test determined the effects on row stability, stand, and yield of using the seeder with and without furrow openers. Planting on the surface was expected to improve seed survivability when heavy rains occur 1 or 2 days after planting.

Two 0.25-ha fields at IRRI were divided into four plots each. One plot was planted each day, half of each plot with the seeder with furrow openers and half without furrow openers. The effect of rain on the two seeding methods was not determined because there was only one shower during the entire planting period.

Common cultural practices were used on all plots, except herbicide, which was applied to alternate plots. On the average, lodging was somewhat higher in the plots where the seed was deposited on the surface (without furrow openers), although some individual plots where the furrow openers were used also experienced severe lodging (Table 2). Yield differences were insignificant. There was no apparent correlation between the use of herbicide and yield, but lodging was usually more severe in the untreated plots. Pull increased slightly from 12 kg with furrow openers to 13 kg without the furrow openers. Apparently the furrow openers partially support the main float above the paddy surface.

Additional tests will be conducted to determine the effect of heavy rain on the two planting systems. Design changes to reduce pull and provide means for anchoring the seed to the soil surface will be investigated.

Power tiller survey. A survey was made of power tiller owners, water buffalo owners, and tiller dealers in Laguna and Nueva Ecija provinces, Philippines, during the last half of 1976.

The survey sought information on the nature and degrees of tiller utilization; effects of tiller ownership on cropping patterns and intensity, yield, and income; problems related to service, performance, and credit; and future tiller performance and feature requirements. Preliminary results of the owner survey in Laguna and the dealer survey in Laguna and Nueva Ecija are reported.

Table 2. Results of using multihopper seeder with and without furrow openers. IRRI, 1976.

Plot	Herbicide applied	With furrow openers		Without furrow openers	
		Yield (kg/ha)	Lodging (%)	Yield (kg/ha)	Lodging (%)
1	Yes	5050	30	4730	75
2	No	4810	30	5020	90
3	Yes	4010	0	4750	10
4	No	3970	5	3710	50
5	Yes	4240	5	4030	40
6	No	4620	85	4130	10
7	Yes	4750	25	5480	10
8	No	3830	90	4720	60

A significant number of IRRI-designed tillers are scattered throughout Laguna, but imported units are more widely used. The concentration of brands in particular areas is attributed to conditions for which the particular brand is best suited, i.e. farmers with deep fields prefer lightweight tillers. Farmers cited durability, good puddling performance, and the brand's being first in the area as major reasons for buying a particular brand.

Sixty-seven percent of the tiller owners bought their machine between 1970 and 1976. The majority paid cash from either banks or personal resources. Forty-two percent engage in custom work from which they gross $700 to $1000 annually.

Tiller features desired by farmers are:

- improved handling and maneuverability
- increased reliability
- provision of basic repair tools, manual, and extra belts and spark plugs with the new tiller
- availability of spare parts

The purchase price of water buffaloes 2 to 15 years of age ranged from $27 to $270. Present values range from $95 to $550 and may include the offspring. Length of service ranged from 1 to 20 years. Eighty percent of owners reported using the animal exclusively for agriculture. Half of those interviewed do custom work and gross $80 to $540 annually.

Buffalo owners reported problems that include nuisance in the care and maintenance of the animal; limited use in deep fields; and slowness, weakness, and susceptibility to disease. Animal care requires 2 to 6 hours/day. The majority of buffalo owners reported problems in custom hiring tillers. They cited high costs and lack of cash, unavailability during peak planting season, tiller bogging, and poor quality of land preparation.

Farmers' reasons for not buying tillers are lack of capital, small farm size, cost of repair and maintenance, lack of knowledge and experience in using machines, and difficulty in applying for a loan.

Most tiller dealers interviewed began operation during 1974–76. Some started as machine shop operators, or as dealers of other agricultural machines and chemicals. The emergence of dealers during that period—a phenomenon attributed to the start of bank financing programs—resulted in many new tiller brands, especially in Nueva Ecija. Established dealers in Laguna still carry the older brands.

Problems encountered by dealers in marketing tillers are financing (bank moratoriums on the processing of loan applications and delays in loan processing); lack of capital of farmers who cannot meet requirements set by the bank; unpaid installment sales; slow delivery of units and engines from suppliers; dishonest salesmen and high salesmen turnover when incentives are low; people posing as dealers who obtain from farmers a down payment for a tiller that is never delivered; poor appearance of local tillers compared with that of imported units; and competition among dealers.

Test and evaluation. Test and evaluation of IRRI designs is a vital part of the development cycle of designs. Performance tests evaluate the ability of the machine to meet previously determined operating requirements, such as capacity, power, efficiency, cleaning effectiveness, etc. Durability or endurance testing determines the reliability of the machine and its components as a function of time.

During 1976 test activities included:

- 3,000 hours of endurance testing on 20 machines
- 21 performance tests on IRRI prototypes
- 21 performance tests on manufacturers' prototypes

A dynamometer was designed and built for endurance testing of power tiller transmissions and related components. The machine allows continuous testing under controlled conditions and shortens the overall time period required to evaluate the durability of IRRI designs.

INDUSTRIAL EXTENSION PROGRAM

Regional Industrial Extension projects funded by the US Agency for International Development, working in conjunction with the IRRI core-funded Industrial Extension Subcontract program, produced measurable results during 1976. There was a significant increase in the number of IRRI-design machines manufactured, cooperating manufacturers, and cooperative programs.

The regional projects in Thailand and Pakistan started in March and May, respectively, and began extension of IRRI designs to manufacturers.

The Industrial Extension Subcontract programs are hosted by in-country organizations whose objectives are similar to those of IRRI's Machinery Development Program. Currently, there are seven subcontract programs: two in India and one each in Bangladesh, Indonesia, Korea, Malaysia, and Sri Lanka. Cooperative programs were started in 1976 with the Bangladesh Agricultural Research Council, the Malaysian Agricultural Research and Development Institute, and India's Suri Research Foundation. The subcontract in Thailand with the Engineering Division, Department of Agriculture, was merged with the Industrial Extension project.

Since IRRI's Machinery Development Program was started in 1965, approximately 70,000 machines based on IRRI design have been produced. Of this total, 30,456, or about 44%, were manufactured during 1976 (Table 3).

Table 3. Number of IRRI-designed machines commercially produced in 1976.

Country	Manufacturers (no.)	Machines (no.)						
		5- to 7-hp tiller	Axial-flow thresher	Batch dryer	Power weeder	Multihopper seeder	Chemical applicators	Total
India[a]	5	—	70	—	—	6	—	76
Indonesia	6	72	43	7	—	3	120	245
Japan[a]	6	—	—	—	24,500	—	—	24,500
Philippines	19	2,586	552	93	—	57	141	3,429
Sri Lanka	3	45	3	—	—	2	—	50
Taiwan	1	—	—	1,000	—	—	—	1,000
Thailand	8	1,053	97	—	—	1	—	1,151
Total	48	3,756	765	1,100	24,500	69	261	30,451

[a]Estimated production for second half of 1976.

Associated formal training

The educational and training projects at IRRI are an integral part of both the core research program and the international cooperative efforts of the Institute.

In 1976, a total of 244 fellows, scholars, and trainees from 27 countries participated in the training programs. This is a 12.5% increase over the number of participants in 1975. The Institute provided 1,147 man-months or 96 man-years of training in 1976, 11% more man-years than it did in 1975 (Table 1).

RESEARCH PARTICIPANTS

Of the 103 individuals participating in the research-oriented programs in 1976, 16 were postdoctoral fellows, 25 post-M.S. fellows, and 62 research scholars. Sixty percent (60%) of the participants were in four research departments: 22 in agronomy, 16 in agricultural economics, 13 in multiple cropping, and 11 in plant breeding (Table 2).

In 1976, about 76% of the post-M.S. fellows

Table 1. Training (in man-months) provided by IRRI, 1976.[a]

Country	Training provided by IRRI							Country total
				Organized short courses				
	Post-doctoral fellowship	Post-M.S. fellowship[b]	Research fellowship[c]	GEU[d]	6-mo. rice production course[e]	Cropping systems[f]	Agricultural engineering[g]	
Bangladesh		49.5 (5)	26.5 (5)	8.0 (2)	12.0 (2)	7.0 (2)		103.0 (16)
Burma			27.5 (5)	8.0 (2)		10.5 (3)		46.0 (10)
Colombia			12.0 (1)					12.0 (1)
Egypt		12.0 (1)						12.0 (1)
England			12.0 (1)					12.0 (1)
France			2.0 (1)					2.0 (1)
India	73.5 (8)	24.0 (2)		16.0 (4)	18.0 (3)	7.0 (2)	1.5 (3)	140.0 (22)
Indonesia		39.0 (5)	71.0 (12)	36.0 (9)	36.0 (6)	38.0 (14)	1.5 (3)	221.5 (49)
Iran		1.0 (1)		4.0 (1)				5.0 (2)
Japan	16.0 (2)	5.5 (1)	3.5 (1)			3.5 (1)		28.5 (5)
Korea		12.0 (1)	10.5 (3)			3.5 (1)	1.0 (2)	27.0 (7)
Malaysia		12.0 (1)				25.0 (15)	1.0 (2)	38.0 (18)
Mali			10.0 (2)					10.0 (2)
Mexico				4.0 (1)				4.0 (1)
Nepal	12.0 (1)			4.0 (1)	6.0 (1)			22.0 (3)
Netherlands	7.5 (1)							7.5 (1)
Pakistan	11.5 (1)		2.5	20.0 (5)	6.0 (1)		0.5 (1)	40.5 (8)
Philippines	9.5 (2)	21.0 (3)	41.0 (9)		30.0 (5)	13.0 (8)	0.5 (1)	115.0 (28)
Senegal			15.0 (3)					15.0 (3)
Sierra Leone			7.0		12.0 (2)			19.0 (2)
Sri Lanka			12.0 (1)			12.0 (8)	1.5 (3)	25.5 (12)
Taiwan		6.0 (1)	29.0 (4)					35.0 (5)
Thailand		7.0 (1)	60.0 (10)	8.0 (2)	48.0 (8)	23.5 (13)	1.5 (3)	148.0 (37)
Trinidad			3.0				0.5 (1)	3.5 (1)
U.S.A.		13.0 (2)	22.5 (2)					35.5 (4)
Vietnam	6.0 (1)	3.0 (1)	7.0 (1)					16.0 (3)
West Germany			3.5 (1)					3.5 (1)
Total man-months	136.0	205.0	377.5	108.0	168.0	142.5	9.5	1147.0
Total number of participants	(16)	(25)	(62)	(27)	(28)	(67)	(19)	(244)

[a]Numbers not enclosed in parentheses indicate man-months; those enclosed, number of participants. [b]For rice scientists with M.S. degrees, working for either the Ph.D. or a second M.S. degree, or working in association with IRRI scientists on specific research problems. [c]For rice scientists with B.S. degrees, working either for the M.S. degree or with IRRI scientists on specific research problems; four participants are listed under organized short courses. [d]Four-month Genetic Evaluation and Utilization (GEU) training program designed for individuals involved in the development of improved rice varieties. The course emphasizes the multidisciplinary approach. [e]Designed to train rice production specialists and extension workers in the principles and practices of modern rice production so that they can train individuals to conduct similar training programs in their home countries. [f]Includes the 6-month cropping systems course, a 2-week course for applied research personnel, a 1-month training program for site coordinators and supervisors of the cropping systems network, and a 1-month economics training for field staff of the cropping systems network. [g]Two-week training program dealing with the manufacture and utilization of IRRI-designed machines and intended for individuals from the engineering staff of cooperating organizations, who are now or plan to be closely associated in the manufacture of IRRI-designed machines.

Table 2. Distribution of research-oriented participants in IRRI departments, 1976.

Department	Participants[a] (no.)			
	Postdoctoral fellows	Post-M.S. fellows	Research scholars[b]	Total
Agricultural Economics		6 (6)	10 (10)	16
Agricultural Engineering	2		2 (1)	4
Agronomy	1	2 (2)	19 (9)	22
Chemistry	1			1
Entomology	1	4 (4)	3 (1)	8
Multiple Cropping	2	3 (3)	8 (6)	13
Office of Information Services			1	1
Plant Breeding	2	2 (1)	7 (2)	11
Plant Pathology	1	2 (2)	2 (2)	5
Plant Physiology	2		2 (1)	4
RPTR[c]		2 (2)		2
Soil Chemistry	2		2	4
Soil Microbiology	2	1	1	4
Statistics		2 (1)	3 (2)	5
Water Management		1 (1)	2 (2)	3
Total	16	25 (22)	62 (36)	103

[a]Numbers in parentheses represent degree candidates at the University of the Philippines at Los Baños (UPLB) or candidates conducting a research project at IRRI to fulfill the theses requirements at another University. [b]Excluding four individuals listed in Table 1: one in the IRRI Library, two doing instrument and laboratory equipment repair, and one in the office of the farm superintendent. [c]Rice Production Training and Research.

matriculated for the Ph.D. degree and 24% for a second M.S. degree; 58% of the research scholars were working for the M.S. degree. All the M.S. candidates worked for the degree at the University of the Philippines at Los Baños (UPLB). Some of the Ph.D. candidates conducted their research projects at IRRI to fulfill the dissertation requirements at other universities.

TRAINING PROGRAMS IN SUPPORT OF INTERNATIONAL RESEARCH NETWORKS

The training programs included the 4-month Genetic Evaluation and Utilization (GEU) course, four short courses in cropping systems, and two 2-week agricultural engineering training programs.

The number of participants (27) from 9 countries in the GEU training program in 1976 was about twice the number of participants from 6 countries in 1975.

The four short courses in cropping systems were 1) a 6-month cropping systems course for researchers involved in the international cropping systems network sites or in national cropping systems programs; 2) a 2-week course for applied research personnel at the network sites; 3) a 1-month training program for network site coordinators; and 4) 1 month of economic training for field staff of the cropping systems network. The 6-month cropping systems training program was started in September during the rainy season to enable the participants to grow crops under rainfed conditions.

Nineteen engineers from nine countries attended the two 2-week agricultural engineering courses. The participants were either from government organizations or private manufacturers who are currently or plan to be associated with the manufacture and evaluation of IRRI-designed machinery.

RICE PRODUCTION COURSES

Six-month rice production training program. The 6-month rice production course began in March 1976 and was attended by 28 trainees from 8 countries. The participants, all employed by their respective governments, were involved in rice research and extension work. Those from Indonesia were extension workers working in the BIMAS Program (a government program for increased rice production). The BIMAS Program gave funds for the travel of its staff and IRRI provided billeting and stipend.

Two-week rice production courses. A 2-week rice production course was conducted during 19–30 January for the Institute's junior researchers, and research fellows and scholars in the more specialized research departments. The 32 participants were trainees who could not be accommodated, because of the large number of requests, in the December 1975 2-week course.

The four other 2-week rice production courses were offered 1) 5–17 January for participants in the 1-month cropping systems course for site coordinators and supervisors of the cropping systems network; 2) 1–12 March for participants in the 4-month GEU training program; 3) 30 August–10 September, as practical experience for the 6-month rice production trainees in training others under similar training programs when they return to their countries; and 4) 6–17 December for IRRI research scholars and junior researchers.

A total of 148 individuals participated in the 2-week courses. That number is not reflected in Table 1 because the participants are reported under the other training programs, such as GEU, cropping systems, and others.

NAMES AND COUNTRIES OF PARTICIPANTS

Individuals who completed their programs during 1976, including those studying abroad under IRRI scholarships provided by the different country programs, are listed. Their countries and research project areas are given. An asterisk (*) indicates completion of the M.S. degree; two asterisks (**) denote completion of the Ph.D. during the year.

RESEARCH SCHOLARS

Agricultural economics

Sumalee Apiraksirikul.* Thailand. Rice trade between the Philippines and Thailand.

Chucheep Piputsee.* Thailand. An economic analysis of manufacturing and distribution activities in the agricultural machinery industry of the Philippines.

Somsak Prakongtanapan.* Thailand. Rice supply relation in Thailand.

Jerome Sison.* Philippines. Rice supply relation in the Philippines.

Suh Wan Soo.* Korea. Factors affecting the rate of adoption of Tongil rice variety in selected locations of Korea.

Supan Suwanpimolkul.* Thailand. Factors affecting adopting HYV's in Thailand.

Tsai Shy-Lih.* Taiwan. Historical examination of costs and returns and changing structure and resources use in rice farming in Taiwan.

Agricultural engineering

Charles Dinanath. Trinidad. Training in agricultural machinery design/development/evaluation.

Agronomy

Victorcito Babiera. Philippines. Increasing fertilizer nitrogen and insecticide efficiency in transplanted and direct-seeded flooded rice.

Farid Bahar.* Indonesia. Prospects for raising productivity of rice ratooning.

Maria Baquiast. France. Study on farm yield constraints in Central Luzon.

Papa Cisse Lo. Senegal. Chemical and cultural practices to control weeds in lowland rice.

Amadou Diarra. Mali. Chemical weed control in transplanted IR26 rice; effects of varietal type and intensity of land preparation on weed control in upland rice; effects of variety, tillage and water depth on weed control in broadcast-seeded flooded rice.

Lin Wen-Long.* Taiwan. Effects of herbicides on weed control in relation to water management.

Evangelista Peruel. Philippines. Testing methods for the estimation of evapotranspiration under Philippine conditions.

Onyas Hertatin Subhan. Indonesia. Nitrogen sources in lowland rice.

Akwut Thasanacongchan. Thailand. Methods, sources, and time of N application for upland rice.

Entomology

Charles Dembele. Mali. Studies on pesticide application/evaluation; ecology; varietal resistance; rodent control; virus diseases.

Tahir Diop. Senegal. Studies on pesticide application/evaluation; ecology; varietal resistance; rodent control; virus diseases.

Than Htun.* Burma. Population dynamics of the yellow rice borer, *Tryporyza incertulas* (Walker), and its damage to the rice plant.

Multiple cropping

Dennis Garrity.* U.S.A. Classifying physical environments as a tool in cropping systems research: Upland rice in the Philippines.

Plant breeding

Choi Sang Jin. Korea. Study on rice quality.

Moon Huhn Pal. Korea. Studies on resistance to major insects and diseases; inheritance of rice grain quality, especially amylose and protein content of rice grain, and grain appearance.

Arbab Ali Soomro. Pakistan. Salt tolerance of rice varieties.

Plant physiology

Alioune Coly. Senegal. Screening of cold-tolerant varieties at seedling and booting stages.

Soil microbiology

Masao Sato. Japan. Isolation and identification of nitrogen-fixing bacteria from rice roots.

POST-M.S. FELLOWS

Agricultural economics

Richard Bernsten. USA. Explaining the rice yield gap in the Philippines.

Trung Ngo Quoc.** Vietnam. An analysis of land resource constraints limiting agricultural growth in Thailand and Vietnam.

Wang Hu-Mei. Taiwan. The analysis of risk associated with fertilizer input and variety—implications for economic behavior.

Entomology

Santiago Pablo. Philippines. Resistance to whitebacked planthopper *Sogatella furcifera* Horvarth in rice varieties.

Multiple cropping

Surjatna Sastrawinata Effendi.** Indonesia. Nutrient uptake, insect, disease, labor use and productivity characteristics of selected traditional intercropping patterns which together affect their continued use by farmers.

Tirso Paris. Philippines. Systems analysis and simulation of rice-based multiple cropping systems at the farm level in the Philippines.

Statistics

Sridodo. Indonesia. General statistical work.

POSTDOCTORAL FELLOWS

Plant breeding

Sekhar Chandra Sur. India. Work on trisomic lines of rice established in a background of improved plant type; crosses between the trisomic lines and stocks carrying genes for disease and insect resistance in order to local these genes to respective chromosomes.; linkage relations between the important genes for disease and insect resistance and genes governing important traits such as height, nature of endosperm, grain size and shape, etc.

Plant pathology

K. Manibhusan Rao. India. Some genetical and cytological studies in *Pyricularia oryzae* Cav.

Soil microbiology

Kuk-Ki Lee. Japan. Nitrogen fixation in the rhizosphere and nitrogen metabolism in plants.

SCHOLARS ABROAD

A. J. M. Azizul Islam. Bangladesh. The influence of specific gravity and deterioration of rice seed on field performance under two plant population densities. Ph.D. in Agronomy. Mississippi State University, USA.

RICE PRODUCTION TRAINEES

Gatot Adjisoetopo, Chief of Planning & Programming Subdivision, Badan Pembina Bimas, Central Java Province, Semarang, Indonesia

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CROPPING SYSTEMS TRAINEES

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GEU TRAINEES

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AGRICULTURAL ENGINEERING TRAINEES

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Machlan Ghozali, General Manager, Kacho Company, Tegan, Indonesia
Jayasiri Gunasekera, Lecturer, Industrial Development Board, Department of Production Engineering, University of Sri Lanka, Peradeniya, Sri Lanka
Mohammad Ilyas, Research Aide, IRRI-PAK Agricultural Machinery Program, Rawalpindi, Pakistan
Isak Irawan, Engineer, P. T. Unimas Motor Wasta, Jakarta, Indonesia
Kim Yeong Dull, Design Engineer, Korean Institute of

Science and Technology, Dong Dae-Mun, Seoul, Korea
Swaminathan Kollengode, Professor, Tamil Nadul University, Coimbatore, India
Henricus Nanayakkara, Engineer, Industrial Development Board, Moratuwa, Sri Lanka
Thirunavukarasu Nithianandan, Agricultural Engineer, Farm Machinery Research Centre, Maha Illuppallama, Sri Lanka
Ong Boon Kok, Works Supervisor, Hup Yuen Engineering Works, Sungei Besi, Kuala Lumpur, Malaysia
Surapong Panichjaroen, Agricultural Engineer, Jyoti Limited, Baroda, India
Park Young-chool, President, Hyup Shin Industrial Corporation, Dangdaemun-ku, Seoul, Korea
Suratman Partohardono, Manager, CV Suratman, Sala, Indonesia
Kanaiyalal Patel, Agricultural Engineer, Jyoto Limited, Baroda, India
Pairoje Phongrapasanit, Engineer, ISI, Chiangmai, Thailand
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ONE-MONTH TRAINING PROGRAM FOR SITE COORDINATORS AND SUPERVISORS

Shariff bin Ahmad, Malaysian Agricultural Research and Development Research Institute (MARDI), Serdang, Selangor, Malaysia
Nukul Bumroongthai, Agricultural Economics Department, Kasetsart University, Bangkok, Thailand
Chee Mooi Kok, MARDI, Serdang, Selangor, Malaysia
Gangodawila, Department of Agriculture, Peradeniya, Sri Lanka
Nasrun bin Hamid, MARDI, Serdang, Selangor, Malaysia
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S. Mahendraraja, Department of Agriculture, Peradeniya, Sri Lanka
Xavier Nathan, MARDI, Serdang, Selangor, Malaysia
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B. K. T. Senaratne, Department of Agriculture, Peradeniya, Sri Lanka
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ONE-MONTH ECONOMICS TRAINING FOR FIELD STAFF OF CROPPING SYSTEMS NETWORK

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TWO-WEEK CROPPING SYSTEMS COURSE FOR APPLIED RESEARCH PERSONNEL

Armando Barachina, Plant Pest Control Officer, BPI-IRRI Multiple Cropping Project, Tanawan, Batangas, Philippines
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Asep Saefuddin, Research Assistant, Department of Agronomy, Central Research Institute for Agriculture, Bogor, Indramayu, Indonesia
Cherm Sangtian, Agriculturist 6, Ubon Rice Experiment Station, Ubon, Thailand
Endang Suhartik, Research Assistant, Department of Agronomy, Central Research Institute for Agriculture, Bogor, Indonesia
Don Edward Suraweera, Agricultural Economist, Land Use Division, Department of Agriculture, Peradeniya, Sri Lanka
Nadh Tesachabutara, Agriculturist 2, Technical Division, Department of Agriculture, Bangkok, Thailand
Romulo Torralba, Plant Pest Control Officer, BPI-IRRI Multiple Cropping Outreach Station, Manaoag, Pangasinan, Philippines
Romeo Villanueva, Plant Pest Control Officer, BPI-IRRI Multiple Cropping Project, Santo Tomas, Batangas, Philippines.

International activities

The general objective of IRRI's international activities is to develop linkages with national programs and to cooperate with them in solving rice production problems under a range of environmental conditions. National programs show a wide range of capabilities and their requirements for IRRI services vary. IRRI offers a variety of services to suit the needs of individual countries.

IRRI uses four major approaches to achieve the objectives of its international program: general services, cooperative country projects, regional collaboration and services, and international networks.

GENERAL SERVICES

The general services that IRRI provides in response to requests from rice-growing nations include those offered by the Office of Information Services and the Library and Documentation Center (described elsewhere in this report), and the training programs outlined in the preceding section. In addition, IRRI provides rice germ plasm and short-term consultancies and gives scientists from national programs the opportunity to participate in IRRI-sponsored conferences and workshops.

IRRI supplied 5,476 seed samples of *Oryzae sativa* cultivars and related species from its genetic collection to 148 researchers in 43 countries. Additionally, it distributed 10,365 seed packets of breeding lines to requesting rice scientists around the world. Seven IRRI experimental lines were named as commercial varieties in national institutions.

Complete information on various characteristics of 18,000 accessions in IRRI's germ plasm bank is now stored on computer tapes. Rice scientists in search of cultivars possessing specified combinations of traits can use IRRI's computerized data services.

Several IRRI scientists traveled in response to requests for short-term consultancies. The requests came from both those countries with which IRRI has cooperative country projects and many other nations with which the Institute endeavors to maintain contact, mainly through exchange of visits (e.g., Burma, Iran, Korea, Pakistan). Several initial contacts resulted in the development of formal cooperative projects; others continued in the form of general cooperation. The cooperation between IRRI and the Office of Rural Development (ORD), Korea, continued to accelerate rice varietal improvement in Korea. Annually, a Korean rice breeder spends about 6 months at IRRI to advance an extra generation of the breeding material during winter. Additionally, the breeder receives training in general rice breeding. IRRI provided similar services to Iran to accelerate the Iranian breeding program.

Strengthened ties with the national program in Burma led to the signing of a general Memorandum of Understanding for cooperative work. Contacts with Vietnam were reestablished. Two Vietnamese attended the April 1976 International Rice Research Conference (IRRC). A delegation of rice scientists from the People's Republic of China visited IRRI in March, and in October seven IRRI scientists visited China. IRRI began to exchange genetic material with both Vietnam and China and hopes to further strengthen working relationships with them.

Several conferences and workshops were held at IRRI to facilitate exchange of information and to develop plans for collaborative work.

International Rice Agro-Economic Network (IRAEN) Workshop. The first of the two 1976 IRAEN workshops was held on 7–11 March at IRRI; the other was held on 12–14 November in Indonesia. A total of 67 participants and observers from 15 countries participated. The March workshop dealt with analytic techniques and methodology, and the November meeting reviewed results and resolved some methodological problems to improve the uniformity of future research.

International Rice Research Conference. About 102 participants and observers from 25 countries attended the IRRC on 12–15 April. The conference involved an evaluation of the 1975 International Rice Testing Program (IRTP) and planning for the 1976 program, as well as discussions on the enhancement of crop production through fertilizer efficiency and evaluation and improvement of the use of insecticides in an integrated pest control program.

International Seminar on Irrigation Policy and Management in Southeast Asia. Thirty-six participants from five countries attended the 22–25 June International Seminar on Irrigation Policy and Management in Southeast Asia. The seminar provided a forum for the presentation of recent research results on irrigation policy and management of irrigation systems, and determined directions for future research.

Symposium on Cropping Systems Research and Development for the Asian Rice Farmer. Fifty-seven participants from 17 countries attended the Symposium on Cropping Systems Research and Development for the Asian Rice Farmer held on 21–24 September. The symposium brought together leading scientists from Asia and other parts of the world 1) to exchange information and ideas on how to accelerate and efficiently conduct research and development of rice-based cropping systems, and 2) to identify areas for further collaboration among the programs in Asia and IRRI.

Deep-Water Rice Workshop. A total of 42 scientists from 8 countries working on deep-water rice attended the Deep-Water Rice Workshop held on 8–10 November in Bangkok, Thailand. They exchanged views, reported on progress in research on deep-water rice, and observed work under way in Thailand.

Conference on the Economic Consequences of the New Rice Technology. Some 48 participants from 13 countries participated in the discussions at the Conference on the Economic Consequences of the New Rice Technology, 13–16 December. The conference had two objectives: 1) to discuss with other knowledgeable research workers information on the impact of modern varieties on agricultural and overall economies, 2) to develop a plan for research on the socio-economic consequences of the new rice technology in the next 10 years.

The proceedings of each conference and workshop, except the IRRC, will be published.

COOPERATIVE COUNTRY PROJECTS

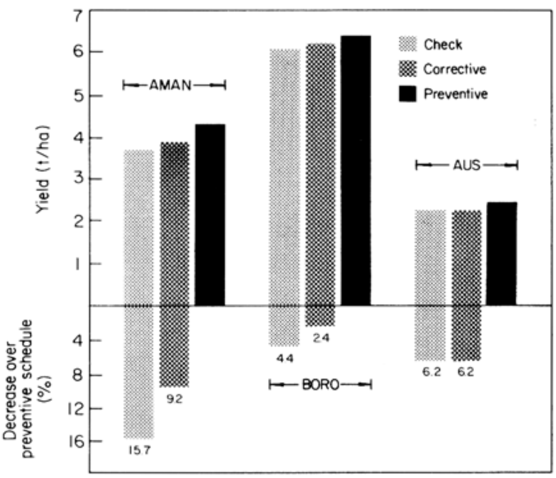
Cooperative country projects help individual countries improve their capacity for rice research and training. They are funded as special projects by different donors. IRRI was involved in cooperative country projects in Bangladesh, Indonesia, the Philippines, and Sri Lanka in 1976. New projects in Burma, Egypt, Pakistan, and Sri Lanka are under discussion.

IRRI scientists in cooperative country projects work as members of the local team. Thus, their efforts are combined in the progress achieved in the joint activities of national and expatriate scientists.

Bangladesh. The cooperative project in Bangladesh was funded by a consortium of donors including the Ford Foundation, the Canadian International Development Agency, and the Australian Development Assistance Agency. The overseas training component of the project was partly funded through a grant by the US Agency for International Development (USAID). Another donor, the International Development Research Centre (IDRC), supported a separate project for strengthening the cropping systems division of the Bangladesh Rice Research Institute (BRRI).

Five IRRI scientists—an entomologist, a rice breeder, a cropping systems agronomist, an agricultural engineer, and a rice production specialist—participated in BRRI's research programs as members of local teams. The IRRI representative worked closely with the director of BRRI, assisted in the development and expansion of research programs, and provided leadership to the IRRI team, in addition to carrying out cooperative work in entomology.

A series of crop-loss assessment experiments, carried out under simulated farmers' field conditions, showed that the use of insecticides was usually not justified in the boro (winter) and aus (early summer) seasons, but that one to two applications were usually required in the aman (monsoon) season (see figure). These results and previous research findings were used in the development of new recommendations for insect control in Bangladesh. The study of the population dynamics of stem borers in farmers' fields around Joydebpur was also completed. The IRRI entomologist assisted the plant protection staff in preparing for publication a comprehensive literature review of the insect pests and diseases of rice in Bangladesh.



Mean rice grain yields for three insect control schedules and decreases over preventive schedule. Data based on 17 crop-loss assessment experiments (6 aman, 6 boro, and 5 aus) carried out in farmers' fields in Bangladesh from early 1974 to mid-1976.

The rice breeder made extensive field trips to become familiar with the main deep-water rice areas in the country, and helped develop a new research program. The genetic material consisting of 5,000 progenies of crosses in different generations was advanced under standard lowland conditions because of a lack of controlled-water tanks. Some undesirable types were eliminated.

Some genetic material was evaluated under natural conditions at the Habiganj substation for deep-water tolerance and at Barisal for adaptation to tidal flooding. In the IRRI-Thailand Cooperative Deep-Water Rice Program, 471 progenies were screened for elongation ability in Thailand, and promising lines were selected. Many new crosses were made and an expanded breeding and testing program for the following year was developed to accelerate the development of varieties for deep-water areas in Bangladesh.

Deep-water rice research is beginning to rate high in priority with BRRI scientists. A new deep-water testing facility with water level control is being installed.

After two Task Force meetings at BRRI and an Asian Cropping Systems Working Group meeting, a new program for research on rice-based cropping systems was developed. It consists of seven projects: 1) survey and evaluation of farmers' existing cropping systems, 2) modification and testing of farmers' cropping patterns, 3) design and testing of potential cropping patterns, 4) identification of suitable crop varieties for intensive cropping systems, 5) identification of constraints to higher yields and more intensive cropping, 6) development of component technologies for intensive cropping systems, and 7) development of mixed cropping, intercropping, and related cropping practices.

Besides the general survey of the existing cropping systems of Bangladesh and some work at the three BRRI substations, much work was done in farmers' fields near the BRRI experiment station, where most farmers grow two rice crops under rainfed conditions and two to three rice crops where irrigation is available.

Experiments involving one to three rice crops combined with other nonrice crops were conducted at the various BRRI stations. Several physical and biological factors influenced the spread of varieties in different seasons. For example, during the season for transplanted aman the shorter seedling height of modern varieties and their susceptibility to low temperature during anthesis in later plantings limited their spread in areas with deep water. In direct-seeded aus rice, poor seedling vigor, poor ability to compete with weeds, susceptibility to early drought, and long duration constrained the spread of high yielding varieties.

Mulching wheat with rice straw increased the efficiency with which wheat utilized residual soil moisture. The mixed cropping system is common in Bangladesh agriculture. Stubble planting of soybeans with transplanted aman rice looked promising for better utilization of residual soil moisture in the dry season.

The IRRI agricultural engineer provided leadership to the Division of Agricultural Engineering in the absence from BRRI of his senior counterparts who were training abroad. He assisted in land development, machinery design and development, and establishment of a maintenance system for vehicles, machinery, and equipment.

Most of the land development work at Joydebpur has been completed. Detailed plans for a permanent irrigation system for the whole farm were completed with the assistance of a consultant. At the Barisal substation a rough grid survey was completed, and a new map on land development was prepared.

The IRRI-designed axial-flow thresher gave good results in the BRRI tests, and plans for its commercial manufacture are being made. An IRRI-designed power tiller built by a local firm will be tested for suitability in Bangladesh. The installation of new equipment improved the BRRI workshop. The agricultural engineering staff initiated small-scale machinery development projects.

The rice production specialist assisted in applied research and production type of training. In addition to the 3- to 5-week short-term training courses, a new 4-month training course was developed for rice production subject-matter specialists who will provide technical supervision and leadership to the extension staff at the subdivision level.

The applied research program, centered in a 148-sq km project area around Joydebpur, was expanded through cooperation with extension agencies. Thirty applied research trials of different types were conducted in farmers' fields. The "farmer-to-farmer" seed-increase program was continued with emphasis on production of seed of new BRRI varieties.

BRRI's operations generally improved. Field research improved in both quality and quantity. The steady increase in simple experiments and trials in farmers' fields in the project area was encouraging. BRRI nominated three new varieties for release: BR5, BR6 (IR28), and BR7. The breeder seed of the varieties was released to the Bangladesh Agricultural Development Corporation for multiplication and dissemination.

The return of scientists who completed their training abroad greatly improved the capability of the various divisions of BRRI. The program of staff development through overseas training progressed well. Eight candidates continued study programs for the Ph.D. degree, and two new Ph.D. candidates began courses during the year. Five are scheduled to return in 1977. The importation of essential equipment and supplies contributed markedly to the development of BRRI. The library and its holdings improved significantly. Several staff housing blocks were completed and more than 60 families were accommodated in Joydebpur by the end of 1976.

In October, a donor Review Mission evaluated BRRI's research programs and activities. It complimented BRRI's research program and recommended that funding be continued.

Indonesia. IRRI and the Central Research Institute for Agriculture (CRIA) continued their cooperative programs at Bogor, Maros, and Sukamandi. The scientists in Bogor were supported by USAID funds; those in Sukamandi, by a credit from the World Bank to the Indonesian Government. The work at Maros was supported by a grant from the Government of the Netherlands. Cooperative activities were undertaken in crop breeding; research in agronomy, entomology, pathology, and rice-based cropping systems; and investigation of constraints to higher rice yields. Some studies were undertaken as components of IRRI's network programs and others as part of CRIA's research programs. In addition to the funds from different donors for special projects, research support was provided by both CRIA and IRRI.

IRRI staff members participated in research, training programs, station development, and research planning. The IRRI agricultural engineer assisted in field development and operations at Sukamandi and Maros.

In 1976, there were four scientists at Bogor (rice breeder, legume breeder, cropping systems agronomist, statistician-economist), three at Maros (agronomist, entomologist, pathologist), and four at Sukamandi (entomologist, pathologist, rice breeder, and agricultural engineer). The statistician-economist at Bogor provided overall leadership and served as IRRI representative in Indonesia.

Early in the year, rice breeders and other scientists developed a set of breeding program priorities on the basis of potential impact on national rice production. Nine basic variety types of rice were defined in terms of the conditions of adaptation. The result improved the definition of breeding objectives and facilitated communication between breeders and problem-area scientists.

The enlarged hybridization facilities at Bogor helped to expand the national crossing program designed to develop rice varieties for lowland irrigated, lowland rainfed, rainfed upland, high-elevation, and tidal swamp conditions. Hybrid populations were screened for resistance to all the major rice diseases and insect pests at different locations.

Pelita-type lines that are resistant to the brown planthopper (BPH) and rice tungro virus (RTV) are being developed. Lines that mature in as many days as Pelita I/1 and those that mature 7 to 10 days earlier look promising. Among them are 10 lines that yield as well as or better than Pelita, mature 7 to 10 days earlier than Pelita, and are resistant to BPH and bacterial leaf blight (BLB). Their reaction to RTV has yet to be determined. They should have good eating quality because the amylose content of their grain ranges from 19.4 to 22.7% (grains of Pelita have 23%). Other promising lines include several B2360 lines that yielded from 4.4 to 7.7 t/ha (Pelita yields 4.5 t/ha) and were resistant to BLB and BPH.

Three IRRI lines grown at Genteng—IR2071-77-3-3, IR2071-473-3-3, and IR2071-6-21-2-3—yielded 6.1, 5.2, and 6.7 t/ha, and showed amylose contents of 23.7, 25.7, and 15.6%, respectively. Pelita produced no yield because of hopperburn. The three lines are resistant to BPH and grassy stunt virus (GSV). These and other promising lines with resistance to BPH and RTV are being screened and yield-tested to determine their potential for commercial release.

The Knl-361 lines continued to show promise at high elevation. One of them was released as Gemur. In a yield trial at Kuningan (moderately high elevation), Gemur yielded 6.7 t/ha while Pelita yielded 5.4 t/ha. At a high elevation (Temanggung) Gemur yielded 3.6 t/ha, but Pelita produced no grains because of sterility. Several B2266 lines show promise and yielded from 4.0 to 4.5 t/ha at Temanggung.

More materials were handled in the Sukamandi breeding program in 1976. The F_1's developed by Sukamandi trainees at IRRI were grown at the station for the first time. Many F_2 crosses and pedigree nursery lines have Pelita as one parent, and many Pelita-type selections were tested for BPH, GSV, RTV, and BLB. The Sukamandi station worked closely with the Bogor and Maros stations in screening rices for resistance to major diseases and insect pests. About 1,000 selections were field screened for resistance to BPH and GSV. Some promising lines exhibited Pelita plant type and resistance to BLB, GSV, BPH, and RTV. Some selections of IR2070 and IR2071 have the BPH2 gene and, possibly, acceptable eating quality.

In the peanut breeding program, high yielding selections with resistance to bacterial wilt, leaf rust, and *Cercospora* leaf spot were planted at Cikemeuh and Genteng. A small preliminary yield trial with 36 of those selections was planted at Cikemeuh.

Two preliminary mung bean trials and early generation materials originating from both intervarietal and interspecific crosses were planted at Cikemeuh. The interspecific crosses transferred the resistance to bean fly of *Vigna mungo* to *V. aureus* (mung bean).

In field trials, cowpea variety No. 126, which is resistant to bean fly and cowpea stunt virus, continued to exhibit resistance to root rot.

BPH populations were studied at three locations in Java. Field surveys of planthoppers in Java, Bali, and North Sumatra showed that the populations were low where the outbreaks had been serious in the previous year, apparently because of a shift to resistant varieties. The populations were high in newly affected areas, such as East Java, West Java, and North Sumatra. The BPH and GSV damaged an estimated 245,000 ha in the 1975–76 wet season and 8,000 ha in the 1976 dry season. IR26 was seriously attacked by the BPH in small areas of North Sumatra in August–September, and by the whitebacked planthopper in Bali in October–November. New BPH biotypes may be present in North Sumatra.

In the screening nurseries in South Sulawesi, several local varieties—Kalibungga, Nggulahi, Pulut rada, and Ase Garis—showed considerable resistance to BPH in the greenhouse. Ase Sawe Saleku and Ntinuwu were resistant to stem borer in the field.

Experiments at Maros on root-zone application of carbofuran in mudballs indicate that it is not advisable to apply the insecticide 5 weeks after transplanting even if no insecticide had been broadcast earlier. Apparently, carbofuran

Table 1. Effect of carbofuran 75SP and BPMC 50EC at 0.5 and 1.0 kg a.i./ha, applied with liquid applicator. Panggentungan, Indonesia, 1976 dry season.

Insecticide	Time of application[a] (WT)	Dosage[b] (kg a.i./ha)	Yield (t/ha)	
			Pelita	IR26
Carbofuran	1	0.5	3.41	5.08
"	4	0.5	3.22	4.92
"	7	0.5	2.45	4.53
"	1	1.0	3.42	4.62
"	4	1.0	3.24	4.72
"	7	1.0	2.55	4.36
Carbofuran, mudball	1	1.0	4.31	4.82
Control		0.0	2.15	4.21
BPMC	1	0.5	3.70	4.89
"	4	0.5	2.81	4.45
"	7	0.5	2.29	2.96
"	1	1.0	4.13	4.53
"	4	1.0	2.93	4.71
"	7	1.0	2.65	4.16
BPMC, mudball	1	1.0	4.21	4.73
Control		0.0	1.32	4.09

[a]WT = weeks after transplanting. [b]a.i. = active ingredient.

is not efficiently absorbed by the roots 3 to 4 weeks after transplanting. Likewise, incorporating carbofuran into the soil before planting does not seem suitable where irrigation cannot be effectively controlled and the land is not properly prepared. The liquid applicator, now being manufactured locally, has considerable potential (Table 1). Yield losses observed on Pelita could be attributed exclusively to RTV, to which IR26 is sufficiently resistant.

Yield losses caused by the rice seedbug and leaf defoliators were studied. The whorl maggot *Hydrellia philippina* did not appear to affect the tiller number of rice under field conditions. The leaf folder *Cnaphalocrosis medinalis* produced between 5 and 15% damage when the flag leaves were severely infested. Likewise, each percentage of whitehead incidence resulted in approximately 1.2% yield loss.

In 1976, 90.2% of the green leafhoppers caught in light traps in Maros was *Nephotettix virescens* and 9.8% was *N. nigropictus*. From 90 to 100% of the stem borer population monitored was *Tryporyza innotata*, and the rest included *Chilo suppressalis* and *Sesamia inferens*.

Plant disease surveys of GSV showed its wide distribution on Java and Bali and serious losses from it in many locations. Losses caused by both the vector (BPH) and the virus declined where the resistant varieties IR26, IR28, IR30, and IR34 were introduced.

In 1976, plant pathologists at Sukamandi screened 11,278 lines for BLB resistance, 493 lines for sheath blight (SB) resistance, and 2,500 lines for GSV resistance. The severity of SB did not increase as plant spacing decreased from 30 × 30 cm to 15 × 15 cm. Rojolele was consistently more resistant than IR28. Leaf spot disease *Cercospora oryzae* was more serious in Sukamandi, and *Helminthosporium oryzae* was more serious in Rembang, Central Java.

When inoculum was present at Maros, 100% tungro infection occurred on susceptible varieties planted in March, April, and May, and 35% when the rice was planted in September and October. Moderately resistant and resistant cultivars showed little infection at both times.

Approximately 90% of the breeding lines tested at Maros showed resistance to BLB; several local varieties—Gewal, Rojolele, and Jeleta—exhibited good resistance.

Evaluation of yield losses caused by SB on Pelita I/1, C4-63, and IR34 rices in the fields at Maros indicated that the time of inoculation—maximum tillering or booting stage—appeared to have no effect on the yield. IR34 exhibited no significant yield loss but the yield loss of Pelita I/1 was 16% and that of C4-63 was 28%.

Indramayu, on the north coast of Java, is characterized by relatively level topography, alluvial clay soils with 4 to 7 months of rainfall exceeding 200 mm, and a long dry season. There the farmers in fully irrigated areas were knowledgeable on new cropping systems technology and have developed stable and productive cropping patterns. In less well-irrigated areas where water was available for only 5 to 7 months, the situation was different. The 1976 dry season was extremely dry, and there was almost no rain from the last week of April until the first week of November. Net returns per hectare almost doubled in places where varieties of shorter duration were used.

Bandarjaya in southern Sumatra, which is characterized by undulating to rolling topography, has more than 6 months of rainfall exceeding 200 mm, and light-textured, red-yellow podzolic soils that are mostly covered with *Imperata cylindrica* or secondary forest. Fertilizer rates similar to those used for lowland rice on good rice land in Java doubled the total production, compared with that in unfertilized plots. In terms of protein production, the yields were equivalent to 11.4 t/ha of rough rice.

Basal applications of nitrogen do not appear to be necessary for rice production in South Sulawesi, particularly where the soil level of available nitrogen is not too low. Previous findings that the broadcast application of all fertilizer nitrogen between active tillering up to a week before flower initiation gave the best yields (even better than three split applications) were confirmed in 1976.

As in 1975, the application of urea in mudballs to lowland rice produced higher grain yields than did the usual method and time of applying nitrogen. Mudball application gave results comparable with those from the application of briqueted urea. The effect of sulfur-coated urea (SCU) was comparable with that of urea, although SCU tended to increase yields more than did briqueted urea or urea in mudballs. The sulfur content apparently improved yields in South Sulawesi, where sulfur deficiency is widespread.

In a series of unreplicated trials at 8 sites in the western part of South Sulawesi, yields at 5 sites responded to applied sulfur with 12 to 45% increases. Improved rice varieties responded to sulfur at all sites; a local rice variety showed a response at only one location. The differential response among the varieties may be attributed to either differences in the amount of fertilizers applied or varietal reaction to low sulfur in the soil.

Philippines. An IRRI crop production specialist continued to work closely with "Masagana 99," the national rice production program, which in 1976 helped maintain rice self-sufficiency in the Philippines for the second year.

About 60% of the Masagana 99 program area was planted to IR26 rice, an increase over the 48% in 1975. Paddy yields of the irrigated area averaged 3.7 t/ha during the dry season and 3.3 t/ha during the wet season; rainfed Masagana 99 yields averaged 2.6 t/ha, which is much higher than the national average of 1.7 t/ha.

The National Food and Agriculture Council (NFAC)-sponsored interagency program, Unified Rice Applied Research Training and Information Program (URARTIP), in which the IRRI crop production specialist actively participated, trained 36 new provincial rice specialists in a 5-month course at Los Baños. In 12 regional 10-day updating short courses, URARTIP trainers, assisted by local resource people, trained 700 rice extension technologists.

Under the URARTIP program, four types of high-priority applied research and farm trials were carried out by field staff of member agencies to provide updated technology for the Masagana 99 program. The seed inspectors of the Philippines Bureau of Plant Industry (BPI) carried out yield trials with new selections. Staff of the Philippine Bureau of Soils conducted fertilizer trials with most promising new rice selections.

Because of the increasing importance of crop protection, the BPI insecticide trials were combined for 1976 with the "verification" trials of the Philippine Bureau of Agricultural Extension. The combined field trials evaluated the 1976–77 Interagency Insecticide Guide for Transplanted Rice by comparing it with the original Masagana 99 guide. The results showed that IR36 yielded 5.1 t/ha with improved management practices but with no insecticide treatment. Application of the 1976–77 insecticide schedule increased the yield by an additional 1.1 t/ha.

The BPH biotype 2 multiplied rapidly in the Philippines during 1976. IR26, the most widely grown rice variety, was seriously affected. Multiplication of seed of the new varieties IR32 and IR36, both resistant to biotypes 1 and 2, was accelerated.

In 1976, the IRRI crop production specialist cooperated with Filipino colleagues in the preparation of 10 Masagana 99 informational publications. More than a million copies of the publications were produced for dissemination.

Sri Lanka. The Ford Foundation-financed Sri Lanka project completed its last year of a 5-year grant. In addition to the project leader who worked for the full year, another technical specialist was employed in the first 6 months. Both assisted in the development of the Paddy Marketing Board (PMB) and its activities; they helped train staff and implement projects for improving paddy procurement, storage, and processing.

The PMB continued to upgrade existing facilities for storage and processing and to build additional storage and processing facilities. Four new complexes were completed during the year, and three others were begun. Each complex includes receiving, cleaning, and drying facilities; space for bulk storage for 5,000; and a 2-t/hour parboiling and rice milling facility. The facilities represent the first integrated storage-processing operation in Sri Lanka.

All civil construction was carried out through local contractors. Machinery for handling, cleaning, drying, parboiling, and most milling operations was manufactured by local firms. The IRRI scientists assisted in the installation of the machinery. With the new integrated facilities, the PMB expects to reduce postharvest losses, improve the quality of rice, and reduce the operational cost of the overall system.

All PMB staff members whose training abroad was supported by the Sri Lanka Project have returned and assumed responsible positions in PMB's development and operational programs. In-country training of PMB technical staff continued at the Project Training Center. Considerable on-the-job training was provided by the IRRI scientists, who also helped in the training program at the newly developed Rice Processing Development Center.

IRRI project staff assisted the government in making detailed studies on the present status of the rice processing industry. The study provided basic information on the equipment and facilities now available to the industry, as well as on the capabilities of the manufacturing sector. Studies on rice production within Sri Lanka and on government policies and plans for increasing rice production were also completed. Revised development plans were completed for future storage and processing requirements.

New projects. Negotiations for implementing a cooperative project in Pakistan were completed. The project requires a rice breeder to help develop a strong national genetic evaluation and utilization program and a rice production specialist to assist in applied research designed to demonstrate the feasibility of greatly increasing production in farmers' fields. The project will be funded by a USAID loan and a Ford Foundation grant. An IRRI engineer is currently working in Pakistan under a regional industrial extension project that was started in 1976.

The Government of Sri Lanka and USAID signed a loan agreement, which provides funds for a cooperative project with IRRI. The project will include the services of an IRRI rice breeder, a cropping systems agronomist, and a crop production specialist to help organize and implement multidisciplinary research programs for varietal improvement and cropping systems.

A cooperative project with Egypt is being considered. The project will ultimately become the base of operations for a regional project to serve the needs of the Middle East.

The growing cooperation between Burma and IRRI assumed a more formal status with the signing of a general Memorandum of Understanding between Burma and IRRI for cooperative work. The Burmese Government has requested IRRI to assign to Burma three scientists in the areas of rice breeding, cropping systems, and machinery development.

REGIONAL COLLABORATION AND SERVICES

IRRI must build long-term linkages with national programs to ensure the relevance of its core research program to important production problems. Only through collaboration with scientists in national programs can research on many problems be most effectively carried out.

Cooperative country projects are funded on a short-term basis and are concerned with specific countries in a region. They do not develop long-term relationships and collaboration. Three liaison scientists will be located in important rice-growing regions in 1977. As country projects phase out, the liaison scientists will continue to provide necessary linkages and channels of communication between IRRI and the different national programs in each region. They will be stationed at strategic locations and associated with either another international center or a strong national program.

The rice-growing world was divided into the following six regions: 1-Indonesia, Malaysia; 2-Thailand, Vietnam, Laos, Cambodia, Burma; 3-India, Sri Lanka, Nepal, Pakistan, Bangladesh; 4-Middle East-Egypt, Iran, Iraq, Syria, Sudan; 5-Africa; and 6-Latin America.

The regional liaison scientists will facilitate the operations of international networks, especially the IRTP, and respond to requests for regional services.

The term "regional collaboration," as used in this report, includes collaborative research jointly carried out by IRRI and national scientists on specific problems of regional importance. Currently, IRRI collaborates with Indian scientists in research on strain variation in the BPH and RTV, and with Thai scientists in research on deep-water rice. A Ford Foundation staff member in New Delhi acts as IRRI liaison scientist in India, and a Rockefeller Foundation staff member in Bangkok serves as IRRI liaison scientist in Thailand.

India. In accordance with a Memorandum of Agreement, IRRI continued to collaborate with the Indian Council of Agricultural Research (ICAR) on the Indian rice program. A grant from the Ford Foundation supports the collaboration.

An agreement reached between ICAR and IRRI provides for the supply to IRRI of all accessions in the Indian collection that are not already available at IRRI for conservation. A collection of 927 samples from the different centers in India was received at IRRI during 1976. For its part, IRRI supplied 661 samples from its germ plasm bank to 14 research centers in India.

IRRI increased the seed of 394 breeding lines that had been included in the National Screening Nursery of the All India Coordinated Rice Improvement Project (AICRIP). The more promising lines will be entered into the 1977 IRTP nurseries.

In 1976, seeds (124 sets) of 14 IRTP nurseries were sent to India for evaluation under stress conditions at 39 sites. The 1976 IRTP nurseries included 378 entries (breeding lines and germ plasm) from India, which represented approximately 20% of the test entries in all nurseries.

IR2071-625-1-252 performed well in the IRTP yield trials in most locations in India and is being tested in the advanced yield trials of AICRIP. The Indian entries IET 2845 and IET 1444 gave good yields in several countries.

Collaborative studies to obtain basic information on strain variation in BPH and RTV and limits of resistance among host varieties and experimental lines continued.

Studies in 1975 at four research stations in India—AICRIP, Hyderabad; Central Rice Research Institute (CRRI), Cuttack; Pattambi; and Pantnagar—demonstrated that the BPH biotypes in India differ from those in the Philippines.

Of the 157 varieties and breeding lines from India tested at IRRI for reaction to 3 BPH biotypes, 7 lines showed resistance to the 3 biotypes, while 38 were resistant to any 2 of the 3 biotypes, but mostly to biotypes 1 and 3. Selected lines that showed resistant reaction to all three biotypes included Ptb 33, four selections of RP825 (Vijaya × Ptb 21) from AICRIP breeding programs, and one selection from each of the crosses Bharati/IR2071-625-3-4 and Triveni/IR1539 from the Pattambi (Kerala) breeding material (Table 2). RP825-71-4-11 showed the highest level of resistance. Most of the ARC lines tested were susceptible to the three biotypes. However, ARC 6650 (resistant at all test sites in India) was resistant to biotypes 1 and 2. Leb Mue Nahng, which was found to

Table 2. Reactions of selected rice varieties and breeding lines from India to brown planthopper biotypes 1, 2, and 3. IRRI greenhouse, 1976.

Line	Reaction[a] to brown planthopper		
	Biotype 1	Biotype 2	Biotype 3
IET 5118 (RP825-24-7-1)	1.2	4.3	3.7
IET 5119 (RP825-41-1-1)	2.3	2.3	5.0
IET 5120 (RP825-74-4-8)	1.7	4.3	3.7
IET 5122 (RP825-71-4-11)	1.0	1.0	1.0
IET 5236 (RP825-24-7-5)	1.7	2.3	4.3
IET 5085 (RP825-70-7-1)	1.0	4.3	5.0
TN1	9.0	9.0	9.0
ASD 7	1.0	1.0	9.0
Mudgo	1.0	9.0	1.0
MR 1523	1.0	3.0	9.0
ARC 6650	3.0	1.0	9.0
Leb Mue Nahng	9.0	9.0	9.0
Jaya /IR1820-210-2 (1635)	1.0	9.0	9.0
Jaya/IR2153-26-3-5-6 (1659)	1.0	9.0	1.0
Triveni/IR1539 (1758)	1.0	1.0	7.0
Triveni/IR1539 (1735)	1.0	3.0	3.0
Bharati/IR2071-625-3-4 (1665)	1.0	3.0	1.0
Ptb 33	1.0	1.0	3.0
Ptb 21	1.0	1.0	5.0

[a]1 = resistant; 9 = susceptible.

Table 3. Reactions to tungro virus of some entries in the International Rice Tungro Nursery in four countries. 1976.

Designation	Reaction[a] to tungro virus					
	India			IRRI, Philippines	Bangkok, Thailand	Lanrang, Indonesia
	AICRIP	CRRI	Sambalpur			
IR30	S	R	S	R	S	S
IR2061-465-1-5-5	S	S	S	R	S	R
BR51-63-1	S	R	S	S	R	S
IR2061-213-2-17 (IR34)	S	S	S	R	R	S
ARC 7140	R	R	R	S	S	R
BJ 1	R	R	S	S	S	S
Kataribhog (2668)	S	S	R	S	R	R
CR44-955-A1	S	R	S	R	R	S
ARC 13677	R	R	R	S	R	R
ARC 13820	R	R	R	R	S	S
ARC 13901	S	R	R	R	R	R
Ptb 18	S	R	R	R	R	R

[a]S = susceptible, R = resistant.

be moderately resistant at Hyderabad, showed susceptibility to the three biotypes.

A total of 169 entries of diverse genetic background from the first International Rice Tungro Nursery were tested for tungro resistance at 3 sites (AICRIP, CRRI, and Sambalpur) in India. The data from those locations and the results from the Philippines, Thailand, and Indonesia indicate the variation in the reactions of the test entries in different countries, as well as in different locations within India (Table 3). Despite the significant variation in reactions, some lines—ARC 13677, ARC 13901, and Ptb 18—showed a resistant reaction at five of the six locations tested. Only ARC 7140, ARC 13677, and ARC 13820 proved resistant at all test locations in India. None of the test varieties showed resistance at all six sites.

The Ford Foundation grant for collaboration with Indian scientists also provides funds for joint work with scientists in Sri Lanka and Nepal. IRRI scientists are collaborating with Sri Lankan scientists in screening germ plasm for tolerance for iron toxicity and phosphorus deficiency. They are also screening several hundred lines for iron toxicity and phosphorus deficiency.

Thailand. The IRRI-Thailand collaborative program on deep-water rice aims to develop varieties that will increase and stabilize grain yield in deep-water rice areas of South and Southeast Asia. The most promising of several superior deep water-tolerant lines are selections from the crosses BKN 6986 and BKN 6987. The new lines have greater farmer acceptability because they incorporate photoperiod sensitivity and improved disease resistance.

The collaborative deep-water program screened for elongation ability the material of breeders from Bangladesh. The Bangladesh breeders observed their own material grown in Thailand and arranged for seed increase of selected lines.

An international workshop on deep-water rice—described elsewhere in this report—was held in Bangkok, 8–10 November 1976.

Collaborative activities between Thailand and IRRI also included work in machinery development, agroeconomic constraints, and cropping systems.

Latin America. IRRI collaborates with the International Center for Tropical Agriculture (CIAT) in Cali, Colombia, in providing services to the Latin American region (see description of the August 1976 conference at CIAT, page 390). In 1977 an IRRI scientist will be stationed at CIAT as a member of the joint CIAT-IRRI team to facilitate the exchange and evaluation of genetic material in the region.

In 1976, IRRI supplied seed of about 71 international nurseries to scientists in Latin America. Three Latin American scientists from different national programs underwent training at IRRI.

Africa. IRRI, the International Institute of Tropical Agriculture, and the West Africa Rice Development Association signed a Memorandum of Understanding for regional collaboration in Africa. Two major areas of collaboration are the collection and preservation of germ plasm, and the exchange and evaluation of genetic material. A series of meetings among representatives of the three agencies was held in 1976 to develop plans for collaboration in the rice testing program.

In 1976, IRRI supplied scientists in Africa with seed of about 83 international nurseries for evaluation, and materials for seven cooperative herbicide trials in the region. Seven scientists from Africa trained at IRRI.

INTERNATIONAL NETWORKS

The networks are designed to establish channels of communication among IRRI and national scientists and to encourage complementarity of efforts in programs with similar objectives. They facilitate the exchange of materials, information, and methodologies, and the development of technologies suited to a range of environments. A network normally consists of an IRRI scientist who serves as the network coordinator, and collaborating scientists who jointly develop the strategy, guidelines, and plan of work.

Currently five networks are operative on a formal basis: IRTP, IRAEN, CSN (Cropping Systems Network), FMDN (Farm Machinery Development Network), and INFER (International Network on Fertilizer Efficiency on Rice).

International Rice Testing Program. During 1976, 614 sets of 14 IRTP nurseries were prepared and distributed to 40 countries: 573 sets were for the regular testing program, the balance met the special research needs of rice research scientists.

The seven monitoring tours in 1976 involved 9 countries and 50 national scientists. The monitoring groups visited 55 experiment stations and contacted 250 scientists.

In August 1976, a regional conference was held for the first time in CIAT, Cali, Colombia, to systematize the rice testing network in Latin America. Forty-four rice research workers from 17 Latin American countries and four IRRI scientists participated. The conference established procedures for the rice testing program in Latin America.

International Rice Agro-Economic Network. The IRAEN continued operations in the Philippines, Indonesia, Thailand, Bangladesh, Taiwan, and Sri Lanka with funds provided by IDRC. The approach and procedures were standardized to ensure comparability among sites and to facilitate implementation and analysis. The results obtained from this combined experimental and survey approach indicated farmers' improper timing and placement of fertilizers. Because insect damage is a major constraint to high yields, high-level application of insecticides has generally not been profitable. The results provided a basis for initiating discussions with extension and research workers to explain the findings and to encourage the implementation of methodology on a wider basis.

Cropping Systems Network. Major efforts in 1976 concentrated on the design and testing of cropping patterns at 12 operational test sites in Bangladesh (1), Indonesia (2), the Philippines (3), Sri Lanka (2), and Thailand (4). Cropping pattern trials were conducted in farmers' fields with farmers' participation.

Much of the network strength depends on the ability to share and pool the information obtained from the national programs. Proof of that was a seminar for research administrators held in January, a workshop on environmental classification in March, and a symposium on cropping systems research and development for Asian rice farmers in September. In addition, research papers from the collaborators were circulated among scientists working on cropping systems. To upgrade the technical capabilities of the research staff in national programs, training was intensified in 1976 through the IRRI 6-month cropping systems course and the special 1-month training for site coordinators and supervisors.

Farm Machinery Development Network. The USAID-funded Industrial Extension projects in Thailand and Pakistan, which became operational in 1976, will hasten the transfer of know-how on IRRI-developed machinery to those countries and the surrounding region. Three new cooperative projects with organizations in Bangladesh, India, and Malaysia were added. The network now includes 10 projects in 9 countries.

Through free exchange of information the network continues to provide a mechanism for assistance to cooperators in solving problems. Feedback from network cooperators has greatly helped the assignment of priorities for machinery development projects.

The 2-week training course held twice a year has strengthened network linkages and provided training in the methodology of designing and extending IRRI-type small-scale machinery. Network cooperators attending the courses have an opportunity to discuss mutual interests with each other and with IRRI staff members. This personal exchange facilitates a more comprehensive exchange of information among cooperators when they return to their respective countries.

International Network on Fertilizer Efficiency on Rice. Scientists at the 1976 IRRC recognized the need for establishing a network for cooperative nitrogen efficiency trials. They agreed that all cooperative work on soil fertility and fertilizer management would be jointly developed under the INFER.

Two INFER projects were implemented in 1976: 1) A nitrogen fertilizer efficiency experiment investigated the relationships between nitrogen source, nitrogen management, and nitrogen efficiency, and monitored nitrogen availability and nitrogen uptake patterns throughout the growing season; 2) A long-term fertility experiment monitored fertility changes under intensive cropping.

Eight countries participated in INFER. During the year a committee developed plans for an experiment to test phosphorus sources in flooded rice.

IRRI's international program has evolved to provide the required services to rice-growing countries and to strengthen ties with national programs. The future strategy will reflect a shift from cooperative country projects designed to provide technical assistance to individual countries, to collaboration in research and network activities.

Information resources and experimental farm

LIBRARY AND DOCUMENTATION CENTER

Bibliographies. The 1975 Supplement to the *International Bibliography of Rice Research* was published in 1976; it has 452 pages, including indexes. The supplement contains 4,415 references to scientific rice literature, the majority of which appeared in 1975 journals. An additional 27 serial titles were scanned and searched in the compilation of this 1975 supplement. The coverage is worldwide; the volume lists 15 rice literature translations, mostly from Japanese to English. The items of reference are classified according to subject matter and the supplement includes author and keyword indexes.

The premiere issue of the *International Bibliography on Cropping Systems* was published; it covers international, published and unpublished technical works produced in 1973 and 1974, dealing with cropping systems that involve food crops. The entries are classified according to subject and within each subject category, items are arranged alphabetically. The bibliography contains author and keyword indexes.

A Bibliography of Rice Literature Translations Available in the IRRI Library and Documentation Center was published in 1976; it is a one-volume reference source that lists all translations that the IRRI Library has acquired since its inception in 1962. It is arranged alphabetically by author; a keyword index is included.

Supplement 1976 to the list of theses and dissertations on rice available in the IRRI Library provides an additional 133 titles. The total number in the collection is now 614.

The montly library list of acquisitions received wider circulation than that in 1975.

The bibliographies were distributed to agricultural libraries and documentation centers of rice-producing regions for the use of rice research workers and others responsible for disseminating information on rice. All the citations are available in the Library.

Reference and circulation. The Library received numerous requests for information and photocopying services during 1976; the majority of these requests came from Indonesia, Malaysia, India, and Bangladesh. The number of requests for short specific subject bibliographies also increased. As in previous years, the number of requests for Japanese literature on genetics and breeding was greater than that for all other aspects of rice culture. Requests for photocopies of papers on water management and irrigation increased markedly. The Library's assistance in library organization and management and in the selection and acquisition of agricultural materials was also sought.

Within the Institute, the number of books and journals and other library materials borrowed during the year increased considerably over that during the previous year. The addition of 2,844 books, pamphlets, and reprints increased the monographic collection to 42,938. A total of 114 additional serial titles were received through subscriptions, exchanges, and donations. Maps, translations, and microfilm were also added to the collection.

Other library activities. To keep the Institute scientists informed on the latest publications on rice, the library continued to circulate tables of contents of newly received journals within the Institute. The service was extended to the Bangladesh Rice Research Institute; the Lembaga Penelitian Pertanian Maros in Indonesia; the Central Rice Research Institute for Agriculture, Sukamandi Branch, Indonesia; and the West Africa Rice Development Association in Liberia.

The Library continued to purchase books for the Institute research scholars and trainees.

THE OFFICE OF INFORMATION SERVICES

IRRI's publications program increased in scope and more publications were distributed.

The bimonthly *International Rice Research Newsletter* was initiated. It carried concise summaries of significant research by scientists working on rice and rice-based cropping systems throughout the world. The new newsletter incorporates most of the functions of two former IRRI newsletters — *The Rice Entomology Newsletter* and *The Rice Pathology Newsletter* — and adds other areas of rice research. The first two issues went to 5,000 scientists, researchers, libraries, and others interested in rice research.

The *IRRI Research Paper Series* was started as a vehicle for the timely publication of research findings by IRRI senior staff and associated scientists that have significant value for research and extension specialists working on rice and rice-based cropping systems. The new series goes regularly to libraries and other institutions.

Four issues of the Institute's regular newsletter, *The IRRI Reporter,* were distributed to about 8,000 researchers, scientists, libraries, and other organizations around the world.

Two IRRI publications were revised and five new titles were published. These include a 1976 revision of the *Flowering Response of the Rice Plant to Photoperiod: A Review of the Literature;* a 1976 revision of the *Training Manual for Rice Production; Manual on Genetic Conservation of Rice Germ Plasm for Evaluation and Utilization; Research Highlights for 1975; 1975 IRRI Annual Report; Proceedings of the Symposium on Climate and Rice;* and *Statistical Procedures for Agricultural Research, with special emphasis on rice.*

A four-color information brochure on the new Laboratory and Training-Conference Center was prepared and published for distribution at the dedication of the building in September. A brochure on the training programs at IRRI was revised.

The proceedings of three meetings are being prepared for publication — an international seminar on *Irrigation Policy and Management in Southeast Asia,* a symposium on *Cropping Systems Research and Development for the Asian Rice Farmer,* and a workshop on *Deep-Water Rice.*

More than 100 sets of colorslides on field problems of tropical rice, which cover insect pests, diseases, and nutritional disorders, were distributed in 1976. Additionally, about 50 sets of the 80 colorslides "Rices of IRRI," which describe the Institute's programs and achievements, were distributed.

A photographic exhibit of black-and-white and color photo enlargements illustrating the activities, goals, and accomplishments of IRRI was prepared and installed in the new Laboratory and Training-Conference Center.

A project to produce a series of audiovisual instructional units was initiated in conjunction with the Office of Rice Production Training and Research. The sets of colorslides with accompanying cassette tapes of descriptive text will be used for individual study of rice production trainees by/and scholars, and by the training personnel. The Office of Information Services handles script writing, visualization, and artwork plus photography for slides.

More than 14,000 visitors came to IRRI from 37 countries in 1976. This was 15% more than the number that came in 1975. More than 60% of the IRRI guests were students and farmers. The multi-image slide presentation about IRRI was shown more than 450 times.

Work continued on a research project, "Genetic, professional, and sociological aspects of rice breeding in Asia." Of the rice breeders surveyed regarding the scientific literature they used as sources of information, 95% indicated that they read the IRRI *Annual Report* regularly and rated it as one of their most important sources of information.

EXPERIMENTAL FARM DEPARTMENT

The Experimental Farm Department continued to support the research departments in land preparation, planting, weeding, fertilizer application, pest control, harvesting, and drying by supplying labor where needed.

Work continued on the development of the land acquired in 1974. About 80 ha of the upland-area land was developed and planted during the wet season. About 65 ha of this area was planted, with rice occupying the largest portion. Two deep wells were dug and tested, the irrigation pipeline was laid, and a water reservoir was built. Farm roads were constructed, and the creek crossing the upland farm was straightened.

More than 700 coconut trees were cut, old levees were removed and new levees were built in the new lowland area. Two deep wells were dug and ditches were dug to divert old irrigation canals. Fencing of the area is almost finished.

A 20-ha farm was rented in Cabuyao, Laguna (about 40 km from IRRI), for the cooperative seed multiplication program of the Plant Breeding and Experimental Farm Departments. During the wet season, five varieties (IR26, IR32, IR34, IR36, and IR38) and six selections (IR2070-414-3-9, IR2071-105-9-1, IR2071-586-5-6-3, IR2823-399-5-6, IR2823-38-1-2, and IR2070-423-2-5-6) were planted on about 19 ha. In the dry season, three varieties (IR32, IR34, and IR36) and the selection IR2070-423-2-5-6 were planted on about 13 ha.

Seed of IR26, IR28, IR29, IR30, IR32, IR34, IR36, and IR38 was sold to Philippine government agencies and to individual farmers. Seed for research purposes was given to government institutions.

The use of all insecticides, except gamma-BHC, increased because of an outbreak of virus disease at IRRI and in farmers' fields. More herbicides were used than in 1975 because larger areas received applications.

Of the 118 t of fertilizers used in 1976, the proportion of ammonium sulfate was highest, followed by that of urea, solophos, and muriate of potash.

Expenditures for contract labor were 37% higher than in 1975, with the largest percentage (about 45%) of the labor expense being used for land preparation, the second largest (38%) for bird control, and the third largest (17%) for weeding and planting.

Rat control work continued with electric fences, baiting with poison, and dusting rat burrows with cyanogas at IRRI and by supplying neighboring farms with poison baits.

Three types of rat fences were used in 1976. The first type has a 6-inch-wide galvanized sheet on top, but no electric current; the second has a bent galvanized sheet with electric current; and the third has electric current, but no galvanized sheet. Rat damage in plots protected by the fence was assessed by a method patterned after the one used by the Rodent Research Center located adjacent to the IRRI research center. The average damage was zero with the first type of fence, 0.32% with the second, and 4.11% with the third.

A fourth type of rat fence was tested by the Rodent Research Center for two cropping seasons. The fence has a low-level electric charge that shocks but does not kill the rats. Preliminary observations showed that rats attempted to enter the experimental plots only during the first few days.

Zinc phosphide, to which the rats had developed bait shyness, was replaced with Tomorin. Extremely high rat populations were quickly reduced by a bait consisting of grated coconut and green corn mixed with compound "1080" or zinc phosphide.

Publications and seminars

PUBLICATIONS

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SEMINARS

The following seminars were held at IRRI during 1976. Unless otherwise stated, the speakers were staff members.

Evolving networks of collaborating rice scientists. Dr. Nyle C. Brady. Identifying elements of Filipino innovativeness. Dr. Ruben S. Cuyugan, Chancellor, Philippine Center for Advanced Studies, University of the Philippines, Diliman, Quezon City, Philippines.

Sex pheromones in insects. Dr. Peter Beevor, Chemist, Tropical Products Institute, London.

ADB's expanding role in promoting agricultural development in Asia. Dr. Sam C. Hsieh, Director, Project Department 1, Asian Development Bank (ADB), Roxas Blvd., Manila, Philippines.

Microbial fixation of nitrogen by nonleguminous plants. Dr. Johanna Dobereiner, Instituto de Pesquisa Agropecuaria Centro Sul, Rio de Janeiro, Brazil.

Simulation of multilines. Dr. David R. MacKenzie, Assistant Professor of Plant Pathology, Pennsylvania State University, USA.

Green revolution progress in South Korea. Drs. Ham Choi and Lee, Office of Rural Development, Suweon, Korea.

Recent tractor development in the United States. Mr. Donald O. Kuether.

Traditional uses of fire for forest management—The Indians of Western Canada. Dr. Henry T. Lewis, Department of Anthropology, University of Alberta, Edmonton, Canada.

The design and management of water for irrigation projects. Dr. Masami Okamoto, Associate Professor of Water Resources Engineering (on leave from University of Tokyo) with the Asian Institute of Technology, Bangkok, Thailand.

International Agricultural Development Service—A new initiative and technical assistance. Dr. Sterling Wortman, Vice President, International Agricultural Development Service, New York, USA.

Monitoring the green and brown waves by satellite. Dr. Bernard Dethier, Visiting Scientist, Multiple Cropping Department, IRRI.

Systems research: philosophy, techniques, and applications. Mr. Stephen Harrison, Lecturer in Economics, Department of External Studies, University of Queensland, Australia.

Development of the new experimental farm of IRRI. Mr. Donald Minehart (Ford Foundation—Egypt), IRRI consultant on Farm Development.

Some facts and fallacies about weed science. Dr. Keith Moody.

Soil fertility research on oxisols in Brazil. Dr. D. R. Bouldin, Visiting Scientist, Soil Microbiology Department, IRRI.

Ammonia volatilization from a flooded rice soil. Dr. D. R. Bouldin (Professor of Soil Science, Cornell University), Visiting Scientist, Agronomy Department, IRRI.

Using biophysical models for fitting crops and cropping patterns to environments. Mr. Henry Nix, Commonwealth Scientific and Industrial Research Organization, Canberra, Australia.

The diffusion of genetic materials and the objectives of rice breeders in India. Mr. Thomas R. Hargrove.

The Ifugao rice terraces. Dr. Nico Van Breeman, Post-Doctoral Fellow, Soil Chemistry Department, IRRI.

The role of inanimate energy inputs in a developing agriculture. Dr. William Chancellor, Senior Fellow, East-West Food Institute, The East-West Center, Honolulu, Hawaii, USA.

Laguna's heritage—some cultural and historical aspects of significance. Dr. David E. Baradas, Consultant, The Asia Foundation, Manila, Philippines.

Field workshops as a method of securing small farmer participation in project development. Mr. G. Cameron Clark, Regional Rural Institutions Officer, Food and Agriculture Organization Regional Office, Bangkok, Thailand.

Review of water management for rice and upland crops in Sri Lanka. Mr. J. A. Lewis, Irrigation Agronomist, Maha-Illuppallama Research Station, Sri Lanka.

Introductory lecture on transcendental meditation program. Mr. Melchor S. Emos, Vice-Chairman for Administration, and Mr. Reynaldo Inocencio, Chairman, Quezon City Age of Enlightenment Center, Philippine Foundation for the Science of Creative Intelligence, Quezon City, Philippines.

Agriculture, environment, and current policy in China. Prof. Kierin Broadbent, Senior Scientific Officer, Commonwealth Bureau of Agricultural Economics, Oxford, England.

Energy for agriculture worldwide. Dr. B. Stout, Professor, Department of Agricultural Engineering, Michigan State University, East Lansing, Michigan, USA.

Cropping systems in Batangas. Dr. Ed C. Price.

New developments in stereomicroscopy. Mr. Hugo Giess, Representative of Wild Heerbrugg, Switzerland.

A critical link in the food chain. Dr. J. Ritchie Cowan.

Crop physiology: its approach to the determinants of economic yields. Dr. Tom F. Neales, Visiting Scientist, Plant Physiology Department, IRRI.

Rice research and production in the Union of Soviet Socialist Republic (Russia). Dr. Eugene P. Aleshin, Chief, Rice Laboratory, Kubang Agricultural Institute, Krasnodar; Dr. Vladimir A. Dzyuba, Chief, Laboratory of Genetics, All-Union Research Institute of Rice, Krasnodar; and Mrs. E. A. Belinskala, Interpreter, Main Administration of Foreign Relations, USSR Ministry of Agriculture, Moscow, Russia.

Report of an IRRI team's visit to the People's Republic of China. Part 1. Rice production systems in China. Dr. Nyle C. Brady.

Report of an IRRI team's visit to the People's Republic of China. Part 2. Rice research in China. Dr. Nyle C. Brady.

Finances

The Institute received cash grants amounting to \$11,626,850 during 1976.

The Ford Foundation gave \$897,682 of which \$565,000 was for core operations and capital expenditures and \$332,682 for support of the Bangladesh Rice Research Institute.

The Rockefeller Foundation contributed \$539,300, which included \$500,000 for core operations and capital needs. It released \$31,800 as part of a 3-year grant to support the program to develop and introduce modern rice technology to Asian farmers and to support an agro-economic survey on the extent to which farmers in the project areas utilize that technology. The Foundation also gave \$7,500 toward support of a research project on the diffusion of genetic materials.

The U.S. Agency for International Development (USAID) released a total of \$2,736,098. The Institute received \$2,150,000 for its core operations; \$50,897 for expanding, strengthening, and further institutionalizing the National Applied Research and Extension Program for Transplanted Rice; \$231,009 for industrial extension of small-scale agricultural equipment developed at IRRI; \$10,488 to assist in organizing-incorporating results of agricultural research into the Philippine National Food and Agriculture Council production programs; and \$25,000 for the rice postproduction project in the Bicol River Basin.

Since 1972 a contract between IRRI and USAID has supported a 5-year project for the accelerated development and utilization of improved rice technology in Indonesia with a total budget of \$896,701 plus R_p479,111,405 managed by USAID in Djakarta. In 1976 USAID released \$179,339 to the Institute.

In 1976, \$42,342 was reimbursed to IRRI on USAID contract that supports accelerated rice research in Vietnam (a 3.5-year period since 1971) with a budget of \$495,718 in addition to VN\$55,150,000.

USAID contributed to IRRI's training program by supporting scholars and trainees from countries where USAID has active programs. The Institute received \$32,439 for this purpose in 1976. USAID/Bangladesh released \$14,584 to finance the training of staff from the Bangladesh Rice Research Institute.

The Ministry of Overseas Development, United Kingdom, gave \$474,206 toward the support of IRRI's core program.

The International Development Research Centre (IDRC), Canada, granted IRRI \$1,020,482. Of that, \$573,146 was part of a 2-year grant to the Institute for cropping systems research in the Philippines. The IDRC grant included \$170,595 as part of a 3-year grant to enable IRRI to develop procedures for identifying constraints to the adoption of a new rice technology and to determine the degree to which constraints are generally or locationally specific; \$20,220 for the operational support of two consultants to advise IRRI on the rice soils of Asia; \$102,254 as part of a 2-year grant to conduct research in Indonesia in cooperation with the Central Research Institute for Agriculture, to develop cropping systems for rainfed and partially irrigated rice areas and to adapt them through cooperative trials in farmers' fields; \$52,754 as part of a 4-year grant to enable the University of the Philippines at Los Baños to conduct, in support of IRRI's multiple cropping program, varietal screening for corn, sorghum, mung beans, eggplants, tomatoes, and sweet potatoes; and \$101,513 as part of a 4-year grant to support a multiple-cropping research project at the Bangladesh Rice Research Institute.

The Japanese Government gave \$1,000,000 in 1976 for the IRRI training program, support of the Institute's plant physiology and soil microbiology departments, for purchase of research equipment, and support of the GEU program.

The International Development Association gave \$1,770,000 toward core operations and capital expenditures of the Institute.

The West German Government gave \$201,398 toward core operations and \$51,923 to support a 1976 symposium, "Cropping Systems Research and Development for the Asian Rice Farmer."

The Australian Government gave $659,989 in 1976. Of that, $498,400 was for core operations; $124,600 supported expansion of technical assistance and collaborative relationships with the Bangladesh Rice Research Institute; $20,221 funded short-term fellowships, and $16,768 completed construction costs relating to the phytotron and an associated generator.

The Canadian International Development Agency gave $610,200 toward the Institute's core operations and $204,000 toward a cooperative program for research and development between the Bangladesh Rice Research Institute and IRRI.

The government of New Zealand gave $79,920 to support the core program.

The Ministry of Agriculture and Water, Saudi Arabia, gave $125,000 toward the core program.

The Government of Iran gave $250,000 for the core program.

The United Nations Environment Programme gave $70,000 toward research for developing rice varieties with low pesticide and fertilizer requirements.

The Government of Indonesia, using a World Bank loan, released $353,305 to IRRI as part of a 7-year contract for development of research facilities at the Sukamandi Branch of the Central Research Institute for Agriculture and for scientific and technical assistance to rice research at Sukamandi.

The Netherlands Government gave $134,320 as part of a 5.5-year grant for a project for regional rice research station development in Indonesia.

The United Nations Development Programme gave $185,000 as part of a 5-year grant for the International Rice Testing Program, and $146,290 as part of a 5-year contract to carry out investigation of nitrogen fixation in association with lowland rice.

In 1976 IRRI entered into a cost-reimbursement contract with the U. S. National Institutes of Health to study ways to increase protein and essential amino acids in the rice grain through plant breeding. In 1976, $6,272 was reimbursed.

The other donors, the areas they supported, and the amounts they contributed are listed below.

• National Food and Agriculture Council, training government extension technicians	$72,297
• Philippine Council for Agriculture and Resources Research, cooperative applied research project on rainfed rice	13,869
• American Cyanamid Company, insect and weed control	6,000
• Imperial Chemical Industries, weed control	5,000
• Hoechst (Joint Stock) Company, institute operation	3,103
• Stauffer Chemical Company, weed control	3,000
• Potash Institute of North America and International Potash Institute, soil fertility	2,200
• FMC International S.A., pesticide research	2,000
• Monsanto, herbicide research	2,000
• National Science Development Board, evaluation of promising rice selections and management practices in the Philippines	846
• East/West Center, research expenses of research scholar	750

Staff changes

February

Dr. Frank R. Moormann, on a 1-year sabbatical as pedologist at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, began work with the Department of Soil Chemistry on a study of rice soils.

April

Dr. J. Ritchie Cowan joined the International Rice Testing Program (IRTP) as plant scientist.

May

Dr. D. V. Seshu began a 2-year leave from the All India Coordinated Rice Improvement Project (AICRIP) at Hyderabad to join IRTP as senior rice breeder.

June

Mr. Richard L. Disney, on a 1-year sabbatical as associate professor of journalism in the Department of Journalism and Mass Communication at Iowa State University, joined the Office of Information Services (OIS) as visiting associate editor.

Dr. Harold E. Kauffman, plant pathologist of IRTP began a 1-year study leave at the Plant Pathology Department, Pennsylvania State University, University Park, USA.

Miss Rebecca C. Pascual, manager of the Food and Dormitory Services, began a 2-month study leave at Cornell University, Ithaca, New York, USA, to pursue advanced course work in hotel and food services management.

Dr. Felix N. Ponnamperuma, principal soil chemist, returned to the Department of Soil Chemistry after completing a 1-year study leave.

July

Dr. Gurdev S. Khush, plant breeder in the Department of Plant Breeding, returned to IRRI after completing a 1-year study leave at the Department of Agronomy, Colorado State University, Fort Collins, USA.

Dr. Duane S. Mikkelsen, professor of agronomy from the Department of Agronomy and Range Science at the University of California, Davis, USA, began a 1-year study of nitrogen efficiency under the joint sponsorship of the Department of Agronomy, the Southeast Asian Regional Center for Graduate Study and Research Agriculture (SEARCA), and the University of the Philippines at Los Baños (UPLB).

Mr. Herminigildo G. Navarro, property superintendent, retired after 16.5 years of service at the Institute.

Attorney Zozimo Q. Pizarro began a 6-month study leave at the School of Management at Case Western Reserve University, Cleveland, Ohio, USA.

August

Dr. A. O. Abifarin, rice breeder at IITA began a 4-month study leave at IRRI to work with the Genetic Evaluation and Utilization (GEU) team.

Dr. V. Arnold Dyck, associate entomologist in the Department of Entomology, began a 1-year study leave at the Biological Control Division, University of California, Berkeley, USA.

Mr. D.L. Esslinger, on a 1-year sabbatical as information specialist in the Agricultural Editor's Office, University of Missouri, Columbia, USA, joined the staff of OIS as visiting associate editor.

Dr. Russell D. Freed transferred temporarily to the Cropping Systems Program at Los Baños as associate breeder from the IRRI Cooperative Project in Indonesia (Bogor).

Dr. Wes W. Gunkel, on a 1-year sabbatical leave as professor in the Department of Agricultural Engineering at Cornell University, joined the IRRI Department of Agricultural Engineering as visiting agricultural engineer.

Mr. Thomas R. Hargrove, associate editor in the OIS, began a 9-month study term at the Department of Agricultural Education, Iowa State University, to do research on GEU-type information exchange to complete the research requirements for the Ph.D. degree.

Dr. Yujiro Hayami completed 2 years of