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About this report

The 16th annual report covers research during 1977. 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, e.g.

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 Agronomy and Plant Breeding Departments cooperated in the project VARIETAL SCREENING. Because the Agronomy Department bore responsibility for one phase of this effort, its name follows the subtopic:

Upland field screening *(Agronomy)*

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 of significance and two asterisks (**) means significantly different 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 (X). For example, IR32 X IR34 is now written IR32/IR34. The sequence of crosses is indicated by the number of slant bars: (IR32 X IR34) X 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 unbunded fields. Rainfed paddy culture means rice grown without irrigation but in fields that are bunded to impound water. Irrigated 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 potential-performance gap

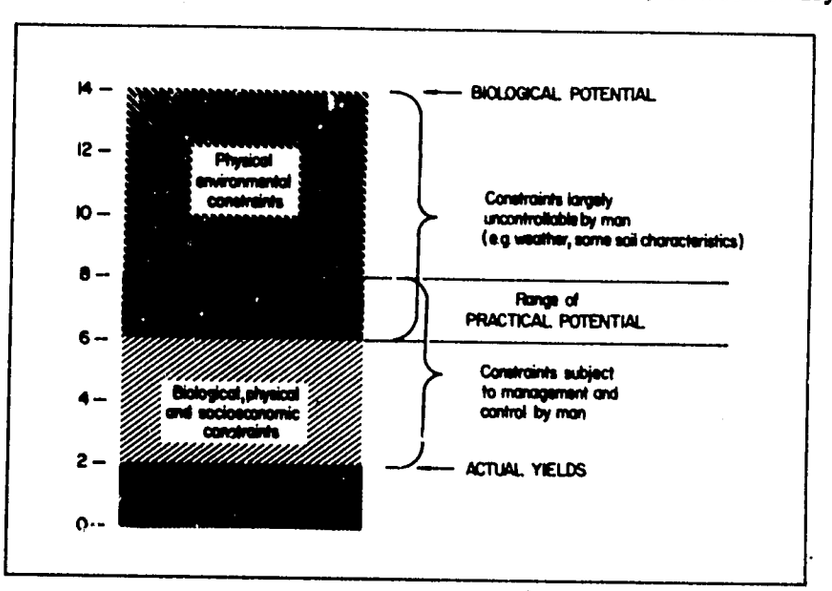
PLANT SCIENTISTS suggest that under ideal conditions modern rice varieties have the biological potential to produce 3 to 10 times the yields commonly obtained by farmers. In temperate regions the potential is 15 to 17 t/ha. In the tropics it is somewhat lower – 13 to 15 t/ha – because of higher respiration rates. Such yield figures dwarf average national rice yields and underscore the extent of a large *potential-performance* gap.

Farmers in tropical countries suffer most from this gap. There would be no cereal food deficiencies in the tropics if rice yields there and in the subtropics were as high as those in Japan, Australia, Europe, and the United States. On the contrary, there would be food surpluses. Adequate food would be available for double – even triple – the current populations in the tropics.

The average rice yields of Japanese farmers are 30 to 40% of the potential yield that can be produced under ideal conditions. But in India, the Philippines, and Indonesia, farmers produce only an average 12 to 15% of the potential yield for the tropics. Reduction of this *potential-performance* gap is our greatest challenge.

Rice scientists have the responsibility of identifying reasons for the wide yield gap and of ascertaining means of reducing it. Research shows three primary factors to be responsible for this wide yield gap.

First are the physical-environmental constraints, most of which either are uncontrollable by man or require excessive cost for their removal (Fig. 1). Climatic extremes of cold and hot, or wet and dry



1. Environmental constraints such as weather and soils prevent the attainment of the full biological yield potential of rice. But the practical potential yields are attainable if man can control biological-physical and socioeconomic constraints. A major objective of IRRI researchers is to provide a basis for improved technologies and public policies that will remove these constraints.

are examples. The low temperatures in Korea and the high ones in Pakistan are not subject to easy manipulation. In areas where floating rices are grown, annual floods will likely continue. Likewise, strongly acid sulfate soil areas will probably remain acid because costs of reducing their acidity are prohibitive.

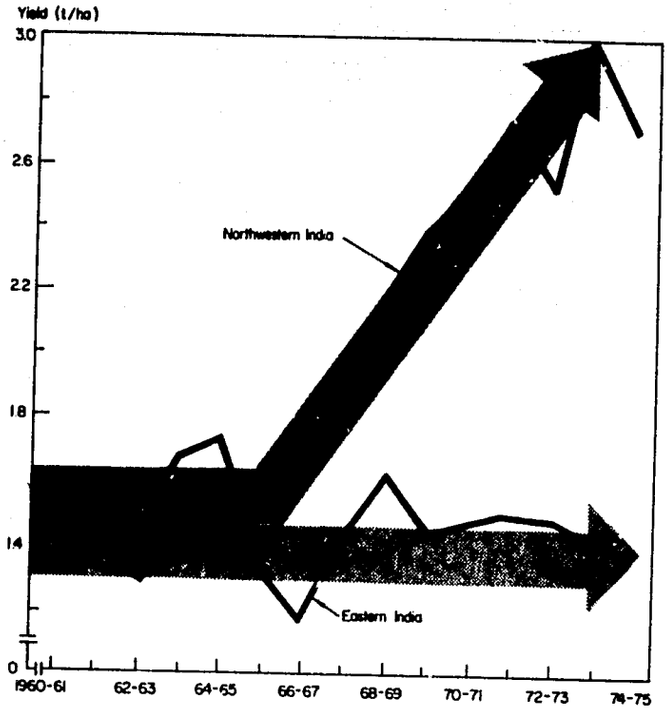
Second are the physical and biological constraints, which are most severe in the tropics, but which are controllable if appropriate technology is available. Population pressures have forced the cultivation of some land areas with poor soil. The monsoon type climates of the tropics bring alternate periods of deficit and excess of water. Diseases and insect pest pressures are much more severe in tropical environments than in temperate regions. Furthermore, favorable year-round temperatures encourage these pests.

These physical-biological constraints are subject to at least partial removal through improved technologies and management practices. Disease and insect pests can be controlled. Varieties tolerant of deficiencies and excesses of water and of toxic soils are on the horizon. And more efficient fertilizer and irrigation practices are being developed.

The *third* gap-producing factors are the socioeconomic constraints faced by the rice farmer in the tropics. His input supply and distribution systems are imperfect and his input costs are relatively high. The system for distribution of irrigation water is often inefficient and beyond his control. And his financial resources are costly and subject to control by others. In addition, his sources of information on improved practices may be undependable or even erroneous. All in all, he lacks motivation to increase production.

Scientists at IRRI are working with counterparts in national programs to first identify yield constraints and then to remove them. Already we have learned that pest management and fertilizer practices are primary constraints over wide areas. But we have also discovered that no technology has as yet been developed to remove yield constraints over even wider areas. In the flood-prone regions of eastern India, for example, where adapted improved varieties and associated cultural practices are not yet available, yields have remained essentially constant over the past 15 years (Fig. 2). This contrasts with the rapidly increasing yields and production in northwestern India where appropriate technology is available and is used by farmers.

IRRI researchers are playing a vital role in identifying the socioeconomic constraints to rice production and in testing the ability of farmers to respond once the constraints are removed. Ultimately social and political leaders must be motivated to take steps to remove such constraints. A farmer must be able to make more money if he accepts a new technology. His risks must be reduced and he must have a ready market for his produce. Furthermore, the adoption of



2. Rice yield trends for eastern and northwestern India since 1961 clearly exhibit the potential-performance gap. In eastern India, where farmers are plagued by floods and where adapted modern rices and their accompanying technology are not yet available, yields have stayed in the 1.2 to 1.6 t/ha range. But in northwestern India irrigation and an accompanying new rice technology have given farmers a start on bridging the gap.

the technology, while benefiting him, should not adversely affect those who work for and with him, or those who consume rice.

To supplement the research and development activities aimed at increasing rice yields, concomitant activities to improve the cropping and farming systems are in progress. Most farmers work with more than one crop and have more than one enterprise. The researchers at IRRI and in cooperating national institutions focus on the farmer and his cropping system in their attempts to develop improved total farm systems.

Progress in 1977

National rice production levels for 1977 in Asia were variable but generally good. Drought struck some countries of Southeast Asia and parts of China, and lowered production levels. Brown planthopper and other pests also took their toll. But production in India, Korea, and the Philippines was at record levels. In general, rice production appeared to have at least kept up with demand.

Two basic research premises

The two basic premises on which IRRI's general research direction is based continued to guide our research activities in 1977:

- Because most production-constraint problems tend to go beyond political boundaries, they can best be solved through *interna-*

tional cooperation and collaboration. No single institution – international or national – can solve such problems alone.

- Within a given international or national institute, interdisciplinary inputs are essential to solve production-constraint problems. No single discipline can, by itself, solve such problems.

In keeping with these premises, IRRI continued its interdisciplinary teams approach *at home* and worked with networks of cooperating scientists overseas.

Long-range focus

In 1977 we intensified efforts to plan well ahead so as to be more certain of the appropriateness of our research direction. We developed estimates of the probable sources of increased food production in major rice-growing areas of Asia (Table 1). We concluded that about 55% of the future food production increase would come from increased yields and about 45% from increased cropping intensities. Irrigated areas in South and Southeast Asia will likely provide about 46% of the increased production and rainfed areas about 34%. While the anticipated increased production from upland and deep-water areas is much less, the fact that these production areas have largely been ignored in the past justifies their receiving increased research attention.

We are reevaluating our research priorities and relative emphases in the light of the estimates in Table 1. Consideration is given, not only to potential production increases but also to the welfare needs of the farmers, the landless laborers, and the rice consumers.

Specificity of programs

We continued our efforts to sharpen the focus of research on specific problem areas. To make us more sensitive to the needs of farmers in different agroclimatic environments, we have focused our genetic evaluation and utilization (GEU) programs on four types of rice culture:

Table 1. The percentages of future benefits from research that can be expected from yield increases and from crop intensification under different environmental complexes as estimated by an IRRI Long-Range Planning Committee during 1977.

Environmental complex	Future research benefits (%) expected from		
	Yield increases	Crop intensification	Total
Irrigated	22	24	46
Rainfed (shallow)	15	11	26
Rainfed (medium deep)	6	2	8
Deep water	2	1	3
Upland	3	1	4
Arid, high temperature	6	5	11
Long day, low temperature	1	< 1	1
	55	45	100

- Irrigated
- Rainfed, medium deep-water
- Deep-water
- Upland

We believe the opportunities for technology payoffs from research still remain high in irrigated areas. Furthermore, considerable research is needed to maintain the high yield levels already achieved under irrigation. But rainfed, deep-water, and upland areas must receive higher priority than was given them in the past. These areas have received inadequate attention from national and international centers alike.

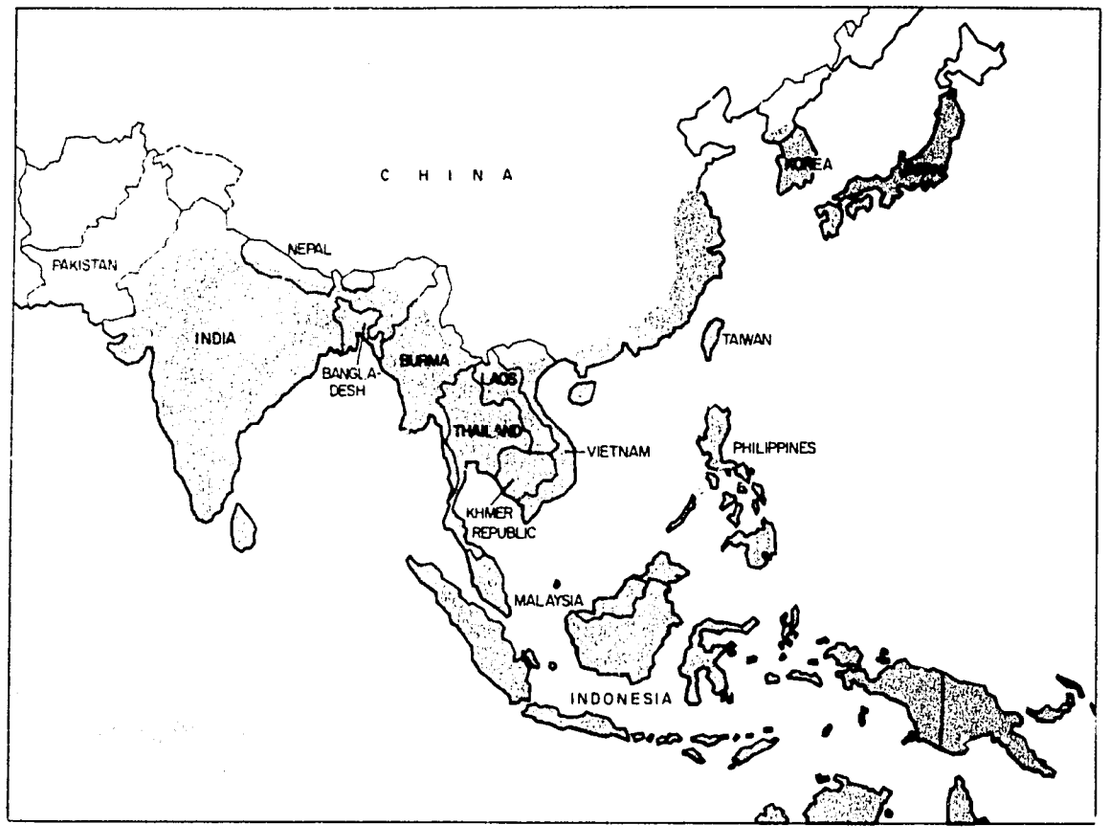
We also focused on specific problem areas through collaborative research with scientists in national programs. Increased emphasis was placed on topics such as temperature extremes (high and low), problem soils, and deep water. By joining forces with scientists in countries where the problems are most acute, we are helping to plan and carry out experiments in the adversely affected areas:

- Drought resistance studies in Indonesia and Thailand;
- High temperature tolerance work in India, Iran, and Pakistan;
- Cold tolerance work in Korea and the Philippines;
- Deep-water tolerance research in Bangladesh, India, and Thailand;
- Acid sulfate soils study in Indonesia, Malaysia, and Thailand;
- Iron toxicity work in Sri Lanka; and
- Salinity (coastal) tolerance study in India, the Philippines, and Thailand.

Broadened approach to disease and insect pest control

The resurgence of the brown planthopper and the discovery of a new rice virus disease emphasized the need to broaden our research base on pest control and management. Two years ago the brown planthopper appeared to have been controlled by the release of resistant varieties. Since then, we have identified at least three biotypes of this insect and have confirmed that most modern varieties are susceptible to at least one of them. The development of other biotypes is likely. We have screened about 65,000 breeding lines for resistance to one or more of the brown planthopper biotypes. Even though many show some degree of resistance, it is obvious that a simplistic host-resistance approach alone will not suffice in the management of the pest. The seriousness of the problem is emphasized by the fact that the brown planthopper is a threat over a wide area from tropical Indonesia to as far north as Central Japan, China, and Korea (Fig. 3).

In early 1977 Filipino scientists discovered *ragged stunt*, a new rice disease that we have since found to be caused by a virus. The disease is transmitted by the brown planthopper and has also been found in Indonesia, Thailand, Sri Lanka, Bangladesh, and Vietnam. We have already field-screened several thousand lines for resistance to



3. The brown planthopper is a potential threat to rice production in most of the shaded area. The hopper does not overwinter in Korea and Japan, but annual migrations cause serious damage.

the disease. Only varieties with resistance to prevalent brown planthopper biotypes show field resistance to this new virus disease.

The emergence of ragged stunt adds urgency to the need to control or manage the brown planthopper. We are seeking added means of management. Some pesticides were effective initially, but over time the pest has developed resistance to them. Predators have been found and are being tested in the greenhouse and in the field. Cultural methods are also being employed. Collaborative research on the insect is under way in India, Indonesia, Sri Lanka, Thailand, Bangladesh, and Korea. We also cooperate with the International Center on Insect Physiology and Ecology (ICIPE) and with British scientists supported by the Overseas Development Ministry (ODM) to study the pest.

Innovative GEU approaches

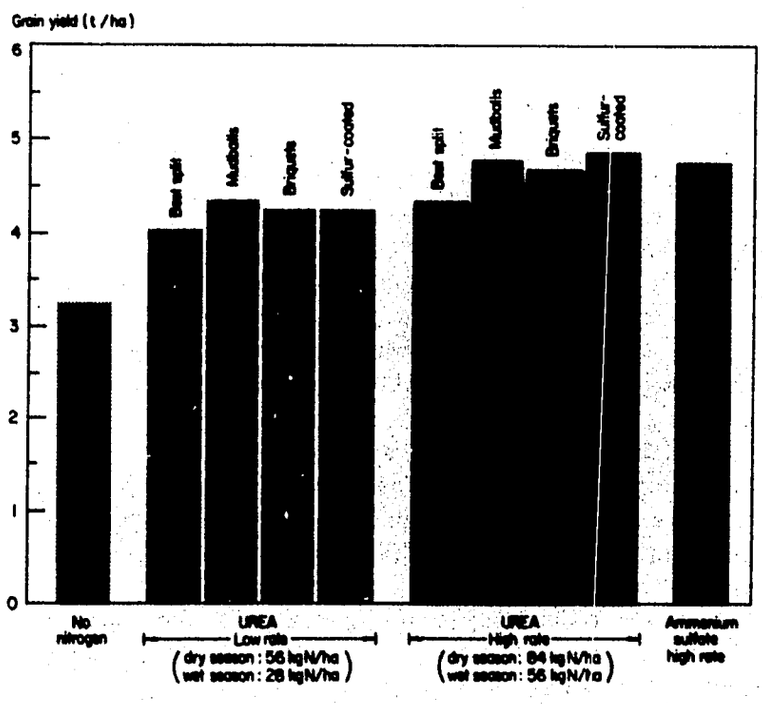
Several approaches are being taken to accelerate the rate of dissemination of rice genetic resources. The procedure – started in 1976 – of disseminating F_2 and F_3 seeds to cooperators in other countries was expanded. The rapid generation advance technique of producing three generations of photoperiod-sensitive lines for distribution to cooperators working on rainfed and deep-water rice was further refined and expanded.

We invited plant breeders from nine major rice-growing countries to come to IRRI to evaluate breeding materials in our nurseries and gave them seeds of materials they selected. We also intensified our efforts to ascertain the gene source of resistance to diseases and other pests and of tolerance for adverse environmental conditions. Through the international Rice Testing Program (IRTP) more than 100,000 seed packets of various varieties and lines were distributed in 1977. Data from a survey, started in 1974, to trace the diffusion of modern varieties through national rice programs in Asia continued to be analyzed. Rice breeders at 27 research centers in 10 countries cooperated in this survey.

Nitrogen studies

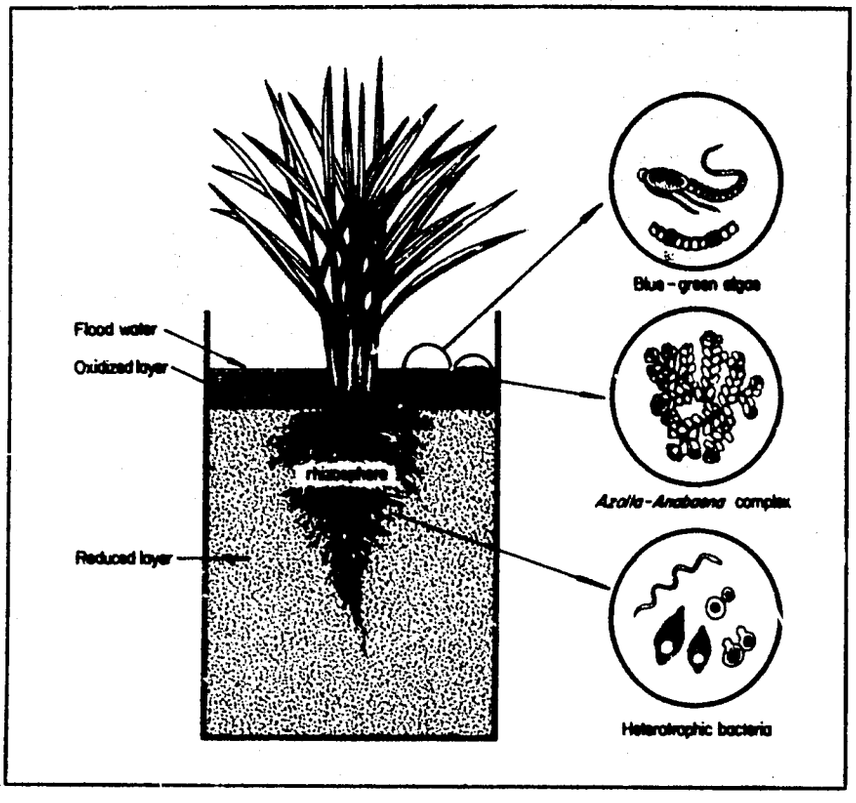
The superiority of root-zone placement of nitrogen fertilizers to surface applications was again demonstrated. Surface treatment resulted in significant losses of gaseous ammonia. Fertilizer efficiency of the root-zone treatments and of sulfur-coated urea was nearly double that of the split surface-application commonly used by farmers. Similar results were obtained by scientists from 19 countries who ran 84 trials during 1975–77 as part of the International Network on Fertilizer Efficiency for Rice (INFER) (Fig. 4).

We have evidence that nitrogen fixation by blue-green algae or by *Anabaena* algae associated with *Azolla* can supply large quantities of nitrogen in flooded soils (Fig. 5). Such biological fixation probably



4. Root-zone placement of surface applied urea (mudball and briquet) or sulfur-coated urea gave higher rice grain yields than split nitrogen applications on the surface (best split). Data are from 84 trials in 10 countries of the International Network on Fertilizer Efficiency in Rice (INFER), 1975–77 crop seasons. Note that the low rates of mudball, briquet, and sulfur-coated urea gave average yield equal to those of the high rate of the best split treatment.

5. IRRI researchers are studying the biological fixation of nitrogen from three sources: in the paddy water by blue-green algae and by algae associated with a water fern (*Azolla-Anabaena* complex), and in the reduced layer of the soil by heterotrophic bacteria associated with rice roots (rhizosphere). The *Azolla-Anabaena* complex fixed more than 300 kg N/ha in a 7-month period.



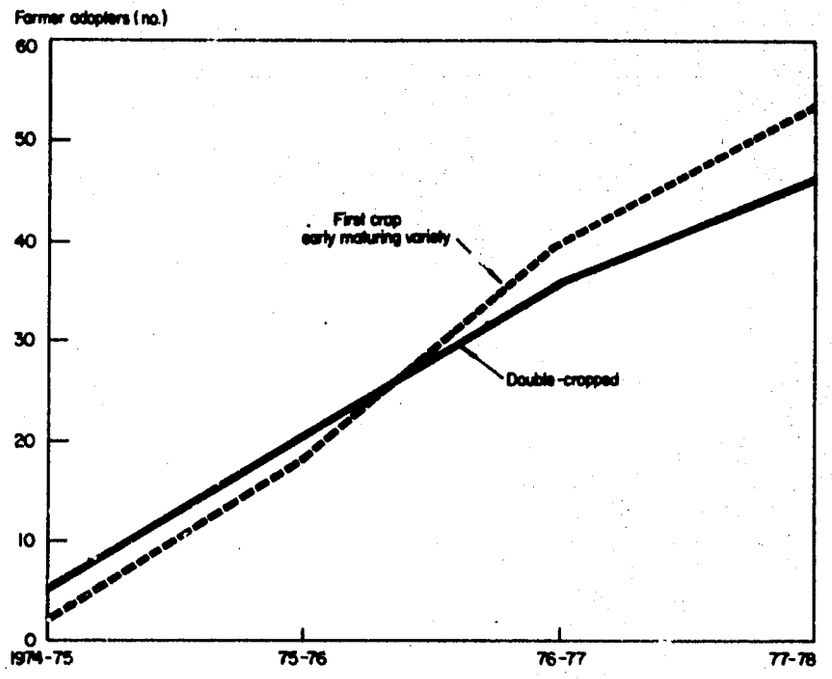
accounts for the marked increase in soil nitrogen and organic matter contents in continuously flooded soils on which 10 successive crops of rice had been grown.

Cropping systems research

The availability of high yielding rices with short growth duration enhanced the potential for cropping intensification. In 1977 we grew 4 crops of IR36, a variety that requires only 90 days in the field (transplant to harvest). Through the continuous rice system we produced 23.3 t/ha in 1 year. The system also provided the farmer with a continuous supply of rice, and kept his labor requirement and input needs steady throughout the year. The system has good potential to increase rice production where ample irrigation water is available.

Farmers quickly adopt intensive cropping patterns that fit their needs. Figure 6 illustrates the rapid adoption of early maturing rices and the practice of double-cropping in Iloilo province, Philippines.

We developed environmental classification schemes for rainfall and for landscapes, and tested different cropping patterns in relation to such schemes. We found farmers' willingness to try more intensive cropping patterns to be closely related to the landscape classification scheme and, in turn, to soil moisture levels.



6. Farmers in Iloilo province, Philippines, have rapidly adopted early maturing varieties and double-cropping as a result of cropping systems work there since 1974–75.

The availability and, in turn, the cost of labor often dictate the farmers' willingness to adopt new cropping systems. We found labor rates at harvest time to be 3 to 4 times those common during the early growing season. Such high labor costs could discourage farmers from adopting cropping patterns that require short turnaround times at harvest when labor costs are high.

Focus on low-income people

We continue to focus research on low-income people. We are studying the consequences of the new rice technology that we, and others, have produced. In one village study, farm size was found to be decreasing and the number of landless laborers to be increasing. Although the landless laborers have shared in the increased income of the past 10 years, they have benefited less than the farm tenants.

Genetic evaluation and utilization (GEU) program

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GENETIC RESOURCES PROGRAM

IRRI now has about 36,960 registered accessions and 8,230 new seed samples of *O. sativa*, 1,541 strains of *O. glaberrima*, 866 wild taxa, and 637 genetic testers in the germplasm bank. About 30,380 accessions of *O. sativa* are completely described and their morphoagronomic data are on computer tape.

In 1977 IRRI collaborated with rice workers in the national rice research programs of Bangladesh and the Philippines to canvass and collect local germplasm. About 270 samples were directly collected in Bangladesh and local extension workers gathered 206 samples. A total of 195 samples were collected in the Philippines. Collaborators in 9 other countries provided IRRI with 933 samples.

Since the field collection project began in 1972, the collaborative efforts have led to the acquisition of 19,216 samples of Asian cultivars, of which 8,063 samples were collected with IRRI's direct participation. IRRI also collaborated with the Institut de Recherches Agronomique Tropicales et des Cultures Vivrières, Office de la Recherche Scientifique et Technique d'Outre-Mer, International Institute of Tropical Agriculture, and West Africa Rice Development Association in the conservation of African rices.

The Institute continues systematic exchange of conserved stocks with major national centers. It has taken steps to develop a global network of genetic resources centers that will share responsibilities for the overall conservation of rice germplasm.

A workshop on the genetic conservation of rice was held at IRRI in December. IRRI staff and 44 participants from 18 countries reviewed the existing genetic diversity and past conservation efforts. The participants developed a 5-year plan for the field collection of germplasm in South Asia, Southeast Asia, West Asia, Africa, and Latin America.

In response to 196 requests, IRRI sent foreign researchers 4,126 seed samples. Within IRRI, 50,354 samples were provided to different research departments for various experiments under the Genetic Evaluation and Utilization program.

Use of the new Rice Genetic Resources Laboratory began in November.

AGRONOMIC CHARACTERISTICS

Several promising lines were evaluated for yield performance in nitrogen response trials at IRRI, at Philippine Bureau of Plant Industry (BPI) stations, and in farmers' fields. At IRRI, IR2071-586-5-6-3 gave the most stable yield at all levels of nitrogen in both crop seasons, and IR2071-588-6-2. IR2797-125-3-2-2-2, IR4432-52-6-4, and IR4432-103-6-4 yielded well during the dry season without added nitrogen. During the wet season, IR4570-83-3-3-2, IR4570-117-2, and IR5853-162-1-2 were outstanding. At the three BPI stations IR2071-586-5-6-3 was the most stable yielder and was named IR42 in the Philippines. The early maturing selection IR2070-414-3-9 was named IR40.

A comparison of yield potential of the existing varieties indicated that larger grain size was closely correlated with larger yield potential. In an attempt to increase the yield potential of rice, selections with improved plant type and large grains were obtained from the crosses of Khao Lo and IR8, and Khao Lo and IR747B_2-6. Harvest index (HI) studies showed that stable and higher HI indicated higher yield potential. Short stature, short growth duration, and moderate temperatures during grain filling contribute to high HI.

GRAIN QUALITY

Emphasis on intermediate amylose content continues in the breeding program. About 12,000 entries of the world germplasm collection were analyzed for amylose content. The current amylose test at pH 4.5 for undefatted milled rice was found superior to testing at pH 10.2, because the pH 4.5 test is less sensitive to differences in residual fat of the rice.

In a food texture tester, the stickiness of cooked rice between two metal surfaces correlated better than hardness (resistance to extrusion) with amylose content for all rices. Sticki-

ness also correlated with gelatinization temperature among waxy rices. Hardness differences among varieties of similar amylose content were related to known differences in eating quality of these rices. Stickiness and hardness of cooked rice can indicate eating quality of promising IRRI lines.

The starch of indigenous tropical rices tends to have intermediate gelatinization temperature. The crystalline or corrosion-resistant portion of starch granules (7 to 21%) in 2.2 N HCl for 15 days at 35°C was higher in samples with higher gelatinization temperature and, to a lesser extent, higher amylose content. Differences in mean molecular weight of the acid-corroded starches were related to differences in the ratio of its two major dextrin fractions.

DISEASE RESISTANCE

Routine screening of breeding lines for disease resistance and screening of the germplasm collection for new resistance sources involved 66,248 entries for blast, 7,564 for sheath blight, 373 for *Cercospora* leaf spot, 4,459 for leaf scald, and 73,538 for bacterial blight. Field scoring involved 65,447 entries for tungro and 4,643 for ragged stunt. Disease resistance in breeding lines has been steadily increased. Genetic studies to identify new genes for resistance to bacterial blight in 55 varieties found 6 with *Xa 4*, 49 with *xa 5* genes, but none with new genes.

Breeding for stable resistance to blast is a difficult task. The International Rice Blast Nursery had, however, identified in all cooperating countries several lines with broad-spectrum resistance comparable with that of such varieties as Tetep and Carreon. The finding suggests that stable resistance to blast can be developed if the breeding materials are tested during early generations at many locations.

We tried alternative methods — other than the International Rice Blast Nursery — to determine blast resistance and to measure the so-called horizontal resistance. Of the eight varieties of various degrees of resistance in tests, Tetep, Dawn, and Sensho had small number of lesions; NP-125 and Dular had intermediate number of lesions; and Peta, Khao-tah-haeng 17 (KTH), and Fanny had many lesions, when each was inoculated with several isolates from their own lesions.

Tetep, Dawn, and Sensho, among the varieties tested, appeared to have a high level of horizontal resistance. However, varieties similarly tested and considered to have *field resistance* in Japan become susceptible at IRRI. In the measurement of the rate of disease development (*r*-value) by inoculating three virulent isolates to all varieties, Tetep, Dawn, and Sensho showed very low *r*-value, NP-125 and Dular had low *r*-value, KTH and Peta had high, and Fanny had the highest.

A preliminary trial compared the total and the rate of disease development in a plot with five single (various degrees of resistance) lines and one susceptible variety with those of a multiline plot of the five resistant lines with and without the susceptible variety. The plants were inoculated with three virulent races. The disease incidences were in accordance with levels of resistance in each line or variety. Some of the resistant lines had little disease. The test did not show any advantage of multiline planting over the single resistant lines.

A method of screening resistance to leaf scald was developed. The perfect stage of the fungus was found to be common in the field. The name *Metasphaeria albescens* is suggested for the perfect stage.

Pathotype 2, similar to the Isabela strain of the bacterial blight organism, has increased at IRRI, rendering varieties carrying the *Xa 4* resistance gene susceptible.

The virulence of *Xanthomonas oryzae* was of two types: continuous and discontinuous. It can be demonstrated by a number of rice varieties and the bacterial isolates.

Inoculation experiments showed that bacterial isolates from kresek symptoms caused more kresek than those isolates from leaf blight symptoms. The kresek bacteria also seemed to survive in paddy water better than the leaf-blight bacteria.

A new virus disease, ragged stunt, appeared in the Philippines in 1977. Methods were developed to evaluate the resistance to the new disease and varietal reaction was noted.

INSECT RESISTANCE

The number of entries screened for insect resistance continued to increase in 1977. As a result of diallel crossing, resistance to yellow stem borer surpassed for the first time that of the resistant check IR1820-52-2. Screening for leaf folder resistance was initiated and a rating scale was devised.

Twenty varieties resistant to the brown planthopper were analyzed to find new genes for resistance. Ptb 19, Gangala (Acc. 7733), Gangala (Acc. 15207), Horana Mawee, Kuruhondarawala, Mudu Kiriyal, and Muthumanikam have *Bph 3* gene for resistance; Gambada Samba, Heenhoranamawee, Hotel Samba, Kahata Samba, Kalukuruwee, Lekam Samba, Senawee, Sulai, Thirissa, and Vellai Illankali have *bph 4* for resistance; and the varieties Ptb 33, Sudu Hondarawala, and Sinna Sivappu each have two genes for resistance: one dominant and the other recessive. The amount of honeydew excreted on different varieties was established as a criterion for identification of the brown planthopper biotypes.

Selected promising lines having the N22 gene for resistance to the whitebacked planthopper are being evaluated in India and Indonesia. The lines are resistant to other major diseases and insects, and have excellent grain quality and a growth duration of 100 to 130 days.

Improved plant type progenies that carry green leafhopper resistance from three different accessions (Acc. 101845, 102485, 102550) of *O. glaberrima* and are fully fertile were developed.

Tests in the international collaborative study on gall midge biotypes showed that Eswarakora derivatives were susceptible to gall midge in Indonesia but resistant in Thailand. Siam 29 derivatives were resistant in Indonesia and Sri Lanka but susceptible in Thailand.

When the plant extract from TKM 6, a variety resistant to striped borer, was sprayed on susceptible Rexoro plants, the striped borer moths laid fewer eggs on Rexoro than on TKM 6 plants. On the other hand, eight times more eggs were laid on resistant TKM 6 sprayed with susceptible Rexoro extract.

Brown planthoppers caged on resistant plants with intact leaf sheaths ingested significantly less food than those caged on plants with leaf sheaths removed and stems exposed. The factor causing antibiosis appears to be present in much greater concentration in the leaf sheath than in the stem.

PROTEIN CONTENT

About 18,000 more entries in the world rice collection were screened for brown-rice protein, and high-protein nonjaponica entries from more than 29,000 screened to date were selected for further evaluation as sources for high-protein content. In contrast with those in earlier trials, in replicated yield trials grain yield and brown-rice protein were not significantly negatively correlated.

In high-protein rice, the subaleurone or outermost cells of the endosperm, rather than the bran, has the highest protein content. The bran, polish, and outer endosperm of high-protein rice are richer in ash than those of low-protein rice.

Destarched milled rice with 70 to 80% protein content may be prepared in quantity by pregelatinizing the starch granules before treating them with fungal or bacterial α-amylase. The preparations have protein quality identical to that of raw rice protein and protein recovery is more than 75%.

Protein bodies from raw milled rice were confirmed to be more susceptible to pepsin digestion than protein bodies from cooked rice; that agreed with digestibility data for rats. Transmission electron microscopy showed that the undigested protein bodies from pepsin digestion and fecal protein particles represent the core of the rice protein bodies. The core protein preparation was poorer in lysine, lower in molecular weight, and richer in fat than the whole protein body. Cooking made the glycolipid and phospholipid fractions of fat less digestible.

DROUGHT RESISTANCE

The IRRI crossing program was expanded to include drought resistance in both upland and rainfed lowland cultures. In 1977, 167 addi-

tional single crosses and 205 multiple crosses were made in the upland program. Another 89 single crosses and 21 topcrosses were made to incorporate drought resistance into improved lines for rainfed, lowland culture. Among the traditional varieties widely used as parents were Leb Mue Nahng, JC-81, Khao Dawk Mali 105, Nam Sagui 19, 20A, 63–83, IAC 25, IAC 1246, and advanced IRRI breeding lines that showed drought resistance in both greenhouse and field screening.

About 18,000 genotypes were evaluated for response to drought in wet and dry season field trials. Reproducibility of the test results across seasons and years increased IRRI scientists' confidence in identifying genotypic differences and the screening methods that have been developed. Traditional varieties such as CTG 1516, DZ 41, Dular, Padi Tatakin, 20A, and Surjamukhi have consistently received desirable scores over the past 3 years in upland field screening.

In 1977, emphasis on identifying highly adapted traditional varieties for rainfed, lowland conditions was increased. In a comparison of 270 genotypes grown in water-deficient and irrigated conditions during the dry season, Mahsuri, IR34, Knlb–368–1–8–6–7, Sigadis, and IR3646–8–1–1 showed high levels of drought resistance in lowland culture.

The 1977 upland rice variety trials to select promising lines with drought resistance and the ability to recover from drought, as well as high yield potential and pest resistance, were conducted at four Philippine sites.

The favorable rainfall at all sites allowed agronomists to evaluate the yielding ability, agronomic characteristics, and pest resistance of the lines selected earlier for drought response. The results contributed data to the International Upland Rice Yield Nursery (IURYN) and identified new entries for the 1978 IURYN.

Yield trials of 346 rices for rainfed, lowland culture were conducted at IRRI. The results will be used to nominate entries to the first International Rainfed Lowland Rice Observational Nursery (IRLRON) in 1978.

Twelve varieties and lines were compared under fully irrigated, partially irrigated, and rainfed lowland cultures in farmers' fields at two sites in Central Luzon. The plantings ran into a protracted dry spell during the reproductive phase. The results showed that early maturing varieties escaped the adverse effects of drought and produced good yields, but late-maturing varieties were markedly affected in yield. True difference in drought resistance was identified among late varieties of similar maturity.

Intensive studies of root systems of rice grown in root boxes in the greenhouse and in upland fields further illustrated genotypic diversity in such factors as rooting depth and density, and root diameter and branching pattern. Core sampling proved to be a satisfactory method of investigating vertical and lateral root distribution in upland fields.

Experiments were also conducted to examine rice root sensitivity to aluminum toxicity, a factor often responsible for retarding rice root growth in acid upland soils. A screening procedure using the IRRI phytotron and nutrient solution culture at two levels of aluminum concentration proved adequate for evaluating rice root growth in response to aluminum toxicity. Upland varieties were generally tolerant of aluminum toxicity, but lowland varieties were susceptible.

The importance of deep, extensive root systems is obvious. However, this trait may not be expressed where the soil's physical or chemical properties inhibit root penetration. Greenhouse experiments and evaluation of varieties tolerant of severe soil moisture stress where rooting depth is limited were continued in 1977.

Studies on the soil-plant-atmosphere water continuum in upland fields led to methods of expressing plant water deficits, based on soil and atmospheric data. The studies were useful in providing a means of expressing the effects of intensity and duration of drought on crop yield. The expressions agreed well with observed growth and yield response of upland rice crops.

Previous research illustrated the significant effect of atmospheric evaporative demand on crop and soil water status. Experiments were initiated to evaluate the effect of corn-rice intercrop on the canopy-level atmospheric evaporative demand and plant-water status of the intercropped rice crop. Changes in the intercrop

microclimate significantly affected the rice crop water status, indicating that intercropping rice with a taller crop species may be an agronomic means of protecting upland rice from drought.

TOLERANCE FOR ADVERSE SOILS

The main activities in adverse soils tolerance in 1977 were: 1) investigating screening techniques; 2) screening elite lines for tolerance for salinity, alkalinity, iron toxicity, Histosol problems, and deficiencies of phosphorus and zinc; 3) screening the progeny from the salt- and alkali-tolerance hybridization programs; 4) mass field screening of the world germplasm collection for tolerance for phosphorus and zinc deficiencies and for iron toxicity; 5) field testing rices for salt- and phosphorus-deficiency tolerance; 6) investigating the chemical basis of soil stress tolerance; and 7) breeding for adverse soils tolerance.

The greenhouse capacity for salinity and alkalinity screening was tripled by increasing the number of plants per tray. Piezometric monitoring of salinity improved the reliability of field screening for salt tolerance.

Of a total of 13,459 rices screened in 1977, 259 gave nearly normal growth under adverse soil conditions: for salinity, 52 tolerant rices were identified; for alkalinity, 31; iron toxicity, 27; Histosol problems, 1; phosphorus deficiency, 76; and zinc deficiency, 72.

IR4360-22-3 yielded 2.6 t/ha on a coastal saline soil in Camarines Sur, Philippines, where three IR varieties yielded less than 1.3 t/ha. On a zinc-deficient soil in Bohol, the local variety Lumbang gave 2.8 t/ha, outyielding 9 IR varieties. IR2307-247-2 yielded 3.9 t/ha without P fertilizer on a P-deficient soil on which IR36 gave only 2 t/ha.

Salt tolerance in rice was associated with a high electrolyte content in the root and a low content in the shoot. The alkali-tolerant rice Pokkali had a higher shoot concentration of total bases, potassium, phosphorus, and manganese than the sensitive IR26.

Although repeatability is not as high as desired, heredity of salt tolerance is quantitative. Pokkali's salt tolerance can be combined with other desirable traits.

More than 2,000 pedigree lines from 20 crosses were tested in the greenhouse; 3,000 were grown on a coastal saline soil in Camarines Sur.

DEEP WATER AND FLOOD TOLERANCE

Screening methods for different plant characters needed in deep-water rice varieties were developed and modified during the past 2 years. Major emphasis in 1977 was on screening of varieties in the germplasm collection and of new breeding lines. Several new varieties were identified as possible donors of plant characters needed in deep-water rice.

In Thailand, work on fertilizer response of deep-water lines at varying water depths, begun in 1976, was continued in 1977. Work on weed control, drilled seeding, drought resistance at seedling stage, and flood tolerance was also initiated.

Greenhouse testing involving four photoperiods has been useful in differentiating rices that have flowering dates suitable for the areas where photoperiod-sensitive varieties are used.

Basic studies on branching and its significance in deep-water rice were started at IRRI. Three deep-water tanks were completed to expand screening and agronomic research.

More crosses and intercrosses were made to generate diverse materials and to improve the elongation ability of promising lines. Several advanced breeding lines have been identified and planted in multilocational trials in Thailand. In tests, the new lines performed better than the traditional varieties and compared favorably with the improved varieties even in shallow water.

TEMPERATURE TOLERANCE

Since 1974, 17,689 rices have been screened for cold tolerance at different growth stages. Eleven varieties with cold tolerance at seedling, panicle initiation, and anthesis stages have been identified. They have optimum plant height and growth duration when grown in low-temperature areas. Many are being used in crosses and their progeny are being screened in greenhouses and fields.

The IRRI breeding program has been greatly expanded and field evaluation of breeding materials at Banaue, Philippines, has been intensified. New crosses between newly identified cold-tolerant varieties and elite GEU lines were made in 1977. Early generation seed and bulk seed of promising lines were distributed to collaborating rice improvement programs in low-temperature areas around the world.

A collaborative program with Korea on cold tolerance was initiated; experiments in Korea will begin in 1978.

A simple screening procedure has been developed for high-temperature tolerance. From more than 390 selections, 14 donors of high-temperature tolerance were identified for use in the 1978 breeding program.

Clear differences in anthesis time were found among selections of *O. sativa* and *O. glaberrima*. *O. glaberrima* selections began to flower earlier in the morning than *O. sativa*. Early anthesis may be an escape mechanism from sterility induced by high temperature. The high-temperature tolerant varieties that were identified did not have early morning anthesis; thus, they are truly tolerant.

INTERNATIONAL RICE TESTING PROGRAM

The International Rice Testing Program (IRTP) dispatched 577 sets of 15 types of nurseries in 1977, about the same number as in 1976. The national programs increased their contribution of nursery entries from 35% in 1975 to 65% in 1977. The IRTP continued to develop more nurseries for specific cultural conditions. A yield nursery of long-duration rices (IRYN-L) was initiated with materials suited to large delta regions of monsoon Asia where rice cannot be harvested until the monsoons end. Six nurseries were prepared jointly with the Centro Internacional de Agricultura Tropical (CIAT) for Latin America. Widespread use of the IRTP nursery entries in the national programs in hybridizations, and their promotion to local yield trials and production programs are becoming evident.

The IRTP monitoring tours encourage collaborative research among regional rice scientists and rapid adoption of new genetic materials and techniques. Monitoring tours were conducted in North Africa, West Asia, and Latin America for the first time in 1977.

INTEGRATED GEU PROGRAM

In response to special requests, 9,200 seed packets of improved breeding lines and varieties were distributed in 1977. The International Rice Testing Program (IRTP) provided another 36,583 packets of the best GEU lines and varieties to participating national programs. Seve hundred and twenty-four packets of F_2 se from 159 crosses were distributed to 28 locations in 15 countries. Collaborative projects with several national programs were initiated in 1977; early generation materials, advanced breeding lines, and varieties were exchanged for evaluation and hybridization.

The Philippine Seed Board named two IRRI lines as varieties in 1977, bringing the number of IRRI lines named in national programs to 51. IR2070-414-3-9, an early maturing (115 days), short-statured variety, was named IR40. IR2071-586-5-6-3, a high yielding, short statured variety with particularly high yield potential at low levels of applied nitrogen, was named IR42.

The volume of the IRRI crossing program decreased slightly in 1977, while the number of F_2 combinations and pedigree lines grown continued to increase as a reflection of the expanded crossing effort in previous years. The number of seed packets dispatched decreased due to a reduction in the volume of IRRI material included in the IRTP as national programs increased IRTP participation.

The responsibilities of the GEU plant breeders were reorganized to focus more directly on important target areas. More emphasis was placed on rainfed lowland areas, which make up about half of the rice area in South and Southeast Asia.

Several new breeding lines with adaptability to irrigated, rainfed lowland, and upland areas were identified.

Rapid generation advance was further evaluated as a breeding technique for the development of improved photoperiod-sensitive germplasm. IR36 seed was treated with

ethyleneimine; the 10 plants recovered from the M_2 had extremely low pollen viability and normal ovule function. Monogenic male sterile lines may be identified from the 10 materials.

COMPUTERIZED DATA MANAGEMENT

The IRRI germplasm bank has 36,956 registered accessions of *O. sativa,* 26,000 of which are completely characterized for 38 basic morphoagronomic characteristics. Complete information on 35 GEU traits for 33,946 accessions was in the germplasm data bank as of 1977.

A computer-based system to monitor movement of, and provide instant information on, seed stocks was tested in 1977. Volume I of *Parentage of IRRI crosses* was published. From the history-of-cross file a computer program was developed to complete the family tree of each cross.

Computerized data management systems were developed for seven IRTP nurseries in 1977 making a total of 10 nurseries now in the system.

RICE BREEDING IN ASIA

The diffusion of rice genetic materials used as parents during 1965–67, 1970–71, and 1974–75 was traced at 14 agricultural research centers in 7 Asian nations.

In 1965–67, at least one semidwarf parent was involved in 61% of the crosses; by 1974–75, semidwarfs were involved in 84%. Crosses that involved a tall variety dropped from 74% to 45% during that time. In 1965–67, 28% of the total gene pool was semidwarf and 40% tall. Ten years later the percentage of semidwarfs almost doubled and that of tall and intermediate-statured material dropped sharply.

Taichung Native 1 (TN1) and IR8 were the most popular gene sources in 1965–67; each was used in about 20% of the crosses. But they were used in only 1–3% of 1974–75 crosses. Use of other IRRI semidwarfs increased to 44%. The strongest upward trend was in the use of locally developed semidwarfs — from almost none in 1965–67 to about half of the 1974–75 crosses. Three-fourths of the local semidwarf parents had IR8 or other IRRI rices as parents. Because Dee-geo-woo-gen (DGWG) is a common ancestor of almost all semidwarfs, the DGWG gene can be assumed to be in about 80% of the 1974–75 crosses.

Genetic evaluation and utilization (GEU) program

Genetic resources program

Plant Breeding Department and International Rice Testing Program

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FIELD COLLECTION

Plant Breeding Department

Since IRRI's field collection of rice germplasm began in 1972, collaborative efforts with national agricultural research centers in South and Southeast Asia have assembled 19,216 cultivars. Of the number, 8,063 samples were collected with the direct participation of IRRI staff. In 1977 collaborators in Bhutan, France, Indonesia, the Ivory Coast, Malaysia, Nigeria, Pakistan, the Philippines, Sri Lanka, and Thailand sent in 1,139 collected samples.

The Institute continues to collaborate with several Asian countries in assembling indigenous varieties. During July and August, canvassing in Bangladesh in cooperation with the Bangladesh Rice Research Institute resulted in the assemblage of 274 seed samples, most of which are aus varieties. Extension workers gathered 206 more samples.

Work in northwestern Mindanao, Philippines, with the staff of the Bureau of Agricultural Extension netted 231 samples. The Bureau of Plant Industry and the University of the Philippines at Los Baños also participated in the development of field collection plans for various parts of the Philippines.

IRRI contributed funds toward the collaborative collection of the African rices in West Africa — a project involving the International Institute of Tropical Agriculture, Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières, Office de la Recherche Scientifique et Technique d'Outre-Mer, West Africa Rice Development Association, International Board for Plant Genetic Resources (IBPGR), and IRRI.

INSTITUTIONAL EXCHANGES

Plant Breeding Department

A continuing dialogue with national and state organizations in India led to the systematic transfer of Indian genetic stocks to the IRRI germplasm bank. During the year the bank received 2,896 seed samples from the Central Rice Research Institute, 2,800 seed samples from the Chinsurah Rice Experiment Station of West Bengal, and 88 boro varieties from the G.B. Pant Agricultural University.

The Rice Division of Thailand turned over 190 accessions to IRRI; the Department of Land Development provided 12 special types.

A visiting delegation from the People's Republic of China and IRRI staff members visiting China added 107 Chinese varieties to IRRI's collection.

A systematic exchange of accessions between the Plant Germplasm Laboratory of the United States Department of Agriculture (USDA) and IRRI continued, following a comparison of registered accessions. The Laboratory sent IRRI 609 samples that included 52 collected in Pakistan. A set of 21 Pakistani varieties was received from the Foundation of Plant Breeding in the Netherlands.

Through correspondence and personal contact, IRRI acquired 32 Nepalese rices collected by the staff of University College of North Wales in the United Kingdom.

Visiting scientists from the Union of Soviet Socialist Republics brought 11 varieties to IRRI.

SEED INCREASE, REJUVENATION, AND DISTRIBUTION

Plant Breeding Department

Land space available for seed increase and rejuvenation was reduced during 1975-77 by construction of the Laboratory and Training-Conference Center and the Rice Genetic Resources Laboratory on former Plant Breeding Department fields. As a result, seed stocks of thousands of accessions were reduced to the *insufficient-for-distribution* level, i.e., around 20 g each, or less. During August 2,020 accessions were grown for seed rejuvenation on a newly developed lowland area. Another group of 2,648 photoperiod-sensitive accessions was sown in November. Seed of 180 strains of *O. glaberrima* was also increased. Before harvesting, the seed of each rejuvenated accession was examined for morphoagronomic characteristics; the characteristics were then compared with those recorded in the varietal catalog to maintain trueness of an accession.

During the systematic characterization phase, seed of recently received samples was multiplied mainly in the field. Seed of small seed lots was increased in screened nursery beds or in pots inside the phytotron. Because of ragged stunt virus and brown planthopper epidemics at IRRI during the dry season, cultivars and wild taxa with few seeds left were grown in the phytotron or in nursery beds enclosed with fine-mesh wire screen to keep out planthoppers. During the wet season, a considerable number of seed-increase plots were damaged by the hoppers and associated virus diseases.

Seed distribution operations continued to be a major service feature of the germplasm bank: 4,126 samples of *O. sativa* cultivars were sent to 148 foreign researchers, and 50,354 samples on 196 occasions were provided for various GEU tests at IRRI. Foreign researchers and IRRI staff members received 517 seed samples of *O. glaberrima* and 164 samples of wild taxa. The number of seed packages distributed during the year surpassed that of 1976 (Table 1).

INVENTORY, CHARACTERIZATION, DATA PROCESSING, AND STORAGE

Plant Breeding Department

In 1977 IRRI received 8,410 seed samples from institutions, scientists, missionaries, and international service volunteers. Another 629 samples were recovered from experiment stations as replacements for nonviable samples received earlier.

At the year's end, the IRRI germplasm bank had 36,956 registered accessions of *O. sativa*, 1,541 accessions of *O. glaberrima*, 866 populations of the wild species or taxa, and 637 genetic testers and mutants. It has 8,234 recently received seed samples of *O. sativa* cultivars that need to be planted and compared with those with identical variety names before they can be registered as new accessions (Table 1). Some of the new acquisitions are promising breeding lines developed by national programs and by IRRI, lines with special traits and used as parents in IRRI's hybridization program, and hundreds of entries in the International Rice Testing Program (IRTP) nurseries.

Of the *O. sativa* accessions 30,380 have been completely characterized for 37 basic morphoagronomic characteristics. About 3,565 more accessions have been completely characterized in the field, but data from laboratory measurements on 8 remaining items need to be recorded. The alphabetical and numerical listing of the accessions was manually arranged and the 43-item printout supplied by the Statistics Department was proofread before the corrected information was entered on computer tape.

Of the accessions of *O. sativa* that are fully characterized, about 29,000 have been dried to 9% moisture content, put in glass jars, and placed in medium-term storage. Thousands of accessions are stored in large drums because the manufacturer of the glass jars has been unable to supply them.

Seed of control varieties in medium-term storage were periodically tested for their viabili-

Table 1. Progress of the IRRI Genetic Resources Program in field collection, preservation, and seed distribution of *Oryza sativa* cultivars, 1970–77.

Year	Samples collected in Asia (no.)	Distinct accessions in germplasm bank (no.)	Samples distributed (no.)	
			Inside IRRI	National programs
1970	—	12,800	16,000	5,600
1971	—	14,712	10,600	2,300
1972	732	16,893	2,740	2,500
1973	1,405	24,162	8,275	9,777
1974	2,982	26,818	19,236	2,603
1975	566	30,332	22,155	4,043
1976	1,466	34,229	40,200	4,819
1977	808	36,956[a]	50,354	4,126

[a]About 8,234 recently received seed samples are yet to be registered; 5,498 duplicate accessions and 1,822 nonviable seed samples were removed from the registry during 1972–77.

ty. Near the end of the year, 13.5-year-old seeds of two tropical varieties had germination percentages above 95, while seed of the nondormant *ponlai* variety of Taiwan (Chianan 8) had only 40. During the 1976 dry season, 2,467 nondormant accessions from the temperate zone were rejuvenated.

RICE GENETIC RESOURCES LABORATORY

Plant Breeding Department and International Rice Testing Program

Construction of the Rice Genetic Resources Laboratory was completed during the year. The new building was formally dedicated on 12 December. It houses the laboratories, storage rooms, and offices of the germplasm bank, the Plant Breeding Department, and the IRTP. It provides 360 m^2 floor space for seed processing; 54 m^2 for fumigation, drying, and vacuum packing of seed; 165 m^2 for short-term storage of fumigated seed; 348 m^2 for short-term storage of nonfumigated seed; 178 m^2 for medium-term storage; and 50 m^2 for long-term storage. The storage rooms will provide ranges of temperature and relative humidity (RH): short-term — 20°C ± 2°C, 45% RH; medium-term — 2°C ± 2°C, 45% RH; and long-term — −10° ± 2°C, 30% RH.

WORKSHOP ON THE GENETIC CONSERVATION OF RICE

Plant Breeding Department

A workshop on the genetic conservation of rice genetic resources was held 12–15 December at IRRI, under the joint sponsorship of IRRI and IBPGR. The United Nations Development Programme, through the World Bank, provided the funds. The conferees — 44 from 18 countries and IRRI staff — surveyed existing rice germplasm in each of the major rice-producing countries, assessed past conservation efforts, and developed a 5-year collaborative collection plan for the systematic canvassing of indigenous genetic resources in South Asia, Southeast Asia, West Asia, Africa, and Latin America. The participants urged IRRI's collaboration in most of the countries where further field collection is needed.

Genetic evaluation and utilization (GEU) program

Agronomic characteristics

Agronomy, Plant Physiology, and Plant Breeding Departments

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YIELD PERFORMANCE AND NITROGEN RESPONSE OF IRRIGATED RICE

Agronomy Department

The performance of promising breeding lines and varieties was evaluated during both seasons at IRRI, at Philippine Bureau of Plant Industry (BPI) stations, and on farms. IR8 and IR26 were the check varieties.

IRRI. Table 1 shows the yield of selected lines at different nitrogen levels. Among the varieties, IR42 had the most stable high yields at all nitrogen levels. For the first time during the dry season, IR42 (IR2071-586-5-6-3 in previous reports) gave the highest yield without fertilizer nitrogen. Breeding lines that yielded 4.5 t/ha or higher without fertilizer nitrogen were IR2071-588-6-2-6-4, IR4432-103-6-4, IR2797-125-3-2-2-2, and IR4432-52-6-4.

In the wet season, IR42 again produced high and stable yields at all levels of nitrogen. For the third consecutive wet season, it produced the highest yield without added nitrogen. Breeding lines that appeared promising in the dry season also appeared promising during the wet season. New lines that yielded 5.0 t/ha or higher were IR4570-117-2-1-2, IR5853-162-1-2, and IR4570-83-3-3-2 (Table 1).

Virus (ragged stunt and tungro) and bacterial diseases (bacterial leaf blight and bacterial leaf streak) were particularly severe on IR8, IR20, IR26, and Peta in the wet season. Some breeding lines were affected by virus and bacterial diseases in both seasons. IR40 appeared vigorous during the vegetative period but lodged at the panicle initiation stage in both seasons.

Philippine BPI stations. The grain yields of 18 rices were evaluated during both crop seasons at the BPI stations at Maligaya, Bicol, and Visayas.

The dry-season trial at Visayas was discontinued because of water shortage. Because there were no serious insect and disease problems at any station, IR8 had high yield. IR26, IR38, and IR42 had high yields at 60 kg N/ha or higher (Table 2). IR42 had stable high yield without fertilizer nitrogen. In the wet season (av. for three stations) IR42 had similarly stable high yields at all nitrogen levels. Most rices appeared to respond favorably to 60 kg N/ha in the wet season (Table 3).

In all stations, stem borers and bacterial leaf streak caused damage during the wet season. At Maligaya and Bicol, a typhoon before harvest (November) caused severe lodging and generally low yields.

Table 1. Yields of rice varieties and promising lines at five nitrogen levels in irrigated plots.[a] IRRI, 1977 dry and wet seasons.

Variety or line	Dry season						Wet season					
	Maturity (days)	Yield[b] (t/ha)					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		0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha
IR8	133	2.3	3.9	4.8	4.7	4.8	136	0.5	0.5[c]	0.6[d]	0.6	0.6
IR20	119	3.8	4.6	4.7	6.0	5.5	120	1.2	1.0	1.0	1.5	1.0
IR26	133	4.0	6.0	6.0	6.0	6.0	130	1.3	1.2	1.0[c]	0.7	0.8
IR34	126	3.9	5.7	6.2	5.8	6.6	128	2.3	2.4	2.3	2.4	1.6
IR36	102	3.5	4.5	5.3	5.8	6.1	113	2.8	3.4	4.2	4.9	5.2
IR38	126	3.3	5.4	5.9	6.4	7.3	128	2.9	4.0	4.5	4.4	4.8
IR40	112	3.9	5.5	6.1	6.0	6.1	124	2.7	3.3	3.2	3.0	2.8
IR42	143	5.1	6.7	6.7	7.5	8.0	140	4.8	4.8	5.7	5.2	5.7
IR2307-247-2-2-3	116	4.2	5.2	6.7	6.8	7.2	120	3.4	4.2	4.4	5.1	5.4
IR2797-125-3-2-2-2	126	4.7	7.3	7.6	7.6	8.1	124	3.8	4.4	4.0	5.0	5.0
IR2863-36-1	129	3.7	5.6	6.0	6.7	7.5	128	3.5	4.7	4.4	4.9	5.3
IR4432-52-6-4	129	4.8	6.7	6.8	7.4	8.0	130	3.8	5.2	5.1	5.5	4.5
IR4432-103-6-4	126	4.5	6.5	6.5	7.5	8.4	—	—	—	—	—	—
IR2071-588-6-2-6-4	143	5.0	6.8	7.2	7.1	7.6	140	3.7	4.5	4.5	5.2	5.8
IR4570-83-3-3-2	—	—	—	—	—	—	140	4.1	4.5	4.7	5.0	5.0
IR4570-117-2-1-2	—	—	—	—	—	—	140	4.2	4.4	5.8	5.2	5.2
IR4613-54-5	126	4.1	6.0	6.1	7.2	7.3	130	1.6	2.8[c]	2.1[c]	1.9	2.0[c]
IR5853-162-1-2	—	—	—	—	—	—	124	4.0	5.4	5.1	5.5	5.4
Peta	148	2.3	4.0	3.5	4.5	4.3	148	0.7	1.0[c]	0.8	0.7	0.9[d]

[a]Each treatment includes 30 kg N/ha topdressed at panicle initiation in the dry season and 10 kg N/ha topdressed at panicle initiation in the wet season. [b]Av. of three replications. LSD (5%) = 1.1 t/ha. [c]Av. of two replications only. [d]One replication only.

Table 2. Yields of varieties and promising lines at six levels of nitrogen[a] in irrigated plots of Maligaya Rice Research and Training Center and Bicol Rice and Corn Experiment Station, Philippines, 1977 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
IR8	136	3.6	5.9	7.0	6.7	6.7	6.8
IR20	120	3.0	5.2	6.1	4.9	5.6	4.9
IR26	132	3.7	6.0	6.6	7.0	6.4	5.8
IR34	125	4.0	5.9	6.1	5.8	4.4	4.6
IR36	110	3.3	5.6	6.0	6.0	6.1	5.3
IR38	123	3.7	5.4	6.2	5.6	5.7	5.7
IR40	115	3.3	5.1	5.4	4.7	5.3	5.1
IR42	139	4.0	5.0	6.3	6.2	6.6	6.7
IR2071-137-5-5-1	112	2.7	4.8	6.0	5.8	5.4	5.7
IR2307-217-2-3	107	3.4	4.6	5.4	4.7	5.3	4.5
IR2307-247-2-2-3	119	4.0	6.3	7.2	6.6	6.9	6.2
IR2797-125-3-2-2-2	114	4.0	6.2	6.4	6.1	5.4	4.7
IR2863-38-1	120	3.0	5.7	6.8	6.8	6.4	5.4
IR4417-179-1-5-2	120	3.5	4.7	5.2	5.4	5.3	4.9
IR4432-52-6-4	111	3.5	5.4	6.0	5.7	5.1	5.3
IR4432-103-6-4	123	4.1	5.9	6.4	6.7	6.3	5.8
IR4413-54-5	126	3.8	5.6	5.7	5.4	4.4	3.3
Peta	141	3.9	4.3	3.1	3.1	1.8	1.8

[a]Each treatment, except 0 kg N/ha, includes 30 kg N/ha topdressed at panicle initiation. [b]Av. of two locations, each with three replications. LSD (5%) = 0.8 t/ha.

Table 3. Yields of varieties and promising lines at six levels of nitrogen[a] in irrigated plots at Maligaya Rice Research and Training Center, Bicol Rice and Corn Experiment Station, and Visayas Rice Experiment Station, Philippines, 1977 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
IR8	126	3.2	3.9	4.0	4.3	4.3	3.8
IR20	125	3.1	4.4	4.9	4.9	4.2	3.8
IR26	123	3.3	3.9	4.8	4.6	4.5	4.2
IR36	109	3.6	4.6	5.0	4.8	4.6	4.5
IR38	123	3.7	4.4	4.6	4.4	4.5	3.6
IR42	131	4.0	4.8	5.2	5.3	5.1	4.8
IR2307-217-2-3	108	3.4	3.9	4.3	4.6	4.4	4.6
IR2797-125-3-2-2	127	3.5	4.2	4.8	4.4	4.5	4.6
IR2863-38-1	126	3.5	4.3	4.6	4.5	4.7	4.3
IR4219-35-3-3	136	3.7	3.9	3.9	3.7	3.2	2.4
IR4417-179-1-5-2	127	3.1	3.8	4.1	3.9	3.7	3.7
IR4432-52-6-4	125	4.2	4.8	4.9	4.6	4.1	3.5
IR4563-52-1-3-6	125	3.7	4.4	4.8	4.5	4.9	3.5
IR4568-86-1-3-2	124	3.7	4.4	4.5	4.8	4.8	4.7
IR4570-83-3-3-2	129	3.7	4.2	4.7	4.8	4.5	4.2
IR4570-117-2-1-1	130	3.9	4.4	4.9	4.6	4.6	4.3
IR5853-162-1-2	125	4.2	4.8	5.0	4.9	4.3	3.5
Peta	147	3.7	3.1	2.7	2.1	2.2	2.1

[a]Each treatment, except 0 kg N/ha, includes 20 kg N/ha topdressed at panicle initiation. [b]Av. of three locations, each with three replications. LSD (5%) = 0.5 t/ha.

Farmers' fields. IRRI varieties and lines were tested at different nitrogen levels in farmers' fields.

During the dry season, IR42 and IR4432-52-6-4 produced high yields of 7.7 t/ha (Table 4). IR42 had the second highest yield without fertilizer nitrogen and, like IR4432-52-6-4, had high and stable yields at all levels of nitrogen. The low yields of IR2307-217-2-3 at all nitrogen levels were due to bacterial diseases and grain shattering.

During the wet season, IR42's yield of 5.8 t/ha without fertilizer nitrogen was consistent with results obtained at IRRI. A typhoon in

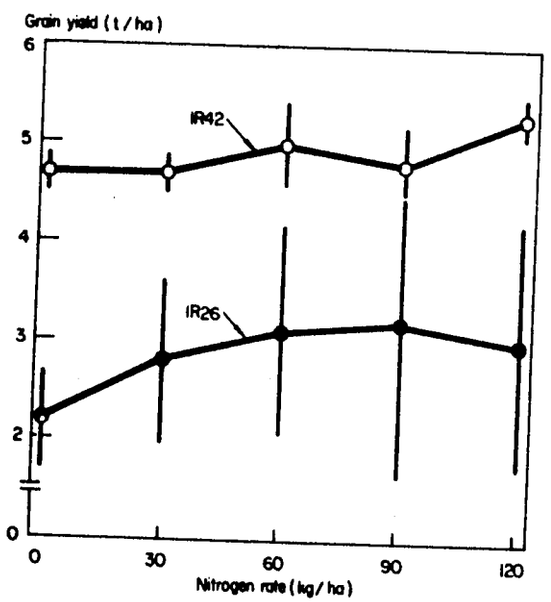
Table 4. Yields of varieties and promising lines at four levels of nitrogen[a]. Av. of three replications in irrigated farmers' fields, Laguna province,[b] 1977 dry and wet seasons.

Variety or line	Dry season					Wet season				
	Maturity (days)	Yield[c] (t/ha)				Maturity (days)	Yield[d] (t/ha)			
		0 kg N/ha	50 kg N/ha	100 kg N/ha	150 kg N/ha		0 kg N/ha	40 kg N/ha	80 kg N/ha	120 kg N/ha
IR8	131	4.7	4.8	5.5	5.6	124	4.8	5.3	6.1	6.0
IR26	131	4.8	5.5	5.9	7.0	124	5.8	5.9	6.8	6.7
IR36	102	4.0	4.4	5.0	6.1	110	5.3	5.6	6.4	5.5
IR38	122	4.4	5.4	6.2	6.0	—	—	—	—	—
IR42	135	5.1	6.2	7.3	7.7	126	5.8	6.2	7.3	5.8
IR2307-217-2-3	102	3.4	4.5	4.9	5.2	—	—	—	—	—
IR2863-38-1	122	3.9	5.0	6.3	6.8	126	5.7	5.8	6.2	5.2
IR4432-52-6-4	131	5.6	5.2	7.5	7.7	126	5.5	6.1	4.9	5.0
IR4563-52-1-36	—	—	—	—	—	115	5.1	5.5	5.3	4.7
IR4570-83-3-3-2	—	—	—	—	—	126	5.6	6.3	6.6	6.2

[a]Each treatment, except 0 kg N/ha, includes 20 kg N/ha at panicle initiation for both seasons. [b]Dry season at Calamba, wet season at Cabuyao. [c]LSD (5%) = 0.9 t/ha. [d]LSD (5%) = 0.6 t/ha.

November caused severe lodging near maturity.

Performance of IR42 without fertilizer nitrogen. Many Asian rice farmers do not apply fertilizer and those who do, use a low rate. Figures 1 and 2 show how IR42 performed relative to IR26 with and without fertilizer nitrogen for three consecutive wet seasons at IRRI and for two consecutive wet seasons at three BPI stations. The consistency of IR42's relatively high yield without fertilizer nitrogen makes it a valuable variety for low-fertility conditions.



1. Nitrogen response of IR26 and IR42 (IR2071-586-5-6-3). IRRI, 1975, 1976, and 1977 (av.) wet season (± standard error).

Date-of-planting experiment. A date-of-planting experiment, in which crops are planted monthly, was continued during 1976 and 1977. Data for 4 harvest months of 1977 are not yet available. Figure 3 shows the nitrogen response of IR8, IR38, IR42, and H4.

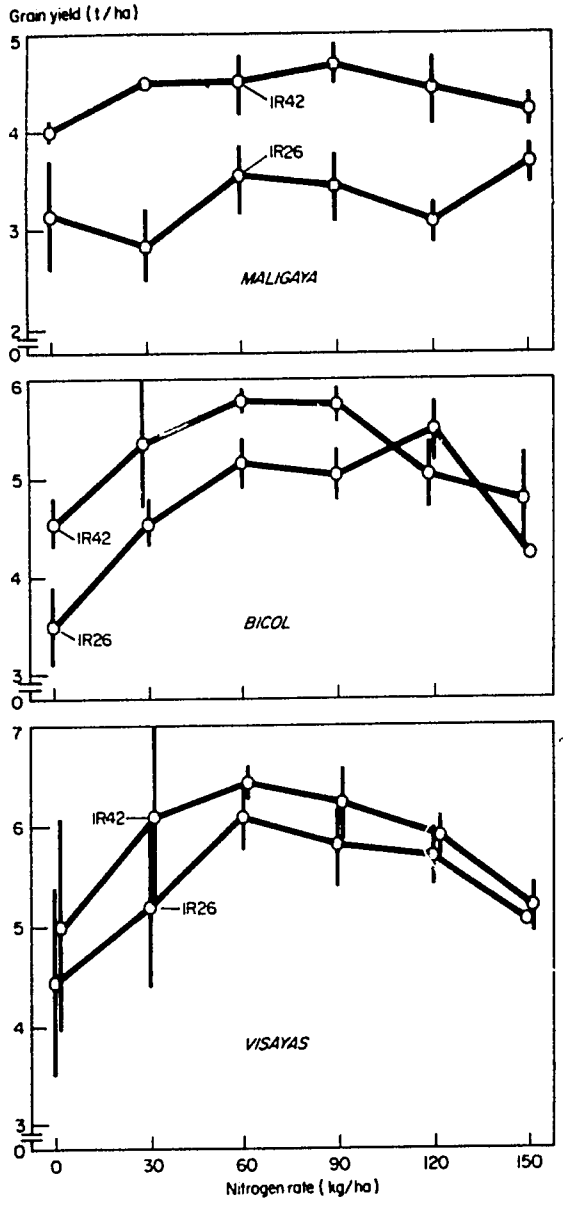
In most harvest months, the later maturing IR42 yielded the highest at all nitrogen levels, including no nitrogen (Fig. 3). The solar energy at 45 days before harvest and the grain yield were highest for the May harvest. The outstanding performance of IR42 without fertilizer nitrogen at most harvest months indicates its good potential at various solar energy levels.

YIELD PERFORMANCE AND NITROGEN RESPONSE OF RAINFED LOWLAND RICE

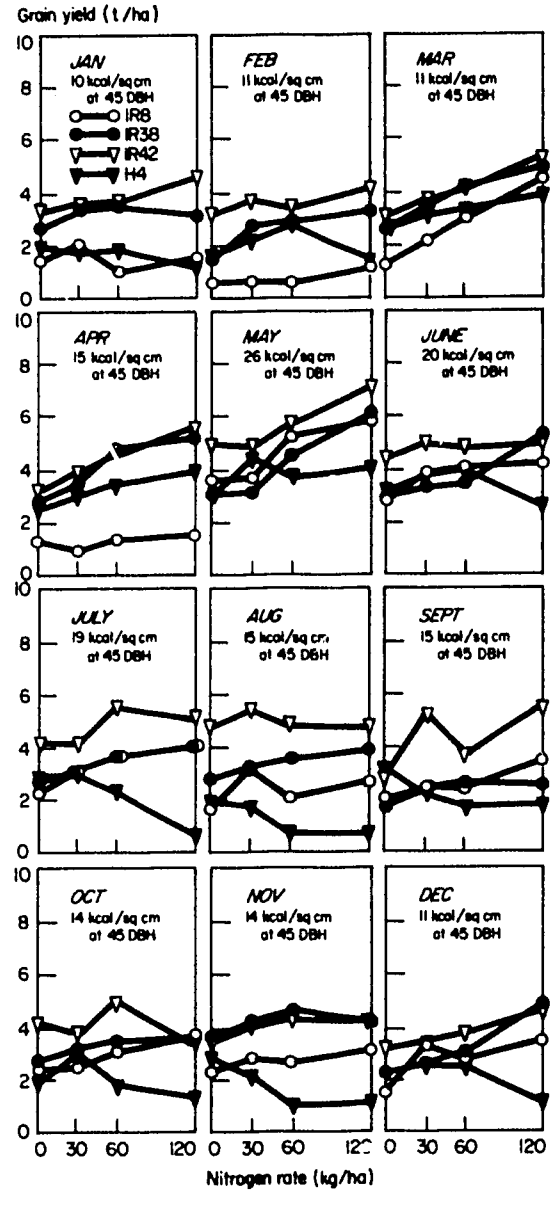
Agronomy Department

The performance of promising rainfed lowland rice was evaluated at IRRI and in farmers' fields.

IRRI. Seven promising lines and five varieties were evaluated in rainfed-lowland plots at IRRI during the wet season (Table 5). Total rainfall during the crop season (1,000 mm from August to December) was sufficient for a good rice crop, but was only 129 mm in October and 143 mm in November. Rainfall at 200 mm/month is considered minimum for normal growth of rice.



2. Nitrogen response of IR26 and IR42 (IR2071-586-5-6-3). Bureau of Plant Industry stations (Maligaya, Bicol, and Visayas). 1976–77 wet season (± standard error).



3. Nitrogen response by month of harvest of four rice varieties, plotted with total solar radiation (av. of four varieties) for 45 days before harvest (DBH). Date-of-planting experiment, IRRI, 1976.

The promising line IR2058-78-1-3-2-3 had the highest yield except at 120 kg N/ha (Table 5). IR42 yielded above 4.0 t/ha with fertilizer; but without fertilizer, it yielded less than it did when irrigated (Table 3). Severe lodging was caused by a typhoon in November.

IR5, IR26, Mahsuri, and IR4683-54-2-2-3 were severely affected by bacterial diseases, IR26 was severely affected by ragged stunt virus, and IR5 and Mahsuri were affected by tungro and grassy stunt viruses. IR4219-35-7-3 was affected by blast (leaf blast and neck rot) during the vegetative and reproductive stages.

Farmer's field. A wet-season experiment in a farmer's rainfed field evaluated the performance of varieties and promising lines (Table

Table 5. Yields of varieties and promising lines at four levels of nitrogen[a] in rainfed - lowland plots, IRRI, 1977 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
IR5	133	0.8	0.5	[c]	[c]	[c]
IR26	123	0.9	2.2	0.9	1.0	0.6
IR36	105	2.3	4.2	4.5	4.7	4.5
IR42	129	3.1	4.2	4.9	4.5	4.7
IR2058-78-1-3-2-3	123	4.8	5.3	5.6	5.4	4.7
IR2307-247-2-2-3	110	4.5	5.0	5.5	5.3	5.5
IR2863-38-1	123	3.7	4.6	5.2	4.8	4.5
IR3351-38-3-1	133	3.7	4.0	3.8	3.8	3.8
IR4219-35-3-3	133	1.9	2.1	2.0	1.4	1.2
IR4683-54-2-2-3	123	1.3	2.1	1.6	1.3	0.9
IR5863-118-5	110	3.2	4.1	4.1	4.0	3.9
Mahsuri	129	0.7	0.7	[c]	[c]	[c]

[a]Each treatment, except 10 kg N/ha, includes 20 kg N/ha topdressed at panicle initiation. [b]Av. of three replications. LSD (5%) = 0.9 t/ha. [c]Poor yields due to heavy virus infection. [d]From two replications only.

6). IR42 had high yields without nitrogen and with 40 kg N/ha (Table 6); its low yields at 80 and 120 kg N/ha were caused by lodging.

IR8 had high yields in the trial because serious disease and insect problems were absent.

GRAIN SIZE AND YIELD POTENTIAL

Plant Physiology and Plant Breeding Departments

Twelve varieties were grown at 10- × 10-cm spacing in the field to confirm a 1976 finding that yield potential is correlated positively with grain size. Yield potential is defined as the product of spikelet (grain) number per square meter and average weight per grain. Spikelet number per square meter (N) decreased linearly with increasing grain size (W) (Fig. 4):

$$N = N_o - aW \qquad (1)$$

where N_o and a are constant. By definition, yield potential is given by:

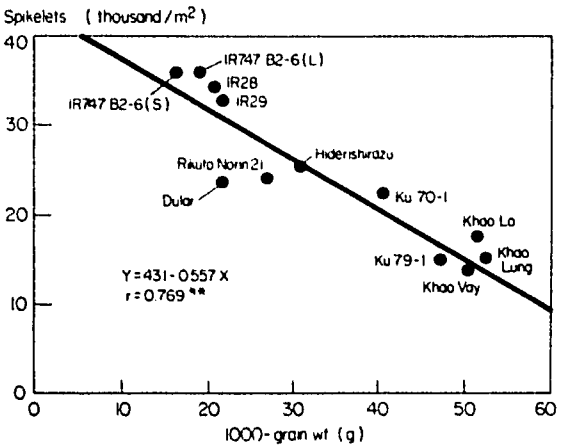
$$N \times W = (N_o - aW)W \qquad (2)$$

This relationship is shown in Figure 5, where the solid line indicates the relationship computed from equation (2) and the broken line is *an expected* relationship if large grain size is combined with short stature. The estimated optimum grain size to give the maximum yield potential is about 39 g/1,000 grains. Considering partition of photosynthates between growing panicles and vegetative parts before heading, the optimum grain size will become larger if the present large-grain varieties are reduced in stature.

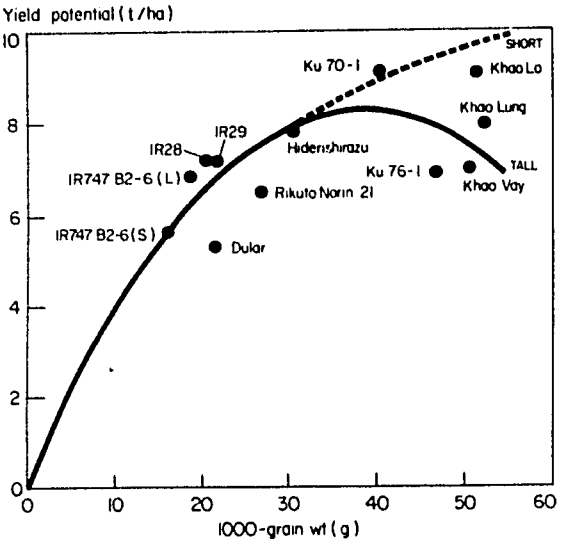
Table 6. Yields of varieties and promising lines at four levels of nitrogen[a] in a farmer's rainfed field, Laguna, 1977 wet season.

Variety or line	Maturity (days)	Yield[b] (t/ha)			
		0 kg N/ha	40 kg N/ha	80 kg N/ha	120 kg N/ha
IR8	125	5.2	5.1	4.6	4.2
IR26	126	5.5	5.5	4.7	3.8
IR36	114	5.2	4.7	4.3	4.4
IR42	133	5.2	4.5	3.7	2.3
IR2058-78-1-3-2-3	125	5.0	4.2	3.2	2.2
IR2863-38-1	126	5.1	4.4	3.1	3.5
IR4219-35-3-3	135	3.7	2.8	1.7	1.3
IR5853-118-5	114	5.0	5.2	5.3	4.0

[a]Each treatment, except 0 kg N/ha, includes 20 kg N/ha topdressed at panicle initiation. [b]Av. of three replications. LSD (5%) = 1.3 t/ha.



4. Relationship between grain size and spikelet number. IRRI, 1977.



5. Relationship between grain size and yield potential. Broken line indicates an expected relation if large grain size is combined with short plant stature. IRRI, 1977.

Among the varieties used, IR747B2-6 (L) and IR747B2-6 (S) are isogenic lines. They differ only in grain size. As shown in Table 7, the difference in grain size of 2.6 g/1,000 grains makes about 1-t/ha difference in yield potential.

IR8, a selection from a cross between Peta and Dee-geo-woo-gen, is believed to be high yielding because it has high lodging resistance and erect leaves. It has larger grain size and larger grain number per square meter than its parents and, consequently, a much higher yield potential. The high yielding nature of IR8 can be attributed not only to high lodging resistance and the improved canopy photosynthesis by its erect leaves, but to increased sink size (yield potential). At present, the grain size of many varieties ranges from 15 to 25 g/1,000 grains. This study suggests that selection for larger grain size is a possible way of increasing the yield potential of existing varieties. Furthermore, if large grain size is combined with short plant stature, the yield potential may become higher than that of IR8 and similar dwarf indicas.

Producing a prototype of dwarf, large-grain varieties. All currently available large-grain varieties are tall. An attempt to incorporate the large-grain character into dwarf varieties is under way. F_2 seeds of crosses between large-grain varieties and dwarf varieties have a high percentage of sterility. Despite that difficulty, four promising large-grain F_3 selections with dwarf stature — from crosses between Khao Lo and IR8, and Khao Lo and IR747B2-6 — were produced. Their grain weight ranges from 38 to 47 g/1,000 grains.

Crosses between large-grain varieties and IR36 or IR29 were also made. Seeds of some large-grain varieties were subjected to gamma irradiation. Selection for short plant stature is under way.

Table 7. Grain size and spikelet number of interrelated selections. IRRI, 1977 wet season.

Selection	Spikelets (thousand/m²)	1,000-grain wt (g)	Yield capacity (t/ha)
IR747B2-6(L)	35.9	19.1	6.86
IR747B2-6(S)	35.6	16.5	5.87
Peta	33.8	26.1	8.82
Dee-geo-woo-gen	33.2	23.0	7.64
IR8	37.6	29.0	10.90

Table 8. Effect of 50% clipping of spikelets on grain weight of four varieties. IRRI, 1977.

Variety	Treatment	Filled grains (%)	Filled grains (no./panicle)	1,000-grain wt (g)
Bomdia	Control	89	179	12.4
	Clipped	91	108	12.6
IR747(S)	Control	93	79	15.5
	Clipped	93	43	15.2
Khao Lo	Control	94	66	45.0
	Clipped	98	37	45.8
Kap Nhay	Control	68	41	45.2
	Clipped	74	24	45.7

GRAIN-FILLING PERIOD OF SINGLE GRAINS

Plant Physiology Department

The grain-filling period of single grains in a 32- to 24°C range was measured on 28 varieties, which included both indica and japonica rices. Varieties with 1,000-grain weight of more than 40 g matured from 16 to 21 days after anthesis and those with 1,000-grain weight of less than 18 g matured in 11 to 12 days. Middle-size-grain varieties (20-30 g/1,000 grains), however, had grain-filling periods that widely varied in length from 11 to 12 days.

EFFECTS OF PARTIAL CLIPPING OF SPIKELETS AND DROUGHT ON 1,000-GRAIN WEIGHT

Plant Physiology Department

Four varieties differing in grain weight were grown in pots with standard cultural practices to examine the effect of partial clipping of spikelets on the final weight of remaining grains. At heading, plants were divided into a group with intact spikelets and a group with 50% spikelets along the main axis in each panicle removed to double the relative strength of source to sink. The final grain weight remained almost unchanged even when strength of source relative to sink size was doubled (Table 8). The experiment confirms that maximum grain size of rice varieties is rigidly determined by hull size, which is mainly a varietal characteristic.

With drought, the grain weight of the same variety varies considerably (Table 9) because of either limited photosynthesis during ripening or reduced size of hull. The 1,000-grain weight of rice varieties is a stable varietal characteristic under irrigation. With drought, however, variation in the grain weight occurs below the maximum grain weight that is characteristic of a variety.

HARVEST INDEX: CRITERION FOR SELECTING FOR HIGH YIELD ABILITY

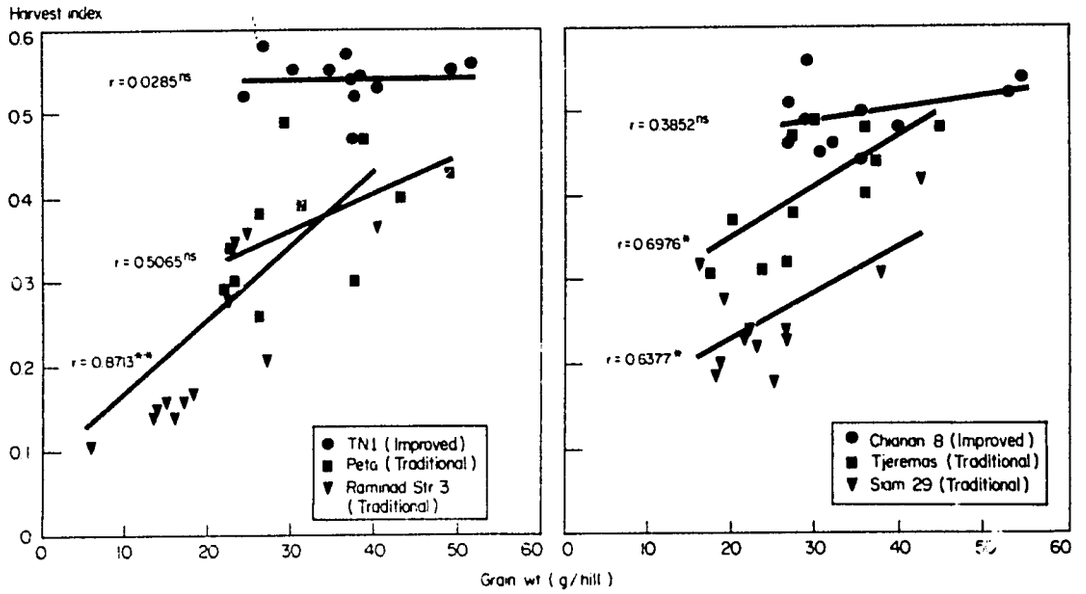
Plant Physiology Department

The ideal plant type of varieties with high grain-yield potentials includes erect leaves, stiff straw, short stature, and high tillering capacity. Breeding lines selected for these criteria have high grain-yield potentials, but grain yield varies with season, spacing, nitrogen level, and site.

In recent years, rice breeders have selected

Table 9. Effect of drought on 1,000-grain weight of varieties grown with different depths to water table. IRRI, 1977.

Variety	1,000-grain wt (g) at			
	30 cm	45 cm	60 cm	100 cm
Deep-rooted				
N22	17.2	16.5	16.2	16.0
OS4	25.4	24.3	23.1	23.7
Shallow-rooted				
IR2035-120-3	19.1	13.9	13.6	13.6
IR2035-117-2	16.2	12.0	12.2	11.8



6. Harvest index and grain weight of six varieties sown monthly at IRRI, 1962.

for intermediate plant type (as opposed to semidwarfs) and very early or late maturity. Except for plant height, the criteria listed above are applied in the selection for high yielding lines. It is not known, however, if the grain yield potential is changed by increased plant height even though no lodging occurs, or if the potential is changed with changes in growth duration.

For high grain yields, a balanced growth at different stages must be achieved. Balanced growth is reflected in the high ratio of the weight of the panicle to that of total dry matter produced — harvest index (HI). The factors affecting HI and its possible consequences were studied with data from numerous IRRI experiments for different purposes.

Grain weight and harvest index. Monthly planting experiments show that grain weight per plant generally increases with HI (Fig. 6). The relationship, however, is more for the traditional varieties than for the improved varieties. The improved varieties Taichung (N) 1 and Chianan 8 are distinct; they have high and stable HI regardless of the time of planting, and show no significant correlation between HI and grain weight. The HI of the traditional varieties was unstable; it generally increased (except for Peta) with increase in grain weight.

Table 10 shows the high and stable HI of the improved varieties Fujisaka 5, Hakkoda, and Sukhwel 20 grown at different spacings and nitrogen levels when compared with seven low

Table 10. Effect of spacing and nitrogen level on the harvest index (HI) of 10 varieties. IRRI, 1963 dry season.[a]

	High HI			Low HI						
Treatment	Fujisaka 5	Hakkoda	Sukhwel 20	Nang Quot	Cjon Tran	Tjere Mas	Peta	59-368	Acheh	Serayap
0 N	0.56 a	0.57 a	0.58 a	0.50 a	0.51 a	0.49 a	0.49 a	0.48 a	0.40 a	0.42 a
50 N	0.58 a	0.60 a	0.57 a	0.50 a	0.46 ab	0.43 ab	0.47 ab	0.48 a	0.37 a	0.42 a
150 N	0.59 a	0.62 a	0.54 a	0.41 b	0.43 b	0.41 b	0.40 b	0.39 b	0.35 a	0.37 a
10-cm spacing	0.55 a	0.56 a	0.57 a	0.49 a	0.47 ab	0.45 ab	0.42 ab	0.44 ab	0.36 a	0.38 a
25-cm spacing	0.56 a	0.61 a	0.55 a	0.47 ab	0.50 ab	0.47 ab	0.46 ab	0.42 a	0.36 a	0.38 a
50-cm spacing	0.55 a	0.56 a	0.58 a	0.51 a	0.45 ab	0.50 a	0.46 ab	0.47 a	0.38 a	0.40 a
CVc[b] (%)	2.9	4.5	2.9	7.7	6.5	7.6	7.4	8.2	4.8	5.5

[a] In each column, means followed by a common letter are not significantly different at 5% level. [b] Coefficient of variation of change.

Table 11. Effect of spacing and nitrogen level on the harvest index of Peta and Peta lines. IRRI, 1967.

Treatment		Harvest index[a]				
Spacing (cm)	N-level (kg/ha)	Early short	Early tall	Late short	Late tall	Peta
			Dry season			
20	0	0.59 a	0.55 a	0.55 a	0.51 a	0.52 a
40	0	0.61 a	0.56 a	0.55 a	0.52 a	0.52 a
20	150	0.60 a	0.49 b	0.51 b	0.41 b	0.43 b
40	150	0.59 a	0.51 b	0.52 b	0.42 b	0.44 b
Av.		0.60	0.53	0.53	0.46	0.48
CVc[b] (%)		1.6	6.3	3.9	12.5	10.3
			Wet season			
20	0	0.59 a	0.53 a	0.50 a	0.44 a	0.43 a
40	0	0.60 a	0.55 a	0.51 a	0.43 ab	0.43 a
20	150	0.58 a	0.49 b	0.49 a	0.41 b	0.40 b
40	150	0.60 a	0.55 a	0.50 a	0.41 b	0.42 ab
Av.		0.59	0.53	0.50	0.42	0.42
CVc (%)		1.6	5.3	1.6	3.6	3.4

[a]In each column under each season, means followed by a common letter are not significantly different at 5% level. [b]Coefficient variation of change.

yielding indica varieties. The improved varieties showed no significant difference in HI due to plant spacing or nitrogen level. They also had low coefficient of variation of change (CVc) values or *degrees of changes*, indicating a stable HI. The traditional varieties showed a high degree of change in HI.

An experiment with Peta and its isogenic lines (Table 11) showed that the high yielding Early short line has a high and a stable HI (CVc is 1.6 for Early short, 10.3 for Peta in the dry season).

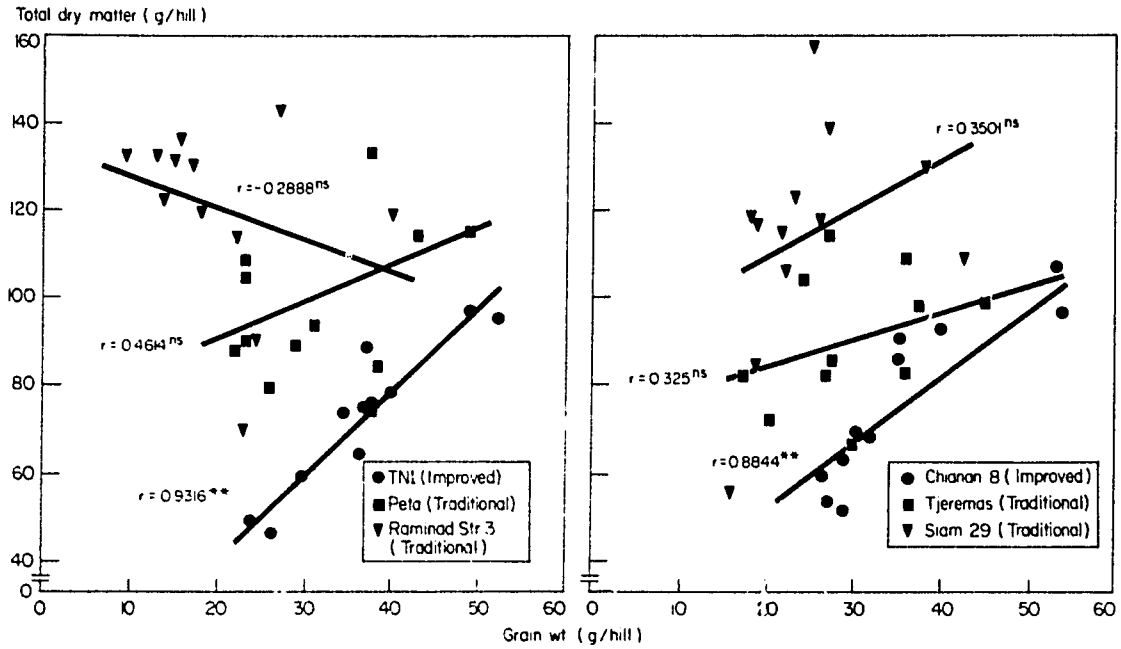
The high and stable HI of the improved varieties is a useful character because increasing the dry matter production could mean a corresponding increase in grain yield. This relationship is shown in Figure 7. In the improved varieties grain yield and total dry matter were positively related, and the increase in dry matter production came with a significant increase in grain yield. In the traditional varieties, increase in dry matter production does not necessarily increase the grain yield; thus, extra dry matter produced by application of fertilizer is not usually compensated for by higher grain yields.

In the tropics, grain yield is not correlated with total dry matter production but high dry matter production is needed for high grain yields. Traditional varieties have low grain yields, despite high dry matter production, because they have low HI.

In an IRRI 1964–65 cooperative experiment (5 countries and 15 sites) to determine the yield potentials of the leading varieties with optimum management, HI showed a positive correlation with grain yield ($r = 0.5417^{**}$). All varieties that had high yields had high HI. This maximum-yield-potential experiment used only the best varieties of the areas. Low grain yields were from traditional varieties, which were the best at that time. Despite the best possible management, the grain yields were still low — the yield potentials and the HI were low.

Factors affecting harvest index. The data have shown that for high grain-yield potential, lines or varieties with high HI should be selected and management practices should be geared to produce high dry-matter weight. A variety with high HI would be more responsive to cultural inputs, and any increase in dry matter would increase grain yields. Because the criterion recommended for selection is HI, a knowledge of how it is affected by different environmental factors, cultural management, and variety would be helpful not only in selection but in improving the HI.

Plant height. Reduction in plant height has often been cited as the most important factor in determining the nitrogen responsiveness and higher yields of the modern rice varieties. The shorter culms mean lower respiration loss by the culm and therefore improve the net gains in the



7. Total dry matter produced and grain weight of six varieties sown monthly at IRRI, 1962.

photosynthesis-respiration balance.

Recently, intermediate plant height has gained favor in areas where deep water (30–150 cm) or weeds are a problem. The current shift to selection of intermediate plant height as opposed to semidwarf may have decreased the grain yield potentials, even though lodging resistance is maintained.

Studies on isogenic Peta lines planted during the wet and dry seasons and at 0 and 100 kg nitrogen/ha showed that increase in plant height generally decreased the HI (r = 0.8625**). Individually, the increase in plant height as a result of wet-season planting or high nitrogen level resulted in a decrease in HI. The decrease in HI was greater in the tall than in the short lines.

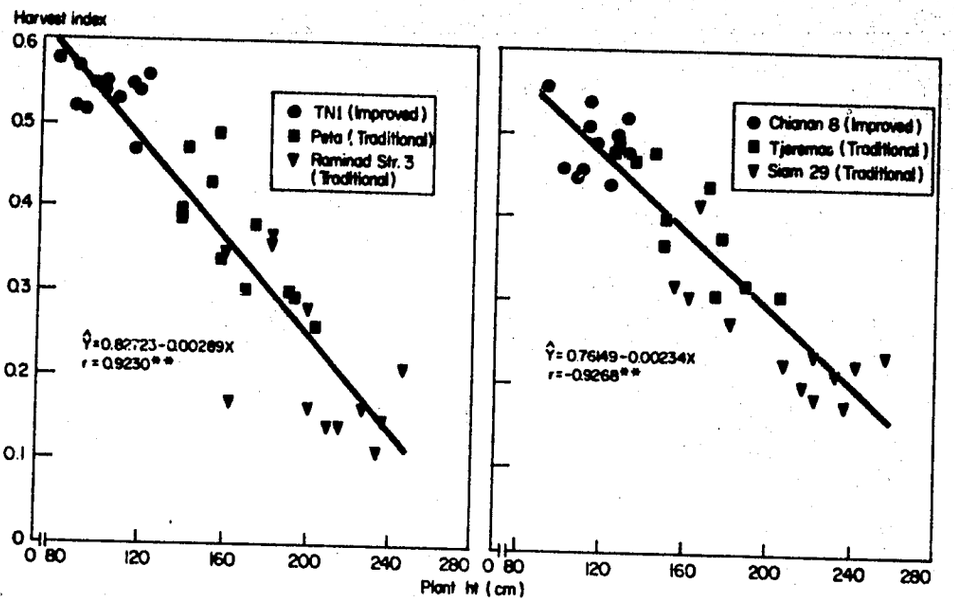
The HI also decreases with increase in plant height of varieties planted at different dates (Fig. 8). However, the variation in plant height as a result of different sowing dates showed that only the HI of the traditional varieties decreased with increase in plant height; the improved varieties had little variation in plant height, and thus in HI.

Data from a maximum-yield-potential experiment showed plant height to be negatively correlated with HI (r = −0.5637**).

In IRRI nitrogen-response experiments with Peta and 11 high yielding varieties, HI also decreased with increase in plant height during the wet (r = −0.8107**) and dry (r = −0.7598**) seasons. The results are the average of three replicates and six nitrogen levels. The relationship shows the importance of selecting for short stature.

Spacing and nitrogen. In the experiment with 10 varieties and different spacings, the HI did not change significantly with spacing for both the high- and low-HI varieties (Table 10). In a study using Peta and its isogenic lines, spacing also had no effect on the HI except in Early tall Peta in the wet season (Table 11). Spacing is, therefore, immaterial in selecting for high HI. With increase in nitrogen the high-HI varieties showed no significant increase in HI (Table 10), but five of the seven low-HI varieties showed a significant decrease in HI.

Increase in nitrogen level for Peta and its isogenic lines (Table 11) resulted in a decrease in HI, except in Early short Peta during both seasons and Late short Peta during the wet sea-



8. Plant height and harvest index of six varieties planted monthly at IRRI, 1962.

son. As in the previous experiment, Early short Peta — the line with high HI — had little variation in HI despite changes in spacing and nitrogen level.

The differences in response to nitrogen between the high- and low-HI varieties are apparent in the two experiments. High-HI varieties showed little or no decrease in HI from higher nitrogen. Increase in grain yields as a result of nitrogen application would, therefore, be greater from varieties with high HI than from those with low HI. Nitrogen responsiveness can be selected by measuring the HI.

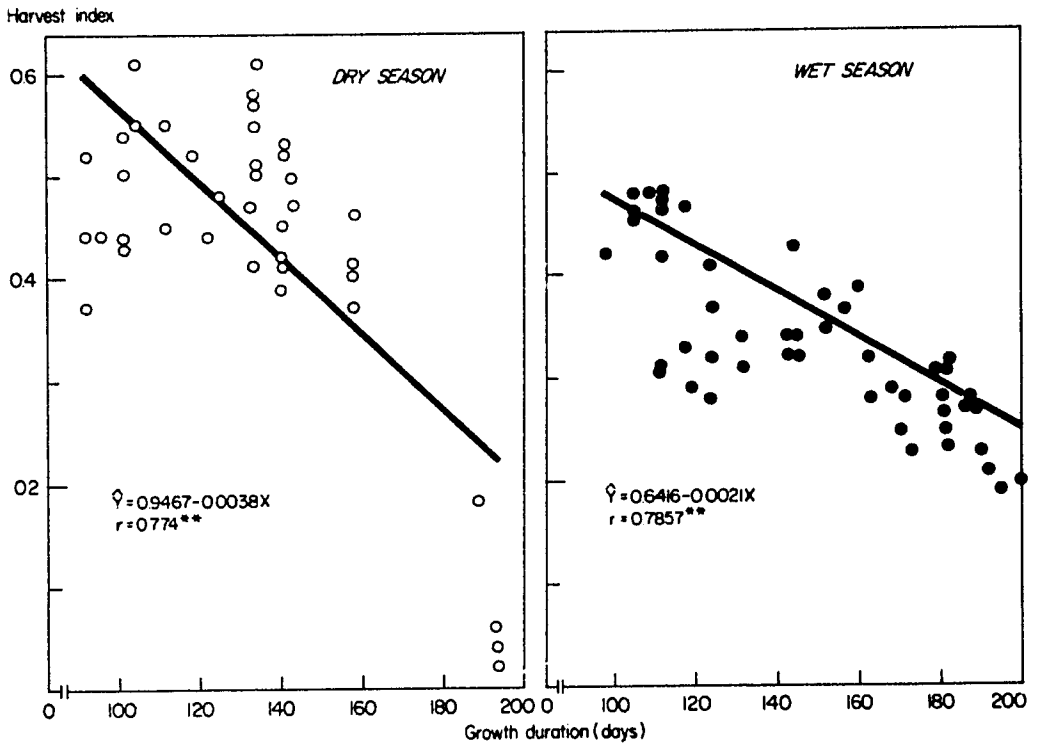
Because the varieties with high yield potentials showed little variation in HI, and the HI remained high regardless of spacing or nitrogen level, reliable selection for high HI can be done with any spacing or nitrogen level.

Season of planting. The experiment with Peta and its isogenic lines showed a marked decrease in HI during the wet season than during the dry season, partly because of the taller plants and the increased vegetative dry matter production during the wet season. As in the previous study, increase in plant height decreased the HI.

Numerous Japanese workers have reported that high temperatures decrease HI. This factor should also be considered when measuring HI of plants sown at different months or locations.

Growth duration. Increase in growth duration increases the amount of dry matter produced, but does not necessarily increase grain yields. HI actually decreases with increase in growth duration, so that the resulting grain yield is not any higher than that of the medium growth duration varieties (Fig. 9). The results from the wet season show a clearer negative relationship between HI and growth duration. However, since no optimum duration is indicated, growth duration of less than 100 days might still give a higher HI. During the dry season, the HI of varieties with growth durations of less than 100 days slightly decreased. The varieties with HI above 0.55 had growth durations between 100 and 130 days.

A 1964 experiment that used only one variety (BPI-76) but varied the growth duration by manipulation of the photoperiod showed that HI and grain yield increase with growth duration of up to 128 days and then decrease up to 194 days (Fig. 10).

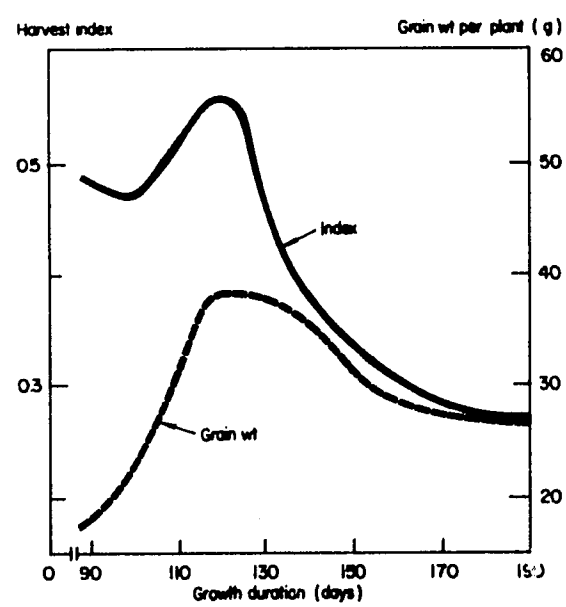


9. Growth duration and harvest index of several varieties planted during the wet and dry seasons. IRRI, 1963.

In selecting for high HI, the lines should be grouped according to maturity because the late-maturing selections will have a greater tendency for low HI. In many deep-water areas, long-growth-duration varieties are necessary and high HI must be sacrificed.

Improving the grain yield potential. Many ideas on ways for increasing the yield potential of rice have been presented. Increasing the photosynthetic efficiency and increasing the sink size are the most popular approaches. Although varieties with high photosynthetic rates have been identified, no respectable increase in grain yields has been obtained. Similarly, many varieties with large panicle size or sink size have been identified, but they also have a proportionally large straw weight that limits the number of tillers possible per unit area. Sink size is determined mainly by the plant's capacity to fill up the sink.

Another possible approach to increased grain yield potential may be selection of varieties with high HI and development of a management practice for high dry matter production.



10. Effect of different growth durations on the grain yield and harvest index of photoperiod-sensitive rice variety BPI-76. IRRI, 1964.

GROWTH DURATION

Plant Breeding Department

For a number of years IRRI has emphasized the development of rices with short growth duration. Numerous breeding lines with a growth duration of 105 to 110 days were developed. Some, particularly IR36, have been widely accepted by farmers. Present work aims to develop breeding materials with growth duration of 90 to 95 days. The earliest maturing IRRI line IR747B2-6 (100 days) has good vigor but is susceptible to tungro.

Several early maturing improved varieties from China and traditional varieties from India mature in 90 days, but they have low yield potential and are susceptible to diseases and insects. They were crossed with IR747B2-6 and backcrossed once with IR747B2-6. Progenies from those backcrosses were evaluated during 1977. Some lines selected from those materials mature in 90 days, have the vigor and yield potential of IR747B2-6, and are resistant to blast, bacterial blight, and brown planthopper. They are being used in the hybridization program. The crosses from which those early maturing lines were selected are listed in Table 12.

Table 12. Crosses from which selections with short growth duration (90 days) were obtained. IRRI, 1977.

Cross	Parents
IR10154	ADT 4/IR747B2-6//IR747B2-6
IR10155	ADT 30/IR747B2-6//IR747B2-6
IR10176	IR747B2-6/29 Lu 1//IR747B2-6
IR10179	IR747B2-6/Ai-nan-tsao 1//IR747B2-6
IR10183	IR746B2-6/Kwang-chang-ai/IR747B2-6
IR10185	IR747B2-6/Kwang-Lu-ai 4/IR747B2-6
IR10187	IR747B2-6/Nanking 14/IR747B2-6
IR10189	IR747B2-6/Shensi variety/IR747B2-6.

SOURCES OF SEMIDWARFISM

Plant Breeding Department

Semidwarfs continue to be received among accessions for the germplasm bank. The new semidwarfs are crossed with the semidwarf varieties carrying the Dee-geo-woo-gen (DGWG) recessive gene to determine whether the semidwarfs concerned have an identical gene for semidwarfism.

The parents, F_1 hybrids, and F_2 populations of 28 crosses were grown in the wet season to study segregation patterns. Among the new semidwarfs, five Chinese varieties developed on the mainland — Chen-chu-ai 11, Chen-chu-ya, Ai-nan-tsao 1, Ai-chio-nan-te, and Kwang-chang-ai — carry the same recessive gene as DGWG. The study also revealed that the two major parental sources of semidwarfism used by rice breeders on the China mainland — Ai-chio-nan-te and Ai-tze-chuan — carry an identical semidwarfing gene.

Among five short-statured lines of hybrid origin developed by the Central Rice Research Institute of India, Culture 147 from GEB 24/Baok, Culture 155 from MTU 15/Baok, and one line from T141/Baok 360 also appeared to have the same recessive gene as DGWG. Several tall F_2 plants (1.5 to 1.6 m) were found in the crosses involving Culture 854 and Culture 956, both of which came from Ptb 10/Baok. The two lines could carry another gene or genes for semidwarfism.

One Indian semidwarf from Assam, ARC 5981A, also has the DGWG gene.

Two Indonesian sources, Lembat and Djamadi, produced several tall F_2 plants. But the height of the Indonesian parents varied from 85 cm in short day length to more than 135 cm in long day length in different plantings. Therefore, Djamadi and Lembat are not true semidwarfs.

Among three short-statured (100-115 cm) varieties of Burmese origin, several tall (140-150 cm) F_2 plants were found in the crosses involving Khunnaymayin (s) and Khunni Shay, while Khunnaymayin (p) produced short F_2 plants only. Because few F_2 plants were tall and the majority of the plants ranged from 60 to 100 cm, the Burmese parents may not have a distinctly nonallelic gene for tallness but could have some of the common genetic background of the DGWG genotype for short stature. Further studies are needed to clarify the quantitative inheritance of plant height in the above crosses.

Genetic evaluation and utilization (GEU) program

Grain quality

Chemistry and Plant Breeding Departments

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BREEDING PROGRAM

Plant Breeding Department

Amylose content. Several promising lines with intermediate amylose content were evaluated. The most promising are IR4215-301-2, IR4570-74-2-2-3, IR4570-124-3-2, and IR7963-30-2. The lines have, in addition to intermediate amylose content, resistance to major diseases and insects. They were used as parents in a large number of single crosses and topcrosses, and the progenies will be evaluated in the early generations.

Grain elongation. Some varieties increase 100% in length during cooking, a desired trait in high-quality rices of several countries. Basmati 370 and similar varieties from Pakistan and north India, a group of Barah varieties from Afghanistan, and several high-quality Sadri rices from Iran have that characteristic. In many crosses, Basmati and Barah varieties as well as varieties from Iran, were poor combiners. Progenies of 1975 crosses with D25-4, a high-quality variety from Burma that doubles in length during cooking, were evaluated in 1977. D25-4 combines well and several lines with improved plant type that have its grain elongation characteristic were selected.

FACTORS THAT AFFECT GRAIN QUALITY

Chemistry Department

Amylose test at pH 10.2 and on brown rice. The simplified amylose assay of undefatted milled rice at pH 4.5 has the disadvantage of interference from amylopectin-iodine absorption at 590 nm. The use of sodium bicarbonate-carbonate buffer at pH 10.2 and 590 to 630 nm eliminated such interference, but the color was more sensitive to fat than at pH 4.5 (Table 1). This was especially true for brown rice whose undefatted samples gave amylose readings less than one-half those of defatted samples. The amylose values of milled rice defatted with cold ethanol were about 1 percentage point lower at pH 4.5, but more than 3 percentage points lower at pH 10.2 than those of milled rice defatted with refluxing 95% ethanol. Defatting with cold water-saturated butanol at room temperature had the same effect on amylose content at both pH values as defatting with refluxing 95% ethanol.

The results indicate that the current simplified assay using undefatted milled rice at pH 4.5 is preferred to the assay at pH 10.2 because of the extreme sensitivity at alkaline pH of the amylose-iodine color to the variable amounts of extraneous fat, which in milled rice ranges from 0.3 to 0.6%. The use of milled-rice samples instead of pure amylose as a check effectively reduces the complication of amylopectin-iodine absorption at pH 4.5 (1976 Annual Report). The terms *apparent* and *absolute* amylose content are proposed to distinguish between the amylose values of rice samples defatted with cold ethanol and refluxing ethanol. Apparent amylose content refers to values obtained from cold-ethanol defatted rice, and absolute amylose content refers to values obtained from rice defatted with refluxing ethanol or cold

Table 1. Effect of pH, defatting method, and milling on rice amylose by iodine-blue color. IRRI, 1977.

Sample	Brown rice			Milled rice				
	pH 4.5		pH 10.2	pH 4.5			pH 10.2	
	Refluxing EtOH*	Undefatted	undefatted	Cold EtOH*	Refluxing EtOH*	Cold water saturated butanol	Cold EtOH*	Refluxing EtOH*
IR2071-137-5	12.8	9.2	4.9	12.1	12.4	13.6	8.8	11.7
IR24	15.0	11.3	6.2	14.6	17.2	16.3	11.5	15.7
IR480-5-9	23.5	19.6	11.6	24.0	25.3	25.8	22.6	26.3
IR8	28.8	23.6	12.8	29.2	30.0	30.2	28.8	31.8
Mean	20.0	15.9	8.9	20.0	21.2	21.5	17.9	21.4

*Ethanol, 95%.

Table 2. Range of physicochemical properties of milled rice from five countries. IRRI, 1977.

Country	Milled rices (no.)	Protein (%)	Apparent amylose type[a]	Gel consistency type[b]	Alkali spreading type[c]
Peoples Republic of China	34	6–11	H>L>I>Wx	S>M>H	L>I
Colombia	5	8–10	I>H	S>H	L
Japan	4	5– 7	L	S	L
Malaysia (West)	10	6– 8	H>I>Wx	S>M	H>L>I
Senegal	3	5– 8	H	S>M	I>L

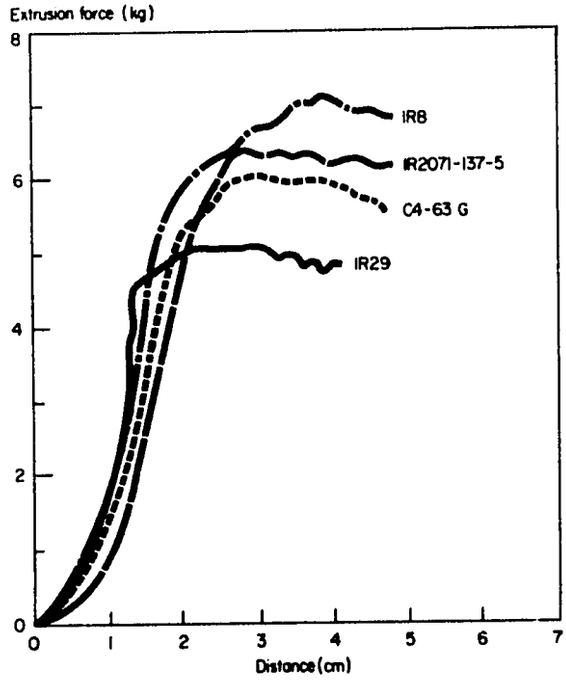
[a]L = low, 9–20%; I = intermediate, 20–25%; H = high, >25%; Wx = waxy, 1–2% dry basis. [b]S = soft, 61–100 mm; M = medium, 41–60 mm; H = hard, 26–40 mm. [c]Gelatinization temperature type based on alkali degradation: L = low, 6–7; I = intermediate, 4–5; and H = high, 2–3.

water-saturated butanol. Interestingly, apparent amylose content of milled rice coincided with the absolute amylose content of brown rice (Table 1).

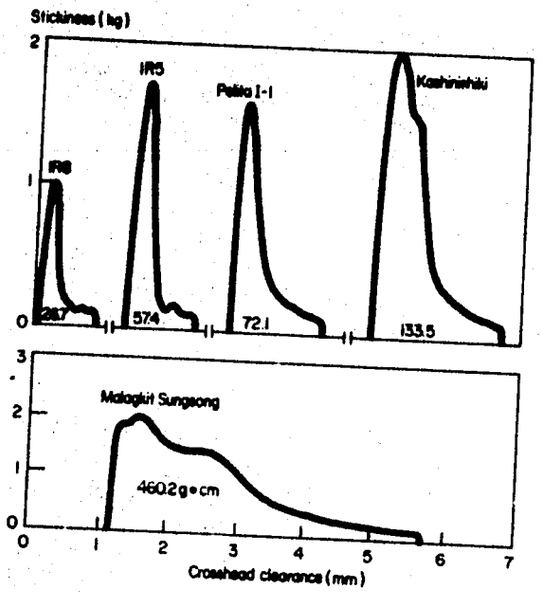
Amylose screening of world rice collection. Amylose screening of the world rice collection was initiated using brown rice defatted with refluxing 95% ethanol. The 12,000 samples used were those previously analyzed for brown-rice protein. Values obtained were considered identical to apparent amylose content of milled rice. The distribution of amylose content in the samples was 14.5% waxy (0-8% amylose), 15.6% low (9-19% amylose), 39.5% intermediate (20-24% amylose), and 30.4% high (≥25% amylose).

Survey of world rice varieties. Rices from five countries were analyzed. High-amylose rices predominated in three countries, intermediate-amylose in one, and low-amylose in one (Table 2). However, soft gel predominated even among high-amylose rices. Low gelatinization-temperature rices predominated in three countries.

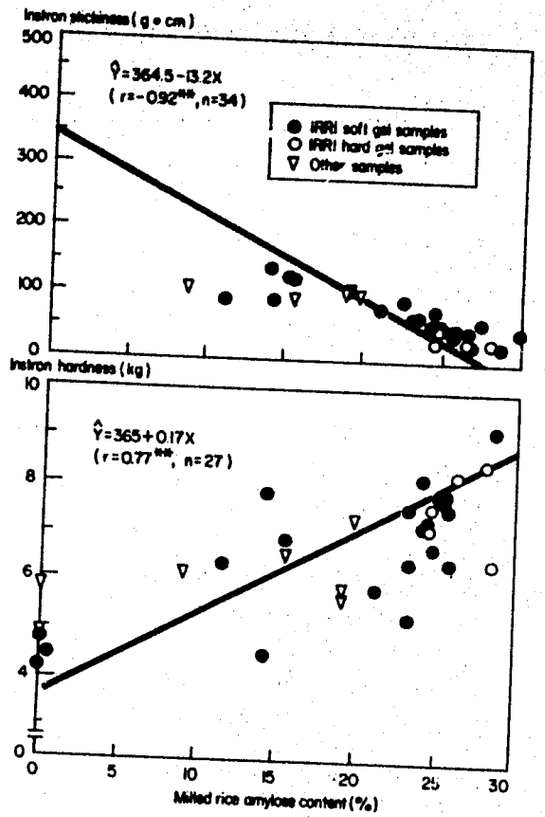
Hardness and stickiness of cooked rice. Taste-panel evaluation of high-amylose rices or waxy rices differing in gel consistency has not given significantly different scores for tenderness and cohesiveness of cooked rice. An Instron food tester was used to obtain objective measurement of hardness and stickiness of cooked rice. Milled rice (20 g) was placed in 150-ml beakers, with predetermined optimum cooking water based on amylose content, and cooked in an automatic rice cooker for 20 minutes with excess water in the outer pot. Hardness was determined for duplicate 17-g cooled cooked-rice samples with the Instron tester's Ottawa Texture Measuring System (OTMS) cell modified to reduce the cross-sectional area of the cell to about 15% of the original. Hardness was measured as the maximum force required to extrude the cooked rice through the perforated base (Fig. 1). To determine stickiness, rice from the hardness test was pressed by the OTMS cell's plunger to a 0.4-mm clearance on the tester platform. Stickiness is



1. Representative Instron curves for hardness of cooked rice using a modified Ottawa Texture Measuring System cell. Distance refers to that traveled by the plunger during extrusion. IRRI, 1977.



2. Representative Instron curves for stickiness of cooked rice. Stickiness value under the curve is the area of the force (grams) times the crosshead distance traveled (centimeters). IRRI, 1977.



3. Relationship between amylose content of milled rice, and stickiness and hardness values of cooked rice. IRRI, 1977.

the area of the curve obtained during the lifting of the plunger and is expressed as the product of force (in grams) and distance traveled by the plunger (in centimeters) (Fig. 2).

The relationship between hardness and stickiness of cooked rice and amylose content of raw rice was studied using mainly IRRI varieties and lines. Stickiness of cooked rice was more closely related to amylose content than was hardness (Fig. 3). Gel consistency differences had little effect on stickiness of cooked rice. Cooked waxy rices showed the widest range in stickiness among the various amylose types.

Among selected waxy rices from the Philippines, South Korea, and Thailand, the softest rices (low hardness values) had neutral gel values higher than 60 mm and final gelatinization temperature (BEPT) below 70°C (Table 3). That agreed with previous results (1974 Annual Report). These waxy rices also tend to be more sticky. Samples intermediate in gelatinization temperature and in alkali spreading values had hardness values as high as and stickiness values as low as those of samples with high gelatinization temperature. Malagkit Sungsong is desired for its texture and aroma by Philippine processors of waxy rice products. Among the IRRI lines, IR3464-75-1 and IR4427-58-5 were closer to Malagkit Sungsong in texture of cooked rice than was IR29.

Extreme softness and stickiness, as in the case of freshly harvested samples of UPL-Ri-1, may be objectionable in processed waxy rice products. A 1975 sample of UPL-Ri-1, with 7% protein, had hardness of 5.0 kg and stickiness of 262 g·cm. The effect of protein content and aging on the texture of boiled waxy rice of a variety needs to be verified.

The General Food texturometer is used in Japan and Korea to measure the hardness and stickiness of individual grains of cooked rice. In a cooperative study, four samples of Japanese rice of known texturometer values were sent to IRRI for Instron texture measurement. Comparable ratings of the four rices in hardness and

Table 3. Physicochemical properties of raw and cooked waxy rices arranged in the order of increasing final gelatinization temperature (BEPT). IRRI, 1977.

Variety or line	Source	Alkali spreading values in		Neutral gel consistency[a] (mm)	Final BEPT (°C)	Protein (%)	Cooked rice values of	
		1.7% KOH	1.3% KOH				Hardness (kg)	Stickiness (g·cm)
Malagkit Sungsong	Philippines	6.4	6.0	76	62.5	6.5	3.5	432
IR3464-75-1	IRRI	7.0	5.8	60	62.5	5.6	4.2	428
Tongil chal	Korea	7.0	5.8	70	62.5	8.8	4.9	330
IR29	IRRI	7.0	4.2	52	63	7.7	5.6	264
RD6	Thailand	7.0	5.0	74	63.5	6.1	5.9	390
IR4427-58-5	IRRI	6.5	5.0	60	64	6.9	4.7	407
UPL-Ri-1	Philippines	6.5	4.6	62	64	6.1	3.3	520
Wx219-3-5-5	Korea	4.0	3.0	61	70	9.9	6.3	272
Wx219-3-5-3	Korea	4.2	3.0	60	70.5	10.2	6.8	287
RD4	Thailand	2.0	2.0	46	73.5	7.0	6.6	267
Wx202-13-9	Korea	3.2	2.2	66	73.5	8.3	6.0	362
Panpet 63	Philippines	2.3	2.0	42	77	6.4	5.9	210

[a]200 mg rice flour/2 ml 0.15 N potassium acetate.

cohesiveness or adhesiveness values were obtained with the two instruments (Table 4). Kinpa was the most flaky because of its higher amylose content. Stickiness again closely followed amylose content, but hardness was also affected by both gel and amylograph consistency, and probably by protein content.

The Instron food tester can readily distinguish differences in cohesiveness, and hardness of cooked rice among high-amylose rices such as IR8 (hard gel) and IR5 (soft gel). The 1977 studies indicate that this is also true for intermediate- and low-amylose rices, and that among rices of similar amylose content, hardness is a more reliable indicator of quality than stickiness. Among four intermediate-amylose Indonesian rices, arranged in the order of decreasing eating quality in Table 5, Rojolele had the softest cooked rice grain. Bengawan had the hardest gel and the highest hardness value for cooked rice. Pelita I-1 is the least preferred despite its soft gel probably because its higher gelatinization temperature (based on alkali spreading, Table 5) affects its cooking properties. Similarly intermediate-amylose lines derived from BPI-121-407 and C4-63G maintained the contrasting gelatinization temperature and hardness of cooked rice of their parents.

Similar results were obtained for low-amylose rices, as shown by South Korean rices in Table 5. Tongil, a semidwarf indica × japonica hybrid with poor eating quality, had the same stickiness score as Jinheung, the check japonica variety, but had higher hardness value of cooked rice consistent with its harder gel.

Gelatinization-temperature screening of world rice collection. Final gelatinization temperature is the temperature of hot water needed to gelatinize or irreversibly swell 90% of starch granules of a rice sample. In the breed-

Table 4. Comparison of physicochemical, texturometer, and Instron data on four cooked milled rices from Fukui, Japan. National Food Research Institute (NFRI), Japan, and IRRI, 1977.

Property[a]	Kinpa	Honen-wase	Koshi-hikari	Koshi-nishiki
Protein (%)	6.1	7.5	5.7	6.8
Apparent amylose (%)	19.1	16.7	17.3	16.2
Alkali spreading (1.15% KOH)	6.0	5.0	4.9	5.0
Gel consistency (mm) (120 mg/2 ml)	55	68	66	66
Amylograph consistency (12% paste, Brabender units)	185	185	65	85
Texturometer data (individual grains)				
Hardness (kg)	2.03	2.11	1.97	1.98
Cohesiveness	0.36	0.38	0.36	0.36
Adhesiveness	0.03	0.05	0.09	0.04
Instron data (bulk)				
Hardness (kg)	6.1	6.8	5.9	6.0
Stickiness (g·cm)	72	89	81	92

[a]All obtained at IRRI except texturometer data from NFRI, Tokyo.

Table 5. Physicochemical properties of raw and cooked intermediate- and low-amylose rices. IRRI, 1977.

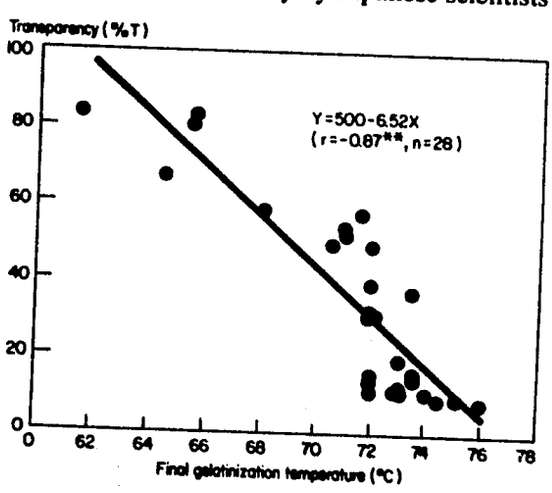
Variety	Source	Apparent amylose (%)	Protein (%)	Alkali spreading value	Gel consistency (mm)	Instron cooked rice	
						Hardness (kg)	Stickiness (g·cm)
Rojolele	Indonesia	23.8	8.0	5.9	63[a]	6.1	76
Seratus malam	Indonesia	24.0	6.6	6.0	62[a]	6.7	76
Bengawan	Indonesia	24.4	5.3	6.0	46[a]	7.1	88
Pelita I-1	Indonesia	23.4	6.7	3.6	80[a]	6.5	72
BPI-121-407	Philippines	24.6	10.1	6.9	96[a]	7.6	117
3 BPI-121-407 lines	IRRI	24.1–25.1	7.7–9.4	6.9–7.0	93–94[a]	7.2–7.9	75–90
C4-63G	Philippines	23.0	7.7	2.0	92[a]	5.9	78
3 C4-63G lines	IRRI	21.4–24.7	7.3–9.7	2.5	80–100[a]	5.5–6.4	84–122
Jinheung	S. Korea	19.1	7.0	7.0	76[b]	5.7	102
Yushin	S. Korea	19.2	7.8	7.0	66[b]	5.9	111
Tongil	S. Korea	19.9	7.0	7.0	54[b]	7.4	102

[a]100 mg rice flour/2 ml 0.2 N KOH. [b]120 mg rice flour/2 ml 0.2 N KOH.

ing program it is measured by the alkali digestibility of whole milled rice.

The starch of most indigenous tropical rices has intermediate gelatinization temperature except the bulu (javanica) and Thai varieties, and most waxy rices have low starch gelatinization temperature. The dwarfing gene introduces low gelatinization temperature into many of the semidwarf varieties. The full importance of gelatinization temperature is neither well appreciated nor understood. However, studies to date indicate that gelatinization temperatute is related to texture of cooked rice among waxy rices, Indonesian intermediate-amylose rices, and high-amylose rices (see previous section)

A turbidometric assay by Japanese scientists

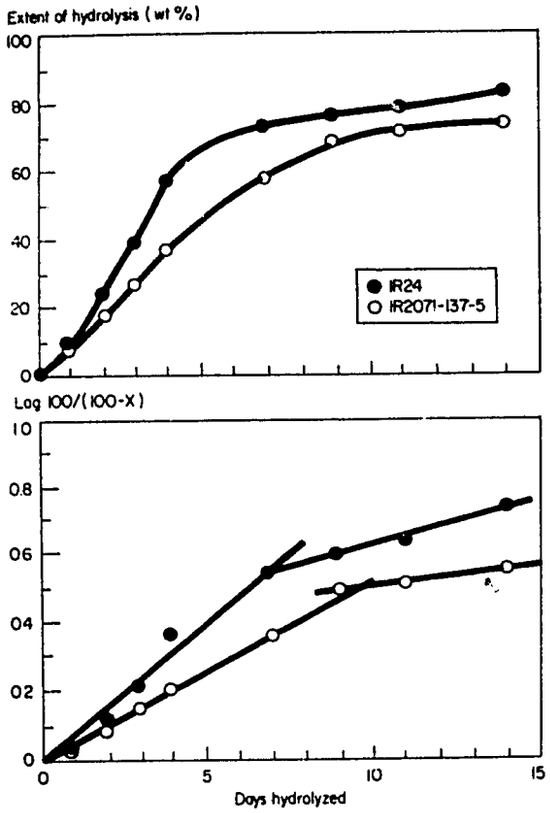


4. Transparency of defatted brown rice flour in 1.6% KOH after 24 hours at 30°C, and final gelatinization temperature of starch. IRRI, 1977.

for alkali test was adapted to screen the world rice collection for gelatinization temperature. A method was developed using 50 mg defatted brown-rice flour soaked in 10 ml 1.6% KOH incubated in a test tube at 30°C for 24 hours. Turbidity of the solution (% transmittance) was measured at 620 nm with a probe colorimeter with 8-mm path length. A plot of the transparency of the solution against final gelatinization temperature of starch showed good correspondence. High final-gelatinization temperature of starch (>74°C) corresponds to a turbid suspension of less than 10% T; a low gelatinization temperature (<70°C) corresponds to a clear solution of >60% T and an intermediate gelatinization temperature corresponds to 21 to 50% (Fig. 4). This photometric method is more objective than the alkali spreading value, which is scored visually using a six-point score system (2 to 7).

Lintnerized starch and gelatinization temperature differences. Corrosion of starch granules in 2.2 N HCl at 35°C is known to preferentially involve the amorphous or noncrystalline portion of the starch granule. Four-day HCl treatment showed positive correlation between the undigested fraction and gelatinization temperature of the starch granule. Lintnerized starch was prepared for eight rices to obtain more information about the crystalline fraction of rice starch granules and how its properties are affected by amylose content and gelatinization temperature of the granule.

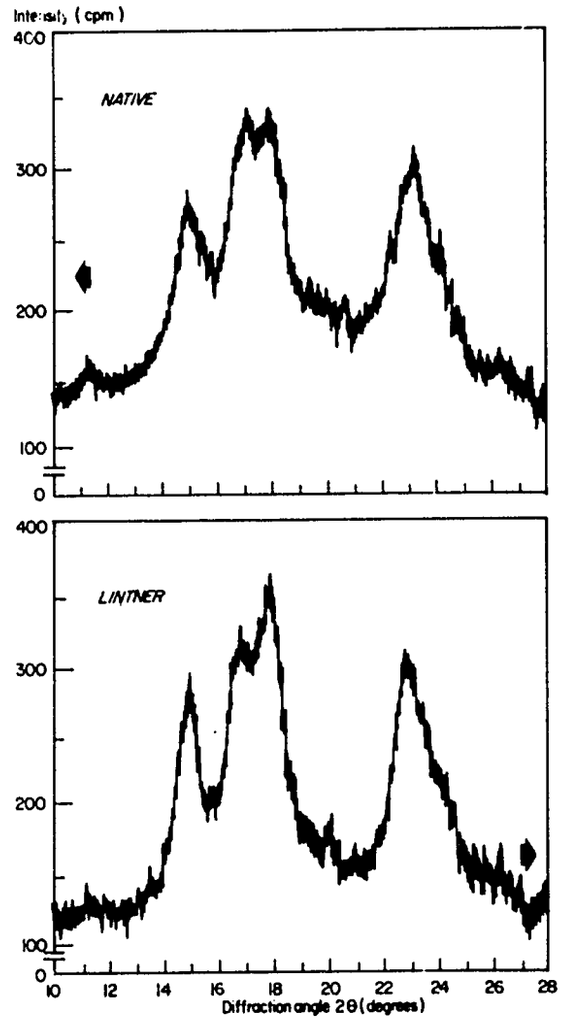
A corrosion period of 15 days was chosen



5. Acid hydrolysis or lintnerization curve in 2.2 N HCl at 35°C of two rice starches differing in gelatinization temperature. IRRI, 1977.

since preliminary data on two starches showed that the corrosion rates tended to level off within 14 days (Fig. 5). Re-expression of the extent of hydrolysis as log 100/(100-X) showed clearly the two-stage corrosion of rice starch granules, the first stage involving the amorphous fraction requiring 7 to 9 days (Fig. 5). The corrosion rates were faster for IR24 (gelatinization temp. 66°C) than for IR2071-137-5 (gelatinization temp. 75°C). Maximum difference in extent of corrosion was confirmed to be 4 days, which is the period now used for differentiating rice starches for susceptibility to lintnerization.

Properties of native and lintnerized starches of four pairs of rice starches differing in gelatinization temperature and representing the four amylose types were studied. Lintnerization causes little decrease in volume of the starch granules (1975 Annual Report) but results in



6. X-ray diffractogram of native and 93% lintnerized or acid-corroded IR29 starch granules. Kagoshima University, Japan, 1977.

corrosion of concentric amorphous layers of the granule (1969 Annual Report). Little difference in thickness of resistant layers was noted in the transmission electron micrographs (at the University of Nottingham, England) of 4-day lintnerized starch granules of IR24 (62% lintnerized) and IR2071-137-5 (32% lintnerized).

Crystallinity of starch granules may be due to amylopectin rather than to amylose, since waxy starch is crystalline. X-ray diffractograms using Cu K α radiation showed that lintnerized starch was more crystalline than native starch (Fig. 6). The peaks at $2\theta = 18°$ and $23°$ increased in intensity in IR29 but in some rices one of those

Table 6. Properties of native and lintnerized starches of selected rices differing in gelatinization temperature and amylose content. IRRI, 1977.

Property	IR29	Panpet 63	IR24	IR2071-137-5	IR480-5-9	C4-63G	IR8	IR5
Native starch								
Apparent amylose (%)	<1	<1	19.6	16.0	29.2	27.2	31.6	33.0
Final gelatinization temp. (°C)	64	74.5	66	75	61	73.5	63	72
Lintnerized starch								
Wt loss (%)	93	86	90	82	89	79	88	79
Mean DP (glucose)	26	23	17	15	29	29	24	25
Mean DP[a] (glucose units)	27	24	24	19	30	30	26	27
β-amylolysis limit (%)	83	83	75	74	76	85	80	92
Linear fraction[a] (mole%)	52	61	53	64	67	61	66	70

[a]Excluding free glucose.

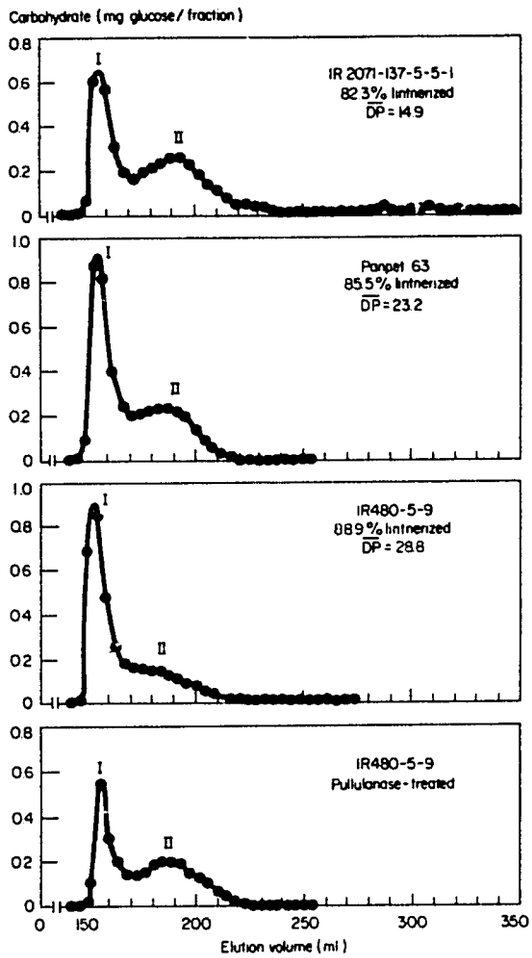
peaks increased in intensity more than the other. Among the nonwaxy starches, lintnerization made the minor peak at $2\theta = 20°$ (nearly absent in waxy starch) more prominent in the three low gelatinization temperature rices IR8, IR24, and IR480-5-9.

In all four pairs, the low-gelatinization-temperature samples were more readily lintnerized or the recovery of the lintnerized starch was lower (Table 6). However, the intermediate- and high-amylose starches were more resistant to lintnerization than the low-amylose pair, and the waxy pair was the least resistant. Thus, crystallinity of rice starch granules is directly affected by gelatinization temperature and, to a lesser extent, by amylose content.

Mean degree of polymerization (DP) or chain length of the lintnerized starch or dextrin ranged from 23 to 29 glucose units for six samples and below 20 units for the low-amylose samples (Table 6). The low mean DP for the latter samples may be due in part to their high content (1.5-1.8%) of free glucose; the others had only 0.1 to 0.3% free glucose. Correction for free glucose improved the mean DP values. β-amylolysis limit, a measure of the linear fractions hydrolyzed to maltose with β-amylase, was higher in lintnerized starch since β-amylolysis limit was 58% for native IR29, 61% for native Panpet 63 (>99% amylopectin), and 73 to 76% for rice amylose. Corresponding mole percent linear dextrins based on the amount of glucose liberated during β-amylolysis were somewhat lower at 52 to 70%. Among the nonwaxy samples, lintnerized starch with low gelatinization temperature had higher iodine-blue value at 680 nm than the higher-temperature sample.

In a study of the nature of the lintnerized dextrins, three samples representing the DP range were subjected to molecular weight fractionation at 50°C in a Bio-Gel P-2 polyacrylamide gel column calibrated with linear maltooligosaccharides. The exclusion or void volume corresponded to DP 23.4 based on maltooligosaccharides. A bimodal distribution was observed for all three samples with peak I at the void volume and peak II corresponding to DP 14 to 17 (Fig. 7). Calculated DP for peak I was 32 for Panpet 63 and 34 for IR480-5-9 lintnerized starches. DP for peak I of IR2071-137-5 must be >23, as the calculated value would be too low considering the presence of maltooligosaccharides with DP <12 (Fig. 7) and glucose in its lintnerized starch as also verified by thin-layer chromatography. The proportion of peak I to peak II increased with the increase in DP of lintnerized starch.

Treatment of IR480-5-9 lintnerized starch with pullulanase or debranching enzyme before gel filtration increased peak II relative to peak I (Fig. 7). French chemists have previously shown a similar molecular weight distribution for corn and potato dextrins corresponding to DP 25 (one branching) and 12-13 (linear) glucose units. The actual DP of peak II for Panpet 63 lintnerized starch of 16 glucose units was identical to the value from the calibration curve using linear maltosaccharides. The results suggest that peak II is linear and peak I has a single branch as it has twice the DP as peak II and



7. Molecular weight (MW) fractionation of three lintnerized starches in Bio-Gel P-2 polyacrylamide gel (2.6 X 85 cm) at 50°C. The samples showed differences in the ratio of the two MW peaks. Peak II increased on pullulanase debranching of IR480-5-9 lintnerized starch. IRRI, 1977.

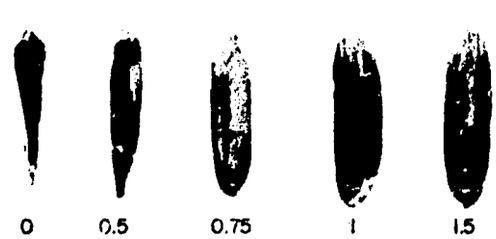
gives rise to peak II on pullulanase action. On this basis, DP for peak I of IR2071-137-5-5-1 must be 28 glucose units.

Amylose-fatty acid complex. Scientists in England suggested that the residual amylose V-pattern at $2\theta = 20°$ in the X-ray diffractogram of cooked and parboiled low-amylose rice correlates with apparent solubility of amylose and amylopectin and is determined both by amylose and oil contents of the rice. It is due to helical amylose-fatty acid complexes. Freshly harvested and 6-month stored milled rice of IR29 (waxy, 1.1% oil), Khao Dawk Mali 105 (low amylose, 0.7% oil), and IR28 (high amylose, 0.9% oil) were cooked and their X-ray diffractograms were determined on dried cooked-rice powder at Kagoshima University, Japan. Only the nonwaxy rices gave a small $2\theta = 20°$ peak, and it was more prominent in Khao Dawk Mali than in IR28. The intensity of the peak increased only by 10 cpm in both rices. The results indicate that the residual V-pattern of cooked rice is small and not simply related to amylose and oil contents among milled rices. Also, apparent starch solubility of IR28, which has hard gel, was verified to be lower than that of Khao Dawk Mali and IR29.

STARCH ACCUMULATION

Chemistry Department

Detached panicles in liquid culture. Australian scientists have successfully grown detached wheat heads in liquid culture and found that starch accumulation in the grain followed closely the sucrose level in the medium. Detached rice panicles (1 to 2 days after flowering) were successfully incubated in liquid medium containing 1% sucrose and 0.1% glutamine in addition to minerals and vitamins. The panicles were kept at 25 to 27°C in 8 klux and 16-hour day length, and the medium was kept at 2 to 3°C. Sucrose level (0 to 1.5%) in the medium determined the extent of dry matter and starch accumulation, but unfortunately it also influenced the physiological development of the ripening grains (Fig. 8). Maximum



8. Effect of sucrose concentration of liquid medium on the development of IR22 grains in detached panicles cultured for 160 hours. Glutamine was 10% of sucrose except that the 0% sucrose solution had 0.05% glutamine. IRRI, 1977.

UDP-glucose pyrophosphorylase level occurred at the 0.75 to 1.0% sucrose level, rather than at the maximum sucrose level of 1.5%. Chemical and enzymic composition of the grains were similar to previously reported levels of grain analyzed at regular intervals after anthesis (1974 and 1976 annual reports). Thus, the detached-panicle system has little advantage over field panicles in the study of starch accumulation, except in facilitating simultaneous sampling of all treatments. The system would, however, be a useful technique for the labeling of compounds, such as proteins.

Genetic evaluation and utilization (GEU) program

Disease resistance

Plant Pathology and Plant Breeding Departments

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EVALUATING DISEASE RESISTANCE OF BREEDING MATERIALS

Plant Breeding and Plant Pathology Departments

Multiple disease resistance of elite lines (*Plant Pathology*). The most promising elite breeding lines and some IRRI-named varieties were evaluated for resistance to major diseases (Table 1). Many lines have multiple disease resistance.

Screening earlier generations against major diseases (*Plant Pathology*). Large numbers of early generation breeding lines continued to be screened for selection of disease-resistant progenies. Tested for resistance to the fungus diseases were 66,248 entries for blast (Table 2); 7,564 for sheath blight (Table 3); 373 for *Cercospora* leaf spot (Table 4) by artificial inoculation in the field; and 4,459 for leaf scald by natural field infection (Table 5).

More than 73,000 breeding lines were evaluated for bacterial blight resistance. A high percentage were resistant to pathotype 1 of *Xanthomonas oryzae* in the Philippines (Table 6). Lines carrying the dominant gene *Xa 4* are generally resistant to that pathotype. During the year, pathotype 2, which can overcome the *Xa 4* gene, was widespread at IRRI. Most IRRI materials with *Xa 4* did not show resistance to pathotype 2.

The field reactions to tungro disease of 65,447 entries — varieties, pedigree nursery lines, trials, and other testing nurseries — were evaluated. About 95% of the entries evaluated were rated 3 or less on the international scale for resistance to tungro (1 = resistant; 3 = moderately resistant). The overall tungro incidence at IRRI in 1977 was low.

NEW SOURCES OF DISEASE RESISTANCE

Plant Pathology and Plant Breeding Departments

Additional materials from the germplasm collection were tested to identify new and better sources of resistance to major diseases. Screen-

Table 1. Disease reaction[a] of elite breeding lines, IRRI, 1977.

Designation	Disease[b] reaction to									
	LS[c]	CLS	ShB	BST	BLB	BLS	RTV	RTV[c]	RGS	RRS[c]
IR8	MS	M	M	S	S	MS	M	M	S	S
IR20	MR	S	M	S	MR	R	S	R	S	R
IR26	S	S	M	MS	MR	MR	M	R	M	M
IR29	S	S	M	MR	MR	MS	R	R	R	M
IR30	MR	S	M	S	MR	MR	S	R	R	M
IR32	MS	S	M	MR	MR	MR	M	R	R	R
IR36	MS	M	MS	R	MR	MR	S	M	R	M
IR38	MS	R	M	R	MR	R	S	R	R	R
IR40	S[c]	—	M	R	—	—	R	R	R	M
IR42	MS[c]	M	M	R	—	—	M	R	R	R
IR1529-430-3-1	S[c]	M	M	S	—	—	M	M	M	M
IR1754-F5B-22	MR[c]	—	M	S	—	—	S	R	R	M
IR2035-108-2	MR[c]	M	M	R	—	—	S	R	R	R
IR2035-242	MR[c]	—	M	MS	—	—	M	M	R	S
IR2058-78-1-3-2-3	MS[c]	R	MS	R	—	—	S	R	R	R
IR2061-465-1-5-5	MS	S	MS	S	MR	—	R	R	R	S
IR2061-522-6-9	MS	R	M	MS	MR	R	R	R	R	S
IR2071-137-5-5-1	MS	S	M	MS	MS	MS	M	R	R	S
IR2071-178-1-2-1	MR[c]	M	M	R	—	—	M	R	R	R
IR2071-486-9-2-6	MS	S	M	S	MS	R	R	R	R	S
IR2071-588-6-2-6-4	MS	R	M	MR	S	MR	M	R	R	R
IR2307-217-2-3	MR	R	M	MR	S	MS	S	R	M	S
IR2307-247-2-2-3	MR	M	M	MR	S	—	S	R	S	M
IR2797-105-2-2-3	MR	M	M	R	MR	MS	M	R	R	R
IR2797-125-3-2-2-2	S	S	M	R	MR	MR	R	R	R	R
IR2823-103-5-1	S	M	M	R	MS	R	M	R	R	R
IR2863-35-3-3	MS	S	M	S	MR	MR	S	R	M	R
IR2863-35-1-2	MS[c]	—	M	MR	MS	MR	S	R	R	R
IR3280-3-2	—	—	M	MS	—	—	—	—	—	—
IR3304-23	MS[c]	—	M	MS	—	—	S	M	R	S

(continued on opposite page)

Table 1 *continued*

Designation	Disease[b] reaction to									
	LS[c]	CLS	ShB	BST	BLB	BLS	RTV	RTV[c]	RGS	RRS[c]
IR3351-38-3-1	MR[c]	R	M	R	—	R	M	R	R	R
IR3397-44-1-4-3	MS[c]	M	M	R	—	—	R	R	R	R
IR3464-75-1-1	S[c]	M	M	S	MS	S	M	R	M	R
IR3464-126-1-3	S[c]	M	M	MS	MR	S	M	R	R	R
IR32518-96-2-2-2	S[c]	R	M	MR	—	—	M	R	R	R
IR3816-2-2-1	S[c]	—	M	R	—	—	S	R	R	M
IR3839-1	MR[c]	M	M	R	—	—	M	M	R	S
IR3839-1	MR[c]	—	M	R	—	—	M	M	R	S
IR3880-5	MS[c]	R[c]	M	S	—	—	M	R	R	S
IR3880-10	MR[c]	R[c]	M	S	—	—	M	M	M	S
IR3880-13	MS[c]	—	M	MS	—	—	S	R	R	M
IR3880-13	S[c]	M	M	MR	—	—	S	R	R	M
IR3880-17	S[c]	—	M	MS	—	—	M	R	M	S
IR3880-17	S[c]	R	M	MS	—	—	M	R	R	S
IR3941-9-2	MS	S	M	S	MR	MS	M	R	R	M
IR3941-25-1	MS	M	M	S	MR	MR	R	R	R	S
IR3941-97-1	MS	M	M	MS	MR	MR	M	R	R	S
IR4215-400-2-6	MS	S	M	S	MR	MS	R	R	R	R
IR4219-35-3-3	MS	S	M	S	S	S	R	R	R	R
IR4227-28-3-2	MR	S	M	MS	MS	MS	R	R	R	R
IR4405-287-3-2-3	S	R	M	MS	MR	MS	R	R	R	M
IR4417-179-1-5-2	MS[c]	M	M	R	—	—	R	R	R	R
IR4422-6-2-3-1	MS	R	M	MR	MS	S	M	R	R	S
IR4422-51-1-1-2	MR	M	M	S	MR	MS	M	R	R	R
IR4422-143-2-1	MR	M	M	S	S	MR	S	R	R	R
IR4422-450-2-3-3	MS[c]	M	M	S	—	—	M	R	R	R
IR4427-51-6-3	MS	S	M	R	S	MS	M	R	R	M
IR4427-58-5-2	MR	S	M	R	MR	MR	R	R	R	S
IR4427-109-1-3-3	MS[c]	—	M	R	—	—	R	R	R	R
IR4427-315-2-3	R	S	M	R	R	MR	R	R	R	S
IR4432-28-5	MR	R	M	MR	S	S	M	R	R	R
IR4432-38-6	MS	—	MS	R	MS	MS	M	R	R	R
IR4432-52-6-4	S	R	M	R	MS	S	M	R	R	R
IR4432-103-6-4	MS	M	M	MR	MR	S	M	R	R	R
IR4432-207-2-3-2	S	R	M	R	S	MS	R	R	R	R
IR4445-63-1-2-2	S[c]	M	M	MS	—	—	R	R	R	R
IR4563-52-1-3-6	R[c]	S	M	R	—	—	M	R	S	R
IR4568-86-1-3-2	MR[c]	R	M	R	—	—	M	R	R	R
IR4568-225-3-2	MS	M	M	S	MR	—	M	R	R	R
IR4570-83-3-3-2	S[c]	R	M	R	—	—	S	R	R	R
IR4570-117-2-1-2	MS[c]	R	M	MS	—	—	M	R	R	R
IR4613-54-5	S	M	M	MS	MS	MS	M	R	R	R
IR4625-219-2-2	S	M	M	R	MR	MS	M	R	M	R
IR4683-54-2	S	R	M	MS	MR	MS	M	R	R	R
IR4698-176-2-2	MS	R	M	R	MR	R	R	R	R	M
IR4683-54-2	S	R	M	R	MR	MS	R	R	M	M
IR4707-123-3	MS	S	MS	MR	MR	R	R	R	R	M
IR4707-140-1-3	MS	M	M	R	R	R	R	R	R	M
IR4707-225-2-3	MS	S	M	S	MR	MS	R	R	R	M
IR4744-295-2-3	S	M	M	R	MR	—	R	R	R	M
IR4816-70-1	S	M	M	S	MR	—	R	R	R	M
IR4819-77-3-2	S	M	M	S	MR	—	R	R	R	M
IR4895-1-1-5	MS[c]	R[c]	—	ns	MR	—	—	—	—	—
IR5105-93-2-2	MS	R	M	MR	MR	—	R	R	R	M
IR5201-127-2	MS	R	M	MR	—	—	R	R	R	M
IR5785-37-1	S	R	M	R	MR	MS	R	R	R	M
IR5853-118-5	S	M	M	R	MS	—	R	R	M	M
IR5853-162-1-2	S[c]	—	M	R	—	—	R	R	R	R
IR5853-165-1	S[c]	R[c]	M	R	—	—	R	R	S	M
IR7760-4-8-2	—	—	M	ns	—	—	—	—	—	—
IR9575, BPI-76[a]/Dawn	MS[c]	—	M	MR	—	—	S	M	M	S
IR9669, IR8[a]/Carreon	S[c]	—	M	MS	—	—	M	S	M	S
BR 51-91-6	MS[c]	S	M	S	—	—	M	R	S	M

[a]R = resistant, MR = moderately resistant, M = intermediate, MS = moderately susceptible, S = susceptible. [b]LSc = leaf scald, CLS = *Cercospora* leaf spot, ShB = sheath blight, BST = blast, BLB = bacterial leaf blight, BLS = bacterial leaf streak, RTV = rice tungro virus, RGS = rice grassy stunt, RRS = rice ragged stunt. [c]Field reaction to natural infection, all others to artificial inoculation in greenhouse or in field.

Table 2. Summary of screening for blast resistance. IRRI, 1977.

Source	Entries (no.)		
	Resistant	Intermediate	Susceptible
Argentine varieties	14	4	7
Elite breeding lines	40	29	20
Replicated yield trial (RYT)	311	132	120
Observational yield trial (OYT)	702	616	909
Upland RYT	105	52	8
Bensue OYT	405	378	206
Bensue cold tolerance pedigree nursery	863	469	353
Bensue cold tolerance OYT	26	28	7
Pedigree nursery lines	29,003	15,527	10,685
Plant pathology lines	125	69	387
Korean lines	1	3	212
Brown planthopper-blast	980	708	239
Hybridization block	38	92	159
Germplasm bank	105	249	888
International nurseries			
IRBN	297	86	85
IRON	48	73	258
IRSHBN	35	52	67
IRYN-E	5	4	14
IRYN-M	5	5	15
IRYN-L	7	8	10
Total	33,115	18,584	14,549

ing involved 1,242 entries for blast, 2,166 entries for sheath blight, and 2,755 entries for leaf scald. Entries resistant to blast will be further tested to select those with a broad spectrum of resistance. As in previous years, no entries with a high level of resistance to sheath blight were found. Many varieties were resistant to leaf scald.

A total of 6,256 varieties from the germplasm collection were field inoculated with pathotype 1 of *Xanthomonas oryzae* to identify new sources of resistance. About 555 entries (8.9%) were rated resistant, and 124 entries (2.0%), moderately resistant. More than 2,000 rices from the germplasm collection that were rated resistant or moderately resistant were retested to confirm their reaction to pathotype 1 in the field. The plants were tested by inoculation at two stages of growth — maximum tillering (MT) and flowering (FL). As indicated in Table 7, 1,064 entries (45.4%) were resistant and 75 (3.2%) were susceptible at MT, whereas 1,044

Table 3. Summary of screening for sheath blight resistance.[a] IRRI, 1977.

Source	Total	Entries (no.)					
		R	MR	M	MS	S	VS
Elite varieties and breeding lines							
Replicated yield trial	167	0	0	159	6	2	0
Observational yield trial	650	0	14	598	35	3	0
Upland lines	1,260	0	113	1,139	7	1	0
Plant pathology lines	53	0	2	51	0	0	0
Korean materials	31	0	1	30	0	0	0
June rainfed lowland pedigree nursery	674	0	39	630	5	0	0
Hybridization block	28	0	0	17	7	4	0
International nurseries	591	0	3	558	24	1	5
IRSHBN	153	0	22	130	0	1	0
IRYN-E	28	0	2	26	0	0	0
IRYN-M	28	0	6	22	0	0	0
IRYN-L	27	0	6	21	0	0	0
IRON	376	0	17	359	0	0	0
IRBN	432	0	9	421	2	0	0
Confirmation tests							
Elite breeding lines							
Replicated yield trial	12	0	0	12	0	0	0
Observational yield trial	39	0	1	38	0	0	0
Plant pathology lines	143	0	17	125	1	0	0
Germplasm bank	13	0	0	13	0	0	0
All India Coordinated Rice Improvement Project	650	0	31	617	2	0	0
Korean materials	6	0	1	5	0	0	0
Total	37	0	2	35	0	0	0
	7,564	0	299	7,143	101	13	8

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

Table 4. Summary of reactions to *Cercospora* leaf spot of elite varieties and breeding lines and replicated yield trial lines, artificially inoculated in field. IRRI, 1977.

Reaction[a]	Elite varieties and breeding lines		Replicated yield trial lines	
	No.	%	No.	%
Resistant	40	52.6	112	37.7
Moderately resistant	12	15.8	169	56.9
Susceptible	24	31.6	16	5.4

[a]On a 0–9 scale, resistant = 0–1, moderately resistant 3–5, susceptible = 7–9.

Table 5. Reactions of varieties and lines to leaf scald in naturally infected fields. IRRI, 1977.

Source	Entries[a] (no.)			
	R	M	S	Total
Elite lines	2	23	57	2
Germplasm bank	1257	1021	477	2755
Observational yield trial	128	454	518	1100
Replicated yield trial	10	234	204	448
Upland replicated yield trial	13	45	16	74
Total	1410	1777	1272	4459

[a]R = resistant (0–1), M = intermediate (3), S = susceptible (5–9). See Table 12 for description of 0–9 scale.

(44.5%) were resistant and 44 (1.9%) were susceptible at FL.

Blast-resistant lines. Rice varieties with a broad spectrum of resistance to blast have been identified through the International Rice Blast Nursery (IRBN). Transferring blast resistance from those varieties to new varieties has, however, been difficult because many genes are involved and because the prevailing blast races differ among places and seasons.

In a project to develop blast-resistant near-isogenic lines, many resistant donor varieties were crossed with IR8 as recurrent parent and the progenies were screened two or three times a year for many years. IRRI now has more than 100 blast-resistant lines, some of which have been in the IRBN since 1975 and under high

Table 7. Summary of entries field tested for resistance to pathotype 1 of *Xanthomonas oryzae* at two growth stages. IRRI, 1977.

Reaction[a]	Entries tested at			
	Maximum tillering[b]		Flowering[c]	
	No.	%	No.	%
R	1064	45	1044	44
MR	518	22	684	29
MS	239	10	187	8
S	75	3	44	2
R to S	92	4	29	1
No test	357	15	357	15
Total	2345		2345	

[a]R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible. [b]50 days after seeding (DS). [c]80 DS.

Table 6. Summary of breeding materials resistant to bacterial blight. IRRI, 1977.

Source	Entries[a] (no.)					Entries tested (no.)
	R	MR	MS	S	R/S	
Replicated yield trial (RYT)	566	14	2	32	36	
Observational yield trial (OYT)	947	157	92	1,032	62	36
Germplasm bank	604	125	3	4,408	164	230
Hybridization block	251	48	12	217	42	14
Pedigrees						
F_8	40			5		
F_7	332			11		
F_6	1,632			69	22	
F_5	4,360			229	239	41
F_4	15,652			262	149	17
F_3	26,740			3,531	7,400	112
Seed increase	223	4	3	5	11	
Upland lines — RYT	191	28	42	152	336	
OYT	681	129	329	985	16	25
International Rice Cold Tolerance Nursery	156	48	22	177	12	20
Total	52,375	553	505	11,115	8,495	495

[a]R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible, R/S = segregation.

Table 8. Reaction of 10 blast-resistant lines, with four varieties for comparison, in the International Rice Blast Nursery tests for 1976–77.

Designation and cross	Testing countries (no.)	Testing stations (no.)	Tests (no.)	Frequency of reaction[a]								
				1	2	3	4	5	6	7	8	9
Blast resistant												
IR1905-81-3-1 IR8/Tetep	17	32	48	29	9	7	2					
IR1905-PP21-73-4 IR8/Tetep	14	19	23	16	4	3						
IR3259-PP11-186-4 IR8[a]/Tetep	14	19	24	19	2	2	1					
IR3259-PP11-182-4 IR8[a]/Tetep	14	20	25	20	2	1	1	1				
IR3259-PP8-172-6 IR8[a]/Tetep	14	19	24	19	3	1		1				
IR4547-14-3-1 IR3273/IR4495	14	19	24	16	6	2						
IR5533-PP856-1 IR8/ / /IR8/Carreon/ / IR8/Tetep	13	18	23	19	3	1						
IR5533-PP850-1 IR8/ / /IR8/Carreon/ / IR8/Tetep	14	19	24	16	6	1	1					
IR9559-PP889-1 IR8[a]/ / /IR8/Tetep/ / IR8/Carreon	14	19	24	16	5	2	1					
IR9669-PP836-1 IR8[a]/Carreon	14	19	24	18	6							
For comparison												
Tetep	17	30	46	27	12	4	3					
Carreon	17	32	48	26	14	5	2		1			
Khao-tah-Haeng 17	17	31	47	5	3	2	3	1	4	6	10	13
IR26	16	31	46	13	5	3	5	3	3	1	7	6

[a]1976 Standard Evaluation System for Rice scale 1–9: 1 = most resistant, 9 = most susceptible.

disease pressure at many testing sites. Table 8 shows the reaction of 10 blast-resistant lines in the IRBN. The data suggest that the 10 lines have as high a level of blast resistance as the donor varieties.

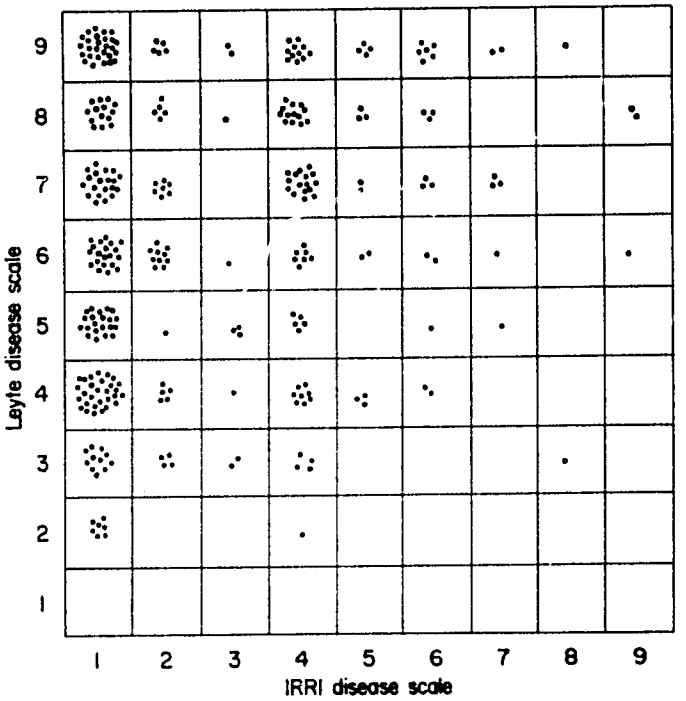
The 1976 and 1977 IRBN identified several other breeding lines with high level of resistance.

Genetic studies to identify new genes for bacterial blight resistance. Fifty-five varieties from different geographic areas were analyzed to identify new genes for bacterial blight resistance, but no new gene was discovered. A large number of the varieties came from the Assam rice collection of India. The PXO 61 isolate, a representative of pathotype 1, was used in the study. The resistant varieties were crossed with Taichung Native 1 (TN1), which is highly susceptible to bacterial blight.

The F_1 plants of 49 varieties were susceptible, indicating that the resistance is recessive. The F_2 population of the crosses segregated in a ratio of one resistant to three susceptible, showing that the resistance was governed by single recessive genes. The F_1 plants of six varieties were resistant, indicating the dominant nature of resistance. The F_2 populations of the crosses segregated in a ratio of three resistant to one susceptible, showing that resistance was conferred by a single dominant gene.

The six varieties with dominant genes were crosses with IR22, which carries the *Xa 4* gene for resistance. As expected, the F_1 progenies were resistant and the F_2 populations had no segregation for susceptibility. It therefore appears that the six varieties have *Xa 4* for resistance.

The 49 varieties with recessive genes for



1. Correlation of blast reaction in replicated yield trials in two locations. IRRI and Leyte, Philippines, 1977 dry season. 1976 Standard Evaluation System for Rice scale 1–9: 1 = none to small brown specks of pinhead size; 9 = about 100% of leaf area infected.

resistance were crossed with IR1545-284, which carries the *xa 5* gene for resistance. The F_1 progenies were resistant, showing that the recessive genes for resistance in these varieties are allelic to *xa 5*.

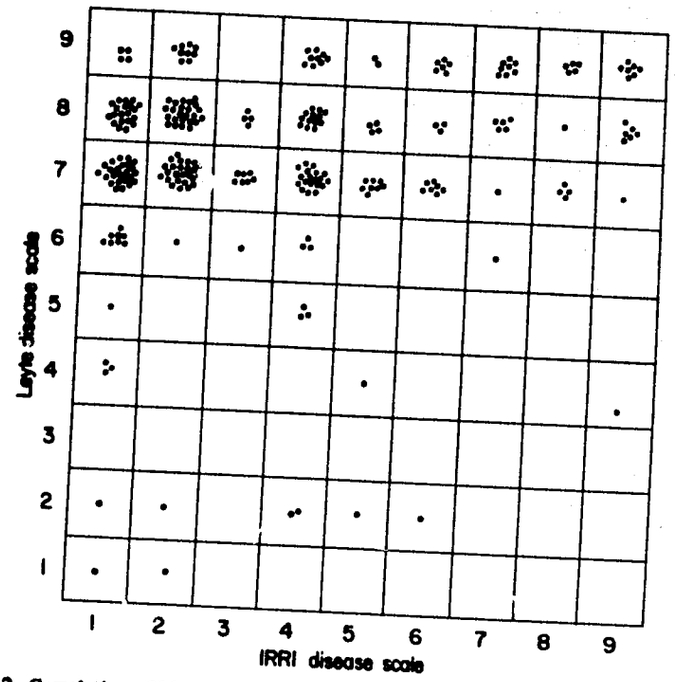
FURTHER INCORPORATION OF DISEASE RESISTANCE

Plant Breeding Department

Breeding for resistance to blast. In 1977 all entries in the replicated yield trials were tested in dry- and wet-season blast nurseries at IRRI and at San Isidoro, Leyte province, Philippines. Most of the advanced lines selected as resistant at IRRI were moderately susceptible or susceptible at Leyte (Fig. 1, 2). That illustrates the inadequacy of selecting progenies at a single test site. Although blast is not a major threat in most irrigated rice fields in the tropics, the advanced breeding lines are not adequately resistant to it in areas where it seriously constrains rice production.

Initial trials toward multilocation testing. Large numbers of pedigree lines from general and upland rice projects were regularly screened at IRRI and at San Isidoro. In addition, a project especially designed for blast resistance was initiated. The flow of materials is shown in Figure 3. From about 2,900 F_3 lines from 22 crosses between elite breeding lines and noted blast resistance sources — Tetep, Carreon, Sigadis, Dawn, Zenith, and other breeding lines—tested at IRRI and at San Isidoro, 823 lines were selected. They should possess a wider spectrum of resistance than the selections from one site. All will be grown for good agronomic characteristics. They will be distributed to national projects for further selection for blast resistance.

Development of race-indicators or differentials and related methodology. Blast resistance sources such as Tetep and Carreon are resistant at diverse sites. But while they remain resistant, many breeding lines derived from them often become susceptible. Certain resistant genes are



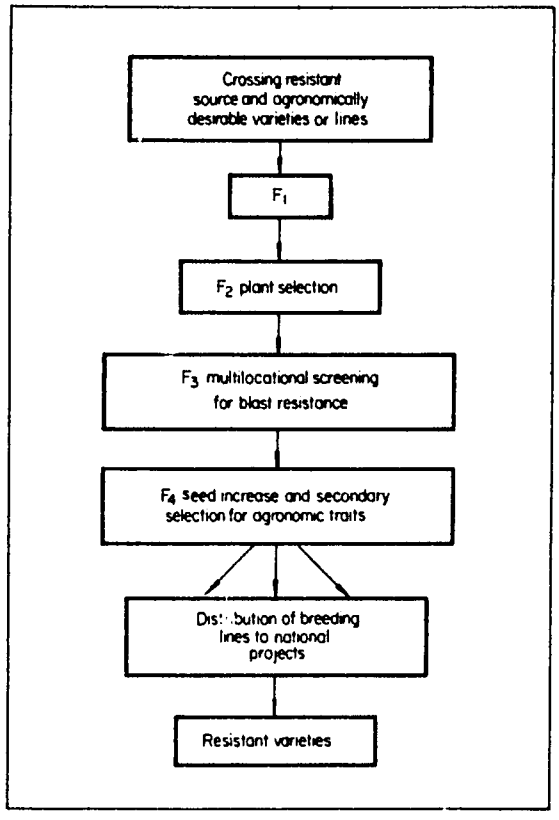
2. Correlation of blast reaction in replicated yield trials and observation in two locations. IRRI and Leyte, Philippines, 1977 wet season. 1976 Standard Evaluation System for Rice scale 1–9: 1 = none to small brown specks of pinhead size; 9 = about 100% of leaf area infected.

probably lost during selection; thus, such resistance as that found in Tetep and Carreon must be systematically incorporated into improved varieties or lines. Such incorporation will require simultaneous testing at different sites where there are different virulent genes of the fungus, and use of race-indicators to detect diverse races at test sites. The two aspects are closely related. The similar reactions of race-indicators at all sites do not guarantee that diverse resistant genes have been incorporated, even though selected lines may show resistance at all sites.

To test that concept, IRRI took initial steps to develop race-indicators from Tetep's progeny. A set of 100 lines each from Tetep/IR30 and IR30/Tetep/ /IR30 were selected at random in the population, and tested at different locations. In an initial test, some lines showed sharply contrasting reactions at IRRI and at San Isidoro. The tests will be repeated at different locations and the progeny lines that show specific resistance at many sites will compose a set of race-indicators. These lines will be tested at many sites in cooperation with national programs.

Incorporating new genes for bacterial blight resistance. As indicated in Table 6, an overwhelming proportion of IRRI breeding materials are resistant to the common isolate (pathotype 1) of bacterial blight and carry the *Xa 4* gene for resistance. Those lines are susceptible to pathotype 2, however. During the last few years, IR1545-284, which carries *xa 5* and conveys resistance to pathotypes 1 and 2, has been used in the crossing program. The most promising line with resistance to pathotypes 1 and 2 conditioned by *xa 5* is IR4563-52-1-3-6. The percentage of materials carrying *xa 5* is increasing.

An isolate of bacterial blight, designated PXO 71, and to which selections carrying *xa 5* are susceptible, was recently discovered. There are, however, varieties such as DZ78 and DV85 that are resistant to pathotypes 1 and 2 and to isolate PXO 71. These varieties possess two genes for resistance. Several single crosses



3. Flow of materials in a special IRRI breeding project for blast resistance. 1977.

and topcrosses with DV85 and with ARC 5756, another variety that conveys resistance to PXO 71, were made during 1977. Segregating populations from crosses are being evaluated.

DISEASE RESISTANCE STUDIES

Plant Pathology and Plant Breeding Departments

Blast *(Plant Pathology)*. The great variability of the fungus and the presence of different pathogenic race groups in different areas and seasons make resistance to rice blast difficult to determine. The international rice blast nurseries of the past 14 years have identified several varieties with a broad spectrum of resistance. Those varieties are believed to have many genes for vertical resistance that can confer stable resistance, not horizontal resistance. Reliable methods for screening for horizontal resistance are not available. Attempts were made in 1977 to measure it in some Japanese varieties that are said to have "field" (horizontal) resistance.

Measuring resistance by inoculating varieties with isolates from their own lesions. Resistant varieties were inoculated with isolates from their own blast lesions to test whether inoculating a plant with a virulent race or races causes removal of vertical resistance and retention of horizontal resistance. Such tests were made earlier (1969, 1970, 1971 annual reports) primarily to demonstrate the stability of resistance in such varieties.

The 1977 experiment used eight varieties with different levels of resistance (by IRBN evaluation), and from 2 to 11 fungus isolates from each variety. Inoculation chambers were constructed to allow uniform deposit of spores, and the test varieties were arranged at random. Each isolate was inoculated to the variety from whose lesion it had been made and to other varieties as well. Sixty-one isolates were used on the eight varieties (3 replications) and the lesions were counted 7 days after inoculation. The results are summarized in Table 9.

On Tetep, some lesions were caused by isolates from its own lesions, and a few were caused by all other isolates. Dawn had few lesions caused by its own isolates and by other isolates. Results on both confirmed that isolates from resistant (R) varieties produced few lesions on their original host. Sensho, on which its own isolates and other isolates caused few lesions, is considered only moderately resistant in blast nursery tests. Tetep, Dawn, and Sensho may be considered to have *horizontal* resistance to the 61 tested isolates. Except in Sensho, the disease intensity (number of lesions) corresponded with that in blast nursery tests.

Isolates from Sensho and from the susceptible varieties infected only susceptible varieties. Both Sensho and Dular are upland varieties.

Determining level of resistance by measuring the rate of disease development. The measurement of rate of disease development to determine level of resistance is based on the idea that once the virulent race occurs, the disease develops slowly in varieties with horizontal resistance, but fast in varieties with major gene resistance alone. The eight varieties used in the previous experiments were planted in 4- × 1-m

Table 8. Quantitative resistance (number of lesions) of eight varieties to *P. oryzae* isolates from their own lesions. IRRI, 1977.

	Quantitative resistance of eight varieties to *P. oryzae* isolates											Av.	Overall av.
	Tetep												
Isolate	T15	T17	T18	T21	T22	T23	T24	T26	T27	T31			
Lesions (no.)	6.3	8.1	3.1	18.7	0.1	0.2	4.2	0	4.8	0		4.6	0.9
Lesions (relative no.)*	13.5	14.5	11.6	24.4	0.5	0.5	22.3	0	14.6	0		10.2	2.0
	Dawn												
Isolate	D1	D2	D3	D5	D6	D7	D9	D11	D13	D14			
Lesions (no.)	0	1.7	2.8	2.5	0.1	0.5	10	4.3	1.2	1.9		2.5	1.6
Lesions (relative no.)	0	3.1	11.9	11.4	0.5	2.3	25.9	13.48	4.0	6.4		7.9	4.5
	Sensho												
Isolate	S2	S4	S8	S9	S10	S11	S12	S13	S16	S17	S19		
Lesions (no.)	0	0	0	0	0.2	0.8	0	0	2.5	2.6	0.1	0.6	0.3
Lesions (relative no.)	0	0	0	0	0.6	2.5	0	0	7.6	8.3	0.3	1.8	1.1
	NP-125												
Isolate	NP4	NP5	NP6	NP7	NP8	NP9	NP10	NP11	NP12				
Lesions (no.)	13.1	9.7	13.4	7.6	4.5	2.3	2.9	11.5	2.7			7.5	3.5
Lesions (relative no.)	29.7	26.4	36.0	23.5	18.8	7.9	15.9	27.3	12.4			22.0	11.8
	Dular												
Isolate	DR1	DR2	DR3	DR4	DR5	DR6	DR7	DR8	DR9	DR10			
Lesions (no.)	13.3	10.3	15	18.8	1.5	7.6	12.4	6.9	12.1	15		11.3	6.4
Lesions (relative no.)	57.6	41.0	30.6	68.1	5.6	27.9	20.4	18.1	45.8	36.1		35.1	18.6
	Peta												
Isolate	P2	P3	P5	P7	P9	P13							
Lesions (no.)	31.4	13.4	28.9	39.1	25.9	10						25.5	21.9
Lesions (relative no.)	95.4	59.4	81.4	100	68.9	30.8						74.0	65.6
	Khao-tah-haeng 17												
Isolate	K27	K28											
Lesions (no.)	44.4	41.3										42.9	29.4
Lesions (relative no.)	100	100										100	86.8
	Fanny												
Isolate	F33	F34											
Lesions (no.)	30.4	17.8										24.1	23.0
Lesions (relative no.)	100	80.9										90.5	70.2

*A percentage calculated by using the largest number of lesions on any of the eight varieties as 100. Each group of isolates was obtained from a host variety.

(12-row) plots separated by 2.5 m to reduce cross infection. The plants of the fourth row in each plot were inoculated with an isolate virulent to all varieties. However, because degree of virulence varies among varieties, three isolates were used, one for each series of eight plots. After inoculation, all plots were covered with a plastic sheet from 1700 to 0800 daily to ensure infection and disease development. Lesions from 5 plants selected at random from each row (8 rows) were counted every 4 days, starting 7 days after inoculation.

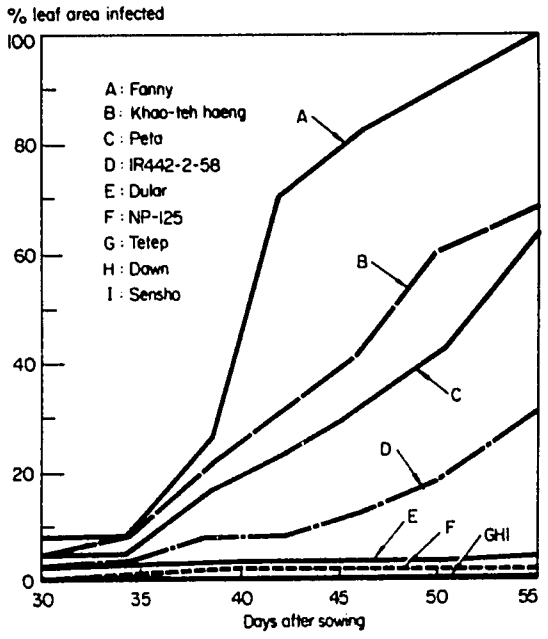
This test differs from the blast nursery test:

1. It uses pathogenic (or virulent) races. In a blast nursery there is a mixture of races from natural infection but pathogenic races may not be present for some varieties.

2. In this test, the inoculum is generated only by the variety itself. In a blast nursery, the inoculum comes from all neighboring infected plants, as well as from lesions of a particular variety.

The results are shown in Figures 4 and 5.

Severe blast developed on the susceptible group, but almost none on other varieties (Fig. 4). The rate of development by regression coefficient (r-value) is shown in Figure 5. The r-values were high in susceptible varieties and low in resistant varieties. Further tests with isolates (races) of the fungus, preferably in other rice-growing countries where blast is severe, may determine whether the low r-values were due to horizontal resistance. The variety Bluebonnet tested in the Ivory Coast, for exam-



4. Blast disease development on rice varieties inoculated with three virulent isolates of *Pyricularia oryzae*. IRRI, 1977.

ple, had a low *r*-value but was susceptible in Latin America.

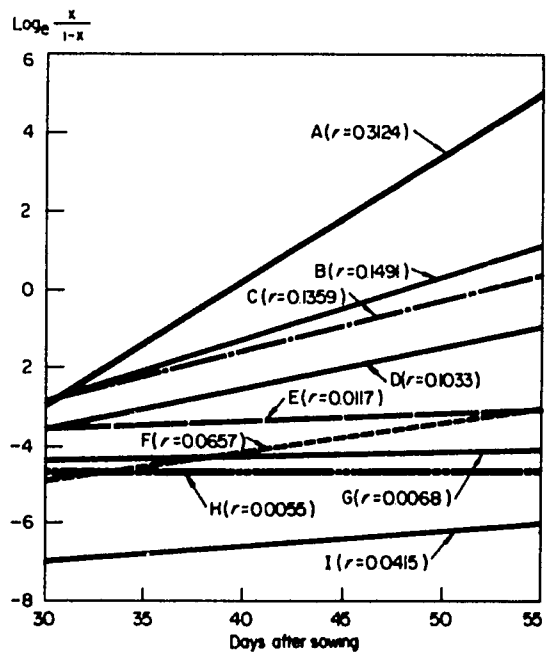
One reason for the low rate of disease development in some varieties could be the lesion type. On some varieties such as Dular, the lesions were large but had a broad brown margin and a relatively small necrotic center. Such lesions are suspected to produce a small amount of spores. Another more important reason is low infection rate. For example, the artificial inoculation experiment showed fewer lesions on some varieties than on the susceptible varieties, even when the same number of spores was inoculated.

The low infection rate in each cycle of the fungus also greatly reduced the number of lesions. It was believed due to the change of pathogenicity of the spore population (different races produced) and to the small number of spores that were able to infect the resistant varieties. In both this and other experiments Tetep remained highly resistant to blast.

Testing Japanese varieties with "field resistance" to blast. Sixty-three varieties known to have *field resistance* and R-genes in Japan were provided by the National Institute of Agricultural Sciences for tests in the IRRI blast nursery. Many were not resistant and were nearly or completely killed by the disease (Table 10). Within a group of varieties with specific R-gene (*Pi-a* or *Pi-i*), the reactions in the IRRI blast nursery were different (*r, m, s,* or *ss*), indicating that other R-genes are involved and the genotypes differ among varieties within each group. The varieties will be tested for horizontal resistance in the IRBN.

Blast-resistant multiline trial. A preliminary trial for testing the benefit of multiline planting included five blast-resistant, near-isogenic lines with a common IR8 background. The five lines and IR8 were planted in 8- × 8-m plots (16 rows) separately and in combinations, in equal proportions, to compare the rate of and total disease development.

An isolate virulent to all lines was first inoculated to potted seedlings of IR442 and Peta, two susceptible varieties. Three small pots of IR442 and two pots of Peta were set in the center of each plot 3 weeks after sowing. The plants in a 1- or 4-m area in each plot, including the potted source of inoculum, were covered with a plastic



5. Rate of disease development (*r*-value) on rice varieties inoculated with three virulent isolates of *Pyricularia oryzae*. IRRI, 1977.

Table 19. Reaction of Japanese *field resistant* varieties in the IRRI blast nursery,[a] 1977.

Variety	Genotype for true resistance	Field resistance (Japan)	Reaction in blast nursery (IRRI)
Chiyohikari	+	rr-r[b]	m[**]
Ou 247	+	rr	m
Tokai 26	+	rr	m
San'in 63	+	rr	s
Harima	+	rr	m
Murasaki-ine	+	rr	ss
Suzuhara-mochi	+	rr	ss
Rikuto Norin 24	+	rr	m
Ishioka 3	+	rr	ss
Sensho	+	rr	s
Fukuton	+	rr	s
Rikuto Norin Mochi 4	+	rr	m
Rikuto Norin Mochi 26	+	rr	m
Rikuto Norin 12	+	r	m
Honen Wase	+	r	s
Kansai 6	+	r	m
Saikai 90	+	r	ss
Tangin Bozu	+	r	s
Ukon Nishiki	+	r	ss
Kogane Nishiki	+	r	ss
Ginga	+	r	s
Kogane-masari	+	r	s
Koshiji Wase	+	r	m
Miyama Wase	+	r	s
Yamaji Wase	+	r	s
65A-8	Pi-a	rr	s
Heiruko-mochi	Pi-a	rr	—
Rikuto Norin 11	Pi-a	rr	m
Shin Hakaburi	Pi-a	rr	m
Hideri-shirazu	Pi-a	rr	m
Kuroka	Pi-a	rr	m
Kirishima	Pi-a	rr	m
Kahei	Pi-a	rr	m
Hirayama	Pi-a	rr	m
Yamabiko	Pi-a	r	ss
Fujiminori	Pi-a	r	s
Reimei	Pi-a	r	s
Homare Nishiki	Pi-a	r	ss
Toyonishiki	Pi-a	r	m
Toyonishiki	Pi-a	r	m
Himehonami	Pi-a	r	m
Mutsu-kogane	Pi-a	r	m
Sawanishiki	Pi-a	r	s
Asagiri	Pi-a	r	ss
Yoneshiro	Pi-i	rr	m
Joiku 232	Pi-i	rr	—
Kuiku 9	Pi-i	rr	m
Kukei 22	Pi-i	rr	m
Toyoma Wase	Pi-i	rr	m
Isao-mochi	Pi-i	rr	ss
Sorachi	Pi-i	rr	rr
Fujisaka 5	Pi-i	r	s
Todoroki Wase	Pi-i	r	m
Akishino-mochi	Pi-a Pi-i	r	m
Takasago-mochi	Pi-a Pi-i	r	m
Shinsetsu	Pi-a Pi-i	r	m
San'in 68	Pi-k	r	rr
Tatsumi-mochi	Pi-k	r	rr
Matsumae	Pi-k	r	rr
Ishikari	Pi-a Pi-k	r	rr
BR No. 1	Pi-a Pi-k Pi-m	rr	rr
Hokushin 1	Pi-a Pi-k Pi-m	r	rr
Ou 244	Pi-z	rr	rr
54BC-68	Pi-z	rr	rr

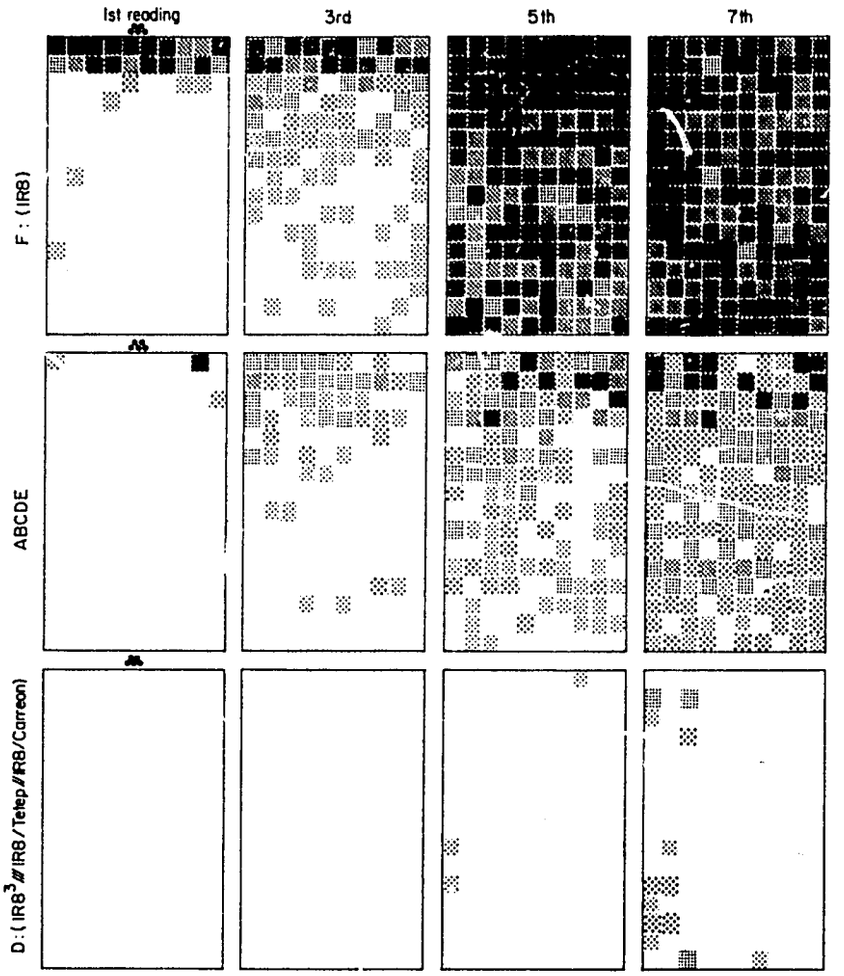
[a]rr (=1) = highly resistant, r (=2) = resistant, m (=3 and 4) = moderately resistant, s (=5 and 6) = susceptible, ss(=7, 8, and 9) = very susceptible. Figures in parentheses are the numerical scale 1 to 9, adopted for international testing.

sheet to ensure disease development. Disease incidence (percentage of leaf area infected) was determined by examining 10 seedlings selected at random from each row every 3 days. The results of the first, third, fifth, and seventh readings of 12 rows are shown in Table 11, Figure 6 (in part), and Figure 7. The four rows near the inoculum source were excluded to avoid the effect of heavy inoculum from the source.

Among the single resistant lines, $IR8^6$/PK203, $IR8^3$/Tetep, and $IR8^3$///IR8/Tetep//IR8/Carreon had little disease while $IR8^3$/Carreon and $IR8^7$/Dawn were affected considerably. IR8 had severe disease development.

To evaluate the benefits of multilines, the rate of disease development (*r*-value) for each plot was plotted (Fig. 8). The theoretical value of total disease development in Table 11 was calculated by adding final disease scores of individual lines and dividing by the number of lines involved. At IRRI, the benefits of multilines — reduced *r*-value and, consequently, less total disease development — were not demonstrated. Further experiments will be based on the results of this trial.

Leaf scald disease *(Plant Pathology). Methods of screening and varietal resistance.* When first isolated, the leaf scald fungus produces abundant mycelial growth and small islands of pink conidial masses. Streaking the conidia on an agar plate produces large quantities of conidia



6. Disease development in some blast-resistant multiline trial plots. IRRI, 1977.

sufficient for a conidial suspension for inoculation. Leaf clipping and spraying inoculation methods were used. Clipping ensures inoculation, requires less inoculum than the spraying method, and prevents unnecessary dispersion of the inoculum in nontarget areas.

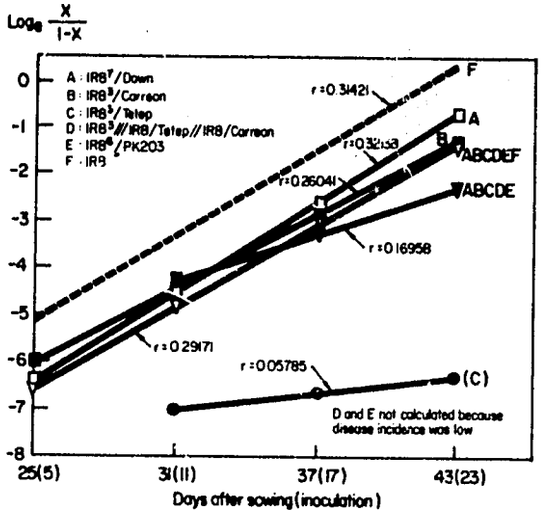
A large-scale leaf scald inoculation trial involving 321 varieties was made in a hybridization block in the 1977 wet season, when the rices were in the late tillering stage. Three hills of each variety were clip-inoculated with conidial suspension late in the afternoon. The reaction of each variety was measured by the extent to which lesions developed from the cut end of the leaves 3 weeks after inoculation.

The lesions on susceptible varieties were 20 to 30 cm while those on resistant varieties were

Table 11. Percentage of leaf area infected by blast in multiline and single-line plots. IRRI, 1977.

Line or variety	Leaf area infected (%) at 25 DS[a]	31 DS	37 DS	43 DS	Theoretical value, terminal disease reading
IR8³/Dawn (A)	0.05	1.44	18.56	19.66	—
IR8³/Carreon (B)	0.19	1.02	6.73	16.03	—
IR8³/Tetep (C)	0.0	0.1	0.1	0.2	—
IR8³/ / /IR8/Tetep/ / IR8/Carreon (D)	0.0	0.0	0.13	1.9	—
IR8⁴/PK 203 (E)	0.01	0.2	0.0	0.0	—
IR8 (F)	0.37	3.09	39.39	44.13	—
ABCDEF	0.14	0.91	7.08	14.36	13.69
ABCDE	0.0	1.43	4.78	9.82	7.6

[a]DS = days after seeding.



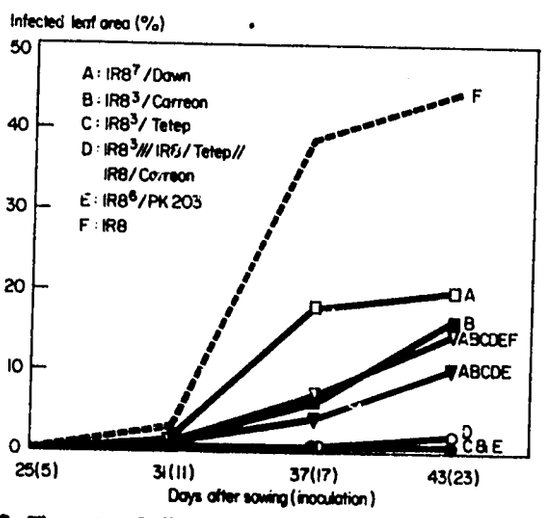
7. Blast development in plots of single resistant lines and multilines. IRRI, 1977.

1 to 2 cm. Table 12 gives a tentative 1 to 9 scale and the summary of the field inoculation experiment.

Most of the varieties were resistant or moderately resistant. The reaction of the resistant varieties will be confirmed by further tests.

We also scored 4,459 varieties and lines for their reaction to leaf scald in a naturally infected field at IRRI (Table 5).

Perfect stage of Rhynchosporium oryzae. The perfect stage of *Rhynchosporium oryzae*, usually found on diseased leaves, might play an important role in spreading the disease. Moisture conditions appeared to affect the formation of the perithecia. When the lesions dried rapidly, either no perithecia or immature ones were formed. The morphology and cultural characteristics were identical with those of *Metasphaeria albescens* Von Thuemen. The perfect stage with identical morphology and cultural characteristics has been reported in China, Japan, and Korea, but various names for it, including *Fusarium*, have been suggested. The IRRI study suggests that *M. albescens*, the name under which it was described much earlier, should be used.



8. The rate of disease development in plots of single resistant lines and multilines. IRRI, 1977.

Table 12. Leaf scald disease scale and summary of reaction of rice varieties in an IRRI hybridization block. 1977 wet season.

Scale	Description	Varieties (no.)
0	No visible lesion	0
1	Lesions 1–2 cm	39
3	Lesions 3–5 cm	130
5	Lesions 6–12 cm	105
7	Lesions 13–20 cm	45
9	Lesions more than 20.0 cm	2

The fungus also produced various symptoms that led to the description in Japan of four diseases — brown leaf blight, leaf tip blight, leaf scald, and leaf sheath browning — caused by the same fungus. Leaf scald was reported earlier in China as leaf tip drying. The description of leaf scald is based on zonated lesions, but the lesions may not always be zonated (Fig. 9). Despite earlier names, the name leaf scald is suggested because it has international acceptance.

A *Helminthosporium* disease on Sekiguchi Asahi (*Plant Pathology*). A rice disease of spectacular appearance exhibiting numerous rust-colored, rectangular-oblong, and zonated spots on leaves was observed in IRRI plots (Fig. 10). Its causal fungus was a *Helminthosporium* sp., presumably *H. oryzae*, but the symptoms were different from those of the ordinary brown spot disease. The infected variety Sekiguchi Asahi is a mutant of Asahi, originally found in Japan by Sekiguchi, and is extremely sensitive to infection by *Helminthosporium* and some strains of *Pyricularia oryzae*. In the field it is always heavily infected by *Helminthosporium*. In the United States, it has been used as the disease spreader in screenings for resistance to brown

9. Symptoms of leaf scald disease of rice showing zonated and nonzonated lesions (IRRI, 1977).

spot disease. It could be used as such in Asia.

Bacterial blight *(Plant Pathology and Plant Breeding).* The Philippine isolates of *X. oryzae* can be classified into three distinct pathogenic types on the basis of their reaction to varieties with known genes for resistance (1976 Annual Report). Type 1, represented by PXO 61 isolates, infects varieties with no functional genes for resistance to bacterial blight in the Philippines; type 2, represented by PXO 79 (formerly Isabela strain), attacks varieties carrying *Xa 4* for resistance; and type 3, represented by PXO 71, attacks varieties carrying *xa 5* for resistance.

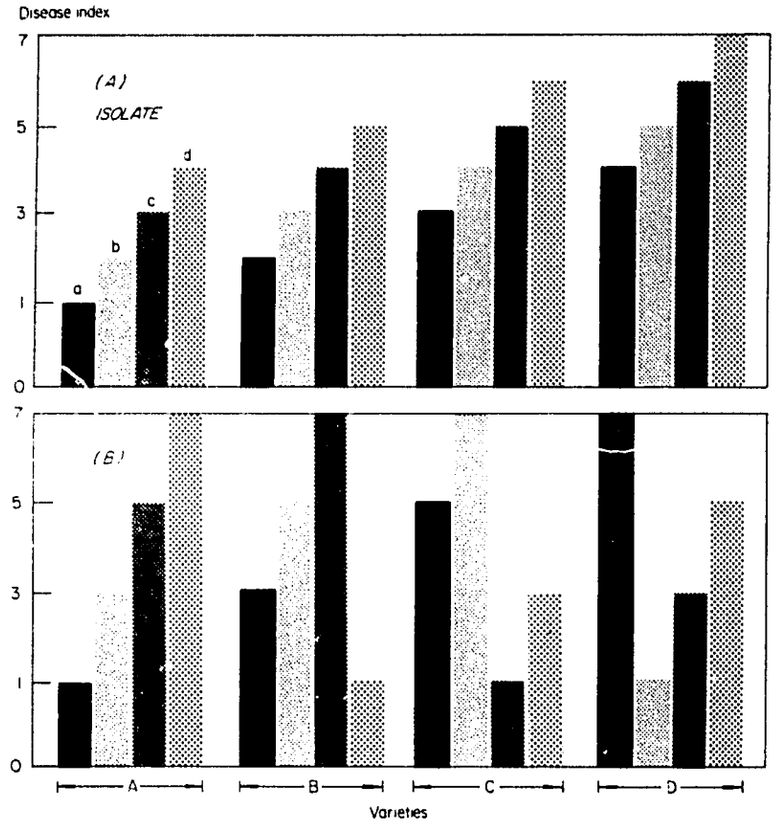
Differentiation of virulence in Xanthomonas oryzae *(Plant Pathology).* To detect continuous and discontinuous variations in virulence of *X. oryzae* on resistant rice, a scheme based on the current concept of host-parasite interactions was proposed. Figure 11A shows continuous variation in virulence among the isolates and no specificity of infection. Figure 11B illustrates the specificity with which the isolates infected the test varieties, and discontinuous variation in virulence.

Results of tests with the Philippine isolates and selected varieties with specific genes for

10. ***Helminthosporium*** **leaf spot on the rice variety Sekiguchi Asahi. IRRI, 1977.**

resistance indicate that PXO 61 can produce lesions on varieties of various specific resistance, yet it is more compatible with IR8, i.e. it produces larger lesions on varieties carrying no functional genes for resistance in the Philippines. Likewise, PXO 79 causes more lesions on varieties with either no functional genes or the dominant gene *Xa 4* for resistance. PXO 71 is more specific to varieties with no functional genes and to those with the recessive gene *xa 5* for resistance (Fig. 12). DV85, which has two genes for resistance, is resistant to all these isolates. PXO 71, however, seems to always produce longer lesions on DV85 than do the two other isolates. That could indicate its aggressiveness. Analysis of variance indicated that the effect of the variety-isolate interaction was highly significant. The relative reaction among the selected differential varieties varied from one isolate to another. When the varieties were inoculated with the isolates at different ages, differential interactions showed specificity in infection between the isolates and compatible varieties (Fig. 13).

Analysis based on individual young and old leaves from plants revealed significant effects with varieties, but not with isolates. However, the interactions between varieties and isolates were significant (Table 13). In evaluation of varietal resistance with specific isolates, the reaction may be affected by leaf position. On this basis, the bacterial blight resistance or suscepti-

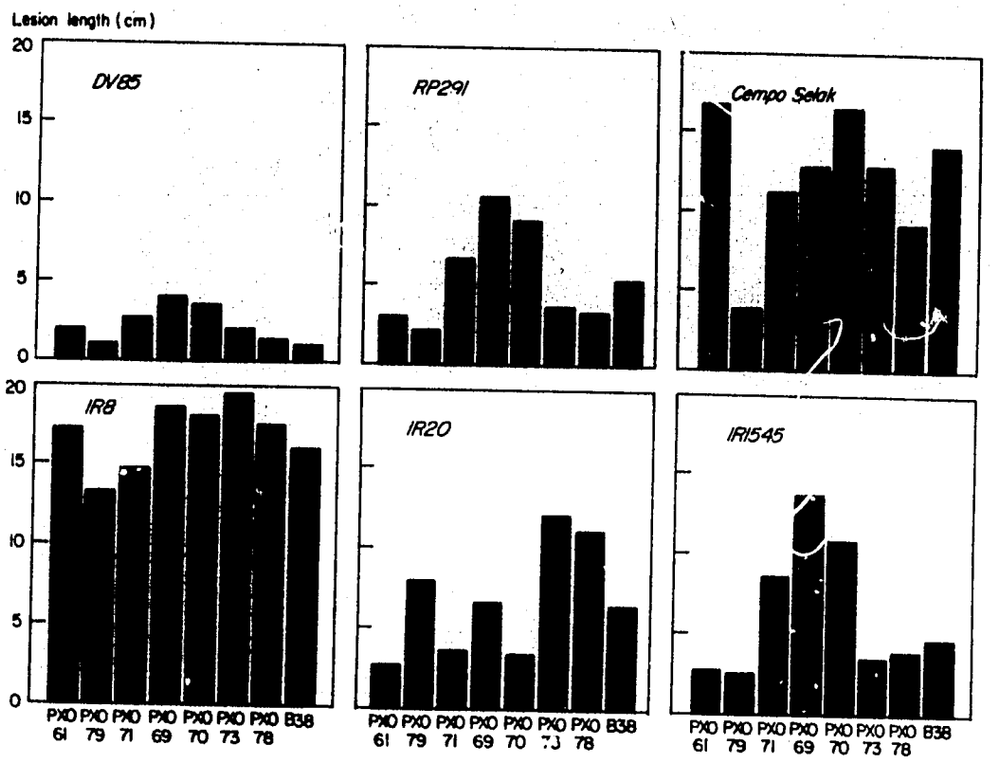


11. Disease severities of four varieties inoculated with four isolates of *Xanthomonas oryzae:* (A) Continuous variation in virulence of isolates and ranking of resistance in varieties. (B) Interactions between isolates and varieties showing vertical pathogenicity and vertical resistance. IRRI, 1977.

bility of IR8, IR545, DV85, and RP291-20 placed them in the same group; that of IR20 and Cempo Selak, in a group that varied in reactions according to leaf position. Within each group there was no significant interaction with leaf positions. Larger differences in leaf position were detected in the varieties of the IR20 and Cempo Selak group than in the former group.

Generally rice plants are more susceptible to bacterial blight infection at the seedling than at the adult stage. As shown in Figure 13, specificity between test isolates and certain varieties was observed at different ages of the varieties. In its reaction to specific isolates, the resistance of a variety appears to be independent of plant age but dependent on compatibility between host variety and the isolate. The varieties IR8, IR20, IR1545, and DV85 were tested for their resistance to PXO 82 from 9 days after sowing (DS) to 37 DS. Because PXO 82 overcomes the resistance of IR20 (*xa 4*) and IR8, the two varieties were infected at the seedling stage. The two had longer lesions than IR1545 and DV85, which were resistant to PXO 82 (Table 14). Although lesions on IR1545 and DV85 were longer at 9 DS than at 16 DS, the overall disease reaction at 9 DS was moderately resistant to resistant.

Development of improved plant type differentials with specific genes for resistance (Plant Breeding). To date, five genes for resistance to the Philippine isolates of bacterial blight have been identified. The varieties with those genes differed in maturity and other plant characteristics. A backcrossing program was started to transfer the genes for resistance to an isogenic



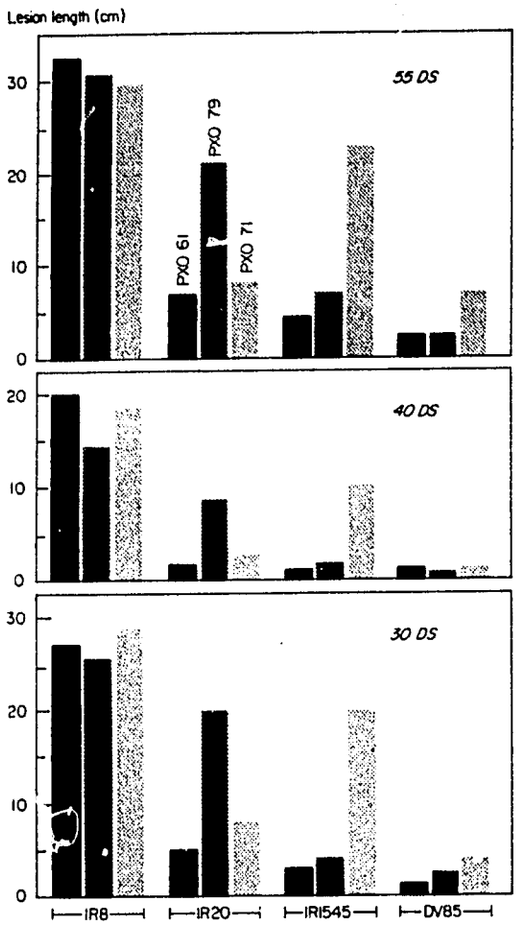
12. Interactions between the Philippine isolates of *Xanthomonas oryzae* and rice varieties to show pathogenic specificity and differential resistance. IRRI phytotron (temperature 21–29°C), 1977.

background. IR9101-46-3-1, a bacterial blight-susceptible line of improved plant type, was used as a recurrent parent. It is resistant to other major diseases and insects. Within a few seasons, isogenic lines with different genes for resistance to bacterial blight should be availa-

Table 13. Effect of leaf age on the differential interactions between selected varieties and *Xanthomonas oryzae* isolates. IRRI, 1977.

Variety	Leaf position[a]	Lesion length (cm)							
		PXO 61	PXO 69	PXO 70	PXO 71	PXO 73	PXO 78	PXO 79	B38
IR8	1	18	20	19	15	20	18	13	17
	2	17	18	19	15	19	17	14	17
	3	17	19	17	15	20	18	13	15
IR20	1	6	9	5	5	13	13	9	9
	2	4	7	3	4	12	11	7	8
	3	4	5	3	3	11	10	8	7
IR1545	1	3	14	13	10	6	4	3	5
	2	3	14	11	9	6	4	3	5
	3	3	13	10	8	6	4	3	4
DV85	1	2	5	4	3	2	2	1	1
	2	2	4	3	3	2	1	1	1
	3	2	3	3	2	2	1	1	1
RP291-20	1	3	11	10	7	4	4	2	5
	2	3	10	9	6	3	3	2	5
	3	3	11	8	6	4	3	2	6
Cempo Selak	1	19	14	18	12	14	12	5	15
	2	16	12	16	11	12	9	3	14
	3	16	13	15	10	12	7	3	14

[a]1 = youngest, 3 = oldest.



13. Interactions between isolates of *Xanthomonas oryzae* and rice varieties, showing vertical pathogenicity and resistance at different stages of plant growth. IRRI greenhouse, 1977. DS = days after seeding.

ble. Such lines will provide differentials for worldwide detection of variation in *X. oryzae*.

Occurrence of pathotype 2 (Isabela strain) of Xanthomonas oryzae *at IRRI (Plant Pathology).* Varieties or lines with the dominant gene *Xa 4* for resistance to pathotype 2 of *X. oryzae* have been observed to be susceptible to bacterial blight at IRRI. Pathogenicity tests showed the similarity between isolates from the infected leaves and isolates of the strain previously known as Isabela, or pathotype 2. Beginning in the 1976 dry season, naturally infected leaves from different varieties were sampled in various IRRI fields.

Pathotype 2 of the bacterium has increased at IRRI (Table 15). That may reflect pressure for

Table 14. Resistance of four rice varieties to infection by isolate PXO 82 of *Xanthomonas oryzae* at different plant ages. IRRI, 1977.

Variety	Lesion:leaf length ratio[a] at				
	9 DS	16 DS	23 DS	30 DS	37 DS
IR8	1.00	1.00	1.00	0.99	0.90
IR20	1.00	0.97	0.99	0.74	0.67
IR1545	0.39	0.34	0.21	0.11	0.13
DV85	0.33	0.10	0.08	0.04	0.03

[a]Lesion length ÷ leaf length. DS = days after seeding.

the bacterium to shift because since 1974, more than 95% of the crosses made at IRRI for bacterial blight resistance involved the *Xa 4* gene.

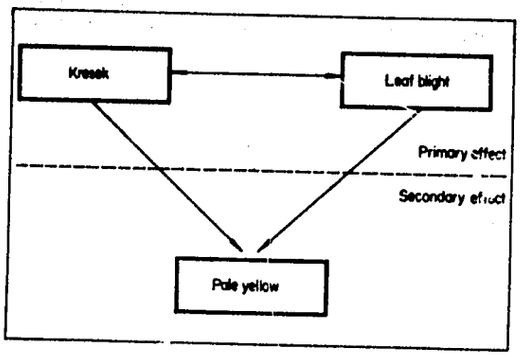
Effect of mixed inoculum on lesion development (Plant Pathology). The infectivity of a virulent isolate interferes with that of a less virulent isolate when both isolates are introduced on the same host plant either simultaneously or one after another. This phenomenon was studied with the use of three isolates of specific virulence and five varieties with specific resistance or susceptibility.

The inoculum was prepared by mixing two isolates in either the same or different proportions. The density of individual isolates was standardized by their absorbance reading at 600 nm of a spectrometer. The effect of each isolate on each variety represented its infectivity on that variety. PXO 71 caused more lesions than did PXO 61 or PXO 82 on all five varieties. When PXO 71 was mixed with either one of the other isolates, the lesions were much shorter than those caused by PXO 71 alone. That became obvious when the proportion of the other isolate in the inoculum was increased (Table 16). The lesions, however, were always larger than those that either PXO 61 or PXO 82

Table 15. The virulence pattern of pathotype 2 of *Xanthomonas oryzae*[a] at IRRI. 1976 and 1977 dry seasons.

Host genotype	Reaction group (%)			
	Resistant		Susceptible	
	1976	1977	1976	1977
IR8	0	5	100	95
IR20	90	75	10	25
IR1545	100	100	0	0
DV85	100	100	0	0

[a]Isolates from rice naturally infected with bacterial blight: 125 isolates for 1976 and 101 isolates for 1977.



14. The relationship of the bacterial blight syndrome.

alone could induce when they are mixed individually with PXO 71. Mixing PXO 61 and PXO 82 appeared to have no drastic effect on lesion development. The similarity of the effects of the two isolates on the set of varieties suggests that PXO 82 may be closely related to PXO 61.

Isolates belonging to the same group are being tested further to determine if mixing two isolates of similar virulence (vertical pathogenicity) affects infectivity. Such information could be used to distinguish heterogeneous populations of the bacterium or isolates from different geographical regions, and to classify them into homogeneous groups.

Table 16. Effect of mixed inoculum of *Xanthomonas oryzae* isolates on bacterial blight development. IRRI, 1977.

Inoculum mixture	Lesion length (cm)				
	IR8	IR34	IR1545	IR944	IR1698
PXO 61 and PXO 71					
1 : 1	14.2	3.0	8.9	17.0	16.5
9 : 1	10.7	3.3	2.7	12.1	9.8
1 : 9	16.2	5.0	10.4	15.7	18.0
PXO 61 and PXO 82					
1 : 1	9.9	8.1	1.8	9.8	11.5
9 : 1	11.1	6.3	1.7	10.3	11.8
1 : 9	10.2	8.3	1.7	7.5	11.7
PXO 71 and PXO 82					
1 : 1	11.2	7.6	3.4	12.3	10.9
9 : 1	10.7	4.5	10.4	14.0	19.6
1 : 9	16.5	9.2	2.2	11.1	9.4
PXO 61	9.7	3.4	1.5	9.6	9.5
PXO 71	18.1	7.4	11.9	18.3	20.3
PXO 82	9.5	7.5	1.4	7.7	9.7

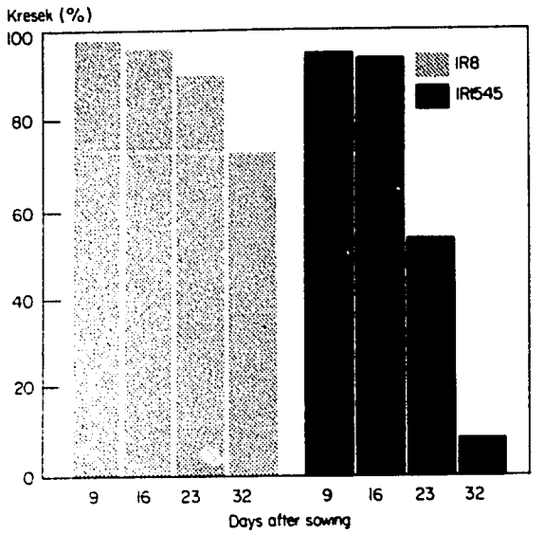
Kresek *(Plant Pathology).* The bacterial blight syndrome has three types of symptoms in the tropics — the leaf blight, the kresek, and the pale-yellow plant. The relationship among them, based on the inoculation tests and observations, is outlined in Figure 14. *X. oryzae* is involved in all symptoms, but kresek and leaf blight seem distinct and independent of each other, i.e. individual plants may suffer from either kresek or leaf blight infection. The kresek-infected plants may serve as a source of inoculum for secondary infection leading to leaf blight, or leaf blight infection may turn to kresek if the infection occurs in the early growth stage or if the variety is susceptible to bacterial blight. That indicates that kresek and leaf blight are the primary effects of infection. Pale yellow is a secondary effect of either leaf blight or kresek.

Effect of plant age on kresek development. In the field, kresek is normally observed from 1 to 4 weeks after transplanting. It may occur in adult plants if disease conditions are favorable and the variety is susceptible. In experimental conditions, young seedlings have more kresek infection than older seedlings.

IR8, which has no gene for bacterial blight resistance, and IR1545, which has the recessive gene *xa 5*, were evaluated for response to kresek infection at different ages. Plants were inoculated with a 5-minute root-dip in a bacterial suspension. The results suggested that IR8 was susceptible to kresek from 9 to 32 DS (Fig. 15). IR1545 at 9 and 16 DS was as susceptible as IR8, but at 23 and 32 DS, it had 54% and 8% infection. The information indicates that resistance to kresek is expected between varieties and also within varieties at different ages.

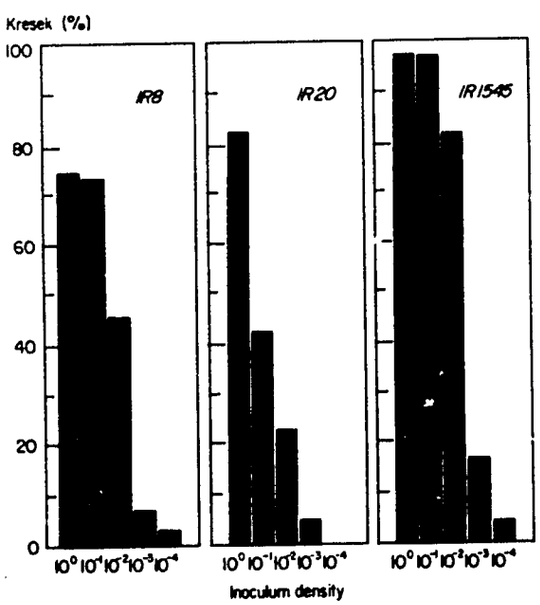
Varietal reaction. It was previously observed that when IR8, IR20, IR1545, and DV85, which differ in resistance to bacterial blight, were tested by the root-dip method of kresek inoculation, DV85 showed less kresek than the three other varieties (1976 Annual Report). The three varieties also differed in response to kresek at different inoculum concentrations of PXO 82 (Fig. 16).

Fourteen varieties were evaluated in the greenhouse and in the field for their kresek reaction to the isolates PXO 61 and PXO 82.



15. Development of *kresek* at different ages of IR8, with no resistance gene, and IR1545, with a recessive gene for leaf blight resistance. IRRI, 1977.

All except IR8, India Dular, Ketan Lumbu, and Lakshini Digha varied in reaction to the two isolates. India Dular was resistant and IR8 susceptible (Table 17). Their reaction to the three Philippine pathotypes of *X. oryzae* for leaf blight indicated that the reaction to kresek of these varieties was not correlated with their reaction to leaf blight.



16. Response of three varieties with different degrees of resistance to leaf blight to kresek infection at different inoculum (PXO 82) densities. IRRI, 1977.

Table 17. Kresek and leaf blight reactions of selected varieties to isolates of *Xanthomonas oryzae*. IRRI, 1977.

Variety	Reaction				
	Kresek (%)		Leaf blight[a]		
	PXO 61	PXO 82	PXO 61	PXO 79	PXO 71
IR8	82	79	S	S	S
IR20	55	70	MR	S	MR
IR1545-339	67	92	R	R	S
DV85	34	24	R	R	R
ARC 6076	52	79	S	R	S
Bowalia	65	44	R	R	MR-MS
Buri Katari	38	26	R	R	R
Dharial	[b]	57	R	R	MR-MS
Djawa Tulen	47	35	S	S	MS-S
India Dular	14	13	R	R	R
Kasia Panja	84	62	R	MR	MR
Ketan Lumbu	21	21	[b]	[b]	[b]
Lakshini Digha	37	31	R	R	R
Pelita I-1	78	86	MR	S	MR

[a]R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible. [b]No test results.

Ranking of the 14 varieties on the basis of their overall reaction to the isolates in the greenhouse showed India Dular was most resistant while the susceptible check IR8 ranked 13 (Table 17). Testing of the varieties in the field by the same method of inoculation showed India Dular was most resistant and IR8 most susceptible (Table 18). Reactions in the

Table 18. Ranking of selected rice varieties tested for resistance to kresek infection by root-dip method of inoculation in the greenhouse.[a] IRRI, 1977.

Greenhouse ranking	Variety	IRRI acc. no.	Greenhouse infection[b] (%)	Field ranking
1	India Dular	26070	14	1
2	Ketan Lumbu	16461	21	5
3	DV85	8839	29	4
4	Buri Katari	27539	32	5
5	Lakshini Digha	26390	34	5
6	Djawa Tulen	17519	41	7
7	Bowalia	27537	54	3
8	Dharial	3396	57[c]	6
9	IR20	11355	62	[d]
10	ARC 6076	12205	65	4
11	Kasia Panja	27588	73	2
12	IR1545-339	32624	79	9
13	IR8	10320	80	10
14	Pelita I-1	14560	82	8

[a]Varieties were scored 3 weeks after inoculation (WI) in greenhouse test and 6 WI in field test. [b]Av. of infection by isolates PXO 61 and PXO 82. [c]Based on PXO 82 only. [d]No test results.

Table 19. Coefficient of variation[a] for percentage of infection based on number of plants tested (IR8) by root-dip method of inoculation. IRRI, 1977.

Days after inoculation	Coefficient of variation (%)				
	20 plants	40 plants	60 plants	80 plants	100 plants
6	171	161	143	133	89
11	67	46	43	33	30
15	21	29	22	18	17
18	26	20	20	15	14
22	26	14	16	13	12
27	20	13	13	10	9

[a]Estimated standard error of the mean.

greenhouse were scored 3 weeks after inoculation, whereas those in the field were scored 6 weeks after inoculation.

Scoring for varietal resistance to kresek infection. Because kresek is a systemic form of bacterial blight, scoring of the percentage of infection at a certain time after inoculation should be standardized. In a preliminary test, the percentage of kresek development peaked from 3 to 4 weeks after root-dip inoculation in the greenhouse. Experiments were thus designed to determine the proper number of plants (IR8) that should be the basis for varietal testing and screening, and the time of scoring expressed as *days after inoculation.* Obviously, the higher the number of plants, the lower the coefficient of variation (Table 19). This held true for the prolonged duration of infection after inoculation. For practical purposes, from 60 to 80 plants scored at any time from 21 to 24 days after inoculation are adequate for greenhouse tests. In the field, on the basis of 100 hills per variety scored, the fifth week from artificial inoculation at transplanting is the proper time for scoring (Table 20).

Effect of isolates on kresek development. Bacterial blight of rice is a vascular disease and kresek is the wilting phase of the syndrome. It is highly probable that there could be more than one infection court, including wounds of roots and other plant parts. It is therefore likely that the isolates of *X. oryzae* that are capable of causing kresek may be ecologically distinct from those that are capable of causing leaf blight in the aboveground parts. Isolates from plants infected with leaf blight (LB isolates) and isolates from plants infected with kresek (Kr isolates) were compared for their capacity to produce kresek. Five isolates for each group were collected from naturally infected plants. Each isolate was capable of causing kresek (and leaf blight), but the percentage of kresek plants varied among the four varieties (IR8, IR36, IR1545, and IR1698) tested, and also among isolates (Table 21). Some LB isolates caused as much kresek as, or more kresek than, other Kr isolates. On IR8, for instance, the LB isolate PXO 61 caused 100% kresek, but the isolate Kr 5 caused 84.6% kresek. But on the basis of overall reaction, Kr isolates produced a considerably higher percentage of kresek on plants than the LB isolates on each of the four varieties (Table 22). IR8 was the most susceptible of the four varieties and IR1698 was the most resistant. It is known that IR1698 inherited from

Table 20. Varietal differences in kresek infection in the field (PXO 82) 1 to 6 weeks after inoculation. IRRI, 1977.

Variety	Kresek[a] (%)					
	1 wk	2 wk	3 wk	4 wk	5 wk	6 wk
India Dular	1 a	1 a	4 a	7 a	10 a	10 a
Semora Mangga	0 a	1 a	4 a	8 a	10 a	11 ab
Kasi Panja	1 a	1 a	8 ab	14 ab	17 ab	17 abc
Bowalia	1 a	3 ab	6 ab	15 ab	18 ab	19 abc
ARC 6076	1 a	3 ab	7 ab	15 ab	20 ab	22 abcd
DV85	1 a	5 ab	11 ab	21 b	25 bc	22 abcd
Buri Katari	1 a	3 ab	9 ab	17 ab	21 abc	23 abcd
Ketan Lumbu	2 a	3 ab	8 ab	14 ab	19 ab	23 abcd
Lakhsini Digha	0 a	1 a	11 ab	17 ab	23 abc	23 abcd
Dahrial	2 a	5 ab	13 ab	17 ab	22 abc	25 bcd
Djawa Tulen	2 a	6 abc	12 ab	22 b	28 bc	28 cd
IR1545	0 a	2 ab	14 ab	26 b	36 cd	37 de
Pelita I-1	2 a	6 abc	17 b	24 b	29 bc	29 cd
IR8 (check)	1 a	13 c	29 c	38 c	41 d	42 e

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

Table 21. Kresek production by leaf blight (LB) and kresek (Kr) isolates of *Xanthomonas oryzae* in four rice varieties. IRRI, 1977.

Isolate	Infection[a] (%)				Mean
	IR8	IR36	IR1545	IR1698	
LB 158	37 a	1 a	25 a	3 a	16
LB 200	90 bc	77 cd	48 ab	51 bcd	67
LB 227	94 bcd	72 cd	51 b	44 bc	65
LB 273	97 bcd	37 b	50 b	32 b	54
PXO 61	100 d	68 cd	67 bc	75 d	78
Kr 4	98 bcd	86 d	78 c	65 cd	82
Kr 5	85 b	78 cd	58 bc	50 bcd	68
Kr 10	91 bcd	82 cd	70 bc	50 bcd	73
Kr 55	85 b	60 bc	68 bc	45 bc	65
Kr 79	99 cd	86 d	77 c	67 cd	82

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

Zenith bacterial blight resistance that is functional at the adult stage. Whether it has some resistance to kresek needs to be confirmed.

The results indicated that LB isolates and Kr isolates differ in capacity to produce kresek. The isolates are not likely to differ in virulence, but they may differ in ecology through evolution at the sites of natural infection. The data give no evidence that the more virulent isolates cause kresek and the less virulent isolates cause leaf blight. The varieties' response to the two types of infection may be related to different factors that control resistance.

Survival of kresek and leaf blight isolates. Two isolates, one Kr (PXO 82) and the other LB (PXO 61), were studied for their ability to survive in paddy water of different treatments. The paddy water was collected from IRRI plots and allowed to settle for 24 hours. One part of the paddy water was passed through filter paper, then autoclaved; one part was passed through millipore filter; and one part was not filtered.

Table 22. Difference in kresek infection from leaf blight (LB) isolates and kresek (Kr) isolates of *Xanthomonas oryzae*, and overall varietal response. IRRI, 1977.

Variety	Kresek infection (%)			Overall[a] reaction
	LB isolate	Kr isolate	Difference	
IR8	84[b]	92	8**	88
IR36	51	79	27**	65
IR1545	48	70	22**	59
IR1698	41	56	14**	48

[a]Mean of LB isolates and Kr isolates. [b]Mean of kresek percentage based on five isolates in each group.

Each treatment (five tubes each) received a suspension of either PXO 82 or PXO 61 of the same inoculum density and of the same volume. The tubes were incubated at 24-27°C, and periodically examined for bacterial survival. The same isolates and suspension in sterile distilled water were used as check (Table 23). Neither isolate could be recovered from distilled water after 21 days of incubation. PXO 61 could not be recovered in paddy water filtered through millipore filter after 29 days of incubation. PXO 82 with good growth was recovered from more tubes than was PXO 61 at 103 days after incubation. The information indicates that Kr isolates differ from LB isolates in ability to survive in paddy water, and therefore are more effective in producing kresek infection. Selection of infection court through the process of adaptation may explain this ecological differentiation.

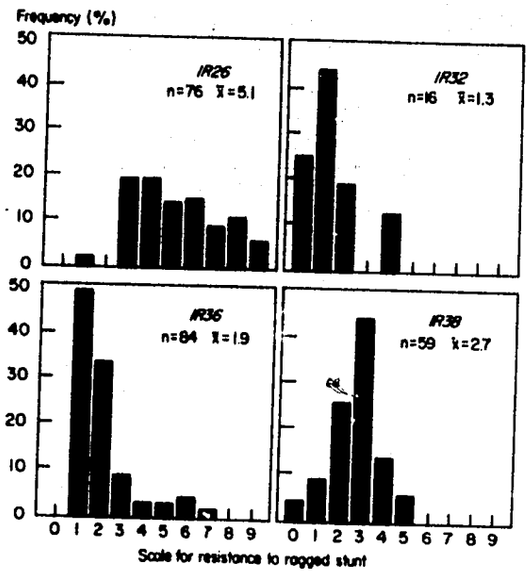
Ragged stunt *(Plant Pathology).* After rice ragged stunt disease occurred at IRRI in February 1977, attempts were made to evaluate and identify varietal resistance to the disease, to develop a screening method, and to search for sources of resistance.

Field reactions to ragged stunt. Because ragged stunt is a systemic disease, the standard evaluation system for rice virus disease by natural infection was adopted. The system includes a 0 to 9 scale to measure the percentage

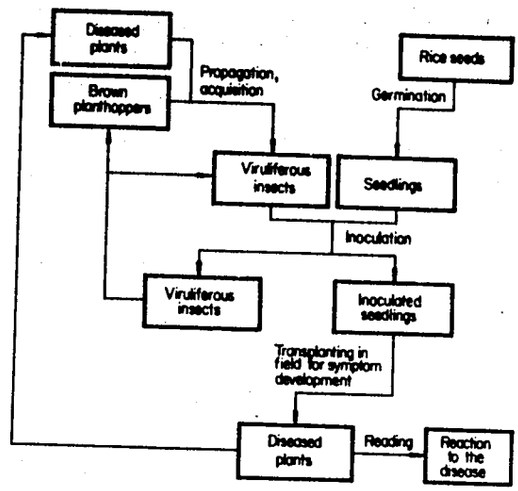
Table 23. Survival of *Xanthomonas oryzae* isolate PXO 61 (from leaf blight) and PXO 82 (from kresek) in paddy water (24-27°C). IRRI, 1977.

Treatment	PXO 61		PXO 82	
	Incubation (days)	Recovery[a]	Incubation (days)	Recovery[a]
Paddy water				
Filtered and autoclaved	103	+(2)[b], −(3)	103	+(4)[c], −(1)
Nonfiltered	103	+(1)[b], −(4)	103	+(3)[c], −(2)
Millipore-filtered	29	+(0), −(5)	29	+(1)[c], −(4)
Sterile distilled water	21	+(0), −(5)	21	+(0), −(5)

[a]Growth of isolates each incubated in 5 tubes of different treatments by streaking on potato sucrose agar plates. Figures in parentheses are number of tubes. + = positive growth of the bacterium, − = no growth. [b]Positive but few colonies. [c]Positive and abundant colonies.



17. Field reaction of rice varieties to ragged stunt disease in replicate tests. IRRI, 1977.



18. Operational procedure of the screenhouse method for testing varietal resistance to rice ragged stunt. IRRI, 1977.

of infected rice hills in the field. The higher the number on the scale, the greater is the susceptibility of the rice to the disease.

The field reactions of 4,643 rice varieties and lines in various trials were scored. About 40% of the entries scored 3 or less. Rices that showed a low average of susceptibility in the field in more than 12 replicates were

IR32	IR4219-35-3-3
IR36	IR4227-28-3-2
IR2071-588-6-2-6-4	IR4417-179-1-5-2
IR38	IR4432-28-5
IR2307-247-2-2-3	IR4432-52-6-4
IR3351-38-3-1	IR4432-103-6-4
IR3464-75-1-1	IR5853-118-5

Because disease pressure could be low, a low susceptibility reaction in the field may not necessarily imply a high plant resistance to the disease. The virus that causes ragged stunt is transmitted by the brown planthopper. Therefore, the apparent varietal resistance to the disease could result from varietal resistance to the insect vector or varietal resistance to the virus, or both.

Because disease pressure in the field is not constant, the field reaction of a rice to ragged stunt fluctuates from time to time and from place to place, regardless of variety (Fig. 17). However, a rice that has a consistently low field reaction should be more resistant than a rice that does not show such a reaction.

Screenhouse method. A 700-m² screenhouse was built to develop a screenhouse method for testing varietal resistance to ragged stunt. The method consisted of

- rearing the brown planthopper — the disease vector — on diseased plants in the screenhouse to generate viruliferous insects for inoculation,
- germinating test seeds in trays,
- moving the trays with test seedlings to the screenhouse for inoculation,
- transplanting the inoculated seedlings in the field to allow symptoms to develop, and
- scoring the reaction of the test materials.

The procedure is charted in Figure 18.

Genetic evaluation and utilization (GEU) program

Insect resistance

Entomology and Plant Breeding Departments

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SOURCES OF RESISTANCE

Entomology and Plant Breeding Departments

The volume of insect resistance screening for 1977 is summarized in Table 1. The number of breeding lines screened was nearly four times that of 1976.

Stem borers. Among the entries tested for resistance to the striped borer, the breeding lines CR94-13, IET 2845, IR4791-80, and IR4791-89 were as resistant as or more resistant than the resistant check variety TKM 6. The IR4791 lines are from diallel crosses of seven moderately resistant varieties. IR20, IR32, and IR40, and the breeding lines IR5793-328-2-3, IR5619-48-3-3-2, and IR4794-129-4-1 were also moderately resistant.

A moderate level of resistance to yellow stem borer was noted in 144 breeding lines. No highly resistant lines have yet been identified. Among 33 selected varieties, 28 had previously shown a resistant reaction to the yellow stem borer in Coimbatore, India. CO 4, CO 7, and IARI 5829 were as resistant as IR1820-52-2 in IRRI tests.

Eighteen of 176 GEU elite breeding lines had yellow stem borer resistance comparable with that of IR1820-52-2. Some of the lines are listed in Table 2.

Diallel crosses involving moderately resistant parents were made in an attempt to increase the level of yellow stem borer resistance. As high as 22% of the lines in the cross IR13635 had less than 10% deadhearts, although the percentages for the resistant parents ranged from 17 to 29% (Table 3). Several lines had less than 5% deadhearts, indicating a possible increase in the level of resistance through diallel crossing. For the first time, resistance levels surpassed those of the resistant check IR1820-52-2.

In the screenhouse evaluation of resistance to yellow stem borer, larvae reared from field-collected eggs were used to manually infest plants. To develop a method to provide sufficient first-instar larvae at a given time, the effect of temperature on egg hatchability was studied. Results indicated that egg hatch can be delayed for 14 days at 15°C with no decrease in viability when eggs were later subjected to 28°C. Temperatures below 15°C killed the eggs.

Comprehensive screening of the world germplasm collection was resumed to identify sources with higher levels of yellow stem borer resistance. During the 1977-78 dry season, 5,000 varieties will be evaluated at the Maligaya Rice Research Training Center in Central Luzon.

Green leafhopper. A total of 16,510 varieties from the germplasm collection have been evaluated for green leafhopper (GLH) resistance. In the 1977 screening of the GEU elite breeding lines, 85% of lines in the wet season and 87% in the dry season were resistant or moderately resistant. Lines IR2061-522-6-9, IR3941-97-1, and IR4227-109-1-3-3 were most resistant. Screening of 52 promising breeding lines from the upland nursery showed that about 50% were at least moderately resistant. IR6327-8-2 and IR7760-4-8-2 were most

Table 1. Number of entries of rice tested and selected for resistance to several insect pests of rice.

Insect pest	Germplasm collection (no.)		Breeding lines (no.)		Others[a] (no.)	
	Tested	Selected	Tested	Selected	Tested	Selected
Green leafhopper	586	177	40,177	25,935	0	0
Whitebacked planthopper	0	0	1,981	1,405	0	0
Brown planthopper						
Biotype 1	3,301	331	64,743	53,870	909	163
Biotype 2	765	4	45,871	28,560	1,098	155
Biotype 3	965	2	12,049	7,309	1,074	312
Stem borer						
Striped borer	0	0	652	5	0	0
Yellow borer	33	3	713	144	0	0
Whorl maggot	956	5	221	16	22[b]	19
Leaf folder	27	5	1,159	114	0	0

[a]Materials from other countries (India, Korea, Bangladesh, Indonesia, Solomon Islands, and Ivory Coast). [b]Wild rices.

Table 2. List of 1977 GEU elite lines with resistance to the yellow stem borer. IRRI screenhouse, 1977.

Line	Deadhearts (%)
Dry season	
IR2061-465-1-5-5	19
IR2307-247-2-2-3	19
IR3941-25-1	20
IR40	22
IR4816-70-1	22
IR2153-26-3-5-6	25
IR2863-35-3-3	26
Rexoro (susceptible check)	75
IR1820-52-2 (resistant check)	30
Wet season	
IR2071-486-9-2-6	22
IR3941-97-1	25
Rexoro (susceptible check)	58
IR1820-52-2 (resistant check)	24

resistant. Two of four lines from *Oryza sativa* × *Oryza glaberrima* crosses from the Ivory Coast were resistant, and five of 11 strains of red rice from the British Solomon Islands were resistant.

Brown planthopper. In 1977 many varieties and lines were recorded as resistant to the different biotypes of the brown planthopper (BPH). Twelve elite breeding lines were identified as resistant or moderately resistant to three biotypes (Table 4). Each line had CR94-13 as a parent. Of the 118 varieties that had been identified as resistant to the BPH at the All India Coordinated Rice Improvement Project (AICRIP), Hyderabad, only 52 were resistant to three biotypes at IRRI. Ten varieties were resistant to biotypes 1 and 2; 42 were susceptible to the three biotypes. That indicates that the BPH at Hyderabad is different from the biotypes at IRRI.

Whitebacked planthopper. More than half of nearly 2,000 lines evaluated for resistance to the whitebacked planthopper (WBPH) were resistant. Most of the lines, except the GEU elite breeding lines, have a resistant gene contributed by N22. Of the GEU elite lines, IR2035-108-2, IR4227-109-1-3-3, IR4613-54-5, IR5785-37-1, IR5853-118-5, IR9575 (BPI 76[9]/Dawn), and IR9669 (IR8[4]/Carreon) gave resistant reactions.

In a separate study, the 118 varieties from AICRIP evaluated for resistance to the

Table 3. Evaluation of diallel crosses for resistance to the yellow stem borer. IRRI screenhouse, 1977.

Cross	Lines tested (no.)	Lines (no.) with < 10% deadhearts	Lines (%) with < 10% deadhearts	Lowest deadheart reading (%)
IR13635, IR1628-632-1/IR1917-3-19-2/ /IR1539-823-1-4/ IR2071-625-1-252	50	11	22	3
IR13639, IR1704-3-2-3/IR1514A-E666/ /IR1628-632-1/ IR2071-625-1-252	46	8	17	6
IR13640, IR1704-3-2-3/IR2307-64-2-2/ /IR1628-632-1/ IR2071-625-1-252	72	1	1	3
IR13641-IR1721-11-6-8-3-2/IR2307-64-2-2/ /IR1628-632-1/IR1514A-E666	35	4	12	4
IR13643, IR1820-52-2-4-1/IR2307-64-2-2/ /IR1628-632-1/ IR2061-628-1-6-4-3	10	0	0	13
IR13304, WC1253/IR1514A-E666/ /Patnai 23/IR2071-625-1-252	25	0	0	10
IR13660, WC1253/IR1917-3-19-2/ /Ratna/IR2071-625-1-252	27	2	7	9
Rexoro (susceptible check)				80
IR1820-52-2 (resistant check)				20
Resistant parents				
Ratna				17
WC1253				19
WC1263				22
IR2061-628-1-6-4-3				26
IR1917-3-19-2				29

Table 4. Elite breeding lines resistant or moderately resistant to the three brown planthopper biotypes.[a] IRRI, 1977.

Line	Damage rating[b]		
	Biotype 1	Biotype 2	Biotype 3
IR2307-247-2-2-3	1	1	5
IR2797-105-2-2-3	1	1	5
IR2797-125-3-2-2-2	1	3	5
IR2863-35-3-3	3	3	5
IR2863-38-1-2	1	3	3
IR3518-96-2-2-2	1	1	3
IR4432-28-5	1	1	3
IR4432-38-6-5-2	1	1	1
IR4432-52-6-4	1	1	1
IR4432-103-6-4	3	3	3
IR4563-52-1-3-6	1	1	3
IR5853-118-5	1	3	5
Mudgo (check)	1	9	3
ASD 7 (check)	1	3	9
TN1 (check)	9	9	9

[a]Entries were elite breeding lines in 1977 replicated yield trials. [b]1976 Standard Evaluation System for Rice scale of 1–9: 1 = little to no damage (= to resistant check); 3 = first and second leaves partially yellow; 5 = pronounced yellowing and some stunting or wilting; 9 = plants dead (= to susceptible check).

WBPH — and to the BPH in India — were also evaluated for WBPH at IRRI. Forty-nine varieties showed differential reactions at the two sites. Nine were resistant at Hyderabad but susceptible at IRRI; 40 were resistant at IRRI but susceptible at Hyderabad, indicating that the WBPH in India and that in the Philippines may be different biotypes. The following varieties were resistant to the WBPH and BPH, both at IRRI (three biotypes) and in India: Vellai Langayan, Ptb 33, Eswaramangalam, Chitteri, T 1471, Kodiyan, Cheriya Chittari, Pandi, Chempan, GS 531, Ptb 21, Velutha Chera, ADR 52, Chemparam Pandi, Chenni Nayakan, T 1421, T 1426, Ptb 19, Ptb 12, Parabulum, ARC 6564, and ARC 14342.

Table 5. Field screening of germplasm collection for rice varieties resistant to whorl maggot.[a] IRRI, 1977 dry season.

Acc. no.	Variety name	Origin	Damage rating[b] 25 DT[c]
29450	Chao Hay	Laos	5
29451	Chao Lepnok	Laos	5
29452	Chao Phanthong	Laos	5
29453	Chaopi	Laos	5
30312	Mu chuan chung	China	5
105	TN1 (susceptible check)	Taiwan	9
—	IR40 (resistant check)	IRRI	4

[a]Total of 959 entries in an unreplicated experiment. [b]Rating of 0 = no damage; 9 = >50% of leaves damaged. [c]DT = days after transplanting.

Whorl maggot. Field screening of the germplasm collection for whorl maggot (WM) resistance showed five varieties with a moderate level of resistance in an unreplicated test; however, not one was as resistant as IR40 (Table 5). All had poor agronomic characteristics and were susceptible to virus diseases. None of the elite breeding lines screened had adequate resistance. Forty-seven diallel crosses of selected varieties with moderate levels of resistance were evaluated. Only the crosses IR8026 (IR1514A-E583-1/ARC 10299/ /IR1514A-E583/Gin-shan-tsan 189///ARC 6231) and IR8028 (IR1514A-E583-1/ARC 10299// IR1514A-E583-1/R_3 sultugurmatia/ / / ARC 6231) had resistance equal to that of IR40. Most of the wild-rice accessions screened had high levels of resistance in field screening, but they are useless as sources of resistance because they are difficult to cross with *O. sativa*.

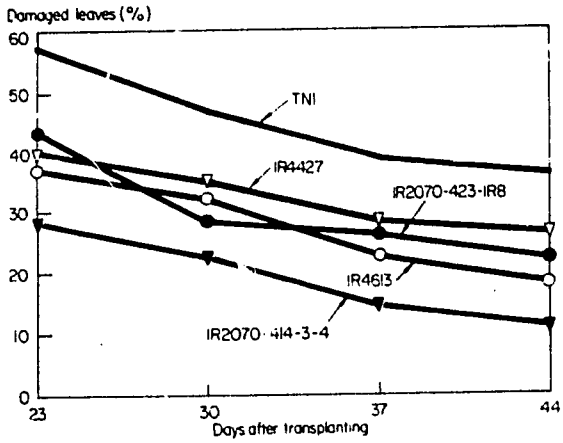
Field resistance to WM previously appeared related to the ability of a variety to tolerate damage and to continue tillering and growing. The ability of lines with different levels of resistance to recover from leaf damage was studied in the field and in the greenhouse. Recovery from leaf damage was similar for all lines (Fig. 1). Field and greenhouse results were similar.

Oviposition preference and larval survival of WM on selected wild rice accessions were studied in the greenhouse. Few wild rice accessions were preferred for oviposition. Larval survival was lowest on those with least damage.

Leaf folder. Screening for resistance to the leaf folder *Cnaphalocrosis medinalis* was begun in 1977; it involved 1,186 breeding lines and varieties. In field evaluation of 840 lowland breeding lines and varieties, each entry was planted at a spacing of 25 x 25 cm in two adjacent 5-m rows. IR36 was planted every 20 rows as a susceptible check.

The percentage of damaged leaves was recorded and damage was rated numerically as follows: 1 = < 1% leaves damaged; 3 = 1-10% of leaves damaged; 5 = 10-25% of leaves damaged; 7 = 25-50% of leaves damaged; 9 = > 50% of leaves damaged.

Of the 1,186 lines and varieties, 23 scored 3. Some of the lines and varieties are listed in Table 6. Several were known to be resistant.



1. Recovery rate of different lines and varieties from whorl maggot infestation. IRRI greenhouse, 1977.

The International Rice Brown Planthopper Nursery was scored for leaf folder resistance. Ptb 21, Ptb 33, and Thirissa appeared resistant.

CAUSES OF RESISTANCE

Entomology Department

Striped borer. Study of the ovipositional response of the striped borer to plant extracts continued (1976 Annual Report). Ground leaves and leaf sheaths of TKM 6 and Rexoro plants were steam distilled for 6 to 7 hours and 100 ml of distillates was double extracted with diethyl ether solvent. When evaporated, the solvent produced a yellow oily substance. When the extract from the striped borer-resistant

Table 6. List of the selected varieties and IRRI lines with low level of leaf folder damage in a field test. All have a rating of 3. IRRI, 1977 wet season.

Variety or line[a]	Origin
DV 85	Bangladesh
WC 1263	India
Hom Thong	Laos
Muthumanikam (Acc. 15327)	Sri Lanka
Muthumanikam (Acc. 15545)	Sri Lanka
ARC 10932	India
IR4707-106-3-2	IRRI
IR4744-295-2-3	IRRI
IR5093-147-4-2-2	IRRI
IR5629-108-2-3	IRRI
IR2070-423-5-5-2	IRRI
IR2071-88-8-10	IRRI
IR4568-225-3-2	IRRI

[a]All IR lines have both TKM 6 and *O. nivara* as parents.

Table 7. Ovipositional response of striped borer moths on resistant and susceptible varieties sprayed with extracts of both groups.[a] IRRI, 1977.

Variety	Egg masses laid (no.)	Eggs laid (no.)	Eggs (no./mass)
Rexoro (susceptible)	79	5870	74
TKM 6 sprayed with Rexoro extract	87	4311	50
TKM 6 (resistant)	28	1051	38
Rexoro plant sprayed with TKM 6 extract	33	530	16

[a]Av. of 3 replications; 20 pairs of moths tested in each replication.

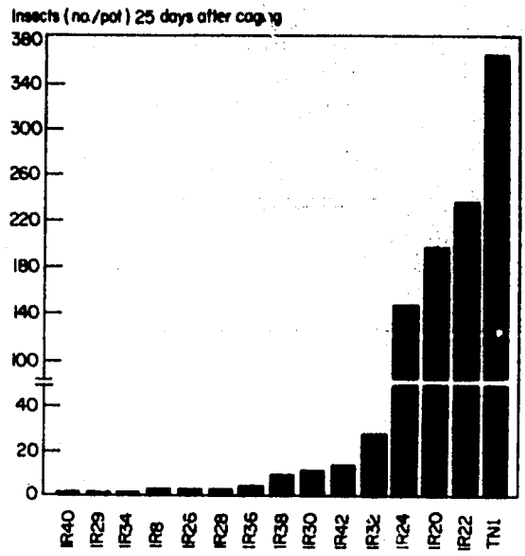
TKM 6 was sprayed on susceptible Rexoro plants, the insect laid fewer eggs on Rexoro than on TKM 6 plants. On the other hand, eight times more eggs were laid on resistant TKM 6 sprayed with an extract from susceptible Rexoro (Table 7). The ether extract of TKM 6 contains substances that inhibit striped borer oviposition; that of Rexoro contains substances that stimulate oviposition.

In another experiment, larvae in the last instar and in the prepupal stage were treated once with 1 microliter of the TKM 6 extract applied on the thorax of each larva. The last-instar larvae died 3 days after treatment, but larvae at the prepupal stage developed into larval-pupal intermediates. Contact of freshly laid eggs with cotton cheesecloth treated with TKM 6 extract adversely affected hatching while eggs kept on untreated cheesecloth hatched normally.

Green leafhopper. The buildup of GLH populations on IR varieties was studied. Three pairs of newly emerged adults were caged with one pot containing five 30-day-old seedlings. The GLH progeny were counted at 25 days after caging — the time when susceptible TN1 plants were hopperburned.

IR22 was the most susceptible variety, followed by IR20 and IR24. The lowest population increase was on IR40, IR29, and IR34. Low populations were also present on IR8, IR26, and IR28 (Fig. 2).

A study of the survival of green leafhopper adults on two resistant and one susceptible variety indicated that compared with resistant IR29, IR8 may have a moderate level of resis-



2. Population buildup of the green leafhopper *Nephotettix virescens* on different IR varieties. IRRI, 1977.

tance. Ovarian development in surviving females was slower on IR8 than on TN1. Histological examination of the rice lines that the GLH fed on indicated that the insects are xylem feeders rather than phloem feeders. In TN1, a susceptible variety, 70% of the stylet sheaths terminated in the xylem.

Brown planthopper. Selected rice varieties and BPH biotypes 2 and 3 were used to investigate basic insect-host plant interrelationships. The varietal resistance to biotypes 2 and 3 was based mainly on nonpreference and antibiosis. When given free choice, the insects distributed themselves randomly on all test varieties within 6 hours after infestation. After 24 hours, the resistant plants had fewer insects than the susceptible plants; differences became more pronounced after 48 hours of infestation.

Such response is presumed to be gustatory rather than olfactory or visual; it may be caused by the lack of certain stimuli or by the presence of a strong repellent taste in resistant varieties (1976 Annual Report).

As early as 3 days after infestation, the survival of BPH nymphs on some resistant varieties was significantly lower than that on other varieties. In other varieties the survival was moderately high even 18 days after infestation (Table 8, 9), suggesting differences in the levels of antibiosis in those varieties. Nymphal development was generally longer on resistant varieties. The life span of the female adults of both biotypes 2 and 3 was longer, the preoviposition period shorter, and fecundity higher on susceptible than on resistant varieties. Egg hatch on all the resistant varieties was significantly lower than that on the susceptible varieties. That conforms with 1976 results (1976 Annual Report) and adds a factor affecting varietal resistance.

Insects caged on susceptible varieties gained

Table 8. Factors determining resistance of selected rice varieties to brown planthopper biotype 2.[a] IRRI, 1976–77.

Variety	Nymphal survival (%)	Nymphal duration (days)[b]	Quantity ingested (mg)	Change in body wt (%)	Wt of newly emerged female (mg)	Life span of female (days)	Preoviposition period (days)	Eggs (no./female)	Egg hatch (%)	Population buildup in 90 days
M 302	56 bc	16.6 b	5.04 c	27 b	1.4 de	4 b	5 b	20 bc	57 e	99 de
H 105	46 c	16.7 b	3.42 cde	14 b	1.6 cd	4 b	5 b	34 b	73 bcd	159 de
ASD 1	44 c	15.2 a	2.03 ef	11 b	1.7 cd	4 b	5 b	28 bc	72 bcd	107 cd
SLO 13	76 ab	14.8 a	5.14 c	17 b	1.9 bc	4 b	5 b	12 cd	61 cde	3 e
CO 9	46 c	15.4 a	3.90 cd	15 b	2.0 ab	4 b	5 b	16 bcd	76 b	205 cd
ASD 7 (resistant check)	40 c	17.1 ab	3.32 cde	16 b	2.0 ab	3 b	6 ab	30 b	74 bc	287 bc
IR32 (resistant check)	32 c	19.4 b	2.47 de	12 b	1.1 f	3 b	7 ab	9 d	43 f	0 e
Rathu Heenati (resistant check)	14 d	20.2 b	0.96 f	14 b	1.2 ef	3 b	9 a	7 d	60 de	0 e
TN1 (susceptible check)	76 ab	13.3 a	34.93 a	50 a	2.2 a	12 a	3 c	195 a	93 a	4,179 a
Mudgo (susceptible check)	82 a	13.8 a	20.44 b	50 a	2.1 ab	12 a	3 c	153 a	97 a	1,834 ab

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

Table 9. Factors determining resistance of selected rice varieties to brown planthopper biotype 3.[a] IRRI, 1976–77.

Variety	Nymphal survival (%)	Nymphal duration (days)[a]	Quantity ingested (mg)	Change in body wt (%)	Wt of newly emerged female (mg)	Life span of female (days)	Preoviposition period (days)	Eggs (no./female)	Egg hatch (%)	Population buildup in 60 days
Rex/2 × BBT 50	40 abc	16.0 b	2.03 bc	11.58 ab	1.96 b	4 a	5 bc	58 ab	68.60 a	112 ab
Suduri 306	34 ab	16.1 b	1.30 a	9.48 ab	1.73 a	4 a	5 bc	36 ab	69.60 a	51 ab
Murunga 137	33 ab	17.2 b	1.27 a	5.67 ab	1.81 ab	5 a	5 bc	234 cd	66.80 a	296 b
Murunga 307	33 ab	15.4 b	2.12 bc	5.67 ab	1.95 b	4 a	4 bc	36 ab	67.60 a	91 ab
PI 20048	32 ab	16.8 b	2.32 c	4.02 a	1.70 a	4 a	5 bc	37 ab	69.80 a	38 ab
RDR 2	60 cd	15.6 b	1.35 ab	4.99 ab	1.94 b	4 a	6 c	185 bcd	68.40 a	39 ab
HR 8	42 abc	16.0 b	2.00 abc	14.07 ab	1.94 b	3 a	5 bc	43 ab	78.00 a	117 b
MTU 20	57 bcd	16.4 b	2.36 c	16.79 b	1.84 ab	5 a	4 b	189 bcd	67.40 a	143 a
HR 98	72 d	16.4 b	1.25 a	12.00 ab	1.93 b	4 a	4 b	106 abc	70.20 a	192 b
Mudgo (resistant check)	33 ab	17.8 b	1.83 abc	6.52 ab	1.74 a	3 a	6 c	14 a	69.00 a	21 a
TN1 (susceptible check)	94 e	13.2 a	34.49 f	70.82 d	2.87 c	23 b	2 a	660 d	89.20 b	3780 c
ASD 7 (susceptible check)	93 e	13.4 a	32.72 f	60.01 d	2.80 c	22 b	2 a	432 d	86.00 b	2794 c

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

significantly more weight than those caged on resistant varieties. They also excreted honeydew copiously on susceptible varieties but scantily and intermittently on resistant varieties. The amount excreted generally depended on the amount of food ingested.

BPH resistance in leaf sheaths of rice plants. In several experiments, the BPH survived on the stems of resistant plants after the lower leaf sheath had been removed. Further experiments showed that the insects caged on the leaf sheaths of resistant plants ingested significantly smaller amounts of food and lost more weight than those caged on stems without a leaf sheath (Table 10). That indicates a higher antibiosis factor in the leaf sheaths than in the stalks of resistant plants.

BIOTYPE STUDIES

Entomology Department

Brown planthopper. The occurrence of BPH biotype 2 during the 1975 wet season and the 1976 dry season in the Philippines led to the increase in the area planted to varieties containing the *bph 2* gene for resistance. Little hopperburn was recorded in the Philippines during 1977.

Distinguishing characteristics of different biotypes. Morphological examination was made of insect specimens collected from several places in the Philippines, Thailand, India, and Sri Lanka. The macropterous female of biotype 3 in the Philippines generally had a smaller number of spines on the basal segment of the hind tarsus than the macropterous females of biotypes 1 and 2. Similarly, the Philippine biotypes differed in the frequency of abnormal fore wing venation. A larger proportion of male biotype 3 insects showed stronger esterase activity than did males of other biotypes. But the differences, which became evident only

Table 10. Ingestion of food and change in body weight of newly emerged females of brown planthopper biotype 2 during 24 hours on the leaf sheath or stem of selected rice varieties, 60 days after transplanting.[a] IRRI, 1977.

Variety	Quantity ingested[b] (mg)		Change in body wt[b] (%)	
	Leaf sheath	Stem	Leaf sheath	Stem
M 302	0.3 a	14.6 b	9 a	46 b
H 105	0.6 a	19.3 b	18 a	42 b
ASD 1	0.7 a	15.8 b	12 a	41 b
SLO 13	3.2 a	5.0 a	20 a	30 a
CO 9	1.4 a	3.8 b	20 a	20 a
ASD 7 (resistant check)	0.3 a	2.0 b	9 a	26 b
IR32 (resistant check)	0.3 a	4.0 b	5 a	39 b
Rathu Heenati	1.5 a	20.8 b	4 a	47 b
TN1 (susceptible check)	21.3 a	29.0 a	61 a	67 a
Mudgo (susceptible check)	14.6 a	29.8 a	44 a	61 b

[a]Similar results were obtained on plants at 90 days after transplanting. [b]In the pair of columns spanned, any two means on the same line are not significantly different at 5% level when they are followed by a common letter.

when large numbers of insects were examined, could not be used as criteria for distinguishing different biotypes.

It appears that the amount of honeydew excreted by the insect when caged on different varieties can be used as a criterion for distinguishing biotypes. In general, it showed a direct relationship to the survival of the insect on different varieties, and was a much faster test to identify biotypes.

To verify the observation on honeydew excretion, three BPH adults of the same age were starved for 5 hours, caged on 10-day-old seedlings of selected rice varieties, and allowed to feed for 18-20 hours. The honeydew excreted was collected on filter paper at the base of the plant. The filter papers were collected and treated with 0.1% ninhydrin in acetone solution. The areas wetted by honeydew of different biotypes caged on different test varieties indicated the general amount of feeding by the insects (Table 11).

Biotype 1 excreted more honeydew on TN1 than on resistant Mudgo or ASD 7; biotype 2 excreted more on TN1 and Mudgo than on ASD7; and biotype 3 excreted more on ASD 7 and TN1 than on Mudgo. Biotype 3 also excreted somewhat more honeydew on Babawee and Rathu Heenati than biotypes 1 and 2, but unless new biotypes develop, the test on TN1, Mudgo, and ASD 7 provides a preliminary indication about the nature of these biotypes. Survival data are needed to confirm these results.

Genetics of BPH biotypes. Fifth-instar nymphs from pure greenhouse cultures of biotypes 1, 2, and 3 were selected for studies on biotype genetics. The insects were reared to adult stage on TN1 plants and the following crosses, together with their corresponding reciprocal crosses were made: biotype 1 female × biotype 2 male, biotype 1 female × biotype 3 male, and biotype 2 female × biotype 3 male.

First-instar nymphs of the F_1 were tested for survival on TN1, Mudgo, and ASD 7. Biotype 1 was dominant over biotypes 2 and 3, and biotype 3 was dominant over biotype 2, in ability to survive on varieties possessing different genes for resistance.

Gall midge biotypes. Results of the 1976 International Rice Gall Midge Nursery indicated different reactions at the various test sites. Even within India, the reactions of IR32 varied from one area to another. The reasons for the differential reactions have not been determined but the existence of biotypes is a possibility. In 1977 a collaborative gall midge study was started to determine whether biotypes exist and, if they do, to identify genetic sources for resistance to all biotypes. Seed sets of 26 lines and varieties were sent to Indonesia, India, Sri Lanka, and Thailand.

Results indicated several differential reactions. Eswarakora derivatives are susceptible in Indonesia but resistant in Thailand and Sri Lanka. Siam 29 derivatives are resistant in Indonesia and Sri Lanka but susceptible in Thailand.

Table 11. Amount of honeydew excreted by greenhouse-cultured brown planthopper biotypes during 18 hours of feeding on selected resistant and susceptible rice varieties. IRRI, 1977.

Variety	Area[a] (mm²) of ninhydrin-positive excreted honeydew		
	Biotype 1	Biotype 2	Biotype 3
TN1	28.4 a	32.3 a	34.6 a
Mudgo	13.6 b	23.6 a	17.0 b
ASD 7	11.2 b	18.0 ab	26.2 a
Babawee	8.5 b	9.8 c	13.8 b
Rathu Heenati	12.8 b	12.2 b	13.4 b
Ptb 33	5.4 c	11.2 c	14.8 b

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

INHERITANCE OF AND BREEDING FOR RESISTANCE

Plant Breeding and Entomology Departments

Green leafhopper. The *Glh 1*, *Glh 2*, and *Glh 3* genes for resistance to green leafhopper have been incorporated into IRRI breeding materials. In 1975, many accessions of *O. glaberrima* were found resistant to GLH. Many crosses were made with those accessions and with *O. sativa* lines and varieties with improved plant type, but all F_1's were sterile. The F_1's of three accessions of *O. glaberrima* and IR1561-228-3 were backcrossed with IR1561-228-3 twice. Each backcross F_1 population was screened for resistance to GLH, and resistant plants were used for making the second backcross.

Table 12. Brown-planthopper-resistant rice cultivars studied to identify new genes for resistance. IRRI, 1977.

Cultivar	IRRI acc. no.	Country of origin
Ptb 19	6107	India
Ptb 33	19325	India
Gambada Samba	15406	Sri Lanka
Gangala	7733	Sri Lanka
Gangala	15207	Sri Lanka
Heenhoranamawee	15286	Sri Lanka
Horana Mawee	15332	Sri Lanka
Hotel Samba	15206	Sri Lanka
Kahata Samba	15297	Sri Lanka
Kalukuruwee	15279	Sri Lanka
Kuruhondarawala	7731	Sri Lanka
Lekam Samba	15389	Sri Lanka
Mudu Kiriyal	15489	Sri Lanka
Muthumanikam	8960	Sri Lanka
Senawee	15281	Sri Lanka
Sinna Sivappu	15444	Sri Lanka
Sudu Hondarawala	15541	Sri Lanka
Sulai	15421	Sri Lanka
Thirissa	7732	Sri Lanka
Vellai Illankali	15233	Sri Lanka

Improved plant type progenies that carry the GLH resistance derived from three different accessions of *O. glaberrima* and are fully fertile now exist. These progenies were derived from the crosses IR15612 (IR1561-228-3^3/*O. glaberrima* Acc. 101845), IR15613 (IR1561-228-3^3/*O. glaberrima* Acc. 102485), and IR15615 (IR1561-228-3^3/*O. glaberrima* Acc. 102550).

It is hoped that crosses with these backcross-derived lines will be interfertile with *O. sativa* lines.

Brown planthopper. Twenty BPH-resistant varieties were analyzed to find new genes for resistance (Table 12). They were crossed with the susceptible variety TN1. The F_1, F_2, and F_3 progenies from the crosses were analyzed to determine the mode of inheritance. The data are presented in Table 13.

The F_1 progenies of TN1 with Ptb 19, Ptb 33, Gangala (Acc. 7733), Gangala (Acc. 15207), Horana Mawee, Kuruhondarawala, Mudu Kiriyal, Muthumanikam, Sinna Sivappu, and Sudu Hondarawala were resistant, indicating that those varieties have dominant genes for resistance. The F_2 populations from the crosses of these varieties, except those of TN1/Ptb 33 and TN1/Sinna Sivappu, segregated in a ratio of three resistant to one susceptible, indicating that a single dominant gene confers resistance in these varieties.

The results from the F_3 progenies confirmed these conclusions (except in the case of TN1/Sudu Hondarawala) as the observed data agreed with the expected 1:2:1 (resistant:segregating:susceptible) ratio. However, the F_3 data from the crosses of TN1/Ptb 33,

Table 13. Reactions[a] to brown planthopper of F_1 and F_2 populations and F_3 lines from crosses of TN1 with resistant varieties. IRRI, 1977.

Cross	F_1 reaction	F_2 seedlings			F_3 lines			
		R (no.)	S (no.)	X^2 3:1	R (no.)	Segr (no.)	S (no.)	X^2 1:2:1
TN1 × Ptb 19	R	373	112	0.93	48	73	30	4.46
TN1 × Ptb 33	R	318	88	2.39[b]	131	130	15	1.68[d]
TN1 × Gambada Samba	S	103	326	0.22[c]	42	71	39	0.78
TN1 × Gangala (Acc. 7733)	R	246	95	1.49	45	79	27	4.62
TN1 × Gangala (Acc. 15207)	R	417	109	5.13	37	72	41	0.44
TN1 × Heenhoranamawee	S	103	264	1.83[c]	40	81	29	2.57
TN1 × Horana Mawee	R	271	97	0.36	41	75	33	0.87
TN1 × Hotel Samba	S	103	420	7.85[c]	30	80	40	2.00
TN1 × Kahata Samba	S	115	288	2.69[c]	40	74	36	0.24
TN1 × Kalukuruwee	S	86	295	1.20[c]	35	71	41	0.56
TN1 × Kuruhondarawala	R	300	116	1.84	41	73	30	2.04
TN1 × Lekam Samba	S	82	308	3.28[c]	38	71	40	0.72
TN1 × Mudu Kiriyal	R	392	152	1.83	46	76	29	3.83
TN1 × Muthumanikam	R	235	96	2.83	37	83	32	1.60
TN1 × Senawee	S	95	260	0.59[c]	31	77	42	1.92
TN1 × Sinna Sivappu	R	281	58	0.60[b]	60	77	15	3.83[d]
TN1 × Sudu Hondarawala	R	318	115	0.56	73	66	11	2.19[d]
TN1 × Sulai	S	115	310	0.96[c]	30	86	33	3.61
TN1 × Thirissa	S	95	249	1.25[c]	41	81	29	2.71
TN1 × Vellai Illankali	S	80	273	1.03[c]	44	72	34	1.58

[a]R = resistant, S = susceptible, Segr = segregating. [b] – X^2 for 13:3 expected ratio. [c] – X^2 for 1:3 expected ratio. [d] – X^2 for 7:8:1 expected ratio.

TN1/Sinna Sivappu, and TN1/Sudu Hondarawala agreed with the 7:8:1 ratio expected for two-gene control of resistance.

In fact, the F_2 data from the crosses of TN1/Ptb 33 and TN1/Sinna Sivappu agree better with the 13:3 ratio expected for two-gene (one dominant and one recessive) control of resistance. F_2 data from the cross TN1/Sudu Hondarawala, when reanalyzed, also gave a good fit to the 13:3 ratio. It appears that Ptb 33, Sinna Sivappu, and Sudu Hondarawala each have one dominant and one recessive gene for resistance.

The F_1 progenies from the crosses of TN1 with Gambada Samba, Heenhoranamawee, Hotel Samba, Kahata Samba, Kalukuruwee, Lekam Samba, Senawee, Sulai, Thirissa, and Vellai Illankali were susceptible. The F_2 populations from these crosses segregated in the ratio of one resistant to three susceptible, indicating that resistance in the varieties is conferred by a single recessive gene. The F_3 populations from these crosses gave a good fit to the 1:2:1 ratio, thereby confirming the monogenic nature of resistance.

Allele tests. The varieties with dominant genes were crossed with IR1539-823, a dwarf selection having *Bph 1* for resistance, as well as with Rathu Heenati, which has *Bph 3* for resistance. As expected, the F_1 progenies from the crosses were resistant. The data on the F_2 populations and F_3 families are in Table 14. The F_2 populations from the crosses of IR1539-823 with Ptb 19, Gangala (Acc. 7733), Gangala (Acc. 15207), Horana Mawee, Kuruhondarawala, Mudu Kiriyal, and Muthumanikam segregated in the ratio of 15 resistant to 1 susceptible expected on the basis of independent segregation of 2 dominant genes for resistance. The F_3 populations from these crosses gave a good fit to the 7:8:1 ratio expected on the basis of 2 independently segregating genes. It is obvious that the dominant genes for resistance in these varieties segregate independently of *Bph 1*.

In the F_2 populations of the crosses of IR1539-823 with Ptb 33, Sinna Sivappu, and Sudu Hondarawala, only a few susceptible seedlings were observed. The susceptible seedlings were not more than those generally observed in the resistant parents. Similarly, no genetic segregation for susceptibility was evident in the F_3 families of the crosses IR1539-823/Ptb 33 and IR1539-823/Sudu Hondarawala. The F_3 populations of IR1539-823/Sinna Sivappu had 134 resistant, 15 segregating, and 2 susceptible families (Table 14). From these data it is difficult to conclude whether there is genetic segregation for susceptibility in this cross. However, it appears that one of the genes for resistance possessed by Ptb 33, Sudu Hondarawala, and Sinna Sivappu is identical to either *Bph 1* or *bph 2*. Because *Bph 1* and *bph 2* do not recombine genetically, it is difficult to infer which of the two genes is present in the three varieties.

The 10 varieties with dominant genes for resistance were crossed with Rathu Heenati, which has *Bph 3* for resistance. As expected, the F_1 progenies were resistant. The data on the reaction of F_2 populations and F_3 families are presented in Table 15. A few susceptible plants

Table 14. Reactions[a] to brown planthopper of F_2 populations and F_3 lines from crosses of IR1539-823 with cultivars having a dominant gene for resistance.

Cross	F_2 seedlings			F_3 lines			
	R (no.)	S (no.)	X^2 15:1	R (no.)	Segr (no.)	S (no.)	X^2 7:8:1
IR1539-823 × Ptb 19	460	37	1.22	70	73	7	0.94
IR1539-823 × Ptb 33	480	6	—	149	2	0	—
IR1539-823 × Gangala (Acc. 7733)	425	30	0.09	72	75	7	0.96
IR1539-823 × Gangala (Acc. 15207)	430	40	4.10	80	60	9	6.29
IR1539-823 × Horana Mawee	410	30	0.24	71	64	14	4.34
IR1539-823 × Kuruhondarawala	450	40	3.06	68	69	11	0.83
IR1539-823 × Mudu Kiriyal	461	25	1.58	65	70	15	3.70
IR1539-823 × Muthumanikam	432	35	1.24	66	71	11	0.47
IR1539-823 × Sinna Sivappu	430	18	—	134	15	2	—
IR1539-823 × Sudu Hondarawala	455	5	—	151	0	0	—

[a]R = resistant, S = susceptible, Segr = segregating.

Table 15. Reactions[a] to brown planthopper of F_2 populations and F_3 lines from the crosses of Rathu Heenati with cultivars that have a dominant gene for resistance. IRRI, 1977.

Cross	F_2 seedlings (no.)		F_3 lines (no.)		
	R	S	R	Segr	S
Rathu Heenati × Ptb 19	433	1	150	0	0
Rathu Heenati × Ptb 33	450	0	147	0	0
Rathu Heenati × Gangala (Acc. 7733)	480	2	150	0	0
Rathu Heenati × Gangala (Acc. 15207)	450	8	150	0	0
Rathu Heenati × Horana Mawee	513	3	147	0	0
Rathu Heenati × Kuru-hondarawala	661	1	150	0	0
Rathu Heenati × Mudu Kiriyal	545	3	152	0	0
Rathu Heenati × Muthu-manikam	405	10	151	0	0
Rathu Heenati × Sinna Sivappu	448	12	151	0	0
Rathu Heenati × Sudu Hondarawala	520	0	150	0	0

[a]R = resistant, S = susceptible, Segr = segregating.

were observed in some of the F_2 populations, but the F_3 families were all homozygous resistant. It appears that Ptb 19, Gangala (Acc. 7733), Gangala (Acc. 15207), Horana Mawee, Kuruhondarawala, Mudu Kiriyal, and Muthumanikam have *Bph 3* for resistance. One of the two genes of Ptb 33, Sudu Hondarawala, and Sinna Sivappu may be identical to *Bph 3*.

The 10 varieties with monogenic recessive resistance were crossed with IR1154-243, which has *bph 2* for resistance, and with Babawee, which has *bph 4* for resistance. The F_1 progenies from the crosses of IR1154-243 were all susceptible, indicating that the recessive genes for resistance in these varieties are nonallelic to *bph 2*. Therefore, F_2 or F_3 progenies from the crosses were not studied. The F_1 progenies from the crosses of Babawee with the 10 varieties were resistant and only a few F_2 seedlings were susceptible. However, no segregating or susceptible F_3 family was observed in any of the crosses (Table 16). It appears that the recessive gene for resistance in each of the 10 varieties is allelic to *bph 4*.

The results of the study can be summarized as follows:

- Of the 20 varieties analyzed, seven — Ptb 19, Gangala (Acc. 7733), Gangala (Acc. 15207), Horana Mawee, Kuruhondarawala, Mudu Kiriyal, and Muthumanikam — have *Bph 3* for resistance.
- Ten varieties — Gambada Samba, Heenhoranamawee, Hotel Samba, Kahata Samba, Kalukuruwee, Lekam Samba, Senawee, Sulai, Thirissa, and Vellai Illankali — have *bph 4* for resistance.
- Three varieties — Ptb 33, Sudu Hondarawala, and Sinna Sivappu — each have two genes for resistance, one dominant and the other recessive; and the allelic relationships of these genes with other known genes are being ascertained.

A great majority of IRRI breeding materials have either *Bph 1* or *bph 2* for resistance. However, after *Bph 3* and *bph 4* were identified in 1975, a program was started to incorporate

Table 16. Reactions[a] to brown planthopper of F_1 and F_2 populations and F_3 lines from the crosses of Babawee with cultivars that have a recessive gene for resistance. IRRI, 1977.

Cross	F_1 reaction[a]	F_2 seedlings (no.)		F_3 lines (no.)		
		R	S	R	Segr	S
Babawee × Gambada Samba	R	500	16	148	0	0
Babawee × Heenhoranamawee	R	480	20	150	0	0
Babawee × Hotel Samba	R	480	15	152	0	0
Babawee × Kahata Samba	R	720	15	149	0	0
Babawee × Kalukuruwee	R	580	7	150	0	0
Babawee × Lekam Samba	R	633	25	150	0	0
Babawee × Senawee	R	530	15	147	0	0
Babawee × Sulai	R	468	12	149	0	0
Babawee × Thirissa	R	456	10	150	0	0
Babawee × Vellai Illankali	R	495	5	150	0	0

[a]R = resistant, S = susceptible, Segr = segregating.

Table 17. Some promising crosses from which lines with *Bph 3* and *bph 4* for resistance to brown planthopper were selected. IRRI, 1977.

Cross	Parents
IR13240	IR2153-159-1/Babawee/ /IR36
IR13427	IR3403-267-1/Ptb 33/ /IR36
IR13429	IR4432-53-3/Ptb 33/ /IR36
IR13523	Ptb 33/IR2153-159-1/ /IR2061-628-1
IR13524	Ptb 33/IR2153-159-1/ /IR42
IR13525	Ptb 33/IR2153-159-1/ /IR36
IR13526	Ptb 33/IR2153-159-1/ /IR2863-1
IR13535	Rathu Heenati/IR2153-159-1/ /IR28
IR13539	Rathu Heenati/IR2153-159-1/ /IR36
IR13540	Rathu Heenati/IR2153-159-1/ /IR2823-399-5
IR13545	Rathu Heenati/IR3403-267-1/ /IR2863-38-1
IR13548	Rathu Heenati/IR4432-53-3/ /IR36
IR13550	Rathu Heenati/IR4432-53-3/ /IR5491-4-8
IR15314	Babawee/IR4432-53-3/ /IR2061-628-1
IR15315	Babawee/IR4432-53-3/ /IR4432-84-3
IR17488	Babawee/IR3403-267-1[3]
IR17491	Rathu Heenati/IR3403-267-1[3]
IR17496	Ptb 33/IR3403-267-1[3]
IR17521	Rathu Heenati/IR4432-53-3[3]
IR17525	Ptb 33/IR4432-53-3[3]

those genes into the breeding materials. Donors of *Bph 3* (Rathu Heenati) and *bph 4* (Babawee) have poor plant type and grain quality. Similarly, Ptb 33, another variety which has either *Bph 3* or *bph 4*, has poor plant type. These three varieties were crossed with IR3403-26701, IR4432-53-3-3, and IR2153-159-1 selections, which have improved plant type but are susceptible to BPH but resistant to most of the other major diseases and insects.

The F_1's were either backcrossed to the improved plant type parent, or topcrossed with another improved variety or a breeding line. F_3 progenies from the crosses were grown in 1977. Some promising breeding lines with the new genes for resistance were selected and will be evaluated in 1978 at IRRI and in national programs. Some of the promising crosses are listed in Table 17.

Table 18. Crosses from which lines with resistance to whitebacked planthopper were selected. IRRI, 1977.

Cross	Parents
IR11933	IR28[3]/N22
IR11934	IR30[3]/N22
IR13294	IR1632-93-2/N22/ /IR36
IR13384	IR36[3]/N22
IR13453	N22/BG90-2/ /IR36
IR13467	N22/IR2061-465-1/ /IR36
IR13471	N22/IR2061-628-1/ /IR36

Whitebacked planthopper. N22 from India has been used as a source of resistance to WBPH. Because it is early maturing and is a poor combiner, it was crossed with several improved plant type varieties, and one or two backcrosses were made with the improved parent. Promising selections from the backcrosses were evaluated, and promising lines with resistance to WBPH and other major diseases and insects were selected. The selections have excellent grain quality and mature in 100 to 130 days. Some of the lines are being cooperatively evaluated in India and Indonesia for resistance to WBPH. Some of the crosses from which the WBPH-resistant lines have been selected are listed in Table 18.

Genetic evaluation and utilization (GEU) program

Protein content

Chemistry, Plant Breeding, Agronomy, and Statistics Departments

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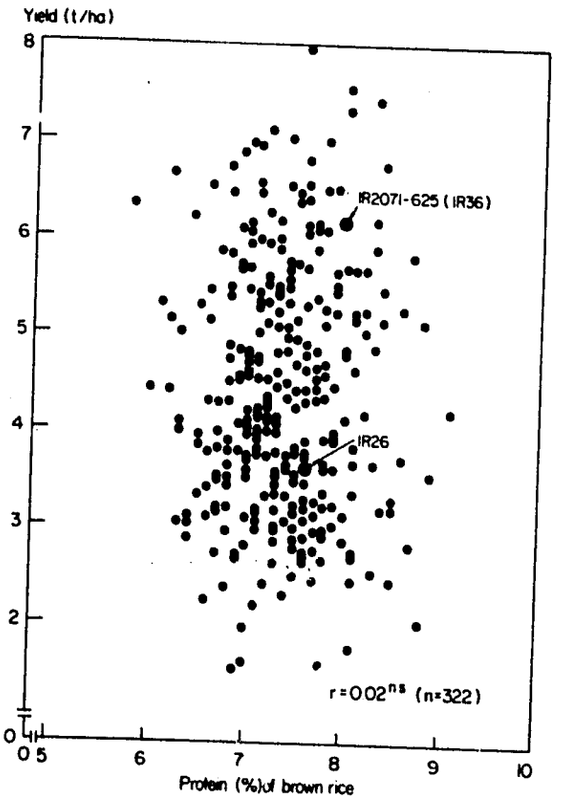
EVALUATION TRIALS

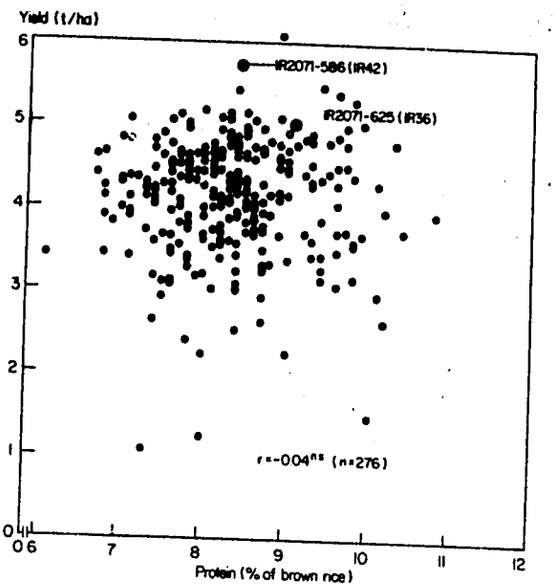
Plant Breeding, Agronomy, Statistics, and Chemistry Departments

Replicated yield trials *(Plant Breeding, Statistics, and Chemistry).* Plant breeders evaluated for protein content 322 varieties and lines during the dry season (Fig. 1) and 276 during the wet season (Fig. 2). IR2071-625, named as IR36 and now widely grown in the Philippines, was among the highest in both protein content and yield during both seasons. IR2071-586, recently named IR42 in the Philippines and grown as a check during the wet season, also performed well. That indicates that the newer varieties available to farmers are equal, and perhaps superior, in protein content to other available varieties.

In past years, analyses of IRRI replicated yield trials have always shown significant negative correlations between percent protein content and yield. However, the trend was toward a lower negative correlation (Table 1) and in 1977, for the first time, the correlation in both the dry season and the wet season was not significant. That indicates overall progress in efforts to improve protein content without sacrificing yield potential.



1. Grain yield of rough rice and protein content of brown rice of 322 entries in replicated yield trials (4 replications). IRRI, 1977 dry season.



2. Grain yield of rough rice and protein content of brown rice of 276 entries in replicated yield trials (4 replications). IRRI, 1977 wet season.

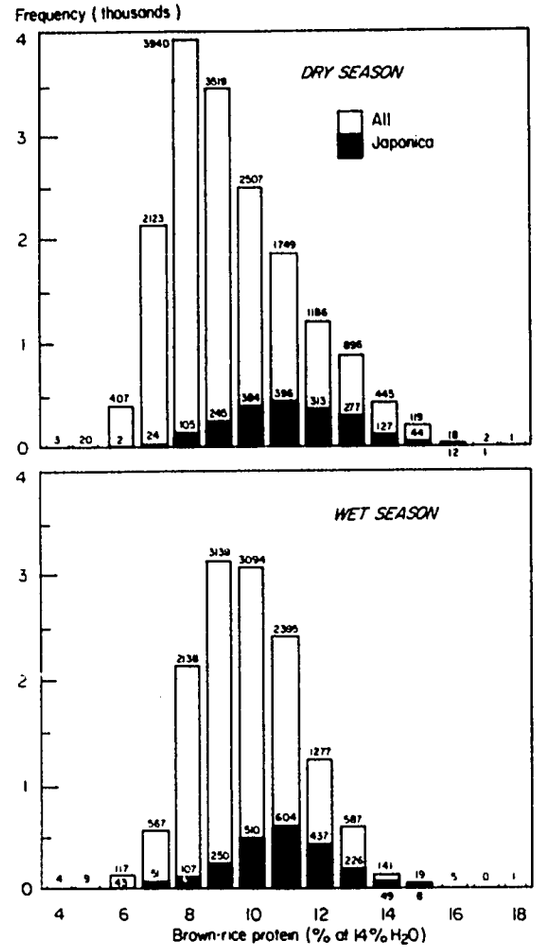
Yield potential of high-protein rice *(Agronomy).* Agronomists evaluated the yield potential and protein content of several promising lines using IR8, IR26, and the high-protein line IR480-5-9 as standard controls on fertilized and unfertilized plots. A few lines performed well but a severe incidence of ragged stunt disease complicated the results, especially in the wet season (Table 2). IR2153-338-3, which had performed well in both protein content and yield during previous years, had a low yield. IR2863-35-3-3 and IR2863-38-1-2, which exhibit some resistance to ragged stunt in the field, yielded well, but their protein content was not outstanding. Some of the newer entries (also resistant) such as IR5741-73-2-3 and IR6503-24-3-1, were in the trials for the first time

Table 1. Correlation coefficients between grain yield and protein content of brown rice in replicated yield trials. IRRI, 1973–77.

Year	Dry season		Wet season	
	Entries (no.)	Correlation coefficient	Entries (no.)	Correlation coefficient
1973	232	−0.36**	184	−0.24**
1974	416	−0.13**	370	−0.47**
1975	301	−0.50**	278	−0.36**
1976	370	−0.24**	416	−0.15**
1977	324	0.02ns	278	−0.03ns

during the wet season and performed reasonably well in both protein content and yield, especially at high levels of nitrogen fertilizer.

Screening world rice collection for protein *(Chemistry, Analytical Service Laboratory, Plant Breeding, and Statistics).* The screening of he world collection for brown-rice protein 1967 and 1971 annual reports) was updated to nclude 18,000 later accessions to identify additional sources of high protein content. Analysis as either by infrared reflectance spectroscopy r by micro Kjeldahl analysis. The frequency listribution of 16,935 dry-season crop entries as skewed, with most entries having 8% protein (Fig. 3). The mean protein content was),4%. The 1,930 japonica entries had higher rotein content and mean protein of 11.1%. n the wet season, the mean protein content of 3,493 entries was 9.8%; the 2,285 japonica ntries had a higher mean protein content f 10.7%. Earlier screening concentrated on ntries with 14% protein, which were all japonicas; the lines obtained from crosses with



3. Distribution of protein content of brown rice of the dry and wet season IRRI crops of all and japonica entries of the world collection. IRRI, 1977.

Table 2. Brown-rice protein and rough-rice yield of selected high-protein lines compared with those of IR8 and IR26 in yield trials. IRRI, 1977.

Variety or line	Dry season				Wet season			
	0 N		150 kg N/ha		0 N		70 kg N/ha	
	Protein (%)	Yield (t/ha)	Protein (%)	Yield (t/ha)	Protein (%)	Yield (t/ha)	Protein (%)	Yield (t/ha)
IR8	7.1	1.0	7.6	0.9		[a]		[a]
IR26	7.9	2.0	7.5	2.8	8.2	0.9[b]	9.6	1.4[c]
IR480-5-9-3	8.4	1.7	8.8	1.9	9.6	0.8		[a]
IR2153-338-3	7.6	1.7	8.7	3.0	9.1	0.8	8.8	0.6[b]
IR2863-35-3-3	6.7	3.1	7.8	6.1	8.2	2.5	9.6	3.8
IR2863-38-1-2	7.0	2.9	7.5	6.3	7.7	2.2	9.0	4.1
IR4111-2-2-1-2	7.6	2.8	8.2	5.2	8.5	2.4	10.0	3.8
IR5741-73-2-3	—	—	—	—	9.1	2.8	10.8	4.0
IR6503-24-3-1	—	—	—	—	9.5	1.8	10.6	4.1
LSD (5%)	0.3	1.0	0.8	1.0	0.8	0.6	0.8	0.6

[a]No yield data because of 100% infection with ragged stunt. [b]Mean of only 3 replications because 1 replication had 100% disease infection. [c]From 1 replication only because 3 replications had 100% disease infection.

IR8 had poor yield potential. Nonjaponica rices with 12% or higher protein in the wet season or 11% or higher protein in the dry season and with normal 100-grain weight, maturity, and spikelet fertility were selected for evaluation in 1978.

NUTRIENT DISTRIBUTION IN MILLING FRACTIONS

Chemistry Department

The effect of increased protein content on nutrient distribution in five abrasive-milling fractions of rice was studied for an average-protein rice (IR32) and a high-protein rice (IR480-5-9). Protein decreased progressively from periphery to core of IR32 grain. It was maximum in the subaleurone layer of IR480-5-9 (Table 3), confirming previous results on other high-protein rices. IR480-5-9 brown rice had higher crude ash and total phosphorus in the outer layers than did IR32. Magnesium and potassium showed a trend similar to that of phosphorus but the trend for iron and zinc was less distinct. In contrast, crude fat content and distribution were identical in the two rices and unaffected by their difference in protein content.

Starch content showed a trend opposite to that of the other nutrients; it increased progressively from periphery to core in both rices. Amylose content of starch also increased progressively from periphery to core in both rices.

Amino acid analysis of subaleurone and inner endosperm (core) of IR480-5-9 showed a lower lysine content (3.2 vs 3.8/16.8 g N) for the subaleurone layer. However, the protein of the IR32 subaleurone layer had 3.6 g lysine/16.8 g N, while that of the inner endosperm had 3.7 g lysine/16.8 g N.

PROPERTIES OF RICE PROTEIN

Chemistry Department

Protein quality of high-protein rice in rats. In a cooperative study with nutritionists at Osaka City University, Japan, the protein quality of IR480-5-9 milled rice (11% protein) was compared with that of a Japanese milled rice (6.7% protein) using α-amylase-treated (partially destarched) cooked rice. With male Sprague-Dawley weanling rats and a 10% dietary protein level, the two rices had similar net protein utilization (NPU) values relative to commercial egg (Table 4). Relative nutritive value (RNV) by slope ratio technique (0, 4, 8, 12, and 15% protein diets) (1972 Annual Report) based on increase in body weight, nitrogen, or water also gave almost identical results for the two rices—the RNV of Japanese rice were based on commercial egg, which had a slightly lower NPU than laboratory-prepared egg. The results showed that the use of identical dietary protein levels in rat assays, which are made possible with destarched rice, reduces the differences in protein quality obtained for 7%- and 11%-protein milled rices with different dietary protein levels: 7 percentage points range for NPU and 10 for RNV.

Digestibility studies in rats. In cooperative studies with the Agricultural Research Laboratory, Copenhagen, Denmark (1976 Annual Report), the protein of cooked milled rice had lower true digestibility but correspond-

Table 3. Nutrient distribution in successive abrasive layers of IR32 and IR480-5-9 brown rice.[a] IRRI, 1977.

Nutrient	Sample	Brown rice (0–100)	Milled rice (90–100)	Bran (0–6)	Polish (6–12)	Endosperm: Subaleurone (12–20)	Endosperm: Outer (20–30)	Endosperm: Core (30–100)
Crude protein (% N x 5.95)	IR32	7.7	6.8	14.0	13.0	12.2	9.7	5.5
	IR480-5-9	11.0	10.5	13.8	18.0	21.2	16.6	7.4
Crude ash (%)	IR32	0.8	0.3	5.8	3.4	1.0	0.3	0.2
	IR480-5-9	1.5	0.8	11.9	6.7	1.8	0.6	0.3
Total P (%)	IR32	0.2	0.1	1.0	0.7	0.2	0.1	0.1
	IR480-5-9	0.4	0.2	2.6	1.6	0.4	0.1	0.1
Crude fat (%)	IR32	3.0	0.5	20.7	12.8	3.0	0.3	0.2
	IR480-5-9	2.7	0.4	20.9	13.7	2.9	0.3	0.1

[a]Figures in parentheses are weight fractions in %.

Table 4. Protein quality of IR480-5-9 and Japanese milled rices in rats on partially destarched cooked rice diets.[a] Osaka City University and IRRI, 1977.

Property[b]	IR480-5-9 rice	Japanese rice	Egg: Commercial	Egg: Laboratory prepared
Protein (% N x 6.25)	11.0	6.7	61.1	72.9
Lysine (g/16 g N)	3.08	3.24	—	—
Amino acid score (%)	55	59	—	—
NPU — N balance (%)	53.5 (63)	—	85.4 (100)	88.3 (103)
NPU — Carcass N (%)	40.7 (56)	—	72.9 (100)	80.8 (110)
	34.3 (55)	35.5 (56)	62.8 (100)	—
RNV — Body wt gain (%)	48	(51)	—	100
RNV — Body N gain (%)	45	(46)	—	100
RNV — Body water gain (%)	44	(51)	—	100

[a]Figures in parentheses are values relative to commercial egg protein as 100%. [b]NPU = net protein utilization; RNV = relative nutritive value. [c]Relative to 3.5 g lysine/16 g N as 100%.

ingly higher biological value than protein of raw rice. Thus, NPU[b] is not adversely affected by cooking. Amino acid digestibility data this year confirmed the protein digestibility of raw and cooked IR29 and IR480-5-9 milled rice (Table 5). The results confirmed that the undigested protein is of poor nutritional quality and is low in lysine, which is the first limiting essential amino acid in rice protein. Starch and energy digestibilities remained high after cooking.

Actual isolation, at IRRI, of water-insoluble protein particles from feces of Wistar rats fed IR480-5-9 cooked rice at Copenhagen indicated only limited similarity of amino acid composition to the calculated undigested *protein* (Table 5). The fecal protein, however, was low in the basic amino acids lysine, histidine, and arginine. Sodium dodecyl sulfate (SDS)-polyacrylamide gel electrophoresis of the rat fecal particles indicated lower molecular weight (MW) subunits for them than for native rice protein, with the MW 16000 subunit being the major fraction. Fecal protein particles recovered at lower yield from Sprague-Dawley rats fed raw IR480-5-9 rice had a similar electrophoretic pattern but a higher lysine content of 3.9 g/16 g N.

Preparation and properties of destarched rice. Japanese nutritionists have prepared partially destarched cooked milled rice with 40% protein by treatment with bacterial α-amylase. The feasibility of obtaining high-protein destarched rice, which can be used in human feeding trials, was studied. Analytical grade *Rhizopus* glucoamylase gave poor protein recoveries, especially from cooked rice. The glucoamylase used was high in protease. The preparations were low in lysine but not in threonine, the second limiting amino acid (Table 6). In contrast, *Aspergillus* α-amylase had poor destarching efficiency on raw rice, particularly for IR32. Further experiments indicated that the higher susceptibility of IR480-5-9 starch to hydrolysis was due both to its low gelatinization temperature and to its intermediate (lower) amylose content. IR32 had intermediate gelatinization temperature and high amylose content.

Table 5. Mean digestibility in rats of essential amino acids in raw and cooked IR29 and IR480-5-9 milled rice, calculated amino acid content of undigested *protein* of cooked rice, and amino acid content of fecal protein particles from rats fed cooked rice. Agricultural Research Laboratory, Copenhagen, and IRRI, 1977.

Amino acid	True digestibility (%): Raw rice	True digestibility (%): Cooked rice	Amino acid content (g/16 g N): Undigested *protein* of cooked rice (calculated)	Amino acid content (g/16 g N): Protein particles in rat feces
Threonine	99.6	90.7	2.8	3.6
Valine	99.3	88.0	6.3	5.9
Isoleucine	99.6	88.4	4.6	4.6
Leucine	99.6	85.6	11.8	11.1
Tyrosine	100.0	86.0	7.1	7.8
Phenylalanine	99.2	86.8	6.1	6.4
Lysine	99.9	99.4	0.2	1.4
Histidine	99.4	96.8	0.6	1.5
Methionine	99.2	90.7	2.0	4.2
Cystine	99.5	82.0	3.6	3.9
Tryptophan	99.8	87.4	1.6	0.9
Energy	96.8	95.4		
Starch	99.9	99.9		

Table 6. Effect of various amylolytic enzymes on raw and cooked IR32 and IR480-5-9 milled rices in the preparation of destarched rice. IRRI, 1977.

Enzyme and substrate	Properties of destarched milled rice			
	Protein			
	Content (%)	Recovery (%)	Lysine (g/16 g N)	Threonine (g/16 g N)
Rhizopus glucoamylase (analytical grade)				
Raw IR480-5-9	74	45	2.2	3.5
Cooked IR480-5-9	55	24	1.8	3.6
Aspergillus α-amylase (food grade)				
Raw IR480-5-9	49	75	3.3	4.0
Gelatinized IR480-5-9, 65–70°C	80	84	3.6	4.2
Cooked IR480-5-9	82	92	3.6	4.4
Raw IR32	19	91	4.0	4.4
Gelatinized IR32, 75–80°C	75	100	4.0	5.1
Cooked IR32	71	84	4.1	4.5
Hog pancreatic α-amylase (crystalline)				
Raw IR480-5-9	74	80	3.3	3.7

The efficiency of destarching, indexed by protein content of destarched rice, increased with gelatinization of starch or cooking before α-amylolysis (Table 6). That was probably due to the increased susceptibility of gelatinized starch to amylolysis, reduced loss of soluble proteins by heat denaturation, and heat solubilization of hemicelluloses. Rat nitrogen-balance studies at Copenhagen showed these preparations to have NPU values similar to those of whole rice protein. Crystalline bacterial α-amylase may also be used in place of *Aspergillus* α-amylase for destarching cooked rice provided the amylase is relatively free from protease. Hog pancreatic α-amylase is expensive and of variable activity.

Nitrogen balance in Filipino children. Previous cooperative human nitrogen-balance studies used different dietary protein levels and the protein quality of the rices used could not be accurately compared. To confirm data on protein quality obtained in rats, a cooperative study with the Food and Nutrition Research Institute, Manila, examined the relative protein quality of high-protein rice (IR480-5-9, 11.0% protein) and low-protein rice (IR32, 7.2% protein) through nitrogen balance studies with 1.5- to 2.0-year-old Filipino children at the same protein intake. Destarched IR32 rice (8.7% protein) was added to IR32 milled rice to enable the children to consume the required 1.56-g protein (250 mg N)/kg body weight daily in 16.0 g rice. This amount (16 g/kg) corresponds to the optimum bulk of rice a child can consume daily in three full meals plus snacks.

Results on the first set of four children showed slightly lower apparent digestibility and retention of the IR480-5-9 protein (Table 7). Published obligatory fecal and urinary nitrogen losses suggest the difference to be mainly the result of poorer digestibility of IR480-5-9 protein since biological values were similar. However, these two rices had similar apparent diges-

Table 7. Summary of nitrogen (N) balance data in four Filipino children, Food and Nutrient Research Institute and IRRI, 1977.

Property	Diet[a]			
	First casein	Milled rice		Second casein
		IR32	IR480-5-9	
Protein content of protein sources (% N x 6.25)	>80	7.2	11.0	>80
Lysine content of diet (g/16 g N)	7.5	4.0	3.5	8.6
Property per day				
N intake (mg/kg body wt)	252.2	253.0	253.2	255.2
Fecal N (mg/kg body wt)	53.8 a	84.2 b	102.0 c	47.8 a
Urine N (mg/kg body wt)	121.0 b	97.5 a	90.2 c	112.0 b
N retained (mg/kg body wt)	77.5 ab	71.2 b	60.0 b	95.5 a
Apparent N digestibility (% of intake)	78.7 a	66.8 b	59.3 c	81.2 a
Apparent N retention (% of intake)	30.8 ab	28.3 bc	23.3 c	37.3 a
True digestibility[b] (%)	87.0	75.1	67.6	89.4
Biological value[b] (%)	69.2	76.4	78.5	74.2
NPU[b] (%)	60.1	57.5	53.0	66.3
Wt gain (g/kg)	2.1	1.5	1.5	1.8

[a]In a line, means followed by a common letter are not significantly different at the 5% level. [b]Based on published obligatory fecal N loss of 21 mg/kg body wt and obligatory urinary N loss of 53 mg/kg body wt.

Table 8. Chemical composition of whole and enzyme-indigestible IR480-5-9 milled-rice protein bodies (PB), IRRI, 1977.[a]

Property	Cooked-rice PB (control)	Pepsin-treated: Cooked-rice PB	Pepsin-treated: Raw-rice PB	Fecal protein particles of adults on cooked rice diet
Protein recovery (% of cooked rice PB)	100.0	32	13	15
Pepsin digestibility (%)	68.0	34.5	43.3	31.9
Crude protein (% N x 5.95)	84.0	73.7	55.5	66.1
Carbohydrate (% anhydroglucose)	0.4	1.2	11.0	0.5
Ash (%)	0.53	1.20	0.77	5.79
P (%)	0.04	0.21	0.04	1.11
Mg (%)	0.01	0.01	0.01	0.15
Fat (%)	7.28 (100)	17.7 (78)	21.0 (37)	21.3 (44)
Neutral lipids (% of total fat)	76 (100)	66 (67)	57 (38)	46 (27)
Glycolipids (% of total fat)	12 (100)	17 (100)	28 (45)	27 (99)
Phospholipids (% of total fat)	12 (100)	17 (100)	15 (26)	27 (99)

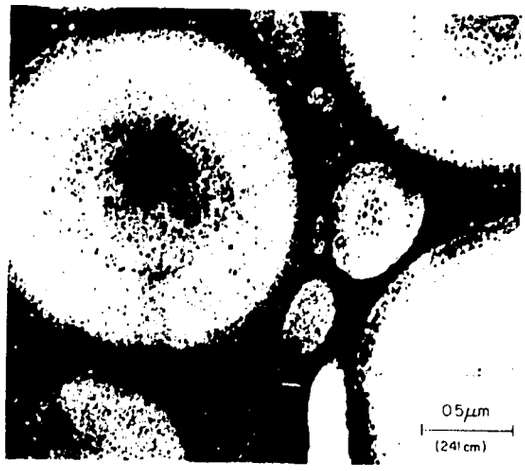
[a]Numbers in parentheses refer to recovery of fat or fat fraction based on whole cooked rice protein bodies.

tibility in eight younger Peruvian children convalescing from malnutrition.

Protein bodies and enzyme-digested protein bodies. Japanese researchers have previously shown that 70% by weight of cooked protein bodies from the outer layer of milled rice is readily digested by pepsin and the rest is more slowly digested. No data are available on protein bodies from whole milled rice or from raw rice. As a continuation of a study on the effect of cooking on properties of rice protein bodies, pepsin-treated cooked rice protein bodies were prepared by treating cooked IR480-5-9 rice with crystalline bacterial α-amylase and then with pepsin. A similar preparation from raw rice was made by treatment with *Rhizopus* glucoamylase and then pepsin. Fecal protein particles were prepared by repeated sedimentation from aqueous suspension of fresh feces of Taiwanese adults and Filipino children on IR480-5-9 cooked-rice diets.

Protein bodies from cooked IR480-5-9 milled rice (10.5% protein) had a high protein and a low fat content (Table 8). A similar preparation from cooked IR32 milled rice (6.8% protein) had 12 to 13% fat and less protein content. Protein bodies from raw IR480-5-9 rice also tended to have lower protein content except those prepared with crystalline hog pancreatic α-amylase. The lower fat content of protein bodies from high-protein rice must be due mainly to the similarity in fat content of milled rice of IR480-5-9 and IR32 (Table 3). In addition, cooked protein bodies from the subaleurone or outer layer of Japanese milled rice reportedly contain 70% protein, 3.7% ash, 0.65% phosphorus, and 14.5% fat. Presumably, the fat content of protein bodies is affected by the fat:protein ratio of the native rice endosperm fraction. However, not all the fat in the preparation may be directly associated with protein bodies because the samples were prepared by destarching milled rice and may include amyloplastic fat.

The pepsin digestion data showed that at the same incubation period of 5 hours, protein bodies of raw rice (already partly hydrolyzed during glucoamylase treatment) were more readily digested than were those of cooked rice, as reflected in the lower protein recovery (Table 8). In addition, pepsin digestibility of the residual raw rice preparation was still higher. The pepsin-treated bodies were richer in fat than the whole protein body; the richer fat content is also reflected in the lower protein content. Pepsin-treated cooked-rice protein bodies from the outer layer of Japanese milled rice had 72% protein, 3.9% ash, 0.67% phosphorus, and 15.0% fat. Whole raw-rice protein bodies are difficult to prepare because albumin-globulin leaches out during destarching. Simultaneous amylolysis-proteolysis, done with *Rhizopus* glucoamylase at pH 4 to minimize acid protease activity, was followed by pepsin treatment. The protein bodies from raw rice had lower protein content and had high carbohy-



4. Transmittance electron microscopy of protein bodies of cooked IR480-5-9 rice. US Grain Marketing Research Center, Manhattan, Kansas, 1977.

drate contamination, which was mainly small starch granules.

Fecal protein particles from adult humans on cooked IR480-5-9 rice also had high fat content (Table 8). An earlier preparation in Japan had 66% protein, 3.5% ash, 0.69% phosphorus, and 16% fat. The fat of cooked-rice protein bodies had a proportion of neutral lipids, glycolipids, and phospholipids similar to that of milled-rice fat of 76:12:12. The fat of fecal protein particles and the pepsin-treated cooked-rice protein bodies showed preferential loss of neutral lipids; glycolipids and also phospholipids were more resistant to hydrolysis than neutral lipids; all fat fractions were hydrolyzed in pepsin-treated raw protein bodies. Evidently cooking, which reduces the digestibility of protein, also reduced the digestibility of glycolipids and phospholipids. Differences in fatty acid composition were also observed in the lipid fractions as a result of digestion.

Histological examination of the protein body preparations by transmission electron microscopy at the US Grain Marketing Research Center, Manhattan, Kansas, showed that the digested preparations represented the core of the protein bodies based on the arrangement of electron dense spots in the protein bodies (Fig. 4, 5). The digested particles were only 0.5 to 2 μm but predominantly less than 1 μm in size:

5. Transmittance electron microscopy of pepsin-treated cooked-rice protein bodies and fecal protein particles from humans fed IR480-5-9 milled rice. US Grain Marketing Research Center, Manhattan, Kansas, 1977.

the whole particles were 0.5 to 2.2 μm. In addition, crystalline protein bodies located in the subaleurone layer (1975 Annual Report) were observed in the protein-body preparation from cooked rice, but were absent in the pepsin-treated sample and in the fecal protein particles. Thus crystalline protein bodies are probably more digestible than the regular protein bodies of rice endosperm.

The various enzyme-digested, protein-body preparations showed lower levels of basic amino acids (lysine, histidine, and arginine), particularly lysine, than the whole protein bodies (Table 9). The whole protein bodies had

Table 9. Amino acid content (g/16.8 g N) of whole and enzyme-indigestible IR480-5-9 rice protein bodies (PB). IRRI, 1977.

Amino acid	Cooked-rice PB	Pepsin-treated PB		Fecal protein particles		
		Cooked rice	Raw rice	Taiwanese adults	Japanese adults	Filipino children
Lysine	3.6	1.6	0.5	2.1	1.8	1.9
Histidine	2.5	2.0	1.7	2.1	2.0	1.9
Arginine	8.8	5.6	5.5	5.2	6.0	5.8
Aspartic acid	10.3	12.0	6.4	7.6	6.9	8.3
Serine	5.0	7.4	5.9	7.2	5.5	5.6
Glutamic acid	20.6	24.6	29.2	27.1	25.5	28.2
Glycine	4.2	4.7	3.2	3.7	3.5	3.6
Cystine	2.3	3.6	3.5	3.9	3.5	2.5
Methionine	2.4	3.4	3.9	4.7	3.9	3.3
Isoleucine	3.8	5.0	4.6	4.5	4.5	4.8
Leucine	8.7	11.6	12.1	10.5	10.4	11.7
Tyrosine	6.1	7.8	8.2	7.2	7.6	7.3

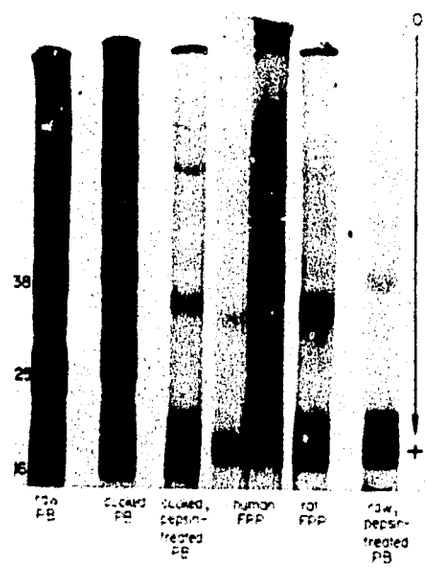
the same amino acid composition as the milled-rice protein. The results indicate that the inner 50% (by weight) of protein bodies obtained from the action of pepsin, or ingestion by rat or man, had a different amino acid composition and lower protein quality than whole protein bodies.

SDS-polyacrylamide disc gel electrophoresis of the protein body preparations revealed that enzyme treatment by pepsin or ingestion by rat or man produced treated bodies with much lower MW subunits than the whole protein body (Fig. 6). The major subunit had MW 16000 together with a minor band with MW of about 30000 to 33000.

Prolamin and glutelin. Continuation of the study of the nature of the contaminants of the direct 70% ethanol extract of prolamin from milled IR480-5-9 rice (1976 Annual Report) revealed that the major contaminants of prolamin were 30.4% fat, 6.0% phenols, and only 1.0% carbohydrate. The fat was mainly 88% neutral lipids with lesser amounts of glycolipids and phospholipids from silica gel column elution, which is similar to the ratio of milled rice fat. The phenols that complexed with prolamin were identified to be mainly esters of *p*-coumaric, ferulic, and vanillic acids, which are also the major phenolic acids of rice straw.

A study of the amino acid composition of the protein subunits of reduced alkylated glutelins from three rices obtained by gel filtration (1976 Annual Report) showed that the protein subunits with MW > 38000 had a higher lysine content than the lower MW subunits. The loss of these higher MW subunits on pepsin digestion of protein bodies (Fig. 6) may explain the lower lysine content of these preparations (Table 9).

Crystalline protein bodies in subaleurone layer. Transmittance electron micrographs of developing IR22 and IR480-5-9 grain (dough stage) at the US Grain Marketing Research Center confirmed the presence of crystalline protein bodies in the subaleurone layer or two outermost cell layers of the endosperm. The crystalline bodies stained heavier than the usual protein bodies and appeared segmented.



6. Sodium dodecyl sulfate-polyacrylamide gel electrophoregrams of whole and enzyme-treated rice protein bodies. Numbers at left margin are mol wt x 10^{-3}. IRRI, 1977.

Genetic evaluation and utilization (GEU) program

Drought resistance

Agronomy, Plant Breeding, Plant Physiology, and Irrigation and Water Management Departments

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HYBRIDIZATION AND SELECTION

Plant Breeding Department

The IRRI crossing program was expanded to include drought resistance in both upland and rainfed-lowland cultures. In 1977, 167 additional single crosses and 205 multiple crosses were made in the upland program. Another 89 single crosses and 21 topcrosses were made to incorporate drought resistance into improved lines for rainfed-lowland culture. Among the traditional varieties widely used as parents were Leb Mue Nahng, JC-81, Khao Dawk Mali 105, Nam Sagui 19, 20A, 63–83, IAC25, IAC1246, and advanced IRRI breeding lines that showed drought resistance in both greenhouse and field screening.

Plant selection under upland culture in the wet season was broadened to include phenotypes that may also be suited for rainfed lowland culture. The cutoff date for growth duration was extended to 130–145 days after seeding to fit some rainfed-lowland needs. From the 439 cross combinations, 4,163 F_2 plants were selected in a farmer's field in Batangas, Philippines, and a fertile field at IRRI.

VARIETAL SCREENING

Agronomy and Plant Breeding Departments

Upland field screening *(Agronomy)*. In the 1977 dry season, 4,200 rices from the IRRI germplasm bank and 1976 pedigree nurseries were

Table 1. Promising varieties (seeded 24 Jan. 1977) screened in the field for drought resistance. IRRI, 1977 dry season.

Designation	Origin	First scoring		Second scoring		Third scoring		
		1 May (1 bar)		14 May (4 bars)		20 May (10 bars)		
		Growth stage[a]	Drought resistance[b]	Growth stage[a]	Drought resistance[b]	Growth stage[a]	Drought resistance[b]	Recovery[c]
ARC 10952	India	7	1	7	2	8	3	3
ARC 11836	India	2	2	2	3	2	3	3
ARC 11940	India	2	2	2	3	2	3	3
ARC 12851	India	2	2	2	3	2	3	3
Holamaldiga	India	2	2	2	3	2	3	3
Ctg 1516	Bangladesh	4	2	4	2	5	3	2
Hashikalmi	Bangladesh via Surinam	6	2	7	3	8	3	3
KU 86	Thailand	4	2	5	2	6	2	3
KU 276	Thailand	3	2	4	3	4	3	3
Leb Mue Nahng III	Thailand	2	2	2	3	2	3	3
BKN 6986-108-2	Thailand	2	2	2	3	2	3	3
KLG 6986-133-4-P	Thailand	2	2	2	3	2	3	3
KLG 6986-165-3	Thailand	2	2	2	3	2	3	3
J 520	USA	2	2	2	2	2	3	3
Hill Sel. × Blue Bonnet	USA	7	2	8	2	9	3	3
4-11-1-8 × Rexoro 252	USA	3	2	4	2	5	3	3
C1 9122 × Rexoro	USA	2	2	3	2	4	3	3
Vista (CI 9628-2)	USA	2	2	2	3	2	3	3
Bico Preto	El Salvador	2	2	2	3	2	3	3
Boa Vista	El Salvador	2	2	2	3	2	3	3
Mateo Lizo	El Salvador	2	2	3	2	4	2	3
Chungta 312 Hao × Binastian	China	2	2	3	2	4	3	3
Ai Yeh Lu	China	2	2	3	2	4	3	3
Khao Luong (A)	Laos	2	2	2	2	2	3	2
Mak Kheua	Laos	2	2	2	3	2	3	3
Congo	Africa	2	2	2	2	2	3	3
II Fukempagai	Taiwan	3	2	4	2	5	2	2
Padi Tambayungan	Malaysia	2	2	2	3	2	3	3

(continued on opposite page)

Table 1 *continued*

Designation	Origin	First scoring		Second scoring		Third scoring		
		1 May (1 bar)		14 May (4 bars)		20 May (10 bars)		
		Growth stage[a]	Drought resistance[b]	Growth stage[a]	Drought resistance[b]	Growth stage[a]	Drought resistance[b]	Recovery[c]
Moroberekan	Guinea	2	2	2	3	2	3	3
Binatangan	Philippines	2	2	2	3	2	3	3
Carreon	Philippines	2	2	2	3	2	3	3
IR3304-20-1-3-3	IRRI	2	2	2	3	2	3	3
IR4427-207-2-2-2	IRRI	2	2	2	3	2	3	3
IR8098-53-1	IRRI	2	2	2	2	2	3	2
IR8098-53-2	IRRI	2	2	2	2	2	3	2
IR8098-142-1	IRRI	2	2	2	2	2	3	3
IR8098-146-3	IRRI	2	2	2	2	2	3	3
IR8098-152-1	IRRI	2	2	2	3	2	3	3
IR8098-152-2	IRRI	2	2	2	2	2	3	3
IR8098-152-3	IRRI	2	2	2	2	2	3	3
IR8098-169-3	IRRI	2	2	2	3	2	3	3
IR8098-170-3	IRRI	2	2	2	2	2	3	3
IR8098-171-1	IRRI	2	2	2	3	2	3	3
IR8098-117-3	IRRI	2	2	2	3	2	3	3
IR8098-194-1	IRRI	2	2	2	3	2	3	3
IR8098-194-2	IRRI	2	2	2	2	2	3	3
IR8098-231-2	IRRI	2	2	2	3	2	3	3
IR8103-120-3	IRRI	2	2	2	3	2	3	3
IR8105-35-3	IRRI	2	2	2	3	2	3	3
IR8105-50-1	IRRI	2	2	2	3	2	3	3
IR5853-118-5	IRRI	2	2	2	3	2	3	3
IR20 (susceptible check)	IRRI	2	6	2	7	2	8	7
IR442-2-58 (tolerant check)	IRRI	2	3	2	4	2	5	3
IRAT 9 (susceptible check)	Ivory Coast	2	6	2	7	2	8	8
Salumpikit (tolerant check)	Philippines	2	3	2	4	2	5	4

[a]1975 Standard Evaluation System for Rice (SES) scale 1-9: 1 = germination; 9 = maturity. [b]SES scale 1-9: 1 = no sign of stress; 9 = plants apparently dead. [c]SES scale 1-9: 1 = full recovery; 9 = no plants fully recovered.

screened in fields. Rice was direct seeded in furrows, fertilized, and irrigated by sprinkler to ensure good stand establishment. The plots were then allowed to dry naturally until soil moisture tension (SMT) at 20-cm depth (using gypsum blocks) reached an average of 1-2 bars. Each entry was then scored for drought resistance using the 1975 Standard Evaluation System for Rice (SES). Growth stages were noted during scoring. The entries were scored 2 more times, at 3-4 and 9-10 bars SMT. The rices were subsequently irrigated to saturation and scored for recovery after 1 week.

Under severe stress or SMT of 9-10 bars, 109 entries were scored 4 or better (1 = no sign of stress; 9 = plants apparently dead) and the tolerant checks Salumpikit and IR442-2-58 were scored 5 (Table 1). Figure 1 shows the comparative performance of Salumpikit and IR442-2-58 and the susceptible check IRAT 9 at high soil moisture tension. The 51 best entries with scores of 3 or better are in Table 1. Six are from Thailand; 5 each from India and USA; 3 from El Salvador; 2 each from China, Laos, Philippines, and Guinea; and 1 each from Taiwan and Malaysia. Promising IRRI breeding lines were from the IR8098 cross. The outstanding rices with drought score of 2 at 9-10 SMT were II Fukerupagai from Taiwan, Mateo Lizo from El Salvador, and KU 86 from Thailand (Table 1).

Reproducibility of field screening. The drought scores from field screening in 1975, 1976, and 1977 were highly consistent (Table 2). They confirmed that dry-season field screening and scoring methods to determine varietal differences in drought resistance, using tensiometers and gypsum blocks to monitor

1. While two check rice varieties with high level of drought resistance (Salumpikit and IR442-2-58) showed mild effects of drought stress at 8–10 bars soil moisture tension, the susceptible check IRAT 9 from Africa was completely killed. Field screening for drought resistance, IRRI, 1977 dry season.

drought, give reproducible results. But rices should be evaluated on two widely different soils that differ distinctly in texture and water-holding capacity.

Upland mass screening (*Plant Breeding*). In the 1977 dry season, IRRI screened 4,249 germplasm bank accessions, advanced upland breeding lines, elite lowland breeding lines, and hybridization block entries. Another 5,500 F_3 lines from the upland nurseries were also screened.

The identification of potential parents for drought resistance from the germplasm bank was continued (Table 3). Most of the 1,413 traditional varieties tested had relatively high drought resistance at the vegetative stage. Only a few had good resistance at the reproductive stage; most are of the upland type.

Traditional rainfed-lowland varieties also had high drought resistance at the vegetative stage, but were generally susceptible at the reproductive stage. Signs of drought susceptibility at the reproductive stage are a markedly prolonged period from seeding to heading and high panicle sterility. In the lowland group, ARC 10908 and ARC 10916 scored 5 at both vegetative and reproductive stages.

Among traditional upland varieties, IRAT 13, 20A, Padi Tatakin, RT 1006, and Dular consistently had high drought resistance at both growth stages, as in previous years.

Through repeated testing at both stages, upland breeding lines with higher drought resistance at the reproductive stage than those screened in 1976 have been identified (1976 Annual Report).

Table 2. Comparative drought resistance ratings[a] of promising varieties screened for 3 successive years. IRRI, 1975, 1976, and 1977 dry seasons.

Variety	Origin	1st scoring (1-2 bars)						2nd scoring (3-4 bars)						3rd scoring (9-10 bars)					
		1975		1976		1977		1975		1976		1977		1975		1976		1977	
		GS	DT	GS	DT	GS	DT	GS	DT	GS	DT	GS	DT	GS	DT	GS	DT	GS	DT
Ctg 1516	Bangladesh	2	2	3	2	4	2	2	4	4	4	4	2	3	5	4	7	5	3
DJ 29	Bangladesh	2	3	2	2	4	2	3	3	2	2	4	3	3	5	4	4	5	4
DM 59	Bangladesh	2	2	2	2	3	2	2	4	2	3	4	3	3	5	6	5	5	4
DV 110	Bangladesh	2	2	3	2	2	2	4	3	4	3	2	4	5	5	8	4	2	5
DZ 41	Bangladesh	3	2	3	2	8	3	6	4	5	3	8	4	7	5	8	4	9	5
DNJ 60	Bangladesh	2	2	2	1	4	3	2	4	3	3	5	4	3	5	6	4	6	5
DNJ 146	Bangladesh	2	2	2	1	4	2	2	4	2	3	5	4	3	5	4	5	6	5
DNJ 177	Bangladesh	3	3	2	1	4	3	4	4	2	3	5	4	5	5	5	5	6	5
Dular	India	3	3	3	2	7	3	6	3	4	3	8	5	7	5	8	5	9	5
Surjamkuhi	India	2	2	3	1	4	3	4	3	4	2	5	5	5	5	7	5	6	5
IR442-2-59-2-3-3	IRRI	—	—	2	2	2	2	—	—	2	2	2	4	—	—	2	2	2	4
IR20 (drought-susceptible check)	IRRI	—	—	2	4	2	6	—	—	2	8	2	7	—	—	2	9	2	8
IR442-2-58 (drought-resistant check)	IRRI	2	2	2	2	2	3	2	4	2	4	2	4	2	5	2	5	2	5

[a]Based on 1975 Standard Evaluation System for Rice (SES) scales. GS = growth stage. Scale: 0 = germination (prior to emergence), 1 = seedling/seedling bed, 2 = tillering, 3 = stem elongation, 4 = booting, 5 = heading, 6 = flowering, 7 = filling (milk stage), 8 = dough stage, 9 = rice/mature. DT = drought resistance rating. Scale: 1 = none to slight effects of stress, 5 = one-quarter to one-half of total number of leaves fully dried, 9 = all plants apparently dead.

Table 3. Summary of field scores on drought resistance of 4,354 varieties and lines.[a] IRRI, 1977 dry season.

Group	Entries tested (no.)	Growth stage	Varieties and lines (%) with field scores[b]								
			1	2	3	4	5	6	7	8	9
Upland breeding lines	2009	Vegetative	8.0	14.0	26.9	34.5	15.2	1.4			
		Reproductive			0.1	0.3	5.5	7.0	39.7	30.1	17.3
Traditional varieties	1413	Vegetative	1.4	3.8	12.7	30.8	39.9	10.8	0.6		
		Reproductive			0.3	0.1	2.4	4.2	3[illegible].8	28.7	32.5
Lowland breeding lines	652	Vegetative		0.1	2.8	16.0	40.0	38.0	3.1		
		Reproductive				0.1	3.7	4.6	27.6	41.4	22.5
Hybridization block entries	280	Vegetative			6.4	21.3	46.8	25.5			
		Reproductive						0.4	26.1	30.4	43.2

[a]Another group of 5,500 F_3 lines was also screened. [b]Standard Evaluation System scale: 1 = highly resistant; 5 = intermediate; 9 = highly susceptible.

Rainfed-lowland field screening *(Plant Breeding)*. In the 1977 dry season, the reactions of 270 entries and 2 check varieties to moisture stress were tested in rainfed-lowland fields. To simulate rainfed-lowland planting, the fields were drained at 30 days after transplanting and allowed to dry for 15-20 days. The test varieties were scored according to their responses to moisture stress, expressed as leaf rolling, leaf death, stunting, and delayed heading — traits similar to those used in the upland mass-screening test. Several agronomic traits were also measured. The data were compared with those taken from a smaller set of varieties grown in an adjoining field that had standing water or that was saturated with moisture throughout the season. The second planting was similar to a partially irrigated culture because water seepage was marked. Table 4 compares the agronomic traits, yield, panicle sterility, and drought reactions of selected rices.

Prolonged stress periods resulted in delayed heading, reduced plant height, low panicle number, high spikelet sterility, and low yields.

Some rices that had higher drought resistance in the rainfed-lowland field are Mahsuri, IR34, Knlb-368-1-8-6-7, Sigadis, and IR3646-8-1-1. Sigadis had not only drought resistance at the vegetative stage but also good recovery ability and well-filled grain.

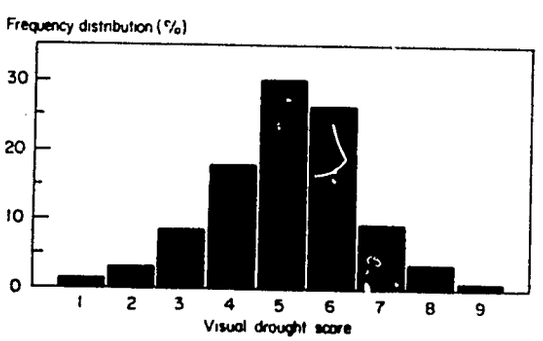
Table 4. Comparison of agronomic traits of selected varieties and lines grown under simulated rainfed-lowland (RL) and partially irrigated (PI) cultures. IRRI, 1977 dry season.

Designation	Days (no.) to full heading		Plant ht (cm)		Panicles (no.)		Sterility (%)		Drought reaction scores[a]		Recovery score[b]
	RL	PI	RL	PI	RL	PI	RL	PI	Vegetative	Reproductive	
Balio	113	87	82	143	10	10	32	15	5	8	3
Heenbalawee	102	84	85	132	10	19	49	22	5	7	1
Mahsuri	140	110	94	142	18	13	23	—	3	4	1
Sigadis	137	103	114	139	10	9	45	34	4	6	1
Kn1b-368-1-8-6-7	92	85	88	132	13	11	26	25	4	6	2
IR34	119	96	84	119	24	10	52	28	4	6	1
IR36	114	78	53	84	21	17	83	21	6	7	1
IR3646-8-1-1	102	100	90	138	10	10	49	—	4	4	1
IR2071-105-9-1	125	85	77	95	16	16	23	—	4	7	1
IR4227-28-3-2	114	103	79	114	16	11	52	—	5	7	1
IR4432-28-5	96	93	67	102	11	11	34	—	2	7	3
IR4707-123-3	126	84	73	96	17	18	26	—	5	7	3
Intan (check)	153	95	110	128	8	12	49	43	5,6	7,9	1
BPI-76(n.s.) (check)	120	98	80	126	10	10	58	30	4	6	1

[a]Scale: 1=highly resistant; 5=intermediate; 9=highly susceptible. [b]Scale: 1 = 90% of plants produce new leaves and/or tillers 1-2 after watering, 5= 75% of plants produce new leaves and/or tillers 4-5 days after watering, 9 = Less than 50% of plants produce new leaves or tillers, or both, 1 week after watering.

Entries that had lower levels of drought resistance at the vegetative stage but recovered well and produced well-filled grains after early rains in May are Pelita I-1, Pelita I-2, Bulao, IR2061-628-1-6-4-3, IR4215-4-3-1, IR3880-13-11, IR3646-8-1-4, IR3646-8-1-5, and IR3646-13-2-2.

Most elite semidwarf lines were stunted, delayed in heading, and had high panicle sterility under moisture stress. IR2071-105-9-1, IR4432-28-5, IR4703-123-3, and IR4722-36-1; however, performed relatively better. They had panicle sterility of about 23-34%, plant height of 67-77 cm, and moderately delayed heading.



2. Frequency distribution of 1,829 entries tested in the drought screening greenhouse. Drought score: 1 = none to slight effect of stress; 9 = all plants dead. IRRI, 1976 wet and 1977 dry seasons.

Greenhouse screening *(Agronomy)*. Screening for response to water deficit, using previously described operational practices, continued in the special greenhouse designed to simulate upland field conditions (1976 Annual Report) Figure 2 shows the frequency distribution of 1,829 entries screened. The 1977 screening concentrated on elite IRRI GEU entries, IRTP nurseries, and rices that national and international breeding programs specifically requested to be screened. About 12% of the entries were scored from 1 to 3. That group is a distinct resource for breeding and selecting to increase drought resistance. Many entries with a score of 1 are hill or upland rices from West Africa and Brazil (Table 5). Entries that were scored 2 are Asian traditional upland and rainfed-lowland varieties, and a few hybrids or improved varieties. The group with a score of 3 includes rices of proven yield potential and multiple pest resistance, mostly from Philippine and Indonesian breeding programs.

Table 6 lists samples of multiple test results of rices in those three score groups. Other entries are being retested.

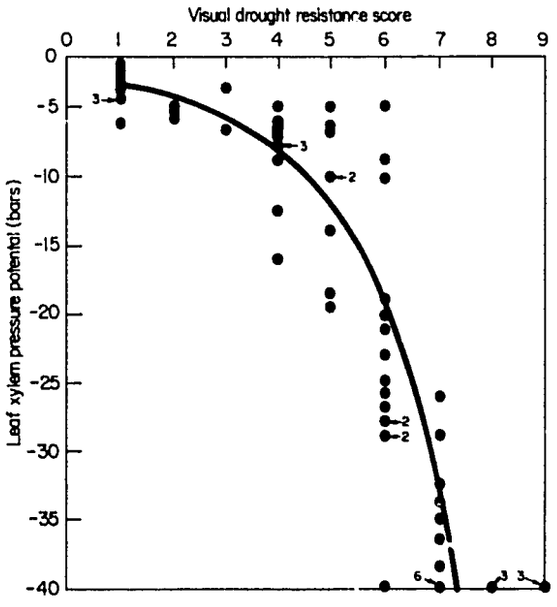
In the greenhouse screening procedure, leaf xylem pressure potential is measured at dawn and then the plants are scored visually at 0900 hours. Figure 3 shows the relationship between those variables and emphasizes the selection of

Table 5. Origin of the 215 entries that received drought scores[a] of from 1 to 3 in the drought screening greenhouse. IRRI, 1977.

Origin	Entries (no.) with drought score of 1	2	3	Total entries (no.)
Philippines	11	33	83	127
Indonesia	2	4	24	30
India	0	1	13	14
West Africa	4	3	3	10
Bangladesh	0	0	8	8
Brazil	4	2	1	7
Thailand	0	0	6	6
Nigeria	0	0	3	3
Colombia	0	1	2	3
Iran	0	2	0	2
Sri Lanka	0	0	1	1
Burma	0	0	1	1
China	0	0	1	1
Japan	0	1	0	1
Guinea	1	0	0	1
Total	22	47	146	215

[a]1975 Standard Evaluation System for Rice: 1 = none to slight effects of stress; 9 = all plants apparently dead.

plants that maintain high plant water potential in deep soil (1 m) in greenhouse tanks. This information should caution against extrapolation of results to rice cultural systems — primarily the rainfed lowland — that differ markedly from upland systems. But the encouraging fact that many entries with scores of 2 or 3 are not from regions of deep aerobic soil may mean that these results can be interpreted somewhat broadly across rainfed rice cultural systems.



3. Relationship between visual drought-resistance score and leaf xylem pressure potential for entries screened in a single tank. 1975 Standard Evaluation System for Rice scale of 1–9: 1 = none to slight effects of stress; 9 = all plants apparently dead.

FIELD PERFORMANCE OF RICES IN RAINFED CULTURE

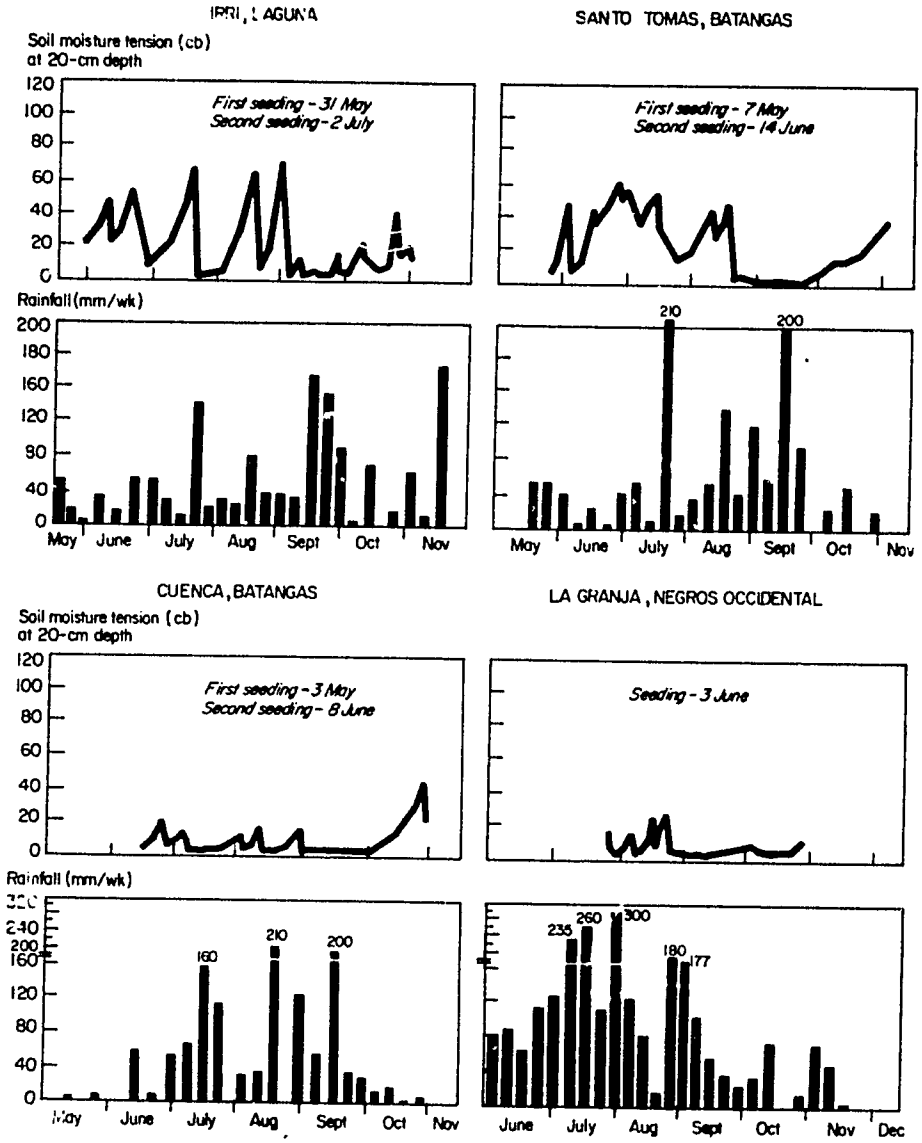
Agronomy and Plant Breeding Departments

Upland variety trials *(Agronomy)*. The 1977 upland rice variety trials to select promising lines with drought resistance and the ability to recover from drought, combined with high yield potential and pest resistance, were conducted at four Philippine sites. At IRRI and two farmers' fields in Batangas (Santo Tomas and Cuenca), rice was seeded at two dates, a month apart. At La Granja, there was only one seeding date. Of

Table 6. Mean drought resistance scores of 30 entries with scores from 1 to 3[a] (±standard error). IRRI drought screening greenhouse, 1977.

Designation	Origin	Mean drought resistance score	SE±
	Drought score of 1		
IAC 47	Brazil	1.3	0.3
IAC 1131	Brazil	1.5	0.5
IRAT 13	Ivory Coast	1.5	0.5
IAC 5032	Brazil	1	—
Salumpikit	Philippines	1.3	0.3
63-83	West Africa	1.2	0.2
Kinandang Patong	Philippines	1.3	0.3
Moroberekan	Guinea	1.3	0.3
	Drought score of 2		
Azucena	Philippines	2	—
IRAT 10	Ivory Coast	2	0.6
IR5853-118-5	Philippines	2.3	0.3
IR1746-194-1-1-1	Philippines	2.5	0.5
Holamaldiga	—	2.5	0.5
Sigadis	Indonesia	2.5	1.5
	Drought score of 3		
IR4227-207-2-2-2	Philippines	3	—
IR4417-179-1-5-2	Philippines	3	+
IR4432-28-5	Philippines	3	—
Pelita I-1	Indonesia	3.3	0.3
SI-20	Indonesia	3.5	0.5
BR51-46-5	Bangladesh	3.5	0.5
IR3501-54-3-2	Philippines	3.5	0.5
IR3259-P5-160-1	Philippines	3.5	0.5
Rikuto Norin 21	Japan	3.5	1.5
IR1754-F5B-19	Philippines	3.5	0.5
IR8	Philippines	3.7	0.3
IR1746-88-1-2-1	Philippines	3.7	1.2
IR2070-414-3-9	Philippines	3.6	0.9
IR2071-105-9-1	Philippines	3.5	1.5
IR2071-586-5-6-3	Philippines	3.7	0.9
IR4422-6-2-3-1	Philippines	3.7	0.9

[a]1975 Standard Evaluation System for Rice scale of 1-9: 1=none to slight effects of stress; 9= all plants apparently dead.



4. Weekly rainfall (mm) and soil moisture tension (cb) at four upland rice yield nursery locations. Philippines, 1977 wet season.

81 entries, 24 were entered in the 1977 International Upland Rice Yield Nursery (IURYN) as part of the International Rice Testing Program (IRTP).

Rainfall distribution. The first seeding at Santo Tomas (7 May) and IRRI (31 May) encountered mild moisture stress during the late vegetative and early reproductive stages (Fig. 4). Nevertheless, the crops at all sites generally received favorable rainfall. At Cuenca rice was seeded on extremely dry soil (15 bars SMT). There was no rain for 6 weeks in the first seeding (3 May) and for 1 week in the second (8 June). As a result, seed from both seeding dates germinated simultaneously. Late emergence of the 3 May crop at Cuenca, however, did not reduce yield (Table 7).

Yielding ability. Among the early maturing rices, IR3839-1 yielded significantly higher than the early maturing check M1-48 in six of seven tests, while four others (IR2061-522-6-9, BG 35-2, IET 1444, and Kn 361-1-8-6) were

Table 7. Grain yield of promising rices with different maturity groups under upland conditions at four sites. Philippines, 1977 wet season.

Designation	Grain yield (t/ha)							
	IRRI		Santo Tomas		Cuenca		La Granja	Av.
	31 May seeding	2 July seeding	7 May seeding	14 June seeding	3 May seeding	8 June seeding	3 June seeding	
				Early maturing group				
IR3839-1	2.7*	2.8*	4.2*	5.0*	3.8*	3.7*	4.0	3.7
BG 35-2	3.1*	2.7*	2.8	3.9	4.0*	4.1*	5.3*	3.7
IR36	3.2*	3.5*	4.0	4.6*	3.3	3.5*	3.0	3.6
IET 1444	2.5*	5.1*	3.9	4.6*	3.5*	3.9*	4.0	3.5
IR2061-522-6-9	2.4*	2.2*	4.7*	3.6	3.8*	4.0*	4.0	3.5
Kn 361-1-8-6	1.8*	1.8*	4.1*	3.5	4.0*	4.0*	4.2	3.3
IR3880-29	2.5*	3.0*	3.3	3.7	3.2	3.4*	3.5	3.2
IR3880-13	1.9*	2.7*	3.4	3.8	3.5*	3.8*	3.1	3.2
IR5179-2	2.3*	2.3*	3.5	3.7	3.6	3.3*	3.3	3.1
62-155	1.5	2.0*	3.6	2.5	3.8*	4.2*	4.0	3.1
ARC 10372	1.9*	1.4	3.2	3.1	3.2	3.2*	4.2	2.9
B57c-Md-10-2	0.8	1.2	3.2	4.1	4.2*	4.1*	3.0	2.9
DJ-29	2.0*	1.7*	2.8	3.2	3.3	3.4*	3.4	2.8
DV 110	1.9*	1.2	3.3	3.0	2.5	4.0*	2.7	2.7
IR1750-F_5B-5	2.4*	2.3*	2.9	2.6	3.0	2.8	2.6	2.7
Se 302G	1.4	2.4*	2.3	2.1[a]	2.9	3.0	4.0	2.6
Chandarhat	1.7	1.0	3.6	2.7	3.2	3.1	2.3	2.5
Surjamukhi	1.3	1.0	2.7	2.9	3.5*	3.4*	3.0	2.5
M1-48 (check)	0.9	0.5	2.7	3.2	2.3	2.4	3.3	2.2
				Medium- and late-maturing group				
IR1529-430-3	2.8	2.9*	3.4	4.6	4.0	4.6	2.8	3.6
IR9575	2.5	2.6	4.4*	4.2	3.2	3.8	3.8	3.5
IR2035-242-1	2.3	1.4	4.0	4.3	5.0[b]	4.0	3.7	3.5
IR9669	1.6	1.2	5.3*	4.5	4.0	4.6	3.3	3.5
Gama 318	2.5	1.5	3.5	4.0	4.2	4.8	3.8	3.5
IR3880-10	2.0	2.6	3.6	4.0	3.8	4.3	4.4	3.5
C22 (Check)	2.2	1.8	3.1	4.5	3.8	4.5	3.9	3.4
MRC 172-9	2.3	1.3	3.6	4.0	4.1	4.5	4.1	3.4
Kn 96	2.2	1.7	2.8	4.0	4.0	4.2	4.0	3.3
IR2035-227-1	2.0	1.8	4.0	3.6	3.9	3.7	4.2	3.3
IR3880-17	2.0	2.1	3.6	4.2	3.5	3.6	3.6	3.2
C46-15/IR24[2]	2.0	1.9	3.7	4.3	3.2	3.8	3.3	3.2
B541b-kn-19-3-4	1.4	2.1	3.1	4.5	3.8	3.4	3.5	3.1
IR3273-P339-1	1.3[a]	0.6	3.9	4.4	4.4	4.4	2.9	3.1
IR3858-6	2.3	0.9	2.9	3.5	4.1	4.2	3.0	3.0
IR3259-P5-160-1	2.4	0.8[a]	3.8	3.3[a]	3.6	4.5	2.2[a]	2.9
IR3179-40	1.8	1.4	3.2	4.4	3.2	3.4[a]	2.8	2.9
BPI 76 (nonseasonal)	1.6	1.9	2.2	3.2[a]	4.1	3.6	3.8	2.9
IR5	2.1	0.8[a]	3.8	2.7[a]	4.2	4.3	2.2[a]	2.9
IR2035-117-3	2.6	2.1	3.8	3.2[a]	3.6	3.4[a]	1.8[a]	2.9
B981d-SI-28-2	1.7	1.9	1.9	2.8[a]	3.5	4.4	3.8	2.9
IR3260-P91-100	2.0	1.1	2.7	3.4[a]	2.8	4.4	2.7	2.7
IR3304-23	1.4	1.7	3.3	2.4[a]	3.2	3.5[a]	3.4	2.7

[a]Grain yield lower than that of the check of the 5% level. [b]Nonreplicated.

better than M1-48 in five tests (Table 8). Those five entries were among the six highest yielding, early maturing rices in the 1977 tests. The other entry, IR36, ranked second in average yield in seven tests (3.6 t/ha vs 3.7 t/ha for IR3839-1 and BG 35-2) and yielded significantly better than M1-48 in four tests.

Of the medium- and late-maturing rices, IR1529-430-3, IR9575, and IR9669 yielded significantly higher than the medium-maturing check C22 in one test. Their average yields, as well as those of IR2035-242-1, IR3880-10, and Gama 318 (3.5-3.6 t/ha), were higher than that of C22 (3.4 t/ha, the same as that of MRC 172-9). C22 averaged better yields than 36 medium- and late-maturing entries (Table 7).

Agronomic characteristics. Phenotypic acceptability of the selected entries ranged from 1 to 5

Table 8. Summary of yield and agronomic characteristics of promising rices with different maturity groups, under upland conditions at four sites, 1977 wet season.

Designation	Av. yield (t/ha)	Phenotypic[a] acceptability		Growth duration[b] (DS)	Plant ht (cm)	Panicles (no/m²)	Lodging[c]								Important pests[d] with ratings of 5 and above		
							IRRI		Santo Tomas		Cuenca		La Granja				
		Vegetative	Reproductive				Rating	Stage	Rating	Stage	Rating	Stage	Rating	Stage	IRRI	Santo Tomas	Cuenca
Early maturing group																	
IR3839-1	3.7	3	5	109	95	285	9	8	1	9	1	9	1	9	BB, ShB	—	Bl, HB
BG 35-2	3.7	3	3	112	90	273	9	8	1	9	1	9	1	9	Bl, BB	Bn	ShB
IR36	3.6	5	5	109	75	357	9	8	1	9	1	9	1	9	BB, ShB	Bn	ShB
IET 1444	3.5	3	5	106	94	280	9	8	1	9	1	9	1	9	Bl, Bn, ShB	Bn	ShB
IR2061-522-6-9	3.5	3	3	110	102	273	9	8	1	9	1	9	1	9	ShB	—	ShB
Kn 361-1-8-6	3.3	3	5	105	127	202	9	7	9	8	3	9	5	9	BB, ShB	Bn, ShB	Bl, ShB
IR3880-29	3.2	3	5	108	102	250	9	8	1	9	1	9	1	9	ShB, HB	Bn, FS, ShB	ShB
IR3880-13	3.1	3	3	104	110	237	9	7	1	9	1	9	1	9	BB, ShB	FS	ShB
IR5179-2	3.2	5	5	108	92	270	1	9	1	9	1	9	1	9	BB, HB	Bn, FS, ShB	Bl, ShB, HB
62-155	3.1	3	7	104	130	245	9	5	9	5	9	8	9	9	BB, ShB	Bn, ShB	—
ARC 10372	2.9	3	7	103	133	227	9	5	9	7	9	8	7	9	ShB	—	Bl
B57c-Md-10-2	2.9	5	5	102	82	275	1	9	1	9	1	9	1	9	Bl, Bn, ShB, HB	Bn, FS, ShB	ShB
DJ-29	2.8	3	7	108	140	220	9	7	9	8	9	8	8	9	Bl	Bl, ShB	—
DV 110	2.7	3	7	101	134	244	9	5	9	8	9	8	1	9	Bl, ShB	ShB	Bl
IR1750-F_5B-5	2.7	3	5	109	96	202	5	8	1	9	1	9	1	9	Bl, BB, ShB, HB	FS, ShB	ShB
Se3020	2.6	5	5	94	76	290	5	8	1	9	1	9	1	9	Bn, BB, ShB	Bn	ShB
Chandarhat	2.5	3	7	111	134	213	9	5	9	5	9	7	1	9	Bn	ShB	Bl
Surjamukhi	2.6	3	7	98	119	234	9	7	9	8	9	8	9	9	ShB	ShB	BB, ShB
M1-48 (check)	2.2	3	5	119	128	176	9	7	1	9	1	9	1	9	ShB	FS	ShB
Medium and late-maturing group																	
IR1529-430-3	3.6	5	5	127	83	242	5	8	1	9	1	9	1	9	Bl, HB	—	ShB
IR9575	3.5	1	3	125	105	231	9	7	1	9	1	9	1	9	Bl, BB, HB	FS	—
IR2035-242-1	3.5	5	5	132	89	294	9	8	1	9	1	9	1	9	Sh, HB	—	ShB
IR9669	3.5	5	5	130	83	235	9	8	1	9	1	9	1	9	ShB, HB	ShB	ShB, Lsd
Gama 318	3.5	3	3	132	100	255	9	8	1	9	1	9	1	9	Bl, BB, ShB	Bl, Bn, ShB	ShB
IR3880-10	3.5	3	3	120	111	255	9	7	1	9	1	9	1	9	Bl, ShB	—	ShB
C-22 (check)	3.4	3	3	128	114	200	9	8	1	9	1	9	1	9	Bl, BB, ShB, HB	Bn, FS	—
MRC 172-9	3.4	3	3	130	114	229	9	8	1	9	1	9	1	9	ShB, HB	FS	—
Kn 96	3.3	3	3	130	116	241	9	7	5	8	1	9	1	9	Bl, ShB	Bl, Bn, FS	Bl, ShB
IR2035-227-1	3.3	5	5	126	90	250	5	8	1	9	1	9	1	9	Bl, ShB	Bn, ShB	ShB
IR3880-17	3.2	3	5	120	113	242	9	7	1	9	1	9	1	9	BB, ShB, HB	ShB	ShB
C46-15/IR24[e]	3.2	5	5	126	91	218	9	8	1	9	1	9	1	9	BB, ShB, HB	—	ShB
B541b-kn-19-3-4	3.1	3	5	122	103	262	9	7	1	9	1	9	1	9	Bl, BN, ShB, HB	Bl, Bn, FS	Bl, ShB, HB
IR3273-P399-1	3.1	5	3	139	89	242	7	7	1	9	1	9	1	9	ShB	FS	ShB
IR3858-6	3.0	3	5	130	116	241	7	7	1	9	1	9	1	9	HB	Bn, ShB	Bl, ShB
IR3259-P5-160-1	2.9	5	5	139	88	215	1	9	1	9	1	9	1	9	HB	—	ShB, Lst
IR3179-40	2.9	3	5	130	107	235	9	8	1	9	1	9	1	9	ShB	ShB	ShB, HB
BPI 76 (n.s.)	2.9	3	3	127	116	206	9	7	1	9	1	9	1	9	Bl, Bn, BB, ShB, HB,	Bn, FS, ShB	—
IR5	2.9	3	5	143	99	222	9	5	1	9	1	9	1	9	Bl, HB	—	Bl, ShB
IR2035-117-3	2.9	5	5	143	94	236	7	5	1	9	1	9	1	9	HB	—	ShB
B981d-Si-28-2	2.9	3	5	129	114	200	9	8	1	9	1	9	1	9	Bl, Bn, HB	Bl, Bn, FS	Bl
IR3260-P91-100	2.7	5	5	138	90	208	7	5	1	9	1	9	1	9	ShB, HB	FS	ShB
IR3304-23	2.7	3	5	121	124	224	9	8	9	8	1	9	1	9	Bl, BB, ShB	Bn, ShB	ShB

[a]1975 Standard Evaluation System for Rice: 1 = excellent; 9 = unacceptable. [b]DS = days after seeding. [c]SES: 1 = no lodging; 9 = all plants flat. [d]Bl = leaf blast; Bn = neck rot; ShB = sheath blight; FS = false smut; Lst = leaf smut; Lsd = leaf scald; HB = hopperburn.

at the vegetative stage and from 3 to 7 at the reproductive stage (Table 8). IR9575 and 10 other entries received better ratings. Those that were rated 7 were relatively tall (130-140 cm), except Surjamukhi (119 cm tall), which lodged in 6 of 7 tests. IR36 had the most panicles (357/m^2).

Pest resistance. Leaf blast, neck rot, and sheath blight were the most serious diseases, except at La Granja (Table 8). Most rices at IRRI, and some at Cuenca, were hopperburned.

Promising lines. On the basis of overall performance, 11 IURYN entries appeared promising and should be further evaluated: IR36, IR1529-430-3, IR2035-242-1, IR2061-522-6-9, IR3839-1, IR3880-13, IR9575, C22, IET1444, Kn 361-1-8-6, and MRC 172-9.

Seven other rices looked promising enough to be considered for the 1978 IURYN trials: IR3880-10, IR3880-29, IR5179-2, IR9669, BG 35-2, Gama 318, and Kn 96.

Yield evaluation of upland breeding lines *(Plant Breeding).* The entries in the upland replicated yield trial for the 1977 wet season were increased to 75. Three planting sites, representing different soil moisture and fertility levels, were maintained.

At IRRI, 1,069 mm of rain fell during the cropping period. The well-drained and drier site of the IRRI farm showed soil moisture stress in early July and early August, prolonging the growth period of the early maturing rices by 2 to 3 weeks and drastically reducing yields (Fig. 5). Although the medium- and late-maturing rices recovered after mid-August showers, yields were generally low.

The high yielders at the drier site were lines that matured late — 142 days after seeding (DS) — and thus benefited from the September rains. They were IR3260-91-100 (1.5 t/ha), followed by IR2035-108-2 and IR7805-22-3-1 (1.3 t/ha each). But another late-maturing entry, IR4227-28-3-2, yielded lowest (0.1 t/ha); at the vegetative stage it had intermediate drought resistance, but at the reproductive stage, it was susceptible.

IR36 yielded 0.2 t/ha. It was stunted by the stress; its grains were small and light (1 g/100 grains), and its panicles had 87% sterility.

The check varieties Kinandang Patong and C22 yielded 0.5-0.6 t/ha. Although Kinandang Patong had well-filled grain, the length of its panicle was reduced, and each panicle had fewer grains. The 100-grain weight was relatively high (2.3 g) and panicle sterility was as low as 15%. Kinandang Patong matured from 124 to 130 DS at all three sites. C22 had lighter grains (1.9 g) and higher panicle sterility (44%).

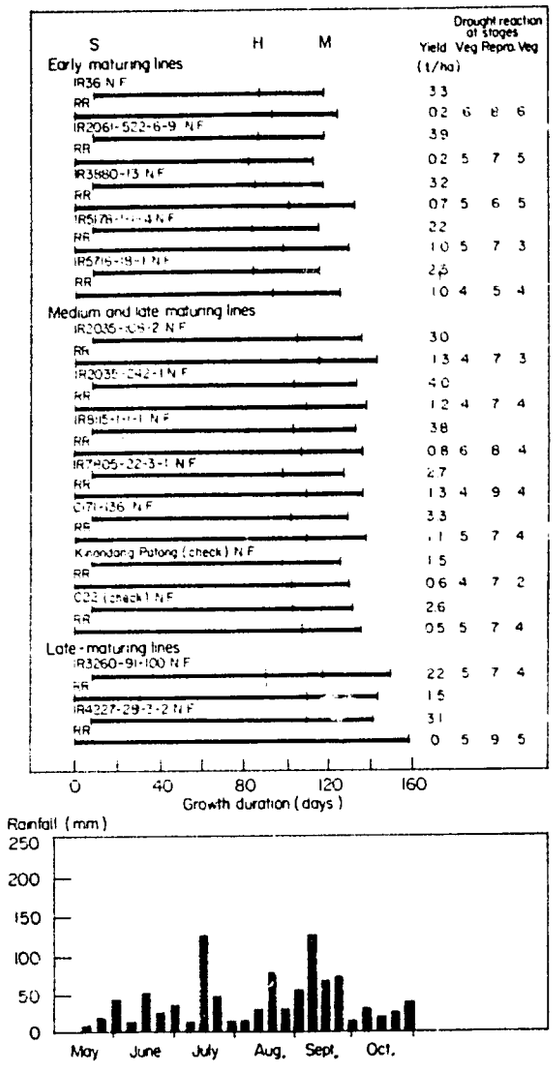
At the wet, fertile site on the new IRRI farm, the top yielders were IR2061-522-6-9 (3.9 t/ha) and IR2035-242-1 (4 t/ha). Nine upland breeding lines, such as IR6115-1-1-1, IR3839-1, and the IR3880 lines, yielded from 3 to 3.8 t/ha. An improved line from the University of the Philippines at Los Baños, C171-136, yielded 3.3 t/ha. The crop suffered slightly from moisture stress early in August and so yields were lower than those in 1976. The check varieties Kinandang Patong and C22 yielded 1.5 and 2.6 t/ha, respectively (Fig. 5).

Abundant rainfall fell at the Santo Tomas (Batangas) field (rented from a farmer) in 1977. The crop generally grew more vigorously and taller than previous crops. The highest yielders (4.3 t/ha) were IR6115-1-1-1 (IR1529-680-3/Moroberekan) and IR9669 (IR8^3/Carreon). They matured at 128 and 136 DS, respectively. Each of the lowland semidwarfs IR1529-430-3-1, IR2042-178-1, IR2035-242-1, and IET 1444 yielded about 3.9 t/ha, probably because rainfall was abundant and evenly distributed.

Among lines from the upland breeding nurseries, IR3839-1 (Pelita I-1/IR1529-680-3//IR442-2-58/Rikuto Norin 21) yielded 3.7 t/ha, and IR3880-10 (IR841-67/C22-51/Pelita I-2/IR1541-76) 3.5 t/ha. The checks Kinandang Patong and C22 yielded 2.1 and 3.2 t/ha, respectively.

Table 9 shows the yields, days to maturity, and drought ratings of selected rices at the three sites. The upland breeding lines IR3880-10, IR5716-18-1, IR6115-1-1-1, and IR7805-22-3-1 appeared stable in yield; they produced 0.8 t/ha to 1.3 t/ha at the dry site, 2.7 to 4.3 t/ha at Santo Tomas, and 2.7 to 3.8 t/ha at the new IRRI farm. But drought extended their maturity dates by 12-17 days.

With stress at the vegetative or reproductive



5. Rainfall distribution, growth duration, drought reactions and yields of 12 breeding lines and two check varieties grown at two upland sites at IRRI. 1977 wet season. [a]N.F. = IRRI new farm, RR = railroad site, H = heading, M = maturity.

stage, the yields of the lowland lines IR2035-108-2 and IR2035-242-1 were reduced at the dry site to about a third of that at the new IRRI farm. The maturity dates of IR2035-108-2 and IR2035-242-1 were prolonged to 138 days or longer. Although the late-maturing IR3260-91-100 benefited from rainfall in late September and early October, its yield at the dry site was only half of that at Santo Tomas.

IR36, which had a low drought-resistance score in IRRI field screening, yielded only 0.2 t/ha at the dry site, but 3.3 t/ha and 3.4 t/ha at the wetter, more fertile sites. Drought prolonged its maturity by 6 to 12 days. Water stress greatly reduced the size of its panicles.

The results confirmed previous years' findings that yield stability requires both drought resistance and recovery ability.

EVALUATION OF DROUGHT RESISTANCE IN RAINFED-LOWLAND CULTURE

Plant Breeding and Irrigation and Water Management Departments

Observational yield trial in rainfed-lowland culture (*Plant Breeding*). A replicated trial of 346 rices was planted in rainfed-lowland fields on the new IRRI farm in the 1977 wet season. Short, dry spells occurred in August and October.

A number of rices had high yield potential (4-6 t/ha) in rainfed culture and will be used as parents in the rainfed-lowland breeding program. They are Nam Sagui 19, Niaw San Pah Tawng, T 141, and BKN6809-74-40 from Thailand; Utri, Paedi Kalibungga, and Pare Laarari from Indonesia; MRC 85 and MRC 911-932 from the Philippines; H4 from Sri Lanka; JBS 688 from India; IR3646 lines, IR3648-1-1-1, IR3659-15-1-1, and IR3880 lines from the upland breeding nurseries; and IR2823-103-5-1, IR4570-83-3-3-2, IR4568-86-1-3-2, and IR4829-89-2 from the lowland breeding nurseries. The check varieties BPI-76(n.s.) and Intan yielded 4 and 2 t/ha, respectively.

Performance of rices in three water regimes (*Plant Breeding and Irrigation and Water Management*). Field experiments were initiated in farmers' fields near Gapan and Talavera, Central Luzon, Philippines, in the 1977 wet season to extend the scope of research on drought resistance in rainfed-lowland culture to areas where large proportions of the rice crop are planted without irrigation. In each place, three sites were selected to represent fully irrigated, partially irrigated, and rainfed water regimes. At each site 12 rices known to react differently to moisture stress were planted. The three sites in Gapan were in three different fields, while

Table 9. Comparison of selected rices grown at three upland test sites. IRRI and Batangas, Philippines, 1977 wet season.

Designation	Cross	IRRI (dry site)		Santo Tomas (intermediate)		New IRRI farm (wet, fertile site)		Drought reaction score[a] at		Recovery
		Yield (t/ha)	Maturity (days)	Yield (t/ha)	Maturity (days)	Yield (t/ha)	Maturity (days)	Vegetative stage	Reproductive stage	
IR2035-108-2	IR1416-128-5/IR1364-37-3-1 ///IR1539-269// IR661-1-140-3-2[3]/*O. nivara*	1.3	142	3.2	131	3.0	128	4	7	1
IR2035-242-1	"	1.2	138	3.9	134	4.0	126	4	7	2
IR3260-91-100	IR8/Dawn//IR8/Kataktara	1.5	142	3.4	140	2.2	142	5	7	1
IR3880-10	IR841-67/C22-51 //Pelita I-2/IR1541-76	0.9	136	3.5	125	3.1	117	4	5	2
IR5716-18-1	IR1833-203-1-3 //MRC 172-9/IR2146-68-1	1.0	123	3.4	121	2.5	112	4	5	1
IR6115-1-1-1	IR1529-680-3/Moroberekan	0.8	106	4.3	98	3.8	94	6	8	3
IR7805-22-3-1	IR833-6-2/IR1746-194-1-1-1 //MRC 172-9	1.3	137	2.7	131	2.7	120	4	9	5
IR36	IR1561-228//IR24[4] /*O. nivara*///CR 94-13	0.2	122	3.4	116	3.3	110	6	8	1
Kinandang Patong (check)		0.6	130	2.1	127	1.5	120	4	7	3
C22 (check)	Tjeremas/BPI-76 //Palawan/Azucena	0.5	136	3.2	128	2.6	124	5	7	2

[a]1975 Standard Evaluation System for Rice: 1 = highly resistant; 5= intermediate; 9 = highly susceptible.

the partially irrigated and the rainfed sites in Talavera were adjoining fields. Most sites had light soils; sandy loam, loam, or sandy clay loam. But the fully and partially irrigated sites at Gapan had coarser soil than the rainfed site, where about 40% of the sample particles were bigger than sand.

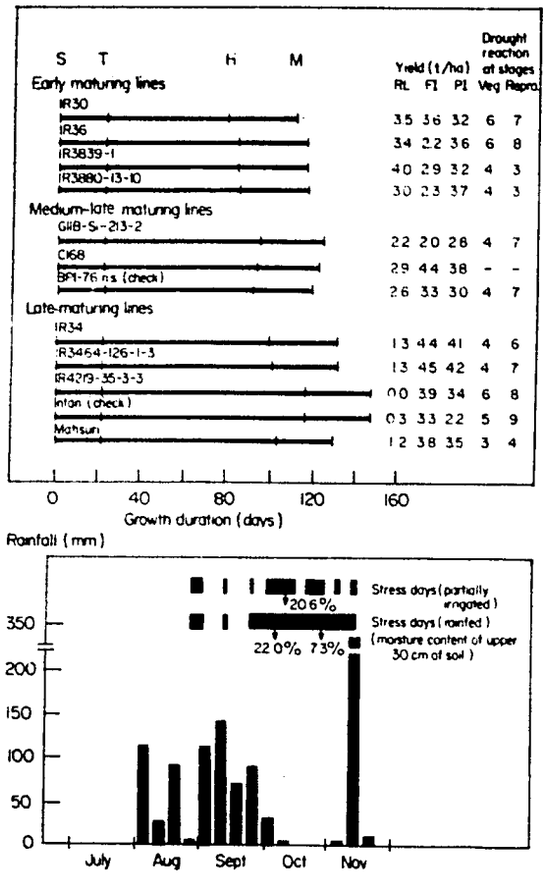
The fully irrigated fields were continuously flooded from transplanting to the hard-dough stage. The partially irrigated fields received irrigation irregularly because water was difficult to obtain from the canal. Irrigation water was periodically applied, however, to ensure that the number of consecutive stress days — days in excess of 3 without standing water — did not exceed 12. At the rainfed site, no supplementary irrigation was used.

Figures 6 and 7 combine information on the drought resistance scores and vegetative and reproductive growth phases of test varieties, rainfall distribution at sites from August through November, stress occurrence in the partially irrigated and rainfed plots, and the yields of the 12 varieties in each treatment.

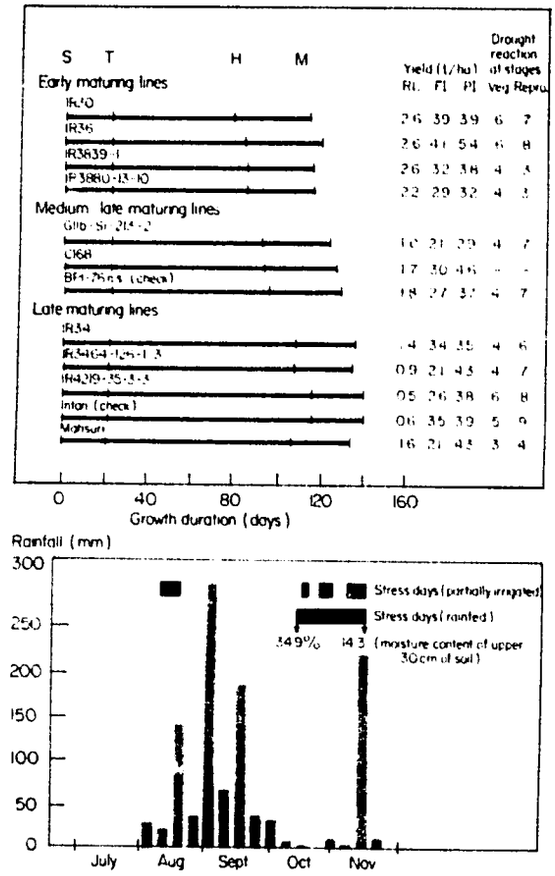
At Talavera the four early maturing rices yielded high in all three treatments (3-4 t/ha) (Fig. 6). Severe rat infestations at the soft-dough stage reduced the yields of three early lines in the fully irrigated plots. The rainfall distribution in Figure 6 shows that the relatively high yields of the four early entries in the rainfed field were due to adequate water supply from transplanting to the soft-dough stage. Although short dry periods occurred in the early tillering stage, drought did not materially affect the yields of the early maturing lines in either partially irrigated or rainfed treatments. Those strains escaped the severe moisture stress, which began in early October. At harvest, the soil moisture content was 7.3% at the upper 30 cm.

At Gapan the early maturing varieties in the rainfed treatment also escaped the stress period and yielded from 2.2. to 2.6 t/ha. Three of the four early entries yielded highest (Fig. 7). Stress at Gapan began about 15 days later than at Talavera.

Yields of the three medium-maturing varieties continuously declined from the fully irrigated to the partially irrigated and rainfed treatments at Talavera and, particularly, at Gapan. Because stress set in shortly after head-



6. Rainfall distribution, stress days, growth duration, drought reactions, and yields of 12 rices tested at Talavera, Nueva Ecija province, Philippines, 1977 wet season. S = seeding, T = transplanting, H = heading, M = maturity, RL = rainfed lowland, FI = fully irrigated, PI = partially irrigated.



7. Rainfall distribution, stress days, growth duration, drought reactions, and yields of 12 rices tested at Gapan, Nueva Ecija province, Philippines, 1977 wet season. S = seeding, T = transplanting, H = heading; M = maturity, RL = rainfed lowland, FI = fully irrigated, PI = partially irrigated.

ing, maturity was not delayed in the rainfed treatment. But the mean panicle sterility of 45% may explain the yield reduction. C168 and BPI-76 performed better than G11b-Si-213-2.

Yields of the five late-maturing rices were reduced far more markedly in the rainfed than in the two other treatments at both Talavera and Gapan. At Talavera water stress set in shortly after panicle initiation; at Gapan, shortly before heading. The rainfed-plot yields ranged from 0 to 2.2 t/ha at Talavera and from 0.5 to 1.6 t/ha at Gapan — a sharp contrast to yields in the fully irrigated treatment of 3.3-4.5 t/ha at Talavera and 2.1-3.5 t/ha at Gapan. The partially irrigated plots yielded from 2.2 to 4.2 t/ha at Talavera and 3.5 to 4.3 t/ha at Gapan. In the fully irrigated field at Gapan, the plants showed visible symptoms of zinc deficiency, associated with the high soil pH value of 7.8. These soils were coarse textured with a shallow puddled layer (about 8 cm) and a hard, compact subsoil underneath. All varieties yielded low at that site.

Among the five late-maturing varieties, IR34 had high drought resistance (vegetative stage, 4; reproductive, 6) in previous mass-screenings, and yielded highest in both the partially irrigated and rainfed plots. Its yields of 3.5 and 1.4 t/ha contrast sharply with those of the drought-susceptible IR4219-35-3-3 (vegetative stage, 6;

reproductive, 8): 0 t/ha at Talavera and 0.5 t/ha at Gapan. The latter plants were completely sterile in the Talavera rainfed site.

Intan, a popular variety in rainfed-lowland areas, yielded 2.2 to 3.9 t/ha in partially irrigated plots. It matured slightly later in the rainfed plots. The prolonged drought stress, which lasted almost throughout the reproductive phase, affected its spikelet fertility and grain filling. Intan's drought resistance is good at the vegetative stage (score, 5) but rather low at the reproductive stage (9). The rainfed yields were 0.4 t/ha at Talavera and 0.6 t/ha at Gapan.

Mahsuri, a popular variety in Malaysia and India, yielded about the same as IR3464-126-1-3 (1.2-1.6 vs 1.3-0.9 t/ha) in the Talavera rainfed site but higher at Gapan, even though the heading dates of the two entries were identical. Mahsuri's drought resistance ratings were higher than those of IR3464-126 in the mass-screening test.

Although testing in farmers' fields did not allow critical comparison of different water regimes in one field or in adjoining fields, the wet-season experiments verified the importance of adequate and sustained water supply in the reproductive phase. Early maturity may enable a variety to escape drought, especially during grain development. For varieties with medium-long or long growth duration, sufficient varietal differences in drought resistance in the vegetative phase are available for rice breeders to use. Drought resistance appears more crucial during the reproductive than during the vegetative phase. Varietal differences in recovery ability after the termination of drought could not be studied in the Central Luzon fields, but should be further investigated with efficient water control.

ROOT STUDIES

Plant Physiology Department

Screening for deep root systems. Screening of rice varieties for deep root systems by the root-box technique continued in 1977. Table 10 shows the distribution of 768 entries among root depths. The root depth of IR20 was scored as shallow (5) and that of OS4, as moderately deep (2). Many rices have root systems as deep as those of OS4, or deeper. Most are upland varieties and hybrids with upland rices in their parentage.

Table 10. The distribution of root depth among 768 varieties and lines tested by the root-box technique. IRRI, 1977.

Root depth score	Depth characteristic	Entries (no.)
1	Deep	256
2	Moderately deep	156
3	Intermediate	143
4	Moderately shallow	137
5	Shallow	76

Total dry weight and root dry weight. Root dry weight can be related to total dry weight by the formula:

$$W_R = H\ W_T^h \qquad (1)$$

where W_R is root dry weight, W_T is total dry weight (i.e., shoot weight plus root weight), and H and h are constants.

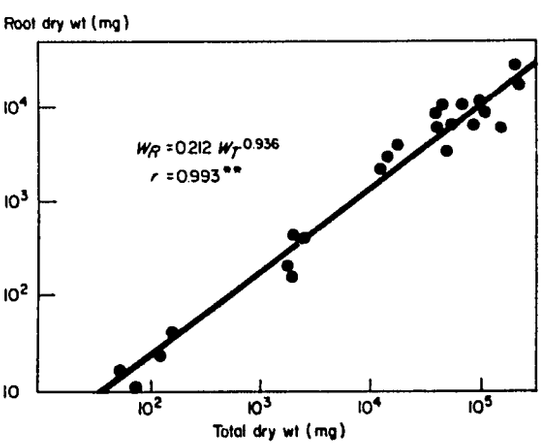
Equation (1) can be converted into a logarithmic form:

$$\log W_R = \log H + h \log W_T. \qquad (2)$$

Thus, $\log W_R$ is a linear function of $\log W_T$.

To determine if the above relationship holds for rice varieties grown under upland conditions, four varieties — IR20, OS4, N22, and Jappeni Tungkungo — were grown in root boxes in the screenhouse. Data on dry weight of shoots and roots were collected 4 times, from 2 weeks after sowing to heading.

Figure 8 shows a simple allometric relationship between root dry weight and total dry weight:



8. Relation between total dry weight and root dry weight of four rice varieties. IRRI, 1977.

$$W_R = 0.212\ W_t^{0.836}$$

When plants are small, the value of W_R:W_T is about 0.2; as the plants become larger, W_R:W_T approaches 0.1. In other words, the ratio of root dry weight to total dry weight ranges from 0.1 to 0.2 from sowing to heading for the varieties tested and many others. In a separate measurement on field-grown crops, W_R:W_T values at heading were 0.09 for OS4 and 0.10 for IR20. Some strains, however, have high W_R:W_T values at heading. For example, a W_R:W_T value of 0.23 was recorded for a strain of the wild rice *O. australiensis*, and 0.16 for 610, a deep-rooted upland selection.

The above relationship between root and total dry weight estimates the root mass left in the soil if shoot or straw weight is known. For example, a crop that produced 3 t rough rice/ha with a harvest index at 0.5 left about 330 kg dry root/ha in the soil.

Root branching. Under lowland conditions, rice develops its sixth branched roots as it approaches maturity. The fifth branched roots were observed under a microscope under upland conditions and at flowering. Table 11 shows diameters of nodal roots of different orders. A root's diameter becomes successively smaller as the order of branching increases, ranging from about 40 to 1,000 microns. A large number of root hairs about 10 microns in diameter and about 50 microns in length were observed.

Maximum root depth and total root length. In soft soil the maximum root depth of most rice varieties is 1 m or even deeper. The actual root depth in the field is controlled by both genetic ability and environmental conditions. The total root length increases as shoot growth advances. At flowering, it is about 2 to 3 km/plant under root-box conditions. Under field conditions, the total root length ranges from 15 to 34 km/m² of soil surface.

Table 11. Average diameters (microns) of rice nodal roots of different orders grown under upland conditions. IRRI, 1977.

Order of roots	Av. diameter (microns) of rice nodal roots		
	OS4	IR20	IR2992-27-1-2
1st	1073	574	812
2nd	257	160	218
3rd	109	69	97
4th	88	67	55
5th	81	67	44
Hairs	10	8	12

Table 12. Effects of variety, depth, and growth stage on length-to-weight ratio (m/g) of roots of four rice varieties, IRRI, 1977.

Variety	Length-to-weight ratio (m/g)			
	4 wk		Heading	
	Total roots	Roots below 30 cm	Total roots	Roots below 30 cm
Jappeni Tungkungo	334	651	440	705
IR20	238	530	433	973
N22	310	497	319	549
OS4	204	355	163	285
Mean	272	508	339	628

Length-to-weight ratio. In past studies, root dry weight has been used to characterize degree of root development. But total root length is a more meaningful measure of water absorption and nutrient uptake. The total root length of four rice varieties grown in root boxes was measured by Newman's technique and was related to root weight.

The length-to-weight ratio of rice roots varied with variety, depth, and growth stage (Table 12). Greater length-to-weight ratios imply smaller diameters. One gram of root dry weight is generally equal to about 300 m of length.

Assuming that a root segment has uniform cylindrical shape, its diameter, length, and fresh weight can be related to each other by the following formula:

$$\tfrac{1}{4}\ \pi \times d^2 \times L \times \rho = W_f \qquad (1)$$

where π is 3.14, d = root diameter in centimeters; L = root length in centimeters; p = density of root in grams per cubic centimeter; and W_f = weight of fresh root in grams.

The percentage of dry matter in rice roots ranges from 5 to 15%, depending on the root's physiological age. Assuming that the average dry-matter percentage of sample roots is 10, equation (1) can be rewritten as:

$$d = \sqrt{\frac{40}{\pi \times p} \times \frac{W_d}{L}} \qquad (2)$$

Table 13. Rooting pattern of OS4 at flowering (mean of three replicates). IRRI, 1977.

Tiller order	Roots (no.)	Maximum length (cm)	Weighted av. length (cm)
0	63.6	135	47.5
1	37.3	125	45.5
11	25.3	125	24.8
111	7.0	75	21.2
112	5.0	15	7.0
12	26.6	115	22.4
121	8.0	55	13.8
122	7.5	5	5.0
13	17.5	85	19.0
131	18.0	65	21.7
132	13.0	5	5.0
14	15.0	85	18.3
15	11.0	15	5.4
2	35.0	125	29.8
21	15.3	105	14.7
22	15.3	105	15.0
3	26.6	125	30.5
31	13.3	55	10.3
32	6.0	25	8.6
4	17.0	105	16.4
41	3.0	5	5.0
5	8.3	15	5.7
6	5.5	5	5.0

where W_d is weight of dry root in grams. Equation (2) can be used to estimate relationships between root diameter and length-to-weight ratio. Thus, if the length-to-weight ratio is 300 m/g dry root, the diameter is estimated as 0.2 mm.

Root characteristics of main shoot and tillers. The rice root system is largely composed of nodal roots; only one radicle develops to a maximum length of about 15 cm; it functions until the 7-leaf stage. Nodal roots of the main shoot and tillers as well as leaves develop from each node. Thus, a rice root system is a mixture of nodal roots emerging from nodes of both the main shoot and the tillers.

Four varieties of different root depths and drought resistance were grown in root boxes, and their root characteristics were examined. Table 13 shows the general rooting pattern of OS4 (which also represents that of the three other varieties) at flowering. Roots of the main shoot (tiller 0) are the longest and most numerous. The tillers from lower nodes of a given order, or those of lower orders, are more numerous and have a higher weighted average length of roots than the others. Thus, among the primary tillers, tiller 1 has more and longer roots than tillers 2 or 3. The weighted average root length of the primary tillers is longer than that of the secondary tillers, which is in turn longer than that of the tertiary tillers (Table 14). All four varieties had some roots longer than 100 cm on their main shoots. They clearly differed in weighted average root length; the drought-resistant variety Lalnakanda 41 had the longest root system, and the drought-susceptible IR20, the shortest.

To examine transport linkages between the main shoot and tillers, Rb-86 was fed on the fully developed topmost leaf of the main shoot of 56-day-old OS4 plants grown in root boxes; the radioactivity was then measured on roots of the main shoot and tillers (Table 15). Radioactivity was found only in the roots of the main shoot and in the shoot portion of tillers 4 and 5, which were actively growing tillers at that time. Tillers 1 and 2 (from the lower nodes) were observed, through a dissecting microscope, to be loosely connected to the main shoot. That observation, along with the translocation of Rb-86, suggests

Table 14. Number of roots found on the tillers of different orders at flowering (mean of three replicates). IRRI, 1977.

Tiller order	Tillers (no.)	Roots[a] (no.)	Roots (no./tiller)	Maximum length (cm)	Weighted av. length (cm)
		IR20			
Main shoot	1	64.0 (7.6)	64.0	105	22.9
Primary	9	302.3 (35.9)	33.6	95	9.7
Secondary	20	355.4 (42.3)	17.8	72	6.7
Tertiary	9	119.0 (14.1)	13.2	25	5.5
Total	39	840.7	128.6		
		OS4			
Main shoot	1	63.6 (15.9)	63.6	135	47.5
Primary	6	129.7 (32.4)	21.6	125	22.1
Secondary	10	148.3 (37.1)	14.8	125	14.3
Tertiary	6	58.5 (14.6)	9.7	75	12.3
Total	23	400.1	109.7		
		Lalnakanda-41			
Main shoot	1	59.3 (16.1)	59.3	135	71.7
Primary	6	152.2 (41.5)	25.4	115	33.7
Secondary	14	141.6 (38.6)	10.1	115	14.0
Tertiary	2	14.0 (3.8)	7.0	55	11.4
Total	23	367.1	101.8		
		CR143-2-2			
Main shoot	1	65.3 (22.8)	65.3	105	49.1
Primary	5	120.2 (42.0)	24.0	105	31.1
Secondary	13	95.4 (33.4)	7.3	95	11.4
Tertiary	1	5.0 (1.7)	5.0	5	5.0
Total	20	285.9	101.6		

[a]Figures in parentheses are percentages for the entire plant.

Table 15. Distribution of radioactive Rb-86 in the roots and shoots of the variety OS4 (mean of two replicates). IRRI, 1977.

Position of primary tillers[a]	Radioactive Rb-86 in Root: Dry wt (g)	Root: Count/g per min	Root: Total activity/ tissue per min	Shoot: Dry wt (g)	Shoot: Count/g per min	Shoot: Total activity/ tissue per min
			24 h after feeding			
0	2.2	150 ± 8	324	[b]	[b]	[b]
1	1.3	Trace	Trace	15.1	Trace	Trace
2	0.8	Trace	Trace	10.6	Trace	Trace
3	0.2	Trace	Trace	5.1	Trace	Trace
4	0.1	Trace	Trace	3.1	Trace	Trace
5	[c]	[c]	[c]	0.8	26 ± 6	21
			48 h after feeding			
0	2.6	277 ± 8	712	[b]	[b]	[b]
1	1.2	Trace	Trace	13.7	Trace	Trace
2	0.7	Trace	Trace	9.4	Trace	Trace
3	0.1	Trace	Trace	4.7	Trace	Trace
4	0.03	Trace	Trace	2.7	48 ± 8	130
5	[c]	[c]	[c]	0.9	121 ± 8	112

[a]Each comprises a primary tiller and associated secondary and tertiary tillers. [b]Removed as highly active waste. [c]Did not have visible roots.

that tillers become self-sustained units; with age they become independent of the main shoot and dependent on their own root systems for water and nutrients. The study also suggests a need to carefully evaluate rooting patterns of tillering cereal crops by injecting P-32 or Rb-86 into the stems. Because the radioactivity concentrates mainly in the roots of the injected shoot, such a method might not, however, evaluate the entire root system.

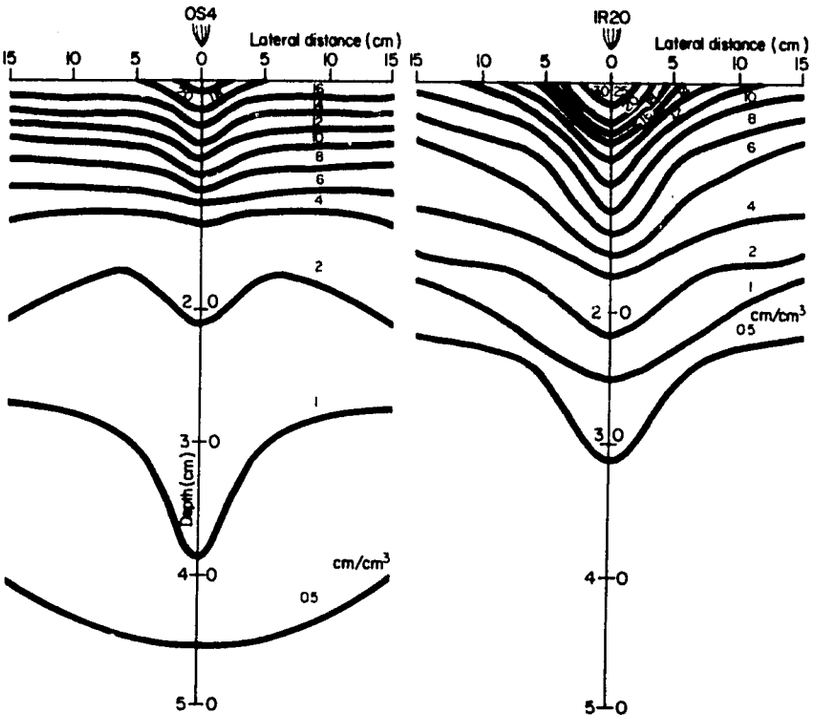
Root development in field. *Core-sampling method to estimate root density in field.* A core-sampling method has been tested to study rice root systems in the field. Soil cores are sampled in the field. Roots are then separated from soil, spread in a petri dish of known size, and photographed. Total root length is then measured by Newman's method as modified by Marsh in 1971. The results are expressed as root density, defined as

$$\text{Root density} = \frac{\text{total root length (cm)}}{\text{volume of soil core (cm}^3\text{)}}.$$

Thus, a root density value of 1 implies a root segment 1 cm long in 1 cm^3 soil. The core-sampling method is useful in the study of both lateral and vertical distribution of roots in the field, the effects of root density on water extraction (and hence on determination of effective root depth), and root development in different environments. But it is laborious and is used only for comparing selected varieties, not for routine comparison of many varieties in the field.

Vertical and lateral root distribution. Vertical and lateral root distribution of varieties OS4 and IR20, planted at 30- × 5-cm spacing in the field, was examined by the core-sampling method (Fig. 9). Iso-root density curves were constructed to show points of the same root density both vertically and laterally. Roots of IR20 were concentrated around the center of the plant; those of OS4 were well spread laterally. Below 30 cm from the soil surface, the vertical distribution of roots of the two varieties differed significantly.

Varietal differences in vertical distribution of root density. The vertical distribution of the root density of 7 varieties planted in a field at 30 - × 5-cm spacing was studied. Deep-rooted varieties, identified by the root-box technique, also penetrated deeply in the field (Table 16). Differences in the root density of deep- and shallow-rooted varieties were found in soil layers deeper than 30 cm below the soil surface. Thus, root depth growth in root boxes appears to correlate well with root penetration in the field. But a high degree of mechanical impedance often limited to shallow soil layers the root growth of deep-rooted varieties. There-



9. Iso-root density diagram of rice varieties OS4 and IR20 grown in the field, IRRI, 1977.

fore, the uniformity of field soil to the required depth must be predetermined if the root depths of different varieties are to be compared.

Aluminum toxicity. Aluminum toxicity retards rice growth in acid upland soils. It is sometimes a problem even in lowland soils, such as acid sulfate soils in Thailand, where rice is grown under upland conditions for a few months before the field is inundated. Aluminum toxicity retards root growth, thereby impairing nutrient uptake and decreasing drought resistance. Experiments examined the mode of aluminum toxicity and varietal differences in tolerance for it.

Varietal differences in tolerance for aluminum toxicity. Because aluminum toxicity is a problem in direct-seeded rice and because early growth affects subsequent growth, varietal differences in tolerance for aluminum toxicity were tested at 0 to 2 weeks after pregermination. Pregerminated seed were placed on nylon mesh screens floating on a culture solution with 30 ppm Al. Two weeks later, the maximum root length was used to measure tolerance for

Table 16. Vertical distribution of root density of seven rice varieties grown in an upland field. IRRI, 1977.

Designation	Vertical distribution (cm) at depth of							
	0-10 cm	10-20 cm	20-30 cm	30-40 cm	40-50 cm	50-60 cm	60-70 cm	70-80 cm
IR20	14.4	2.8	0.9	0.4	0.1	—	—	—
IR2035-117-3	22.7	5.8	0.8	0.1	0.1	—	—	—
IR442-2-58	16.8	7.1	1.2	0.3	0.1	0.1	0.1	0.1
OS4	12.6	1.4	0.8	0.9	0.8	0.5	0.5	0.5
Moroberekan	11.8	2.3	0.9	0.8	0.6	0.8	0.4	0.2
Salumpikit	16.2	5.5	1.9	1.4	0.8	0.6	0.3	0.1
20 A	19.8	2.6	0.9	0.8	0.9	0.9	0.6	0.4

Table 17. Root length and relative root length of 20 varieties at 0 and 30 ppm (aluminum) in culture solution. IRRI, 1977.

Designation	Root length (cm) at 30 ppm Al	Root length (cm) at 0 ppm Al	Relative root length[a] (cm)
E425	9.1	19.5	0.47
Monolaya	8.1	19.3	0.42
OS6	7.8	16.6	0.47
OS4	7.3	18.7	0.39
M1-48	6.2	14.8	0.42
Moroberekan	5.9	16.1	0.37
Palawan	5.7	16.6	0.34
Colombia 1	5.6	15.1	0.37
Bluebonnet	5.3	15.5	0.34
20 A	5.3	14.5	0.37
IR 5	4.0	14.8	0.27
IR 8	3.0	13.9	0.22
IR442-2-58	3.0	11.2	0.27
Dark Mali	3.0	10.9	0.28
HR 334	2.7	9.3	0.29
HR 335	2.7	11.0	0.25
Neuy Nawng	2.5	11.3	0.22
CICA 4	2.4	13.0	0.18
IR22	2.0	11.9	0.17
IR20	1.5	7.2	0.21

[a]Ratio of root length at 30 ppm Al to root length at 0 ppm Al.

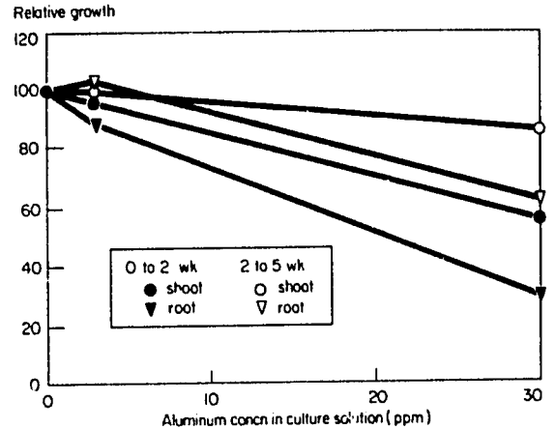
aluminum toxicity. Some researchers use relative root length (RRL) [the ratio of root length at 30 ppm (RL_{30}) to root length at 3 or 0 ppm Al (RL_0)] as an aluminum-tolerance measure. The use of RRL may distinguish aluminum tolerance from inherent root growth in the absence of aluminum toxicity. The following relationship holds among the three quantities involved:

$$RL_{30} = RL_0 \times \frac{RL_{30}}{RL_0}$$

$$= RL_0 \times RRL.$$

In 20 varieties the three quantities are closely associated (Table 17), i.e. in the absence of aluminum, varieties with deep roots also have high RRL values; consequently, their roots are long at 30 ppm.

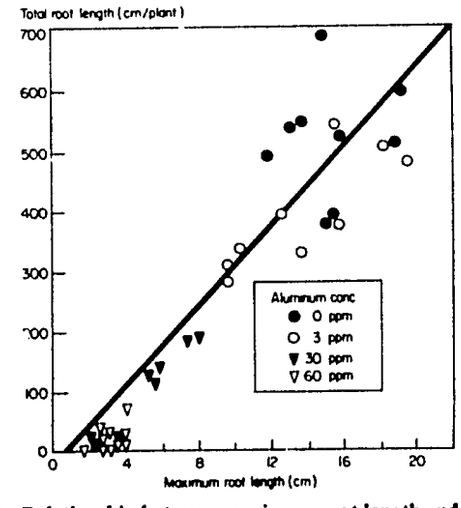
For acid upland soils, both aluminum-toxicity tolerance and deep root growth are desirable; hence, root length at 30 ppm Al was used to measure their tolerance for aluminum toxicity. Although measurement of root length is simpler at one concentration of aluminum than at two, it is subject to seasonal variation. The problem was solved by growing plants in a glasshouse room in the IRRI phytotron. Upland varieties are generally tolerant of aluminum toxicity



10. Effects of aluminum on growth of rice shoot and root length at two growth stages (av. of 9 varieties). IRRI, 1977.

while lowland varieties are susceptible. Among lowland varieties, Bluebonnet is relatively tolerant.

Mode of aluminum toxicity. Seedlings were grown in culture solution at pH 4.0; aluminum at concentrations from 0 to 60 ppm was added to the solution. Aluminum retarded the growth of roots more than it did the growth of shoots (Fig. 10). Rice was more susceptible to aluminum toxicity at 0 to 2 weeks old than at 2 to 5 weeks. Aluminum retarded the growth of nodal roots and branching, and, therefore, affected both maximum and total root length. Maximum root length and total root length correlated well



11. Relationship between maximum root length and total root length at various concentrations of aluminum. IRRI, 1977.

(Fig. 11). At 60 ppm Al, aluminum toxicity was so severe that varieties differed only slightly in maximum and total root length. At 30 ppm Al, varietal differences were large. At 3 ppm Al, only susceptible varieties were affected. Lowland varieties have shorter maximum root length than upland varieties, but their total root length is comparable to, or even greater than, that of upland rices.

SOIL-PLANT-WATER RELATIONSHIPS IN RICE

Agronomy Department

Water stress effects under high evaporative demand. A lysimeter study initiated at IRRI in the 1976 dry season was continued in 1977. Rices were evaluated for drought tolerance under high evaporative demand in the dry season at various moisture regimes that were determined by evapotranspiration (ET) values. Pregerminated seeds were dibbled into a dry granulated soil in lysimeter tanks at a spacing of 20 × 20 cm. Soils in the tanks were irrigated to saturation with overhead sprinklers. Two rices with similar growth duration were seeded in each tank. Ten days after emergence, the seedlings were thinned to 3/hill.

Evapotranspiration in the control tanks (5-cm continuous flooding) was measured daily. At the end of each week, ET values were added and their fraction — 3/4, 1/2, or 1/4 — was used in adding water to the respective tanks. The procedure gave quantitative basis to the control of the moisture regime based on ET value of a specific group of rice varieties. One treatment consisted of daily water supply of 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 by rewatering.

The ET value was greatest (11.1 mm/day) in the tanks of IR20 and IR4422-6-2 rices with 5 cm of continuous flooding; the tanks planted to Moroberekan and IR4432-28-5 had the lowest ET value, 9.7 mm/day. ET values were generally highest at about 64 to 70 days after seedling emergence (panicle initiation stage in most varieties). The presence of border plants surrounding the tanks resulted in lower ET values than those previously reported (1976 Annual Report).

Plant characters. The plant height at 65 days after seedling emergence was reduced significantly and tiller number decreased as moisture supply decreased. Continuous flooding at 5 cm increased plant height and tiller number. Plant height and tiller number at 1/4 of ET and continuous 1/4 of ET treatments were statistically similar. On the basis of mean height of each variety under all water regimes, the upland variety Moroberekan was the tallest but had the lowest number of tillers at 65 days after seedling emergence; IR36 was the shortest but had the most tillers. IR2035-117-3, IR442-2-58, IR4442-165-2-4, and IR4422-6-2 were among the relatively high tillering lines even at higher stress.

Table 18 shows the heading period, and the number of days that different stress treatments delayed heading. The rices that headed about a month later at 1/4 or continuous 1/4 of ET than at continuous flooding are IR1529-430-3, IR2035-117-3, IR3941-25-1, and IR20. Consequently, their maturity was also delayed. In the field, a 1-month delay in maturity may render a rice variety vulnerable to inadequate rainfall during grain filling. The advantage of a short-duration variety such as IR36 is overriding under a short but unimodal rainy season. Heading was also delayed, but less so, at 3/4 or 1/2 ET. The heading periods of Moroberekan and IR3880-13 were least affected by moisture supply at 1/4 ET or continuous 1/4 of ET values (Table 18).

Soil moisture tension (SMT). Moisture stress in the soil, measured by tensiometers, corresponded well with the moisture supply according to ET values (Fig. 12). At no time was SMT more than 45 cb; nevertheless, varietal differences due to the cumulative effect of moisture stress were evident.

Leaf xylem potential and drought tolerance. Varietal response of the 12 rices — in terms of leaf xylem potential (determined with a pressure chamber) — to the different water regimes was measured at 70 days after seedling emergence. Under 5 cm continuous flooding and 3/4 of ET, the varieties reacted like IR4432-28-5 and Moroberekan, registering the

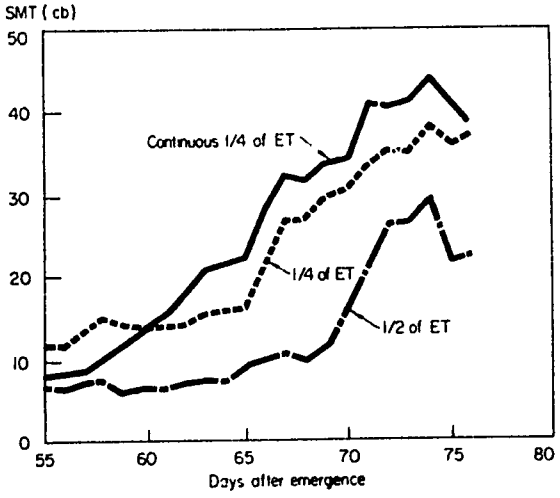
Table 18. Number of days to heading of 12 rices grown at different evapotranspiration (ET) levels.[a] Lysimeter study in the field, IRRI, 1977 dry season.

Designation	Days (no.) to heading				
	Continuous flooding at 5 cm	3/4 of ET	1/2 of ET	1/4 of ET	Continuous 1/4 of ET
Moroberekan	90	96 (6)	100 (10)	111 (21)	110 (20)
IR4432-28-5	87	95 (8)	103 (16)	113 (26)	110 (23)
IR1529-430-3	96	107 (11)	113 (17)	126 (30)	126 (30)
IR2035-117-3	96	110 (14)	110 (14)	126 (30)	126 (30)
IR442-2-58	91	104 (13)	110 (19)	116 (25)	116 (25)
IR4442-165-2-4	87	104 (17)	110 (23)	111 (24)	111 (24)
IR36	68	79 (11)	85 (17)	92 (24)	90 (22)
IR3941-25-1	69	83 (14)	89 (20)	99 (30)	95 (26)
IR20	83	92 (9)	94 (11)	111 (28)	111 (28)
IR4422-6-2	89	99 (10)	103 (14)	111 (22)	111 (22)
IR3880-13	82	91 (9)	98 (16)	103 (21)	100 (18)
IET 1444	74	82 (8)	89 (15)	97 (23)	95 (21)

[a]Figures in parentheses are the number of days that the stress treatments delayed the heading period beyond that of rice continuously flooded at 5 cm.

lowest and highest respective leaf xylem potentials (Table 19). When 1/2 of ET was imposed, IR1529-430-3 (-22.2 bars) and IR3941-25-1 (-21.6 bars) had the lowest leaf xylem potentials. Those values, however, were statistically similar to values of most of the lines. At 1/4 of ET and continuous 1/4 of ET, IR3941-25-1 and IR20 gave the lowest (about -29 bars) xylem potentials, while IR442-2-58 gave the highest (-18.8 bars).

Recent results from greenhouse experiments showed that drought resistance rating and leaf xylem potential are highly correlated. Under high evaporative demand and high soil moisture stress, the drought-tolerance ratings of IR20 and IR3941-25-1 were poorest (Table 20). Under identical but earlier treatments, those two rices also had the lowest leaf xylem potentials. On the other hand, 7 of the 12 rices had relatively good drought tolerance ratings (Table 20). On the basis of xylem potentials at 1/4 of ET and continuous 1/4 of ET and drought tolerance score, IR442-2-58 and IR4442-165-2 appeared promising; IR4442-165-2 was highly promising for drought tolerance in a study of limited rooting depth in the greenhouse (1976 Annual Report).



12. Soil moisture tension (SMT) at 20-cm depth in lysimeter tanks in the field at different evapotranspiration (ET) levels. IRRI, 1977 dry season.

Drought tolerance under limited rooting depth. The rooting depth of rice is limited by such factors as rainfed lowland or shallow surface soil conditions in upland culture with an impervious layer or hardpan. When rooting depths are limited, rices must withstand drought by other means. Therefore, the evaluation of rices for drought tolerance and the ability to recover from moisture stress under limited rooting depths is imperative. A methodology study on improved drought tolerance under shallow rooting depth, initiated in 1975, continued through 1977.

In the 1977 dry season, the parents of the promising lines selected in the 1976 wet season were screened. Among them, Khao Dawk Mali from Thailand and TKM6 from India had high levels of drought resistance (Fig. 13). But Mudgo, another Indian variety, was susceptible. Both TKM6 and Mudgo have been used exten-

Table 19. Leaf xylem potential[a] of 12 rices grown at different evapotranspiration (ET) levels at 70 days after rice emergence. Lysimeter study in the field, IRRI, 1977 dry season.

Designation	Leaf xylem potentials (bars) at				
	Continuous flooding at 5 cm	3/4 of ET	1/2 of ET	1/4 of ET	Continuous 1/4 of ET
Moroberekan	−10.4 b	−12.4 b	−16.4 ab	−20.2 ef	−20.6 cd
IR4432-28-5	−17.9 a	−18.4 a	−20.6 ab	−22.7 bcdef	−21.0 cd
IR1529-430-3	−15.9 ab	−15.5 ab	−22.2 a	−23.3 bcdef	−23.8 abcd
IR2035-117-3	−13.8 ab	−17.4 ab	−20.5 ab	−22.5 bcdef	−22.7 bcd
IR442-2-58	−13.7 ab	−15.2 ab	−15.0 b	−18.8 f	−18.8 d
IR4442-165-2-4	−16.1 ab	−16.8 ab	−18.6 ab	−22.0 cdef	−19.7 cd
IR36	−12.0 ab	−17.4 ab	−21.1 ab	−25.9 abcde	−25.3 abc
IR3941-25-1	−15.6 ab	−15.4 ab	−21.6 a	−30.0 a	−29.2 a
IR20	−16.0 ab	−18.1 ab	−20.3 ab	−28.6 ab	−28.9 ab
IR4422-6-2	−13.7 ab	−17.3 ab	−19.2 ab	−26.6 abcd	−25.9 abc
IR3880-13	−16.6 ab	−17.4 ab	−17.4 ab	−21.9 def	−20.8 cd
IET1444	−14.1 ab	−14.8 ab	−19.7 ab	−27.3 abc	−27.9 ab

[a]In a column, means followed by the same letter do not differ significantly at the 5% level.

sively as parents for resistance to the green leafhopper or brown planthopper at IRRI and elsewhere.

When several deep-water and floating rice varieties were tested in the 1977 dry season, Rayada R16-03 and HBJ DW8 also appeared promising for drought tolerance (Fig. 13). Two promising entries for submergence tolerance — IR5825-41-3-P_1 and IR5825-44-3-P_2 (Fig. 14) — were also promising for drought tolerance. One such line, IR5825-41-2-P_1, regrew when rewatered after severe moisture stress while most other rices were killed (Fig. 14). Among the elite breeding lines, IR3941-25-1, IR4432-28-5, and IR4722-361-1 appeared to have good drought tolerance (Fig. 14).

The results indicate that many breeding lines appear to have both good drought tolerance and most desirable traits such as high pest resistance and tolerance for problem soils.

Promising drought-tolerant lines will be evaluated for suitability as rainfed lowland and upland rice under various environmental stresses, particularly uncontrolled water and unfavorable rooting depths.

Drought tolerance at constant soil moisture tension. A modified greenhouse technique (1974 Annual Report) for rewatering pots helped maintain a predetermined and relatively constant soil moisture tension in a study of varietal response to soil moisture stress at different growth stages in the 1977 dry season.

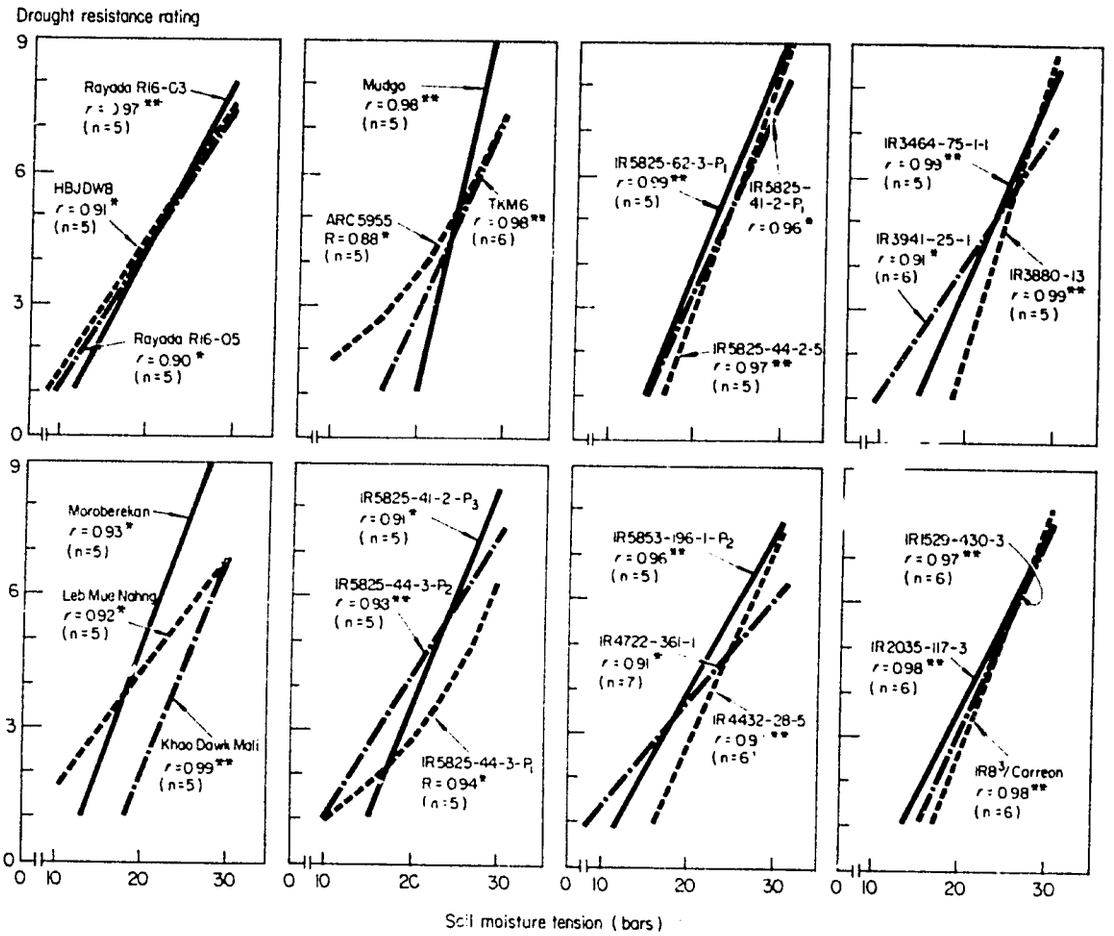
Twelve rices were subjected to 85 cb SMT from 5 days after seedling emergence to panicle initiation; then the soil was continuously saturated. In another treatment, the varieties were grown under continuous saturation from seedling emergence to panicle initiation, and then subjected to 40 cb SMT until crop maturity. A third set of varieties was continuously saturated throughout crop growth as a check. Each treatment was replicated four times. The plants subjected to vegetative stress were scored for drought tolerance at 52, 59, and 66 days after seedling emergence.

Moisture stress at the vegetative stage generally reduced plant height as well as tiller number per pot (Table 21). Those plant characters were affected slightly at reproductive stress. At all

Table 20. Drought tolerance ratings[a] of 12 rices grown at different evapotranspiration (ET) levels at 70 days after rice emergence. Lysimeter study in the field, IRRI, 1977 dry season.

Designation	Drought tolerance rating at		
	1/2 of ET	1/4 of ET	Continuous 1/4 of ET
Moroberekan	1	2	2
IR4432-28-5	1	2	2
IR1529-430-3	2	3	3
IR2035-117-3	1	2	2
IR442-2-58	1	2	2
IR4442-165-2-4	1	2	2
IR36	1	2	2
IR3941-25-1	2	4	4
IR20	2	4	4
IR4422-6-2	1	3	3
IR3880-13	1	2	2
IET 1444	2	3	3

[a]1976 Standard Evaluation System for Rice scale: 1 = no to very slight effects of stress; 9 = all plants apparently dead.



13. Drought tolerance ratings of rices under different levels of soil moisture tension. IRRI greenhouse, 1977 dry season. 1976 Standard Evaluation for Rice: 1 = no to very slight effects of stress, 9 = all plants apparently dead.

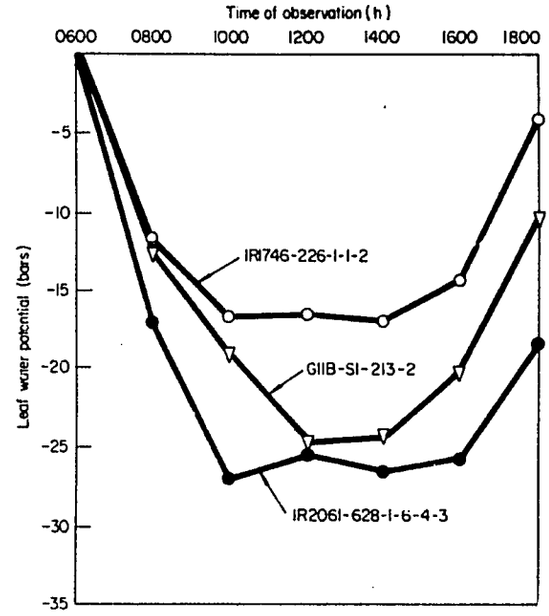
SMT levels, IR36 produced the highest number of tillers per pot; the upland variety Moroberekan had the lowest. Likewise, IR36 yielded highest when continuously saturated or stressed at the vegetative stage. Under reproductive stress, only IR36 (in all three replications) bore panicles with half-filled grains, indicating its relatively superior drought tolerance. The others either bore panicles with generally unfilled grains or were at the booting stage when the experiment terminated. Although Moroberekan had the best drought score in the third scoring under vegetative stress, it yielded lowest, mainly because its tillering ability is poor (Table 21).

At final scoring, IR20, IR3941-25-1, IR4422-6-2, and IET 1444 appeared relatively drought susceptible.

Results further indicate that the technique is suitable for evaluation of drought tolerance of rices at a specific growth stage under low but constant SMT. Because rooting depth is extremely limited, it may be used in evaluating rices for tolerance capabilities that are not aided by deep rooting.

Visual scoring and plant water status. Initial field screening for drought in lowland fields (wetland preparation, puddled soil) showed that changes in growth and development from induced water deficit were the same as those in previous upland screening trials. In the 1976 wet season, visual scoring in upland field screen-

14. When after 65 days without added moisture, a soil moisture tension of more than 30 bars was relieved, IR5825-41-2-P_1 (previously recorded as tolerant of submergence) regrew while most other rices were completely killed. IRRI greenhouse, 1977 dry season.



15. Leaf water potential values of three rices through the day, 28 March 1977. Lowland drought screening, IRRI farm, 1977 dry season.

ing was found to be associated with maintenance of high leaf water potential in the better varieties (1976 Annual Report). That relationship was further tested in lowland drought screening in the 1977 dry season.

Ten rices were visually scored and the leaf water potentials monitored at 74 days after transplanting and at 24 days after the field was drained. Typical curves for the diurnal change in leaf water potential of different varieties are shown in Figure 15. After 2 consecutive days of monitoring leaf water potential every 2 hours, the daily mean leaf water potential of each variety was calculated. Table 22 shows the separation and ranking of varieties by this index of plant water deficit.

The relationship of those values to values obtained by visual scoring (Fig. 16) is similar to that reported for upland field screening (1976 Annual Report). A variety's capability to maintain high leaf water potential or to avoid internal water deficit is assessed by visual scoring of

Table 21. Plant characters at harvest, yields, and drought resistance ratings of 12 rices at 3 levels of soil moisture tension.[a] IRRI greenhouse studies, 1977 dry season.

Designation	Plant ht (cm)			Tillers (no./pot)			Yield (g/pot)		Drought resistance rating[b] at VS		
	CS	VS	RS	CS	VS	RS	CS	VS	1st scoring	2nd scoring	3rd scoring
IR20	100	79	92	25	20	27	35	19	1	2	4
IR3880-13	107	91	98	27	20	23	36	21	1	2	3
IR3941-25-1	101	86	102	29	24	26	34	21	2	3	6
IR4422-6-2	105	81	101	24	21	24	32	18	2	2	4
IR4432-28-5	105	98	102	28	19	25	36	21	1	2	3
IR4442-165-2-4	101	80	102	21	21	19	33	21	1	2	3
Moroberekan	137	124	137	11	7	10	14	12	1	2	2
IR1529-430-3	89	80	89	20	19	19	33	19	2	2	3
IR2035-117-3	102	101	103	19	17	19	30	21	1	2	3
IR36	91	79	85	32	26	27	46	23	1	2	3
IR442-2-58	106	82	102	20	19	19	31	21	1	2	3
IET 1444	110	102	106	27	23	22	32	19	2	3	4

[a]CS = continuous saturation; VS = vegetative stress at 85 cb soil moisture tension (from 5 days after seedling emergence until panicle initiation); RS = reproductive stress at 40 cb soil moisture tension (from panicle initiation to crop maturity). [b]1976 Standard Evaluation for Rice: 1 = no to very slight effects of stress; 9 = all plants apparently dead.

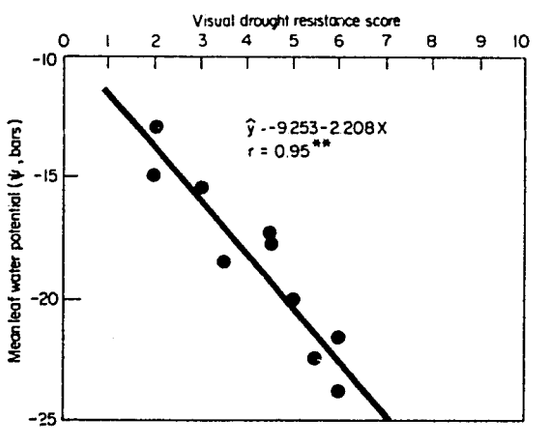
Table 22. Separation[a] of rice varieties and lines based on mean leaf water potential (ψ) during 1 day of dry-season lowland drought screening. IRRI, 1977 dry season.

Designation	1800 Mean $\Sigma\psi$ 2 h/7 (bar) 0600
IR1754-F$_5$B-23	13.0
IR1746-226-1-1-2	14.8
IRAT 13	15.28
IR 34	17.4
Kaibid	17.6
G11b-SI-213-1	18.7
IR2070-320-6-5-3	20.1
IR4215-4-3-1	21.6
Intan	22.4
IR2061-628-1-6-4-3	23.8

[a]Means followed by a common line do not differ significantly at the 5% level.

varieties in lowland drought screening in the dry season. Note that this correlation does not rule out the existence or action of mechanisms by which varieties tolerate low leaf water potential; it simply points out the current inability to measure and assess the role of such mechanisms.

Water deficit intensity, duration, and yield. The soil matric potential at 15-cm depth and atmospheric evaporative demand 1.5 m above ground were monitored daily in an upland rice farmer's field in Batangas, Philippines, during the 1975 and 1976 wet seasons. The daily minimum leaf water potential of three rice varieties was periodically measured. The influence of these soil and atmospheric variables on the leaf water potential was shown in the 1976



16. Relationship between visual drought resistant scores of 10 rice varieties and the mean leaf water potential over the day. Lowland field screening, IRRI, 1977 dry season.

Annual Report. Regression equations were developed for the three varieties used in this study:

$$\hat{Y} = 3.8 + 0.51X_1 - 0.00338X_1^2 - 0.497X_2 + 0.00253X_2^2 \ (R = 0.81^{**}) \text{ for IR20,}$$

$$\hat{Y} = 4.51 + 0.064X_1 - 0.00257X_1^2 - 0.458X_2 + 0.00192X_2^2 \ (R = 0.81^{**}) \text{ for IR1529-680-3-2, and}$$

$$\hat{Y} = 6.23 + 0.24X_1 - 0.00156X_1^2 - 0.615X_2 + 0.00484X_2^2 \ (R = 0.76^{**}) \text{ for M1-48}$$

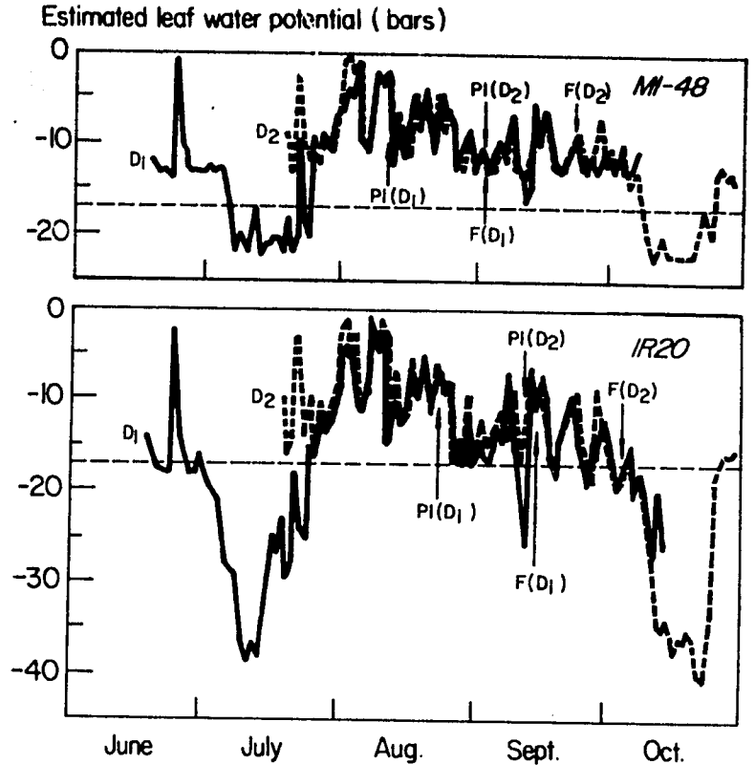
where $\hat{Y}$ is daily minimum leaf water potential (bars), X_1 is soil matric potential (cb), and X_2 is deficit of air water vapor pressure (mb) summed

from 0600 to 1800 hours $\sum_{0600}^{1800}$ VPD 2h

The regression equation for each variety was then used to estimate the daily minimum leaf water potential throughout growth and development from two planting dates, D_1 and D_2, in 1976. The two cropping periods allowed separate examination of the effects of water deficits on the vegetative (D_1) and reproductive stages (D_2).

Figure 18 illustrates the daily estimates of minimum leaf water potential for M1-48 and IR20 (IR1529-680-3-2 results were omitted because they were similar to those of IR20). The varietal differences in maintenance of leaf water potential, noted in previous reports (1976 Annual Report), are obvious.

Measures of plant water deficit from field-grown crops have rarely been directly associated with growth, development, and yield. The primary nontechnical factors that have obscured this intuitive association are the difficulty of quantifying the interaction of intensity and duration of water deficits and the varying sensitivity of different growth stages. Table 23 shows efforts to overcome these problems. The intensity of water deficit was computed as the difference between the daily minimum leaf water potential and the -17 bar arbitrary value. The duration of water deficit was calculated as the sum of days when the estimated minimum leaf water potential was less than -17 bars. Figure 17 shows how those values and their multi-



17. Estimated minimum daily leaf water potential (LWP) during growth of M1-48 and IR20 (the minimum daily LWP of IR1529-680-3-2 is similar to that of IR20). PI = panicle initiation; F = flowering; D_1 = 1 June 1976; and D_2 = 1 July 1976. Broken line (-17 bars) is an arbitrary threshold level of leaf water potential. Cuenca, Batangas province, 1976 wet season.

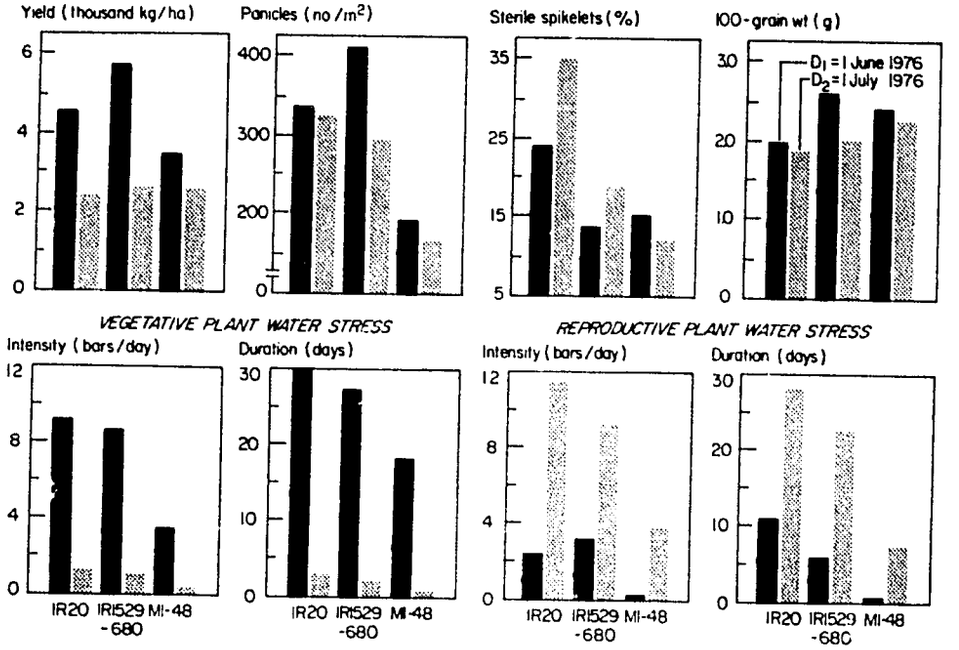
ples (intensity × duration) can be accounted for during the specific growth stages found in Table 23.

Note that the three varieties are not phenologically matched. Thus, the water-deficit parameters were quantified independently for

Table 23. Intensity and duration of plant water stress on IR20, IR1529-680-3-2, and M1-48.[a] Batangas province, Philippines, 1976 wet season.

Planting date[b]	Vegetative stage: 10 DE - PI			Reproductive stage: PI - 21 DF			10 DBF - F			F - 21 DF		
	Intensity (bars/day)	Duration (days)	Intensity × duration (bars)	Intensity (bars/day)	Duration (days)	Intensity × duration (bars)	Intensity (bars/day)	Duration (days)	Intensity × duration (bars)	Intensity (bars/day)	Duration (days)	Intensity × duration (bars)
						IR20						
D_1	-9.02	-30	-270.60	-2.44	13	-31.72	-6.34	3	-19.01	-1.48	7	-10.36
D_2	-1.00	-2	-2.00	-11.19	27	-302.16	-5.83	4	-23.33	-14.64	20	-292.88
						IR1529-680-3-2						
D_1	-8.46	-27	-228.49	-2.97	8	-23.76	-4.71	3	-14.13	-2.25	4	-9.01
D_2	-0.70	-1	-0.70	-8.82	22	-194.15	-3.24	2	-6.47	-10.29	18	-185.18
						M1-48						
D_1	-3.34	-18	-60.12	0	0	0	0	0	0	0	0	0
D_2	0	0	0	-3.74	6	-22.47	0	0	0	-3.74	6	-22.47

[a]DE = days after emergence, PI = panicle initiation; DF = days after 80% flowering of the crop; DBF = days before flowering, F = 80% flowering; [b]D_1 = seeding date 1 (1 June 1976), D_2 = seeding date 2 (1 July 1976).



18. Yield and yield components of IR20, IR1529-680, and M1-48. Intensity and duration of plant water stress at vegetative and reproductive stages. Batangas province, Philippines, 1976 wet season.

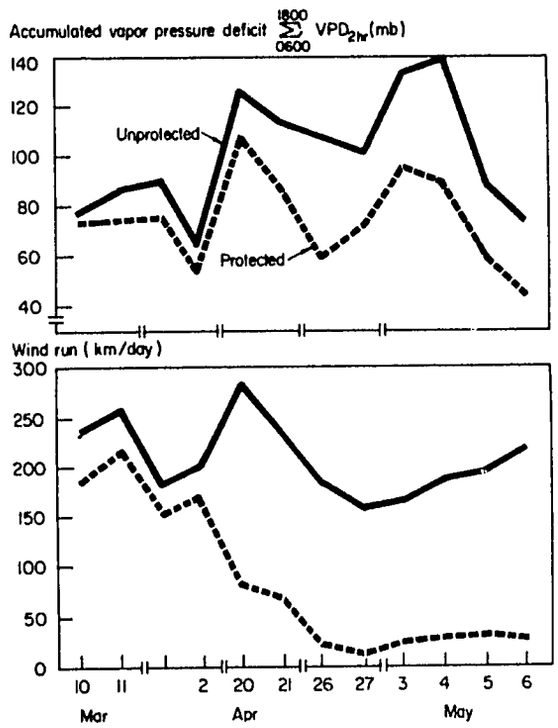
each variety by combination of its growth stage and date of seeding. Table 23 illustrates how the two planting dates and the three varieties differ in duration, intensity, and duration × intensity of internal plant water deficit. For the two IR varieties, the crop seeded on 1 June 1976 (D_1) suffered much more in the vegetative stage while that seeded on 1 July 1976 (D_2) was affected mainly in the reproductive stage. The upland variety M1-48, however, responded less to the same soil and climatic conditions at both growth stages. The higher root-to-shoot ratio (mg:g) of M1-48 may partially explain that (1974 Annual Report). The plasticity of leaf rolling in M1-48, which is also more than that in the lowland hybrids, may relate to maintenance of leaf water potential.

Before relating this quantification of plant water deficit to growth and yield, note that the two IR varieties have inherently greater yield potential than M1-48 (Fig. 18, D_1). Figure 18 shows the effects of those plant water deficit parameters on yield, panicle number per square meter, sterility percentage, and 100-grain weight. The trends for intensity and duration of plant water deficit and varietal differences show close cause-and-effect relationships with the measures of growth and yield components.

Figure 18 shows the crop's capability to compensate for water deficits during the early vegetative stage. All D_1 crops yielded well despite the high intensity and duration of vegetative stage deficits. The D_2 crops in the reproductive stage showed characteristic sensitivity to water deficit in terms of affected yield components. With reference to the timing of reproductive stages in Figure 18 and Table 23, the effects on specific yield components can be correlated with the level of plant water deficit.

The efforts to quantify intensity and duration of plant water deficits and to use their interactions to interpret crop response have been useful in understanding the dynamic nature of the upland-rice soil-plant-atmospheric water continuum. The technique should be useful in any research project where the crop's water status through time is evaluated as a yield determinant.

Modification of evaporative demand in a rice-corn intercrop. The sensitivity of rice leaf water potential to atmospheric evaporative demand has previously been illustrated (1976



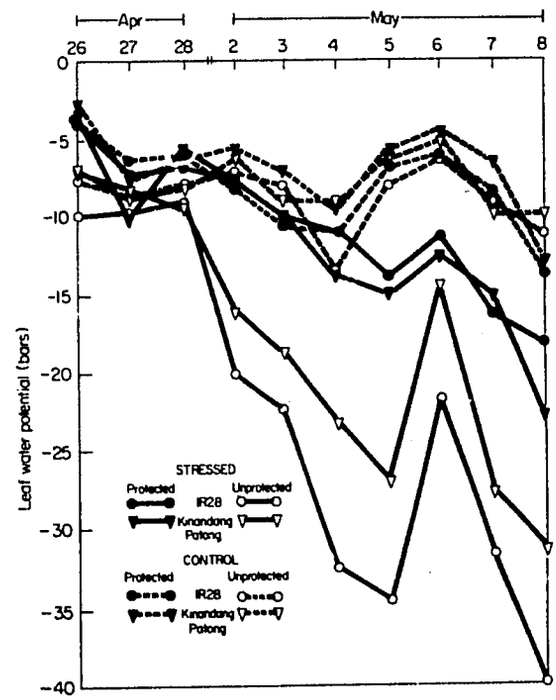
19. Changes in the rice crop microclimate attributable to intercropping with corn at selected dates during the growing season. The rice and corn were seeded 2 and 9 February 1977, respectively. IRRI, 1977.

Annual Report). Cultural practices that ameliorate that condition should be investigated for use in drought-prone rice cultural systems.

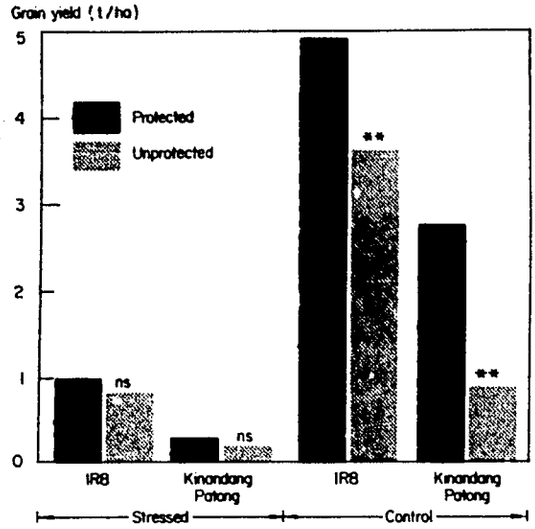
During the 1977 dry season, the effects of a corn intercrop on the microclimate and plant water relationships of upland rice were studied. In the dry season at Los Baños, solar radiation and air temperature are high, relative humidity is low, days are windy, and a seasonal advective energy flux exists. The conditions are excellent for evaluation of the potential to modify atmospheric conditions of the rice canopy by intercropping with a taller species. In this study, corn was used as a wind barrier, and the plant and atmospheric water status of the rice crop were monitored through time. Double rows of corn were planted 6 m apart and rice was sown in the interrow space in rows 25 cm apart.

A stress period was induced about 10 days before 50% flowering. Water was withheld from the plots until the daily maximum and minimum leaf water potentials were equal. On the basis of yield, that level of stress proved too severe.

Figure 19 shows the effect of the corn wind barrier on the microclimate of the rice canopy through the growing period. The wind speed and water vapor pressure deficit of the air (1.25 m above ground) decreased above the rice canopy in the protected or inter-cropped plots. Figure 20 demonstrates the response of average daily leaf water potential $\left[\frac{\psi\,max + \psi\,min}{2}\right]$ of rice to this modification of the canopy microclimate during the stress period. The effect is most evident in protected vs. unprotected stress plots; the control plots appear to have responded mainly to daily fluctuations in evaporative demand. The average of dawn and midday leaf water potentials illustrates the effect of the stress treatment and the moderating influence of the corn wind barrier.



20. Average daily leaf water potential $\left[\frac{\psi\,max + \psi\,min}{2}\right]$ response of two rice varieties (the lowland hybrid IR28 and the Philippine upland variety Kinandang Patong) in an open upland field (unprotected) and on the leeward side of a corn wind barrier (protected). The control was irrigated, the stress treatment was not, from 19 April to 8 May 1977. IRRI upland farm, 1977.



21. Yields of two rice varieties (the lowland hybrid IR28 and the Philippine upland variety Kinandang Patong) in an open upland field (unprotected) and on the leeward side of a corn wind barrier (protected). The control was irrigated, while the stress treatment was not, from 19 April to 8 May 1977. IRRI upland farm, 1977.

The rice yield also showed the effects of modified microclimate (Fig. 21), but the results are not as expected. The yields of the stressed plots did not significantly differ, but those of the well-watered control plots did. The stress levels imposed were obviously too severe and thus cancelled out the protection of the wind barrier. Recent research on the yield of other field crops has shown that severe stress levels override the changes induced by a wind barrier. The significant yield increase in the protected control plots over the unprotected, however, underscores the important finding that intercropped rice benefits significantly from mediated microclimatic changes in the soil-plant atmosphere continuum. More detailed monitoring of plant water status to document the effects that cause those yield differences is planned.

Interestingly, intercropping of upland rice with corn, cassava, or other relatively tall species is quite common on many Asian upland farms. But intercropping of lowland rice with wind-barrier species is rare, even in chronically drought-prone regions. Further research is needed to verify the findings and test their applicability in various cultural systems and seasons.

Genetic evaluation and utilization (GEU) program

Tolerance for adverse soils

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SALINITY

Soil Chemistry and Plant Breeding Departments

Screening techniques. The current greenhouse technique for salinity screening, using one tray (1975 Annual Report) per entry, permits screening of only 4,000 entries/year per 100 m^2 of bench space. To increase screening capacity, 3 varieties/tray were planted in 3 rows of 15 plants each. Ratings by the two methods did not differ significantly (Table 1). The modified method will triple screening capacity.

The salt concentration of 0.5% in the soil used for screening at IRRI corresponds to a 10 mmho/cm electrical conductivity in the saturation extract (EC_e). Because in saline rice fields the salt content often exceeds 0.5%, 20 salt-tolerant varieties were grown at a salt concentration of 0.6% (EC_e = 12 mmho/cm). Only two entries, IET 1444 and IR4630-22-2, gave a score of 3 (scale: 1 = almost normal plants; 9 = almost all plants dying), indicating tolerance for a salt concentration of 0.6%. Nine varieties that scored 1 at 0.5% barely survived at 0.6% (score, 9).

A common objection to the screening technique is that salt injury at 4 weeks after transplanting may not correlate with grain yield. An earlier study (1976 Annual Report) indicated a good correlation between the salt injury scores and yields of 17 varieties with varying salt tolerance. A similar test with 9 tolerant varieties showed no correlation between tolerance score at 4 weeks (1 to 4) and relative grain yield (15 to 96%), although the relative salt tolerance scores were roughly constant from transplanting to harvest.

Mass screening. Of 5,462 entries screened for salt tolerance in 1977 in the greenhouse, 52 scored 1, 71 scored 2, and 550 scored 3 (scale: 1 = almost normal plants; 9 = almost all plants dying). Fifty of the most tolerant entries came from the salt-tolerance hybridization program (Table 2).

Table 1. Influence of two planting methods on salt injury. IRRI greenhouse, 1977 wet season.

Entries (no.)	Plants (no.)	Salt injury mean score[a]		
		Pokkali	IR2153-26	M1-48
1	6	2.0	2.7	9.0
3	45	2.3	2.3	9.0

[a]Scale: 1 = almost normal plants; 9 = almost all plants dying.

Screening in concrete beds. Of 16 entries screened on a concrete bed, Kalarata 1-24, IR4-11, IR2153-26-3, IR4111-2-2, IR4630-22-2, and IR4763-141-2 showed tolerance for salt at a concentration corresponding to an EC_e of 9 mmho/cm.

Monitoring field salinity. The progeny from the salinity hybridization program is tested in an artificial saline soil at the IRRI farm. A problem is that salinity varies spatially and with time. To monitor salinity, 16 piezometers (Fig. 1) were installed in the 0.1-ha testing field. The EC (electrical conductivity) of the solutions in the piezometers (EC_p), and that of the soil solutions extracted from the mud, were measured. The piezometer readings ranged from 7.0 to 10.0 mmho/cm (X = 7.3) at ambient temperature (~30°). The soil-solution EC values were almost the same, 6.6 to 9.6 mmho/cm (X = 7.7) at 25°C.

In a separate experiment, the EC of the solutions inside eight piezometer tubes and that of the surface water outside were monitored over 4 months in the wet season. Figure 2 shows that the salt concentration, as measured by EC, decreased both in and outside the tubes but decreased more in the solution outside. Salt was broadcast at intervals to restore the losses.

When screening for salt tolerance in the field, salinity must be monitored and salt losses restored, especially in the wet season.

Field screening at IRRI (*Soil Chemistry*). Of 2,336 pedigree lines from the salinity hybridization program tested in an artificial saline soil at IRRI in 1977, 61 were salt tolerant (score: 1 to 3), 806 were moderately tolerant (3.5 to 5.0), and the others, susceptible (7-9).

Field testing of promising selections *(Soil Chemistry and Plant Breeding).* Rices identified as salt tolerant in IRRI greenhouse and field screening were tested in saline fields at five locations in the Philippines: Sinacaban, Misamis Occidental province; Calapan, Mindoro; Lubao, Pampanga; Sabang, Camarines Sur; and Taal, Batangas.

The reactions of the entries varied with location, largely because of soil differences. The pH

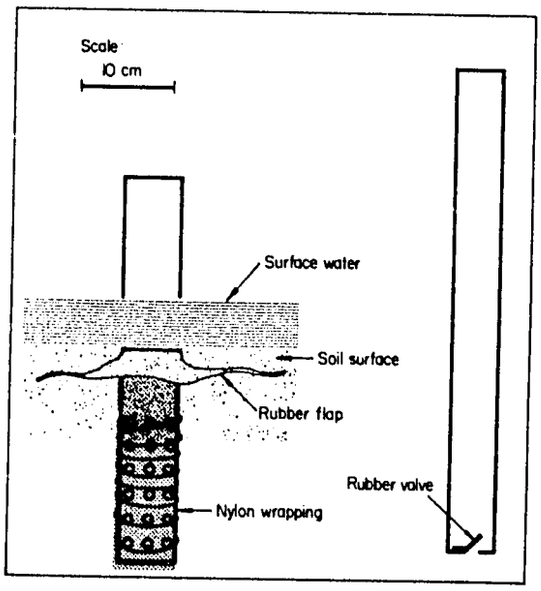
Table 2. Distribution among salt-tolerance scores of rices from various sources. IRRI greenhouse, 1977.

Source	Rices (no.) with salt-tolerance score[a] of						Total
	1	2	3	5	7	9	
Germplasm bank	0	9	36	132	162	514	853
Salt-tolerance hybridization program	50	53	396	718	892	1112	3221
IRSATON[b] (1976 & 1977)	0	1	7	24	30	23	85
OYT[c] (1977)	1	1	27	34	57	177	297
RYT[d] (1977)	0	2	23	19	78	446	568
Elite lines (1977)	0	0	16	10	51	98	175
Hybridization block (1976 & 1977)	0	4	13	14	37	32	100
Reportedly salt-tolerant varieties	0	0	0	1	0	20	21
Deep-water rices	0	0	14	22	22	8	66
Others	1	1	11	23	22	22	80
Total	52	71	550	997	1358	2534	5562

[a]Scale: 1 = almost normal plants; 9 = almost all plants dying. [b]International Rice Salinity & Alkalinity Tolerance Observational Nursery. [c]Observational yield trial. [d]Replicated yield trial.

ranged from 6.6 to 7.8, the organic matter content from 3.1 to 15.4%, and the EC_e from 5.3 to 12 mmho/cm. The EC_e varied horizontally, vertically, and with time. At Taal the soil was severely deficient in zinc.

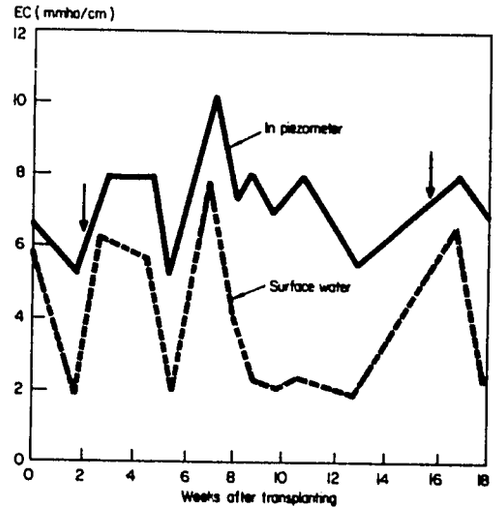
Visual observations revealed that the following are moderately salt tolerant: IR2071-88-8, IR2071-586-5, IR2153-26-5, IR4422-6-2, IR4422-164-3, IR4432-52-6, IR4630-22-3, and IR5657-33-2.



A. Piezometric tube (sketch) B. Bailer (cross section)

1. Piezometric tube and bailer.

Floods, rat damage, or zinc deficiency prevented completion of the experiments at all locations except Calapan and Sabang, where the soil had a mean EC_p (sampling 5-20 cm of the soil from the surface) of 9-11 mmho/cm at transplanting and 12.7 cm 3 months later. Six of the 10 selections there yielded 4 t/ha or more in the 1977 wet season, suggesting high salt tolerance (Table 3). A study of the vertical distribution of salt in the soil (shown below), however, indicated that the roots (which were confined to the first 7 cm of soil) were subjected to a salt concentration corresponding to an EC in the soil solution of 1.2 to 8.3 mmho/cm.



2. Changes in electrical conductivity (EC) of water in piezometer tubes and in the surface water in a salinized IRRI field, 1977 wet season.

Table 3. Performance of 10 lines on a saline soil at Calapan, Mindoro, Philippines, 1977 wet season.

Line	Yield (t/ha)
IR2071-88-8	4.8
IR2071-586-5	4.4
IR2153-26-3	3.8
IR2863-39-1	4.4
IR4422-6-2	4.0
IR4422-164-3	4.4
IR4432-28-5	3.4
IR4432-52-6	3.4
IR4432-103-6	4.1
IR5657-33-2	2.9

Depth (cm)	EC of soil solution (mmho/cm)
0–1	1.2
1–2	3.0
2–4	5.0
4–7	8.3
7–10	10.8
13–15	14.6
15–17	16.7
17–20	18.7

The comparative performance of 14 rices was studied in a replicated field experiment on a coastal saline soil at Sabang, Camarines Sur, in the 1977 dry season. Two improved lines, IR4630-22-3-3-2 and IR2071-105-4-5, yielded almost as much as Pokkali, the tolerant check (Table 4). IR4630-22-3-3-2, because of its salt tolerance and its height, appears promising as a variety suited to coastal saline soils subject to tides.

Table 4. Performance of some cultivars and salt-tolerant lines in a coastal saline area. Sabang, Camarines Sur province, Philippines, 1977 dry season.

Designation	Date of flowering	Plant ht (cm)	Yield[a] (t/ha)	
IR26	11-14 Oct.	62	1.0	e
IR28	14 Sept.	65	1.0	e
IR30	4- 6 Oct.	69	1.3	de
IR2070-820-3	19-21 Oct.	69	1.6	cde
IR2071-105-4-5	11-14 Oct.	81	2.8	ab
IR2071-586-5-6-3-4	23-25 Oct.	79	2.3	abc
IR2153-96-1-5-3	4-10 Oct.	74	1.9	bcde
IR2823-399-5-6	11-17 Oct.	78	2.5	abc
IR2153-26-3-5-2	4- 6 Oct.	76	2.4	abc
IR2071-88-8-10	6-11 Oct.	73	2.1	abcd
IR4630-22-3-3-2	11-16 Oct.	92	2.6	ab
BPI-76 (NS)	13-21 Oct.	95	2.4	abc
C4-63G	11-14 Oct.	89	2.6	ab
Pokkali (tolerant check)	4-10 Oct.	146	2.9	a

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

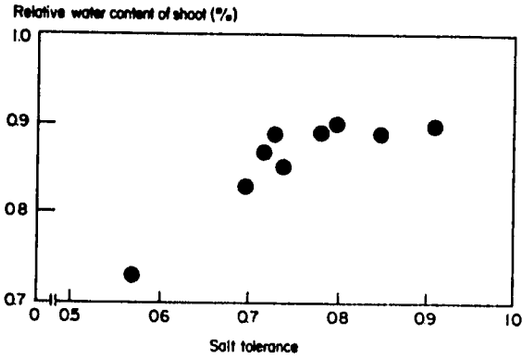
IRSATON at IRRI *(Soil Chemistry).* Seventy-four entries of the International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON) were planted in a salinized field at IRRI in the 1977 dry season. The pH was 6.6. The mean EC_e was 7.8 mmho/cm at transplanting and 3.4 10 weeks later. Four weeks after transplanting, only IR3265-193-3, IR2070-719-3, and B58b MD-105-2 gave mean scores of 4 or less. Ten weeks later, when the mean EC_e had dropped to 3.4 mmho/cm, the following scored 3 or less: IR36, IR2832-141-2, Mahsuri, Patnai 23, IR4-11, IR2031-729-2, IR2053-160-1, IR2070-719-3, IR2071-323-2, IR2145-20-4, B57c-Md-10, Kencana, Pelita I-1, and IR4-11. The best overall performer was IR70-719-3; the poorest, IRAT 8.

In the 1977 wet season, 80 entries were planted. The mean EC_p ranged from 5.8 to 7.6 mmho/cm. The plants were scored at 4, 6, 8, and 10 weeks after transplanting. The following gave mean scores that were equal to or better than that of the resistant check Pokkali (3.4): Damodar, Nona Bokra, Getu, Patnai 23, IR32, Nonasail (sel), Cul. No. 25, Cul. No. 29, Cul. 69, Cul. No. 93, Cul. No. 100, and Getu mutant No. 2735.

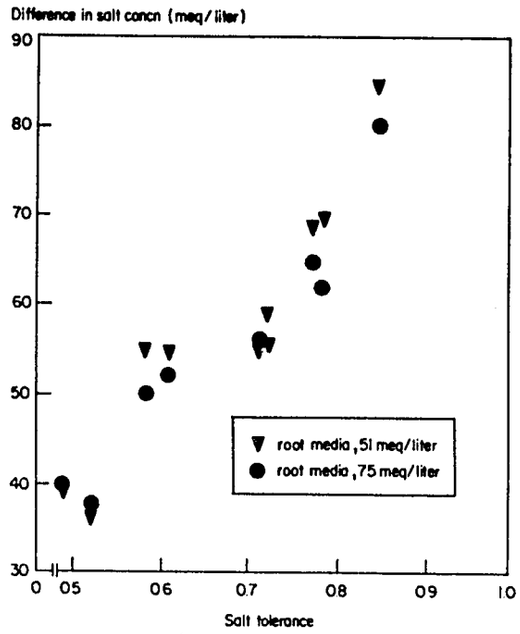
Mineral content of roots as salt-tolerance index *(Soil Chemistry).* The main adverse effect of excess salt on nonwoody plants is believed to be osmotic. If so, varieties that adjust better to the external salt concentration should tolerate salt better than others. Both shoots and roots adjust osmotically to increased salt concentration in the root medium by increasing ion uptake and by generating harmless water-soluble organic substances. To ascertain the role of ion accumulation in salt tolerance, the mineral contents of the roots and shoots of rice varieties of varying salt tolerance were determined in separate experiments.

In one experiment 9 rice varieties were grown in a complete nutrient solution with sodium chloride at 12 meq/liter and calcium chloride at 24 meq/liter in the first 2 weeks, and 34 meq/liter and 24 meq/liter, respectively in the next 2 weeks.

Dry weights of the 4-week-old shoots grown in saline solutions as a fraction of the weights



3. Relation of shoot water content to salt tolerance of rice cultivars grown on saline and nonsaline culture solutions.



4. Salt tolerance $\left(\frac{\text{saline shoot growth}}{\text{nonsaline shoot growth}}\right)$ of rice cultivars as related to differences in salt concentration between root water and root media.

obtained in nonsaline solution were plotted against relative water contents of the fresh shoots (Fig. 3). The water of the saline solution shoots never exceeded 0.9 of the water content of the nonsaline shoots, indicating that salt injury in rice may involve water stress.

Root studies indicate that salt tolerance is associated with osmotic adjustment. When plotted, the difference between the salt content of the roots and culture solution correlated well with the salt tolerance of the rice varieties expressed as relative shoot growth (Fig. 4).

Shoot mineral content as salt-tolerance index *(Soil Chemistry)*. No significant correlation between sodium or cation content of the straw and salt tolerance was found in 50 varieties grown in pots in a soil with an EC_e of 10 mmho/cm. But the straw of the five most tolerant varieties had a significantly lower cation content than that of the five most susceptible (Table 5).

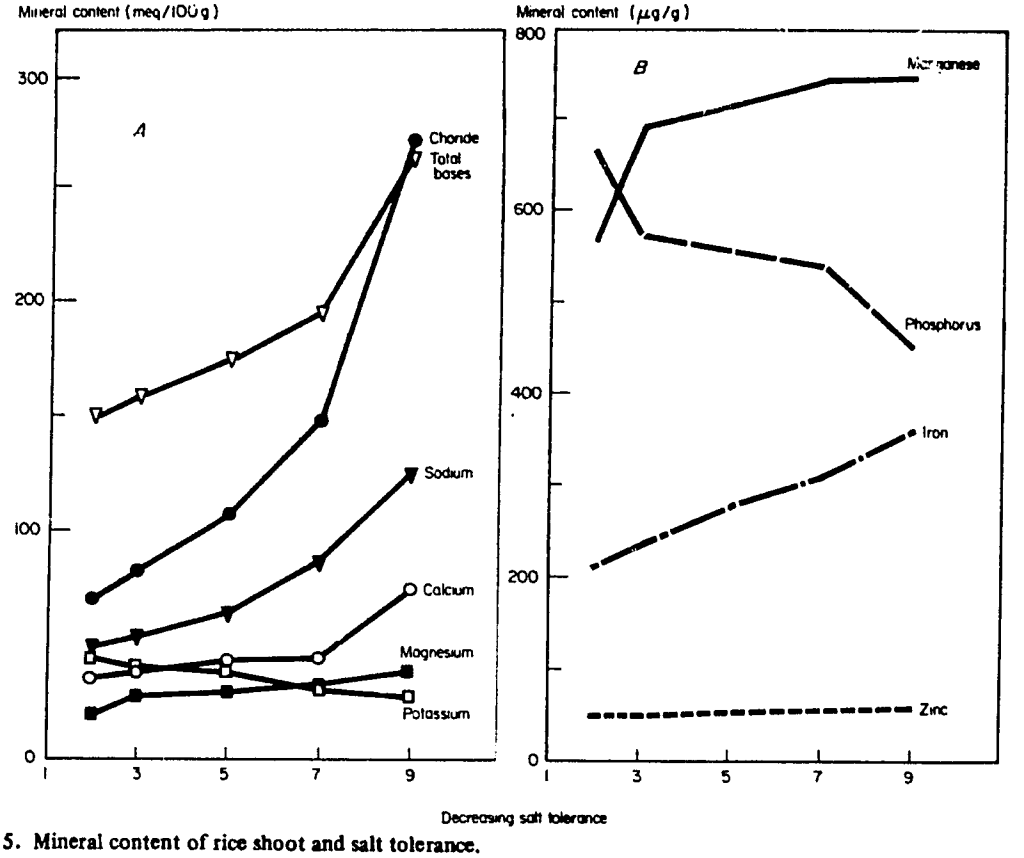
That finding was confirmed in a subsequent study of the relationship between the mineral content of the shoot and salt tolerance. The contents of total cations, sodium, calcium, and magnesium, as well as the chloride content of the shoot, increased with decreasing salt tolerance (Fig. 5A). The potassium and phosphate contents, however, decreased with decreasing salt tolerance (Fig. 5). The content of manganese increased markedly, that of iron appreciably, and that of zinc slightly as salt tolerance decreased (Fig. 5B).

Those results indicate that salt tolerance in rice is associated with a high electrolyte content in the roots and a low content in the shoot. The ability to accumulate potassium in the shoot correlated well with salt tolerance. Apparently salt-tolerant rices achieve osmotic balance be-

Table 5. Comparison of the cation content of the straw of the 5 most tolerant and the 5 most susceptible of 50 varieties grown in a soil with an EC_e (electrical conductivity in saturation extract) of 10 mmho/cm in an unreplicated greenhouse experiment. IRRI, 1972 wet season.

Variety	Relative grain yield*	(Na+K+Ca+Mg) of straw (meq/100 g)
Most tolerant		
Pokkali	119	130
Doc Phung R-37	112	112
SML Awini	106	106
IR712-23-2	99	129
Doc Phung Lun AR-16	98	119
Mean	107	120
Most susceptible		
Bala	53	156
IR442-2-58	51	125
T26	45	145
RP5-3	32	146
MI-48	4	164
Mean	37	147

*$\frac{\text{Yield on normal soil}}{\text{Yield on saline soil}} \times 100$.



5. Mineral content of rice shoot and salt tolerance.

tween the roots and the medium by accumulating ions and retaining them against transfer to the shoot. The shoots probably attain osmotic balance by generating harmless soluble organic substances such as proline. For example, the salt-tolerant variety Pokkali accumulated 13.3 times more proline in the shoot when grown in a saline soil than when grown in a normal soil, but the sensitive variety MI-48 accumulated only 6.3 times more.

Chloride toxicity and salt injury *(Soil Chemistry)*. To determine if chloride toxicity is a factor in salt injury in rice, four rices of varying salt tolerance were grown in a nutrient solution in the greenhouse for 23 days after transplanting and in an identical solution treated with sodium chloride and with sodium sulfate to give an osmotic potential of -2 bars. Table 6 shows that relative growth, relative shoot water content, and difference in osmotic potentials of root

Table 6. Effect of chloride and sulfate salts on salt tolerance, relative shoot water content, and root salt level of four rice cultivars grown at an osmotic potential (OP) of -2 bars. IRRI, 1977 wet season.

Variety	Chlorides			Sulfates		
	Salt tolerance[a] (ratio)	Relative shoot H_2O content[b] (%)	Root salt level[c] (bar)	Salt tolerance[a] (ratio)	Relative shoot H_2O content[b] (%)	Root salt level[c] (bar)
Pokkali	0.81	0.94	-2.8	0.77	0.92	-2.3
IR8	0.75	0.95	-1.9	0.74	0.93	-2.0
IR26	0.60	0.94	-1.5	0.68	0.93	-1.8
MI-48	0.64	0.85	-1.4	0.65	0.88	-1.3
Mean	0.70	0.920	-1.90	0.71	0.915	-1.85

[a]Saline growth ÷ nonsaline growth. [b]Saline H_2O ÷ nonsaline H_2O. [c]AOP (OP of root — OP of root media estimated by electrical conductivity).

Table 7. Salt tolerance, relative shoot water content, and root salt level of *O. glaberrima* and drought-resistant cultivars of *O. sativa*. IRRI greenhouse, 1977 wet season.

Species designation	Salt tolerance[a] (ratio)	Relative shoot H_2O content[b] (%)	Root salt level[c] (meq/liter)
O. glaberrima No. 102377	0.89	0.96	73
O. glaberrima No. 102674	0.75	0.92	65
O. glaberrima No. 102572	0.67	0.88	61
O. glaberrima No. 102659	0.65	0.89	62
O. glaberrima No. 102655	0.64	0.87	60
O. glaberrima No. 102693	0.60	0.89	56
O. glaberrima No. 102669	0.44	0.72	45
O. sativa 63-83 Ft-3-1964	0.86	0.98	62
O. sativa IRAT 10	0.70	0.92	63
O. sativa Pokkali (control)	0.73	0.93	80

[a]Saline shoot growth ÷ nonsaline shoot growth. [b]Saline shoot H_2O ÷ nonsaline shoot H_2O [c]Salt concentration in root H_2O – salt concentration in root media.

water and the culture solution are essentially the same for chloride and sulfate. That indicates the absence of chloride toxicity and of any benefit from sulfate.

Salt tolerance of *O. glaberrima* and drought-tolerant rices *(Soil Chemistry)*. Although Pokkali is one of the most salt-tolerant rices, it does not accumulate enough salts to give it the degree of salt tolerance that barley and wheat have. Therefore, the behavior of six varieties of *O. glaberrima*, the drought-tolerant rices 63-83 and IRAT 10, and Pokkali was studied in solution culture at an osmotic potential of -2 bars (Table 7). Salt tolerance and relative shoot water content as well as salt tolerance and salt levels were strongly and positively correlated. *O. glaberrima* No. 102377 and 63-83 appear more salt tolerant than Pokkali. The ability of 63-83 to maintain a high shoot water content without a high root salt concentration indicates that its salt tolerance is due to a water-conserving mechanism.

ALKALINITY

Soil Chemistry and Plant Breeding Departments

Screening techniques (*Soil Chemistry*). To save space in greenhouse screening, three entries, instead of one, were planted on each tray. As in the salinity test, the scores by the new test did not differ significantly from those by the single-entry test.

To ascertain if increasing the concentration of sodium carbonate in the soil used for screening from 1.4 to 1.5% would increase the reliability of the test, 17 tolerant varieties were planted, following the technique described in the 1975 Annual Report in Maahas clay treated with 1.5% sodium carbonate. All but two scored from 5 to 9, indicating that the higher concentration of sodium carbonate was unsuitable.

Mass screening for alkali tolerance (*Soil Chemistry*). In 1976–77, 1,891 entries were screened in the greenhouse on an artificial soil of pH 8.6. The entries and results are in Table 8.

Field screening (*Soil Chemistry and Plant Breeding*). In 1977 more than 2,000 entries, including elite breeding lines and pedigree lines from the alkali tolerance hybridization program, were screened in an artificial alkali field (pH 8.6) at the IRRI farm. The seedlings were dipped in a 2% suspension of zinc oxide in water to minimize zinc deficiency. Seventy-six entries gave scores of 2.5 to 3.0 (tolerant) (Table 9).

In a test in concrete beds in which the pH was controlled at 8.5 to 8.6, IR4227-28-3 scored 2, and IR4227-164-1 and IR5853-60-2, 3.

Table 8. Alkali tolerance of rices from various sources. IRRI greenhouse, 1977.

Source	Rices (no.) with alkali tolerance score[a] of						Total
	1	2	3	5	7	9	
Germplasm bank	13	43	130	322	204	50	762
Alkali tolerance breeding program	4	3	16	68	46	8	145
IRSATON[b] (1977)		7	25	28	13	5	78
OYT[c] (1977)	8	11	33	65	43	88	248
RYT[d] (1977)	6	2	51	159	75	23	316
Elite lines (1977)		3	18	54	50	34	159
Hybridization block (1977)		2	19	34	35	78	168
Total	31	71	292	730	466	286	1876

[a]Scale: 1 = almost normal plants; 9 = almost all plants dying. [b]International Rice Salinity and Alkalinity Tolerance Observational Nursery. [c]Observational yield trial. [d]Replicated yield trial.

Varietal reactions to exchangeable sodium percentage (*Soil Chemistry*). Varietal reactions to yield and mineral content to increasing levels of exchangeable sodium percentage (ESP) were studied with three cultivars of different alkali tolerance in a replicated greenhouse experiment.

Pokkali, IR26, and IR2058-78-1 were grown on Pila silt loam (pH:7.4; CEC:36 meq/100 g; exchangeable K, Ca, Mg:0.20, 23.8, and 9.9 meq/100 g, respectively) adjusted to ESP levels of 14.1, 25.4, and 38.1 with sodium carbonate.

Four 2-week-old seedlings, dipped in a 2% suspension of zinc oxide in water, were transplanted per pot after incorporation of 100 ppm N, 25 ppm P, and 50 ppm K. Two plants were harvested at 6 weeks, the others at the regular harvest time.

After a maximum of 14.1 ESP, both relative growth and yield declined as ESP increased (Fig. 6, 7). The decrease beyond 25.4 ESP was least in Pokkali and most in IR26, a sensitive variety.

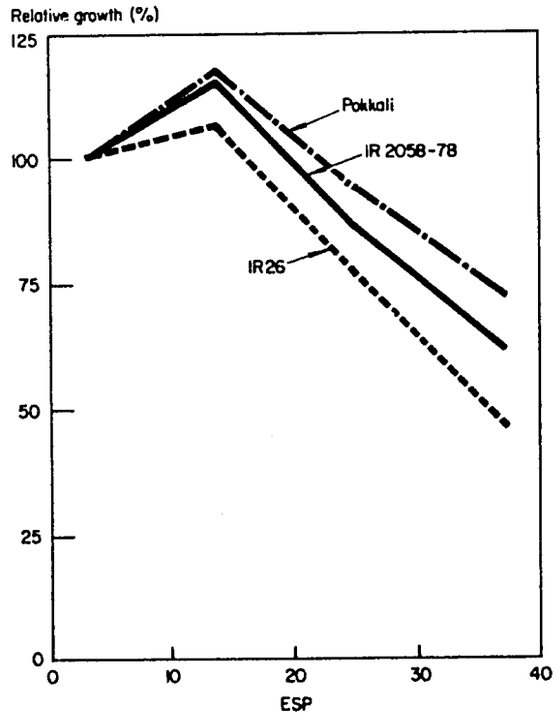
Plant analyses reflected the effects of ESP. Regardless of variety, increased ESP increased the concentration of sodium and decreased that of calcium and potassium. Accompanying the increased sodium concentration was a yield depression that was lowest in Pokkali and highest in IR26. The increase in sodium was associated with a decrease in growth.

The potassium content of the plant was highly correlated negatively with the K:Na ratio of the soil solution and the sodium content of the plant, but not with the potassium absorption ratio, $K/(Ca + Mg)^{\frac{1}{2}}$.

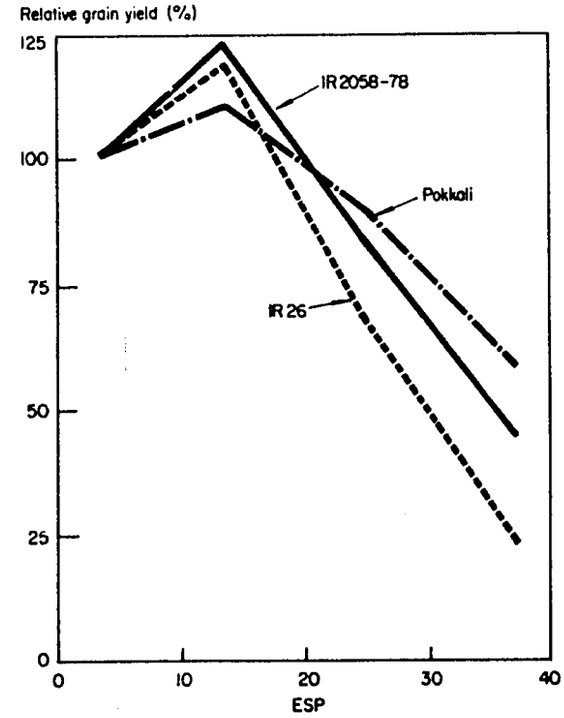
ESP levels exceeding 14.1 depressed the zinc, copper, and manganese contents in the plant but not its iron concentration (Fig. 8).

IRSATON 1977 (*Soil Chemistry*). Sixty-nine entries were planted in an artificial alkali soil (pH:8.4 to 3.5; sodium absorption ratio [SAR]: 35) in the dry season. Only IR2058–78–1 and IR2061–464–2 survived and produced grain.

In the wet season, the pH was 8.3 at planting and was raised to 8.5 by adding sodium carbonate. The following entries performed better than the resistant check Pokkali: CSSR 3,



6. Effect of exchangeable sodium percentage (ESP) on relative growth of 6-week-old plants.



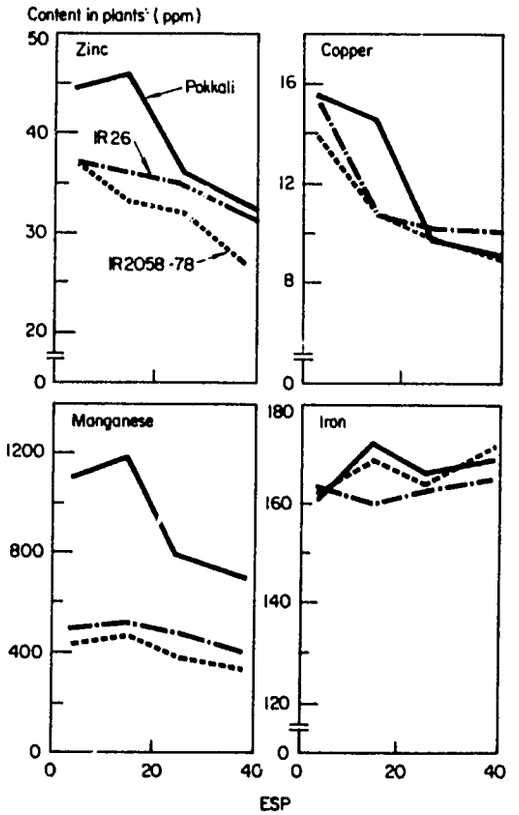
7. Effect of exchangeable sodium percentage (ESP) on relative grain yield.

IR2058-71-1, IR2058-78-1, IR4227-28-3, Cul. Nos. 93 and 100, Getu mutant Nos. 2735 and 2603, and IR5853-65-3.

Plant mineral composition as alkali stress index (*Soil Chemistry*). Fifty-four varieties were grown in an artificial alkali soil in trays in the greenhouse. At 4 weeks after transplanting, the plants were scored for alkali injury and harvested. Plants that were dead or dying (score: 9) were discarded.

As alkali tolerance decreased, the contents of total bases, potassium, phosphorus, and manganese decreased, while those of magnesium, calcium, and iron increased (Fig. 9). The zinc content was slightly above the critical limit and did not vary appreciably with alkali tolerance.

As both salt and alkali tolerance decreased, the sodium content increased and the contents of potassium and phosphorus decreased.

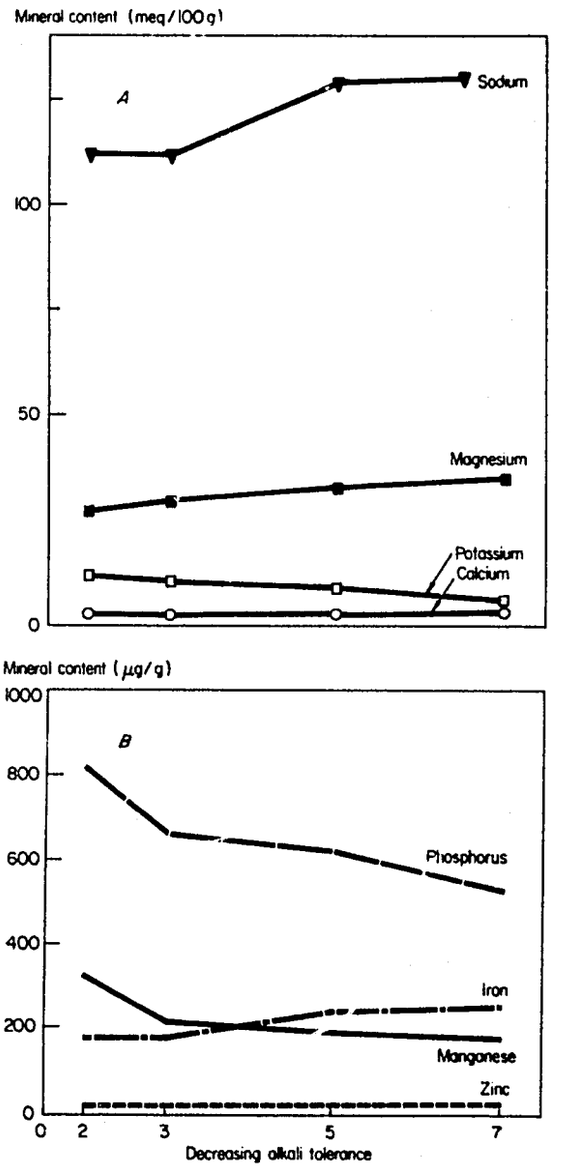


8. Effect of exchangeable sodium percentage (ESP) on zinc, copper, manganese, and iron contents of 6-week-old plants.

IRON TOXICITY

Soil Chemistry Department

Screening techniques. The present screening method for tolerance for excess iron involves growing rice in an acid soil that builds up and maintains high concentrations of ferrous iron in the soil solution. Because such soils are not readily available, solution and sand cultures, as



9. Mineral content of the rice shoot and alkali tolerance.

Table 9. Distribution among alkali ratings of entries in alkali field. IRRI, 1977.

Score[a]	Entries (no.) transplanted on					Entries (total no.)
	18 Jan.	13 Apr.	7 July	26 Aug.	4 Nov.	
<3.0	14	—	30	2	30	76
3.1–5.0	79	30	176	7	185	477
5.1–7.0	212	167	153	87	198	817
>7.1	174	250	120	293	91	928
Total	479	447	479	389	504	2298

[a]Scale: 1 = almost normal plants; 9 = dead or almost dead plants.

Table 10. Iron toxicity tolerance scores of rices from various sources. IRRI greenhouse, 1977.

Source	Rices (no.) with iron toxicity tolerance score							Rices (total no.)
	1	2	3	4	5	6	7	
Germplasm bank	2	8	12	2	0	0	0	24
Elite breeding lines (1976 and 1977)	16	31	44	35	13	20	3	162
RYT[b] 1977 dry season	4	7	5	1	3	0	1	21
OYT[c] 1977 dry season	1	17	11	6	4	1	0	40
Hybridization block 1977 dry season	2	13	9	1	0	0	0	25
Varieties from Thailand	2	2	8	4	0	0	0	16
Total	27	78	99	49	20	21	4	288

[a]Scale: 1 = almost normal plants; 9 = almost all plants dying. [b]Replicated yield trial. [c]Observational yield trial.

well as an acidified reduced soil, were investigated.

Solution cultures, even with sucrose as an antioxidant, were unsatisfactory because of the rapid precipitation of iron. Sand culture with 500 ppm iron and 50 ppm sucrose in the solution made possible the correct scoring of four varieties of known reactions to excess iron. But because the solution must be changed every 2 days, the method is too expensive for mass screening. The third method was tested in an attempt to produce a high and stable iron concentration in the soil solution by treating with acid an Ultisol reduced by incubation with sucrose. The scores of 6 varieties 13 days after transplanting agreed with their known iron tolerance. Acidified reduced soil is reliable but too slow for mass screening.

Greenhouse screening for iron tolerance. In 1977, 288 rices from several sources were screened; 16 of the 27 rices that scored 1 were elite breeding lines (Table 10.)

Mass screening. Sri Lankan scientists screened more than 750 rices on an iron-toxic soil at Padukka, Sri Lanka, from November 1976 to February 1977 in cooperation with IRRI. The field was fertilized with 40 kg/ha of each of N, P_2O_5, and K_2O. Then 3-week-old seedlings raised in a neighboring wet seedbed were planted in 5-m rows, 20 cm apart, at 1 seedling/hill spaced 20 cm apart. The plants were scored at 70 days after planting and the mature ones were harvested in February 1977. The results are summarized in Table 11.

Entries that scored <3.7 and yielded >90 g/10 hills are in Table 12.

HISTOSOL PROBLEMS

Soil Chemistry Department

Screening for tolerance. Sixty-one rices were screened in the greenhouse on Histosols from the Philippine provinces of Laguna, Leyte, Quezon, and Rizal, in the presence of N, P, and K fertilizer. The following gave scores of 3: IR34, IR40, IR42, IR3518-96-2, IR3880-10, IR4405-287-3, IR4432-103-6, IR4698-176-2, IR4816-70, IR5201-127-2, Kuatik Malaysia, and Cepat. Rices that died or barely survived

Table 11. Iron toxicity tolerance scores and average grain yields of entries in a mass-screening test. Padukka, Sri Lanka, Oct. 1976-Apr. 1977.

Entries (no.)	Iron toxicity tolerance score[a]	Av. grain wt (g/10 hills)
45	1.0–3.0	66.5
451	3.1–5.0	57.9
182	5.1–7.0	50.7
68	7.1–9.0	34.5

[a]At 70 days after transplanting. Scale: 1 = almost normal plants; 9 = almost all plants dying.

were E425, IR1529-430-3, IR4417-179-1, IR9669, and Serendah Kuning.

Ten varieties were tested in a Histosol from Kalayaan, Laguna, in two outdoor concrete beds. The soil in one bed received N, P, and K fertilizers; that in the other received N, P, K plus silicon, copper, molybdenum, and zinc. The scores for the two treatments were almost the same, with IR34 scoring 3 to 4 and E425, 9, indicating the presence of retarding factors other than simple nutrient deficiencies.

Mass field screening. In 1977, 1,862 rices were screened in farmers' fields in Calauan, Famy, Kalayaan, and Pangil in Laguna; and in Santa Fe in Leyte. The fields are boggy and waterlogged, with seepage from adjoining hills.

At each site, about 250 3-week-old seedlings were transplanted in 5-m rows replicated three times during both the dry and wet seasons. No fertilizer was applied. Seven weeks after transplanting, the plants were scored on a scale of 0–9.

The plants' reactions to adverse conditions varied with location and season (Table 13, 14). Plants reacted more severely on the poorly drained soils at Calauan and Halang than on the better drained soils at Famy and Kalayaan; reactions were also more severe in the wet than in the dry season. Phosphorus and zinc deficiencies at the Laguna sites and blast disease at Santa Fe, Leyte, complicated the evaluation of plant reactions to soil toxins. But three varieties performed well (score 1 to 3) at three Laguna sites, in the dry season. They are Kuatik Putih, CI-8636-5, and Bengawan. In the wet season Kuatik Putih, Boelaon, Polar, IR4422-6-2, and IR4432-38-6 performed consistently well at those locations. Kuatik Putih also did well in Leyte. E425 was uniformly the worst. All IRRI

Table 12. Scores and grain yields of some promising rices mass-screened for iron toxicity tolerance. Padukka, Sri Lanka, Nov. 1976-March 1977.

Designation	Iron toxicity tolerance score[a]	Grain yield (g/10 hills)
Cadung Go Gung	3.7	96
IR32	3.0	113
Mahsuri	2.3	105
IR4124-72-5	3.7	97
IR4422-98-3	3.7	91
IR4422-349-1	3.3	92
IR4422-143-2	3.7	91
IR4535-6-8	3.0	90
IR4712-208-1	3.3	91
IR4819-77-1	3.0	90
IR4819-77-2	3.3	92
IR4859-39-2	2.7	110
IR4870-15-1	3.3	99

[a]At 70 days after transplanting. Scale: 1= almost normal plants; 9 = almost all plants dying.

varieties and most IRRI lines were more sensitive to Histosol injury than the traditional varieties from Histosol areas of Indonesia and Malaysia.

Varietal reactions. Histosols vary widely in chemical and physical characteristics. To ascertain if those differences affect their growth-retarding properties, 10 varieties were grown in pots on four soils fertilized with N, P, and K. The chemical characteristics are in Table 15.

Table 13. Distribution of entries among Histosol tolerance scores at three sites. Philippines, 1977 dry season.

Histosol tolerance score[a]	Entries (no.)		
	Calauan	Halang	Kalayaan
1	1	1	15
2	10	9	42
3	74	219	178
5	140	60	49
7	31	1	0
9	30	0	0

[a]Scale: 1 = almost normal plants; 9 = almost all plants dying.

Table 14. Distribution of entries among Histosol tolerance scores at four sites. Philippines, 1977 wet season.

Histosol tolerance score[a]	Entries (no.)			
	Famy	Halang	Lamaw	Santa Fe
1	0	0	0	0
2	10	3	6	9
3	75	24	44	126
5	117	171	138	121
7	14	11	26	6
9	7	12	0	2

[a]Scale: 1 = almost normal plants; 9 = almost all plants dying.

Table 15. Performance and mineral composition of the straw of 10 varieties averaged for four Histosols. Philippines, 1977.

Variety	Score[a]	Straw (g/pot)	Grain (g/pot)	Mineral composition of straw								
				Zn (ppm)	Fe (ppm)	Mn (ppm)	Cu (ppm)	B (ppm)	K (%)	Mg (%)	P (%)	Si (%)
IR5	4.5	91	40	45	103	169	1.6	19	1.1	0.22	0.07	3.9
IR8	5.0	46	34	43	173	252	1.5	19	1.3	0.40	0.09	6.3
IR20	5.0	38	33	35	137	260	1.5	15	1.4	0.31	0.10	5.8
IR22	6.5	39	28	32	137	309	1.6	16	1.6	0.34	0.14	5.6
IR24	6.8	41	24	32	175	330	2.1	18	1.5	0.35	0.12	6.7
IR26	5.0	41	34	40	153	210	1.4	19	1.3	0.34	0.10	5.3
IR28	5.7	30	29	30	174	302	1.9	20	1.6	0.30	0.16	6.5
IR29	7.3	36	25	31	159	447	1.9	18	1.4	0.36	0.16	6.2
IR30	6.0	35	27	31	142	268	1.3	17	1.6	0.30	0.12	5.6
IR32	3.5	76	43	53	119	169	1.5	22	1.2	0.27	0.08	4.9

[a]Scale: 1 = almost normal plants; 9 = dead or almost dead plants.

IR5 and IR32 yielded highest in both straw and grain on all four soils, IR28 and IR29 yielded lowest, and IR8 intermediate (Table 15). The mean yields of straw and grain were highest on the Pangil soil and lowest on Calauan. Histosol tolerance was associated with a higher zinc content in the straw and lower contents of iron, manganese, magnesium, potassium, phosphorus, and silicon (Table 15). The copper content of all varieties on all soils was below the critical limit. The zinc content of IR24, IR28, IR29, and IR30 on the Calauan soil was below the critical deficiency limit. Zinc deficiency symptoms were observed on that soil and on the soil from Morong.

Varietal differences were far more pronounced than differential soil effects, and appeared to be associated with tolerance for zinc deficiency.

ZINC DEFICIENCY

Soil Chemistry Department

Screening in concrete beds. Almost 2,500 entries were screened in Lipa clay loam (pH: 8.2; O.M.: 9.0%; available Zn: 0.2 ppm) in concrete beds at IRRI. Seventy-two scored 1 (Table 16).

Mass field screening. Mass screening of the world collection of germplasm was begun in

Table 16. Distribution among zinc deficiency tolerance scores of rices from various sources. IRRI concrete beds, 1977.

Source	Rices (no.) with score[a] of						Rices (total no.)
	1	2	3	5	7	9	
Germplasm bank	0	0	25	42	60	13	140
Elite lines	4	7	73	64	1	0	149
Salt-tolerant lines	2	5	15	11	0	0	33
Alkali-tolerant lines	1	0	2	1	0	0	4
Deep water-tolerant lines	1	0	3	33	10	2	49
IRSATON[b] (1976–77)	26	3	34	24	42	6	135
Salt-tolerant lines	0	0	6	48	112	32	198
RYT[c] (1977)	6	30	123	125	27	0	311
OYT[d] (1977)	16	80	165	194	165	41	661
OYT[d] cold tolerance (1977)	2	3	55	104	23	1	188
IRCTN[e]	8	21	92	116	129	4	370
Hybridization block	4	51	111	44	1	0	211
Thailand varieties	2	0	9	6	1	0	18
Others	0	0	1	5	1	0	7
Total	72	200	714	817	572	99	2474

[a]Scale: 1 = almost normal plants; 9 = almost all plants dying. [b]International Rice Salinity and Alkalinity Tolerance Observational Nursery. [c]Replicated yield trial. [d]Observational yield trial. [e]International Rice Cold Tolerance Nursery.

Table 17. Reactions of rice cultivars to zinc deficiency in the field. Tiaong, Quezon, Philippines, 1977.

Period	Entries (no.)	Amendment	Rices (no.) with zinc deficiency score[a] of					
			1	2	3	5	7	9
March–April	500	None	0	0	0	0	9	491
May–July	640	1% ZnO dip	0	0	0	17	290	333
July–Sept.	570	2% ZnO dip	0	3	29	26	209	193

[a]Scale: 1 = almost normal plants; 9 = almost all plants dying.

1976 in a zinc-deficient soil (pH:8.2; O.M.: 9.6%; available Zn:0.04 ppm) at Tiaong, Quezon Province, Philippines. More than 500 3-week-old seedlings raised on a normal soil were transplanted in 5-m rows replicated three times. Zinc deficiency symptoms were scored visually 4 weeks later. Because few plants survived the first test, zinc oxide was applied in the second and third screenings. On this strongly zinc-deficient soil, only 32 of 1,700 entries gave tolerant readings (1 to 3) (Table 17).

Varietal reactions. IRRI varieties are not grown on the calcareous soils of Bohol, Philippines, because they are said to yield less than local ones. To test that observation, nine IRRI varieties were grown along with Lubang, the farmers' choice, in a replicated experiment in a Bohol farmer's field on Faraon clay (pH:7.5; O.M.:15.1%; available Zn:0.1 ppm), without added zinc, but with 50–20–50 kg N, P, K/ha.

Eight weeks after transplanting IR34 (the tolerant check) and Lubang scored 1, while IR26 (the susceptible check) scored 6. Lubang yielded highest, and IR34 lowest (Table 18) because of *Helminthosporium* leaf spot. The zinc content of the straw indicated marginal deficiency in five varieties.

Without zinc application, the local variety Lubang is best suited to the soil at Bilar.

PHOSPHORUS DEFICIENCY

Soil Chemistry Department

Screening techniques. To test the validity of the greenhouse screening method (1976 Annual Report), 19 rices whose greenhouse scores ranged from 1 to 7 were grown in a phosphorus-deficient soil (pH:4.8; Olsen P:3 ppm) with and without phosphate in 3- × 5-m plots replicated three times. The plants were scored according to the relative tiller number.

The field scores paralleled the greenhouse scores except in one variety. Seven varieties gave identical ratings by both methods; nine gave field scores only one step lower than the greenhouse scores; only two were out of line.

Greenhouse screening. Fifty elite lines were screened by the method described in the 1976 Annual Report. The phosphorus concentration in the deficient medium, however, was reduced to 0.5%. The following lines scored 1: IR3449-172-2, IR4219-35-3, and IR4227-28-3.

Mass field screening. Mass screening of germplasm for tolerance for phosphorus deficiency was started in 1977. More than 250 elite lines were grown each season in 5-m rows, replicated three times, with and without 25 kg P/ha at Pangil, Laguna, on flooded Luisiana clay (pH:4.8; Olsen P:3 ppm). Tolerance was scored according to the relative tiller count ($P_0/P \times 100$) at 4 weeks after transplanting (Table 19).

Of 161 rices screened in the wet season, 28 scored 1 by the relative-tiller method.

Varietal reactions to phosphorus deficiency. In the 1977 dry season, 60 elite lines were grown in a replicated field experiment on a phosphorus-deficient soil (Lumban clay) with

Table 18. Yield and zinc content of straw of 10 varieties on a zinc-deficient soil. Bilar, Bohol, Philippines, 1977 wet season.

Variety	Straw (t/ha)	Grain (t/ha)	Zinc content (ppm) of straw
Lubang	5.1	2.8	43
IR26	3.2	2.0	29
IR28	n.a.	n.a.	25
IR29	n.a.	n.a.	27
IR30	2.8	2.3	26
IR32	5.8	1.4	37
IR34	3.9	0.2	24
IR36	2.5	2.0	31
IR38	5.2	1.8	36
IR40	5.0	2.1	42

Table 19. Results of mass screening of rice for phosphorus deficiency. IRRI, 1977 dry season.

Relative tiller count[a] (%)	Phosphorus deficiency score	Entries (no.)
>85	1	76
50–84	3	82
25–49	5	57
< 24	7	37

[a]$P_n/P \times 100$.

and without 25 kg P/ha. The following scored 1 and were rated as tolerant of phosphorus deficiency on Luisiana clay: IR34, IR2367-247-2, IR2823-299-5, IR3941-9-2, IR4442-207-2, IR4698-176-1, and IR4744-295-1.

Some of the most tolerant rices are in Table 20.

BREEDING FOR ADVERSE SOILS TOLERANCE

Plant Breeding Department

Salinity. Three types of mass screening systematized in 1977 the selection of pedigree lines from massive hybridization with tolerant sources made earlier. The first replicated yield trial was in coastal saline soils in the Philippines. Four replicated tests were grown six times a year. Selections from the test were included in the 6,190-line pedigree nursery, which was grown in an ordinary field.

In the greenhouse, 2,367 pedigree lines from 20 crosses were screened in 1977 (Table 21). This is the first salinity test of a large number of pedigree lines under controlled conditions at IRRI or, possibly, elsewhere. Pokkali and IR2153-26-3-5 were consistently rated as tolerant (rating 2 or 3). Considerable environmental variation interfered with the genetic distribution of tolerance — patterns of tolerance in progeny of the same cross differed in repeated tests (Table 22). Therefore, although the genetic behavior of salt tolerance cannot be estimated decisively, the heredity of salt tolerance is obviously quantitative in nature. The recovery of tolerant progeny was about 5 to 20% regardless of source of tolerance or number of topcrosses or double crosses involved in it.

In a coastal saline field at Sabang, Camarines Sur, Philippines, a pedigree nursery of 1,800 lines was tested in the 1977 dry season and one of 1,200 lines was tested in the wet season. In the dry season, the salt level was unexpectedly low, so pedigree lines were selected for tolerance for zinc deficiency. In the wet season, many salt-tolerant lines were retained at salinity levels of from 5 to 11 mmho/cm (Fig. 10). Yields of three replicates of 14 rices were tested at the same site. The tolerant variety Pokkali yielded 2.9 t/ha, followed by the salt-tolerant lines IR2071-105-4-5 (2.8 t/ha) and IR4630-22-3-3-2 (2.6 t/ha). IR26 yielded only 1 t/ha (Table 4). Yields of the early varieties IR28 and IR30 were remarkably reduced because of the limited recovery period after initial depression. Low plant height seemed closely related with lower yield. Four entries that were less than 70 cm tall yielded equally low, less than 2 t/ha.

Among the advanced breeding lines derived from Pokkali, the sister lines from IR4630-22

Table 20. Rices with tolerance (score = 1[a]) for adverse soils in 1977 screening at IRRI.

Salinity[b]	Alkalinity[c]	Iron toxicity[d]	Histosol[e] problems	Phosphorus[f] deficiency	Zinc deficiency[g]
IR2863-35-3	C59	Banut	Kuatik Putih	IR26	IR20
IR4432-28-5	Lubang	Cadung Go Gung	CI 8636–5[h]	IR34	IR34
IR5657-33-2	Aronlea	Radin Goi 36	Bengawan[h]	IR2061-522-6	Orkayama
IR7199-28	Kwei Yi Wei	IR20		IR2367-247-2	Pokkali
IR8073 (19 lines)	CP 231	IR36		IR2823-299-5	IR2070-414-3
IR10168-1	Gottelu	IR2070-189-4		IR3445-172-2	IR2307-247-2
IR10206 (3 lines)	CSR 2	IR2070-414-3		IR3941-9-2	IR2681-163-5
IR13583 (3 lines)	Damodar	IR2071-176-1		IR4227-28-3	IR3941-25-1
IR13644-27	IR4763-141	IR2071-486-9		IR4427-51-6	IR4432-103-6
IR4630-22-2		IR2797-105		IR4432-28-5	IR4613-54-5
Nona Bokra		IR2863-38-1		IR4432-38-6	

[a]Based on the Standard Evaluation System for Rice: 1 = almost normal plants; 9 = dead or almost dead plants. [b]5,562 rices screened. [c]1,876 rices screened. [d]288 rices screened. [e]1,923 rices screened at three locations in Laguna province, Philippines. [f]731 rices screened at Pangil, Laguna. [g]4,200 rices screened. [h]Score =2.

Table 21. Distribution among salt tolerance scores of 2,367 F_3 lines from 20 crosses. IRRI greenhouse, 1977.

Cross	Lines tested (no.)	Rices (no.) with tolerance rating[a] of						Remarks
		1	2	3	5	7	9	
IR8073[b]	609	7	2	16	24	25	26	Topcross
IR8236	102	0	1	10	15	28	46	"
IR9434	50	0	0	0	6	26	68	"
IR9436	81	0	0	4	6	25	65	"
IR9769	100	1	0	15	25	37	22	"
IR9770	100	0	5	7	16	32	40	"
IR9849	100	0	6	18	20	40	16	"
IR9859	149	5	0	17	28	33	16	"
IR9884	139	0	2	23	29	26	20	"
IR10167	97	0	0	0	0	7	93	"
IR10168	58	0	0	3	7	15	74	"
IR10206	49	6	4	12	14	25	39	"
IR13050	44	0	0	29	39	27	5	"
IR13188	100	0	0	1	0	3	96	"
IR13486	100	0	0	0	0	15	85	"
IR13583	80	0	6	15	39	25	15	"
IR13622	150	0	0	9	23	40	28	Double cross
IR13644	59	2	0	6	20	34	37	"
IR14568	100	0	0	5	15	40	40	Single cross
IR14581	100	0	0	10	11	42	37	"

[a]Scale: 1 = almost normal plants; 9 = almost all plants dying. [b]F_5 lines.

—IR4630-22-2-5-1 and IR4630-22-3-3-2—had consistently high survival rates comparable with that of Pokkali, in greenhouse tests as well as in salinized concrete beds (Fig. 11). With their intermediate height and resistance to tungro, bacterial blight, and brown planthopper biotype 1, those lines may meet immediate needs in salty areas. Other progeny of crosses with Pokkali — IR4763-73-1-11, IR4763-141-2-17, and IR4595-4-1-13 — had good survival rates, indicating that with systematic screening Pokkali's salt tolerance can be introduced into good agronomic background.

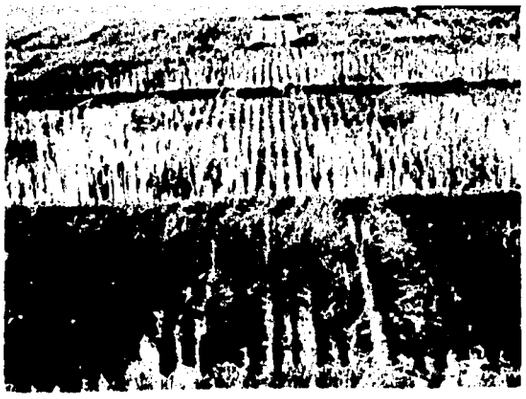
The elite lines IR2863-35-3-3, IR4432-28-5, and IR5657-33-2 have been repeatedly identified as salt tolerant in regular screenings of advanced breeding lines from the general breeding program. In addition, about 10 breeding lines were rated moderately tolerant, but their ratings were not consistent, probably because of their moderate tolerance. But ratings of tolerant checks such as Pokkali and IR2153-3-5-6 were almost invariably tolerant.

Table 22. Distribution among salt tolerance ratings of selections of the cross IR8073 tested 4 times. IRRI, 1977.

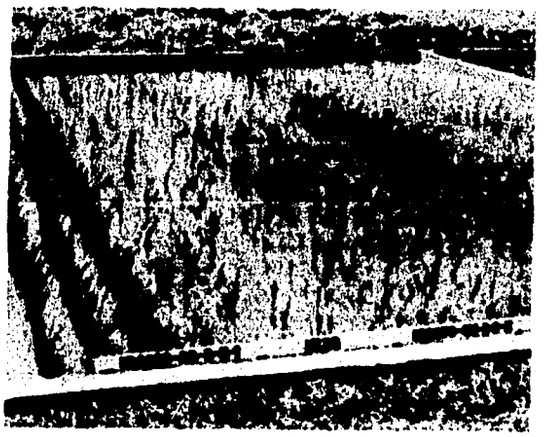
Test no.	Selections tested (no.)	Selections (%) with tolerance rating[a] of					
		1	2	3	5	7	9
1	67	2	3	4	24	31	36
2	164	18	3	26	19	22	12
3	116	8	1	23	39	23	5
4	262	1	1	10	15	23	50
Mean		7	2	16	24	25	26

[a]Scale: 1 = almost normal plants; 9 = almost all plants dying.

Alkalinity. The following advanced lines have been identified as highly tolerant of alkalinity through routine screening in alkalized fields at IRRI: IR4630-22-2-19, IR4630-22-2-12, IR2058-78-1-3-2-3, IR4763-141-3, IR4763-141-4, IR2061-181-46-3, IR4570-83-3-3-2, IR9439-20, and IR4227-28-3-2.



10. Varietal test on a coastal saline soil, Philippines.



11. Varietal test on an artificial saline soil, IRRI.

As a result, the distribution of selected tolerant lines requested by national programs has been emphasized, and tolerance is checked in situ. Sets of 43 lines have been sent to 3 locations each in India, Pakistan, Mexico, and Australia.

Indian scientists at the Kapurthala Station, Punjab Agricultural University, reported that the early maturing lines IR2153-96-1-5-3 and IR5785-162-1 are tolerant and some medium- to late-maturing lines are as tolerant as the resistant check Damodar.

IRSATON. Data on 71 entries from the second International Rice Salinity Alkalinity Tolerance Observational Nursery (IRSATON) tested at 10 locations in 1976 became available in 1977. The 35 sets of the third IRSATON (77 entries) were distributed to 18 countries, and also evaluated at IRRI and through visits to test sites at Kapurthala, Punjab; Hyderabad, A.P.; Port Canning, W. Bengal in India; and at Samutsakhon, Thailand. Initial data indicate that testing was so affected by varying environmental factors, particularly patchy salt stress, that comparing the tolerance of entries even under replicated trials is difficult. Tall varieties often seemed vigorous and were rated tolerant, but the ratings did not always relate to actual yields.

Because of methodological difficulties in salt tolerance testing it seems better to provide each local station with the best 5 or 10 entries with agronomic traits specifically suited to local conditions, and to conduct primary tests of large numbers of breeding lines at international and national centers with good facilities.

Alkalinity-tolerant materials may be disseminated differently from the salt-tolerant materials because they can be identified more easily. Rice programs in alkaline areas may leave certain fields unamended for routine alkalinity screening.

Phosphorus-deficiency screening in Sri Lanka and Thailand. About 420 rices were dispatched for screening phosphorus-deficient soils at Gampola, Sri Lanka. Collaborating scientists from the Central Agricultural Research Institute and IRRI jointly observed that some IRRI parental sources such as IR22, IR24, IR480, and IR1514A-E666 had outstanding tolerance, confirming earlier assumptions that advanced IRRI breeding lines would include potentially tolerant lines.

Seventeen breeding lines were tested along with local varieties in newly initiated screening in acid-sulfate soils at the Ongkarak Station, northeast of Bangkok. The local variety Khao Dawk Mali 105 performed best. According to Thai scientists some IRRI lines such as IR2071-137-5-5-1 were relatively tolerant, but their early growth was depressed more than than of the Thai native rices.

Breeding for acid-sulfate soils. Varietal improvement programs for acid-sulfate soils were observed around Ongkarak, Thailand; Muda, Malaysia; and Banjarmasin, southern Kalimantan, Indonesia. Phosphorus deficiency is a major growth-limiting factor in Thailand. That tolerance for iron toxicity is a major requirement was clearly demonstrated in a screening test by Malaysian scientists at Cuar Chembedak, Kedah. Bajar Kuning, Lemo, and other varieties found tolerant there were also tolerant in acid-sulfate soils in Banjarmasin. They were crossed with elite IRRI lines in the 1977 wet season. The iron toxicity-tolerant varieties Gissi 27, Devarredi, and some BW lines were also crossed with IRRI lines for acid-sulfate or iron-toxic soils.

International collaboration. Several F_2 and F_3 populations derived from crosses with varieties that are tolerant of soil problems were sent to rice breeders at the International Institute of

Tropical Agriculture (IITA), Nigeria, and in Indonesian programs. Working relationships between IRRI and some rice experiment stations with salt tolerance programs in India, Bangladesh, Thailand, and the Philippines are being established.

In breeding for tolerance for nutrition deficiencies such as phosphorus and zinc, as well as for iron toxicity, the screening of the existing pool of advanced breeding lines and varieties should be emphasized; initial screening of the present pool showed potentially tolerant materials. The first step in screening is rejecting sensitive lines; the next is distributing tolerant lines to problem-soil areas. Problem-soil screening should be closely linked with the overall program of varietal testing, particularly in the areas of rainfed or upland rice, which have more widespread and severe soil problems than irrigated areas. Therefore, sets of promising breeding lines from national and international programs should be tested in nutrient-deficient soils.

The relevance of varietal tolerance to yield levels should be investigated. Although tolerance obviously determines yield under severe stress, its role under mild stress (which may be more common in farmers' fields) should be determined. IRRI is initiating a program in that area. Mass screening and selection are needed for adaptability to organic soils, acid-sulfate soils, and tidal swamp soils. A reservoir of rices previously identified as promising should be distributed as initial materials for tests of adaptability to specific soil stress. Without selection some hybrid populations originating from tolerant varieties can also be provided to local plant breeders. IRRI is taking initial steps to compose the reservoir for distribution.

Genetic evaluation and utilization (GEU) program

Deep water and flood tolerance

Plant Physiology, Agronomy, and Plant Breeding Departments and Thai-IRRI Cooperative Deep-Water Project

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SCREENING FOR FLOOD TOLERANCE

Plant Physiology and Plant Breeding Departments

In 1977, 1,398 varieties and 1,658 lines were tested for flood tolerance. Several good lines were identified and planted for further observation and evaluation.

Two hundred and forty-seven, or 15%, of the breeding lines showed excellent flood tolerance. Most were F_3's and F_4's, with Nam Sagui 19 or SML Temerin as possible donors of flood tolerance.

The flood-tolerant advanced lines IR5857-3-2E-1-1, IR5857-3-2E-1-38, and IR5857-64-1E-1-6 yielded well in the 1977 wet season.

The 70 entries from the International Rice Deep-Water Observational Nursery (IRD-WON) were screened for flood tolerance; five — Pelita I-1, BKN7021-85-3, IR5857-3-2E-2, ARC 5955, and CNL 53 — performed excellently when completely submerged for 8 days at the seedling stage. Under field conditions in Thailand and at an average water depth of 155 cm for an extended time, all the five entries died. Only those with elongation ability and flood tolerance survived; most were tall.

FIELD SCREENING FOR FLOOD TOLERANCE

Thai-IRRI Cooperative Deep-Water Project

A deep-water pond was constructed specifically for simultaneous testing at four water levels. Twenty-day-old seedlings of 10 varieties and experimental lines were transplanted. Twenty-one days later the rices were submerged for 7 days at depths of 90, 104, 134, and 154 cm.

At the two deepest levels all plants were destroyed. At 90 cm few entries were badly damaged, but at 104 cm varieties clearly differed: BKN6987-82 and BKN6987-161-3 exhibited the best survival and recovery (Table 1). Several entries recovered better than Nam Sagui 19, a standard check in flood-tolerance tests.

Table 1. Recovery scores of rices after 7 days' submergence in 90-cm and 104-cm water depths. Huntra, Thailand, 1977.

Entry	Recovery score[a] at	
	90 cm	104 cm
BKN6987-82	3	3
BKN6987-161-3	4	3
BKN6986-108-3	3	4
BKN6986-167-2	5	5
BKN6987-68-7	2	6
Nam Sagui 19	2	7
RD7	2	8
BKN6986-66-2	3	8
BKN6986-147-2	4	8
Khao Tah Heng 17	5	8

[a]Based on a scale of 1–9 (1 = fully recovered, 9 = dead).

REEVALUATION OF SUBMERGENCE-TOLERANT VARIETIES

Plant Physiology Department

Of the 4,350 varieties screened for flood tolerance, 62 performed as well as or better than the resistant checks Nam Sagui 19 and SML Temerin when submerged completely for 8 days. In a retest, seedlings of those tolerant varieties were submerged for 10 days.

Several varieties survived better than the two tolerant checks (Table 2). All plants of the Indian variety F. R. 13A survived submergence for 10 days. F. R. 13A generally elongates little when submerged — it remains short, stiff, and erect even after water is removed. Thavalu, Goda Heenati, Kurkaruppan from Sri Lanka, and An long Phnom from Cambodia showed excellent submergence tolerance.

Table 2. Survival of the 15 best of 62 flood-tolerant entries when retested under a longer submergence period (10 days) at the seedling stage. IRRI, 1977.

Variety	Survival (%)	Increase in plant ht (%)
F.R. 13A	100	19
Goda Heenati	85	30
Kurkaruppan	85	24
Thavalu	85	10
Anlong Phnom	80	33
ARC 10661	70	15
Thavalu	65	7
ARC 614-25 (b)	60	41
ARC 12038	60	33
Beti Chikon	60	58
Kalu Gires	60	29
ARC 12059	55	23
ARC 12606	55	60
Cai Don	50	40
Tangul	50	47
SML Temerin (check)	30	82
Nam Sagui 19 (check)	40	25

In areas where floodwaters remain for long periods, Beti Chikon and ARC 12606 would be good donor parents for both flood tolerance and elongation ability at the seedling stage.

ELONGATION TESTING AT HUNTRA

Thai-IRRI Cooperative Deep-Water Project

About 14,000 lines from 200 crosses were screened, using methodology recommended at the 1976 Deep-Water Rice Workshop.

At IRRI, 20 varieties from the germplasm collection showed good elongation ability when water was rapidly increased (30 cm/day) to a 1-m depth at 42 days after sowing. The same varieties were tested in Thailand. Water was increased by 10 cm every other day starting at 30 days after sowing. All but one variety survived at the 125-cm water depth. All elongated even during early growth (30 days).

Several varieties with not only early elongation ability but also good elongation ability (surviving in water as deep as 155 cm) were identified. The best varieties, determined by their height above water of 155 cm, were: Maliabhangar, Badal 106, Baguamon 436, Laki 396, Habiganj Aman 1, DW 6255, Aswina, Alad Kumar, Boran, Lal Amon, Molla Diga, Path Kola, and Raj Bhawalia.

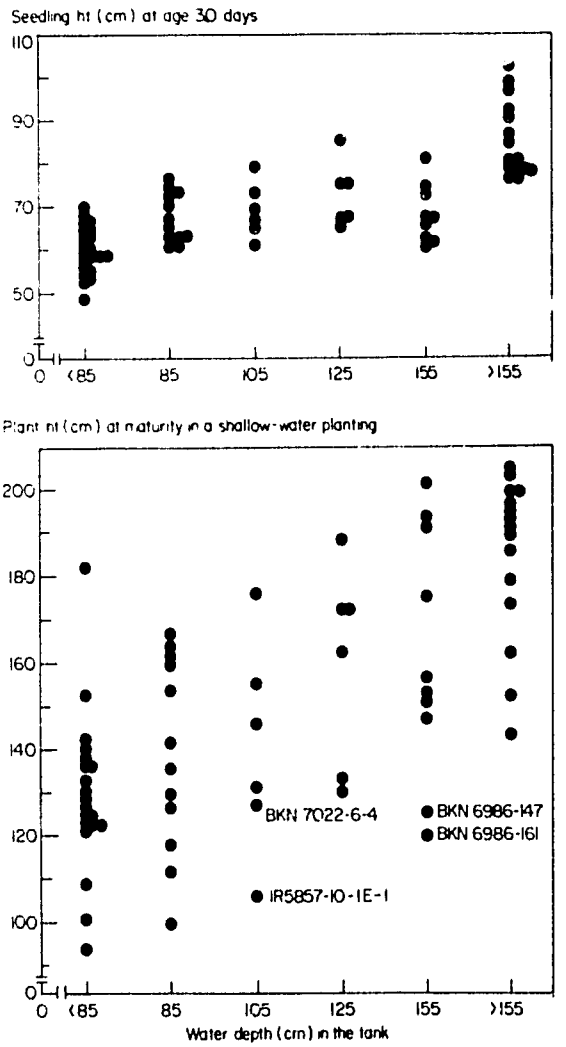
The elongation ability of 270 varieties from Bangladesh and India was also tested. Nineteen varieties survived at the 125-cm water depth. At the 155-cm depths, the following varieties from Bangladesh gave excellent elongation: Arai Raj, Ganga Sagar, Loha Dang, and Pan Kaich.

The elongation ability of 70 entries in the 1977 IRDWON was tested. Plant height was measured at 30 days after sowing in the pond and at maturity in a shallow water planting. Generally, the taller seedlings showed better elongation and survival in deep water (Fig. 1). A similar trend was observed in other tests, including the test of 270 varieties from Bangladesh and India. That emphasizes the importance of vigorous seedling growth. Habiganj Aman I and II had tall seedlings and excellent elongation ability. Although plant height at maturity in shallow water correlated positively with elongation ability, several entries with good plant type (short, nonlodging) in shallow water elongated and survived in 105 to 155 cm of water. The lines IR5857-10-1E-1 and BKN7022-6-4 were short in shallow water but survived at the 105-cm depth; BKN6986-147-2 and BKN6986-161-1-3 survived at the 155-cm depth.

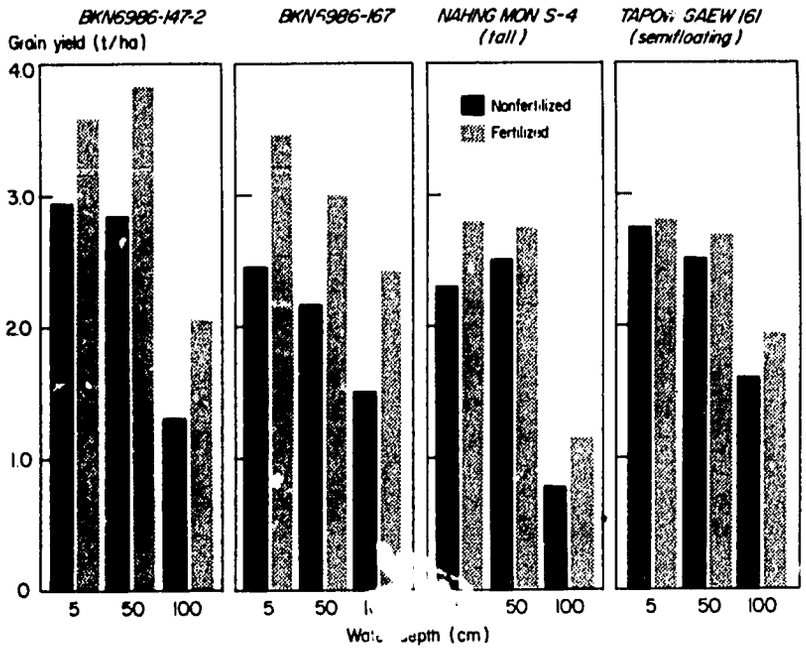
RESPONSE TO FERTILIZER AT DIFFERENT WATER DEPTHS — WET SEASON

Thai-IRRI Cooperative Deep-Water Project

For the past 7 years, breeders have attempted to develop improved varieties that can tolerate water depths of up to 100 cm, but only recently



1. Relationship between elongation ability and plant height of IRDWON entries at 30 days after sowing and at maturity. Huntra, Thailand, 1977.



2. Yields of two elongating semidwarf lines, a traditional tall, and a semifloating variety grown at different water depths and soil fertility levels. Huntra, Thailand, 1977 wet season.

were lines stabilized and sufficient seed produced to extensively test them. Good fertilizer response is a key factor in the breeding of improved varieties that tolerate deep water, because many areas now planted to traditional tall varieties are relatively infertile and receive little or no added fertilizer (possibly because the present types are nonresponsive).

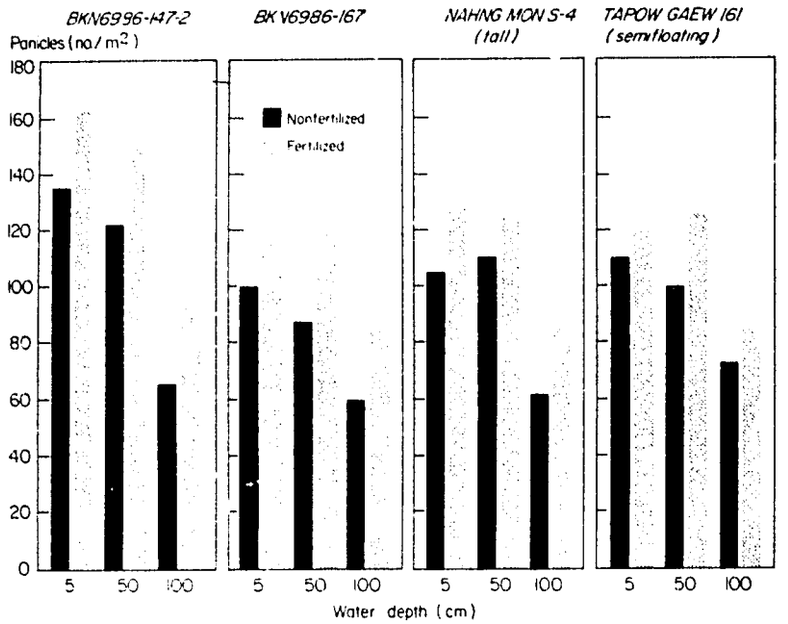
The response of four photoperiod-sensitive rices to added fertilizer at water depths of 5, 50, and 100 cm, and the effect of deep-water stress on yields were studied. Fertilizer was incorporated in three ponds at the rate of 37-37-37 kg NPK/ha at 2 weeks before 25-day-old seedlings were transplanted. Thirty days after transplanting, the water level in two ponds was increased 5 cm/day until water depths reached 50 and 100 cm. In the third pond, water depth was maintained at 5 cm throughout the growing season. Being photoperiod sensitive, all four entries flowered in November, after the monsoon rains ceased.

Yields of the experimental lines BKN6986-147-2 and BKN6986-167 increased markedly with fertilizer application, compared with those of the tall traditional variety Nahng Mon S-4 and the recommended semifloating variety Tapow Gaew 161 (Fig. 2). That suggests that genetic factors, rather than water depth, limit fertilizer response. Yields were lower in deeper water, especially at 100 cm, but response to fertilizer in deep water was as high as, or higher than, that in shallow water. Despite its inherent tallness, Nahng Mon S-4 did not tolerate the deepest water.

Yield differences due to water depth, fertilizer, variety, and variety-water depth and variety-fertilizer interactions were highly significant (Table 3). Yields did not differ sig-

Table 3. Statistical comparison of yield increase due to fertilizer in new and traditional varieties grown in 5-, 50-, and 100-cm water depths, Huntra, Thailand, 1977.

Rice type	Yield difference		
	100 cm	50 cm	5 cm
Elongating hybrid semidwarfs	0.99**	0.85**	0.85**
Tall traditional varieties	0.26^{ns}	0.19^{ns}	0.31^{ns}
Difference	0.73**	0.66**	0.54**



3. Number of panicles per square meter of two elongating hybrid lines, a traditional tall, and a semifloating variety grown at different water depths and at two soil fertility levels. Huntra, Thailand, 1977 wet season.

nificantly between the 5- and 50-cm water depths, but those at 50 and at 100 cm showed highly significant differences. The new deep-water rices performed better than traditional varieties at all three water depths.

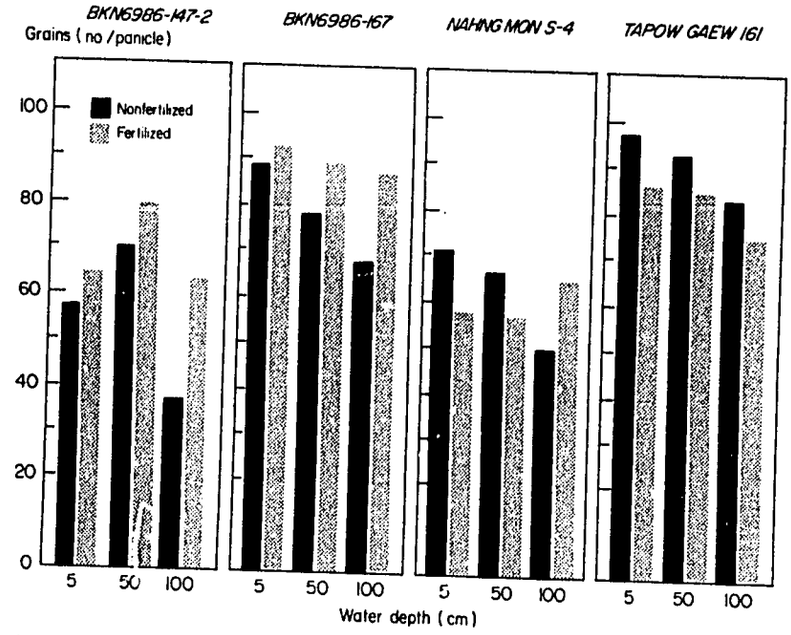
For all entries, the number of panicles per square meter was markedly reduced at the 100-cm water depth and somewhat reduced at 50 cm (Fig. 3). The reduction might have been less had the plants been grown longer in shallow water. BKN6986-147-2, the only semidwarf entry, had high tillering capacity.

Tapow Gaew 161 responded negatively to fertilizer in number of grains per panicle at all water levels; Nahng Mon S-4 responded like Tapow Gaew 161 except at the 100-cm water depth (Fig. 4). But the new experimental lines responded best at the 100-cm depth, and their grains per panicle increased with added fertilizer. The increase in number of both panicles and grains per panicle was responsible for the higher yields.

The two traditional varieties flowered earliest at all water depths. They differed little in response to soil fertility and water depth. But the experimental lines, particularly BKN-6986-167, responded erratically. In fertilized ponds their flowering occurred 38 days later at the 100-cm water depth than at the 5-cm depth.

As expected, plant height increased as water depth and fertilization increased, but the increase was not proportional in all four entries. The experimental lines elongated the most. Tapow Gaew 161 was inherently tall and thus elongated only about 20 cm to remain above water. Although Nahng Mon S-4 was no taller than BKN6986-167 in shallow water, it possessed little elongation capacity or deep-water tolerance.

The grain quality of Nahng Mon S-4 is among the best in Thailand; that of Tapow Gaew 161 is only fair. Because there is considerable interest in the release of an improved deep water-tolerant variety, cooking quality tests were conducted. The elongating lines compared favorably with Nahng Mon S-4, but differed considerably in amylose content, gelatinization temperature, and gel consistency (Table 4). Their cooking characteristics seemed superior to those of Tapow Gaew 161.



4. Number of grains per panicle of two elongating semidwarf lines, a traditional tall, and a semifloating variety grown at different water depths and at two soil fertility levels. Huntra, Thailand, 1977 wet season.

MULTILOCATIONAL YIELD TRIALS

Thai-IRRI Cooperative Deep-Water Project

Multilocational yield trials were continued to determine if the incorporation of elongation genes into semidwarf rices has a deleterious effect on yield. That effect would be important if farmers grew the elongating semidwarfs in shallow water or if water levels were reduced markedly because of low rainfall. The yields of the elongating semidwarfs were comparable to those of RD7 in both dry and wet seasons (Table 5). But in water 90 cm deep, the elongating semidwarf lines were clearly superior to RD7; BKN6986-108-3 was outstanding. BKN6986-66-2, which was promising in a variety-fertilizer-water level experiment and in the multi-locational yield trials, performed well under a wide range of conditions.

FLOWERING RESPONSE TO PHOTOPERIOD

Plant Physiology Department

Deep-water rices usually flower after the water level has reached its peak. Such adaptation is necessary for survival because elongation ceases after flowering and plants die if they flower while the water level is still rising. Deep-water rices are generally sensitive to

Table 4. Cooking and chemical characteristics of promising deep-water lines and check varieties. Huntra, Thailand, 1977 wet season.

Characteristic	BKN6986 147-2	BKN6986-167	Tapow Gaew 161	Nahng Mon S-4 (check)
	Chemical characteristics			
Amylose (%)	25.9	26.9	25.6	22.0
Alkali test				
Spreading value	5.1	5.2	6.2	6.5
Gelatinization temperature[a]	I	I	L	L
Gel consistency (mm)	73	74	37	26
Cooking time (min)	21.5	21.0	[illegible]	17.5
Paste characters				
Gelatinization temperature (°C)	71	71	74	71
Peak viscosity (B.U.)	870	605	800	490
Setback (B.U.)	+370	+390	+460	+345
	Cooking characteristics[b]			
Aroma	[illegible]	5.6	5.3	5.6
Tenderness	5.8	5.6	5.3	5.7
Cohesiveness	[illegible]	6.0	5.0	5.5
Color	2.7	[illegible]	2.9	2.7
Glossiness	5.8	6.0	5.0	5.5

[a]L = low; I = intermediate; H = high. [b]Graded on a scale of 1–9: 1 = best; 9 = poorest.

Table 5. Average yields of six photoperiod-nonsensitive experimental lines and varieties grown in multilocational replicated yield trials during the dry and wet seasons. Thai-IRRI Cooperative Deep-Water Project, 1977.

Entry	Yield (t/ha)		
	In shallow water (5 cm)		In deep water[c] (90 cm)
	Dry season[a]	Wet season[b]	
BKN6987-82	4.6	3.8	1.7
BKN6986-66-2	4.6	3.7	2.5
BKN6987-68-7	4.5	3.6	1.7
BKN6986-108-3	3.4	3.3	3.8[d]
T442-57 (check)	3.5	3.7	3.1
RD7 (check)	4.2	3.7	0.3

[a] Five stations. [b] Six stations. [c] One station. [d] Consistently high yields in all replicates.

photoperiod. Photoperiodism controls their flowering and fits them to the hydrologic conditions. Plants can therefore be sown so that they will flower as the water depth decreases.

An experiment was conducted to determine if artificial protoperiod could be used to predict the flowering behavior of deep-water rices grown at different latitudes. The varieties were the same as those used in the 1975 survey on flowering dates of deep-water rice (1975 Annual Report). All are photoperiod sensitive (Table 6) but they vary in degree of sensitivity, basic vegetative phase, and critical photoperiod. Varieties from Bangladesh and India, which are at higher latitudes and have longer days, generally have longer critical photoperiods than varieties from Thailand and Cambodia (Table 7). They have so adapted that their panicles are initiated at day lengths longer than those for Thai and Cambodian rices.

Because of their longer critical photoperiod, the Bangladesh varieties flower early in both Thailand and Bangladesh. The actual critical photoperiod values agree closely with the field-survey estimates.

Greenhouse tests can differentiate rices with suitable flowering dates for Thailand, Cambodia, Vietnam, India, and Bangladesh. The month of flowering (although not the accurate flowering date) can be roughly predicted by testing in limited darkroom facilities. For example, Leb Mue Nahng 111 of Thailand whose critical photoperiod is 12 hours and 30 minutes, flowers too late (in November) in Bangladesh. But a Bangladesh variety, such as Habiganj Aman 1 whose critical photoperiod is about 13 hours, flowers too early (in September) in Thailand.

In devising a testing method for early generation deep-water rices, the flowering date need

Table 7. Twelve deep-water rice varieties grouped according to critical photoperiods and flowering dates in Thailand and Bangladesh. IRRI, 1975.

Critical photoperiod (h)	Origin	Variety	Flowering date in	
			Thailand	Bangladesh
13–14	Bangladesh	Habiganj A_2	4 Oct.	7 Oct.
	Bangladesh	Laki 192	23 Sept.	17 Oct.
	Bangladesh	Baisbish	6 Oct.	20 Oct.
	Bangladesh	Habiganj A_1	25 Sept.	2 Oct.
	India	Kekoa Bao	25 Sept.	16 Sept.
12.5–13	India	Gowai 84	6 Oct.	24 Oct.
	India	Kalar Harsall	28 Oct.	10 Nov.
	Thailand	Khao Med Lek	15 Nov.	25 Nov.
12–12.5	Thailand	Po Ngern	3 Dec.	20 Nov.
	Thailand	Sai Bua	7 Nov.	20 Nov.
	Thailand	Leb Mue Nahng 111	12 Nov.	19 Nov.
	Cambodia	Saran Kraham	23 Oct.	14 Nov.

Table 6. Number of days from soaking to flowering of 12 deep-water rice varieties under different photoperiods. IRRI, 1975.

Variety	Days (no.) to flowering under a photoperiod of						
	10 h	11.5 h	12 h	12.5 h	13 h	14 h	BVP[a]
Habiganj A_2	44	99	101	108	125	—[b]	9
Laki 192	40	57	62	103	123	—	5
Baisbish	54	73	85	110	143	—	19
Habiganj A_1	41	46	57	101	142	—	6
Kekoa Bao	59	76	97	121	187	—	24
Gowai 84	60	82	90	142	—	—	25
Khao Med Lek	51	92	110	143	—	—	16
Kalar Harsall	75	95	108	165	—	—	40
Po Ngern	61	108	116	—	—	—	26
Sai Bua	59	87	103	—	—	—	24
Leb Mue Nahng 111	60	97	101	—	—	—	25
Saran Kraham	52	80	97	—	—	—	17

[a] Basic vegetative phase. [b] No flowering after 190 days.

not be accurately measured or predicted. But for further field testing a simple method for differentiating the materials that are more likely to adapt to the different deep-water areas is needed. Because deep-water rice has specific photoperiod requirements, lines should be selected in fields in the specific area. Even rices in areas at similar latitudes have different flowering dates, depending on when the water recedes.

DROUGHT TOLERANCE AT SEEDLING STAGE

Thai-IRRI Cooperative Deep-Water Project

The drought tolerance of 128 rices, including 60 deep-water hybrid lines and floating varieties, was tested in the 1977 dry season. Raised beds were used to accelerate drought stress. The floating variety Leb Mue Nahng 111 was the tolerant check.

After seeding, the nursery was watered sufficiently to ensure good stand establishment; then water was withheld. Nineteen deep water-tolerant hybrids tolerated stress well and recovered satisfactorily from it at 66 and at 112 days after sowing. Both BKN6986-108-3 and BKN6986-66-2 were rated relatively high in tolerance. They gave stable yields under a wide range of water conditions.

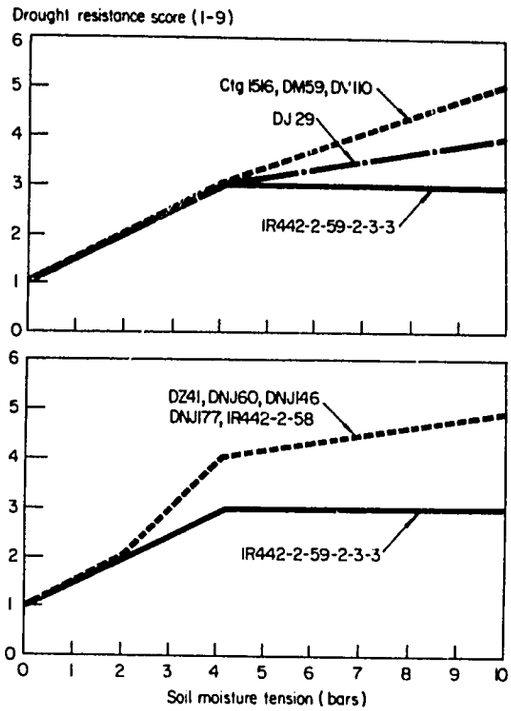
SUBMERGENCE AND DROUGHT TOLERANCE IN A SINGLE VARIETY

Agronomy Department

Traditional rice varieties vary widely in submergence and drought tolerance. If used as parents, these rugged varieties should contribute to the genetic ability to withstand submergence and drought.

During the dry season, 4,115 rices were screened for drought resistance in the field (for details, see section on drought resistance). Several traditional varieties from Bangladesh that normally grow under uncontrolled water conditions had good drought resistance but such resistance was lower than that of IR442-2-59-2-3-3 (Fig. 5).

Many modern rices that were selected for submergence tolerance were screened in the



5. Several rice varieties from Bangladesh had lower drought resistance than IR442-2-59-2-3-3 at 2, 4, and 10 bars of soil moisture tension in field screenings. IRRI, 1975, 1976, and 1977 dry seasons. Rating: 1–9 (1 = none to slight effects of stress, 9 = all plants apparently dead).

greenhouse at a high level of soil moisture tension (–30 bars). Some modern rices such as IR5825-44-3-P1 and IR5825-44-3-P2 had both submergence and drought tolerance. IR5825-44-3-P2 recovered well upon rewatering after about 60 days without water (Fig. 6).

Promising submergence-tolerant and drought-resistant rices will be evaluated for suitability as rainfed-lowland varieties under various environmental stresses, particularly under uncontrolled water in areas of sudden drought of flood.

DIRECT SEEDING IN SHALLOW WATER

Plant Physiology Department

Direct seeding can be useful in controlling weeds, conserving impounded water, reducing the turnaround time between crops, and reducing the cost of transplanting. At IRRI, IR38 was identified as good for direct seeding in 10 cm of

6. Some modern rices such as IR5825-44-3-P2 that had submergence tolerance also had high levels of drought resistance under limited rooting depth in IRRI greenhouse studies.

water because it establishes its roots firmly and emerges through the water. Many other test varieties failed either because the roots would not anchor or because the shoots would not elongate above the water surface.

Direct seeding in dry or puddled-but-drained fields shortens the turnaround time and facilitates the establishment of the first of two crops of rainfed rice. The potentials and problems of rice seeded in 10 cm of water were studied in 1977.

Pregerminated IR38 seeds were sown in water 10 cm deep at 50 seeds/1-m row, spaced 25 cm apart. Simultaneously, 20-day-old seedlings were transplanted at the same spacing.

Transplanted rice yielded more than direct-seeded rice (Table 8) mainly because it had bigger panicles. It actually produced fewer panicles.

Table 8. Yield and yield components of direct-seeded and transplanted IR38 rice. IRRI, 1977 wet season.

Yield parameter	Direct-seeded	Transplanted
Grain yield (t/ha)	3.85	4.66
Panicles (no./m²)	373	270
Wt (g/panicle)	1.52	2.14
1000-grain wt (g)	24.1	24.2

Direct-seeded rice suffered chlorosis at the maximum-tillering stage. Its nitrogen content at flowering was low (0.79% vs 0.96% for transplanted rice). Cultural modification might further increase yields and economic returns from it.

BREEDING PROGRAM AT THAILAND AND IRRI

Thai-IRRI Cooperative Project and IRRI Plant Breeding Department

Crosses were made in Thailand in 1976 and 1977 to determine if additional genes for elongation could be incorporated into semidwarf types. No semidwarf progeny with elongation ability equal to that of floating varieties has been identified. Several semidwarf lines with elongation ability were intercrossed to determine if their genes for elongation were the same; if they were different, transgressive segregation for elongation might occur in the F_2. Elongating semidwarfs were also crossed with floating varieties, including two Rayada introductions from Bangladesh. Because both parents of many of the crosses are sensitive to photoperiod, the crosses did not flower until late in November. The hypothesis that genes for elongation can be recombined has neither been confirmed nor rejected. But when the elongating ability of seedlings of some F_2 populations with photoperiod-nonsensitive parents were tested, few lines were superior to either parent.

More than 1,000 breeding lines were screened for elongation ability at IRRI. No line elongated well and only a few elongated fairly well. As in Thailand, elongation ability appears to be a recessive or incompletely dominant character controlled by several genes acting in a cumulative manner. Backcrossing of the better lines to parents with elongation ability might be needed.

The submergence tolerance of 1,658 lines from 28 crosses was evaluated; 247 lines showed excellent tolerance.

Routine crossing with materials that physiologists recommended for elongation ability and submergence tolerance was continued. In addition the F_1 hybrids of 322 crosses involving deep-water varieties from Bangladesh, made in the 1976 wet season, were used in backcrosses and three-way crosses in the 1977 dry season. F_1 seed of those crosses will be distributed to interested national programs early in 1978. Many of the crosses had to be discarded because of heavy and almost unpreventable infection of ragged stunt disease.

Most improved lines in the 1977 IRDWON elongated poorly compared with the native varieties. Their performance indicated the importance of studying the inheritance of elongation ability.

The newly identified flood-tolerant donors were crossed at IRRI. Several progeny lines were nominated to the IRDWON for more extensive testing.

INTERNATIONAL COOPERATION

Thai-IRRI Cooperative Deep-Water Project and IRRI

An international seminar on photoperiod-sensitive transplanted rice, sponsored cooperatively by the Bangladesh Rice Research Institute (BRRI) and IRRI, was held at BRRI in October 1977. The seminar focused on the rice areas where the prolonged duration of medium-deep water precludes the use of the present improved varieties and on the need for varieties of long growth duration.

The second IRDWON was planted in at least 26 locations. Additional advanced lines from Indonesia, West Africa Rice Development Association, Bangladesh, and India increased the number of entries.

The IRRI deep-water team visited Burma, India, Thailand, and Bangladesh.

Eleven scientists from 7 countries who had completed the GEU training at IRRI participated in a 5-day program in Thailand on the breeding, testing, and selection of deep-water rice. The scientists set up rooting and kneeing tests and later scored the plants. They also scored plants in an elongation test, and evaluated a submergence test. Lectures were given and deep-water rice areas were toured.

Genetic evaluation and utilization (GEU) program

Temperature tolerance

Plant Physiology and Plant Breeding Departments

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LOW TEMPERATURE

Plant Physiology and Plant Breeding Departments

Screening for cold tolerance. Since 1974, 17,689 varieties have been screened for cold tolerance, most in 1977. Five more varieties with cold tolerance at seedling, panicle initiation, and anthesis stages were identified in the screening of the germplasm collection (Table 1). Those, plus the six varieties identified earlier, have optimum plant height and growth duration when planted in low-temperature areas.

Philippines. The 11 varieties and others were used in the cold-tolerance breeding program to combine cold tolerance with other desired traits such as early maturity, pest resistance, fertility, intermediate plant height, and good panicle exsertion. Another desired trait is tolerance for zinc deficiency, which is particularly needed around Banaue, Philippines. The Banaue rice terraces are continuously flooded to prevent the soil from cracking and ultimately eroding, but flooding enhances zinc deficiency.

Collaborative field evaluation of breeding materials with scientists of the Philippine Bureau of Plant Industry (BPI) was intensified at Banaue. Breeding nurseries were expanded so that additional entries in the pedigree nurseries and observational yield trials could be grown.

Several new crosses of newly identified cold-tolerant varieties and elite GEU lines were made. F_2 seed of several 1976 crosses were distributed to collaborating rice improvement programs in low-temperature areas around the world.

Table 1. Indica varieties with tolerance for low temperature based on growth duration, plant height, spikelet sterility, leaf color, and anthesis. Selected from 17,689 entries in the IRRI germplasm bank, 1977.

Variety	Origin	Spikelet sterility (%)	Anthesis at 21°C (%)
Padi Sasahal	Malaysia	29	100
Lambayque 1 (PI 207010-2)	Peru	14	90
Mitak	Indonesia	29	90
Padi Labou Alumbis	Malaysia	11	70
Jumali	Nepal	21	70
Pratao	Brazil	8	100
C 21	Philippines	25	100
Leng Kwang	China	27	70
Silewah	Indonesia	13	100
Thangone	Laos	9	80
Dourado Agullia	Brazil	11	80

Progeny of 21 crosses were grown as F_2 bulk populations at Banaue. Each cross combination had 2,000 to 3,000 plants. Each population was intensively selected for the desired traits. For example, plants were inoculated with the local strain of bacterial blight at the maximum-tillering stage; when lesions appeared, all susceptible plants were rogued. Three populations with high sterility or poor vigor, or both, were discarded. From pedigree rows of the 18 remaining populations, 1,796 plant selections were harvested.

A total of 3,093 pedigree lines from 69 crosses were evaluated. The lines, which ranged from F_3 to F_8, were grown in single-row plots, 4 m in length and spaced at 25 × 20 cm. Every 20th row was planted to standard check varieties. About 1,800 individual plants were saved. Bulk seed of promising lines were harvested and distributed to cooperators in other countries through the International Rice Cold Tolerance Nursery (IRCTN) of the International Rice Testing Program.

Similarly, 141 varieties and lines, selected mostly from the pedigree rows, were evaluated in nonreplicated observational yield trials. Promising lines were from the crosses IR5865, IR5867, IR5908, IR7167, IR8460, and IR9202 (Table 2).

Korea. A collaborative cold-tolerance program with Korea was initiated in 1977. Korea has excellent facilities and field plots that facilitate screening for cold-tolerance.

Cooperative work with Korea will help IRRI's program to increase rice yields on the more than 7 million ha in South and Southeast Asia where low temperature limits yields. IRRI can serve as a liaison between Korea and the other rice-growing areas and can coordinate research and breeding for cold-tolerant varieties for Asia.

HIGH TEMPERATURE

Plant Physiology Department

Screening for high-temperature tolerance. At the flag-leaf stage, test plants were carefully

Table 2. Characteristics of selected improved lines grown at Banaue, Philippines. 1977 dry (D) and wet (W) seasons.

Designation	Cross	Maturity (days)		Plant ht (cm)		Reaction to[a]		Grain quality	
		D	W	D	W	Blast	Bacterial blight	Gel consistency	Amylose (%)
IR30 (reseleclion)	IR5141-102-6-3/ IR2147	150	135	81	80	R	R	medium	22
IR2061-214-3-3-17-2	IR833-6-2-1-1// IR1561-149-1/IR1737	162	138	88	85	R	R	hard	23
IR2061-522-6-9-1	IR833-6-2-1-1// IR1561-149-1/IR1737	162	150	93	87	R	R	hard	23
IR5865-62-2-3	IR747B2-6/Kn-1b-213-1-4-3/ /IR747B2-6/ Kn-1b-361-1-8-6-10	162	151	113	107	R	MR	hard	23
IR5867-45-2-3-2	IR747B2-6/6/Kn-1b-361-1-8-6/ /IR747B2-6/ Kb-1b-213-1-4-3	—	151	—	97	R	MR	medium	24
IR5908-40-3-2-2	IR747B2-6/Kn-1b-361-1-8-6-10/ /IR2053-522-2-3	—	153	—	92	R	R	soft	22
IR5908-125-1-1-3	IR747B2-6/Kn-1b-361-1-8-6-10/ /IR2053-522-2-3	—	145	—	99	R	R	soft	23
IR7167-4-3-2	China 1039/Kn-1b-361-1-8-6-10	—	151	—	93	R	R	medium	25
IR7167-33-2-3	China 1039/Kn-1b-361-1-8-6-10	—	146	—	98	R	R	medium	23
IR8460-86-3	IR28/Shensi Variety	—	152	—	78	R	R	hard	21
IR8866-30-3	K78-13/IR2053-362-1-4	—	153	—	75	R	R	soft	24
IR8866-48-3	K78-13/IR2053-362-1-4	—	153	—	85	R	R	soft	23
IR9202-56-1	IR2053-521-1-1/K116/ Kn-1b-361-1-8-6-9-1	—	145	—	94	R	R	soft	23
Kn-1b-361-B1k-13-6	IR8/Jerak	162	151	108	96	MR	R	soft	24

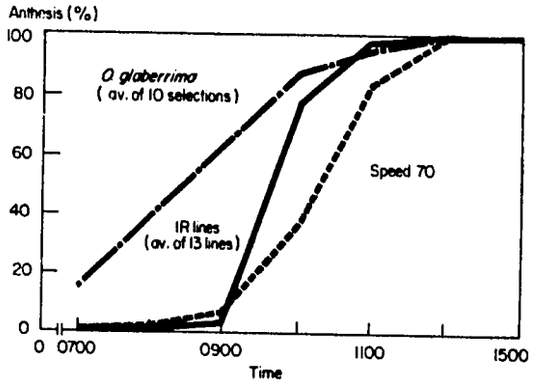
[a] R = resistant; MR = moderately resistant.

uprooted from the fields of the observational yield trial and hybridization blocks, transferred to 4-liter pots, and placed in the glasshouse room at 32°C daytime and 24°C night temperature in the IRRI phytotron. When panicles began to emerge, the plants were subjected to a high-temperature treatment (38°/30°C) in growth cabinets. The plants were taken back to the glasshouse room 5 days after complete emergence of the last flowering panicle. Nonfertilized empty grains were counted at maturity. Although this simplified procedure saves time, labor, and phytotron space, one cannot tell if the sampled plants are healthy or diseased. There is also some indication that climatic conditions during the growth period might affect a variety's tolerance for high temperature. Therefore, screening by this procedure is confined to the dry season.

From 390 selections screened by the above technique, 14 donors of high temperature tolerance were identified (Table 3). N22 consistently shows a high degree of tolerance for high temperatures (1976 Annual Report). Interestingly,

Table 3. Rices found tolerant of high temperature. IRRI, 1977.

Designation	Origin
IR2006-P12-12-2-2	IRRI
IR2798-115-2-3	IRRI
IR3941-97-1	IRRI
IR4427-51-6-3	IRRI
IR4482-5-3-9-5	IRRI
IET4658(UPR96-1-1-1)	India
IET4897(AD-1140)	India
IET5085	India
IET5236	India
CR138-994-A29	India
Krishna	India
N22	India
Ching Yu 1	China
O. glaberrima (Acc. No. 100149)	Guinea



1. Anthesis time of *O. sativa* and *O. glaberrima* selections. IRRI, 1977 dry season.

IR3941-97-1, an early maturing line with waxy grain, has some cold tolerance and a high degree of heat tolerance, but its sister line IR3941-25-1 is susceptible to high temperature.

Variety difference in anthesis time. Results from 1976 indicated that sterility induced by high temperature could be avoided if anthesis occurs in the morning before the temperature rises above a critical level. The anthesis time of 14 *O. sativa* and 10 *O. glaberrima* rices was examined. *O. sativa* and *O. glaberrima* rices differed markedly in anthesis time (Fig. 1). At 0900 about 60% of the *O. glaberrima* spikelets flowered but fewer than 5% of the spikelets of *O. sativas* (IR lines and Speed 70) had anthesis. In high-temperature areas, temperature normally rises above 35°C after 1000 and remains high until 1600 to 1700. Hence, early morning anthesis is a desirable character for varieties for high-temperature areas.

Table 4. Anthesis time of some rices found tolerant of high temperature. 1977 wet season.

Designation	Anthesis (cumulative %) at					
	0700	0800	0900	1000	1200	1400
O. glaberrima (Acc. No. 100149)	20.0	46.0	69.5	81.8	88.1	94.6
N22	0	0.8	18.7	79.3	98.1	100.0
Krishna	0	0	4.2	38.7	93.5	98.2
Ching Yu-1	0	0	1.4	13.6	67.4	96.5
IET4897	0	0	2.3	24.7	86.1	98.3
BKN6624-46-2	0	1.0	4.9	42.8	86.4	98.1

Five tolerant rices and the susceptible check variety BKN6624-46-2 were grown in the wet season, and their anthesis time was examined (Table 4) to see if varieties known to have tolerance for high temperature have early morning anthesis. The *O. glaberrima* selection Acc. No. 100149 had early morning anthesis in the wet as well as in the dry season. The anthesis time of other high temperature-tolerant rices varied considerably and sometimes did not differ from that of the susceptible check. Thus, those rices appear truly tolerant of high temperature.

Genetic evaluation and utilization (GEU) program

International Rice Testing Program

International Rice Testing Program

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INTERNATIONAL NURSERIES

Results from 14 International Rice Testing Program (IRTP) nurseries planted in 1976 (received from Jan. to Nov. 1977) are summarized in Table 1. Results from 338 nursery sets were received from 116 rice research stations in 27 countries in 1977. The nurseries were grown by 296 cooperating scientists.

In 1977, 15 types of nurseries were prepared and dispatched from IRRI. They included the 14 types of 1976. Because late-maturing varieties are important in monsoon Asia, a new yield nursery of long-duration varieties (IRYN-Late) was initiated. The regular cold tolerance nursery was replaced with a preliminary screening set. Six additional nurseries specifically suited to Latin America were distributed by the Centro Internacional de Agricultura Tropical (CIAT) (Table 2).

National contributions to the IRTP nurseries continued to expand; the test entries from

Table 1. Some promising entries from various International Rice Testing Program (IRTP) nurseries, 1976.

Nursery	Promising entries
Yield	
International Rice Yield Nursery-Early (IRYN-E)	IR36, IR1561-228-3-3, BR51-46-1-C1, B541b-Pn-58-5-3-1 B542b-Pn-68-9-2-2, BR4, BR51-46-5, BG374-1
International Rice Yield Nursery-Medium (IRYN-M)	IET 1444, IR36, IR1529-430-3, B541b-Kn-19-3-4, IR2061-522-6-9,
International Upland Rice Yield Nursery (IURYN)	IR3880-13
General observational	
International Rice Observational Nursery (IRON)	B2360-6-7-2, Si 3, BR51-282-8, RD 9, IR4427-315-2-3 (based on wider phenotypic acceptability)
Environmental stress	
International Upland Rice Observational Nursery (IURON)	IR1746-F_5B-24, IR1746-194-1-1-1, C22, MI 48, Salumpikit, ARC 10372, IRAT 13, IR3880-29 (based on wider phenotypic acceptability)
International Rice Deep-Water Observational Nursery (IRDWON)	BKN 6986-147-2, BKN 6986-14, BKN 6986-173-5, BKN 6986-81
International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON)	BG 34-8, BG 94-2, Nona Bokra, Damodar, Patnai 23, SR 26B, Pokkali, IR3265-193-3-3
International Rice Cold Tolerance (Nursery (IRCTN)	China 1039, Eiko, IR1846-284-1-1, IR1846-287-1, IR1846-296-3, IR3941-8-1, IR3941-45, K 84, Kn-1b-361-1-8-6-1-1-6
Biological stress	
International Rice Blast Nursery (IRBN)	IR5533-PP855-1, IR5533-PP856-1, IR9669-PP836-1, IR1416-128-5-8, Ta-poo-cho-z
International Rice Sheath Blight Nursery (IRSHBN)	BR 2-29-2-1-3, IR2071-588-4-4, IR2071-588-5-1, Remadja, Suduwee
International Rice Tungro Nursery (IRTN)	ARC 10531, ARC 13677, ARC 13820, ARC 13901
International Rice Brown Planthopper Nursery (IRBPHN)	Ptb 33, RP825-24-7-1, RP825-71-4-11, Gangala, Ptb 19, Ptb 21, Suduru Samba
International Rice Gall Midge Nursery (IRGMN)	RPW6-17, RP352-28-1, RP9-10-3-2-1, IR4744 selections (11), 75-163 75-203, BKN-BR 1030-3-2, BKN-BR 1031-3-3-6 W 1263
International Rice Stem Borer Nursery (IRSBN)	IET 2815, IET 2830, IET 2845, RP887-46-1, Mahsuri Mut. 3628, CRM 14-29-R75, R34-73-200, IR1820-52-2, W 1263 (based on deadheart incidence)

Table 2. International Rice Testing Program (IRTP) nurseries composed and distributed in Latin America by the Centro Internacional de Agricultura Tropical (CIAT).

Year	Nursery	Composition	Sets (no.)	Recipient countries (no.)
1976	International Yield Nursery for Latin America [Vivero Internacional de Rendimiento Para America Latina (VIRAL)]	19 entries from 9 Latin American countries; 5 from IRYN	27	18
1977	International Yield Nursery for Latin America — Early (VIRAL-Prococes)	10 IRYN-E entries	28	16
	International Yield Nursery for Latin America — Medium (VIRAL-Tempranas)	14 IRYN-M entries	28	16
	International Upland Rice Yield Nursery (VIRAL-Secano)	14 IURYN entries	22	14
	International Rice Sheath Blight Nursery (VIVERO)		9	7
	International Rice Salinity and Tolerance Observational Nursery (VIOSAL)		4	4
	International Rice Deep Water Observational Nursery (VIRAL-F)	10 IRDWON entries	5	5

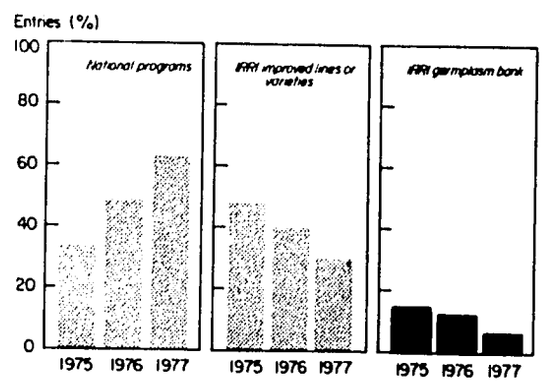
national programs increased from 35% in 1975 to 65% in 1977 (Fig. 1). Requests for nursery sets increased in 1977, although some could not be met because of seed shortages (Table 3). More than 70% of the nurseries went to Asian countries (Table 4). The yield and the observational nurseries were most widely distributed.

The IRTP continued to develop regional programs to ensure that cooperators have access to materials well adapted to their growing conditions (Fig. 2). Because the specific varietal requirements of Latin America and the arid regions of North Africa and West Asia differ in some traits from those of the humid Asian tropics, separate nurseries were established for those two regions. CIAT and IRRI jointly developed a network of test sites in 18 Latin American countries. The first yield nursery for Latin America comprised the best improved Latin American, CIAT, and Asian varieties and breeding lines. After preliminary evaluation at CIAT, other nurseries were composed of the best entries from the regular IRTP nurseries. Similar arrangements are being developed in Africa with the International Institute of Tropical Agriculture (IITA) and the West Africa Rice Development Association (WARDA).

Within countries the IRTP nurseries are distributed through the national programs. The national coordinators and contact scientists are responsible for effective integration of the IRTP nurseries into the overall national programs. Some large national programs that coordinate the testing of a large number of nurseries are the All India Coordinated Rice Improvement Program (115 sets), the Bangladesh Rice Research Institute (47 sets), the National Rice Program of Indonesia (37 sets), and the Thai Rice Program (41 sets).

UTILIZATION OF IRTP NURSERY ENTRIES

The ultimate purpose of the IRTP is to assist in the development and evaluation of diverse rice varieties and their dissemination to rice farmers around the world. Although the IRTP has been operational for only 3 years, some measure of its effectiveness begins to be seen as many IRTP entries are promoted to local yield trials (Table 5). Scientists in countries such as India, Bangladesh, and Burma are effectively using the entries that perform well locally. A significant



1. Sources of nominations for the International Rice Testing Program (IRTP) trials, 1975–77.

Table 3. Number and sources of more than 100,000 seed packets of rice varieties and lines distributed through the International Rice Testing Program (IRTP) nurseries, 1977.

Nursery[a]	Sets dispatched (no.)	Entries[b] (no.)	Entries from: National programs		Entries from: IRRI: Improved rices		Entries from: IRRI: Germplasm bank		Packets (no.)
			No.	%	No.	%	No.	%	
				Yield					
Lowland									
IRYN-E	56	28[c]	20	71	8	29			4704
IRYN-M	50	28[c]	20	71	8	29			4200
IRYN-L	18	28[c]	23	82	5	18			1512
Upland									
IURYN	46	25[c]	13	52	12	48			3450
				General observational					
IRON	97	391	261	66	131	34			37927
				Environmental stress					
IURON	65	153[d]	94	61	52	34	7	5	19890
IRSATON	35	77	38	49	32	42	7	9	2695
IRDWON	26	70	56	80	11	16	3	4	1820
IRCTN (prel. screen.)	11	380	260	68	78	21	42	11	4180
				Biological stress					
IRBN	48	476	232	49	244	51			22848
IRSHBN	32	154	58	38	62	40	34	22	4928
IRTN	15	187	132	71	38	20	17	9	2805
IRBPHN	28	128	85	67	3	2	40	31	3584
IRGMN	24	119	99	83	20	17			2856
IRSBN	26	82	42	51	37	45	3	4	2132
Total	577	2326	1432	64	741	30	153	6	119531

[a]IRYN-E = International Rice Yield Nursery — Early; IRYN-M = International Rice Yield Nursery — Medium; IRYN-L = International Rice Yield Nursery — Late; IURYN = International Upland Rice Yield Nursery; IRON = International Rice Observational Nursery; IURON = International Upland Rice Observational Nursery; IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery; IRDWON = International Rice Deep Water Observational Nursery; IRCTN = International Rice Cold Tolerance Nursery (preliminary screening); 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. [b]Including check varieties. [c]Three replications each. [d]Two sets of seed sent for 2 seeding dates.

number of the best-performing IRTP entries were from national programs. Many entries have been used in national hybridization programs.

Another gauge of use is the number of national entries from IRTP nurseries that are used as breeding materials in the crossing program at IRRI. During the 1976 wet season about 20% of the 2,199 crosses made involved at least one national entry from IRTP trials. During the 1977 dry season 21% of 2,329 crosses were national IRTP entries.

MONITORING PROGRAM

The IRTP monitoring tours bring national scientists together and encourage bilateral cooperation among local scientists in areas of common interest.

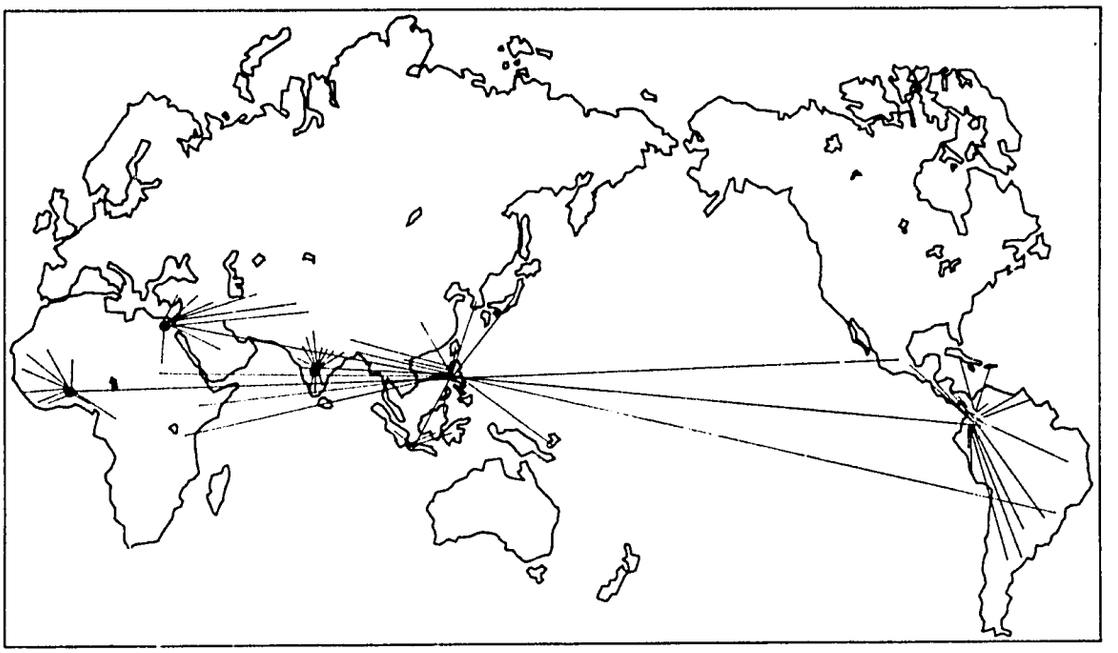
For the first time IRTP monitoring tours were made in North Africa and West Asia, and in Latin America in 1977. Another tour was made in Nepal and East India. Twenty-four scientists from 10 countries visited 9 different countries in the three 1977 monitoring tours (Table 6).

The participants recommended increased regional cooperation to solve common rice research and production problems. During the tours of the arid regions and of Latin America, the scientists observed that many current IRTP entries from tropical Asia lacked specific traits needed in those regions. Both groups recommended more exchange of material among national programs in each region. As a result, an

Table 4. Distribution of International Rice Testing Program (IRTP) nurseries[a] in 1977.

Region and country	Nurseries (no.)														
	Yield				General observational	Environmental stress					Biological stress				
	IRYN-E	IRYN-M	IRYN-L	IURYN	IRON	IURON	IRSATON	IRCTN	IRDWON	IRBN	IRSHBN	IRTN	IRBPHN	IRGMN	IRSBN
East Asia															
Japan													1		
Korea	2				3	1	1	1		2	2		1		1
Taiwan	2									1	1		2		
Southeast Asia															
Burma	1	1	1	1	1	1			2						
Indonesia	3	3		2	2	3	1	2	1	4	4	2	4	2	4
Malaysia	1	1			1					2	1	1	1		1
Philippines	4	4	1	10	8	9	2	2	4	4	2	3	5		4
Thailand	4	4	2	5	3	7	4		2	1	2	2	1	3	1
Vietnam		2		1	1	1	1		1	1	1		1		1
South Asia															
Bangladesh	7	6		3	11	3	1	1	4	2	2	2	2	1	2
India	15	10	5	7	12	6	10	4	4	8	7	4	8	9	6
Nepal	2	3		2	3	2		1		2	1				1
Pakistan	2	2	2	1	2		2		2	1					2
Sri Lanka		2			4	2	1			2	1		1	2	
West Asia and North Africa															
Afghanistan					1										
Egypt	2	2			2		1			2					2
Iran	1	1			3	1				1					
Saudi Arabia						1									
Sudan					1	1	1							1	
Sub-Sahara Africa															
Ivory Coast				2		1				1					
Liberia					2	1				1	1				
Malawi	1			1			1								
Senegal					1						1			1	
Somalia					1										
Tanzania	1				1	1				1				1	
IITA[b]	2	2	1	2	7	9	2		2	2	3	1	1	4	
WARDA[c]	2	3	3		16	1	1		1	1					
Latin America															
Argentina					1										
Brazil				1	3	3	1		1	1					
Bolivia										1					
Colombia	1	1		1	1	1	1		1	2	1				
Costa Rica				1		1					1				
Dominican Republic							1								
Ecuador		1	1	1			1		1	3					
Guatemala				1											
Honduras				1											
Mexico	3	2	2	1	3	4	2								
Panama				2		2				1	1				1
Peru					1	1				1					
Surinam					2	1									
Venezuela						1									
Total	56	50	18	46	97	65	35	11	26	48	32	15	28	24	26

[a]IRYN-E = International Rice Yield Nursery — Early; IRYN-M = International Rice Yield Nursery — Medium; IRYN-L = International Rice Yield Nursery — Late; IURYN = International Upland Rice Yield Nursery; IRON = International Rice Observational Nursery; IURON = International Upland Rice Observational Nursery; IRSATON = International Rice Salinity and Alkalinity Tolerance Observational Nursery; IRCTN = International Rice Cold Tolerance Nursery; IRDWON = International Rice Deep Water 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. [b]International Institute of Tropical Agriculture. [c]West Africa Rice Development Association.



2. Distribution of IRTP nurseries both direct and through national and regional programs.

Table 5. Entries in the International Rice Testing Program (IRTP) that have been promoted to advanced yield or production trials in selected national programs, 1977.

Country	Type of trials	Entries
Burma	National trials	BR 4, BG 90-2, Pelita I-1
Egypt	Regional long-grain trials	IR28, Cica 4, IR2053-43-2-5-1, IR2307-217-2-3, IR36
India	National trials in All India Coordinated Rice Improvement Project (AICRIP)	BG 33-2, BG 34-8; (UVT-2) — IR36; (UVT-4) — Biplab, BR 52-87-1; (PVT-3) — BR 51-46-1-C1; (PVT-4) — IR2058-78-1-3-2-3; (Gall midge trial); IR2070-414-3-9
	Karnataka state trials	Uniform yield trials — IR3941-8-1; IR3941-27-1; IR3941-29-1, IR3487-1-24-1 Cold-tolerant areas — Kn-1b-361-B1k-2-10; IR3941-8-1; IR1846-195-3; IR2637-15; IR2637-9; IR3249-19-1; IR3941-2-1-3; IR3941-45 Others — IR2070-414-3-9, IET 3127, B541b-Pn-58-5-3, BR 51-91-7, Biplab, BG 90-2, BPI 76*9/Dawn, Kn 361-1-8-6, C 22, MRC 172-9, IR2061-522-6-9, IR3880-17
	West Bengal state trials	BR 51-46-1-C1, Ai-nan-tsao no.1, BG 34-8 B9c-Md-3-3 (Gati), B57c-Md-10-2, IR2035-242-1 IR2071-887, MRC 63, MRC 172-9, B981d-Si-35-1, B981d-Si-46-2, IR3880-13, BPI 76*9/Dawn, BPI 76 (Bicol), Kencana, KN 96, KN 144, T442-57, SPT 6837-355-11, PMI 72-22, PMI 72-40, C 22
	Kashmir state trials	IR1846-287-1, IR1846-295-3, IR2516-1-2, IR2637-42-1
	Kerala state trials	IR36, IR2058-78-1-3-2-3, BR 4
Mexico	Campeche state	IR2055-462-3-2-3, IR2055-481-2-1-2, IR2058-328-1-1-1
Nepal		IR1529-677-2, IR2071-124-6-4, BR 51-46-5, BG 90-2 IET 1444, IR577-24-1-1-1, IR2061-628-1-6-4-3, IR36, IET 2938, Chandina
Peru		Sri Malaysia II, IET 2254, PMI 6624-257-1, C 168 IR2070-423-2-5-6, IR32, IR2031-724-2-3-2, BR 2-29-2-8-1, BR 51-46-5, IR1721-11-6-8-3-6, IR1820-210-2, IR2451-183-6-2
Philippines		BR 34-8 used in double-cropping experiments at many locations.
Sudan		IR2153-26-3-5-2, IR2153-43-2-5-3
Tanzania (Zanzibar)		51 entries from the 2nd IRON and 59 entries from the 3rd IRON advanced to national trials.

Table 6. The International Rice Testing Program (IRTP) monitoring tours for 1977.

Focus of tour	Participants (no.)	Countries represented (no.)	Countries visited (no.)	Research stations and institutes visited (no.)	Nurseries observed (no.)
Rice in arid regions	8	5	4	7	30
Nepal and East India	10	4	2	8	18
Upland rice in Central America and Mexico	6	6	4	7	19

International Rice Arid Regions Observational Nursery (IRARON) was established and the yield, observational, and blast nurseries for Latin America were expanded.

Korea, Indonesia, and IRRI are developing collaborative programs on common research problems (cold tolerance, blast resistance, and brown planthopper), partially as a result of participation in monitoring tours. The IRRI Brown Planthopper Symposium in 1977 was partially a result of 1975 and 1976 monitoring tours that focused on hoppers. Screening methodologies for various stresses are being improved and widely adopted because of the exchange visits of scientists.

COMMUNICATION AND DATA MANAGEMENT

Working documents of results from the 14 nurseries in 1976 were published in April. Final reports were published in late 1977. A report of the 1976 monitoring tours, published early in 1977, summarized the observations and recommendations of each of the seven groups for future follow-up by IRTP and the national programs. The report also acquainted administrators with the role of monitoring program.

Program results and future plans were discussed at the 1977 International Rice Research Conference and the IRTP advisory committee meeting held in conjunction with it. At the "Rice in Africa" conference held at the IITA in March 1977, the IRTP program in Africa was discussed. A regional planning meeting for Latin America was held in November at CIAT.

Genetic evaluation and utilization (GEU) program

Integrated GEU program

Plant Breeding and All GEU Departments

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EXCHANGE OF GERMPLASM

Plant Breeding Department

In response to special requests 9,220 seed packets of improved breeding lines and varieties were distributed in 1977. The International Rice Testing Program (IRTP) provided another 36, 583 packets of the best GEU lines and varieties to participating national programs. Seven hundred and twenty-four packets of F_2 seed from 159 crosses were distributed to 28 locations in 15 countries.

Collaborative projects with several national programs were initiated in 1977; early generation materials, advanced breeding lines, and varieties were exchanged for evaluation and hybridization.

IRRI LINES NAMED IN NATIONAL PROGRAMS

Plant Breeding Department

The Philippine Seed Board named two IRRI lines as varieties in 1977 (Table 1). A total of 51 IRRI lines have been named in national programs in addition to 11 varieties named directly by IRRI.

IR40 (IR2070-414-3-9) is early maturing (115 days) and short-statured. Its grain is medium in length and translucent, with high amylose content (25%), intermediate gel consistency, and intermediate gelatinization temperature. IR40 is resistant to blast and grassy stunt, and moderately resistant to tungro, in the Philippines. It appears moderately resistant to a new virus disease, ragged stunt. It is resistant to the predominant Philippine strain of bacterial blight, but susceptible to prevailing local strains in the Palawan, Davao, and Isabela regions and, more recently, around IRRI. IR40 is moderately resistant to bacterial streak. It is resistant to biotypes 1 and 2 of the brown planthopper and to green leafhopper, and moderately resistant to stem borer. IR40 is the first known improved variety with resistance to the rice whorl maggot in the Philippines.

IR40 is moderately resistant to iron toxicity, zinc deficiency, and phosphorus deficiency. It has slight resistance to salinity but not to alkalinity.

IR40 has a relatively weak straw and is not suitable for highly fertile conditions. It is otherwise well suited to irrigated conditions and may be used in certain rainfed lowland areas.

IR42 (IR2071-586-5-6-3) is a short-statured variety with outstanding yield potential at low nitrogen levels in the wet season in the Philippines. It matures in about 130 days. It has medium-length, translucent grain with high amylose content (29%), hard gel consistency, and low gelatinization temperature.

In the Philippines, IR42 is resistant to blast and has intermediate resistance to sheath blight. It is resistant to tungro and grassy stunt and appears resistant to ragged stunt in the field. Like IR40, it is resistant to the predominant Philippine strain of bacterial blight. IR42 is moderately susceptible to bacterial streak. It is resistant to biotypes 1 and 2 of brown planthopper, resistant to green leafhopper, and moderately resistant to stem borer.

IR42 is moderately resistant to zinc deficiency and phosphorus deficiency but is susceptible to salinity, alkalinity, and iron toxicity. It was somewhat resistant to drought in IRRI field tests. It should be well suited to irrigated farms and may grow well in many rainfed lowland areas.

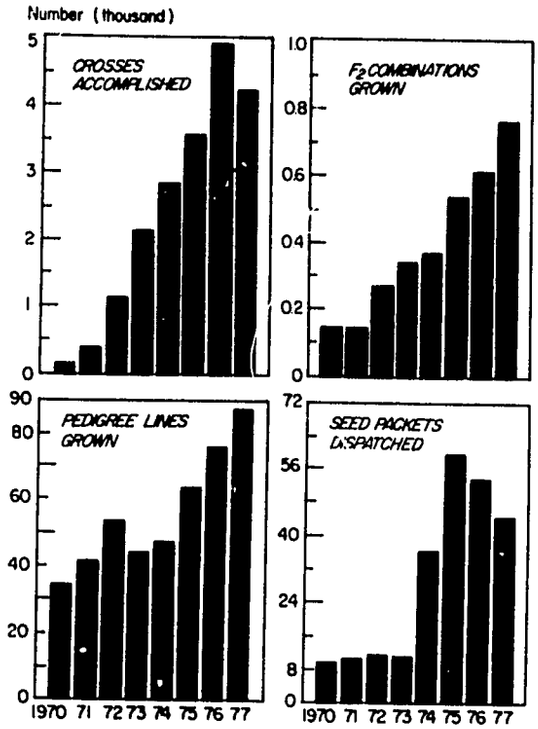
Table 1. IRRI lines named in national programs in 1977.

Variety	Line designation/ cross	Country
IR40	IR2070-414-3-9 IR20*2/*O. nivara*/ /CR94-13	Philippines
IR42	IR2071-586-5-6-3 IR1561-228/IR1737/ /CR94-13	Philippines

BREEDING OPERATIONS

Plant Breeding Department

The volume of the IRRI crossing program decreased slightly in 1977 while the number of F_2 combinations and pedigree lines grown continued to increase, reflecting the expanded crossing effort in previous years (Fig. 1). The number of crosses is expected to stabilize at about the 1977 level or to increase slightly as new collaborative projects increase. The number of seed packets dispatched continued to



1. Growth of the IRRI GEU program.

decrease because of further reduction in the volume of IRRI material included in the IRTP as national programs increased participation in IRTP.

The responsibilities of the GEU plant breeders were reorganized in 1977 to focus more directly on important target areas. One or two breeders now focus on each of the following areas: irrigated, with good water control; rainfed lowland; upland; deep-water; adverse soils; adverse temperature.

Steps have been taken to assure that the selection and subsequent evaluation of early generation materials are relevant to each target area. Efforts in areas of adverse soils, adverse temperatures, and deep water are detailed in other GEU sections.

Irrigated areas. About half of the world's rice area is irrigated with relatively good water control (although in South and Southeast Asia the proportion is considerably less). Yields are relatively high; the largest portion of the world's total rice production is from the irrigated areas.

Farmers in those areas have long accepted improved, short-statured varieties and now grow them almost to the exclusion of traditional types. It is increasingly clear that maintaining and increasing production in irrigated areas hinge on the availability of varieties with adequate resistance to the important pests. Shorter growth duration is also desirable for intensified cropping and economical water use.

Rainfed-lowland areas. The worldwide percentage of rainfed lowland rice is second only to that of irrigated rice. In India and other South and Southeast Asian nations, rainfed-lowland areas greatly exceed those under irrigation and usually account for at least half of the total rice area.

There is, however, no distinct division between rainfed lowland and other rice-growing areas. Many so-called irrigated areas are only partially irrigated and may be subject to drought or floods. Upland areas are distinguished from rainfed-lowland areas mostly by the fact that they are nonbunded and the soil is prepared dry, but growing conditions are often similar. The absence of bunds may also distinguish deep-water from rainfed lowland areas.

The development of improved germplasm specifically for rainfed-lowland conditions has not been emphasized; improved varieties that are reasonably suited to such conditions were a spillover from irrigated-rice improvement programs. Vast rainfed lowland areas are still planted to traditional varieties. Yield stability is of crucial concern there and consideration of water excesses and deficits is imperative. Soil nutrient deficiencies are also a widespread constraint.

Conditions from location to location are far too variable to allow precise elaboration of desirable combinations of traits for rainfed lowland varieties. Intermediate to tall stature combined with sturdy stems is desirable for most areas. Most of the current rainfed lowland varieties have some drought resistance. Flood tolerance (either submergence tolerance or elongation ability) is desirable for most areas. The importance of photoperiod sensitivity is not clear, but the trait is essential in some situations.

Yield stability on adverse soils also determines the adaptability of rice varieties. Many varieties grown in rainfed lowland areas are

specifically noted for their tolerance for one or more adverse soils conditions.

Improved germplasm is being developed through collaborative hybridization and screening with national programs in areas representative of the major types of rainfed lowland conditions. Collaborating scientists provide IRRI with the most widely grown varieties and improved lines from their regions. IRRI makes a large number of crosses and provides national scientists with segregating materials. New breeding lines and other desirable germplasm will be provided to IRRI on a regular basis in the future, and bulk hybrid populations from IRRI and elsewhere will be provided to each collaborator before the main growing season. The *rapid generation advance* technique will be used to provide advanced generation bulk hybrid populations of photoperiod-sensitive materials.

An International Rainfed Lowland Rice Observational Nursery (IRLRON) is planned as part of the IRTP.

Upland areas. The major concern of upland rice farmers is the adequacy of rainfall distribution during the crop season. Upland rice usually suffers from drought during either the vegetative or reproductive phase, or both.

The semidwarfs may yield well in a few areas where the soil is fertile and rainfall is abundant and evenly distributed. But when 2 to 3 weeks of drought occurs at the late vegetative or early reproductive stages, the growth of most semidwarfs is greatly stunted and their panicle development is lowered. High panicle sterility and poor grain development cause low yields and poor grain quality. But drought-resistant upland varieties give low stable yields, even when moisture stress persists throughout a substantial portion of their life cycles.

IRRI is attempting to incorporate drought resistance into semidwarfs, selecting and screening under simulated drought conditions. To minimize incompatibility between upland and lowland crosses, advanced-generation semidwarf lines with high drought resistance are often used as parents.

To meet the needs of different agroclimatic zones, early maturing (110–120 days) to medium-maturing (120–130 days) lines are selected. Most farmers prefer early maturing varieties so they can use the remaining rain to grow crops. The eating qualities that upland rice farmers prefer are also given priority in selection. The upland breeding program emphasizes incorporation of resistance to blast, bacterial blight, sheath blight, leaf scald, whitebacked planthopper, and yellow stem borer.

NEW LINES WITH MULTIPLE ATTRIBUTES

All GEU Departments

Multiple pest resistance is of primary importance for improved varieties, especially for most irrigated areas. Most improved IRRI lines are resistant to the major Philippine pests (Table 2).

Short growth duration is a highly desirable trait for irrigated areas because it allows water to be used more economically and permits high cropping intensity. Early maturity increases cropping intensity on rainfed lowland farms where the first of two crops is direct seeded. Several improved IRRI lines and varieties mature in less than 115 days (Table 2) with no sacrifice in yield.

Several improved lines with relatively long growth duration and intermediate to tall stature have been developed for certain rainfed lowland areas where only one crop is feasible (Table 2). For example, IR3464-75-1-1 (waxy), IR3351-38-3-1 (low amylose), and IR4570-83-3-3 and IR4219-35-3-3 (high amylose) have suitable eating quality as well as plant types, growth durations, and other characters that may make them acceptable to farmers in major rainfed lowland areas.

A few promising upland lines such as IR3880-10 and IR5178-1-11-4 have high levels dispatched to the deep water rice project in major pests, relatively high yield potential, and yield stability (Table 2).

BREEDING METHODS

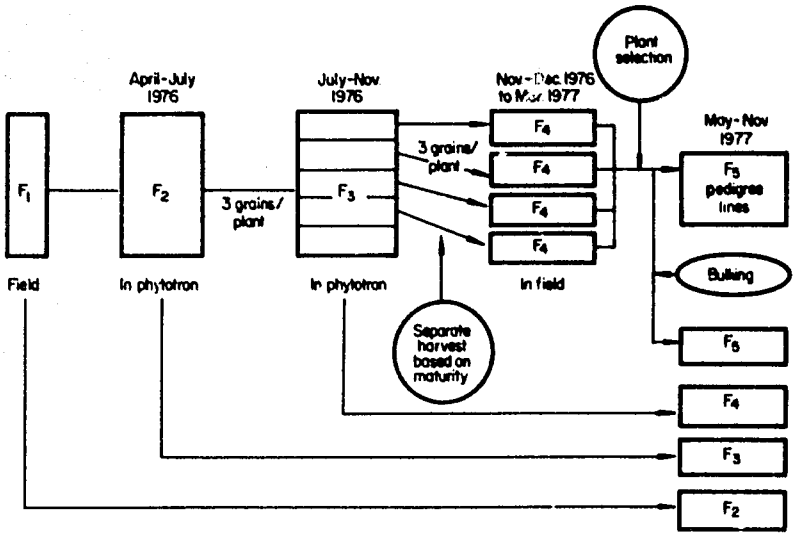
Plant Breeding Department

Rapid generation advance. To facilitate the breeding of photoperiod-sensitive rice, a feasibility test has been conducted since 1976 starting with initial F_2 and F_3 generations grown

Table 2. Important characteristics of selected elite GEU lines. IRRI, 1977.

Designation	Cross	Ht (cm)	Growth duration (days)	Amylose content (%)	Reaction[a] to: Blast	Bacterial blight	Tungro	Grassy stunt	Green leafhopper	Brown planthopper: Biotype 1	Brown planthopper: Biotype 2	Stem borer	Special traits and potentials[b]
IR2058-78-1-3	IR1416-131/IR364-37/ / IR1366-120/IR1539-823	115	120	27	MR	R	MR	—	—	R	S	MR	I; RL
IR2070-414-3-9	IR20*2/*O. nivara*/ /CR94-13	100	115	25	R	R	MR	R	R	R	R	MR	R to whorl maggot; I
IR2071-586-5-6	IR1561-228/IR1737/ / CR94-13	100	130	29	R	R	R	R	R	R	R	MR	High yield potential at low nitrogen levels; I; RL
IR2307-247-2-2	CR94-13/IR1561-228	95	110	27	MS	R	R	—	R	R	R	MR	I; RL
IR2863-38-1-2	IR1529-680/CR94-13/ / IR480	100	130	27	MR	R	R	—	R	R	R	MR	I; RL
IR3351-38-3-1	IR841-85/IR1917-3-17/ / CR94-13	110	130	15	MR	R	R	R	R	R	R	MR	RL
IR3464-75-1-1	IR1628-68/IR841-67/ / IR2061-213	120	140	Waxy	MR	R	R	R	R	R	R	MR	I; RL
IR3518-106-2-2	BKN6806-18/IR1529-680/ / IR 94-13/IR1416-131	130	130	25	R	R	R	—	R	R	S	MR	RL
IR3880-10	IR841-67/C22-51/ /Pelita I-2/IR1541-76	130	130	16	R	S	—	—	R	R	S	MR	R to drought; U
IR4219-35-3-3	IR2061-213/IR480-5-9-3	130	135	27	MR	R	R	R	R	R	S	MR	RL
IR4417-179-1-5	IR2042-101-2/IR825-11-2-3	115	125	25	R	R	R	—	R	R	S	MR	I; RL
IR4432-28-5	IR2061-125-37/CR94-13	100	120	25	R	R	R	R	R	R	R	MR	R to drought; I; RL
IR4568-86-1-3-2	IR1702-74/IR2061-464/ / IR2055-475	110	120	25	R	R	R	—	R	R	R	MR	I
IR4570-83-3-3	IR1702-74/IR1721-11/ / IR2055-481	115	130	23	R	R	R	—	R	R	R	MR	I, RL
IR4630-22-3-3-1-1	Pelita/Pokkali/ /IR2061-464/IR1820-52	125	125	25	MR	R	R	—	R	R	S	—	R to salinity; RL
IR5178-1-1-4	IR1746-194-1-1-1/ IR1487-372-4	130	110	22	MR	MR	—	—	MS	MS	—	MR	R to drought; U
IR5657-33-2-2-3	IR2006-103/IR2146-68/ / IR2061-465/IR2055	110	120	20	MS	R	R	—	R	R	S	—	R to salinity; I; RL
IR5853-118-5	Nam Sagui/IR2071-88/ / IR2061-214	100	110	27	R	R	R	—	R	R	R	MR	R to drought; I, RL
IR5853-162-1-2	Nam Sagui/IR2071-88/ / IR2061-214	110	120	27	R	R	R	—	R	R	R	MR	I
IR9264-321-3	Mahsuri/2*IR2061-213	125	140	27	R	R	R	—	R	R	S	MR	RL

[a]R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible. [b]Potentially suited to certain growing conditions, I = irrigated; R = resistent; RL = rainfed lowland; U = upland.



2. Flow of materials under rapid generation advance. IRRI, 1976–77.

under short day length. From F_4 populations that were grown from December 1976 to March 1977, some photoperiod-sensitive F_5 lines with resistance to major pests were developed (Fig. 2) in the 1977 wet season.

A number of photoperiod-sensitive plants were affected by reduced nitrogen level and dense spacing in the greenhouse. Even under short day length, flowering was sometimes delayed, and relatively few photoperiod-sensitive types were recovered from the populations. But increased nitrogen application seemed to prevent retarded flowering.

Five hundred lines each of two F_5 populations (Tarao Bao/IR34 and Tarao Bao/2*IR34) were dispatched to the deep water rice project in Thailand. The recovery of lines with elongation ability was 10% and those with bacterial blight resistance was 14%, in the single cross. The recovery of elongation ability was extremely low in the backcrossed population. In both crosses, the selection for short stature in the F_4 may have adversely affected the recovery of elongation ability in deep water.

The use of plastic cylindrical film capsules 3 cm in diameter and 5 cm in depth was found effective in growing plants separately and removing discarded plants during rapid generation advance in the Thailand project.

Induction of monogenic male sterility. In several areas of breeding, repeated hybridization of segregating lines enhances recombination. To breed lines with a wide spectrum of blast resistance, secondary crossing of resistant progeny is desirable to incorporate diverse resistance genes. Frequent hybridization is necessary to combine various traits in a composite population with wide potential variation. Monogenic male sterility would facilitate such hybridization.

Dried IR36 seeds were treated with a chemical mutagen, ethyleneimine, in varying concentrations for 1 to 3 hours. Treatment with 0.2% solution for 3 hours and 0.4% solution for 1 hour strongly depressed germination. Almost no seed germinated in the more intensive treatment. About 2,000 M_1 plants from the treatments were planted; most were carried forward to the M_2 generation. Of the 1,954 M_2 lines of 12 plants each, 93 lines segregated partially sterile plants that may have been pollinated by neighboring plants. From the segregating lines, 93 partially sterile plants were transferred to the greenhouse for further inspection of their pollen and of cross-fertility of the female organ. The viability of pollen of 10 plants was extremely low but the ovule function was normal. The genetic behavior of the male-sterile plants has not yet been tested. But some plants with monogenic male sterility will probably be recovered from those mutants.

Genetic evaluation and utilization (GEU) program

Computerized data management

Statistics Department

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GERMPLASM BANK

Data bank. There are 36,956 registered accessions of *O. sativa* in the IRRI germplasm bank, and for those a computer-based data management system provides complete information on varietal origin, seed source, and name. In addition, the system provides

- complete information on 38 basic morphoagronomic characteristics (1976 Annual Report) for 26,000 accessions,
- existing information on 35 GEU traits for 33,946 accessions. Table 1 gives the number of accessions screened for each trait and placed in the germplasm data bank as of 1977.
- information retrieval service for all the data in the system.

Seed bank. A computer-based information management system was developed to monitor the movement of seed stocks and to provide instant information on the current status and location of the seed stocks for each accession. The system was tested in 1977 and will be implemented when seed stocks are transferred to the new Rice Genetic Resources Laboratory early in 1978.

Table 1. Accessions in the IRRI germplasm bank with information for various traits screened by GEU scientists and included in the computer-based data management system as of December 31, 1977.

GEU trait	Accessions (no.)	GEU trait	Accessions (no.)
Bacterial leaf blight	21,105	Protein:	
Blast	17,833	Dry season crop	16,935
		Wet season crop	13,493
Sheath blight	8,728		
		Amylose	13,222
Rice tungro virus	1,671	Drought:	
		Field resistance[a]	2,562
Brown planthopper:		Field tolerance[a]	1,611
Biotype 1	20,913	Problem soil:	
Biotype 2	3,460		
Biotype 3	3,213	Alkalinity	879
		Salinity	883
Green leafhopper	16,046	Zinc	553
Striped stem borer:		Rooting ability	40
Deadhearts	6,870	Elongation	1,393
Whiteheads	1,677		
		Flood tolerance	4,183
Rice whorl maggot	19,115		
		Cold tolerance	660
Whitebacked planthopper	11,034		

[a]Each consisting of six different traits.

BREEDING OPERATIONS

Each cross made at IRRI is recorded in a history-of-cross data file, which contains information on the names and sources of the two parents. The file contained 19,812 crosses at the end of 1977. Volume 1 of *Parentage of IRRI crosses*, which included IRRI crosses 1 through 10,000, was published. Volume 2, which will include IRRI crosses 10,001 through 20,000, was started and will be released in 1978.

From the history-of-cross file, a computer program was developed to complete the family tree of each cross.

The system for computer-generated field books was completed for the hybridization blocks, observational yield trials, replicated yield trials, and early-generation testings (F_1 and F_2 nurseries). The books facilitate the collection of data on entries in those trials by GEU scientists and allow timely distribution of available data among all scientists.

INTERNATIONAL RICE TESTING PROGRAM

Efforts to develop an Internationl Rice Testing Program (IRTP) data management system continued. The systems for the International Rice Yield Nursery, the International Upland Rice Yield Nursery, and the International Rice Blast Nursery were completed in 1976. The computerized systems for the following nurseries were developed in 1977:

- The International Rice Observational Nursery,
- The International Upland Rice Observational Nursery,
- The International Rice Tungro Nursery,
- The International Rice Sheath Blight Nursery,
- The International Rice Brown Planthopper Nursery,
- The International Rice Stem Borer Nursery, and
- The International Rice Gall Midge Nursery.

Genetic evaluation and utilization (GEU) program

Rice breeding in Asia

Office of Information Services

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DIFFUSION OF GENETIC MATERIALS

Through analysis of breeding records and interviews with rice breeders, IRRI traced the diffusion of genetic materials used as parents during a 10-year period from the mid-1960's to the mid-1970's. The study covered 14 agricultural experiment stations and universities in 7 Asian nations: Bangladesh, 1 research center; India, 7 centers; Indonesia, 1 center; Korea, 2 centers; Philippines, 1 center; Sri Lanka, 1 center; and Thailand, 1 center. The work was partially funded by the Rockfeller Foundation. Analysis of breeding records covered 119 crosses, involving 277 parents, for 1965–67; 147 crosses, involving 351 parents, for 1970–71; and 89 crosses, involving 191 parents, for 1974–75.

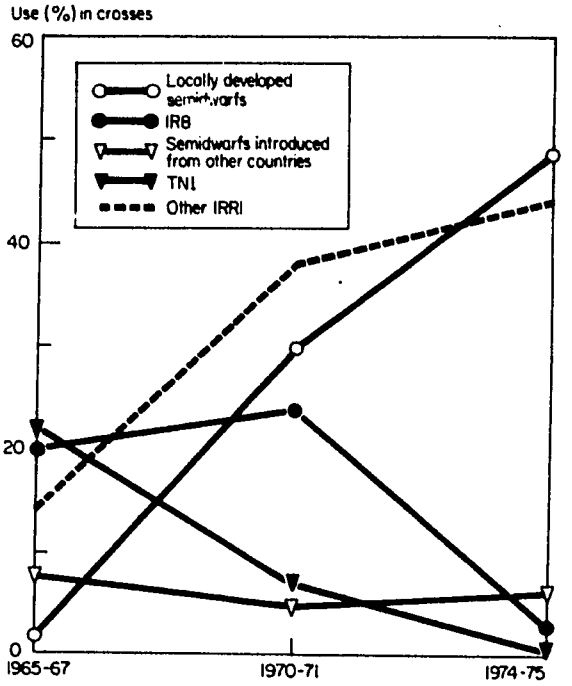
Adoption of semidwarfs as parent material. The percentages of semidwarf intermediate-statured, tall, and deep-water or floating rices were calculated on a cross and an individual-parent basis. The data (Table 1) show increasing use of semidwarfs on both bases. The sharp decrease in the percentage of tall and intermediate-statured rices in the total gene pool, however, indicates that breeders were increasingly crossing semidwarf parents with other semidwarfs.

The most popular single gene source in the 1965–67 sample of crosses was TN1, a semidwarf variety developed in Taiwan in 1956. TN1 was used in 22% of the crosses, IR8 in 20%, and other IRRI lines in 14%. By

Table 1. Percentages of rices of different stature used as parents in crosses or as individual parents, 1965–75 (819 parents used in 355 randomly selected crosses at 14 agricultural experiment stations and universities in 7 Asian nations).

Plant stature	Rices (%) used		
	1965–67[a]	1970–71[b]	1974–75[c]
	In crosses		
Tall	74	57	45
Intermediate	51	39	35
Semidwarf	61	86	84
Floating or deep-water	2	1	2
	As individual parents		
Tall	40	30	24
Intermediate	31	22	17
Semidwarf	28	48	58
Floating or deep-water	1	—	1

[a]277 rice varieties and lines used in 119 crosses. [b]351 rices used in 147 crosses. [c]191 rices used in 89 crosses.

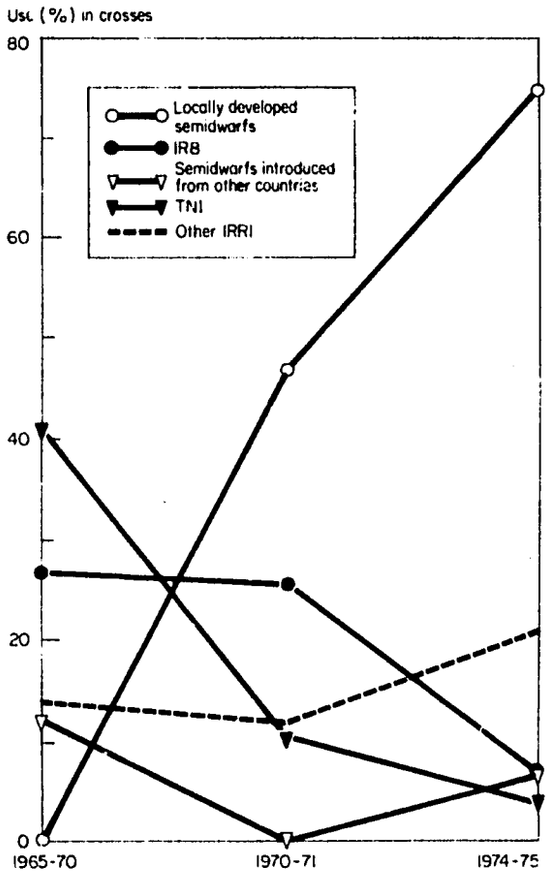


1. Use of semidwarf parents in rice breeding programs of 7 Asian nations, 1965–75 (819 parents used in 355 randomly selected crosses at 14 agricultural experiment stations and universities in 7 Asian nations).

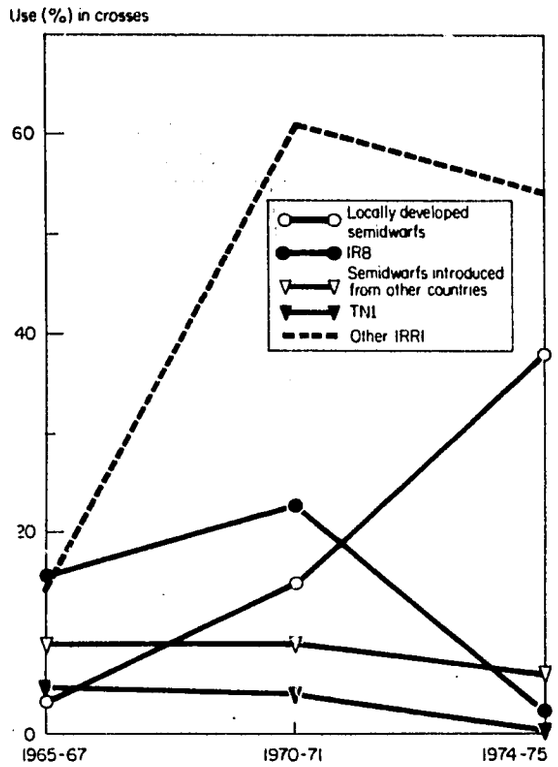
1974–75, only 1% of the crosses involved TN1 as a parent. The use of IR8 increased slightly by 1970–71, but dropped to only 3% in 1974–75. The use of IRRI rices other than IR8 as parents increased to about 44% of the crosses in 1974–75; the use of semidwarf varieties from other countries also increased slightly. But the upward trend was strongest in the use of locally developed semidwarfs — from almost nothing to about half the crosses over 10 years (Fig. 1).

Because more than a third of the crosses analyzed were made in India, the data were analyzed to determine if Indian rice breeders differed from breeders in the six other nations in the adoption of genetic materials.

By 1974–75, 75% of the crosses made in the Indian sample involved a locally developed semidwarf; 21% involved an IRRI parent other than IR8, and 7%, a semidwarf introduced from another country (Fig. 2). In the other six countries, the major source of semidwarf parents was IRRI (Fig. 3), but the same strong trend toward



2. Use of semidwarf parents in Indian rice breeding programs, 1965–75 (300 parents used in 140 randomly selected crosses at 7 agricultural experiment stations and universities, India).



3. Use of semidwarf parents in rice breeding programs of 6 Asian nations (excluding India), 1965–75 (519 parents used in 215 randomly selected crosses at 7 agricultural experiment stations and universities in 6 Asian nations).

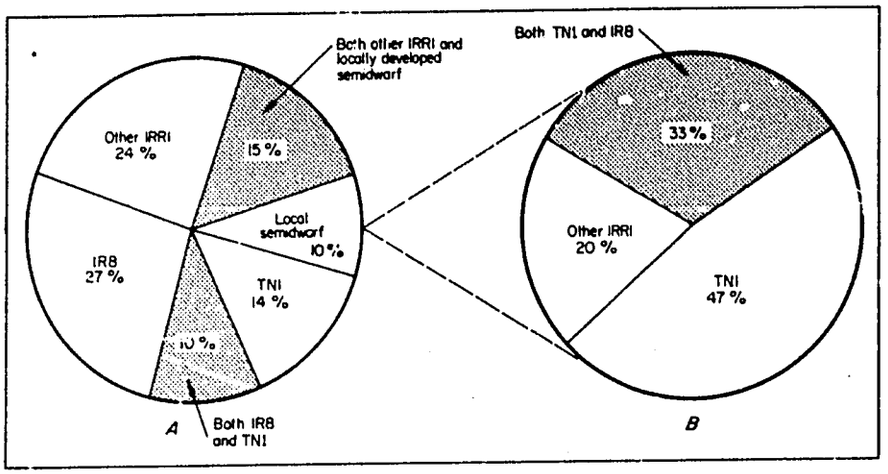
the use of locally developed semidwarfs was found.

The 111 times that a semidwarf variety was used as a parent in 1974–75 involved 83 separate varieties or breeding lines.

Genetic composition of local semidwarfs. The ancestry of the parents was traced back two generations to determine the source of the dwarf genes in the locally developed semidwarf parents. Seventy-six percent had IR8 or other IRRI materials as parents (Fig. 4A). For example, the variety K35, used as a parent in India, is a progeny of the cross IR8/HR19; and RD1 in Thailand is from Leuang Tawng/IR8. Twenty-four percent of the local semidwarfs, such as Sona (TN1/GEB24) and Jaya (TN1/T141), were progeny of TN1. Twenty-five percent of the rices had at least two different semidwarf parents; for example, Tongil, often used in Korean crosses, is from the cross IR8//Yukara/TN1.

About 25% of the local semidwarf parents were themselves progeny of local semidwarfs that had been developed earlier. Of those second-generation ancestor semidwarfs, 80% were found to be progeny of TN1 (Fig. 4B); 33% had both TN1 and IR8 in their ancestry. For example, Pusa 33, used in three crosses, was a progeny of a cross of Ratna (TKM6/IR8) with Improved Sabarmati (TN1/Basmati 370).

Because TN1, IR8, and most other semidwarfs have the Chinese rice Dee-geo-woo-gen (DGWG) as a common ancestor, at least 80% of the 1974–75 crosses had the DGWG gene. Thus, although the original stiff-strawed varieties such as TN1 and IR8 were virtually phased out of breeding programs as direct par-



4. A. Source of dwarf gene in 59 locally developed semidwarf rices used as parents in 1974–75 crosses. B. Source of dwarf gene in the *ancestors* of local semidwarfs that were used as parents in 1974–75 crosses (14 agricultural experiment stations and universities in 7 Asian nations, 1974–75).

ents by the mid-1970's, almost all of the semidwarf parents that replaced them were their progeny.

Origin, races, and development of parent material. During 1965–67, 42% of the total parent material used in randomly selected crosses was either local or locally developed. That figure increased to 64% in 1974–75. Concurrently, the use of IRRI material increased from 17 to 27% and the use of parents introduced from other countries decreased from 41 to 9%.

Analysis of the races of the parent material indicated that the semidwarf indica varieties such as IR8 and TN1 largely pushed japonica, ponlai, and other races out of the breeding programs. Indicas made up 79% of the total gene pool in 1965–67, and 91% of that in 1974–75; use of japonicas declined from 11 to 4%. Although ponlais made up 6% of the 1965–67 material, they were almost absent in the 1974–75 material.

Sixty-four percent of the total parents used in 1964–67 were hybrids; 5 years later and through the mid-1970's, 75% of the parents were hybrids. Interestingly, the percentage of *unimproved* varieties used as parents dropped slightly by 1970–71, but increased to 8% by 1974–75 as programs became increasingly problem oriented and used original sources of specific genetic traits.

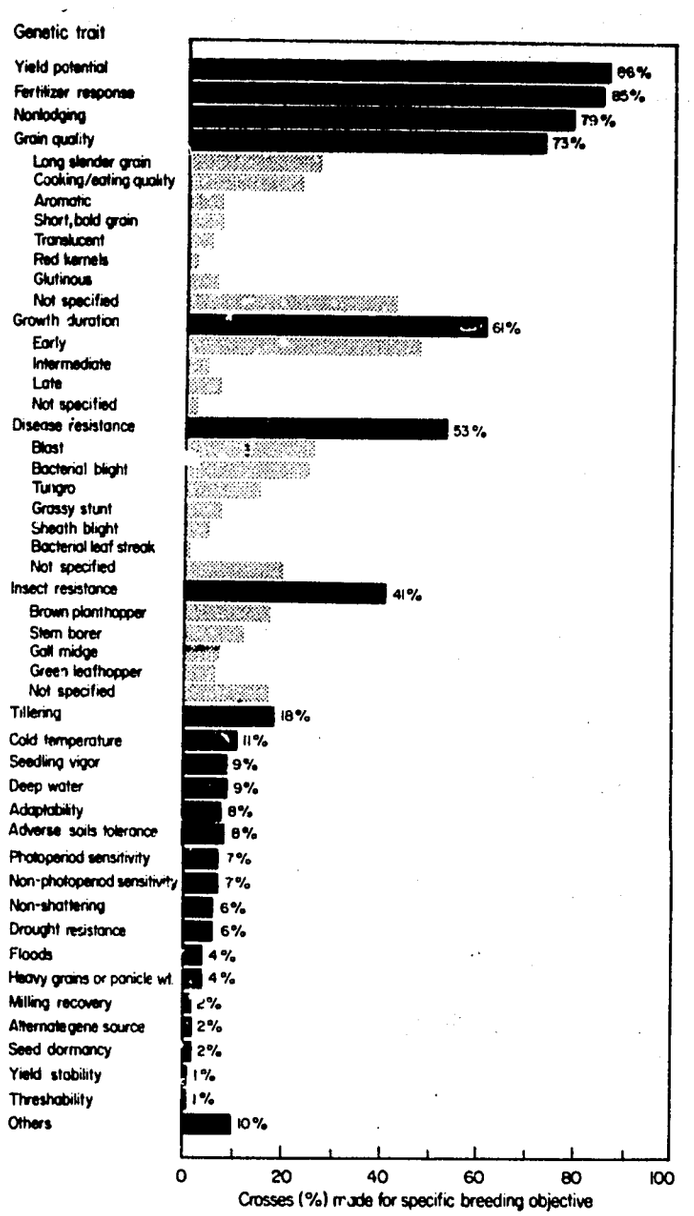
OBJECTIVES OF RICE BREEDERS

The genetic traits for which the breeders indicated they used each parent in each of the randomly selected sample crosses made in 1974–75 were listed to determine the overall breeding objectives. The types of rices used as sources for various characteristics were also listed.

The data were analyzed for 161 crosses, involving 343 parents, at 27 research centers in 10 nations: Bangladesh, 1 center; India, 11 centers; Indonesia, 1 center; Iran, 2 centers; Korea, 3 centers; Nepal, 1 center; Pakistan, 2 centers; the Philippines, 1 center; Sri Lanka, 3 centers; and Thailand, 2 centers.

Increased yield potential was the objective most frequently cited (86% of the crosses), followed by high fertilizer response (85%) and resistance to lodging (Fig. 5). Improved grain quality was cited for 73% of the crosses, but specific grain-quality objectives varied considerably, indicating that consumer preferences varied widely.

Most crosses were aimed at achieving early growth duration but a few were for long duration. The latter were for single-cropped regions with a long monsoon season, where farmers want varieties that mature after the rains have ended.



5. Objectives for which rice breeders made randomly selected crosses in 1974–75. Twenty-seven agricultural experiment stations and universities in 10 Asian nations, 1975.

To determine what types of rices were used as parents to convey specific traits, each rice used for each objective in the 1974–75 crosses was classified by plant type.

Semidwarf rices were almost invariably used as parents for the yield-fertilizer response-nonlodging complex (Table 2). In 65% of the times that tall varieties were used, the breeders hoped to transfer a preferred type of grain from the tall donor into the progeny. Grain quality was a breeding objective 40% of the time that a semidwarf parent was used.

The tall and semidwarf varieties were used about equally as donors of preferred growth

Table 2. The frequency with which rice breeders sought desired genetic traits from 201 semidwarf, 47 intermediate, 85 tall and 10 floating parents in crosses (343 parents in 161 randomly selected crosses made in 1974–75 at 27 agricultural experiment stations, 10 Asian nations).

Breeding objective	Use [a] (%) as parents			
	Semi-dwarf	Inter-mediate	Tall	Floating or deep-water
Lodging	85	40	4	10
Fertilizer response	84	40	5	10
Yield potential	80	51	5	10
Disease resistance	36	64	25	20
Insect resistance	30	15	19	—
Grain quality	40	60	65	20
Growth duration	34	36	31	80
Tillering	10	17	4	—
Seedling vigor	4	17	4	—
Photoperiod sensitivity or insensitivity	4	2	5	90
Adverse soils tolerance	3	19	9	—
Wide adaptability	2	13	2	—
Heavy grains and panicle weight	2	4	—	—
Drought resistance	2	4	5	—
Cold temperature tolerance	1	17	11	—
Nonshattering	—	—	5	—
Threshability	—	—	—	
Alternate gene source	—	2	1	—
Protein levels	—	—	—	—
Milling recovery	—	2	1	—
Yield stability	—	—	—	—
Deep water tolerance	—	4	5	100
Seed dormancy	—	—	1	—
Others	3	11	8	—

[a]Percentage of total times each type of rice was used as a genetic source for each desired trait.

duration. Long growth duration was an objective 80% of the times a deep-water or floating donor was used, and photoperiod sensitivity, 90%. That is because in deep-water areas, farmers need varieties that mature after the water recedes at the end of the monsoon season.

To determine if Asian breeders differed in their reasons for use of semidwarfs that were locally developed, those from IRRI, and those from other countries, the use of semidwarfs for some major traits was analyzed. About half of the 201 semidwarfs used as parents in the total 1974–75 gene pool were from IRRI and 45% were locally developed (Fig. 6A); about 60% of all semidwarfs used for preferred grain quality and for a specific growth duration (usually early) were developed locally (Fig. 6B and C).

On the other hand, 60% of the semidwarfs used as sources of disease resistance and almost 70% of the insect-resistance donors were introduced from IRRI (Fig. 6D and E). Thus, IRRI material often does not meet local farmer and consumer needs for grain quality and growth duration, but pest resistance is a strong reason for its use.

FACTORS RELATED TO ADOPTION

For 78 of the rices used in the 1974–75 crosses, the breeders could recall both the year in which the variety or line was developed (to the fixed-line stage) and the year in which they first used it as a parent. For another 56 rices, they recalled the year that they first heard of a particular rice and the year of its adoption as a parent.

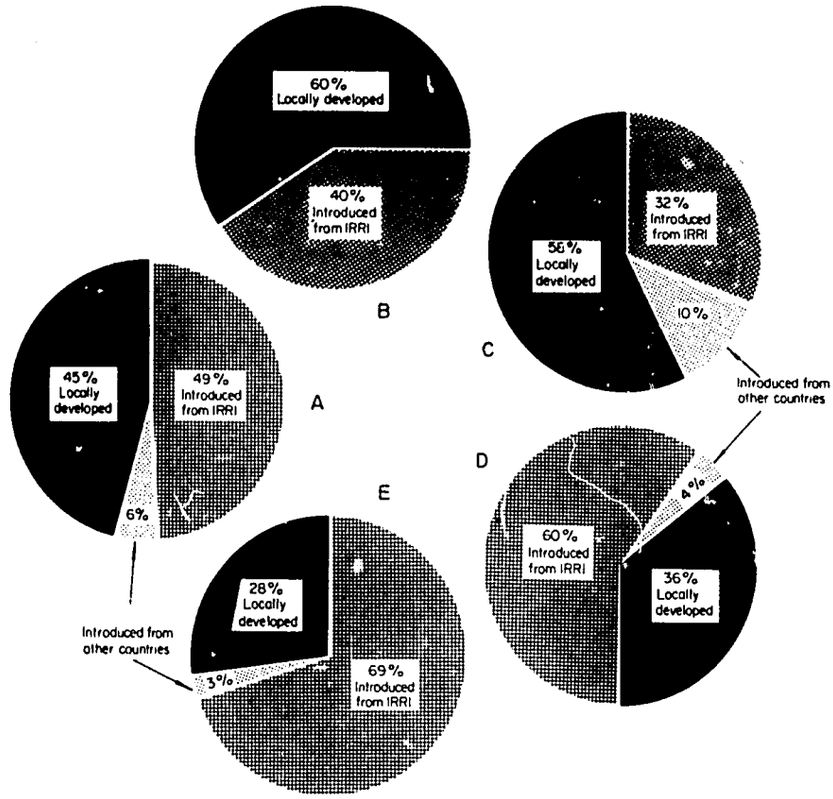
The average time lag from development until adoption in a breeding program was 3.2 years. The time lag from first awareness until adoption averaged 1.3 years.

The breeders could recall how they acquired 157 of the 1974–75 parents. Half of the germplasm was available locally. Test nurseries or trials were the most common sources of outside material (Table 3).

GENETIC COMPOSITION OF VARIETIES

Newest varieties. The flow of rice genes into new varieties that are subsequently fed into seed-production channels and made available to farmers was traced at 27 experimental stations in 10 Asian nations. Breeders were asked to name the newest varieties released at each station. For each rice named, a standardized *genetic data sheet* was completed and each hybrid's ancestry was traced. If a parent of a hybrid was itself a hybrid, its ancestors were identified and the incorporation of genes into the varieties was traced back several generations. The breeders were also asked to give their perceptions of each variety's genetic strengths and weaknesses.

Types and genetic composition. Thirty-six new varieties were cited (Table 4). Of those, 69% were semidwarfs, 25% intermediate statured, and 6% tall. Ninety-one percent were indicas; 86% were developed locally, and 14% were from IRRI. Ninety-one percent were hybrids; three varieties were mutants: CNM25, de-



6. A. Origin of 201 semidwarf parents. B. Origin of 80 semidwarf parents used for grain quality. C. Origin of 69 semidwarf parents used for growth duration. D. Origin of 73 semidwarf parents used for disease resistance. E. Origin of 61 semidwarf parents used for resistance.

veloped in West Bengal, India, was a mutant of IR8; K-84, from Kashmir, was a mutant of T-65. One variety from the Indian Punjab, HM95, was classified both as a hybrid and as a mutant; it was selected from irradiated progeny of the cross Jhona 349/TN1.

Four of the varieties had locally developed semidwarf parents (Table 4); Sabari was developed from a cross of IR8 with Annapoorna (which was from the cross Ptb10/TN1); one parent of CO39 is Kannagi, which is the varietal name in Tamil Nadu state, India, for Pusa 2-21 (IR8/TKM6); Glutinous Tongil from Korea is from a cross of Tongil (IR8//Yukara/TN1) and IR1317. RD9, from Thailand, is from LY34/TN1//W1263///RD2 (RD2 is from TN1/GP15).

Thirteen of 25 new semidwarf varieties are direct progeny of IR8 and 2, of TN1. But TN1 and IR8 appear in the genetic ancestry of the 25 rices a total of 33 times.

Genetic strengths and weaknesses. The breeders were asked to name the genetic strengths and weaknesses — traits that farmers

Table 3. Sources of 157 parents used by rice breeders in crosses at 27 agricultural experiment stations and universities in 10 Asian nations, 1974-75.

Source	Parents	
	No.	%
Local, traditional, locally developed, or in local germplasm collection	78	50
Sent in trials or test nurseries (national or IRRI)	48	31
Requested from IRRI	15	9
Requested from other sources	6	4
Others	10	6
Total	157	100

consider desirable and undesirable — of each of the newest varieties. For almost all 36 new varieties, yield potential, fertilizer response, and resistance to lodging were cited as genetic strengths or favored characteristics (Fig. 7).

A desired growth duration was a favored trait of 64% of the varieties; earliness was cited for 50%. Grain quality was cited as a genetic strength of 53% of the new varieties, and as a weakness of 14%. Individual grain-quality traits varied widely, indicating the diversity of consumer preferences. Red kernels were a favored trait for 8% of the varieties, from southern India, Kashmir, and Sri Lanka.

The breeders cited resistance to at least one disease as a favored trait of 50% of the new rices, and disease susceptibility as a weakness of 47%.

Most widely grown varieties. The infusion of rice genes onto farmers' fields was traced by analyzing the genetic composition of the most popular varieties in each region. Thirty-one breeders at 27 research centers in 10 Asian nations named the three main varieties grown by farmers within the areas served by their experiment stations. At stations where more than one breeder was interviewed, each breeder named the three most popular varieties within a major subregion served by the station. For each rice named, genetic data were compiled.

Types and genetic composition. The breeders cited 95 rices, comprising 73 different varieties,

Table 4. Genetic composition of the 36 newest rice varieties developed at 27 agricultural stations in 10 Asian nations, 1975.

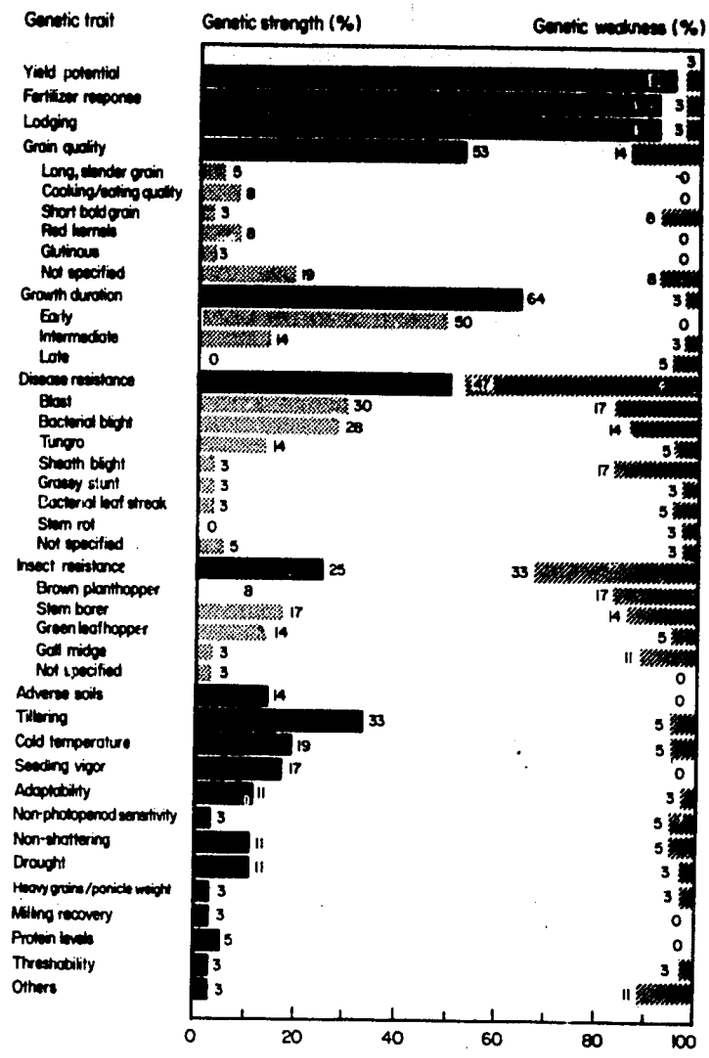
Variety	Station where named[a]	Genetic composition
	Semidwarf	
CNM 25	West Bengal (India)	IR8 mutant
Jyothi	Kerala (India)	Ptb10/IR8
Bharathi	Kerala (India)	Ptb10/IR8
Sabari	Kerala (India)	IR8/Annapoorna[b]
OR 34-16	Orissa (India)	TN1/TKM6
Vani	CRRI (India)	IR8/CR1014
IET 1039	Bihar (India)	T90/IR8
Kalinga 1	CRRI (India)	Dunghanshali/IR8
Kalinga 2	CRRI (India)	Dunghanshali/IR8
Palman 579[c]	Punjab (India)	IR579 (IR8/Taduken)
HM 95	Punjab (India)	Jhona 349/TN1 (hybrid mutant)
RP4-14	AICRIP (India)	T90/IR8
Pusa 2-21	IARI (India)	IR8/TKM6
CO39	Tamil Nadu (India)	Culture 340/Kannagi[d]
IR24[e]	Uttar Pradesh (India)	IR8/ / /CP231/SLO-17// Sigadis
IR24[e]	Nepal	IR8/ / /CP231/SLO-17// Sigadis
BPI-Ri-2	Maligaya (Philippines)	BE3-37-5/IR20
IR841	Sind (Pakistan)	IR262-43-8-11/Khao Dawk Mali
Mehren 69	Kala Shah Kaku (Pakistan)	IR6 (Siam 29/DGWG)
BG 90-2	Batalagoda (Sri Lanka)	IR262/Remadja
PD 106-1	Peradeniya (Sri Lanka)	Warangal 1263/IR8
Glutinous Tongil	Seoul National University (Korea)	Tongil/IR1317-31
Milyang 21	ORD (Korea)	IR1317-316-3-2/IR24
Milyang 23	ORD (Korea)	IR1317-316-5-2/IR24
Gail (B-9c)	CRIA (Indonesia)	Short Sigadis[f] /Basmati
	Intermediate-statured	
K-78-13	Kashmir (India)	Sihi-ei/China 971
K-84	Kashmir (India)	Mutant of T65
Karjat 14-7	Maharashtra (India)	IR8/Ziniya 149
BG-11-11	Batalagoda (Sri Lanka)	H-7/H8
LD 125	Bombuwela (Sri Lanka)	IR262/H7
BR4	BRRI (Bangladesh)	IR20/IR5
RD7	Bangken (Thailand)	C4-63G
RD9	Bangken (Thailand)	LY34/TN1//W1256///RD2[g]
Pelita-1	CRIA (Indonesia)	IR5/Syntha
	Tall	
RD5	Bangken (Thailand)	Puang Nahk/Sigadis
Mehre	Amol (Iran)	Pureline selection

[a]CRRI = Central Rice Research Institute; AICRIP = All India Coordinated Rice Improvement Project; IARI = Indian Agricultural Research Institute; ORD = Office of Rural Development; CRIA = Central Research Institute for Agriculture; BRRI = Bangladesh Rice Research Institute. [b]Annapoorna is a semidwarf variety developed in Kerala from the cross Ptb 10/TN1. [c]IRRI variety or line named locally as a variety. [d]Kannagi, from the cross IR8/TKM6, is the varietal name in Tamil Nadu state for Pusa 2-21. [e]IR8//Yukara/TN1. [f]Sigadis/TN1. [g]TN1/GP15.

Table 5. Characteristics of 95 rices cited as among the 3 most widely grown varieties in farmers' fields in 28 agricultural experiment stations and universities in 10 Asian nations, 1975.

Characteristic	Varieties (%) widely grown				
	Tall	Intermediate	Semidwarf	Floating	All
Plant type					
Indica	97	69	95	100	92
Japonica	—	19	—	—	3
Indica-japonica	—	12	5	—	4
Indica-javanica	3	—	—	—	1
Origin					
Locally developed	97	13	44	100	59
Introduced from IRRI	—	37	54	—	31
Introduced from other country	3	50	2	—	10
Method of development[a]					
Unimproved	36	—	—	67	15
Pure line selection	49	—	2	33	19
Mutant	—	—	2	—	1
Hybrid	15	81	96	—	62

[a]The method of development of three introduced varieties of intermediate stature (China 972, China 988, and China 1039) could not be determined, so the percentages do not add to 100.



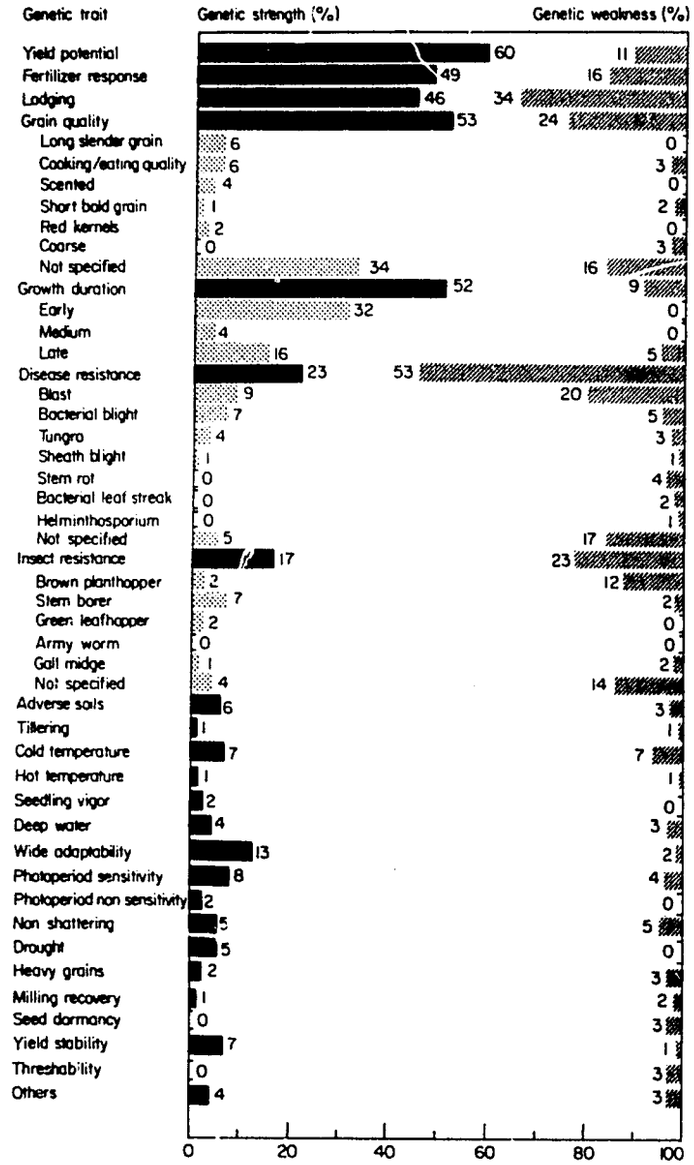
7. The genetic strengths and weaknesses of 36 newest rice varieties released at 27 agricultural experiment stations and universities in 10 Asian nations, 1975.

as the most widely grown in 31 regions. Forty-five percent of the rices were semidwarf, 35% were tall, 17% were intermediate-statured, and 3% were floating.

Only 10 of the rices were cited in two or more regions; of the 10, 8 were semidwarfs. Jaya (TN1/T141) was cited as widely grown in 8 of the 15 regions surveyed in India. The second most cited variety was IR8, but IR8 was a parent or ancestor of four of the remaining seven semidwarfs. TN1 was in the ancestry of three of the rices.

Ninety-two percent of all varieties cited as most widely grown in the regions were indicas (Table 5). About 60% were locally developed, about 30% were introduced from IRRI, and 10% were introduced from other countries. More than 60% were of hybrid origin. Tall varieties showed a high degree of location specificity — none were widely grown in more than one region.

Genetic strengths and weaknesses. The reasons given by the breeders for the popularity among farmers of each of the 95 widely grown varieties were compiled and analyzed as their genetic strengths. The unfavorable traits were



8. The genetic strengths and weaknesses of the 95 rices cited by 31 rice breeders as the most widely grown varieties in the regions served by 28 agricultural experiment stations and universities, 10 Asian nations, 1975.

compiled as their genetic weaknesses.

Yield potential was cited as a genetic strength, or as a major reason for the popularity of 60% of the rices most widely grown across all of the areas (Fig. 8). Yield potential was cited as a genetic weakness of 11% — low yields were a major fault, but farmers grew the varieties for other reasons. Susceptibility to lodging was cited as a weakness of 34% of the rices. Grain quality was considered a major reason for the popularity of 53% of the widely grown varieties; inferior grain quality was a genetic weakness of 24%.

Fifty-two percent of the popular rices had desirable growth duration. For 32% of those varieties, earliness was the preferred trait.

Resistance to at least one disease was listed as a favorable trait of only 23% of the farmers' preferred varieties; susceptibility to disease was cited as a weakness of 53%. Only 17% were insect resistant.

Genetic traits and plant height. To determine if specific genetic traits were more likely to be found among tall, intermediate, or semidwarf rices, the genetic strengths — characters favorable to the farmer — were analyzed on the basis of plant height.

Only 24% of the tall varieties were cited for high yield potential, 12% for fertilizer response, and none for lodging resistance (Table 6). About 75% of the semidwarfs were cited as having good yield potential and 72% for fertilizer response and lodging.

The tall varieties generally had good (locally preferred) grain quality. Of the 60% of the tall varieties with favorable growth characteristics, 33% were cited for earliness and 27% for lateness. But most semidwarfs cited for favored growth duration were early maturing.

Pest resistance, seldom cited as a strength of the tall varieties, was often cited as a strength of the semidwarfs.

Table 6. Genetic strengths of the tall, intermediate-statured, semidwarf, and floating rices cited as the most widely grown on farmers' fields in 31 regions (95 rice varieties cited by 31 rice breeders at 28 agricultural experiment stations in 10 Asian nations).

Genetic strength	Varieties (%) cited for genetic strength			
	Tall	Intermediate	Semidwarf	Floating
Yield potential	24	75	74	0
Fertilizer response	12	44	72	0
Lodging	0	56	72	0
Grain quality	79	56	28	33
Long, slender	15	12	4	0
Cooking/Eating quality	6	12	2	0
Scented	12	0	0	0
Red kernel	3	0	0	0
Short, bold	3	0	0	0
Glutinous	3	0	0	0
Not specified	37	32	22	33
Growth duration	60	44	38	100
Early	33	19	30	0
Intermediate	0	6	6	0
Late	27	19	0	100
Not specified	0	0	2	0
Disease resistance	18	36	36	0
Blast disease	6	6	15	0
Bacterial blight	3	12	6	0
Grassy stunt virus	0	0	2	0
Tungro disease	0	0	6	0
Sheath blight	0	6	0	0
Not specified	9	12	8	0
Insect resistance	9	6	24	0
Brown planthopper	0	0	4	0
Green leafhopper	0	0	4	0
Stem borer	0	0	8	0
Not specified	9	0	8	0
Adverse soils tolerance	3	12	4	0
Wide adaptability	12	37	6	0
Cold tolerance	12	19	0	0
Nonshattering	9	12	4	0
Insensitivity to photoperiod	15	6	2	100
Deep water tolerance	0	6	2	100
Yield stability	3	0	12	0
Seedling vigor	6	0	0	0
Drought resistance	0	12	6	0
Tillering	0	0	2	0
Milling recovery	3	0	0	0
Heavy grains	0	0	0	66
Others	3	6	6	0

COMPARISON OF BREEDERS' PERCEPTIONS OF ENVIRONMENT AND PEST PROBLEMS, AND BREEDING OBJECTIVES

The breeders' perceptions of the extent and severity of environmental and pest problems that farmers face in their fields were measured (1976 Annual Report) and compared with their breeding objectives.

Table 7. A comparison of rice breeders' perceptions of the biological or environmental factors that most limit rice production in farmers' fields in the areas served by their experiment stations and the percentages of crosses for resistance to each problem area (breeding objectives). Thirty-five breeders at 27 experiment stations and universities in 10 Asian nations, 1975.

Biological or environmental factor	Areas (%) where factor was a major constraint[a]	Crosses (%) made for resistance[b]
Disease and insects	100	62[c]
Drought	85	6
Injurious soils	60	8
Excessive monsoon cloudiness	48	0
Floods	36	4
Cold temperature	30	11
Deep water	12	9
Hot temperature	9	0
Waterlogged soils[d]	3	2
Others	6	0

[a]Percent of 35 rice breeders that rated each stress as one of the four most serious problems limiting production in farmers' fields in the region served by each experiment station. [b]Determined by analyzing genetic traits that breeders at 27 experiment stations sought to incorporate into future varieties through 46 randomly selected crosses made in 1974–75 (see Fig. 5). [c]Refers to the 30% of crosses in which at least one parent was used to transfer resistance to at least one disease or insect into progeny, plus the 32% that involved both disease and insect resistance. [d]Also called *ill-drained soils* or *stagnant soils* where stagnant water up to 1 m in depth stands throughout the monsoon season.

Table 8. A comparison of rice breeders' perception of the major diseases and insects that limit rice production in farmers' fields and the percentages of crosses made for resistance to each pest. Thirty-five breeders at 27 agricultural experiment stations and universities in 10 Asian nations, 1975.

Pest	Areas (%) where factor was a major constraint[a]	Crosses (%) made for resistance[b]
Stem borer	57	12
Bacterial blight	54	25
Brown planthopper	45	17
Blast disease	42	26
Gall midge	39	7
Tungro	24	15
Sheath blight	18	5
Helminthosporium	0	0
Striped virus[c]	9	0
Grassy stunt virus	6	7
Sheath rot	6	0
Green leaf hopper	0	6
Other insects	36	0
Other diseases	21	0

[a]Percent of 14 rice breeders that rated each pest as 1 of 4 most serious pest problems limiting production in farmers' fields in the regions served by each experiment station. [b]Determined by analyzing genetic traits that breeders sought to incorporate into future varieties through 46 crosses at 27 experiment stations in 10 Asian nations. [c]In Korea only.

Every breeder rated diseases and insects as one of four major environmental problems (Table 7). In making 62% of the crosses, the same breeders hoped to incorporate genetic resistance to at least one disease or insect into future varieties. Drought was considered a major biological or environmental problem, but only 6% of the randomly selected crosses attempted to incorporate drought resistance. Eight percent of the crosses were made for tolerance for injurious soils, a problem in 60% of the areas.

The breeders' perceptions of the major diseases and insects within the areas served by the experiment stations were compared with their breeding objectives (Table 8). The most widespread field pest was the stem borer — one of the four major pests in farmers' fields in 57% of the areas. But only 12% of the crosses were made for stem borer resistance; that emphasizes the fact that no truly resistant germplasm is available to breeders for stem borer resistance.

The brown planthopper was cited as a problem in 45% of the regions; 17% of the crosses involved hopper resistance. The brown planthopper is the vector of grassy stunt virus disease, which was a major problem in only 6% of the regions. Resistance to grassy stunt was an objective of 7% of the crosses. That might indicate that grassy stunt could become a more serious problem in the future.

Control and management of rice pests

Summary

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DISEASES

A compound called iprodione seems more effective than other compounds previously tested for the chemical control of sheath blight. Dipping rice seedling roots in zinc sulfate, generally recommended for zinc-deficient soils, also effectively controlled the kresek phase of bacterial blight. The compound labeled F370 was found ineffective as spray or drench.

Because high levels of sheath blight resistance have not been found among thousands of rices tested, reduction by other means of damage from the disease was studied. Sclerotia left in the field from previous crops are the major source of inoculum. Field survival of sclerotia, particularly their reduction by natural-enemy microorganisms, was studied. Many of the bacteria found in field water and on sclerotia have antagonistic activity against sclerotia. Sclerotia immersed in bacterial suspensions in an enriched medium grew slowly for 10 days and died in 17 days. Adding rice straw to field water almost doubled the bacterial populations.

A new virus disease of rice, subsequently named ragged stunt, was found in the Philippines early in 1977. Its predominant symptoms are stunting at all growth stages; serrated, twisted, or ragged leaves; vein-swellings or galls on leaf sheaths and stem branches at the upper node at late stages; and incomplete panicle emergence. The disease was transmitted by all the three biotypes of the brown planthopper, but not by mechanical means, nor through soil or seed. The virus is persistent in the vector. Electron micrographs indicated the presence of 50- to 70-μm virus particles in phloem cells. Rice plants can be dually infected with ragged stunt and grassy stunt or with ragged stunt and tungro. The absence of cross protection indicates that the causal agent of ragged stunt is not closely related to the causal agent of grassy stunt or tungro.

The similarity in percentage of active transmitters, latent period, number of infected seedlings per insect, retention period, and percentage of disease-transmitting days among the three brown planthopper biotypes indicated the identical ability of three biotypes to transmit grassy stunt. All biotypes showed transstadial passage.

INSECTS

In 1977 IRRI began to identify arthropods to the family level and to send specimens worldwide to specialists for proper determination. Of the 2,174 specimens sent, 24% comprising 44 species have thus far been identified.

Greenhouse and field evaluation of insecticides identified several new compounds effective against the green leafhopper, whitebacked planthopper, brown planthopper (BPH), and striped stem borer. When applied to the paddy water, bendiocarb, FMC 27289, HOE PFL 812, and oftanol were effective against the three hopper species, and Miral was effective against the striped stem borer.

Either as foliar spray or as paddy-water application, triazophos and carbofuran had ovicidal activity against the BPH. Such activity was dependent on insecticide concentration and egg age at time of application.

Studies on the placement of spray solution for BPH control indicated that sprays directed toward the plant's base were generally more effective. Different volumes of spray solution from 190 to 950 liters/ha were equally effective.

Various insecticide application methods were tested to determine their effectiveness against the rice pests. Incorporating carbofuran granules into the soil at the last harrowing controlled whorl maggot effectively and provided more income than liquid band injection into the root zone, paddy-water application, or foliar spray.

A sevenfold resistance to carbofuran has developed in BPH at IRRI. There was no cross resistance to new insecticides that had not been used there.

Laboratory studies identified some basic causes of BPH resurgence. BPH reproduction was stimulated when the insects were either directly sprayed with a sublethal dose or placed on plants that had previously been sprayed with insecticides.

In experiments conducted at the Central

Luzon State University, insecticide application methods compatible with rice and fish culture were identified.

The application of nitrogen fertilizer, especially in high doses, increased the abundance of BPH. A trap crop was found useful in controlling BPH.

Parasitism of planthopper and leafhopper eggs averaged about 20%; that of nymphs and adults, almost 30%. A damselfly that can kill one or more BPH per day was found. Another predator, *Microvelia,* which attacks hoppers that fall into the paddy water, was identified. *Cyrtorhinus lividipennis* proved to be a moderately important predator of the BPH — it suppressed but did not contain singlehandedly the BPH population growth. When fed on BPH, this predator reproduces at a lower rate than does its prey. But predator and BPH population growth patterns were synchronized. Spider abundance increased as the crop matured.

Field samples and light-trap catches of the BPH showed major peaks once in each crop season. Trap catches showed monthly minor peaks at about the time of the full moon. BPH egg and nymph mortality was often high in the field, because of parasites and predators.

Pheromone-trap catches of male *Chilo suppressalis* moths may indicate when it is best to apply insecticides for stem borer control. Encapsulated pheromone-mimic compounds sprayed onto filter paper around pheromone traps prevented sexual communication.

Yellow pan oil-water traps are suitable for monitoring field colonization by macropterous BPH, and trap catches may indicate timely control measures. A motorized aspirator was developed, and complete samples of all arthropods on and around a hill, and on the water surface were obtained. After adult immigration, BPH distribution among hills was aggregated but became more random as a generation developed. A single-hill sampling unit is suggested. It was found that the higher the insect density, the smaller the sample required for a given degree of precision. A sample size of 30 hills was adequate for most practical purposes. Because egg numbers per tiller were similar in all parts of a hill, only eggs from one part of a hill need to be sampled.

Studies were conducted to determine whether lack of BPH control could be attributed to extremely rapid degradation of carbofuran. The results provide evidence that carbofuran applied to paddy water is rapidly degraded by chemical hydroloysis to carbofuran phenol, and that the rate of degradation is related to pH of paddy water. Both laboratory and field experiments confirmed that repeated surface application of carbofuran did not result in a buildup effect.

The degradation of carbofuran in different rice soils studied was mainly microbiological.

Placement of carbofuran about 3 cm deep in flooded soil resulted in a significant increase in the insecticide's persistence and in its uptake by rice plants.

Adsorption of carbofuran, as influenced by the application of nitrogen fertilizers to three different rice soils, was studied. Both ammonium sulfate and urea exhibited displaced carbofuran.

Isotope studies revealed that carbofuran absorbed by the rice roots travels rapidly to the leaf tips. The insecticide and its breakdown products concentrate in those areas, from which they probably escape into the atmosphere.

WEEDS

The weed research program at IRRI focuses on integration of all available and relevant technologies to reduce yield losses to annual and perennial weeds. Evaluation of direct weed-control methods such as hand weeding, push-type rotary weeders, and herbicides continued. Among the herbicides, pendimethalin appeared promising for transplanted, direct-seeded flooded, upland, and direct-seeded bunded rainfed rice. Research on suitable weed management by crop rotation, soil and water management, tillage practices, use of competitive varieties, and herbicides was intensified.

Control and management of rice pests

Diseases

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BLAST

Chemical control. C22 was planted in 5- × 5-m upland plots, naturally infected with neck blast and *Cercospora* leaf spot, then sprayed with chemicals 1 week after flowering and 1 week later. The treatment was replicated four times. All chemicals reduced both diseases significantly, but yield differences were insignificant because of large variations among replicates (Table 1).

SHEATH BLIGHT

Chemical control. Two experiments in the 1977 wet season used the line IR1317-392-1-2, which is susceptible to sheath blight. The line was planted in 2- × 3.6-m plots, artificially inoculated at the booting stage, and sprayed with chemicals once before inoculation and three times afterward at weekly intervals at rates based on manufacturers' recommendations. The treatment was replicated four times. All chemicals increased yields significantly but iprodione seemed the most effective (Table 2).

Table 1. Chemical control of neck blast and *Cercospora* leaf spot in upland plots.[a] IRRI, 1977.

Chemical[b]	Rate[c] (kg a.i./ha)	Neck blast (%)	*Cercospora* leaf spot lesions (no.)	Yield (t/ha)
EDP Fthalide	1.0	16.8 a	4.5 c	2.7 a
Benomyl	1.0	23.4 a	0.8 a	2.8 a
Chlorothalonil	2.0	22.5 a	2.0 ab	2.8 a
Mancozeb	2.0	20.8 a	2.6 b	2.7 a
Control	Water	69.0 b	16.5 d	2.2 a

[a]Means of 4 replicates. Means followed by a common letter are not significantly different at the 5% level. [b]Triton AE at the rate of 3.2 liters/ha was used as sticker for all chemicals. [c]a.i. = active ingredient.

Table 3. Bacterial isolates from field water and their antagonistic activity[a] relative to the growth of *R. solani*, IRRI, 1977.

Isolate	Inhibition	Isolate	Inhibition	Isolate	Inhibition	Isolate	Inhibition
BW-16	+++	HW-10	+	DW-2	–	GW-10	–
IW-6	+++	AW-1	–	DW-3	–	GW-11	–
IW-11	+++	AW-2	–	DW-4	–	GW-12	–
DW-5	++	AW-3	–	DW-8	–	GW-13	–
DW-6	++	AW-4	–	DW-9	–	HW-1	–
DW-7	++	AW-5	–	DW-10	–	HW-2	–
FW-2	++	AW-6	–	DW-11	–	HW-3	–
FW-7	++	AW-7	–	DW-12	–	HW-4	–
HW-7	++	BW-1	–	EW-1	–	HW-5	–
HW-15	++	BW-2	–	EW-2	–	HW-6	–
IW-9	++	BW-3	–	EW-3	–	HW-9	–
IW-14	++	BW-5	–	EW-4	–	HW-11	–
AW-8	+	BW-6	–	EW-5	–	HW-12	–
BW-4	+	BW-10	–	EW-6	–	HW-13	–
BW-7	+	BW-12	–	EW-8	–	HW-14	–
BW-8	+	BW-13	–	FW-3	–	HW-16	–
BW-9	+	BW-14	–	FW-5	–	IW-1	–
BW-11	+	BW-17	–	FW-6	–	IW-2	–
BW-15	+	BW-21	–	FW-8	–	IW-3	–
BW-18	+	BW-22	–	FW-9	–	IW-5	–
BW-19	+	CW-1	–	FW-10	–	IW-7	–
BW-20	+	CW-2	–	FW-11	–	IW-8	–
CW-9	+	CW-3	–	GW-1	–	IW-10	–
CW-10	+	CW-4	–	GW-2	–	IW-12	–
EW-7	+	CW-5	–	GW-3	–	IW-13	–
FW-1	+	CW-6	–	GW-4	–	IW-16	–
FW-4	+	CW-7	–	GW-5	–	IW-17	–
GW-9	+	CW-8	–	GW-6	–	IW-4	*
GW-14	+	CW-11	–	GW-7	–	IW-15	*
HW-8	+	DW-1	–	GW-8	–		

[a]+ = inhibits the growth of *R. solani*; – = no inhibition; * = stimulates sclerotial formation when mycelia are near bacteria. AW = isolate from water (W) in Calo, Bay, Philippines; BW = Hanggan, Bay, field 1; CW = Hanggan, Bay, field 2; DW = Poblacion, Bay; EW = Masiit, Calauan, field 1; FW = Masiit, Calauan, field 2; GW = IRRI block A; HW = IRRI B_1; IW = IRRI B_2.

Table 2. Chemicals used for control of sheath blight.[a] IRRI, 1977 wet season.

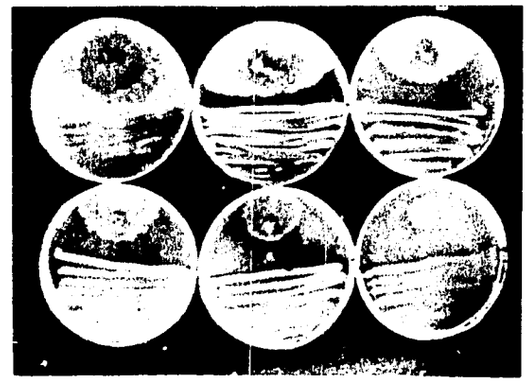
Treatment[b]	Rate/ha	Trial A: Av. sheath blight rating[c]	Trial A: Yield (t/ha)	Trial B: Av. sheath blight rating[c]	Trial B: Yield (t/ha)
Iprodione 50 WP	3.0 kg	2.6 a	6.2 ab	2.9 a	6.1 a
Iprodione 50 FLO	3.01 kg	3.2 b	6.4 a	3.2 a	6.1 a
BASF 3050	1.0 kg	4.6 c	5.6 bc	5.0 b	5.2 b
Validacin Sol.	1.5 liters	5.1 cd	5.4 cd	5.4 b	5.2 b
Chlorothalonil	1.7 kg	5.3 de	5.7 bc	5.5 b	5.6 b
EDP Fthalide	1.0 kg	5.8 ef	5.1 cd	6.3 c	5.1 bc
Kitazin	1.25 liters	5.9 f	5.1 cd	6.0 c	5.3 b
Polyoxin AL	1.0 kg	6.1 fg	5.3 cd	6.1 c	5.3 b
Zinc omadine	1.04 liters	6.5 g	5.2 cd	6.3 c	5.1 bc
Control	Water	7.7 h	4.8 d	7.5 d	4.6 c

[a]Av. of four replications. Means followed by a common letter are not significantly different at the 5% level. [b]WP = wettable powder; FLO = flowable. [c]Standard Evaluation System for Rice scale: 1 = lesions limited to 1/4 leaf sheath; 9 = lesions severe on all leaves.

Epidemiology — survival of sheath blight sclerotia. The primary source of sheath blight inoculum is sclerotia left in the field from the previous crop. An alternative to plant resistance is biological control, i.e. reducing sclerotial survival and infection in the rice field by using their natural enemies, the microorganisms in the rice fields. Paddy fields may be ideal for such control because the numerous types of bacteria present may easily be dispersed in the irrigation water.

Many bacteria of different colony types, isolated from field water and from sheath blight sclerotia, were tested in petri dishes to determine their antagonistic activities against the sheath blight fungus. Many, particularly those isolated from the sclerotia, had strong antagonistic activity (Table 3, 4; Fig. 1). Their inhibitory actions were strong, even when initial bacterial population was low.

To test the effect of specific bacterial isolates on sclerotial survival, the laboratory-cultured sclerotia were kept in suspensions, in peptone-sucrose broth and in sterile water, of three isolates with strong antagonistic activity. The sclerotia were removed from the bacterial suspension after 3, 10, and 17 days, cultured on potato dextrose agar plates, and tested for survival. Sclerotial survival in the bacterial suspension in sterile water was erratic, but the sclerotia in the bacterial suspension in peptone-sucrose broth grew slowly after 10 days and died after 17 days (Table 5).



1. Various degrees of antagonistic activities of bacterial isolates against the sclerotia of *Rhizoctonia solani*. IRRI, 1977.

In a preliminary laboratory test to find ways of increasing the bacterial population in field water and accelerating the bacteria's antagonis-

Table 4. Bacterial isolates from sheath blight sclerotia and their antagonistic activity relative to the growth of *Rhizoctonia solani*. IRRI, 1977.

Isolate	Inhibition[a]	Isolate	Inhibition[a]	Isolate	Inhibition[a]	Isolate	Inhibition[a]
FS 21	+ + + + +	FS 16	+ +	FS 28	–	FS 71	–
33-1	+ + + + +	18	+ +	29	–	72	–
33-2	+ + + + +	20-1	+ +	30	–	75	–
41	+ + + + +	22	+ +	31	–	77	–
66	+ + + + +	23-1	+ +	32	–	78	–
67	+ + + + +	24	+ +	35	–	79	–
76	+ + + + +	26	+ +	36	–	80	–
85	+ + + + +	43-2	+ +	38	–	81	–
94	+ + + + +	53	+ +	39	–	82	–
19	+ + + +	61	+ +	45	–	84	–
27	+ + + +	70	+ +	46	–	86	–
42	+ + + +	74	+ +	48	–	87	–
47	+ + + +	83	+ +	49	–	88	–
9	+ + +	34-1	+	50	–	89	–
17	+ + +	37	+	54	–	90	–
23-2	+ + +	51	+	55	–	92	–
40	+ + +	52	+	56	–	93	–
43-1	+ + +	91-1	+	57	–	95	–
91-2	+ + +	1	–	58	–	96	–
3	+ +	2	–	59	–	97	–
4	+ +	6-1	–	60	–	98	–
5	+ +	7	–	62	–	99	–
6-2	+ +	11	–	63	–	34-2	–[b]
8	+ +	12	–	64	–	44	–[b]
10	+ +	14	–	65	–	73	–[b]
13	+	20-2	–	68	–		
15	+ +	25	–	69	–		

[a] + = inhibits *R. solani* growth; — = no inhibition. [b] Mycelia of *R. solani* grow over bacteria.

tic activity, 10 g rice straw was added to 1 liter field water. A few days after, the bacterial population almost doubled (Table 6). Although preliminary results are encouraging, more work is required before the method can be used.

FIELD AND STORAGE MOLDS OF RICE GRAINS

A study was made to 1) determine the extent to which molds damage rice grains before harvest, and their causal fungi, 2) determine if varieties differ in susceptibility to field molds, and 3) study the change in population of the various fungi from harvest to storage.

About 700 samples were analyzed for presence of various molds both outside the grain and in the endosperm. For each sample, 100 seeds were plated (50 each for outside and in the endosperm). Among the samples were 100 lines each from the 1977 dry- and wet-season replicated yield trial; 60 from dry- and wet-season hybridization blocks; 440 from stored samples from previous seasons; and 50 each of lines with high and low gelatinization temperature.

Table 5. Survival of sclerotia immersed in bacterial suspension in peptone-sucrose broth of three isolates with strong antagonistic activity. IRRI, 1977.

Isolate[a]	Live/dead sclerotia (no.) after immersion for			
	3 days	10 days	17 days	23 days
FS 33-1	10/0	10/0[b]	0/10	0/10
FS 33-2	10/0	10/0[b]	0/10	0/10
FS 21	10/0	10/0[b]	0/10	0/10
No bacteria	10/0	10/0	10/0	10/0

[a]Population of FS 33-1, FS 33-2, and FS 21 was approximately 10×10^5. [b]Mycelial growth from sclerotia was slow.

Table 6. Effect of rice straw on bacterial population in field water. IRRI, 1977.

Treatment	Bacterial population				
	11 Apr. (initial)	13 Apr.	15 Apr.	18 Apr.	20 Apr.
Field water	5.3×10^4	7×10^4	23×10^4	13×10^4	11×10^4
Field water plus rice straw	5.3×10^4	4.7×10^6	18×10^6	15.5×10^6	$12.9 + 10^6$

Table 7. Field molds of rice grain. IRRI, 1976–77.

Fungus	Moldy grains (%)							
	1976 dry and wet seasons		1977 dry season					
	With glumes[a]	Without glumes[b]	With glumes stored[c]			Without glumes stored[d]		
			0 mo	3 mo	6 mo	0 mo	3 mo	6 mo
Trichoconis sp.	79.3	42.6	28.6	31.9	36.9	26.0	17.5	7.9
Curvularia spp.	60.0	5.0	83.7	13.1	1.9	4.2	4.0	0.8
Fusarium spp.	84.0	10.8	66.0	2.9	0.5	1.3	0.1	0.01
Nigrospora sp.	33.1	2.0	16.8	0.2	0.7	31.9	0.6	0.2
Neurospora sp.	5.4	0.4	0.7	0.6	0	0	0	0
Aspergillus spp.	3.4	0.	11.4	39.9	43.3	0	0.8	1.2
Penicillium spp.	2.7	0	17.2	39.5	57.7	0	0.5	1.0
Helminthosporium spp.	—	—	3.7	0.1	0	0	0	0
Phoma sp.	—	—	11.0	0.6	0	0.4	0	0
Rhizopus sp.	—	—	2.5	2.5	0.7	0	0	0
Miscellaneous	7.5	2.9	0.9	3.4	2.6	0.7	0.4	0.2
Unidentified, non-sporulating	18.7	2.4	1.9	3.7	0.8	1.4	0.2	0.2
With fungus growth	100	71.0	100	100	100	62.1	21.9	10.3
No fungus growth	0	29.0	0	0	0	37.9	78.1	89.7

[a]20 samples, 100 grains each. [b]100 samples, 50 grains each. [c]20 samples, 50 grains each. [d]200 samples, 50 grains each.

All rough rice (with glumes) carried from two to four types of field fungi, but some fungi did not penetrate easily into the endosperm (Table 7). Fungi infected about 60 to 70% of the brown rice (without glumes, surface sterilized) at harvest, reducing the rice quality and possibly causing breakage in milling. The predominant fungus, both outside brown rice and inside the endosperm, was a *Trichoconis* sp.; *Fusarium* spp. and *Nigrospora* sp. were also found. The overall fungi population decreased from 62% at harvest to 22% after 3 months of storage, and to 10% 6 months later. Thus, field molds seem more important than storage molds. But *Aspergillus* spp. and *Penicillium* spp. increased during storage, particularly when plated with glumed grains. They may be called *storage molds*.

Hybridization-block lines seemed to differ in amounts of moldy lines. For instance IR32, IR2070-423-2-5-6, and UTRI Rajapan had low mold incidence, while IR24, IR4859-38-3, and IR2003-P7-7-4-2 had high. But whether the differences are genetic or environmental has yet to be confirmed. The correlation coefficient (r = 0.39) between the results of the dry and the wet season is small but significant. Duncan Multiple Range Test determinations showed that the two groups are distinct.

No differences were noted among varieties with high, intermediate, or low gelatinization temperature; only a few high-gelatinizing rices were tested, however.

BACTERIAL BLIGHT

Control of bacterial blight. *Effect of zinc compounds on kresek development.* IR8 plants used to test the effects of nitrogen fertilizer on kresek development in the field were affected by zinc deficiency. In a subsequent greenhouse experiment, kresek developed on plants grown in zinc-deficient soil (Table 8).

Because dipping seedlings in zinc oxide solution or applying zinc sulfate to zinc-deficient fields before transplanting is recommended to amend the soil condition, the effects of zinc dipping on kresek development were tested. Two-week-old seedlings of IR8 were inoculated for kresek with PXO 82 by the root-dipping method and then dipped again in a zinc solution (2% $ZnSO_4$) before transplanting. Zinc dipping apparently controlled kresek development. Almost 31% of the seedlings without the zinc treatment and only about 7% of the treated seedlings were infected.

Table 8. Effect of soil type on development of kresek on IR8 seedlings inoculated by the root-dipping method. IRRI, 1977.

Soil type	Kresek (%)
Upland	30.6
Tiaong loam[a]	69.5
Maahas clay[b]	53.1

[a]Zinc deficient. [b]A zinc-deficient soil at IRRI.

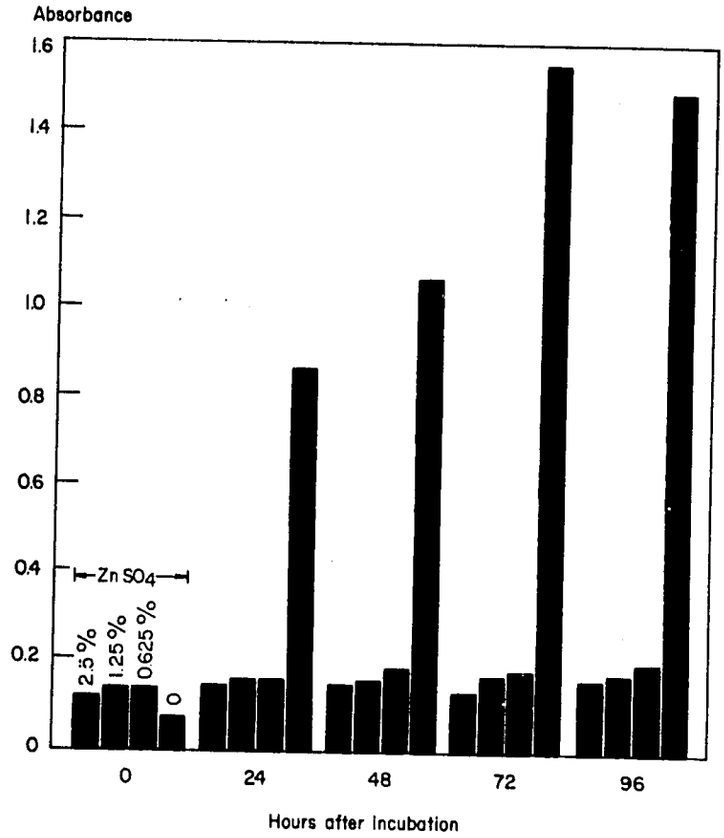
In the laboratory, the effect of zinc sulfate on the growth of *Xanthomonas oryzae* in potato sucrose agar medium was studied. Zinc sulfate applied at 2.5, 1.25, and 0.625% solution by the paper disc method not only inhibited but also reduced the growth of the bacterium on agar plates (Table 9). The inhibition zone decreased as the concentration of zinc sulfate was decreased from 2.5 to 0.625% but the growth reduction zone did not decrease significantly. Zinc sulfate appears to function bacteriocidally at high concentrations and bacteriostatically at low concentrations.

When different concentrations of zinc sulfate were incorporated into the potato sucrose broth medium and incubated from 0 to 96 hours at 28°C, no *X. oryzae* growth was detected. But the bacterium grew well in the same medium without zinc sulfate (Fig. 2).

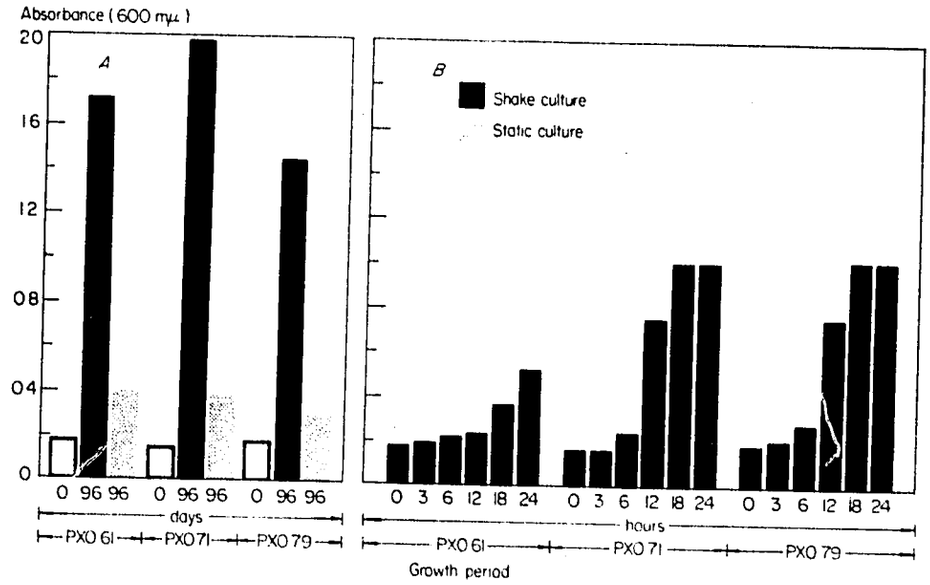
Chemical control. F-370, a chemical reportedly effective in controlling bacterial blight in the field, was tested in 1977. It was applied to pot-grown rice (IR8) by the spray and the drench methods at different recommended rates and at different times before blight inocu-

Table 9. Effect of zinc sulfate applied by the paper-disc method on the inhibition of *Xanthomonas oryzae* on agar plates. IRRI, 1977.

Treatment	Inhibition zone (cm)	Growth reduction zone (cm)
Zinc sulfate (%)		
2.5	1.46	1.77
1.25	1.19	1.47
0.625	0.67	1.48
Water (check)	0.00	0.00



2. Effect of zinc sulfate on the growth of *Xanthomonas oryzae* by shake culture. IRRI, 1977.



3. Growth of three distinct pathogenic isolates in shake and static cultures at 25°C in modified Wakimoto's medium (broth). IRRI, 1977.

Table 10. The effect of F-370 on lesion development of bacterial blight on IR8, IRRI greenhouse, 1977.

Concn	Lesion length (cm)			
	3 DBI	2 DBI	1 DBI	Control[a]
	Seedling treatment			
37.450 mg/l	26.2	19.1	21.0	21.3
1.250 g/l	20.2	19.9	20.6	22.4
4.1060 mg/l	30.0	21.1	19.5	20.8
	Broken treatment			
10 mg/l	19.2	20.6	18.7	17.7
20 mg/l	19.6	18.6	19.5	20.7
10 mg/l	20.6	20.4	20.7	17.6

DBI = days before inoculation. Control = no chemical applied. Mean of 3 replications, 20 leaves replication per treatment. Rates and applications of F-370 (Ag-Chem Corp.).

ation. Applied thus, F-370 was not as effective as claimed (Table 10). Its effectiveness in the field was not tested, however.

Growth of *Xanthomonas oryzae*. A study was made to define the growth conditions for PXO 61, PXO 79, and PXO 71, the three distinct pathotypes of *X. oryzae*, in a modified Wakimoto nutrient medium. No pathotype grew well by static culture at 96 hours after inoculation. But growth by shake culture was good. The isolates did not drastically differ (Fig. 3A). The growth curve of the three isolates within 24 hours seemed to differentiate PXO 79, and PXO 71 from PXO 61 (Fig. 3B).

RAGGED STUNT

In January 1977 the Philippine Bureau of Plant Industry reported a rice malady in North Cotabato. In February, the disease was observed at IRRI, particularly in the hybridization block. Scattered diseased plants were later observed in rice across the Philippines. In severe cases more than 90% of the rice hills in a field were infected, and all yield was lost.

Because its predominant symptoms — stunting of plants, formation of ragged leaves, and production of nodal panicles — differ from those of other known rice diseases, the disease was named *rice ragged stunt*.

Symptomatology. The diseased plants do not differ markedly from healthy ones in color, but they are stunted to various degrees at all growth stages (Fig. 4, Table 11). The difference in number of tillers between diseased and healthy plants varies according to the plant growth stage, but generally is not conspicuous (Table 11). But at maturity diseased plants have more diminutive tillers than healthy ones (Table 12).

Other symptoms vary according to the stage of plant growth. At early growth, the predominant symptom is ragged, tattered, torn, or serrated leaves (Fig. 5). The ragged edges generally appear on one side of the leaf blade before it unrolls. They occasionally appear on both sides and on the leaf sheath. The ragged portions vary in length and occupy only part of the leaf blade, not its entire length (unless the leaf is unusually short). The ragged area is generally white, but may later become yellow or brownish yellow, and finally disintegrate. The ragged leaves gradually become fewer as the plants grow older.

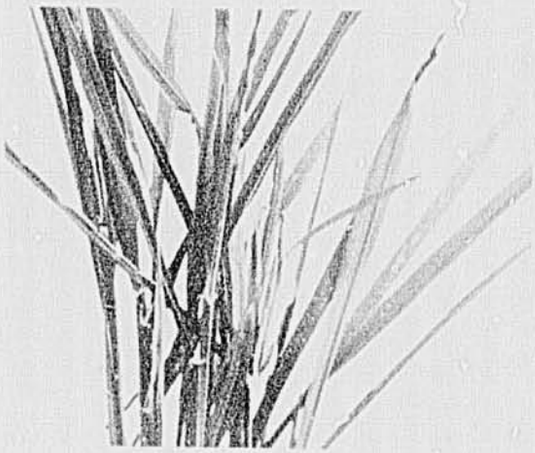
Another symptom is vein-swellings or galls (Fig. 6). The vein-swellings often appear on the

4. Healthy plant (left) and stunted plant infected with ragged stunt disease (right), IRRI, 1977.

Table 11. Comparison of growth in healthy plants (variety Taichung Native 1) and plants with ragged stunt disease at 0 to 3 months after inoculation. IRRI, 1977.

Plants	Plant ht (cm)				Tillers (no.)			
	0 mo	1 mo	2 mo	3 mo	0 mo	1 mo	2 mo	3 mo
Healthy	11.8	64.5	75.4	79.8	1.0	1.9	8.8	8.3
Diseased	11.5	38.8	47.0	52.3	1.0	3.2	8.1	6.6
LSD (5%)	1.6	11.2	13.9	12.9	—	0.7	2.3	2.3

upper portion of the outer surface of the leaf sheath, particularly near the collar, and less often on the lower surface of leaf blades. They are about 1 mm or less wide and from about 1 mm to more than 10 cm long. The vein-swellings, caused by proliferation of phloem cells (Fig. 7), are pale yellow or, less frequently, brown.



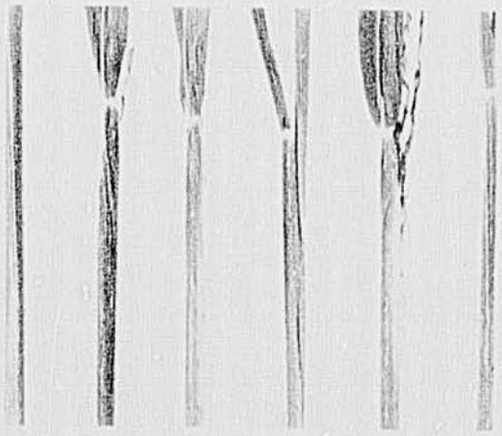
5. Ragged leaves, a symptom of ragged stunt disease. IRRI, 1977.

Diseased plants have small, and often twisted, malformed, or ragged flag leaves, and they often flower late (Fig. 8). Often panicles emerge incompletely and tillers generate nodal branches that bear small panicles (Fig. 9). The diseased plants therefore have more panicles and spikelets than the healthy ones, but few filled grains (Table 12).

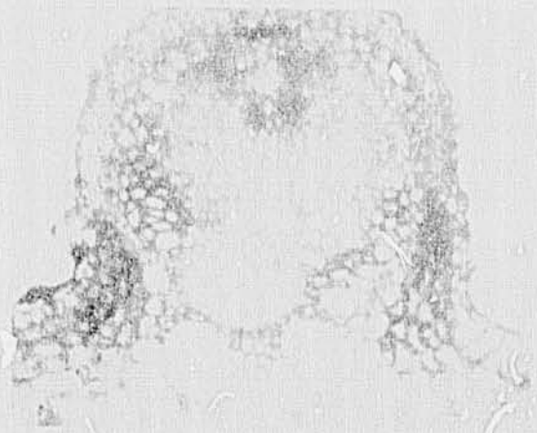
Ragged stunt disease is systemic. When a diseased plant is ratooned, vein-swelling is the only symptom observable in the early regenerated

Table 12. Comparison of healthy plants (variety Taichung Native 1) and plants with ragged stunt disease at maturity. IRRI, 1977.

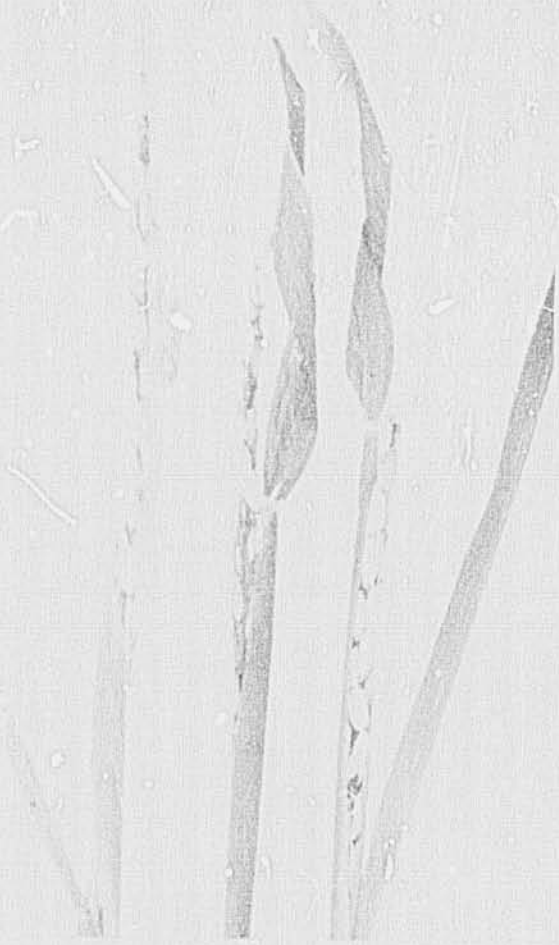
Plants	Tillers (no.)	Nodal branches (no.)	Panicles (no.)	Grains (no.)	Filled grains (no.)
Healthy	4	0	3	223	54
Diseased	11	33	18	62	474
LSD (1%)	5	7	4	54	114



6. Vein-swelling, a symptom of ragged stunt disease. IRRI, 1977.



7. Vein-swelling caused by a proliferation of phloem cells. IRRI, 1977.



8. Distortion of flag leaves and incomplete panicle emergence, symptoms of ragged stunt disease. IRRI, 1977.

9. Symptoms of ragged stunt disease — nodal branches and nodal panicles at later growth stages of infected plants. IRRI, 1977.

growth; other symptoms appear at the booting stage. The diseased plants can survive long after flowering — more than 6 months in the IRRI greenhouse.

When young rice seedlings were inoculated, the first noticeable symptom was stunting, followed by ragged leaves and other symptoms.

Causal agent. Collaborators at the University of Hokkaido (Japan) and IRRI studied the nature of the causal agent of ragged stunt with an electron microscope and by a bioassay method. Electron micrographs of dip preparations and ultrathin sections of rice plants naturally and artificially infected with the disease in the Philippines showed the presence of abundant 50- to 70-nm polyhedral particles in phloem cells and in cells of vein-swellings or galls (Fig. 10).

The infectivity of the causal agent was determined by injecting, with a fine glass capillary, the supernate of macerated diseased plants in a buffer solution into the bodies of BPH. The insects later became infective and caused disease symptoms in rice seedlings.

The results are evidence that the causal agent of ragged stunt is a virus.

Transmission. *Mechanical transmission.* Leaf blades of IR3839-1 rice seedlings were rubbed with the sap of diseased plants, with carborundum as an abrasive. Other seedlings were inoculated by the pinprick method. None of the 96 inoculated seedlings developed disease symptoms, indicating that disease transmission by mechanical means was unsuccessful.

Transmission by soil. Soil near diseased plants in paddy fields was collected. Healthy rice seedlings were immediately grown in soil

10. Electron micrographs showing virus particles in a dip preparation (top) and in a phloem cell of an ultrathin section (bottom) of a rice plant infected with ragged stunt disease. IRRI, 1977.

with stubble of diseased plants and in soil without. Until maturity none of the 204 seedlings became infected, although disease symptoms developed on the regenerated stubble growth. Soil-inhabiting microorganisms did not transmit the disease through soil even in the presence of stubble of diseased plants.

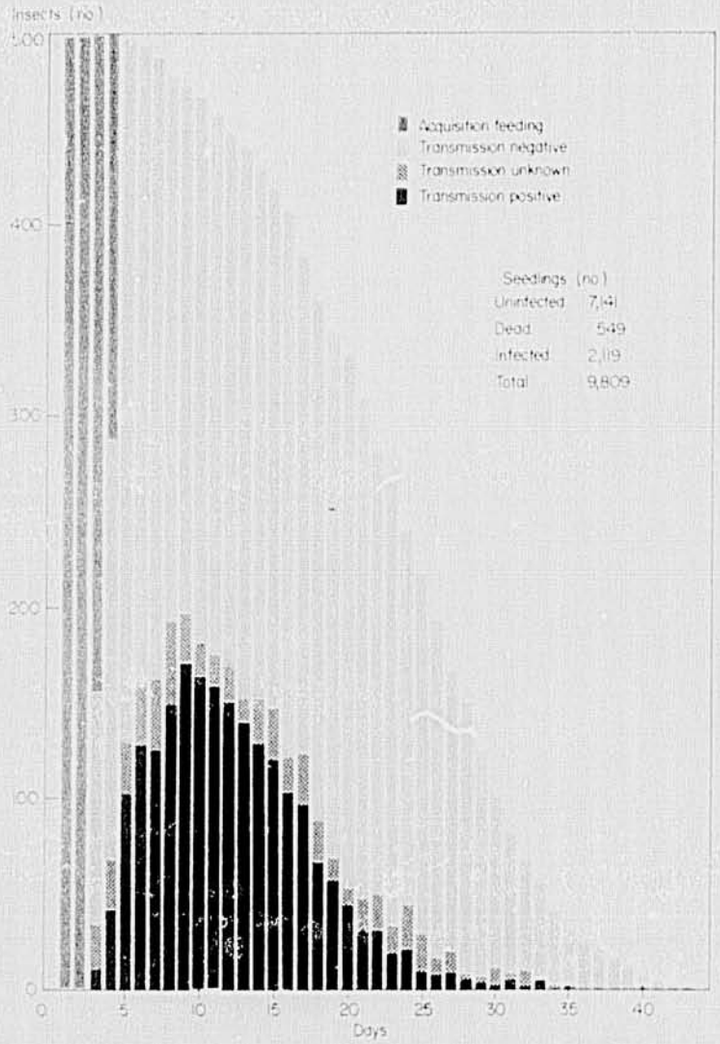
Table 13. Data on transmission of rice ragged stunt disease by *Nilaparvata lugens*. IRRI, 1977.

	Insects tested (no.)	Range	Mean
Active transmitter (%)	1625	14–76	40.3
Nymphs	256	0–100	18.8
Adults	1369	14–82	44.3
Females	714	15–100	46.2
Males	655	6–91	42.3
Brachypterous form	940	16–100	42.4
Macropterous form	429	0–100	48.5
Latent period (days)	500	2–33	8.6
Latent period (% of life span)	500	6–96	39.7
Infected seedlings (no./infective insect)	655	1–22	4.3
Nymphs	48	1–8	2.3
Adults	607	1–22	4.5
Females	330	1–21	4.7
Males	277	1–22	4.2
Brachypterous form	399	1–22	4.6
Macropterous form	208	1–17	4.3
Retention period (days)	500	3–35	14.9
Retention period (% of life span)	500	13–100	68.3
Disease-transmitting days (%)	655	3–100	41.4
Nontransmitting period (days)	655	0–30	7.0
Nontransmitting (% of life span)	655	0–83	29.6
Congenitally infective insects (no.)	165	0–0	0
Life span of infective insects (days)	500	4–44	22.7
Molts (no.)	485	1–5	2.3
Nymphal stadia (days)	440	2–16	8.2

Transmission by seed. Mature seeds from diseased plants were collected and germinated. None of the 633 seedlings showed disease symptoms. Seedlings that were transplanted and grown in screen cages remained healthy until maturity. Hence, no evidence of the transmission of ragged stunt disease through rice seed was obtained.

Transmission by insects. Insects with sucking mouthparts were captured directly from diseased plants in the fields and used to inoculate rice seedlings in the greenhouse. Some seedlings inoculated by BPH developed disease symptoms. Hence, the BPH is a vector of the disease.

Transmission by BPH. The ability of the BPH to transmit the disease to rice seedlings was tested by daily serial transmission after acquisition feedings of 2, 3, 4, or more days until the death of the insects.



11. Daily serial transmission of rice ragged stunt disease by infective *Nilaparvata lugens*. IRRI, 1977.

About 40% of the 1,625 BPH were active transmitters (Table 13). Both nymphs and adults transmitted the disease. No striking difference in percentage of active transmitters was observed between female and male adults (46 vs 42%), and between brachypterous and macropterous forms (42 vs 48%). A few insects became infective immediately after acquisition feedings of 2, 3, or 4 days, while others remained latent for as long as 33 days. The latent period averaged 8.6 days. The insects remained infective after molting, indicating that the virus passage was transstadial. The largest number of seedlings infected by one insect during its life span was 22. But 33% of the infective insects infected only one seedling during their life span; on the average, an infective insect infected about 4 seedlings. The highest percentage of infective insects transmitted the disease 9 days after acquisition feeding. The daily serial transmission pattern was generally intermittent (Fig. 11). The retention period ranged from 3 to 35 days (av. 14.6 days) after acquisition feeding. The disease-transmitting period varied from 3 to 100% (av. 41%) of the period from the time that the insect became infective until its death. As infective insects became older, they often failed to infect seedlings. The nontrans-

mitting period between the last successful transmission and the insect's death ranged from 0 to 30 days (av. 7 days).

The transovarial passage was determined by examining the infectivity of the progeny of viruliferous insects obtained on *Monochoria vaginalis*, a plant species assumed not to be a host of ragged stunt. None of the 2,733 seedlings inoculated by 165 newly hatched progeny insects were infected, indicating the absence of congenitally infective insects.

Therefore, the interaction between the ragged stunt virus and the BPH is categorized in the persistent group without transovarial passage.

Transmission by BPH in Japan. The ability of 50 brown planthoppers to transmit ragged stunt was studied in a temperature-controlled greenhouse (25-28°C) at the University of Hokkaido, Japan. The insects had been reared for 4 years in Sapporo.

Twenty-eight percent of the tested BPH, including both female and male adults and brachypterous and macropterous forms, were active transmitters. Their latent periods ranged from 5 to 11 days (av. 8.6 days) after acquisition feeding. The infective insects transmitted the disease to from 1 to 31 or more seedlings during their life spans. The retention periods ranged from 9 to 41 or more days after acquisition feeding (some insects did not die on the last day of the transmission test, 41 days). From 33 to 100% (av. 81.3%) of the period from the time that the insect became infective until the last day of the transmission test were disease-transmitting days.

The BPH in Japan is capable of transmitting the ragged stunt disease. It did not differ strikingly from the BPH in the Philippines in either the percentage of active transmitters or the latent period. But in Japan the insects infected more rice seedlings during their life spans, had longer retention periods, and had higher percentages of disease-transmitting days. Further studies will be conducted to determine if the differences are due to insect ecotype or to transmission test conditions.

Transmission by BPH biotypes. The ability of different BPH biotypes to transmit ragged stunt was studied by daily serial transmission to rice seedlings after acquisition feedings of 2 or 4 days until the death of the insects. Three biotypes from the IRRI Entomology Department, differing in ability to attack rice varieties that carry different genes of resistance to BPH, were tested. Also included was a colony of BPH that had been reared on TN1 in the greenhouse for several years but whose ability to attack different rice varieties had not been determined. The test involved 985 insects and 18,477 inoculated seedlings.

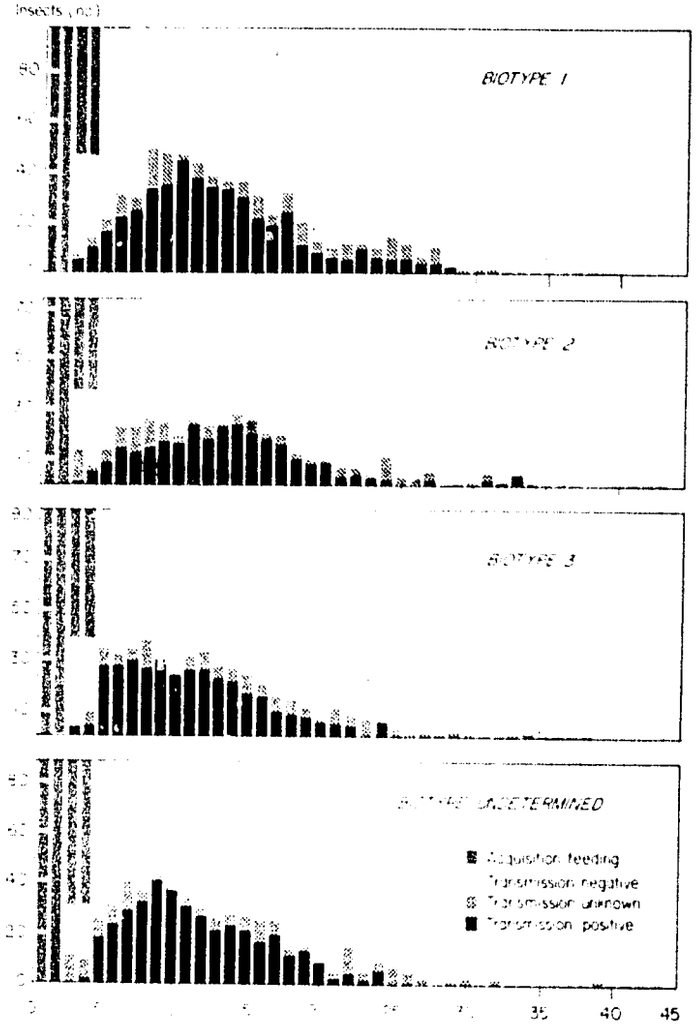
The BPH biotypes did not differ significantly in percentage of active transmitters, latent period, number of infected seedlings per insect, retention period, or percentage of disease-transmitting days (Table 14). All the tested biotypes showed transstadial passage and were similar in daily serial transmission (Fig. 12). It was concluded that they have similar ability to transmit ragged stunt.

Host range. Plants of several species were inoculated with BPH that were viruliferous for rice ragged stunt. Most plants were not infected. But *O. sativa*, *O. latifolia*, and *O. nivara* plants were. The infected plants of *O. latifolia* and *O. nivara* showed symptoms of stunting, ragged leaves (Fig. 13), vein-swellings, and nodal branches — similar to those on infected *O. sati-*

Table 14. Characteristics of *Nilaparvata lugens* biotypes that transmit rice ragged stunt disease.[a] IRRI, 1977.

Biotype	Active transmitters (%)	Latent period (days)	Infected seedlings (no./insect)	Retention period (days)	Disease-transmitting days (%)
1	41.8	8.7	5.1	15.8	36.8
2	33.6	11.0	4.3	16.0	36.2
3	40.6	7.6	4.1	14.1	38.9
Undetermined	36.6	8.0	4.6	13.9	44.7

[a]Differences among entries in any column were not statistically significant.



12. Daily serial transmission of rice ragged stunt disease by biotypes of infective *Nilaparvata lugens*, IRRI, 1977.

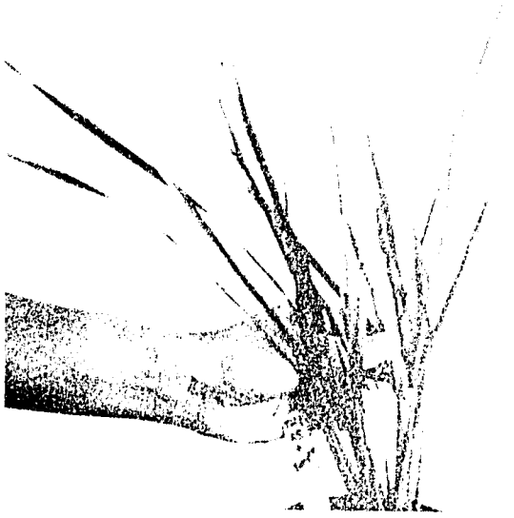
va. BPH recovered the virus from the diseased plants of *O. latifolia* and *O. nivara* and transmitted it successfully to rice plants. Consequently, *O. sativa* is not the only host of the rice ragged stunt virus.

Dual infection. In the Philippines, there are five known virus and virus-like diseases of rice plants — grassy stunt, orange leaf, ragged stunt, tungro, and yellow dwarf. Orange leaf and yellow dwarf are of minor importance. Rice plants can be dually infected with tungro and grassy stunt (1971 Annual Report).

In a study of dual infection by ragged stunt and tungro or by ragged stunt and grassy stunt, seedlings of TN1 were inoculated with viruliferous insects in the greenhouse. The rice plants were dually infected with tungro and ragged stunt (Fig. 14). The infected plants had symptoms of stunting, yellowing of leaves (a symptom of tungro), and ragged leaves (a symptom of ragged stunt).

The rice plants were also dually infected with grassy stunt and ragged stunt (Fig. 15). The symptoms of the infected plants included those

13. Ragged leaves of an *Oryza latifolia* plant infected with ragged stunt disease. IRRI, 1977.



14. A rice plant that is dually infected with ragged stunt and tungro diseases. IRRI, 1977.

of grassy stunt (profuse tillering and narrow leaf blades) and those of ragged stunt (ragged leaves). The dually infected plants were stunted much more, particularly at late plant growth, and some leaves had twisted tips.

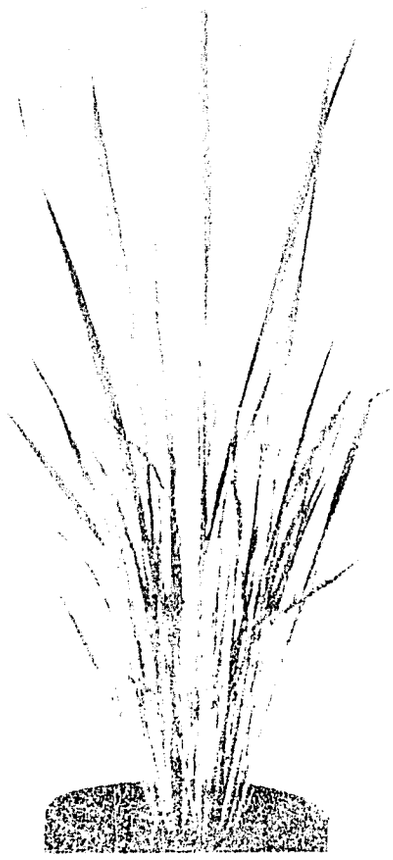
The dual infection indicates the absence of cross protection either between ragged stunt and tungro or between ragged stunt and grassy stunt. Hence, the causal agent of ragged stunt is not closely related to that of tungro or grassy stunt.

Antibiotic treatment. Plants of IR29 and IR30, naturally infected with ragged stunt disease, were transplanted into nine groups of pots at three hills per group and treated with two antibiotic compounds, oxytetracycline and tetracycline hydrochloride. Two concentrations of each compound were sprayed on the diseased plants either once a week or three times a week for 10 weeks. At the end of the treatment and several weeks thereafter, the treated plants of both varieties did not differ from the untreated controls in plant height, tiller number, ragged leaves, vein-swellings, nodal branches, panicles, or grains. Hence, neither compound suppressed the symptoms of the disease.

GRASSY STUNT

IRRI entomologists have identified three BPH biotypes that differ in ability to attack rice varieties possessing different resistance genes. The BPH not only directly damages the rice plant, but also transmits grassy stunt disease. The ability of 4,690 insects of the three biotypes to transmit grassy stunt was studied by daily serial transmission to 27,374 seedlings of the susceptible variety TN1 after acquisition feeding of 2 or 4 days until the death of the insects.

The three BPH biotypes did not differ significantly in percentage of active transmitters, nor in latent period, retention period, number of infected seedlings per insect, or percentage of disease-transmitting days (Table 15). All biotypes showed transstadial passage. They exhibited similar ability to transmit rice grassy stunt.



Epidemiology. The epidemiological study of rice tungro disease in 37 farmers' fields in 5 provinces of Luzon, Philippines, was continued. Disease incidence was observed, insect vectors were collected, and the vectors' infectivity was determined every 2 weeks from November 1976 to October 1977.

Incidence. The incidence of tungro in the study fields was low. The overall incidence averaged 0.07% in 784 observations. But about 17% of the study fields had tungro-infected plants. The disease appeared in each of the five provinces throughout the study period. It was not observed in the seedbeds, however. Tungro incidence was much higher in the stubble than in the paddy field. Most of the cultivars tested were attacked (Table 16).

Table 15. Transmission of rice grassy stunt disease by biotypes of *Nilaparvata lugens*.[a] IRRI, 1977.

Biotype	Active transmitters (%)	Latent period (days)	Infected seedlings (no./insect)	Retention period (days)	Disease-transmitting days (%)
1	12.1	10.2	9.3	21.6	54.9
2	10.1	9.4	9.7	20.2	56.2
3	11.4	10.2	9.8	20.8	64.3

[a]Differences among entries in a column were not significant.

Insect vectors. The number of insect vectors in the study fields was generally low and did not fluctuate markedly from month to month (Table 16). A total of 1,687 insects were obtained from 632 collections; the overall average was 2.7 insects/10 sweeps. Of the collected insects, 20% were nymphs and 80% were adults; 34, 57, and 9% were *Nephotettix virescens*, *N. nigropictus*, and *Recilia dorsalis*, respectively.

Infective insects. During the study period, 7,088 insects of 318 collections from the study fields were tested for infectivity. Of the tested insects, 16% were nymphs and 84% were adults; 31, 60, and 9% were *N. virescens*, *N. nigropictus*, and *R. dorsalis*, respectively. The percentage of infective insects was low throughout the study period; the overall average was 0.25% (Table 16).

Insect vectors and incidence. The tungro virus is transmitted only by insect vectors. Therefore, the disease incidence is determined by the vector population and the percentage of infective insects, if other factors remain unchanged.

Last year's speculation that the average number of insect vectors and the percentage of infective insects in April, May, and June seemed to determine the tungro incidence from June to October (1976 Annual Report) was substantiated this year (Table 17). The number of insect vectors and the percentage of infective insects in April, May, and June were lower than in previous years. Similarly, the 1977 tungro incidence from June to October, the rainy season, was also lower.

Light trap. Trapping of insect vectors at IRRI was continued. Insects were trapped by light between 1700 hours and 2 hours after sunset once a week. Some trapped insects were tested for infectivity.

Table 16. Tungro incidence and insect vectors in study fields in Luzon, Philippines, classified by month, province, field, and cultivar. IRRI, 1977.

Designation	Observations (no.)	Tungro		Insect vectors			
		Fields (%)	Incidence (%)	Collections (no.)	Av. no. per 10 sweeps	Tested (no.)	Infective (%)
			Month				
November 1976	89	38	0.34	59	4.0	684	2.05
December	78	27	0.16	48	1.2	267	0
January 1977	74	25	0.14	37	1.3	270	0
February	74	15	0.02	54	2.9	842	0
March	93	7	0.01	68	3.9	1102	0
April	74	4	0.01	54	3.6	513	0
May	88	7	0.01	62	3.2	467	0
June	79	4	0.01	56	2.3	598	0
July	75	13	0.02	60	2.7	1115	0.09
August	93	14	0.02	59	1.4	478	0
September	74	21	0.04	37	1.3	289	0
October	74	15	0.03	38	3.0	463	0.65
			Province				
Bulacan	262	22	0.13	184	2.8	2326	0.60
Laguna	208	9	0.01	139	3.9	1576	0
Nueva Ecija	130	15	0.02	95	0.9	487	0
Pampanga	157	9	0.02	99	2.5	1427	0.21
Tarlac	208	27	0.15	115	2.6	1272	0.08
			Type of field				
Seedbed	69	0	0	67	4.1	1196	0
Paddy	477	17	0.05	238	1.2	1821	0.05
Stubble	238	21	0.15	238	4.6	3874	0.44
Idle	181	0	0	89	0.5	197	0
			Rice cultivar				
Early Wagwag	24	38	0.08	18	3.7	305	0
IR26	115	25	0.20	90	2.7	1318	1.06
IR28	47	19	0.16	31	4.3	365	0
IR29	23	0	0	16	2.1	236	0
IR30	57	14	0.03	40	2.8	608	0
IR32	32	0	0	25	2.1	261	0
IR36	412	12	0.02	273	3.2	3261	0.12
Others	74	34	0.19	50	2.8	537	0

Table 17. Insect vectors in study fields from April to June and incidence of rice tungro disease in paddy fields from June to October, 1973–1977, Luzon, Philippines.

Year	Insect vectors				Tungro disease		
	Collections (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	3.23
1976	149	3.9	2244	0.18	267	25	0.33
1977	172	3.0	1578	0	253	15	0.03

[a]Rice fields with only a few tungro-infected plants were excluded. [b]The Philippine Government launched a green leafhopper control program in the area in July and August.

The average number of tungro vectors (*N. virescens*, *N. nigropictus*, and *R. dorsalis*) was 545, 13, 109, 16, 105, 158, 104, 154, 516, 278, 685, and 314 per trap for each consecutive month from November 1976 through October 1977. The *N. virescens* : *N. nigropictus* : *R. dorsalis* ratio was 45:33:22. Of 4,277 insects tested, only 0.44% were infective. The overall tungro incidence at IRRI was low.

The average number of BPH *N. lugens*, a vector of both grassy stunt and ragged stunt, was 2,552, 49, 23, 56, 53, 83, 155, 186, 1,017, 480, 1,608, and 4,687 per trap for each consecutive month from November 1976 through October 1977. Of 2,145 insects tested, 0.05% were infective for grassy stunt. The overall grassy stunt incidence at IRRI was low.

Of 858 insects tested, 3.26% were infective for ragged stunt. The overall incidence of ragged stunt disease at IRRI was moderate.

Control and management of rice pests

Insects

Entomology and Soil Microbiology Departments

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TAXONOMY OF PESTS IN RICE ECOSYSTEMS

Entomology Department

The proper identification of rice insect pests is basic to plant resistance, chemical control, and biological studies.

IRRI began to identify arthropods to the family level and to send specimens worldwide to specialists for proper determination. In 1977, 2,174 arthropod specimens were sent to specialists. Of those specimens, 24% comprising 44 species have thus far been identified. Although IRRI maintains a small reference collection of arthropods (currently 18 orders and 265 families) from rice ecosystems, the bulk of the specimens will be deposited in the Entomology Museum of the College of Agriculture, University of the Philippines at Los Baños.

INFORMATION RETRIEVAL SYSTEM

Entomology Department

The magnitude of worldwide scientific publications has increased exponentially in recent decades. Scientists must keep abreast of recent developments and recall past scientific literature to avoid unnecessary duplication of research. IRRI's expanded role into rice-based cropping systems has increased the volume of literature to be covered. IRRI developed a flexible information retrieval system to cope with the volume of entomology literature. Articles are actively solicited, scanned, indexed by subject, and filed for easy retrieval. The outstanding feature of the system is its extensive subject classification by arthropod species, plant species, country, and pesticide, and by more than 900 descriptor words. More than 10,000 articles are already in the system for use by IRRI and collaborating researchers.

INSECTICIDE EVALUATION

Entomology and Soil Microbiology Departments

Insecticides are first evaluated in the laboratory and greenhouse, then promising ones are further tested in the field. In the greenhouse, insecticides are applied by methods depending on the formulation: 1) contact toxicity

Table 1. Activity of insecticides against brown planthopper (BPH), green leafhopper (GLH), and whitebacked planthopper (WBPH). IRRI, 1977.

Insecticide[a]	Formulation[b]		Activity[c]					
			Contact toxicity[d]			Foliar spray[e]		
			BPH	GLH	WBPH	BPH	GLH	WBPH
A 47171	24	EC	+	+	–	+	+	+
ABG 6070	49	EC	–	+	–	–	+	+
ABG 6071	24	EC	–	+	+	–	+	+
AC 64475	25	EC	–	–	–	+	+	+
Acephate	75	SP	–	–	–	+	+	+
Azinphos ethyl	40	EC	–	+	–	+	+	+
Bendiocarb	80	WP	–	+	+	+	+	+
BPMC	50	EC	–	+	–	–	+	–
BPMC + chlorpyrifos	31.5	EC	–	+	–	–	+	–
Carbofuran	36	F	+	+	+	+	+	+
Carbophenothion	30	EC	–	–	–	+	+	+
Carbaryl	85	WP	–	–	–	+	+	+
Chlorfenvinphos	20	EC	–	–	–	–	+	–
Chlorfenvinphos + MTMC	15 + 15	EC	n.t.	n.t	n.t	–	+	–
Chlorpyrifos + trichlorfon	20 + 10	EC	n.t.	n.t.	n.t.	–	+	+
Cypermethrin	40	EC	+	+	+	+	+	+
Dacamox	2	EC	+	+	+	n.t.	n.t.	n.t.
Diazinon	20	EC	–	+	–	–	–	–
Disulfoton	65	EC	–	–	–	–	+	–
Dicrotophos	20	EC	–	+	+			
Endosulfan	35	EC	–	–	–	+	–	+
EPN	45	EC	–	–	+	–	–	–
EXP 5469	50	WP	+	+	–	n.t.	n.t.	n.t.
FMC 35001	48	EC	+	+	+	+	+	+
Fenvalerate	3	EC	–	–	+	+	+	+
Fensulfothion	63	EC	–	–	+	+	+	+
Fenthion	50	EC	–	–	+	–	+	+
Fenitrothion	20	EC	–	+	+	n.t.	n.t.	n.t.
Isoxathion	50	EC	–	–	+	n.t.	n.t.	n.t.
Lindane	20	Ec	–	–	–	–	+	–
Metalkamate	30	EC	+	+	+	–	+	–
Methamidophos	60	EC	–	–	–	–	+	–
Methomyl	19.3	EC	–	+	–	–	+	–
Methyl parathion	50	EC	–	–	–	–	+	+
MIPC	50	WP	–	+	–	–	+	–
Monocrotophos	16.8	EC	–	–	+	+	+	+
Perthane	45	EC	–	–	–	+	+	+
Permethrin	10	EC	+	+	+	+	+	+
Phenthoate	50	EC	–	–	–	–	+	+
Phosphamidon	50	EC	–	–	–	–	+	–
Propoxur	20	EC	+	+	+	–	+	–
Sumibassa	75	EC	–	–	–	–	+	+
S-3206	20	EC	–	+	–	n.t.	n.t.	n.t.
Triazophos	40	EC	–	–	+	n.t.	n.t.	n.t.

[a]Applied as 0.04% spray in contact toxicity test in Potter's spray tower, and foliar spray. [b]EC = emulsifiable concentrate, SP = soluble powder, WP = wettable power, F = flowable. [c]+ = effective (> 80% mortality), – = not effective, n.t. = not tested in 1977. [d]Mortality readings were taken at 48 hours after treatment and adjusted using Abbott's formula. [e]Three sets of insects placed on sprayed plants at 1, 7, and 14 days after treatment. Mortality readings were taken 48 hours after the insects were place on treated plants and adjusted using Abbott's formula.

(direct spray onto the insect), 2) foliar spray, 3) paddy-water broadcast, and 4) root-zone application. In 1977 greenhouse studies, insecticides were evaluated against four rice pests: brown planthopper (BPH) *Nilaparvata lugens*, green leafhopper (GLH) *Nephotettix virescens*, whitebacked planthopper (WBPH) *Sogatella furcifera*, and striped stem borer *Chilo suppressalis*.

The effectiveness of various insecticides was further determined in the field by three application methods: 1) foliar spray, 2) paddy-water application of granules, and 3) various types of root-zone applications. The primary pests in field studies were the whorl maggot *Hydrellia philippina*, GLH, BPH, stem borer, and leaf folder *Cnaphalocrosis medinalis*.

Contact toxicity (*Entomology*). Numerous new insecticides and commercially available insecticides were evaluated in a contact toxicity test using Potter's spray tower (Table 1). Only carbofuran, cypermethrin, dacamox, FMC 35001, metalkamate, permethrin, and propoxur killed at least 80% of each of the three hopper species. The ineffective insecticides, not listed in Table 1, were ABG 6011, Aspon, dimethoate, Hostaquick, MTMC, meobal, padan, and vamidothion.

Foliar sprays (*Entomology*). Greenhouse evaluation of insecticides applied as foliar sprays indicated that carbofuran at a rate as low as 0.16 kg a.i./ha effectively controlled the three species. Carbophenothion at 0.32 kg/ha effectively controlled the GLH and WBPH; at 0.75 kg/ha it effectively controlled the BPH.

Insecticides were evaluated in the field as foliar sprays against the whorl maggot. In the two dry season experiments, acephate, azinphos-ethyl, cypermethrin, isoxathion, and monocrotophos provided some degree of control, whereas bendiocarb, BPMC, Hostaquick, methyl parathion, MIPC, Monitor, endosulfan, and perthane were ineffective. In a wet season experiment, only azinphos-ethyl sprays controlled whorl maggots as well as diazinon granules did (Table 2). Foliar sprays are less effective than granules in the wet season.

Timing. Because BPH control with foliar sprays is often ineffective, the importance of time of application, placement of insecticide, and volume of spray solution was investigated. Perthane spray applications were timed according to the insect's life cycle and a predetermined calendar (Table 3). The most effective was one-spray application at 61 days after transplanting (DT), which coincided with the time that most planthoppers were third- and fourth-instar nymphs of the second generation. Of the calendar-based sprays, only that which included an application at 61 DT was effective. The proper time of application is important in an effective foliar spray program for BPH.

Application site. Because the BPH feeds at the base of the stem near the water level, it is recommended that sprays be directed toward the base for effective control. Spraying above or below the canopy did not result in different levels of hopper damage or yield in the timing study (Table 3). Further studies with perthane confirmed results indicated in the timing study (Table 4). When three insecticides were applied below the canopy, BPH control was about 20% higher with the nonsystemic insecticides metalkamate and perthane but only about 10% higher with monocrotophos than when they were applied above the canopy

Table 2. Evaluation of insecticides for whorl maggot control on variety IR36, IRRI, 1977 wet season.

Insecticide[a]	Damage rating[b] 12 DT	20 DT	30 DT
Diazinon (broadcast)	1 a	3 a	6 ab
Carbofuran (broadcast)	2 ab	4 ab	5 a
Azinphos-ethyl	2 ab	6 bcd	7 bc
Acephate	3 bc	6 bcd	8 c
Carbofuran	3 bc	6 bcd	7 bc
Carbophenothion	3 bc	6 bcd	8 c
Methyl parathion	3 bc	7 cd	8 c
Monocrotophos	3 bc	5 bc	7 bc
Endosulfan	4 cd	8 d	8 c
MIPC	4 cd	7 cd	8 c
BPMC	5 de	8 d	8 c
Perthane	5 de	8 d	8 c
Control	6 e	8 d	8 c

[a]All insecticides were applied as foliar sprays except where indicated. All sprays were applied at 0.75 kg a.i./ha, except carbofuran (0.25 kg a.i./ha). Carbofuran and diazinon broadcast treatments were applied at 1 kg a.i./ha. All treatments were applied once at 5 days after transplanting (DT). [b]Based on a scale of 0–9: 0 = no damage; 9 = > 50% of leaves damaged. In a column, means followed by a common letter are not significantly different at the 5% level.

Table 3. Timing and application site of perthane foliar sprays for brown planthopper (BPH) control.[a] IRRI, 1977 wet season.

Site, time of application[b]	Hopperburn (%) 77 DT	Hopperburn (%) 102 DT	Yield[c] (t/ha)
Timing based on BPH life cycle			
Above canopy			
1st generation	19 ab	38 b	0.6 c
2d generation	0 a	1 a	1.9 ab
3d generation	34 c	50 b	0.3 c
Below canopy			
1st generation	13 abc	29 b	0.6 c
2d generation	0 a	0 a	2.1 a
3d generation	11 abc	28 b	0.4 c
Calendar-based sprays			
Above canopy			
19 and 33 DT	19 abc	31 b	0.6 c
19, 33, and 47 DT	5 ab	14 ab	1.1 bc
19, 33, 47, and 61 DT	1 a	1 a	2.0 a
Control	33 bc	44 b	0.5 c

[a]Buildup of BPH population was induced by spraying all plots with 25 g a.i. cypermethrin (synthetic pyrethroid)/ha at 10-day intervals starting 12 days after transplanting (DT). Six applications were made. Carbofuran (1 kg a.i./ha) was broadcast in the life cycle-timed treatments, and monocrotophos (0.75 kg a.i./ha) sprayed in calendar-based treatments for whorl maggot and virus-vector control at 3 DT. In a column, means followed by a common letter are not significantly different at the 5% level. [b]Insecticide treatments, timed with BPH life cycle, were applied when most BPH were third and fourth instars (when egg population on plant was lowest), i.e. at 33, 61, and 90 DT for the first, second, and third generations, respectively. [c]Two typhoons damaged the crop.

Table 4. Perthane spray treatments at 0.75 kg a.i./ha to control the brown planthopper (BPH).[a] IRRI, 1977 wet season.

Treatment[b]	Spray volume (liters /ha)	BPH (no./10 hills) Before spraying[c]	BPH (no./10 hills) 4 days after spraying[d]	Control (%)
LVS below canopy every row	225	18,748 a	1,248 b	98
LVS above canopy	225	28,096 a	6,102 c	78
HVS below canopy every row	1,446	18,471 a	365 a	98
HVS above canopy	1,446	19,381 a	1,568 b	92
MB below canopy	375	27,870 a	3,241 bc	88
MB above canopy	375	18,224 a	2,875 bc	84
Control	375	23,504 a	20,876 d	11

[a]Buildup of BPH was induced by spraying the entire field 4 times with cypermethrin 25 g a.i./ha at 10-day intervals. The experiment was conducted 61 days after transplanting. [b]LVS = low-volume spray, HVS = high-volume spray, MB = mist blower. [c]Hoppers in the field were third- and fourth-instar nymphs of second generation. In a column, means followed by a common letter are not significantly different at the 5% level. [d]Hoppers in the field were 90% adults.

Table 5. Foliar application of insecticides above and below the rice canopy for brown planthopper (BPH) control. IRRI, 1977.

Treatment[a]	BPH[b] (no./4-linear-m row) Before insecticide application	BPH[b] (no./4-linear-m row) 2 days after application	Control[c] (%)
Applied above rice canopy			
Metalkamate	4,766 a	1,183 a	74
Monocrotophos	4,213 a	3,168 b	60
Perthane	7,342 a	2,589 b	63
Control	6,190 a	5,893 b	5
Applied below rice canopy			
Metalkamate	11,241 a	947 a	92
Monocrotophos	6,723 a	2,074 b	69
Perthane	7,521 a	335 a	96
Control	7,805 a	8,811 c	0

[a]Hopper development was induced by foliar application of decamethrin at 30 g a.i./ha starting at 15 days after transplanting. Three applications were made at 750 g. a.i./ha. Volume of spray material for both methods of treatment was 1,444 liters/ha. [b]Sampled with D-Vac suction machine. In each column, means followed by a common letter are not significantly different at the 5% level. [c]Values shown were adjusted using Abbott's formula.

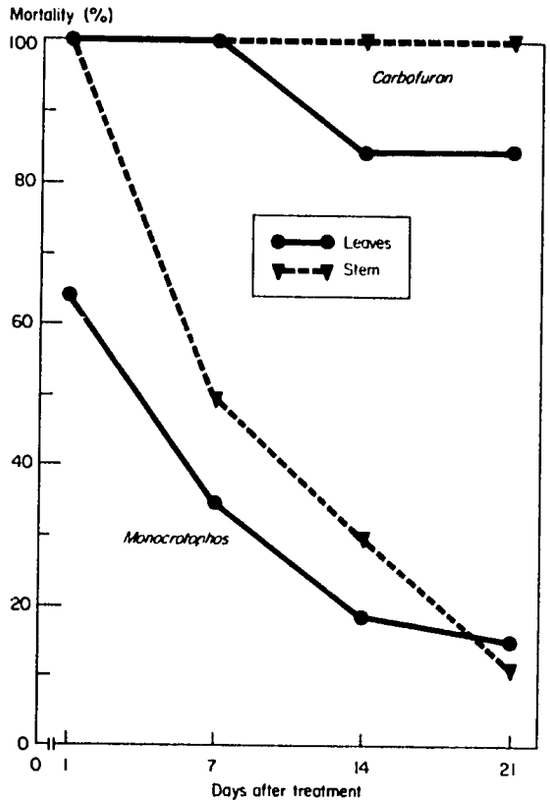
(Table 5). Carbofuran and monocrotophos translocate to some extent to the lower plant parts (Table 6, Fig. 1).

Volume applied. In the Philippines a spray volume of 1,000 liters/ha is recommended for a crop that has completed tillering. Field studies with perthane indicated that a spray solution of 190 to 950 liters controlled the BPH equally in two wet-season tests (Table 7).

Spreader-sticker. There are numerous spreader-sticker compounds that prevent insecticides from being washed off by rains. They increase the effectiveness of foliar sprays by increasing the amount initially deposited and prolonging residual activity.

Spreader-stickers were mixed with acephate and applied as foliar spray. Residue analysis with gas chromatography indicated that a few spreader-stickers increased the spray's initial deposit and residual life (Table 8), but bioassays with insects indicated no increase in residual activity.

Ovicides. Because planthopper eggs are inserted into leaf tissues, they are somewhat protected from direct contact with foliar



1. Mortality of the brown planthopper on plants sprayed with 0.2 kg a.i. carbofuran/ha or monocrotophos directed at the leaves and on the stem. IRRI greenhouse, 1977.

sprays. When insecticide applications are poorly timed, the planthopper population may be higher a few days after spraying than before because of nymphs hatching from the protected eggs. Thus, applications must be repeated. The insecticides that kill eggs at the same time that they kill the nymphs and adults feeding on the plants must be identified. Eight insecticides were initially tested as 0.04% foliar sprays on plants containing 1-day-old BPH eggs (Table 9). Methyl parathion, triazophos, and carbofuran had an ovicidal effect.

Further studies were conducted to determine the effect of insecticide concentration and egg age on ovicidal activity. Carbofuran at 0.04% was highly ovicidal; at the lowest concentration, 0.005%, it had no such effect on newly laid eggs (Fig. 2).

Ovicidal activity was highly dependent on the egg's stage of development at the time of

Table 6. Translocation of carbofuran in Taichung Native 1 rice treated by root systemic and topical applications. IRRI greenhouse, 1977.

Treatment[a]	Residue of parent insecticide[b] (ppm)					
	3 DAT			23 DAT		
	Leaf	Leaf sheath	Stem	Leaf	Leaf sheath	Stem
Root-zone injection	11.5	3.8	1.8	5.2	5.0	0.36
Spray on leaves	608.0	52.4	11.5	210.0	6.0	1.20
Spray on stems	26.0	33.0	4.7	11.2	63.3	3.10

[a]All treatments were applied at 2 kg a.i./ha on 35-day-old plants. Foliar sprays were directed at indicated parts of plant with nontarget parts covered by plastic film. Leaf sheaths were on the stem during spraying, but were removed before analysis. [b]Residues in roots were < 1.0 ppm for all three treatments at both sampling intervals. DAT = days after treatment.

Table 7. Effect of spray volumes on control of brown planthopper (BPH)[a] on variety IR22. IRRI, 1977 wet season.

Treatment (0.75 kg a.i. perthane/ha) at spray volume of	Concn (%)	BPH (no./10 hills)[b]			Control (%)[c]	
		Before spraying[d]	3 DAS	13 DAS[d]	3 DAS	13 DAS
190 liters	0.394	37,399 ab	3,845 b	2,208 a	90	94
380 liters	0.197	36,522 ab	3,434 ab	1,369 a	91	96
570 liters	0.131	37,550 ab	3,702 ab	1,924 a	90	95
760 liters	0.098	29,269 ab	3,290 ab	1,456 a	89	95
950 liters	0.078	29,859 ab	1,999 a	2,681 a	93	91
Control (475 liters H_2O)	0.000	39,222 ab	31,353 c	HB[e]	20	—

[a]To induce the BPH buildup, the field was sprayed 4 times with 25 g a.i. cypermethrin/ha at 10-day intervals. The field was then sprayed above the canopy at 58 days after transplanting. DAS = days after spraying. [b]In a column, means followed by a common letter are not significantly different at the 5% level. [c]Hoppers in the field were third- to fourth-instar nymphs of the second generation. [d]Hopper population was 90–95% adults. [e]Hopperburn.

Table 8. Acephate residues on leaves of IR22 rice treated with foliar sprays (0.75 kg a.i./ha) containing spreader-sticker. IRRI, 1977 wet season.

Treatment[a]	Residues[b] (ppm)		
	1 DAT	5 DAT	10 DAT
Acephate	19.5 b	4.3 cd	0.09 cd
Acephate + Adhesol	26.7 b	21.3 a	0.11 bcd
Acephate + Triton B-1956	37.2 ab	7.5 bc	0.08 cd
Acephate + Tenac	38.2 ab	12.6 b	0.14 bcd
Acephate + Citowett	51.2 a	7.8 bc	0.34 a
Control	n.d. c	n.d. c	0.00 d

[a]Spreader-sticker applied at concentration of 0.5%. [b]Figures are averages of four replications. A 27-mm rain occurred at 8 days after treatment (DAT). n.d. = none detected (< 0.005 ppm). In a column, means followed by a common letter are not significantly different at the 5% level.

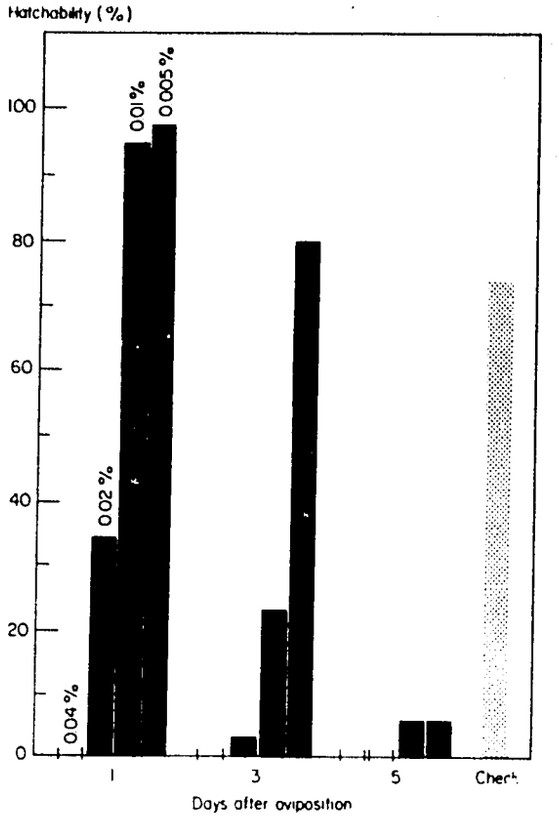
spraying. Older eggs were most susceptible to the insecticide.

At the 0.005% concentration, egg hatch decreased from 96% 1 day after oviposition to 5% at 5 days (Fig. 2). The same trend occurred, but less severely, in the triazophos-treated plants.

Results of ovicidal studies of the WBPH and of the BPH were similar. Again carbofuran's ovicidal activity was highest, but the WBPH eggs were more susceptible to methyl parathion than to triazophos.

Carbofuran granules applied to paddy water also had strong ovicidal activity against BPH eggs.

Ultra-low-volume (ULV) application. Farmers generally apply much less than the recommended volume of foliar spray insecticide because it is laborious to carry the recommended amount. The hand-held, battery-operated ULV applicator applies from 1 to 2 liters of concentrated insecticide dispersed in small droplets (about 80μ) to 1 ha. The ULV applicator was tested to determine vertical and horizontal distribution of spray droplets. In initial studies, the panicles received the most insecticide and the stems only a small amount (Table 10). Further studies are being conducted to determine the effect of droplet size and rice growth stage on droplet distribution to identify droplet sizes that reach the base of the plant, where the BPH feeds.



2. Comparative hatchability of brown planthopper eggs as affected by concentration of carbofuran and age of eggs at application time.

Table 9. Ovicidal activity of insecticides applied as 0.04% foliar sprays on plants with brown planthopper eggs. IRRI greenhouse, 1977.

Insecticide	Egg hatch (%)
Metalkamate	99 a
Propoxur	98 a
BPMC	90 ab
MIPC	88 ab
Dimethoate	83 b
Methyl parathion	61 c
Triazophos	37 c
Carbofuran	0 d
Control	96 a

[a]Applied 1 day after oviposition. [b]All means followed by a common letter are not significantly different at the 5% level.

Paddy water application (*Entomology*). Granular formulations of insecticides were tested in the greenhouse against three hopper

Table 10. Distribution of carbaryl residues on the plant when insecticide was applied with a battery-operated ultra-low-volume (ULV) applicator.[a] IRRI, 1977.

Plant parts	Residue (ppm) of carbaryl sprayed from distance of	
	3 m	5 m
Panicles	690	750
Leaves	90	20
Stems	2	1

[a]About 2 liters of Sevin carbaryl 80% oil formulation/ha was applied with a Union Carbide ULV applicator.

Table 11. Activity of granular insecticides applied in paddy water at 0.5 kg a.i./ha for brown planthopper (BPH), green leafhopper (GLH), and whitebacked planthopper (WBPH) control. IRRI greenhouse, 1977.

Insecticide	Activity[a]		
	BPH	GLH	WBPH
Aldicarb	+	+	+
Bendiocarb	+	+	+
BPMC	+	+	+
Carbofuran	+	+	+
Diazinon	+	+	+
FMC 27289	+	+	+
HOE PFL 812	+	+	+
Metalkamate	+	+	+
Oftanol	+	+	+
Triazophos	+	+	+
Cytrolane	–	+	+
FMC 35001	–	+	–
Padan	–	–	–

[a]Effective (> 80% mortality) = +; not effective = –.

species and the striped stem borer. The new compounds bendiocarb, FMC 27289, HOE PFL 812, and Oftanol were effective against the three hopper species (Table 11).

In greenhouse studies only the application to paddy water of Miral granules effectively controlled the striped stem borer (Table 12).

In a field evaluation, AC 64475, Miral, carbofuran, diazinon, and ethoprop provided varying degrees of whorl maggot control (Table 13). All, except diazinon, controlled the stem borer. Although carbofuran treatment resulted in low mortality of the striped stem borer in the greenhouse (Table 12), it was effective in the field study where the yellow stem borer predominated (Table 13).

Table 12. Paddy water application of granular insecticides at the rate of 0.5 kg a.i./ha for striped stem borer control. IRRI greenhouse, 1977.

Insecticide	Mortality[a] (%)			
	1 DAT	5 DAT	10 DAT	20 DAT
Miral 3G	100 a	100 a	100 a	26 a
Carbofuran	53 b	30 b	8 d	10 bc
Cytrolane 3G	45 b	40 b	17 cd	30 a
Metalkamate 3G	31 bc	35 b	18 bcd	18 ab
FMC 27289 2.5G	29 bc	18 b	35 b	24 a
Acephate 3G	9 cd	24 b	17 cd	25 a
FMC 35001 2.5G	6 cd	35 b	19 bcd	23 a
Oftanol 5G	1 d	41 b	25 bc	36 a

[a]Av. of 4 replications, each consisting of 20 freshly hatched larvae placed on treated cut stems of rice. Mortality was determined 48 hours after larval infestation. In a column, means followed by a common letter are not significantly different at 5% level. DAT = days after treatment.

Combinations of acephate with various granular insecticides were tested in the greenhouse to determine any synergistic effect, as would be indicated by increased BPH and GLH control. None had such effect indicated by prolonged residual activity. Instead, the acephate-diazinon combination had less residual activity against GLH than acephate alone.

Root-zone application (*Entomology*). *Application as granules.* Among test insecticides applied to the root zone as granules at 0.5 kg a.i./ha, only carbofuran, FMC 27289, FMC 35001, and bendiocarb effectively controlled all three hoppers (Table 14). Carbofuran, FMC 27289, and bendiocarb had the longest residual activity, providing at least 80% control at 14 days after treatment (DAT). Cartap, diazinon, hosthathion, gamma-BHC, metalkamate, and Oftanol were ineffective against the three hoppers.

Liquid band injection. The effectiveness of several insecticides applied by the liquid band injector was tested in the field. All insecticides provided some whorl maggot control (Table 15). Carbofuran, FMC 35001, and cartap controlled the stem borer. Carbofuran and FMC 35001 were most effective against BPH. Carbofuran, FMC 35001, and cartap controlled leaf folders at 82 DT.

Root coat. Perlite (a compound high in silica content) is a dapog (method of raising seed-

Table 13. Evaluation of granular insecticides for control of whorl maggot and stem borer.[a] IRRI, 1977 wet season.

Insecticide[b]	Whorl maggot damage[c]		Deadhearts[d] (%)	
	22 DT	35 DT	40 DT	60 DT
AC 64475	0 a	0 a	0.1 a	2.0 ab
Miral	2 b	2 b	0.0 a	1.2 a
Carbofuran	3 b	2 b	0.0 a	0.8 a
Diazinon	3 b	2 b	0.5 bc	10.9 c
Ethoprop	3 b	2 b	0.2 ab	2.8 b
Acephate	5 c	3 c	1.0 cd	10.9 c
Bendiocarb	6 d	4 d	1.7 de	10.0 c
BPMC	6 d	5 e	2.8 e	12.0 c
Metalkamate	8 e	5 e	1.8 de	9.7 c
Control	8 c	7 f	5.5 f	11.2 c

[a]The yellow stem borer *Tryporyza incertulas* was a predominant species. In a column, means followed by a common letter are not significantly different at the 5% level. [b]Applied at 5, 25, 52, and 85 days after transplanting (DT) at 1.0 kg a.i./ha. [c]Based on a scale of 0–9: 0 = no damage; 9 = > 50% of leaves damaged. [d]Primarily due to the yellow stem borer.

Table 14. Activity of granular insecticides applied at 0.5 kg a.i./ha to the root zone of rice to control the brown planthopper (BPH), green leafhopper (GLH), and whitebacked planthopper (WBPH). IRRI greenhouse, 1977.

Insecticide	Activity[a]		
	BPH	GLH	WBPH
Carbofuran	+	+	+
FMC 27289	+	+	+
FMC 35001	+	+	+
Bendiocarb	+	+	+
Aldicarb	–	+	+
BPMC	–	+	+
Cytrolane	–	–	+

[a]Effective (> 80% mortality) = +; not effective = –.

lings) medium made from volcanic ash. It sticks to seedling roots dipped in a suspension of it in water. Flowable carbofuran was added to the perlite suspension and the treatment was compared with that of carbofuran granules in gelatin capsules. In greenhouse tests, 0.15 kg a.i./ha in perlite provided immediate BPH control at 1 DT, but residual activity was less than that of granules in capsules applied at 2 kg a.i./ha near the roots (Fig. 3). When additional insecticides were further tested, only carbofuran controlled BPH for 14 days but several others controlled the GLH.

Seedlings growing in the perlite and ordinary dapog were soaked in a carbofuran solution both overnight and for only a short time just before transplanting. At the low rate of 0.15 kg a.i./ha carbofuran gave poor control of whorl maggot, stem borer, BPH, and GLH.

Soil incorporation. Incorporation of granules at the last harrowing is a practical root-zone application method. Soil incorporation was compared with liquid band injection into the root zone and with several paddy-water broadcast and foliar spray treatments (Table 16). Soil incorporation of carbofuran was better than the other treatments in controlling whorl maggot, but was as effective in controlling stem borers and virus vectors. It did not control BPH, partly because the BPH is resistant to the insecticide. But unlike foliar sprays, it did not cause a BPH resurgence. Profit was highest when carbofuran at 1.0 kg a.i./ha was incorporated into the soil.

Carbofuran residues in rice grain (*Entomology*). Four application methods —

Table 15. Root-zone application with the liquid band injector of some promising compounds for the control of rice pests.[a] IRRI, 1976–77 dry season.

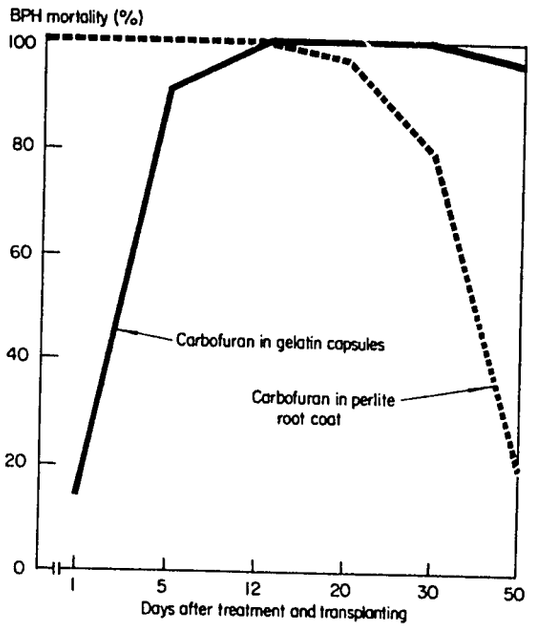
Treatment[b]	Whorl maggot damage[c] 31 DT	Deadhearts (%) 41 DT	BPH (no./4-linear-m row) 40 DT	BPH (no./4-linear-m row) 68 DT	Leaves damaged (%) by leaf folder 82 DT	Yield (t/ha)
Carbofuran 2 F	3.6 ab	1.2 ab	15 abcd	924 ab	13 a	2.2 ab
FMC 35001	4.0 bc	1.1 ab	10 ab	1163 abc	23 a	2.0 ab
Chlorpyrifos	5.7 cde	3.6 c	27 abcd	3142 bc	57 bc	1.7 ab
BPMC	5.7 cde	4.6 c	20 abcd	2105 abc	63 c	2.2 ab
Cartap	5.3 bcde	1.5 b	22 abcd	4435 c	30 ab	1.8 ab
Control	9.0 f	5.2 c	53 d	1233 abc	83 c	1.7 ab

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]All insecticides were applied 3 days after transplanting (DT) at 0.5 kg a.i./ha. [c]Based on a scale of 0–9: 0 = no damage; 9 = > 50% of leaves damaged.

soil incorporation, liquid band injection, broadcast, and foliar spray — were tested to determine their effect on residues in whole rice grain. Residues in all treatments, except the extremely high rate of six broadcast applications at 14-day intervals, were below the accepted levels (Table 17). For the high rate, the combined uncorrected concentration of residues of carbofuran and 3-hydroxycarbofuran (on which the US Environmental Protection Agency tolerance of 0.20 ppm is based) was 0.46 ppm. However, there appears to be little danger of residues at the rates and with the methods that most farmers use to apply carbofuran to rice.

Insecticide resistance (*Entomology*). In 1977 carbofuran failed to control the BPH at IRRI. In laboratory studies, a susceptible greenhouse strain and a field strain were compared to determine if resistance to carbofuran had developed. Additional studies on carbofuran and several other insecticides were conducted to determine the LD_{50} (lethal dosage required to kill 50% of test insects) values for the two strains.

The responses of the two strains in the con-



3. Mortality (%) of brown planthopper (BPH) caged on Taichung Native 1 rice plants treated with gelatin capsules in the root zone (2 kg a.i. carbofuran/ha) and those soaked for 16 hours in a perlite root-coat mixture (0.15 kg a.i. carbofuran/ha) prior to transplanting. IRRI greenhouse, 1977.

Table 16. Effects of frequency, rate, and method of insecticide application on the control on rice pests in variety IR22.[a] IRRI, 1977 dry season.

Treatment[b]	Times (no.)	Rate (kg a.i/ha)	Whorl maggot damage[c] 29 DT	Dead-hearts (%) 60 DT	Virus (%) 60 DT	BPH (no./10-linear-m row) 61 DT	BPH (no./10-linear-m row) 78 DT	Hopper-burn (%) 92 DT	Yield (t/ha)	Net income[d] (US$)	Income change[e]
Carbofuran (SI)	1	1.0	1 ab	1.54 bc	0.2 a	135 a	1,584 a	14 ab	3.669 a	476	238
Carbofuran (SI)	1	2.0	0 a	0.51 a	0.0 a	144 a	2,329 a	16 ab	3.646 a	432	194
Carbofuran (RZ)	1	1.0	3 c	2.01 c	0.2 a	189 a	3,461 a	0 a	3.150 a	404	166
Carbofuran (RZ)	1	2.0	2 b	0.73 ab	0.6 ab	245 a	2,802 a	21 ab	3.520 a	415	177
Carbofuran (B_{14})	6	1.0	4 cd	0.97 ab	0.9 ab	293 a	5,098 ab	13 ab	3.493 a	294	56
Carbofuran (B_{20})	4	1.0	5 d	0.81 ab	1.1 ab	261 a	1,744 a	4 a	3.302 a	329	91
Carbofuran (B_{20})	4	2.0	4 cd	0.46 a	0.8 ab	181 a	3,500 a	25 ab	3.453 a	236	−2
Decamethrin (F_{14})	6	0.05	4 cd	0.73 ab	0.5 ab	2447 b	78,908 c	100 c	1.471 c	169	−69
Methyl parathion (F_{20})	4	0.75	8 e	0.93 ab	2.2 b	350 a	22,276 bc	51 b	2.271 b	276	38
Carbofuran (F_{20})	4	0.50	7 e	1.16 abc	1.4 ab	1216 b	29,965 c	97 c	1.934 bc	166	−72
Control		9.0	9 f	4.93 d	12.5 c	264 a	4,812 ab	8 ab	1.643 c	238	—

[a]In column, means followed by a common letter are not significantly different at the 5% level. [b]SI = soil incorporation, RZ = root zone with liquid band applicator, B_{14} = broadcast every 14 days, B_{20} = broadcast every 20 days, F_{14} = foliar spray application every 14 days, F_{20} = foliar spray application every 20 days. [c]Based on a scale of 0–9: 0 = no damage; 9 = > 50% leaves damaged. DT = days after transplanting. [d]Net income = value of rice at US$0.14/kg − cost of insecticide + labor. Cost of insecticide: carbofuran 3% granule = US$14.92/0.5 kg a.i.; methyl parathion = US$5.82/liter; decamethrin = US$2.58/liter; carbofuran 2F = US$9.19/liter. [e]Income change = net income in treatments − income in control.

tact toxicity study and of those feeding on plants in paddy water that had been treated with carbofuran granules indicated that the field strain was resistant to carbofuran (Table 18). Rates as high as 6 kg a.i./ha were required to control 98% of the field strain while only 1 kg/ha killed 100% of the susceptible greenhouse strain. LD_{50} values of carbofuran indicated an estimated resistance ratio of 7 (Table 19). There was no resistance to new insecticides such as N 3727, A 47171, and A 47170, which had not been used at IRRI. Females and males differed little in resistance.

The susceptibility of the three BPH biotypes to six insecticides applied by direct contact spray with Potter's spray tower was determined. Four insecticides gave lower mortality readings for biotype 1 than for biotype 2 or 3 (Table 20).

Brown planthopper resurgence (*Entomology*). BPH populations in plots sprayed with certain insecticides have resurged at IRRI for several years. Previous IRRI annual reports suggested that resurgence was caused by the destruction of natural enemies or by the production of lush growth that was attractive to the insects. In 1976, resurgence occurred in plots that regularly received carbofuran granules in paddy-water application. Plots that received no insecticides were undamaged, but treated plots were completely hopperburned. In 1977 field and greenhouse experiments were conducted to determine the causes of resurgence.

Field studies were conducted to determine the effect on resurgence of various methods of carbofuran application. In one experiment BPH numbers were higher with three foliar sprays than with three broadcast applications

Table 17. Residues of carbofuran and 3-hydroxycarbofuran in whole grain (rough rice) of IR22 rice plants[a] treated by different application techniques. IRRI, 1976–77.

Treatment[b]	Residues[c] (ppm)	
	Carbofuran	3-hydroxy-carbofuran
Soil incorporation	0.08	0.06
Root zone with liquid band applicator	0.08	0.02
Broadcast at 14-day intervals (6 times)	0.34	0.12
Broadcast at 20-day intervals (4 times)	0.11	0.05
Foliar spray at 20-day intervals (4 times)	0.04	0.02
Control	0.06	0.02

[a]The broadcast and foliar spray applications were begun 5 days after transplanting (DT). Flowering occurred at 70–80 DT, thus 1 of the broadcast treatments at 14-day intervals and 1 of the broadcast and foliar spray treatments at 20-day intervals were applied during the flowering period. All applications except the foliar spray which was applied at 0.5 kg were made at 1.0 kg a.i./ha. [b]Values were not corrected for percent recoveries (91% for carbofuran and 97% for 3-hydroxycarbofuran).

Table 18. Resistance of a field strain of the brown planthopper to carbofuran.[a] IRRI greenhouse, 1977.

Rate (kg a.i./ha)	Mortality (%)		
	Greenhouse strain[b]	Field strain[c]	Difference
	Contact toxicity[d]		
0.025	25 a	5 a	20**
0.050	68 b	9 a	59**
0.100	83 c	29 b	54**
0.250	100 d	56 c	44**
0.500	100 d	59 c	41**
	Paddy-water application		
0.5	67 a	21 a	46**
1.0	100 b	32 a	68**
4.0	100 b	77 b	23**
6.0	100 b	98 b	2 ns

[a]Means within a column, for each application method, followed by a common letter are not significantly different at the 5% level. [b]Cultured in the greenhouse for about 30 generations. [c]Collected from field plots that had received repeated applications of 2 kg a.i. carbofuran/ha over a 3-year period and reared in greenhouse culture cages for 4 generations. [d]Applied with Potter's spray tower.

Table 19. The LD_{50} value of insecticides applied topically to female and male brown planthoppers. IRRI laboratory, 1977.

Insecticide	Female			Male		
	LD_{50} (μg/g)			LD_{50} (μg/g)		
	Greenhouse strain[a]	Field strain[a]	ERR[b]	Greenhouse strain	Field strain	ERR
Carbofuran	0.14	1.05	7.50	0.25	1.78	7.12
Monocrotophos	0.65	3.50	5.38	0.49	2.00	4.08
Metalkamate	1.46	5.37	3.67	2.00	8.68	4.34
Methyl parathion	7.67	23.19	3.02	10.52	13.90	1.32
BPMC	1.95	5.29	2.71	2.89	11.80	4.08
MIPC	1.42	3.29	2.30	5.23	5.59	1.06
Endosulfan	3.09	5.94	1.92	5.12	12.46	2.43
Acephate	2.93	4.96	1.69	3.56	7.79	2.18
N 3727	28.90	32.43	1.12	41.46	43.41	1.04
Perthane	5.13	5.70	1.11	4.45	10.46	2.35
A 47171	4.07	4.07	1.00	6.66	5.81	0.87
A 47170	3.17	2.60	0.82	2.66	2.68	1.01

[a]The greenhouse strain was reared in the greenhouse for about 30 generations and the field strain for about four generations.
[b]Estimated resistance ratio $\frac{LD_{50} \text{ of field strain}}{LD_{50} \text{ of greenhouse strain}}$

Table 20. Contact toxicity of insecticides applied with Potter's spray tower at 0.04% concentration against three brown planthopper (BPH) biotypes. IRRI greenhouse, 1977.

Insecticide	Formulation[a]	Mortality[b] (%) of BPH biotype 1	2	3
Decamethrin	2.5 EC	93 a	97 a	90 a
Carbofuran	2. F	66 b	98 a	97 a
Metalkamate	30 EC	61 b	99 a	97 a
Acephate	75 SP	33 a	44 a	35 a
Diazinon	20 EC	20 b	46 a	41 a
Methyl parathion	50 EC	15 b	44 a	32 a

[a]EC = emulsifiable concentrate, F = flowable, SP = soluble powder. [b]Mortality readings were taken 48 hours after treatment; adjusted av. of 4 replications each consisting of 25 adult insects, using Abbott's formula. All means for each insecticide followed by a common letter are not significantly different at the 5% level.

or soil incorporation at planting (Table 21). However, the foliar-spray and soil-incorporation treatments produced no significant differences in number of the predator *Cyrtorhinus lividipennis*. In another trial, resurgence occurred in the second BPH generation at about 63 DT. Foliar sprays of methyl parathion caused the highest resurgence ratio and also the highest ratio of BPH to *C. lividipennis* (Table 22).

Additional studies were conducted to determine the resurgence caused by various insecticides applied as foliar spray. In one experiment, 25 insecticides were applied to a low-

Table 21. The influence of method of carbofuran application on resurgence of the brown planthopper (BPH) on variety IR22.[a] IRRI, 1977 wet season.

Treatment[b]	Rate (kg a.i./ha per application)	Insect counts[c] (no./hill at 47 DT) BPH (prey)	*C. lividipennis* (predator)	Prey: predator ratio (x:1)	Hopperburn (%) 61 DT
Soil incorporation once	1.0	1043 ab	49 b	21	4 a
Broadcast 3 times	1.0	1449 b	19 a	76	23 ab
Foliar spray 3 times	0.25	2498 c	42 b	59	71 c
Control		800 a	115 c	7	13 ab

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]Broadcast and foliar spray treatments applied at 20-day intervals beginning at 5 days after transplanting (DT). [c]Collected with a D-Vac suction machine (10 hills/replicate sampled 2 days after third treatment).

Table 22. Effects of method of carbofuran application on brown planthopper (BPH) resurgence and the predator *Cyrtorhinus lividipennis* population.[a] IRRI, 1977 dry season.

Treatment[b]	Rate (kg a.i./ha)	Applications (no.)	41 days after transplanting[c] BPH No.	BPH Resurgence ratio[e]	*C. lividipennis* (no.)	BPH: *C. lividipennis* ratio (x:1)	63 days after transplanting[d] BPH No.	BPH Resurgence ratio[e]	*C. lividipennis* (no.)	BPH: *C. lividipennis* ratio (x:1)
Root zone	1.0	1	250 a	1.1	4 ab	62.5	693 b	2.6	188 bc	3.7
Root zone	1.0	2	179 a	0.8	1 a	179.0	1368 b	5.1	66 a	20.7
Broadcast	1.0	2	207 a	0.9	8 b	25.9	623 ab	2.3	268 c	2.3
Broadcast	1.0	3	157 a	0.7	3 ab	52.3	721 b	2.7	106 bc	6.8
Foliar spray	0.25	3	111 a	0.8	27 c	6.7	1494 b	5.5	81 ab	18.4
Foliar spray (Methyl parathion)	0.75	3	258 a	1.2	23 c	11.2	2800 b	10.4	105 abc	26.4
Control			223 a		38 c	5.9	270 a	--	188 bc	1.4

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]Carbofuran was applied in all treatments except where indicated. Root-zone applications were made at 5 and 25 days after transplanting (DT); broadcasts at 5, 25, and 45 DT; foliar sprays at 5, 14, and 33 DT. [c]Insects were collected with a D-Vac suction machine 16 days after the second broadcast and foliar application. Number of BPH and *C. lividipennis* indicates population on a 4 linear-m row (16 hills at 25-cm spacing. [d]Insects were collected with D-Vac 18 days after third broadcast and foliar application. Sampling time coincided with the second BPH generation. [e]$\frac{\text{BPH in insecticide treatment}}{\text{BPH in untreated control plots}}$

land crop at 0.75 kg a.i./ha at 2-week intervals in the dry season. Only azinphos ethyl and triazophos caused significantly more hopperburn than the untreated control. But they did not reduce parasitism or predation of BPH eggs.

In an upland crop, methyl parathion sprays and granular carbofuran applications caused an increase of BPH and WBPH, but predator mortality did not appear to be a factor.

In a lowland experiment several insecticides applied as foliar spray caused resurgences, but predator counts at 14 days after the third application differed little among treatments, even though BPH increased substantially. In another trial in which the ratios of BPH to *C. lividipennis* were determined before and after the fifth application, an increased ratio was not directly related to percentage of hopperburn (Table 23).

After application of granular insecticides, the number of *C. lividipennis* decreased distinctly but that of BPH decreased little (Table 24). The treatments with Miral and carbofuran, which gave the highest BPH : *C. lividipennis* ratio at 56 DT (four days after insecticide application), also had the highest percentage of hopperburned area. Acephate, BPMC, and metalkamate which have never caused BPH resurgences, reduced *C. lividipennis* numbers least, producing a low prey:predator ratio.

After extensive field tests, it became evident that some insecticides have an adverse effect on the *C. lividipennis* population, which may be associated with resurgence. But there is no adequate evidence that the decreased *C. lividipennis* population causes the resurgences directly. Undetermined factors appear to be involved.

To gain more information on the causes of resurgences, a greenhouse study was conducted to eliminate the predator variable. It assumed that sublethal rates of insecticides directly on BPH stimulate reproduction, and regular sprays of insecticides affect plant characteristics. The result is increased reproduction when insects are placed on the plants. The stimulatory effect of resurgence-inducing insecticides was studied by spraying fifth-instar nymphs with insecticides at sublethal rates in a Potter's spray tower.

Insecticide spray concentration distinctly affected reproductivity when the sprayed BPH became adults. The fecundity of those sprayed with methyl parathion and cypermethrin increased as the insecticide concentration was reduced from 0.0004 to 0.0001% (Fig. 4). With FMC 35001 fecundity was highest at 0.0004%. The sex ratio and longevity of the progeny, however, were not affected.

In a foliar-spray experiment, TN1 plants received three 0.04% foliar sprays at weekly

Table 23. Effect of various insecticides applied as foliar spray at 0.75 kg a.i./ha on the population of the brown planthopper (BPH) and the predator *Cyrtorhinus lividipennis*. IRRI, 1977 dry season.

Insecticide	BPH:*C. lividipennis* (x:1) Before fifth spraying 61 DT	After fifth spraying 65 DT	Hopperburn[a] (%) 70 DT
Methyl parathion	2.2	3.8	91 b
Azinphos ethyl	2.3	6.7	63 b
Monocrotophos	2.9	11.5	53 b
BPMC	0.7	3.2	20 a
MIPC	0.9	2.0	18 a
Endosulfan	0.6	0.6	15 a
Metalkamate	3.2	1.7	15 a
Perthane	1.1	1.7	15 a
Acephate	0.7	5.9	5 a
Control	0.9	1.0	15 a

[a]Each insecticide was applied five times at 14-day intervals with the first spray at 5 days after transplanting (DT) and the fifth spray at 61 DT. [b]Means followed by a common letter are not significantly different at the 5% level.

Table 24. The ratio of brown planthopper (BPH) to the predator *Cyrtorhinus lividipennis* as affected by granular insecticide applications at 1 kg a.i./ha. IRRI, 1977 wet season.

Insecticide[a]	BPH:*C. lividipennis*[b] (x:1) 51 DT	56 DT	84 DT	Hopperburn[c] (%) 91 DT
Miral	12.4	650.0	12.4	67 b
Carbofuran	25.0	96.7	43.2	56 b
AC 64475	25.5	85.0	11.3	9 a
Diazinon	2.4	12.0	7.3	17 a
Ethoprop	2.5	9.0	5.6	1 a
Bendiocarb	2.8	9.0	2.0	0 a
Acephate	5.0	2.8	1.7	0 a
BPMC	1.8	1.8	1.8	0 a
Metalkamate	0.8	0.8	1.5	0 a
Control	2.8	1.1	1.6	0 a

[a]Insecticides were applied at 5, 25, 52, and 85 days after transplanting (DT). [b]Insects sampled with D-Vac suction machine on 10 hills/replicate. [c]In a column, means followed by a common letter are not significantly different at the 5% level.

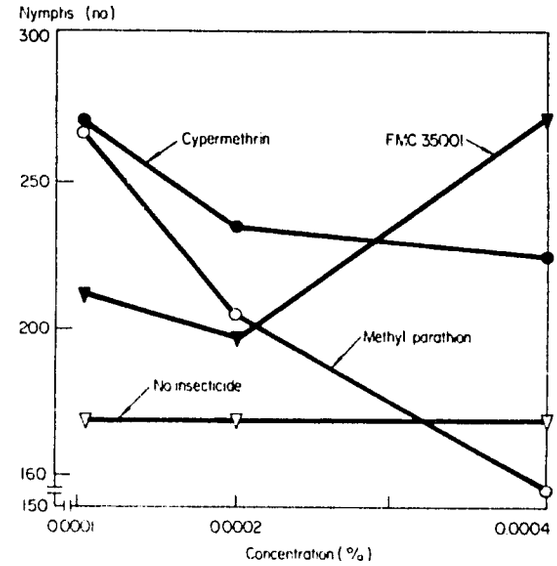
intervals. Female hoppers were allowed to feed and oviposit on plants 15 days after the last spraying. The hoppers on plants sprayed with decamethrin, diazinon, and methyl parathion were 181, 176, and 155% more fecund than those on the untreated control (Fig. 5). However, when the hoppers were exposed to treated plants for 7 days and then transferred to untreated plants, the population did not increase over that of the control.

Hoppers that fed on plants sprayed with decamethrin had shorter nymphal duration than hoppers on plants sprayed with methyl parathion or on control plants (Table 25). The ratio of female to male hoppers was higher on the decamethrin- and methyl parathion-treated plants than on the control.

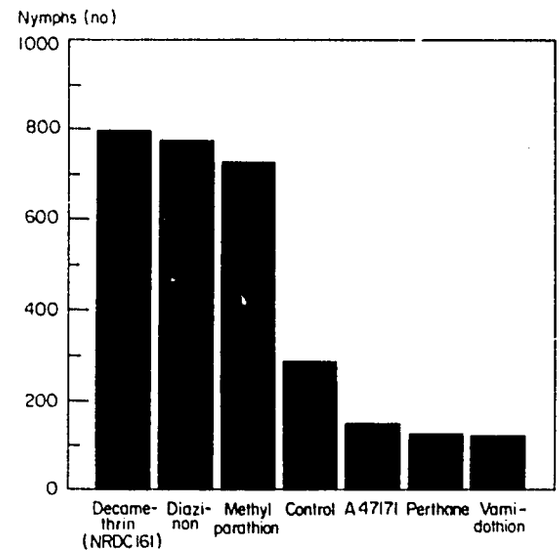
A study on the effect of number of foliar sprays on reproductivity indicated that the one-spray treatment had the greatest stimulatory effect (Table 26). Because the one-spray treatment had the highest nymphal population, it had the highest hopperburn rating. Decamethrin induced the highest reproduction and caused the most severe hopperburn.

The effect of insecticide sprays on plant growth and tillering was studied to determine the influence of those factors on increased reproduction on treated plants. Most insecticides increased tillering and several increased plant height (Table 27). In another experiment, aldicarb, carbofuran, and FMC 31768 applied twice as granules increased tillering and height. In treatments in which the tiller number was highest, the plant height was generally increased least and vice versa. Analysis of major and minor elements in sprayed plants showed that the quantities of copper and iron were higher in plants sprayed with certain insecticides but there appeared to be no relationship between the contents of copper and iron and resurgence. Investigations will continue.

Rice and fish culture (*Entomology*). In collaborative experiments conducted at the Central Luzon State University to determine the compatibility of various methods of carbofuran application with fish culture in rice paddies, granules broadcast after fish seeding killed



4. Effect of sublethal doses of insecticides, applied on 5th-instar nymphs with Potter's spray tower, on the reproductive rate of brown planthopper. Reproduction measured by number of nymphs produced by one female. IRRI, 1977.



5. The influence of insecticide sprays on the reproductive rate of brown planthopper. Insecticides applied on plants three times at 20, 30, and 40 days after transplanting at 0.76 kg a.i./ha (except decamethrin applied at 0.10 kg for the second 2 sprayings). Five female adults were placed on plants at 15 days after last spraying and allowed to oviposit for 7 days. IRRI, 1977.

Table 25. Influence of certain insecticides applied as foliar spray on the nymphal duration and sex ratio of *Nilaparvata lugens* on variety TN1. IRRI insectary, 1977.

Insecticide[a]	Rate (kg a.i./ha)	Total nymphal duration[b] (days)	Sex ratio (♂:♀)
Decamethrin (NRDC 161)	0.1	13.6 a	1:1.7
Methyl parathion	0.75	14.1 ab	1:1.7
Control		14.7 b	1:0.8
C.D (P = 0.05)		0.73	—

[a]Applied as foliar spray at 20, 30, and 40 days after planting at 5.0, 7.5, and 7.5 ml spray fluid/pot of 2 plants. [b]Assessed using newly hatched first-instar nymphs 15 days after last spraying. Mean of 16 nymphs/insecticide. Means followed by a common letter are not significantly different at the 5% level.

Table 26. Reproductive rate of and damage caused by brown planthoppers placed on plants receiving different numbers of foliar spray applications.[a] IRRI insectary, 1977.

Spray application[b]	Nymphs hatched[c] (no.)	Hopper damage rating[d]
0	321 c	3.7 c
1	498 a	7.0 a
2	377 b	4.3 b
3	381 b	4.3 b

[a]In a column, means followed by the same letter are not significantly different at the 1% level. Data are means of three insecticides. [b]Insecticides decamethrin, FMC 35001, and FMC 31768 were applied as foliar spray at 20 (1 application), 30 (2 applications), and 40 (3 applications) days after planting at 0.04% concentration at 5.0, 7.5, and 7.5-ml spray solutions/plant. [c]Result of 7-day oviposition by 5 females placed on plants 15 days after the last spraying. [d]Based on a scale of 0–9: 0 = plants dead. Rating taken at 20 days after the adult females were placed on treated plants.

Table 27. Effect of insecticides applied as 0.04% foliar spray on tillering and plant height of variety TN1.[a] IRRI greenhouse, 1977.

Insecticide[b]	Tillers[c] (no.)	Plant ht[c] (cm)
FMC 35001	45 a	107 c
Methyl parathion	38 b	107 c
Perthane	37 b	112 b
FMC 31768	36 b	116 a
Diazinon	36 b	115 ab
Decamethrin	35 c	118 a
Control	33 c	108 c

[a]In a column, all means followed by a common letter are not significantly different at the 5% level. [b]Applied as foliar spray at 30, 40, and 50 days after planting at 7.5, 10.0, and 12.5 ml spray fluid/replicate. [c]Mean at 31 days after first spraying.

Table 28. Insecticidal activity of carbofuran and a carbofuran metabolite, 3-hydroxycarbofuran, against the green leafhopper (GLH) and brown planthopper (BPH). IRRI greenhouse, 1977.

Insecticide[a]	Mortality[b] (%)							
	1 DAT		20 DAT		30 DAT		50 DAT	
	GLH	BPH	GLH	BPH	GLH	BPH	GLH	BPH
Carbofuran technical	60	30	100	100	100	100	100	100
3-hydroxy-carbofuran	40	30	100	83	100	30	48	2

[a]Applied in the root zone at 2.0 kg a.i./ha in gelatin capsules. [b]DAT = days after treatment.

the fish (1976 Annual Report). In the 1976–77 dry season, a foliar spray treatment at 192 g a.i./ha was applied 4 times, along with the single broadcast treatment before fish seeding; single root-zone treatments were applied before and after fish seeding. No treatment caused fish mortality. Residue analysis using gas liquid-chromatography indicated no measurable carbofuran residues in fish from any treatment. In studies of fish reared in paddies that received 1 kg a.i. carbofuran/ha incorporated into the soil, no detectable residues were found. The Philippine Government is widely testing the incorporation of carbofuran into the soil before fish seeding.

Carbofuran metabolism (*Entomology*). Studies have indicated that the parent carbofuran metabolized to 3-hydroxycarbofuran and 3-ketocarbofuran in the rice plant. Only the parent compound was analyzed in past IRRI residue studies. Greenhouse studies indicated that 3-hydroxycarbofuran has insecticidal activity against the GLH and BPH, but it was less than that of the parent compound (Table 28).

Degradation and fate of carbofuran (*Soil Microbiology*). The effectiveness against BPH of carbofuran granules broadcast on paddy water has recently decreased in IRRI trials. BPH damage in susceptible rice varieties has occasionally been more severe in plots that received regular broadcast applications for the past 4 years than in untreated plots.

Laboratory and field experiments were conducted to determine if decreased planthopper control could be attributed to rapid degradation of carbofuran through chemical or biological action after repeated applications.

Degradation in paddy water. In a study of carbofuran degradation in paddy water of untreated and often-treated rice fields, suit-

Table 29. Effect of autoclaving on degradation of carbofuran in paddy water. IRRI, 1977.

Incubation (days)	Values (μg/ml)			
	Untreated[a]		Treated[b]	
	Carbofuran	Carbofuran phenol recovered	Carbofuran	Carbofuran phenol recovered
	Nonautoclaved			
0	6.48	0.22	6.48	0.11
5	0.23	5.23	0.19	4.15
10	0.05	1.25	0.06	1.42
20	Tr[c]	1.01	Tr	1.11
	Autoclaved			
0	6.48	0.22	6.48	0.11
5	0.06	4.91	0.23	4.49
10	0.09	5.16	0.09	5.09
20	Tr	4.77	Tr	4.58

[a]Paddy water from plots with no history of carbofuran treatment. [b]Paddy water from plots on which carbofuran had been applied for 4 years. [c]Tr = trace.

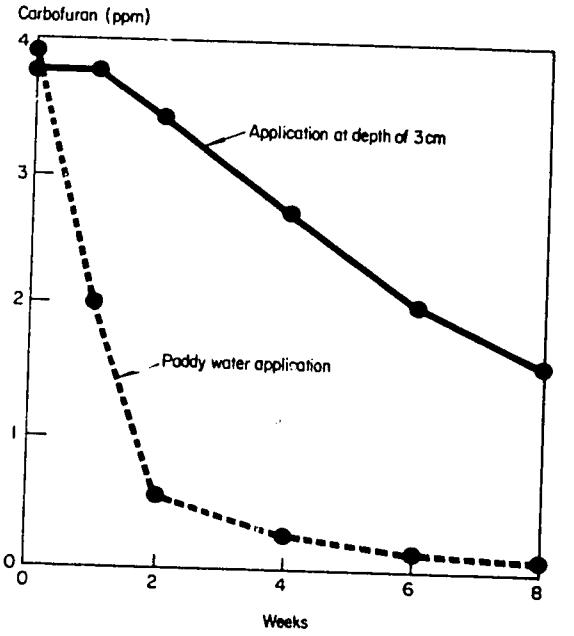
able aliquots of paddy water with aqueous carbofuran solution were incubated in the laboratory. The concentration of carbofuran decreased rapidly in about 5 days. Previous carbofuran applications did not influence the degradation rate. Carbofuran loss in paddy water was associated with the formation of hydrolyzed carbofuran phenol (Table 29). Autoclaving of paddy water did not affect carbofuran degradation but caused the accumulation of carbofuran phenol. Carbofuran degradation occurred in millipore-filtered paddy water and in paddy water treated with streptomycin sulfate. That suggests that carbofuran degradation in paddy water was mainly through nonbiological processes, but that degradation of carbofuran phenol was associated with microbiological properties.

Furthermore, when the pH of the paddy water was adjusted to levels ranging from 6.5 to 9.5, the carbofuran degradation rate related directly to initial paddy water pH: the higher the pH, the greater the insecticide loss. Therefore under realistic field conditions, common diurnal fluctuations of paddy water pH 7.5-9.5 can render the insecticide less persistent.

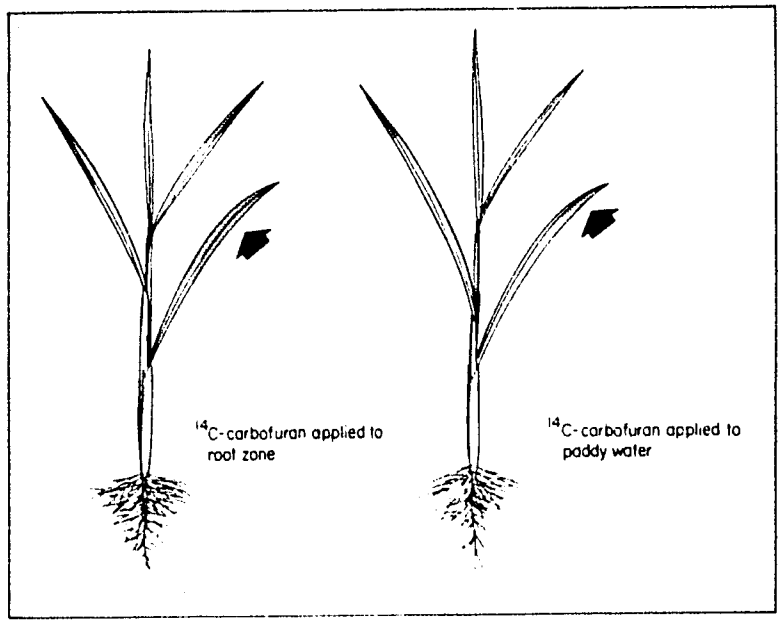
In a field study to determine any buildup effects on the degrading microbes, rate, carbofuran was applied to paddy water of both treated and untreated plots. Periodic analyses of carbofuran residues in paddy water and in soil revealed that repeated surface application of carbofuran did not influence degradation rate. But in soil, prolonged incubation in the laboratory showed that after only 3 weeks, degradation was more rapid in soil from the often-treated than in soil from untreated plots.

Carbofuran was degraded much more slowly when applied to flooded soil than when applied to paddy water.

Degradation in Philippine rice soils. Degradation of incubated carbofuran in flooded soils of Maahas clay (pH 5.9, O.M. 2.24%), Pila clay loam (pH 7.2, O.M. 2.13%), and Luisiana clay (pH 5.0, O.M. 2.96%) was studied. The soils were autoclaved to assess the role of microorganisms in degradation. Carbofuran was degraded in all three soils in the order of Maahas clay > Pila clay loam > Luisiana clay. Carbofuran phenol was the major metabolite detected, but its recovery varied widely among the soils. Autoclaving the soils retarded degradation, which suggests the role of microorganisms.



6. The effect of different methods of application on the persistence of carbofuran in flooded Maahas soil. IRRI, 1977.



7. Distribution of radioactivity (shaded area) in rice plant. Seedlings were grown for 10 days and then exposed to X-ray film. IRRI, 1977.

Application methods and carbofuran persistence in flooded soils. Root-zone application may increase uptake of agricultural chemicals from the root vicinity and protect them from evaporation, surface runoff, and other losses.

Two methods, introduction into paddy water and placement about 3 cm below the surface of flooded soil, were tested in the laboratory to assess the relative persistence of aqueous carbofuran. Carbofuran applied by the latter method was significantly more persistent (Fig. 6).

Adsorption-desorption studies. ^{14}C-carbofuran was used to study the adsorption of carbofuran in soil and the influence of ammonium sulfate and urea on the desorption process. Carbofuran adsorption in different soils followed the order Maahas clay > Pila clay loam > Luisiana clay. The addition of ammonium sulfate to soil released more carbofuran into the soil solution than urea did. But both fertilizers displaced insecticides. Such a displacement into the soil solution may provide more insecticide for removal by the plant or for decomposition.

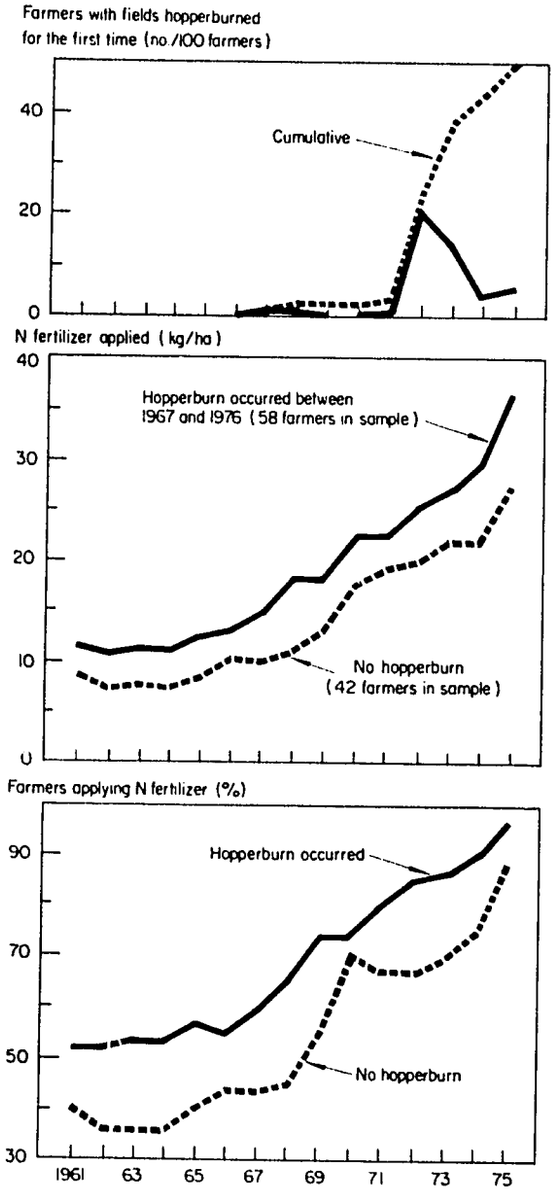
Absorption, metabolism, and loss of carbofuran in rice. The absorption of ^{14}C-carbofuran applied to paddy water or to the rice root zone was studied in the greenhouse. Root-zone application resulted in increased carbofuran uptake and persistence in the soil. Carbofuran in the plant was partly metabolized to carbofuran phenol, 3-ketocarbofuran 3-hydroxycarbofuran, and their phenols. An autoradiograph of the rice plant showed that carbofuran and its breakdown products tend to move and accumulate in the tips of older leaves (Fig. 7).

Isotope studies were conducted to determine the carbofuran losses from the rice plant. Rice plants were grown in culture solution (pH 5.5) containing ^{14}C-carbofuran. The culture solution and the plants were assayed periodically. A significant amount of radioactivity absorbed by the rice plant was not accounted for, an indirect indication that carbofuran may escape into the atmosphere from the leaves.

CULTURAL CONTROL OF BROWN PLANTHOPPER

Entomology Department

Many environmental factors, including those that man manipulates for agricultural pur-

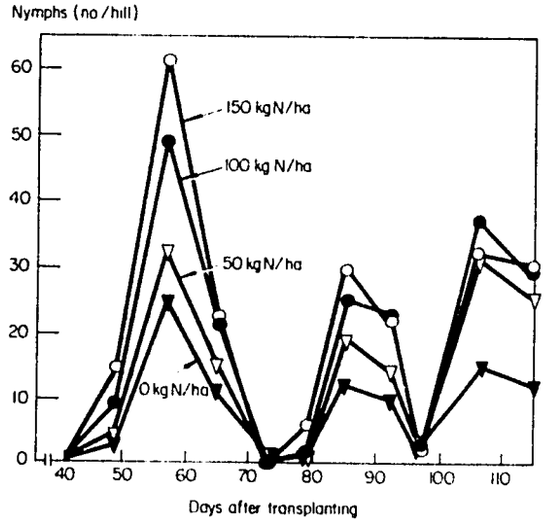


8. Hopperburn from the brown planthopper *Nilaparvata lugens*, and nitrogen (N) fertilizers applied in lowland rice fields during the wet season, according to farmer interviews in 1977. Laguna province, Philippines.

poses, affect insect populations. Several new cultural practices in rice growing may cause insect outbreaks, or, at least, increase pest problems. One hundred farmers were interviewed in 22 towns in Laguna province, Philippines, to determine trends in such practices. Farmers recall definite increases over the last 15 years in the use of improved varieties, the use of fertilizers and insecticides, and double-cropping. Practices changed similarly in wet and dry seasons. Hopperburn incidence was a serious problem between 1972 and 1975, especially in the 1972 wet season when 55 out of 260 ha were hopperburned (Fig. 8). Light-trap catches of BPH at IRRI increased between 1966 and 1973 (1974 annual report). There may be causal relationships between some cultural practices and BPH abundance and crop damage. Insecticide use, however, may not have been a cause of BPH outbreaks, but rather a temporary solution to them.

Fertilization practices appeared to correlate with the extent of the BPH problem. More farmers who applied fertilizer suffered losses from hopperburn. Moreover, farmers whose fields had hopperburn tended to apply higher doses of N fertilizer (Fig. 8).

Several experiments on the relationships between cultural practices and pest populations were conducted. Many workers have assumed, and a few have demonstrated, that adding nitrogen fertilizers to a rice crop increases the BPH density. In an experiment where a range of fertilizer rates (0 to 150 kg



9. Density of brown planthopper *Nilaparvata lugens* nymphs on rice variety IR22 treated with different levels of ammonium sulfate fertilizer in two doses: 60% at 7 days after transplanting and 40% at 42 days. IRRI, 1971 wet season.

Table 30. Density of nymphs and adults of brown planthopper *Nilaparvata lugens* at peaks of the first two generations on rice selection IR1917-3-17, in which the tiller number per hill was artificially regulated. IRRI greenhouse, 1977.

Tillers[a] (no./hill)	Planthoppers[b] (no./cage)			
	35 DI	42 DI	63 DI	70 DI
4	321 a	2079 a	445 a	1121 a
8	786 b	4087 b	928 b	1942 b
12	1057 b	5245 b	1029 b	2104 b

[a]Plants were 60 days old and were changed every 3 weeks. [b]In a column any two means followed by the same letter are not significantly different at the 5% level. Initial population was 3 pairs of adults/cage. DI = days after infestation.

N/ha) was applied, about 100 kg N/ha was needed to increase the pest density significantly above that of the control, but the effect lasted for only a short period in the first pest generation (Fig. 9). However, the density per tiller and per hill at population peaks on plants treated with 150 kg N/ha was more than twice that on untreated plants. Fertilization affected the tiller density per hill only slightly, and so fertility affected the BPH population primarily through factors other than higher tiller production. But in a similar 1977 dry season experiment, application of up to 120 kg N/ha did not significantly increase pest density. Therefore, moderate increases or decreases in fertility do not seem to significantly affect BPH abundance in the field.

Field and greenhouse experiments in 1977 confirmed the earlier finding (1976 Annual Report) that new, high-tillering varieties did not have higher BPH infestations than older, low-tillering varieties. But when the insect densities on hills of one variety in which the tiller number was artificially regulated in different treatments were compared, insects were more abundant on hills with higher tiller number, especially in the greenhouse. Statistically significant differences in pest density, however, were found only between tiller densities of 4 and 8 or more tillers/hill (Table 30).

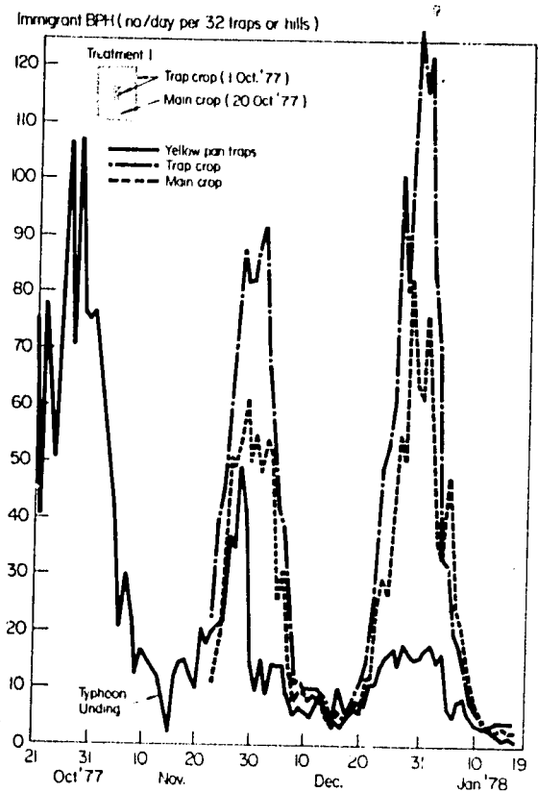
In spacing experiments in the field, insect density and tiller density per hill were positively correlated (Table 31). Since bigger hills of rice use more space, a constant tiller number per square meter might be expected. Nevertheless, number of tillers per square meter decreased somewhat when hill density decreased. Insect and tiller densities per square meter can sometimes be positively correlated. The number of insects per tiller may even increase disproportionately at high plant densities (1972 Annual Report). But for most practical spacings and hill densities, the number of insects per tiller was affected little (Table 31). Therefore it is doubtful that BPH can be controlled by changing the tiller density per hill or the plant spacing in transplanted rice.

To determine if weedy fields have higher BPH densities than weeded ones, two experiments compared planthopper densities in plots differing in weeding practices. In one experiment, no relationship between weeds or weeding and insect abundance was found. But in the other, planthopper density was lower where weeding intensity was high.

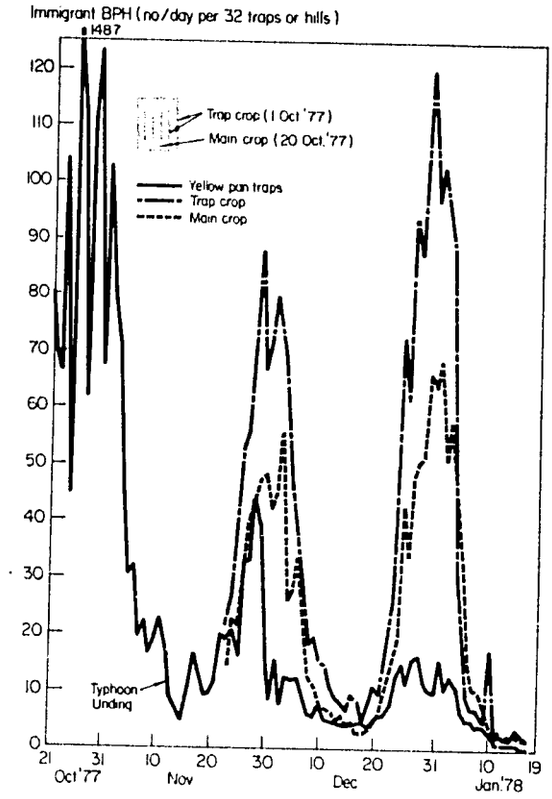
Table 31. Density of nymphs of brown planthopper *Nilaparvata lugens* on rice selection IR1917-3-17 transplanted at various spacings and treated with insecticides.[a] IRRI, 1976 and 1977.

Spacing (cm)	Hills (no./m²)	1976 wet season at 56 DT			1977 dry season at 63 DT		
		Tillers (no./m²)	Planthoppers		Tillers (no./hill)	Planthoppers	
			No./m²	No./tiller		No./hill	No./tiller
40 × 40	6	188 a	204 a	1.1 a	34 a	408 a	12 ab
40 × 20	12	309 bc	675 b	2.1 a	22 b	357 a	16 ab
20 × 20	25	385 c	658 b	1.6 a	17 c	237 ab	14 ab
40 × 5	50	256 ab	680 b	2.8 a	7 d	117 b	18 ab
20 × 5	100	374 c	1,438 b	3.8 a	5 de	48 c	11 a
5 × 5	400	690 d	25,465[b] c	36.4 b	2 e	43 c	25 b

[a]To increase planthopper density, diazinon granules at 1 kg a.i./ha were applied at 7 and 28 days after transplanting (DT), and methyl parathion was sprayed (0.75 kg a.i./ha) biweekly beginning at 42 DT. In a column any two means followed by the same letter are not significantly different at the 5% level. [b]Hopperburned within 1 week.



10. Trends in immigration of macropterous brown planthoppers in a 10- × 21-m rice field with yellow pan traps, a trap crop and a main crop of the selection IR1917-3-17. Hopper numbers were based on daily catches in traps and visual counts on plants. IRRI, 1977–78.

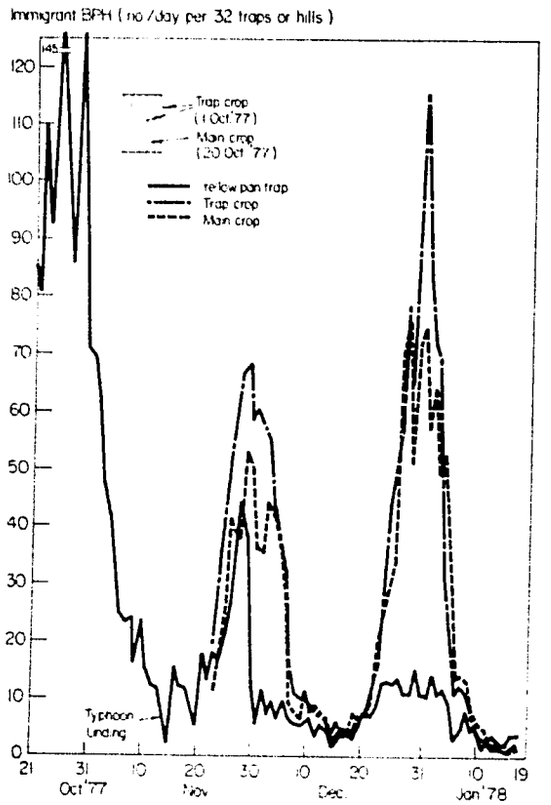


11. Trends in immigration of macropterous brown planthoppers in a 10- × 21-m rice field with yellow pan traps, a trap crop and a main crop of selection IR1917-3-17. Hopper numbers were based on daily catches in the traps and visual counts on plants. IRRI, 1977–78.

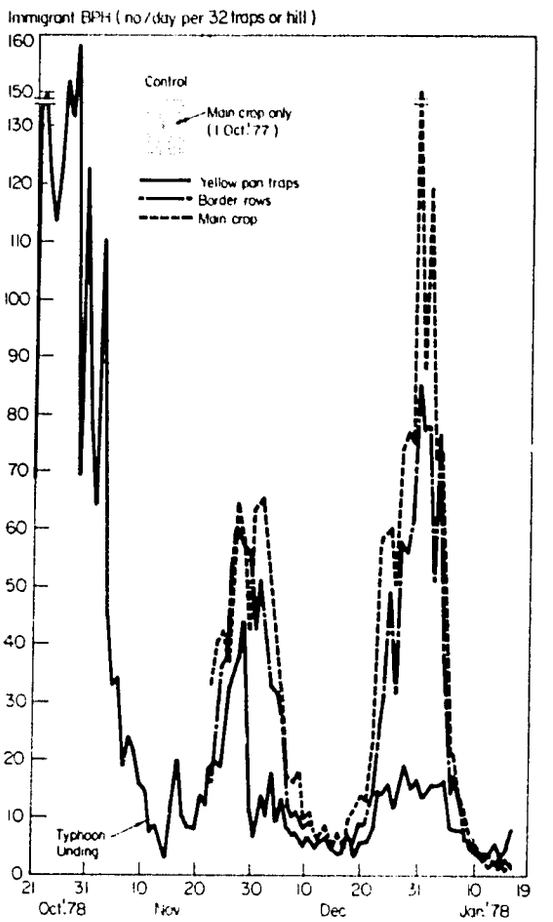
Monitoring field colonization. As a basis for selecting efficient prophylactic and control measures for the BPH, information was obtained on its mode of colonization in rice fields. A simple yellow pan oil-water trap (YPT) was developed to monitor the immigrant, colonizing macropterous hoppers. The traps were made from lightweight, yellow plastic cans of 1-gallon capacity. Twenty days after transplanting (DT), each trap was filled with 1 liter of water and 2 ml of paraffin oil. The traps were staked equidistant at 2 m around the border of the test plots on the IRRI farm. As colonizing hoppers flew into the rice fields, they were attracted to the yellow traps and caught in the oily water surface. Every morning trapped hoppers were removed, counted, and compared with the number visually observed on the rice plants. The biggest YPT catches were those at 20 to 30 DT, followed by those at 55 to 60 DT (Fig. 10–13). At 80 to 100 DT, the YPT catches were low, probably because of the increased shading of the traps and the fully grown rice crop's greater tendency to attract the BPH.

In about 3 months, 35,788 macropterous BPH were caught in 512 YPT in a 0.352-ha rice field. Other hoppers were trapped: WBPH, 5,687; GLH, 4,336; white leafhoppers, 2,100; and zigzag leafhoppers, 1,809. A few mirid predators (2,146) of hopppers were caught.

In a 10-day catch of 4,296 BPH, both males and females were almost equally attracted to the YPT (o:o = 1:1.22). The ratio of gravid females to virgin hoppers was 1:1.44.



12. Trends in immigration of macropterous brown planthoppers in a 10- x 21-m rice field with yellow pan traps a trap crop, and a main crop of the selection IR1917-3-17. Hopper numbers are based on catches in the traps and visual counts on plants. IRRI, 1977–78.



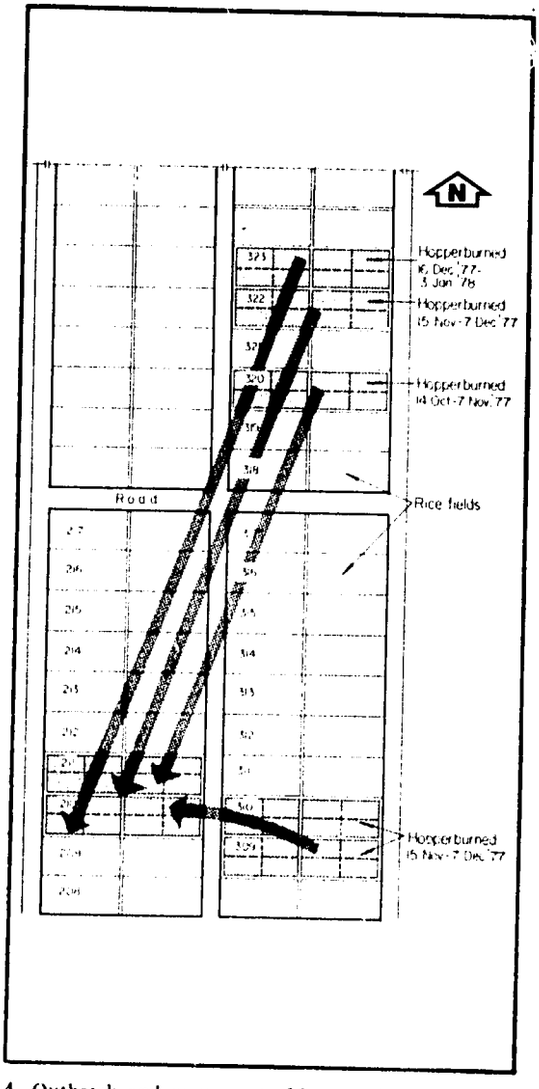
13. Trends in immigration of macropterous brown planthoppers in a 10- x 21-m rice field with yellow pan traps and IR1917-3-17 crop planted on one date. The hopper numbers were based on catches in traps and visual counts on plants. IRRI, 1977–78.

The colonizing BPH were not numerous enough to warrant chemical control until about 90 DT, when more hoppers began to arrive on the plants than in the traps. A single perthane spray (5 ml/liter) gave good control.

The maximum number of macropterous hoppers was caught when the wind was blowing from the northeast and east at 1 to 2 m/second. A survey of the area surrounding the test plots showed that five 0.25-ha rice fields were hopperburned. Three fields about 0.5 km northeast were hopperburned from October 1977 to early January 1978, and two fields on the east side were hopperburned between November and December 1977 (Fig. 14). BPH trap catches were negligible during strong typhoon gales (5 m/second) from the southeast on 13 November, but GLH catches were remarkably high. That indicates that BPH and GLH infestations occurred in different locations and that probably the BPH disperse and colonize the fields in relatively calm air conditions.

The YPT require little maintenance. After cleaning they can be reused.

Trap crop. The cultural concept of a trap crop for BPH control was tested. IR1917-3-17, a selection that is highly susceptible to BPH, was used as trap crop to save a main crop of the same selection from BPH. The trap crop was transplanted on 1 October



14. Outbreak and movement of brown planthopper in a lowland area. IRRI, October 1977 to January 1978.

1977, 20 days before the main crop. About a fourth of the crop area in three different trapped fields was planted to a trap crop (Fig. 10, 11, 12). The entire control crop was transplanted on 1 October (Fig. 13). The BPH nymphs and adults were surveyed daily in the trap crop, main crop, and control plots.

In all the three fields, the number of colonizing hoppers was much smaller on the main than on the trap crop, but at about 75 DT, hoppers arrived equally on both crops. In the control plots, where border and middle rows were planted simultaneously, more hoppers arrived on the middle than on the border rows.

Because immigrant hopper population was not high, insecticidal control on the trap and control crops was delayed until about 95 DT. But the count of immigrant hoppers at all stages remained so low on the main crop that no insecticidal control was needed. Because the main crop was not treated with insecticides, the natural enemies of the BPH were also conserved; spiders and other predators and parasites were found in almost all the hills examined. Natural enemies consumed the BPH nymphs that hatched there. No successive generations of BPH developed in the trapped fields.

The trap crop was economical in insecticide and labor use since only 25% of the total area in the trapped fields was treated with insecticides. In the control plot, blanket insecticidal treatment was necessary to prevent pest damage.

Although no insecticide was applied on the main crop, infestation levels of other insects were no higher than those on the trap crop or control plots. Ragged stunt disease was less serious in the main crop in the trapped fields than in the control plots (Table 32). Rice yields in all the three treatments with the trap crop were significantly greater than the yield in the control plot without the trap crop.

The findings indicate that it is possible to divert the colonizing BPH population to a trap crop, where they can be easily destroyed with insecticides. The results are high yields, a saving on insecticides, and maintenance of a sanctuary for the natural enemies of the BPH. The trap crop concept, however, is meaningful only when rice fields are likely to be infested with high hopper populations.

BIOLOGICAL CONTROL OF INSECTS

Entomology Department

Parasitic insects. For the first time, observations were made on natural parasites of planthopper and leafhopper eggs. Most parasites found belong to the families Mymaridae

Table 32. Comparison of pest infestation and yield in rice fields with and without trap crops. IRRI, October 1977 to 1978.

Treatment[a]	Pest incidence (%)								
	Grassy stunt	Ragged stunt	Tungro virus	Dead-hearts	White-heads	Rice bug (no./m²)	Yield (t/ha)	Proportionate area/ha	Total yield (t/ha)
1. Trap crop	1.7	18.8	2.1	7.0	0.0	0.2	2.4	0.25	
Main crop	2.8	12.2	0.3	6.8	0.3	0.5	3.0	0.75	2.9 a
2. Trap crop	2.2	10.0	0.7	7.5	0.0	0.2	2.3	0.25	
Main crop	0.3	14.4	0.3	8.7	0.2	0.5	3.1	0.75	2.9 a
3. Trap crop	1.9	12.9	1.0	9.7	0.3	0.5	1.8	0.25	
Main crop	0.9	14.7	0.9	8.5	0.4	0.7	2.9	0.75	2.6 a
Control (1 planting)	2.5	22.1	1.7	7.9	0.0	0.4	1.9	1.0	1.9 b

[a]The trap and control crops were planted on 1 October, 1977; the main crop in trapped fields in treatments 1–3 was planted on 20 Oct. 1977. In treatment 1, the trap crop was 2 border rows and a central patch; in treatment 2, the trap crop was 2 border rows and 4 longitudinal double rows in the middle of the trapped field; in treatment 3, the trap crop was in 6 lingitudinal double rows in the trapped fields; the control plot had no trap crop. Each trap crop and the control plots received 3 insecticide treatments; 2 kg a.i. carbofuran 3 g/ha at 5 days after transplanting (DT), 2 kg a.i. diazinon/ha at 45 DT, and 5 milliliters perthane/liter at 95 DT. No insecticide was applied on the main crop. All plots received 60 kg N/ha. Means followed by a common letter are not significantly different at 5% level.

(*Anagrus* and *Gonatocerus*) and Trichogrammatidae. Parasitism of WBPH eggs usually ranged from 10 to 40% (mean of 24%); that of BPH eggs, 10 to 50% (mean, 19%); and that of GLH eggs, 0 to 70% (mean, 22%). Sometimes a greater percentage of BPH eggs was parasitized at a low than at a high density of host eggs.

Parasitism of hopper nymphs and adults was observed at weekly intervals for 2 months in the wet season. The parasites were of the family Dryinidae (*Pseudogonatopus* and *Echthrodelphax*) and order Strepsiptera (*Elenchus*). GLH was also attacked by Pipunculids (*Tomosvaryella*). The percentage of parasitism was determined by rearing hoppers and by dissecting freshly caught specimens. The insects that parasitized BPH were dryinids and strepsiptera, but most GLH parasites were pipunculids (Table 33). Parasitism averaged less than 30%. It sometimes declined as the rice crop matured, but fluctuations during a crop period were always large.

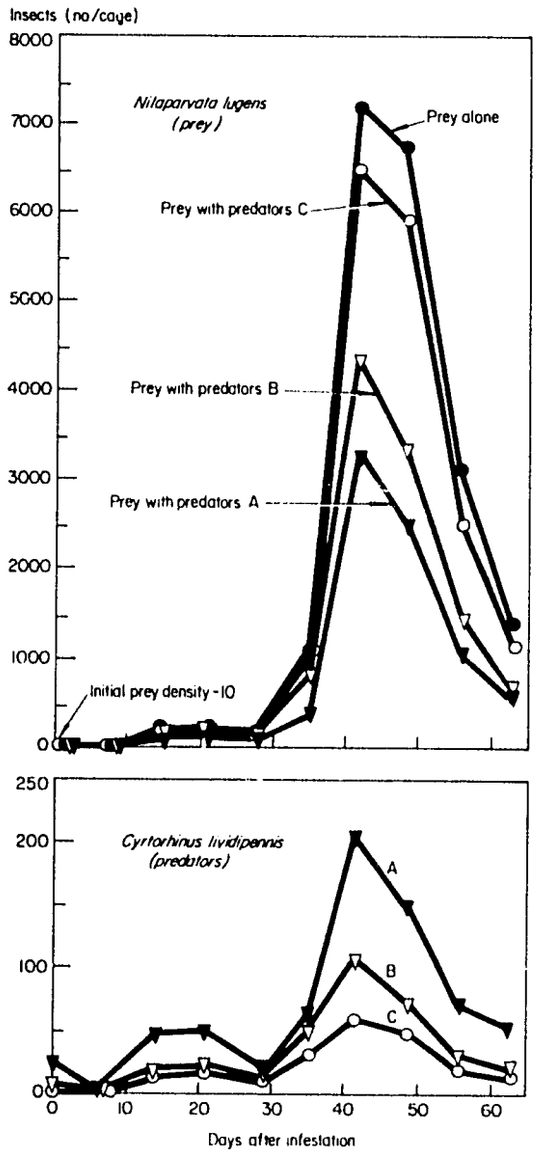
Predators. Two predator species were investigated for the first time in 1977. The damselfly *Agriocnemis pygnaea* was caged in the greenhouse for 12 consecutive days with a constant number of 5 BPH nymphs (4th and 5th instars) or adults. Each adult damselfly killed an average of 1.7 nymphs or adults/day. In another experiment, initial prey density (mixed nymphs and adults) ranged from 7 to 30/predator. Each adult predator killed from 1 to 1.7 prey/day for 6 to 10 days. Thus the damselfly is a moderately important BPH predator.

Another predator, *Microvelia* (family Veliidae), preyed on both BPH and GLH nymphs and adults. This small brown-to-black predator is often found walking rapidly over the water surface of lowland rice fields. Adult females are fecund, laying as many as 60 eggs/day. Both nymphs and adults, often several predators together, attack insects that fall

Table 33. Insect parasitism of nymphs and adults of planthoppers *Nilaparvata lugens* and *Sogatella furcifera* and leafhoppers *Nephotettix* spp. in upland and lowland rice fields. IRRI, 1977 wet season.

Rice culture	Av. parasitism (%)	Parasitism (%) by		
		Dryinidae	Strepsiptera	Pipunculidae
		Nilaparvata lugens		
Upland	21	8.6	12.4	0.0
Lowland	11	7.5	3.5	0.0
		Sogatella furcifera		
Upland	6	3.0	3.0	0.0
Lowland	7	4.9	2.1	0.0
		Nephotettix spp.		
Upland	29	1.2	3.2	24.6
Lowland	21	0.2	0.8	20.0

into the water. They paralyze the prey and then feed on it. The predators usually do not climb plants in search of prey and the prey may escape if it can quickly return to the plant. *Microvelia* seems to be primarily a predator of small, weak, or inactive insects that fall on the water. It may be an important predator of small planthopper nymphs. It can survive starvation for as long as 4 weeks, a valuable character for a biological control agent.



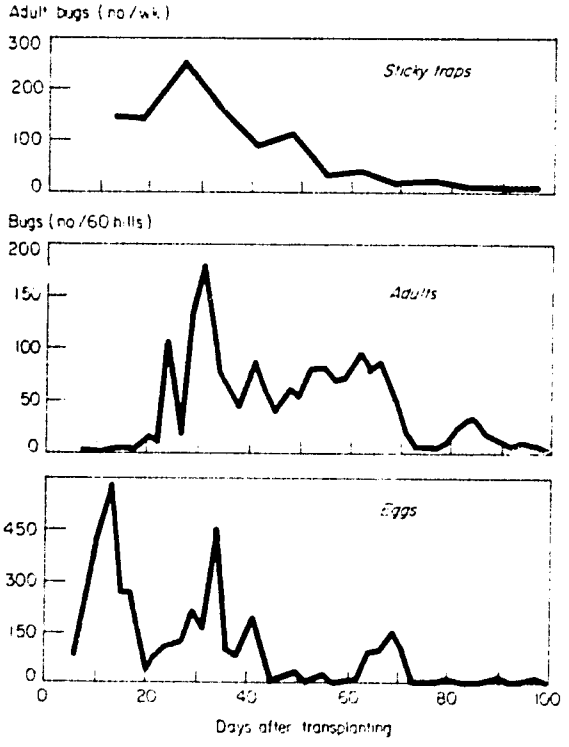
15. Densities of brown planthopper *Nilaparvata lugens* populations when caged with predator *Cyrtorhinus lividipennis* populations on 70- to 90-day-old plants of IR20 in a cage. Infestation started with pairs of fifth-instar nymphs. IRRI greenhouse, 1977.

Cyrtorhinus lividipennis. C. lividipennis is an important predator of GLH and, possibly, of BPH (1972, 1973, 1974 annual reports). Because it is abundant in rice fields, its cumulative suppressive effect on a caged BPH population was measured. In the first generation (up to 30 days), the predators suppressed the pest population only at the highest predator density (Fig. 15A). But in the second generation (after 30 days), two out of three predator populations significantly reduced prey density (Fig. 15, A and B). The predator species suppressed BPH populations up to 50% in this experiment, but the pest population grew rapidly despite predator action. Even favorable predator: prey ratios (1:0.5, 1:1) at the beginning of the experiment did not by itself control the pest. In two generations the predator:prey ratios deteriorated in favor of the pest (changed from 1:0.5 to 1:17, 1:1 to 1:64, and 1:5 to 1:166). The predator would probably suppress the pest even less in the field than in the greenhouse cages. Thus *C. lividipennis* is only moderately important as a natural control agent of BPH.

That *C. lividipennis* is not a very good biological control agent for BPH was suggested by laboratory studies in which the predator was reared on the prey. During an adult life span of about 10 days a female predator lays no more than 13 eggs/day, while the BPH lays about 50 eggs/day. When reared on a BPH population in the greenhouse, *C. lividipennis* completed a generation in 4 or 5 weeks. Although predator density increased three to five times from one generation to the next, the maximum increase in BPH population (Fig. 15) was so much greater that the predator could not effectively control the pest.

For the first time in 1977 the population growth of *C. lividipennis* was intensively observed in rice fields. Records from sticky traps around several experimental fields indicated that adults flew primarily during the first half of the crop period, peaking at about 25

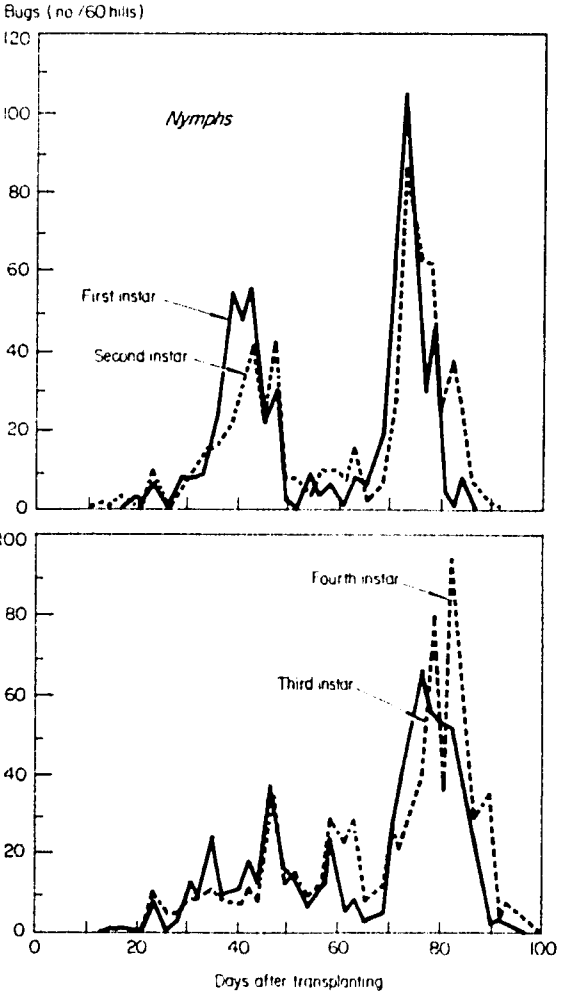
DT in one experiment (Fig. 16). Biological control may be appropriate at that peak time when BPH adults usually fly. As anticipated, the density of adult predators in the field increased during their peak flight period. The adults oviposited and nymphs hatched (Fig. 17). Emerging adults of the second generation produced at about 75 DT the largest number of nymphs present at one time during the entire crop period (Fig. 16, 17). Few adults of the third generation were found, suggesting that they dispersed from the field at crop maturation. Thus, *C. lividipennis* had a distinct generation pattern in the field, similar to that of the BPH. Adult density was maximal during the first half of the crop period in two other crops. The predator's density on levees surrounding a field was also greatest in this period. Peaks in nymphal density were clear, but the number and time of peaks from crop to crop were not uniform.



16. Abundance of predatory bugs *Cyrtorhinus lividipennis* on rice selection IR1917-3-17, according to field samples and catches on both sides of 8 sticky traps (total surface area 1.5 m²) around the field. IRRI, 1977 wet season.

Fewer eggs than expected were laid in the field; even though some parasitism was observed, egg mortality (or possibly, mortality of young first-instar nymphs) appeared rather high in the first generation. But more nymphs and, in the second generation, more eggs survived than expected (Fig. 16, 17). The predator seems to have few natural enemies. The nymphal density peaked at from 70 to 90 DT, when BPH control was critical (Fig. 17).

In upland rice fields at IRRI, the peak *C. lividipennis* density, sometimes reaching 40 bugs/m², is at about 45 or 50 days after rice emergence.



17. Density of nymphal instars of predatory bugs *Cyrtorhinus lividipennis* on rice selection IR1917-3-17. IRRI, 1977 wet season.

Spiders. The spider *Lycosa pseudoannulata* is a good BPH predator (1974, 1975 annual reports). Other spiders — *Theridion* and *Argiope* — are also found in lowland and upland rice fields. Although spider abundance generally fluctuates little in a short time, spider density in several 1977 crops increased with crop age, peaking near crop maturity. Spiders, often scarce, are usually the most abundant predator after *C. lividipennis*. They may reach a density of 1 1/hill, but usually only a few are found on a hill. The maximum density recorded in an upland field was 7/m².

Spiders are found on levees around lowland rice fields; after the crop is established, they may leave the levees to inhabit the fields. In the study, spider density on the levees did not decline as the crop grew older. For biological control, an attempt to increase spider density on levees was made by fertilizing them and releasing prey on them. Driving spiders off the levees by cutting the levee plants was also tried. No technique had a consistently significant effect on predator abundance in the rice field.

Spider density within a lowland rice field was sometimes increased by additional spiders placed in the field or by a sugar solution sprayed on plants. But the increased spider abundance did not appear to affect BPH density. Thus spider management is not yet successful as a pest control measure.

ECOLOGY AND BEHAVIOR OF INSECTS

Entomology Department

Stem borer pheromones. In earlier collaborative work with the Tropical Products Institute, London, U.K. (1975, 1976 annual reports), high doses of synthetic female sex pheromones of *Chilo suppressalis* surrounding an attractant source confused male moths, preventing attraction. The confusion was confirmed by further studies in 1977 using 8 confusion vials, each at a dose of 1 mg/vial, situated at 0.5 m from and around an attractant source in a water pan trap. Similar promising results were obtained when vials were suspended at 2-m intervals over a rice crop.

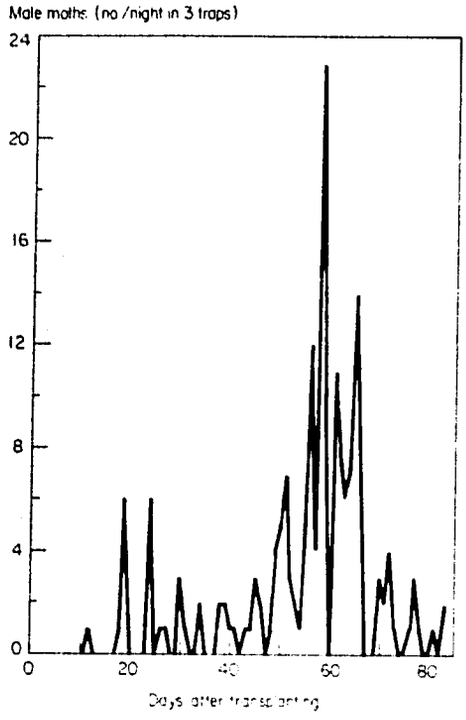
The effects of pheromone-mimic compounds — (Z)-9-tetradecenyl formate and (Z)-11-hexadecenyl formate — on mating behavior are also being studied. In sunlight such compounds degrade much more slowly than the pheromones. In 1976 the mimics were shown to be attractant inhibitors, effective in 8 vials at doses of 1 mg/vial around water pan traps and at a distance of 0.5 m from the pheromone attractant in the trap. Such inhibition was confirmed in 1977, suggesting that mating disruption has potential for practical pest control. Trials using suspended vials in rice fields warrant further experimentation.

A new method for applying the inhibitor formates to the crop — formulating the compounds in microcapsules and spraying them onto filter paper — was as effective as vials. With formates applied in this way, trap catches were reduced to almost zero for a period of 5 days. Work on lengthening the field life of the formulation is in progress.

Water pan traps have always been used in pheromone studies. Because higher catches would accelerate research, sticky traps were initially tested at 45- to 135-cm heights. The maximum catch was at 75 cm, but it was comparable with the catch in water pan traps at 110 cm.

Stem borers. One use of pheromone traps is monitoring the densities of certain insect species. For the first time, the density of *C. suppressalis* male moth was monitored with pheromone traps during a crop period. Even though catches were sporadic over a large part of the period, most moths were caught from 50 to 70 DT; peak catches occurred at about 60 DT (Fig. 18). A peak in egg density would be expected after a period of high moth flight and mating activity. But in this experiment, egg density was low and difficult to relate to trap catches. Earlier studies showed that *C. suppressalis* oviposition at IRRI usually peaks at about 60 DT (1975, 1976 annual reports). Therefore trap catches can probably indicate the appropriate time for applying sprayable insecticides for stem borer control — when eggs are hatching.

In a preliminary trial to measure the height of moth flights, cages without roofs but with



18. Catch of male moths *Chilo suppressalis* in pheromone water pan traps in a field of IR29. IRRI, 1977 wet season.

walls 2 or 5 m high were constructed. In the first 2 months after transplanting, the 2-m cages did not prevent either *C. suppressalis* or *Tryporyza incertulas* moths from flying into the cages and laying eggs. No egg masses were found in the cage with 5-m walls. Thus mated female moths, at least, do not appear to fly as high as 5 m.

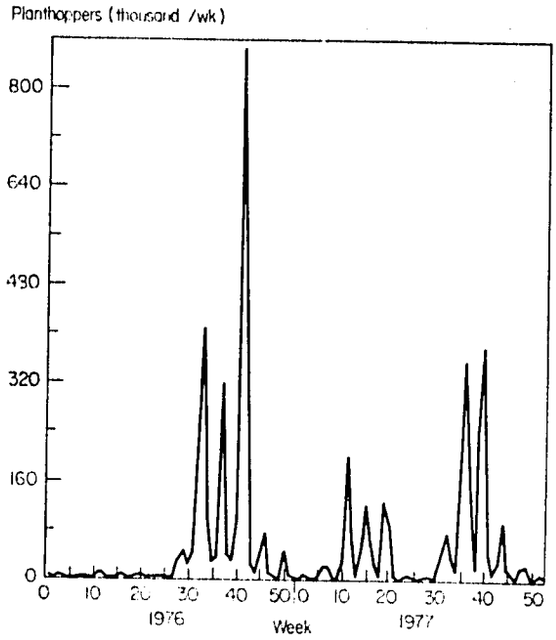
Leafhoppers. Green leafhoppers *Nephotettix* spp. are not abundant in upland rice fields at IRRI. In 1977 the maximum density of adults and nymphs was 7/m² at 70 days after rice emergence. Even though oviposition subsequently increased, the population declined, no doubt partly because egg parasitism increased (reaching 79% at 98 days). The 1976 population was largest at the beginning of the crop period, reaching a density of 20/m² at 54 days. The zigzag leafhopper *Recilia dorsalis* was roughly equal in abundance in the upland rice crop. In 1977 22 insects/m² were collected at 56 days after emergence, but the maximum 1976 density was only 11/m² at 51 days.

The density of GLH at all stages was regularly and frequently observed in a lowland rice field. In an early dry season crop the densities of eggs, nymphs, and adults were highest near harvest. Egg parasitism was high (0 to 71%, averaging 36%). In a wet season crop, however, egg density peaked only once, at about 35 DT. The time of adult immigration is probably a major determinant of the time of peak field density. In the wet season, the catch on sticky traps placed around the experimental field was largest before the large peak in egg density. *C. lividipennis* catches on the sticky traps were also highest at the beginning of the crop period, suggesting that the predator could help reduce the leafhopper population. Survival to the nymphal stage was poor after the big peak in eggs.

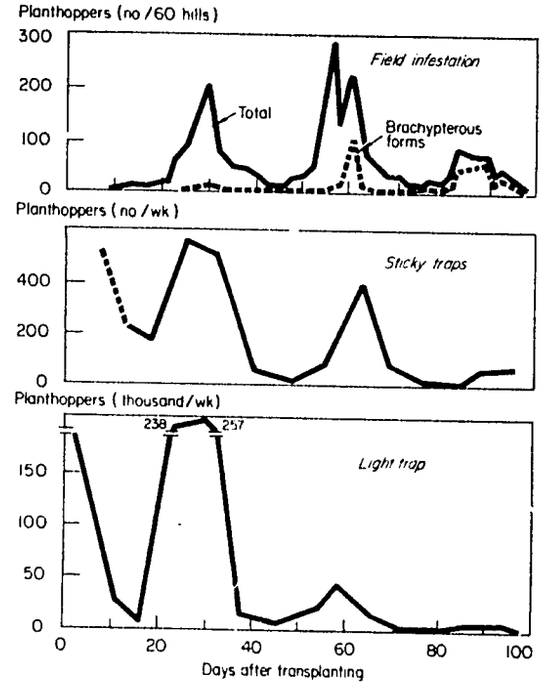
Brown planthoppers. No major BPH outbreaks occurred in 1977. Possibly because of biotype shifts, however, light trap catches indicated moderately high levels of BPH after the 1976 wet season. For the first time monthly peaks of BPH were noticed, in addition to the two major peaks associated with the two crops per year (also seen in GLH and stem borers) (Fig. 19). The monthly peaks may have been products of the one-generation-per-month phenomenon. The lunar cycle may also have influenced the flight behavior of BPH; most peak catches in light traps for the past 1.5 years have occurred at about the time of the full moon.

The densities of the eggs, nymphs, and adults of the BPH were intensively monitored every other day in a dry season crop. Three distinct generations developed, each larger than the one preceding it. Such a consistent increase has not often been observed in IRRI rice fields. Both egg parasitism and egg predation appeared to increase in the third generation, but mean egg parasitism was only 19% and predation, 2%.

In the wet season, an improved sampling device was used three times a week. The suction sampler collected virtually all arthropods on or near a hill, giving much more com-



19. Abundance of adult brown planthopper *Nilaparvata lugens* based on light trap catches (total of 3 traps). IRRI, 1976–77.



20. Abundance of adult brown planthopper *Nilaparvata lugens* by field samples on rice selection IR1917-3-17, catches made on both sides of 8 sticky traps (total surface area 1.5 m^2) around the field, and a nearby light trap. IRRI, 1977 wet season.

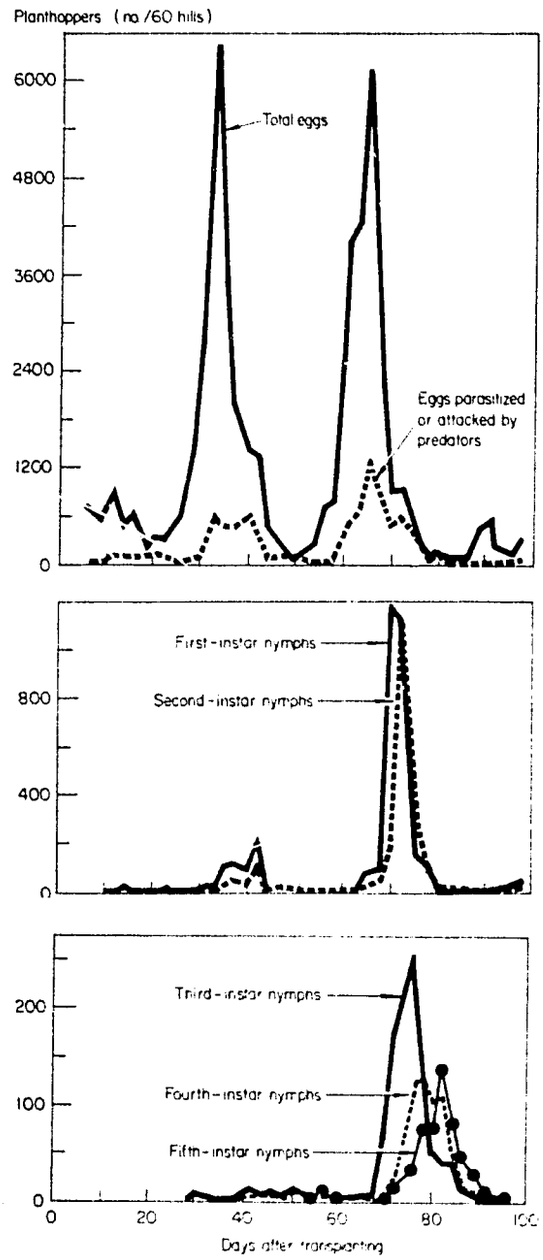
prehensive data on pest population densities than before. Sticky traps were also placed around the field to detect peak periods of insect flight.

By both the sticky traps and a nearby light trap, flights peaked significantly three or four times in the crop period (Fig. 20). Evidently a large flight at transplanting did not result in a major adult infestation, but the next flight did. The first major adult peak in the field, almost all macropterous forms, produced a large batch of eggs (Fig. 21). Many eggs laid near the end of the oviposition period were parasitized (Fig. 22). Although egg predation was highest about the time of peak egg density, nymphs were fewer than expected, suggesting a high nymph mortality immediately after hatching.

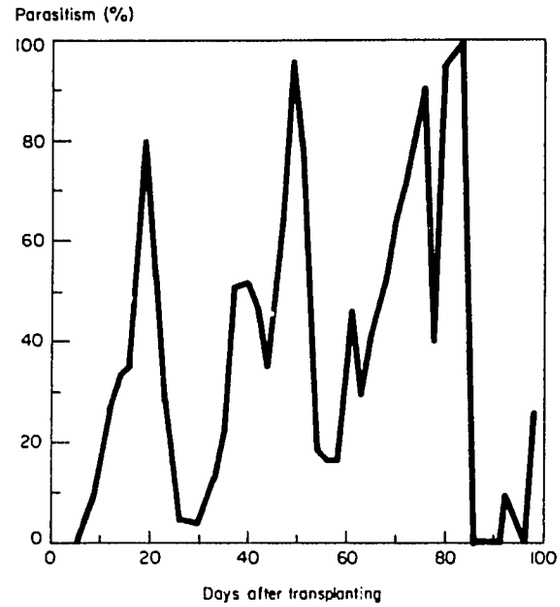
Another wave of immigrant adults, plus a few brachypterous adults, formed a second large adult peak (Fig. 20). The relatively few brachypterous adults are noteworthy, since these short-winged forms were expected to dominate the second generation. But immigrant adults, by necessity macropterous, may have masked the expected ratio of long- to short-winged adults. There were three times as many female as male macropterous adults. Because of the masking effect of many immigrants, adult mortality caused by parasites could not easily be detected, even though adult parasitism was highest at that time.

The second major oviposition period again produced many eggs. But this time, despite a level of egg parasitism similar to that of the previous generation, a substantial number of nymphs survived (Fig. 21, 22). The more suitable plant age at that time was possibly a factor. Nymph mortality was apparently high between the second and third, and third and fourth instars when *Cyrtorhinus* was most abundant, about 75 DT (Fig. 17, 21), and when spider density in the field was maximal.

The final adult peak consisted mostly of brachypterous forms (Fig. 20). That is surpris-



21. Density of various developmental stages of brown planthopper *Nilaparvata lugens* on rice selection IR1917-3-17. IRRI, 1977 wet season.

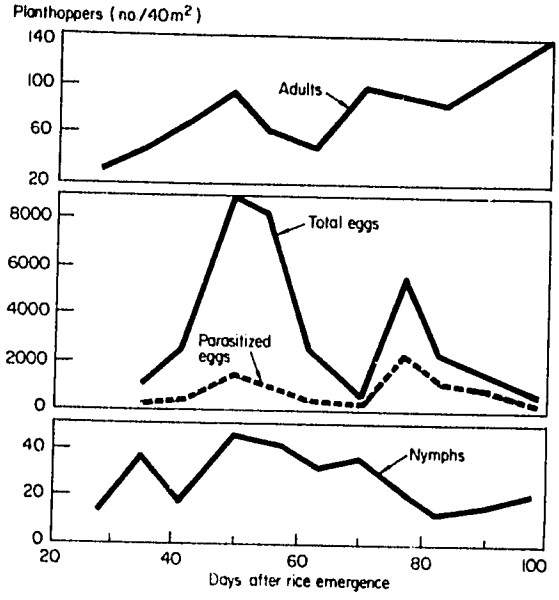


22. Maximum estimate of egg parasitism of brown planthopper *Nilaparvata lugens* on rice selection IR1917-3-17. IRRI, 1977 wet season.

ing because in northeast Asia the last adults before harvest are macropterous. Again three times as many females as males were found, but only a few eggs were laid. The formation of the two wing forms should be further studied.

Preliminary observations in an upland rice field also showed a generation pattern. The maximum nymph density in the last 2 years was reached at about 50 days after rice emergence. Egg parasitism, especially in the second generation, was moderately high, and nymph mortality appeared very high (Fig. 23). Spider density increased greatly after 70 days. In 1976 there were few planthoppers beyond 60 days, but in 1977 the adults increased, particularly near crop maturity, possibly because of immigration (Fig. 23). But compared with that in lowland rice fields, the overall BPH density was still low.

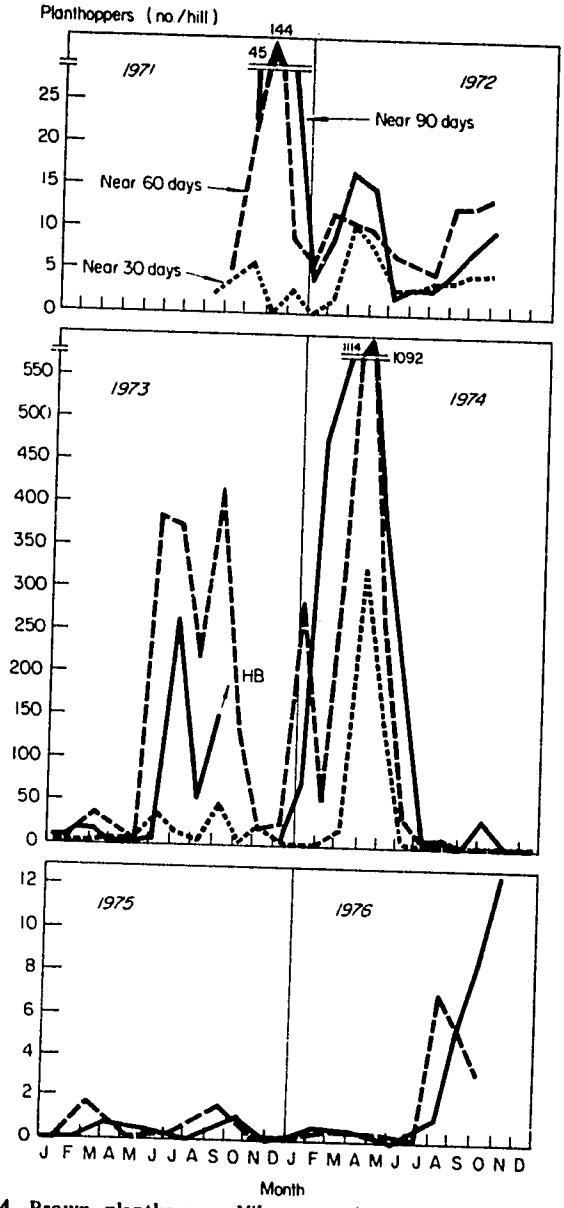
BPH densities fluctuate from generation to generation within a crop period, but major changes in abundance also occur within a year. In the study of these major changes, a new rice crop was planted every month for more than 6 years. The population in each crop was sampled weekly and peak densities for each generation were identified. When the peak densities of a given generation in all crops were graphed (one



23. Insect density at various developmental stages of brown planthopper *Nilaparvata lugens* on variety C22 in an upland rice field. IRRI, 1977 wet season.

point per crop) over the time period, the pest was most abundant in two periods per year: one in the dry season and the other in the wet season (Fig. 24). The two peaks were probably associated with the two yearly rice crops commonly grown around IRRI. Because the highest insect density per year was not always in the same season, climate could not be the major determinant of population size. In regions where the population density is predictable, it should be possible to time planting so as to avoid the most serious pests.

Some preliminary tests were made to develop a marking system for BPH. Fluorescent dyes were dusted onto fifth-instar nymphs, and subsequent survival, movement, and dye retention were observed. Of the dyes tested, "Rocket Red" was the least harmful, causing only 13% mortality after 10 days. The marked insects appeared to have moved somewhat more slowly than unmarked ones over a distance of 2 m in 8 days. The dye was still visible under ultraviolet light on 70% of the insects after 2 weeks, even though they had molted to adults.



24. Brown planthopper *Nilaparvata lugens* density on crops of the medium-maturing rice variety IR20 planted monthly or bimonthly at IRRI. Each curve is the insect generation maximum density on crops of nearly the same age, at 30, 60, or 90 days after transplanting. Data are for both nymphs and adults of 1971–72, but only for nymphs in 1973–76. HB = hopperburn.

BROWN PLANTHOPPER DISTRIBUTION AND SAMPLING TECHNIQUES

Statistics Department

Previous data (1974 Annual Report) on visual counts of BPH adults and nymphs made on

Table 34. Estimated sampling variance[a] (among hills within plots) in the number of brown planthopper adults and nymphs in a rice field. IRRI, 1973–74.

Growth stage of rice plant (DT[b])	Adults			Nymphs		
	Mean (no./hill)	Sampling variance	cv (%)	Mean (no./hill)	Sampling variance	cv (%)
			1973 wet season			
28	0.6	0.55	124	9.8	10.70	33
44	7.1	28.88	76	2.1	1.82	64
71	0.4	0.46	170	3.2	4.64	67
83	0.3	0.25	167	0.3	0.45	224
			1974 dry season			
22	6.0	6.44	42	30.5	63.86	26
27	4.1	5.85	59	52.7	281.97	32
35	5.7	11.75	60	161.4	2880.96	33
51	2.8	3.60	68	22.1	95.08	42
64	1.4	2.02	102	25.5	272.62	65

[a]Estimated from 40 plots, 10 hills/plot in the 1973 wet season, and from 5 plots, 10 hills/plot in the 1974 dry season. [b]Days after transplanting.

individual hills at various growth stages of rice plants in two rice fields in wet and dry seasons were studied. The adult populations in both seasons were similar: the mean density peaks were about 5 to 6 adults/hill. On the other hand, the nymph population was much higher in one season than in the other (mean density peak of 166 nymphs/hill in the 1974 dry season, and 21 nymphs/hill in the 1973 wet season).

The direction of BPH migration was a major cause of the nonuniformity of insect distribution in a rice field. Insects also dispersed by flying from plot to plot in the field during crop growth.

Variation in insect counts among individual hills in a plot was large: coefficients of variation ranged from 42 to 170% for adults and from 26 to 224% for nymphs (Table 34). Some sources of sampling variation identified were border effect, missing hills, diseased hills, and variation in tiller number. Insects were fewer on plants bordering an unplanted alley, on plants surrounding a missing hill, and on diseased hills than on normal hills. The effects were greater for nymphs than for adults and were detected only at relatively high population densities. More insects were found on hills with high tiller number than on those with low.

The spatial distribution of BPH in a plot was not truly random. Neither the poisson nor the negative binomial distributions fitted the BPH counts of adults or nymphs. Deviation from randomness was caused primarily by the tendency of insects to aggregate on adjacent hills. Nymphs aggregated more than adults. The degree of aggregation was also higher with higher population density. Figure 25 shows a sample spatial distribution pattern of BPH adults and nymphs.

Sampling variance decreased as the size of sampling unit increased. But considering the degree of precision and ease of practical operation, a single-hill sampling unit is considered optimal in estimating visually the population of BPH adults and nymphs in the rice plots.

Sample size was dependent on the insect population density: the higher the density, the smaller the sample size required for a given degree of precision.

The ratio estimation technique with plant tiller numbers as the auxiliary variable could not overcome the high variability in the determination of BPH density in rice fields.

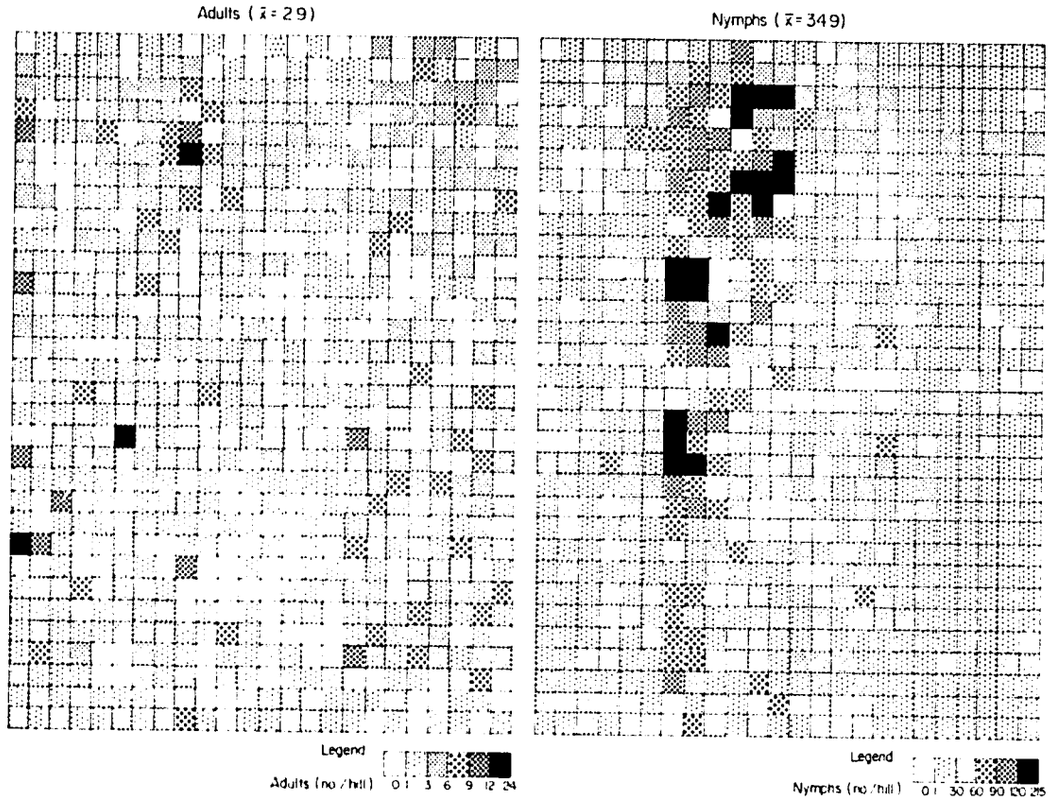
SAMPLING BROWN PLANTHOPPERS

Entomology Department

Nymphs and adults. *Sampling methodology and equipment.* Pest population density was previously measured by visual count or with a mouth aspirator. But the methods may be neither efficient nor accurate. Sampling was time consuming, samples did not represent all the insect stages and species present, and population estimates were suspected to be approximate only. To find a better method, the estimated pest densities obtained by several sampling methods were compared.

A D-vac suction catcher collected the most insects, but a cylinder around the hill was necessary to prevent the catcher from sucking insects from neighboring hills. Adult catches with a mouth aspirator or by visual count were equally good, but both methods, especially the mouth aspirator, were inadequate for young nymphs. The D-vac catcher could not sample the water surface, and the insects collected by the machine had to be processed before storage.

A new collecting device was constructed to



25. Distribution patterns of brown planthopper adults and nymphs, measured at 50 days after transplanting. One square represents one hill. IRRI, 1974 dry season.

eliminate those problems. The device was a portable, battery-operated automobile vacuum cleaner attached to a modified insect aspirator. A glass vial was screwed into the aspirator collection chamber.

Before sampling a large open-ended cylinder was carefully placed over a hill. Through a flexible hose, all arthropods were then sucked from the cylinder walls and from plant and water surfaces into the collection chamber. After the collection, the chamber was drained of water and alcohol was injected into it. The preserved insects were removed with the vial. A sample was taken in about 10 minutes. The device proved quite satisfactory for collecting planthoppers and their natural enemies.

Insect distribution and sampling. The newly developed suction sampler was used to collect virtually all arthropods on and around individual rice hills. From 92 to 240 hills were sampled on 15 occasions from 256 plots (each about 4.5 m^2) in 0.125 ha.

The distribution of immigrant adults among hills was aggregated. Consequently as the oviposited eggs hatched, the nymphs were also aggregated. Later instars and brachypterous adults, however, were distributed more randomly. Immigrant adults evidently set the degree of aggregation, which declined as the generation developed. The second generation was less aggregated than the first. The number of hills needed for a sample at a given precision level varied with the generation, the developmental stage of the insect, and insect density. Considering the relationship of mean crowding to mean density of the population, a sample size of 20 to 30 hills was found adequate for most practical purposes (Table 35). Sample size should be larger only for intense ecological studies on low population densities.

Table 35. Recommended sample size (sample unit = 1 hill) for 20% precision when sampling brown planthopper *Nilaparvata lugens* in a rice field (maximum size, 0.2 ha) according to a systematic procedure and with a motorized suction machine. IRRI, 1977.

Developmental stage of insect	Insect mean density (no./hill)	Sample size (no. of hills)	
		First generation	Second generation
Eggs	10	30	30
	50	28	28
	500	27	27
	1000	27	27
First-instar nymphs	5	35	23
	10	28	16
	25	23	11
Second-instar nymphs	2	34	33
	5	26	22
	10	23	18
	25	22	15
Third-instar nymphs	1	48	45
	2	42	31
	5	31	22
	10	27	20
	25	24	18
Nymphs	0.3	206	235
	0.5	131	144
	1	75	75
	3	38	30
	5	30	21
	10	25	14
	25	21	10
	50	20	8
Adults	0.2	274	180
	0.5	120	76
	1	70	41
	2	44	24
	5	28	13
	10	23	10

The mean insect density per hill was greater at one end of the field than at the other, confirming the need for blocking in experimental designs.

Egg distribution and sampling. For the first time, egg distribution was measured within a hill and within a field. Preliminary and subsequent detailed observations showed that egg number per tiller was similar in all parts of a hill. Egg density was significantly higher ($P = 0.1$) in inner than in outer tillers on only one sample date. No evidence indicated that egg parasitism differed among parts of a hill.

In studies of egg distribution among hills in a field, eggs of the first two oviposition periods were rather aggregated: the distribution pattern was close to a negative binomial. Eggs from the final oviposition period, however, appeared to be randomly distributed. Unlike those in the first two periods, the latter were probably laid mostly by adults that developed within the field. The mean egg density per hill on one part of the field was significantly higher than that of another part in only one instance.

The results suggest the following tentative egg-sampling procedure: an entire hill, or half, or a fourth of a hill may be sampled. The number of hills to be systematically sampled on each sampling occasion at a given precision level is related to the egg density and degree of aggregation. Considering both factors a maximum of 30 hills/sample is suggested (Table 35).

Control and management of rice pests

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Agronomy and Statistics Departments

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WEED CONTROL IN RICE

Agronomy Department

The primary purpose of IRRI weed research is to develop weed-control technology that is compatible with the cultural practices and socioeconomic constraints of Asian rice farmers. Research to identify herbicides that would complement other direct methods of weed control, such as hand pulling or mechanical control, was continued at IRRI; at the Maligaya, Bicol, and Visayas research stations of the Philippine Bureau of Plant Industry; and in farmers' fields.

Transplanted rice. During the dry season, yield differences between herbicide-treated and untreated plots ranged from 3 t/ha at Maligaya to 4 t/ha at IRRI and at Bicol. The crop at Visayas did not yield because of drought.

Infestations of *Echinochloa crus-galli* ssp. *hispidula*, *Echinochloa glabrescens*, *Cyperus difformis*, and *Monochoria vaginalis* were common at all sites. *Scirpus maritimus* was present at IRRI; *Cyperus imbricatus* and *Sphenoclea zeylanica* were present at Bicol.

At IRRI and at Maligaya all chemical treatments gave yields comparable to those of the hand-weeded plots and significantly higher than those of the untreated plots (Table 1). At Bicol, plots treated with Benzglycereth, X-52/2,4-D IPE, and 2,4-D IPE yielded significantly less than the hand-weeded control plots. Benzglycereth-treated plots gave yields comparable to those of the untreated plots. Pendimethalin, butachlor + 2,4-D, NTN 5810/2,4-D IPE, and MT-101/thiobencarb performed consistently well at all sites (Table 1). At IRRI and the Visayas station, all herbicide treatments gave significantly higher yields than the untreated control during the wet season (Table 2). Benzglycereth performed best at the Visayas station. Oxadiazon and 2,4-D IPE at IRRI, and MT-101/thiobencarb at Visayas had significantly lower yields than the hand-weeded check.

A moderate bacterial leaf streak infection caused generally low yields at IRRI.

Direct-seeded flooded rice. In the dry season, all herbicide treatments gave significantly higher yields than the untreated plots at IRRI

Table 1. Effects of granular herbicides applied before weed emergence (4 days after transplanting) on yield of IR26 rice at IRRI, the Maligaya Rice Research and Training Center, and the Bicol Rice and Corn Experiment Station of the Philippine Bureau of Plant Industry, 1977 dry season.

Treatment[a]	Rate (kg a.i.[b]/ha)	Yield[c] (t/ha)		
		IRRI[d]	Maligaya[e]	Bicol
NTN 5810/2,4-D IPE	1.4/0.3	5.6	6.9	7.6
Butachlor + 2,4-D IPE	0.75 + 0.5	5.6	6.4	7.0
Pendimethalin	0.75	5.3	6.3	6.6
MT-101/thiobencarb	1.0/0.7	5.7	5.9	6.4
Oxadiazon	0.5	5.3	5.7	5.2
X-52/2, 4-D IPE	1.4/0.5	4.6	5.3	4.7
2, 4-D IPE	0.8	4.3	4.8	4.2
Benzglycereth (WL 29226)	0.75	4.8	5.2	1.2
NTN 6867/2, 4-D IPE	1.4/0.3	5.8	[f]	[f]
M 3432 + 2,4-D IPE	3.0 + 0.5	5.7	[f]	[f]
M 3432 + 2,4-D IPE	2.0 + 0.5	5.4	[f]	[f]
EXP 3391	0.5	5.0	[f]	[f]
X-150/2, 4-D IPE	1.0/0.5	5.0	[f]	[f]
MCPA/TBA	0.57/0.18	4.8	[f]	[f]
Hand-weeded control[g]	—	5.4	5.3	7.0
Untreated control	—	1.0	2.8	0.9

[a]A slant bar (/) means that two herbicides were formulated on the same carrier or mixed together and applied as a single treatment; + means that the chemicals were applied separately at about the same time. IPE = isopropyl ester. [b]Active ingredient. [c]Av. of four replications per site. [d]All herbicide treatments gave significantly higher yields than the untreated control. [e]Not tested. [f]Weeded at 20 and 40 days after transplanting.

Table 2. Effects of granular herbicides applied before weed emergence (4 days after transplanting) on yield of IR26 rice at IRRI and at the Visayas Rice Experiment Station of the Philippine Bureau of Plant Industry, 1977 wet season.

Treatment[a]	Rate (kg a.i.[b]/ha)	Yield (t/ha)	
		IRRI	Visayas
Benzglycereth (WL 29226)	0.75	3.8	7.6
Pendimethalin	0.75	3.9	6.4
Oxadiazon	0.5	2.8	7.4
Butachlor + 2,4-D IPE	0.75 + 0.5	3.2	7.0
X-52/2, 4-D IPE	1.4/0.5	3.1	7.0
MT-101/thiobencarb	1.0/0.7	3.9	6.0
Piperophos/2,4-D IPE	0.33/0.17	3.4	6.5
2,4-D IPE	0.8	2.8	6.6
M 3432 + 2,4-D IPE	3.0 + 0.5	4.0	[d]
Bifenox/2,4-D EE	2.0/0.66	3.9	[d]
Piperophos/dimethametryn	0.4/0.1	3.7	[d]
Bifenox	3.0	3.3	[d]
EXP 3391	0.3	3.2	[d]
MCPA/TBA	0.76/0.24	3.2	[d]
Hand-weeded control[e]	—	4.0	7.1
Untreated control	—	1.6	4.9

[a]A slant bar (/) means that two herbicides were formulated on the same carrier or mixed together and applied as a single treatment; + means that the chemicals were applied separately at about the same time. IPE = isopropyl ester. EE = ethyl ester. [b]Active ingredient. [c]Av. of four replications per site. All herbicide treatments gave significantly higher yields than the untreated controls at both sides. [d]Not tested. [e]Weeded at 20 and 40 days after transplanting.

and Bicol (Table 3). At Maligaya, weed infestation was so low that the untreated control yielded 5.9 t/ha. At Bicol, Benzglycereth gave the lowest mean yield, 1.9 t/ha.

Thiobencarb/2,4-D IPE, MT-101/thiobencarb, and NTN 5810/2,4-D IPE performed best at all sites.

In the wet season at Visayas, all chemical treatments gave significantly higher yields than the untreated control (Table 4). At IRRI, only plots treated with MT-101/thiobencarb, M 3432 + 2,4-D IPE, and piperophos/2,4-D IPE performed better than the untreated plots. The other herbicides either failed to control *Echinochloa* sp. or were extremely phytotoxic to the crop.

Upland rice. Heavy weed infestation is one of the most serious causes of low yields of upland rice.

Ten herbicide treatments were compared with hand-weeded and untreated checks at IRRI and in a farmer's field in Batangas province, Philippines. Both sites were heavily infested with *Echinochloa colona*, *Eleusine indica*, *Digitaria sanguinalis*, *Commelina diffusa*, *Aeschynomene indica*, and *Cyperus iria*. At IRRI and at Batangas, a drought, which occurred soon after herbicide application and lasted from 3 to 4 weeks, delayed crop and weed emergence and reduced crop stand, particularly at IRRI.

At the IRRI farm, most plots yielded nothing. Because of poor stand and bacterial leaf streak infection, weeds overcame the entire crop. The only herbicides that gave sustained weed control and produced some yields were dinitramine (1.6 t/ha) and pendimethalin (1.8 t/ha). The hand-weeded check yielded 1.8 t/ha.

At Batangas, the untreated plots failed to yield because weed infestation was extremely heavy, but the crop stand was good and disease-free (Table 5). The herbicides oxadiazon, oxyfluorfen, butralin, pendimethalin, dinitramine, and X-150 provided adequate initial weed control and gave yields ranging from 1.4 to 2.4 t/ha. But plots treated with Antor, butachlor, piperophos/dimethametryn, and propanil yielded nothing. Antor controlled broad-leaved weeds well but was toxic to rice. Butachlor and piperophos/dimethametryn injured the crop only slightly but controlled

Table 3. Effects of granular herbicides applied at early postemergence (6 days after seeding) on yield of direct-seeded, flooded IR26 rice at IRRI and the Maligaya Rice Research and Training Center and at the Bicol Rice and Corn Experiment Station of the Philippine Bureau of Plant Industry, 1977 dry season.

Treatment[a]	Rate (kg a.i.[b]/ha)	Yield[c] (t/ha) IRRI	Maligaya	Bicol
NTN 5810/2,4-D IPE	1.4/0.3	5.8 a	7.1 a	6.1 a
MT-101/thiobencarb	1.0/0.7	5.7 a	6.5 a	5.8 a
Thiobencarb/2,4-D IPE	1.0/0.5	6.0 a	6.8 a	5.0 ab
Pendimethalin	0.75	5.4 a	7.4 a	3.3 cd
M 3432 + 2,4-D IPE	3.0 + 0.5	5.0 a	6.4 a	4.4 bc
Butachlor + 2,4-D IPE	0.75 + 0.5	5.1 a	6.1 a	4.2 bc
Oxadiazon	0.5	4.9 a	6.3 a	3.7 cd
X-52/2,4-D IPE	1.4/0.5	5.1 a	6.5 a	3.0 de
Benzglycereth (WL 29226)	0.75	4.5 a	6.6 a	1.9 e
M 3432 + 2,4-D IPE	2.0 + 0.5	5.1 a	[d]	[d]
Nitrofen	2.0	5.1 a	[d]	[d]
X-150/2,4-D IPE	1.0/0.5	5.0 a	[d]	[d]
NTN 6867/2,4-D IPE	1.4/0.3	4.9 a	[d]	[d]
MCPA/TBA	0.57/0.18	4.6 a	[d]	[d]
EXP 3391	0.5	0 c	[d]	[d]
Untreated control	—	2.9 b	5.9 a	0.6 f

[a]A slant bar (/) means two herbicides were formulated on the same carrier or mixed together and applied as a single treatment; + means that the chemicals were applied separately at about the same time. IPE = isopropyl ester. [b]Active ingredient. [c]Av. of four replications per site. In each column, means followed by the same letter are not significantly different at 5% level. [d]Not tested.

Table 4. Effects of granular herbicides applied at early postemergence (6 days after seeding) on yield of direct-seeded flooded IR26 rice at IRRI and at the Visayas Rice Experiment Station of the Philippine Bureau of Plant Industry, 1977 wet season.

Treatment[a]	Rate (kg a.i.[b]/ha)	Yield[c] (t/ha) IRRI	Visayas
M 3432 + 2,4-D IPE	3.0 + 0.5	2.6 a	6.9 ab
Piperophos/2,4-D IPE	0.33/0.17	2.5 a	6.8 ab
MT-101/thiobencarb	1.0/0.7	2.2 ab	6.3 ab
Butachlor + 2,4-D IPE	0.75 + 0.5	1.4 abcd	6.9 ab
Pendimethalin	0.75	2.0 abc	6.2 ab
Thiobencarb/2,4-D IPE	1.0/0.5	2.0 abc	6.1 b
Oxadiazon	0.5	0.9 bcd	7.1 a
X-52/2,4-D IPE	1.4/0.5	1.1 bcd	6.3 ab
Benzglycereth (WL 29226)	0.75	0.3 d	6.8 ab
Piperophos/dimethametryn	0.4/0.1	2.1 abc	[d]
Bifenox	3.0	1.9 abc	[d]
Bifenox/2,4-D EE	2.0/0.66	1.9 abc	[d]
Nitrofen	1.75	1.1 bcd	[d]
MCPA/TBA	0.76/0.24	0.9 bcd	[d]
EXP 3391	0.3	0.3 d	[d]
Untreated control	—	0.7 cd	4.4 c

[a]A slant bar (/) means that two herbicides were formulated on the same carrier or mixed together and applied as a single treatment; + means that the chemicals were applied separately at about the same time. IPE = isopropyl ester. EE = ethyl ester. [b]Active ingredient. [c]Av. of four replications pec site. In each column, means followed by the same letter are not significantly different at 5% level. [d]Not tested.

Table 5. Effects of liquid herbicides applied before crop and weed emergence (3 days after seeding) on weed control, crop tolerance, and yield of IR9575 rice under upland conditions in a farmer's field. Batangas province, Philippines, 1977 wet season.

Treatment[a]	Rate (kg a.i.[b]/ha)	Weeds[c] (g/m²)			Toxicity rating[d]	Yield[e] (t/ha)
		Grasses	Sedges	Broad-leaved weeds		
Oxadiazon	1.0	21	2	14	2	2.4 ab
Oxyfluorfen	0.5	45	0	5	4	1.7 b
Butralin	2.0	24	23	20	4	1.5 b
Pendimethalin	2.0	11	15	24	5	1.4 b
Dinitramine	1.5	36	16	39	5	1.4 b
X-150	4.0	96	4	1	2	1.4 b
Propanil[f]	3.0	84	1	1	2	0.0 c
Butachlor	2.0	92	1	20	2	0.0 c
Piperophos/dimethametryn	1.6/0.4	120	0	6	2	0.0 c
Antor	1.0	119	2	26	8	0.0 c
Hand-weeded control[g]	—	0	0	0	—	2.8 a
Untreated control	—	171	9	5	—	0.0 c

[a]A slant bar (/) means two herbicides were formulated on the same carrier and applied as a single treatment. [b]Active ingredient. [c]Sampled at 39 days after rice emergence (DE). [d]Taken at 16 DE. Scale: 0–10: 0 = no toxicity, 10 = complete kill. [e]Av. of four replications. Means followed by the same letter are not significantly different at 5% level. [f]Applied at 13 DE. [g]Weeded at 16 and 32 DE.

weeds poorly. Propanil not only severely scorched the rice plants and reduced the stand by 50%, but also controlled weeds poorly.

In an upland rice herbicide trial at Iloilo, a plot that was hand weeded at 15 and 30 days after emergence yielded highest (Table 6). No herbicide satisfactorily controlled weeds. All herbicide-treated plots yielded significantly less than the hand-weeded plots (Table 6). Yields of plots treated with butachlor and terbuchlor were significantly higher than that of the unweeded check plot, but yields of plots treated with thiobencarb and butralin did not differ significantly from it.

Dry-seeded rainfed bunded rice. In trials in Pangasinan and Iloilo, eight pre-emergence herbicide treatments were compared with the hand-weeded and untreated checks in dry-seeded, rainfed bunded rice.

In Pangasinan, the weights of broad-leaved weeds and sedges harvested from the plots did not differ significantly at 28 days after seeding, nor at harvest. But grass infestation was significantly lower in the plots treated with Antor and oxadiazon than in those treated with dinitramine and in the unweeded check. No other treatments differed significantly. The hand-weeded check plot had significantly fewer weeds than the others.

All herbicide-treated plots, except those treated with dinitramine, yielded significantly more than the untreated plot (Table 7). Many treated plots yielded as well as or better than the plot that was weeded three times. The latter yielded low because of crop damage during weeding.

Weed growth in dry-seeded rice at Iloilo was again much less than that at IRRI or in Pangasinan in 1977 (1976 Annual Report). A different weed flora also grows there. For example, species such as *Ischaemum rugosum* and *Panicum repens* replace *Echinochloa* sp. as the common grass weeds.

Because heavy rain soon after herbicide application ponded water in the field for several days, herbicides reduced stands. Antor was particularly toxic to rice and reduced its stand by 85%. Even though some herbicides reduced stands appreciably, rice compensated for the reduction. Final yields were not reduced except in plots treated with Antor (Table 8).

Table 6. Yield of upland rice under different weed control practices. Farmer's field, Iloilo province, Philippines, 1976.

Treatment	Herbicide rate (kg a.i.[a]/ha)	Weed wt[b] (g/m²)	Yield[b] (t/ha)
Hand-weeded (15 and 30 DE[c])	—	44 d	3.2 a
Butachlor	2.0	112 c	2.2 b
Terbuchlor	1.0	169 b	2.1 b
Thiobencarb	1.0	159 b	1.9 bc
Butralin	2.0	122 b	1.6 bc
No weeding	—	324 a	1.5 c

[a]Active ingredient. [b]In a column, means followed by the same letter are not significantly different at 5% level. [c]Days after rice emergence.

Table 7. Effects of different weed-control treatments on weed weight and yield of dry-seeded, rainfed bunded rice. Farmer's field, Pangasinan province, Philippines, 1977.

Treatment	Herbicide rate (kg a.i.[a]/ha)	Weed wt at heading[b] (g/0.25 m²)	Yield[b] (t/ha)
Oxadiazon	0.75	61 b	3.3 a
Thiobencarb	3.0	126 b	3.0 ab
Butralin	2.0	103 b	2.7 abc
Butachlor	2.0	80 b	2.6 abc
Antor (Hercules 22234)	1.0	126 b	2.5 abc
Prodiamine	1.5	106 b	2.4 abc
Weeded three times	—	27 a	1.9 abc
Pendimethalin	2.0	258 b	1.8 bc
Dinitramine	1.5	130 b	1.6 cd
Untreated	—	238 b	0.5 d

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

Weed growth in that trial was so light that yields of the weed-free and unweeded checks did not differ significantly. Yields from all treated plots, except those treated with Antor, did not differ significantly from the yields of the checks. Butralin and pendimethalin were less effective than the other herbicides; but because weed growth was light, yields were not significantly lower (Table 8).

In Pangasinan, reducing the space between rows of dry-seeded, rainfed-bunded rice from 25 to 20 cm, or increasing the seeding rate from 80 to 120 kg/ha, or even to 160 kg/ha, did not significantly affect the weeds growing with rice nor the rice yield. At 14 days after seeding and before any hand weeding, broad-leaved weeds and grasses in the plots treated with pendimethalin decreased significantly but sedges increased significantly. At the heading stage of the grasses, significantly more grasses and fewer sedges grew in the untreated plots than in the other plots. Plots treated with pendimethalin had significantly more sedges.

At heading, plots that were weeded twice and those that received pre-emergence treatments of pendimethalin followed by (fb) one hand weeding had significantly fewer weeds than either unweeded plots or those that had received a single pendimethalin treatment (Table 9).

The herbicides used did not reduce stands; yields reflected the degree of weed control. The highest average yield was from the plots that received a pre-emergence treatment of pendimethalin fb one hand weeding 35 days later (Table 9). Those plots did not yield significantly more than the plot that was hand weeded twice, but they significantly outyielded the plot that was weeded once. The plots treated with pendimethalin alone yielded significantly less than those in which pendimethalin was followed by one hand weeding.

In a trial to compare the effects of seeding methods — broadcasting, row seeding, and dibbling — on stand establishment, few differences in weed control or crop yields were found. The weed control treatments were similar to those used in the previous trial. Weed control in the plots where pendimethalin was fb one hand weeding was superior to that in plots treated

Table 8. Effects of various weed-control treatments on weed weight and yield of dry-seeded, rainfed bunded rice. Farmer's field, Iloilo province, Philippines, 1977.

Treatment	Herbicide rate (kg a.i.[a]/ha)	Weed wt[b] (g/0.25 m²) at 45 DE[c]	Plant count[b] (no./m²) at 30 DE[c]	Yield (t/ha)
Thiobencarb	3.0	2.7 b	101 de	4.9 a
Pendimethalin	2.0	4.8 cd	182 cd	4.7 a
Weed-free	—	0 a	306 a	4.6 a
Prodiamine	1.5	3.4 bc	151 cd	4.5 a
Butralin	2.0	8.3 cd	216 b	4.5 a
Butachlor	2.0	2.2 b	101 de	4.4 a
Dinitramine	1.5	3.3 bc	94 de	4.3 a
Untreated	—	9.7 d	289 a	4.2 a
Oxadiazon	0.75	2.8 bc	185 bc	4.1 a
Antor (Hercules 22234)	1.0	2.1 b	45 e	3.2 b

[a]Active ingredient. [b]Av. of three replications. In a column, means followed by the same letter are not significantly different at 5% level. [c]Days after rice emergence.

Table 9. Effect of various weed-control treatments on weed weight and yield of dry-seeded, rainfed bunded rice. Farmer's field, Pangasinan province, Philippines, 1977.

Treatment[a]	Weed wt[b] (g/0.5 m²)	Yield[b] (t/ha)
Pendimethalin (2 kg a.i./ha) fb one hand weeding	35 ab	6.1 a
Hand weeded twice (14 and 35 DS)	15 a	6.0 ab
Hand weeded once (21 DS)	42 bc	4.2 bc
Pendimethalin (2 kg a.i./ha)	131 cd	3.9 cd
No weeding	222 d	0.3 d

[a]a.i. = active ingredient. fb = followed by; DS = days after seeding. [b]Av. of three seeding rates and two row spacings. In a column, means followed by the same letter are not significantly different at 5% level.

with pendimethalin alone and that in the unweeded check plots, but it was inferior to that in plots that were hand weeded twice. The weed weight at harvest in the plots treated with pendimethalin alone did not differ significantly from that in the unweeded check plots. Unlike in the previous trial, sedges did not increase when pendimethalin was used. Again, yields reflected the degree of weed control at harvest. The plot that was treated with pendimethalin fb one hand weeding yielded significantly less (3.2 t/ha) than the plot that was hand weeded twice (4.6 t/ha). But the yield was superior to that from the plot that was treated with pendimethalin alone and that from the unweeded check. The last two treatments did not differ significantly in yield.

SCREENING NEW HERBICIDES

Agronomy Department

Each year herbicides are screened under rainfed conditions to identify those that are safe and effective for transplanted, direct-seeded, and upland rice.

Transplanted rice. The field site was moderately infested with *E. crus-galli* ssp. *hispidula*, *E. glabrescens*, *C. difformis*, *S. maritimus*, and *M. vaginalis*.

Several new herbicides looked promising for transplanted rainfed rice; they gave yields from 1 to 2 t/ha higher than that of the untreated control plot (Table 10). Two new herbicides, HOE 23408 and HOE 29152, killed the rice seedlings. All other new herbicides gave yields similar to those of the hand-weeded control. The coded compound CGA 26423 from Ciba Geigy, when used at 1.0 kg/ha as either preemergence or postemergence treatment, controlled grasses and broad-leaved weeds excellently without injuring the crop. R-40244 and RH 6201 were also promising when applied at the 2- to 3-leaf stage (Table 10).

Direct-seeded rice. No herbicide controlled weeds adequately because a long period of rainless days shortly after seeding caused unusually heavy infestation at the test site.

Upland rice. The new herbicides were generally toxic to upland rice or failed to control weeds.

Table 10. Effects of promising new herbicides on weed control, crop tolerance, and yield of transplanted IR26 rice under rainfed conditions. IRRI, 1977 wet season.

Treatment[a]	Application		Weeds[d] (g/m²)				Yield[f] (t/ha)
	Rate (kg a.i.[b]/ha)	Time (DT[c])	Grasses	Sedges	Broad-leaved weeds	Toxicity[e]	
R-40244 (G)	1.0	4	10	4	6	6	2.4 a
Fluridone (G)	0.08	4	2	9	2	4	2.2 a
RH 6201 (EC)	0.96	10	20	13	12	4	2.2 a
CGA 26423 (G)	1.0	4	0	9	0	0	2.1 a
R-40244 (G)	0.25	10	24	0	6	0	2.1 a
Fluridone (G)	0.04	4	6	23	1	2	2.1 a
CGA 26423 (G)	1.0	10	23	12	12	0	2.1 a
RH 6201 (EC)	0.96	4	22	28	0	3	2.1 a
R-40244 (G)	0.5	10	14	4	2	2	2.0 a
R-40244 (G)	1.0	10	8	8	0	3	1.9 a
Oxyfluorfen (G)	0.25	4	16	5	2	3	1.9 a
Fluridone (G)	0.02	4	11	7	15	0	1.8 a
R-40244 (G)	0.5	4	48	43	0	2	1.8 a
CGA 26423 (G)	0.5	10	6	16	7	0	1.7 a
CGA 26423 (G)	0.5	4	35	3	2	0	1.7 a
Thiobencarb/2,4-D IPE (G)	1.0/0.5	4	26	0	4	0	1.4 ab
HOE 23408	1.0	4	2	113	69	10	0.0 c
HOE 23408	1.0	10	0	22	240	10	0.0 c
HOE 29152	0.5	4	0	65	128	10	0.0 c
HOE 29152	0.5	10	3	175	199	10	0.0 c
Hand-weeded once	—	25	3	1	8	—	2.2 a
Untreated control	—	—	85	17	37	—	0.5 bc

[a]G = granule, EC = emulsifiable concentrate, IPE = isopropyl ester. A slant bar (/) means two herbicides were formulated on the same carrier and applied as a single treatment. [b]Active ingredient. [c]Days after transplanting. [d]Sampled at heading of grasses. [e]Taken at 16 DT. Rating scale: 0–10: 0 = no toxicity, 10 = complete kill. [f]Av. of two replications. Means followed by the same letter are not significantly different at 5% level.

CONTROL OF *CYPERUS ROTUNDUS*

Agronomy Department

Perfluidone, K-223, K-1441, and 2,4-D amine were compared for control of *C. rotundus* and for selectivity to IR9575 rice in a 1977 wet-season trial at IRRI. The weeds present at the experimental site were *C. rotundus*, *Amaranthus spinosus*, *Commelina benghalensis*, *Ipomoea triloba*, *Portulaca oleracea*, and *Eleusine indica*.

Weed infestation was so heavy that the untreated plots yielded nothing (Table 11). All plots treated with the nut sedge herbicides yielded significantly more than the untreated control plots or the plots treated with dinitramine alone. 2,4-D amine looked most promising for control of *C. rotundus* and did not damage the crop. Plots treated with it performed as well as the hand-weeded control (Table 11). K-1441 controlled nut sedge adequately but was moderately toxic to the crop. Likewise, perfluidone was toxic to rice and gave only fair control of *C. rotundus*. On the other hand, K-223 at 6.0 kg/ha was selective to the crop but gave the poorest weed control. For adequate weed control, 8 kg/ha or higher has been reported to be the optimum rate of application for K-223.

Nut sedge infestation directly and indirectly contributed to the zero yields in plots treated with dinitramine alone. Besides reducing crop tiller production, *C. rotundus*, upon senescence, permitted later growth of *C. benghalensis* and *I. triloba*, which took over the entire plots.

INTEGRATED WEED MANAGEMENT

Agronomy Department

Transplanted rice. The effects of variety, degree of tillage, and water depth on weed control in transplanted rice were studied in the 1977 dry season in a split-split-plot experiment with three replications. IR34 — a tall, medium-maturing (120–130 days) variety — and IR36 — a semidwarf, high-tillering, early maturing (105–110 days) rice — were planted in the main plots; the tillage methods used in the subplots were one plowing plus one, two, or three harrowings (Table 12). For the sub-subplots, water depths of 2.5 and 7.5 cm were used. The treatment with granular 2,4-D IPE at 0.5 kg a.i./ha and the untreated control were compared for weed control in the sub-sub-subplots. Twenty-one-day-old seedlings were transplanted at 20- × 20-cm spacing. Nitrogen as ammonium sulfate was applied at 120 kg/ha in three equal split doses: basally and incorporated during harrowing, at maximum tillering, and at panicle initiation.

Because of its higher panicle number, IR36 yielded significantly more than IR34 (Table 12). The yields of the varieties at the two water depths did not differ although total dry matter production of weeds was significantly less at the 7.5-cm level. Tillage treatment and water depth did not significantly affect the yield of either variety (Table 12), but weed control had a highly significant effect. Tillage did not affect the number of weeds present in plots of either variety, but one plowing fb two or three harrow-

Table 11. Effects of herbicides on the control of *Cyperus rotundus* and on yield of upland IR9575 rice. IRRI, 1977 wet season.

Treatment[a]	Application		Weeds[d] (g/m²)		Yield[e] (t/ha)
	Rate (kg a.i.[b]/ha)	Time[c]	*Cyperus rotundus*	Annual weeds	
Hand-weeded twice	—	15 fb 30 DE	1 a	1 a	2.4 a
Dinitramine fb 2,4-D amine	1.5 fb 1.0	2 DS fb 15 DE	15 bc	7 bc	2.2 a
Dinitramine fb 2,4-D amine	1.5 fb 1.0	2 DS fb 20 DE	37 cd	16 bc	1.8 a
K-1441 fb dinitramine	3.0 fb 1.5	PPI fb 2 DS	56 cd	22 c	1.0 b
Perfluidone + dinitramine	2.0 + 1.5	2 DS	112 de	10 bc	0.6 b
K-223 fb dinitramine	6.0 fb 1.5	PPI fb 2 DS	132 de	23 c	0.4 b
Dinitramine	1.5	2 DS	141 e	11 bc	0.0 c
Untreated control	—	—	6 ab	487 d	0.0 c

[a]fb = followed by; + means that the chemicals were applied separately at about the same time. [b]Active ingredient. [c]DE = days after rice emergence. DS = days after seeding. PPI = pre-planting incorporated. [d]Sampled at flowering of *C. rotundus*. In each column, means followed by the same letter are not significantly different at 5% level. [e]Av. of four replications.

Table 12. Yields of transplanted IR34 and IR36 rice cultivars as affected by degree of puddling, water depth (2.5, 7.5 cm), and herbicide application.[a] IRRI, 1977 dry season.

Tillage[b]	Yield[c] (t/ha)											
	IR34						IR36					
	2.5 cm			7.5 cm			2.5 cm			7.5 cm		
	No weed control	2,4-D IPE[c]	Difference	No weed control	2,4-D IPE	Difference	No weed control	2,4-D IPE	Difference	No weed control	2,4-D IPE	Difference
Plowing fb 1 harrowing	3.4	3.4	0.0^{ns}	3.7	4.5	0.8^{ns}	2.6	4.0	1.4^{ns}	4.2	4.6	0.4^{ns}
Plowing fb 2 harrowings	1.2	2.6	1.3^{ns}	1.8	4.0	2.3**	2.3	4.3	2.0*	3.8	4.2	0.4^{ns}
Plowing fb 3 harrowings	1.8	3.7	1.9*	3.7	3.1	-0.6^{ns}	4.4	5.2	0.8^{ns}	2.4	4.7	2.3**

[a]2,4-D IPE (isopropyl ester) at 0.5 kg. a.i./ha, applied 4 days after transplanting. [b]fb = followed by. [c]Av. of three replications.

ings greatly reduced dry matter production of grasses in IR36 plots. Total dry matter production of weeds per square meter was significantly less in IR36 at 7.5-cm water depth. That further indicated that high-tillering rice varieties compete with weeds better than do the low-tillering ones.

The major significant differences in the experiment were in weed-control treatments. Plots treated with granular 2,4-D IPE at 0.5 kg a.i./ha 4 days after transplanting gave significantly lower dry matter production and weed number than the no-weed control plots. That indicates that herbicide rates can be reduced without sacrificing weed control if other cultural practices are included in the integrated management system.

The same experiment was continued in the wet season to further study the effects of tillage and variety on weed control. The varieties and tillage methods were the same as those used in the dry season, but water depth as a treatment was excluded. Weed control treatments were 2,4-D IPE at 0.4 kg a.i./ha, 2,4-D IPE at 0.8 kg a.i./ha, one hand weeding, two hand weedings, and a check with no weed control (Table 13).

Both varieties yielded low because a typhoon damaged the crop a week before harvest (Table 13). Furthermore, most plots, especially the 2,4-D-treated and unweeded plots, were heavily infested with *Paspalum* sp. Tillage methods and varieties did not significantly affect yield, but yields in all treated plots differed highly significantly from those in the untreated control. Plots that were hand-weeded twice yielded significantly higher than those hand weeded once. Because of surviving broad-leaved weeds and sedges, herbicide-treated plots yielded slightly less than hand-weeded plots (Table 13).

Those results should be evaluated on the farm, where conditions are less favorable than those in experiment stations.

Table 13. Effect of degree of puddling and weed-control treatments on yields of transplanted IR34 and IR36 rice. IRRI, 1977 wet season.

Weed control treatment	Yield[a] (t/ha)					
	IR34			IR36		
	One plowing plus			One plowing plus		
	One harrowing	Two harrowings	Three harrowings	One harrowing	Two harrowings	Three harrowings
2,4-D IPE[b] (0.4 kg a.i./ha)	1.8 b	3.2 a	1.7 b	2.9 ab	3.1 a	2.1 bc
2,4-D IPE (0.8 kg a.i./ha)	1.5 b	3.5 b	2.9 a	2.3 b	3.5 a	3.1 ab
One hand weeding	3.1 a	2.5 a	2.8 a	3.3 ab	3.9 a	2.9 ab
Two hand weedings	3.2 a	3.0 a	3.3 a	3.6 a	3.7 a	3.7 a
No weed control	1.0 b	0.5 b	1.8 b	0.8 c	1.0 b	1.5 c

[a]Av. of three replications. In each column, means followed by a common letter are not significantly different at 5% level. [b]IPE = isopropyl ester. Applied 4 days after transplanting.

Table 14. Effects of degree of puddling, water depth, and herbicide applications[a] on yields of direct-seeded IR34 and IR36 rice. IRRI, 1977 dry season.

Tillage	Yield[b] (t/ha)											
	IR34						IR36					
	2.5 cm			7.5 cm			2.5 cm			7.5 cm		
	No weed control	Thio-bencarb/ 2,4-D IPE	Differ-ence	No weed control	Thio-bencarb/ 2,4-D IPE	Differ-ence	No weed control	Thio-bencarb/ 2,4-D IPE	Differ-ence	No weed control	Thio-bencarb/ 2,4-D IPE	Differ-ence
One harrowing	1.4	3.5	2.1*	1.8	4.3	2.5**	0.0	5.1	5.1**	1.8	4.3	2.5**
Two harrowings	1.2	4.2	3.0**	3.6	5.0	1.4ns	0.7	5.2	4.5**	1.8	5.9	4.1**
Three harrowings	3.1	5.3	2.2**	4.7	4.6	−0.1ns	0.9	5.8	4.9**	3.5	6.1	2.6**

[a]A slant line means two herbicides were formulated on the same carrier or mixed together and applied as a single treatment. IPE = isopropyl ester. [b]Av. of three replications.

Direct-seeded rice. The effects of variety, tillage, water depth, and herbicide on weed control in direct-seeded rice were further examined at IRRI in the 1977 dry season. The medium-statured IR34 and the semidwarf IR36 were grown in paddies that were harrowed once, twice, and three times in a single day. Two water depths (2.5 and 7.5 cm) were superimposed on the tillage and herbicide treatments (with and without thiobencarb/2,4-D at 0.67/0.33 kg/ha). The weeds at the experimental site were *E. crus-galli* ssp. *nispidula*, *E. glabrescens*, *M. vaginalis*, *C. difformis*, *Paspalum distichum*, and *S. maritimus*.

Crop height did not significantly affect weed control in paddies with 2.5 cm water and no herbicide applied when harrowed only once. Both IR34 and IR36 yielded low (Table 14). Two harrowings were required to improve the yields of both IR34 and IR36 regardless of water depth and herbicide treatment. The apparent further yield increases of IR34 and IR36 harrowed three times were caused by the thorough puddling made necessary by the occurrence of *P. distichum*. Without herbicides but at higher levels of land preparation, weed control was better and yields increased in IR34 plots with 7.5 cm water. Herbicide application in plots with 2.5 cm water significantly increased the yield of IR34 at all tillage levels, but not its yield in plots with 7.5 cm water with higher tillage. On the other hand, the addition of herbicides significantly increased the yield of IR36 in both water depths and under all degrees of land preparation. Without herbicides, deep water alone slightly improved IR36 yield (Table 14).

The results suggest that for a medium-statured variety such as IR34, good land preparation and standing water adequately control weeds without herbicide application.

Upland rice. The effects of variety, tillage, and herbicide on weed control in upland rice were studied in a split-split-plot in a 1976 wet-season experiment at IRRI. The semidwarf rice line IR1529-430-3, the intermediate-statured IR9575, and the tall M1-48 variety were row-seeded on plots that had been plowed once and rotovated once, twice, and three times during the same day. Superimposed on the tillage treatments were the weed-control treatments K-223 (6.0 kg/ha) fb terbuchlor (1.0 kg/ha), two hand weedings, and an untreated control.

The weeds in the experimental site were annual grasses such as *E. colona*, *D. sanguinalis*, *E. indica;* perennial grasses such as *Paspalum* sp., *Cynodon dactylon;* broad-leaved weeds such as *I. triloba*, *Eclipta alba*, Cleome sp.; and sedges such as *C. rotundus* and *C. iria*.

IR9575 and IR1529-430-3 yielded comparably; both yielded significantly more than M1-48 regardless of tillage degree or weed-control treatment (Table 15).

But weed-control treatments affected yields. The highest yields were in plots that were hand weeded twice, but they did not differ significantly from those of the herbicide treatment K-223 fb terbuchlor. The untreated control yielded significantly less than the treated plots (Table 16).

Table 15. Effect of tillage on weed control and grain yield of three upland rices. IRRI, 1976 wet season.

Tillage treatment[a]	IR1529-430-3		IR9575		M1-48		Tillage mean	
	Weed wt (g/m²)	Yield (t/ha)	Weed wt (g/m²)	Yield (t/ha)	Weed wt (g/m²)	Yield (t/ha)	Weed wt[b]	Yield[c]
Plowing fb 1 rotovation	131	1.5	144	2.1	191	1.1	155 b	1.6 a
Plowing fb 2 rotovations	114	1.7	123	2.3	132	1.1	123 a	1.7 a
Plowing fb 3 rotovations	124	1.8	110	2.1	105	1.0	113 a	1.6 a
				Mean				
	123 a	1.6 a	125 a	2.2 a	143 a	1.1 b		

[a]fb = followed by. [b]Weeds sampled at 50 days after rice emergence. [c]Av. of four replications, three weed control treatments. Means in a column or row followed by a common letter are not significantly different at 5% level.

Table 16. Effects of tillage and weed-control treatments on grain yield of upland rice. IRRI, 1976 wet season.

Weed control treatment[a]	Plowing fb 1 rotovation		Plowing fb 2 rotovations		Plowing fb 3 rotovations		Weed control mean	
	Weed wt (g/m²)	Yield (t/ha)	Weed wt (g/m²)	Yield (t/ha)	Weed wt (g/m²)	Yield (t/ha)	Weed wt[b]	Yield[c]
Two hand weedings	35	2.3	22	2.4	25	2.3	28 a	2.3 a
K-223 fb terbuchlor (6.0 fb 1.0 kg a.i./ha)	181	1.9	119	2.1	109	2.0	136 b	2.0 a
Untreated control	251	0.5	232	0.7	203	0.5	289 c	0.5 b
				Mean				
	155 b	1.6 a	124 a	1.7 a	112 a	1.6 a		

[a]fb = followed by. [b]Sampled at 50 days after rice emergence. Av. of four replications, three rice cultivars. Means in a column or row followed by a common letter are not significantly different at 5% level.

Dry-matter weights of weeds were comparable among varieties, suggesting that height of the rice plant did not affect weed growth. One plowing fb two rotovations and one plowing fb three rotovations gave significantly lower weed dry matter than one plowing fb one rotovation (Table 16). Weed weights in the plots that were hand weeded twice were significantly lower than in those where K-223 was followed by terbuchlor. Weed weight in the untreated control was significantly higher than that in either of the two other treatments.

LONG-TERM EFFECTS OF REDUCED TILLAGE

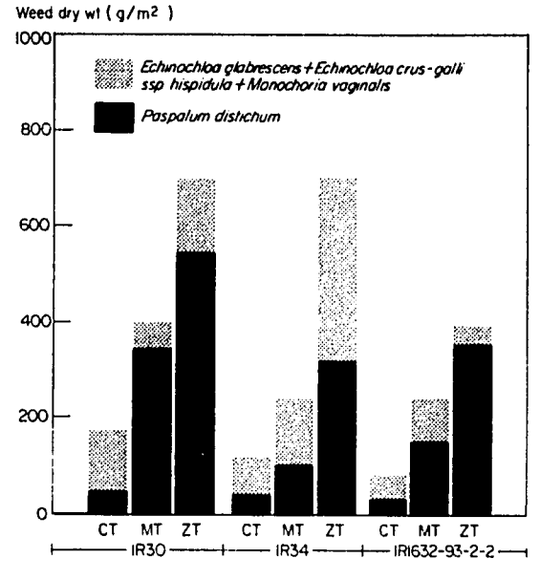
Agronomy Department

The study of the effect of reduced tillage on weed shift and on population density in transplanted rice was continued on the fifth crop (1976 Annual Report). The same rices (IR30, IR34, and IR1632-93-2-2) and tillage treatments (conventional, minimum, and zero) were used. Minimum tillage was one harrowing with three passes rather than thorough soil puddling; zero tillage had a 0.5 kg/ha spray of paraquat, both done at 1 day before transplanting. Other weed-control measures were blanket applications of thiobencarb/2,4-D (1.0 and 0.5 kg/ha) to control annual weeds, and bentazon (1.0 kg/ha) to control *S. maritimus*.

As tillage was reduced from conventional to zero, weeds shifted toward the perennial *P. distichum* (Fig. 1). Dry weights of *P. distichum* under minimum- and zero-tillage treatments were highest in plots of the low-tillering, short-statured IR30, followed by those in the plots of the high-tillering semidwarf IR1632-93-2-2. The dry weight of *P. distichum* was lowest in IR34 plots, suggesting that this intermediate-statured variety competed better than semidwarf rices in a difficult weed situation. But the increased incidence of the annuals *E. crus-galli* ssp. *hispidula*, *E. glabrescens*, and *M. vaginalis* partially negated this gain. IR1632 plots with zero tillage had the lowest total weed weight

mainly because of the low infestation of annual weeds, which indicates that this cultivar can suppress late-growing weeds by shading them out.

Under minimum cultivation, yields of the three rices were influenced by total rather than by specific weed infestation. For example, IR34 and IR1632, which had the same total dry weed weights, gave similar yields although the weight of *P. distichum* was higher in IR1632 plots (Table 17). But under zero tillage, the density of *P. distichum* affected yields. IR30, which did not adequately suppress the spread of this weed, yielded nothing. IR34 and IR1632, on the other hand, shaded out about 50% of *P. distichum* and produced some grain (Table 17).



1. Weed dry weights at harvest of the fifth crop, as indices of weed control by conventional tillage (CT), minimum tillage (MT), and zero tillage (ZT). IRRI, 1977 dry season.

WEED SAMPLING STUDIES

Statistics Department

Two series of experiments on natural weed populations in transplanted rice were conducted at IRRI. In the first (1975 wet and 1976 dry seasons), 12 levels of weed competition, each corresponding to the specific age of the rice plants when a weed-free condition was initiated (1 to 12 weeks after transplanting at 1-week intervals), were tested with IR28 as the indicator variety. Two other levels, weed free throughout growth and no weeding, were used as checks. The experiments were laid out in a randomized complete block design, with 4 replications in the 1975 wet season and 6 in the 1976 dry season.

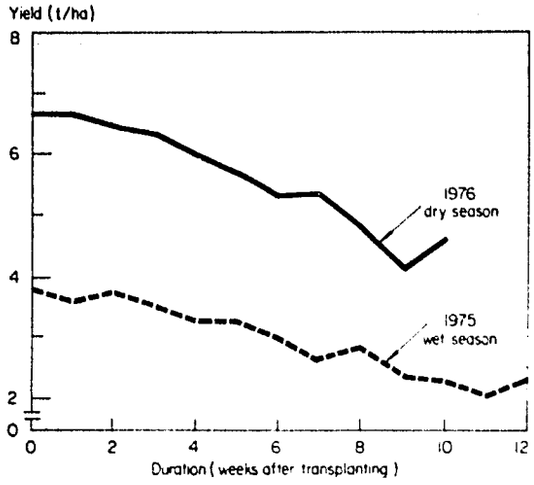
In the second set of experiments (1976 wet season and 1977 dry), the rice lines IR2823-101-6-3 and IR2307-247-2-2-3 were used. IR2823-101-6-3 is slightly taller and has fewer tillers than IR2307-247-2-2-3. Levels of weed population were varied by removing weeds at four growth stages of the rice plants: at 3 weeks after transplanting, at maximum tillering, at panicle initiation, and at flowering. Eight degrees of weed removal were used: 0, 10, 20, 40, 50, 70, 90, and 100%. The experimental design was split plot with variety in the main plot and degree of weed removal in the subplot. The treatments were tested in four replications. In the 1977 dry season, the yield of IR2823-101-6-3 was not analyzed because its plants were heavily infected with virus.

Time of weed sampling. In the first series of experiments, the presence of weeds up to 3

Table 17. Effects of tillage treatments on weed control and yield[a] of the fifth rice crop. IRRI, 1977 dry season.

Tillage treatment	IR30				IR34				IR1632-93-2-2			
	Weed wt[b] (g/m²)			Yield	Weed wt[b] (g/m²)			Yield	Weed wt[b] (g/m²)			Yield
	Annual	Perennial	Total	(t/ha)	Annual	Perennial	Total	(t/ha)	Annual	Perennial	Total	(t/ha)
Conventional tillage	127	45	172	1.3 a	70	38	108	2.1 a	60	18	78	1.4 a
Minimum tillage	45	348	393	0.7 b	142	97	239	1.4 b	87	147	234	1.7 a
Zero tillage	137	555	692	0.0 c	385	309	694	0.7 c	24	356	380	0.6 b

[a]Av. of four replications. Means followed by the same letter are not significantly different at 5% level. [b]Taken at rice harvest. Annuals were *Echinochloa glabrescens, E. crus-galli* ssp. *hispidula,* and *Monochoria vaginalis;* the perennial was *Paspalum distichum.*



2. Effects of weed competition on yield of IR28. IRRI, 1975–76.

weeks after transplanting did not significantly reduce yields (Fig. 2). But when the duration of weed competition reached 4 weeks after transplanting (about the maximum tillering stage), yields were reduced significantly. Weeds present at 9 weeks after transplanting and later (or after the flowering stage) did not contribute appreciably to yield loss. The critical period of weed competition seems to be from 4 to 9 weeks after transplanting, or at maximum tillering to flowering.

In the second series, multiple correlation coefficients between yield and various weed data (i.e., different combinations of weed weight and count, classified by weed type) were computed separately for each of three growth stages: maximum tillering, panicle initiation, and flowering. The correlations were almost always highest, especially with weed weight, when weed data were collected at flowering (Table 18, 19). The differences between the flowering and maximum-tillering stages were more pronounced.

The results indicate that weeds should be sampled during the maximum tillering and flowering stages of the rice plants. If weeds are to be sampled only once, they should be sampled at flowering.

Measures of weeds. The density and population of weeds in rice experimental plots are commonly measured by either their weight or count, or both. Counting weeds takes more time than weighing them. Also, separating weed samples into the three broad types (broadleaved weeds, grasses, and sedges) into which they are usually classified is tedious and time consuming.

In the second series of experiments, total weed weight, weed weight by type, weed count by type, and weed weight and weed count by type were correlated with rice yield.

In the 1976 wet season, classification of weed data, either weight or count, by weed type did

Table 18. Simple correlation coefficients between grain yield of rice and weed weight or weed count, by type of weed, at varying growth stages. IRRI, 1976–77.

Growth stage[a]	Correlation[b] of grain yield with					
	Weed wt			Weed count		
	B	G	S	B	G	S
	1976 wet season: IR2823-101-6-3					
MT	−0.47**	−0.36*	−0.34*	−0.36*	−0.48**	−0.41*
PI	−0.63**	−0.47**	−0.47**	−0.49**	−0.50**	−0.48**
F	−0.58**	−0.49**	−0.59**	−0.39*	−0.43**	−0.58**
	1976 wet season: IR2307-247-2-2-3					
MT	−0.39*	−0.57**	−0.56**	−0.36*	−0.59**	−0.52**
PI	−0.51**	−0.34**	−0.52**	−0.54**	−0.57**	−0.48**
F	−0.66**	−0.65**	−0.67**	−0.61**	−0.70**	−0.64**
	1977 dry season: IR2307-247-2-2-3					
MT	−0.30	−0.35*	−0.53**	−0.44**	−0.54**	−0.53**
PI	−0.31*	−0.17	−0.66**	−0.21	−0.32*	−0.59**
F	−0.38*	−0.42.*	−0.61**	−0.34*	−0.51**	−0.57**

[a]MT = maximum tiller; PI = panicle initiation; F = flowering. [b]Each coefficient was computed from 40 observations. B = broadleaved weeds, G = grasses, S = sedges.

Table 19. Multiple correlation coefficients between grain yield of rice and various combinations of weed data compared with a simple correlation with total weed weight at varying growth stages. IRRI, 1976–77.

Growth stage[a]	Simple corr. coeff. with total weed wt	Multiple correlation coefficient of grain yield with		
		Weed count[b]	Weed wt[b]	Weed count and wt[c]
		1976 wet season: IR2823-101-6-3		
MT	−0.52**	0.57**	0.55**	0.65**
PI	−0.66**	0.66**	0.66**	0.71**
F	−0.71**	0.66**	0.72**	0.72**
		1976 wet season: IR2307-247-2-2-3		
MT	−0.62**	0.68**	0.67**	0.70**
PI	−0.64**	0.71**	0.70**	0.73**
F	−0.82**	0.81**	0.82**	0.84**
		1977 dry season: IR2307-247-2-2-3		
MT	−0.55**	0.65**	0.61**	0.67**
PI	−0.58**	0.63**	0.71**	0.73**
F	−0.57**	0.63**	0.71**	0.74**

[a]MT = maximum tiller; PI = panicle initiation; F = flowering. [b]With three independent variables, each representing a weed type: broad-leaved weeds, grasses, and sedges. [c]With six independent variables, involving both weed weight and weed count, by weed type.

not appreciably improve the correlation between weed density and yield over that obtained by use of a much simpler measure of total weed weight (Table 19). But in the 1977 dry season, the classification of weed weight by type was better than the use of total weed weight.

Weed weight by weed type correlated with rice yields as well as, or even better than, weed count by weed type. Combining both weed weight and weed count, each by weed type, did not appreciably improve the correlation over that obtained with only weed weight classified by type.

The results are summarized as follows: 1) weed weight by weed type, and weed count by type correlated similarly well with rice yields, and 2) the combination of weed weight and weed count did not appreciably improve correlations with yield over those based on either measure. Because measurement of weed weight is simpler, it seems more appropriate to use for weed studies in transplanted rice. Classification of weeds by type may be necessary for more precise measurements, or when treatments are expected to drastically change the proportion of weed types. Otherwise, total weed weight is probably adequate.

Irrigation and water management

Irrigation and Water Management and Agricultural Economics Departments

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SUMMARY

Over 40% of the total water supplied to irrigated lowland rice is often supplied before the crop is actually transplanted. A study of 85 farms in a 145-ha irrigated unit revealed that it took 63 days from the first day of irrigation water supply for all the farmers to complete their transplanting operation. A total of about 940 mm of water was supplied from irrigation source and rainfall during that period. An account of the component uses of the water showed that about 225, 445, and 150 mm were lost as surface drainage from the area, seepage and percolation, and evaporation, respectively; about 110 mm was used for land soaking. Further analysis showed that if irrigation water was supplied throughout land preparation at the maximum designed rate of 22 mm/day, instead of the actual mean discharge of 9 mm/day, the total supply requirement for land soaking could have been achieved in 28 days, 12 days earlier than recorded. This means a saving of 189 mm of water — about 32% of the total irrigation water supplied for land preparation — due to reduced evaporation, and seepage and percolation.

Two instruments, a vane meter for measuring discharge in open channels and an automatic water sampler, were designed, fabricated, and tested in field conditions. The vane meter, which measures the torque produced by flowing water in a channel of known cross-sectional area, was found to be sufficiently accurate, unaffected by backflow, sensitive to almost all water levels and velocities, comparatively inexpensive, and easy to make and install. One disadvantage is that it tends to catch weeds and debris, and is affected by strong winds, especially when the water elevation is low. The automatic water sampler is designed to divert water from a flume into a distribution tube from which water sample flows by gravity to the sample collectors. The readiness of a collector to receive the sample was controlled by either a clock device or a float mechanism. The sampler was found useful in a 1977 study of nutrient movement in surface water flows.

A study of a rainfed area in Nueva Ecija showed that about 47% of the total rainfall was effective, i.e., used by the soil-crop system. Rainfall intensity was also found to influence rainfall effectivity. A simulation model applied to rainfed conditions indicated that the mean effective rainfall for 11 years (1966–76) at the IRRI experimental farm for an effective bund height of 5 cm was 100%, 90%, 85%, and 51% when the daily rainfall intensity was less than 10 mm, 10–20 mm, 20–40 mm, and more than 40 mm, respectively. Comparable values of effective rainfall for Cabanatuan City rainfall data were 100%, 89%, 65%, and 40%. It was also found that in years of normal rainfall, higher bunds resulted in significantly higher effective rainfall and consequently lesser number of stress days in the paddy.

To obtain more information on the costs and benefits associated with groundwater irrigation, a Philippine pilot tube well project with six deep tube wells fitted with electric pumps and irrigating about 286 ha was studied. One hundred and seven farmers were interviewed for production costs and returns for two seasons before and two seasons after the start of the project. Data on costs of system installation, and operation and maintenance were obtained from office records. Yield increase during the first year of the pumps' operation was only about 0.4 t/ha per season. With irrigation water, farmers obtained increased returns of US$67/ha in the wet season and US$34/ha in the dry season. Assuming the computed benefits to continue for the 15-year life of the project, and a discount rate of 12%, the benefit: cost ratio for the project was found to be much less than one. A break-even situation would result if a yearly mean yield increase of 0.2 t/ha could be achieved to reach the target yield of 3.86 t/ha in 1983 without additional costs.

Field-level water management practices affected the loss of nitrogen in water draining from lowland rice fields. The infiltration flow practice, in which the field water was left undisturbed and allowed to soak into the soil for 5 days after application of fertilizer, lost the least amount of nitrogen in the drainage water for both the topdressed and incorporated nitrogen application methods. Most nitrogen was lost in the continuous flow practice. Almost all drain-

age outflows were in the form of ammonium. Significantly higher yields were obtained when nitrogen was incorporated into the soil than when it was topdressed, possibly because of higher nitrogen use in the former method.

Studies under a wide range of conditions revealed that the rates of seepage and percolation (S&P) are influenced by soil texture, water table depth, density of drainage network, and topography and size of the area. Management practices such as continuous flooding or insufficient water supply also affect S&P significantly. Drought at any stage of growth, which is often encountered in poorly irrigated and rainfed rice, results in S&P rates almost 10 times greater after the stress than before.

Generally S&P rates are higher in the dry season than in the wet, reflecting the effects of deeper water tables and greater degree of drought stress in the dry season.

The effects of different landforms on irrigation and the relative water use and yields of chili, soybean, and rice were studied in the dry zone of Sri Lanka. Each crop, with the exception of lowland rice, was grown in graded and bench terraces constructed in well-drained, imperfectly drained, and poorly drained soils. Yield differences among drainage classes and between terrace types were generally not significant for any crop although the well-drained soils used significantly more water for each crop than either of the two other land classes. S&P losses ranged from 0.6 to 2.2 mm/day for the treatment combinations for chili, 0 to 1.0 mm/day for soybean, and 4.3 to 7.3 mm/day for rice. Yields per millimeter of water used by the soil-crop system were 3.4 kg/ha for chili, 4.5 kg/ha for rice, and 6.5 kg/ha for soybean. But as far as use of water by the plant itself is concerned, rice plants were more productive than the two other crops. Rice produced 9.8 kg/ha per mm of water used for evapotranspiration; soybean, 7.7 kg/ha; and chili, 4.9 kg/ha.

ENGINEERING AND MANAGEMENT

Irrigation and Water Management Department

Engineering and management projects completed in 1977 include studies on water supply and time requirement for land preparation, effectiveness of rainfall, and design of instruments for sampling and measuring the flow of water in the field.

Water supply and time requirements for lowland land preparation. The availability of water over time affects the amount of water and time required for land preparation. Over 40% of the total water supplied to lowland rice is often supplied before the crop is transplanted, but it takes farmers in most irrigated areas almost 2 months from the first irrigation to complete land preparation and transplanting (1972, 1973, and 1974 annual reports).

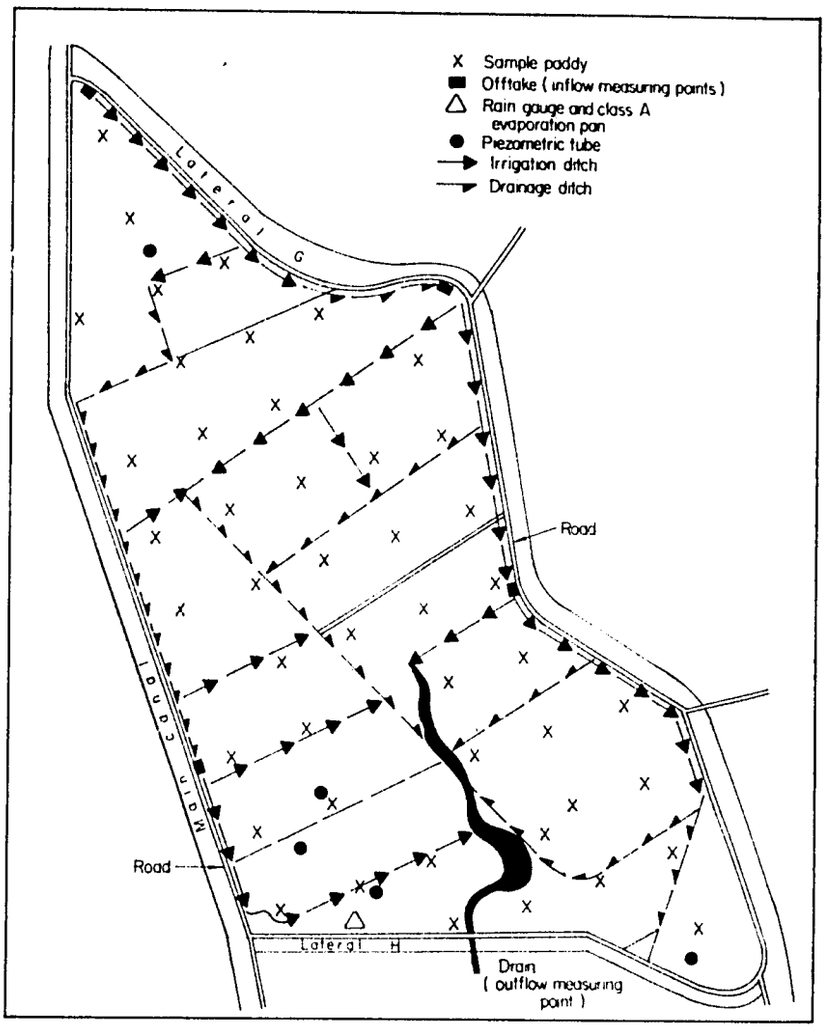
The interrelations of water supply and time to accomplish land preparation are important but poorly understood, partly because the water requirements for land preparation are not accurately known.

Lowland-rice land preparation in the Philippines usually consists of plowing after the soil has been thoroughly soaked for at least 3 days, followed by several harrowings to smooth and puddle the soil. Farmers usually wait at least a week between subsequent operations on the same field.

A joint study with the National Irrigation Administration of a 145-ha irrigated site in Talavera, Nueva Ecija province, examined the total water supplied and its component uses during land preparation, and traced the farmers' progress in completing operations. The study began with the first supply of water during the 1977 dry season. Before irrigation the soil was cracked and had a moisture content ranging from 8 to 13%. This soil moisture regime represents typical conditions during land preparation after an extended dry fallow period, and normally occurs at the beginning of the wet season.

The site received water from four offtakes of the irrigation system, and all surface drainage from the site passed through a single channel (Fig. 1). The soils at depths up to 30 cm were relatively homogeneous with clay loams on most of the site, but some loams on high areas. All were highly elastic alluvial soils, which cracked to mean widths of 7 cm and depths of 25 cm when dried. Inside the area, 85 farmers operated holdings each averaging 1.7 ha.

Parshall measuring flumes with continuous



1. Field site and location of paddies sampled for daily percentage of soil moisture content. Talavera, Nueva Ecija province, Philippines, 1977 wet season.

water level recorders measured the irrigation water from the four offtakes and the water draining from the site. Drainage that exceeded the height of the flumes was measured by calibrating the submerged culvert for flow at different head losses. Fifty-three paddies, selected on a grid basis of 200- × 200-m spacing, were observed daily and sampled for percentage of soil moisture (Fig. 1). Soil moisture data for the 0- to 15-cm and 15- to 30-cm profiles were plotted on enlarged photomaps to show the progress of land soaking within the area. Because the land could be plowed without much difficulty only after the soil moisture reached 38 to 42%, soil sampling for moisture content was stopped at that range in each sample paddy. Other soil and water parameters measured were bulk density of soils from four parts of the area, width and depth of soil cracks, and depths to water table.

After the sample paddies had been sufficiently soaked for plowing, they were monitored daily for dates of plowing, harrowing, and transplanting. When land preparation was complete, 92% of the farmers were interviewed on what they perceived as factors that affected

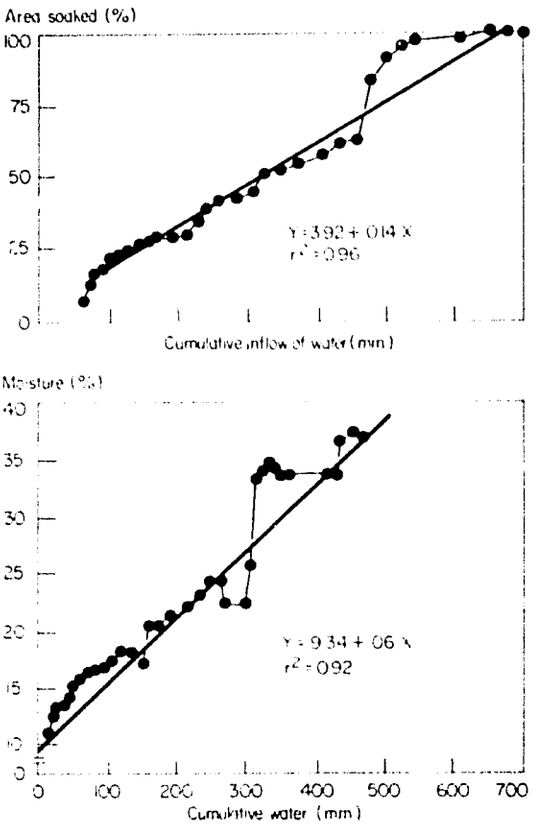
the duration and amount of water used during land preparation, and the constraints that could be removed to permit more rapid land preparation.

Water use for presaturation. The water required for the top 30 cm of soil was estimated by multiplying the change in soil moisture content by the profile depth and by the apparent specific gravity of the soil. The analysis was conducted separately for the 0- to 15-cm and 15- to 30-cm depths because soil parameters were expected to vary. Little variation was found, however, so only the combined results are presented.

Apparent specific gravity, measured for dry and soaked soils, had a mean value of 1.2. Both the percentage of the site soaked and the mean soil moisture content increased steadily, with cumulative water supplied from the irrigation system (Fig. 2). The procedure showed mean weekly increments of water for soaking that ranged from 7 to 37 mm, and a total use of 110 mm (Table 1).

The soaking data reflect the amount of water absorbed into the top 30 cm of soil. Total water requirements for land soaking should include both seepage and percolation (S&P) losses beyond the 30-cm horizon, and evaporation losses. Thus, as the proportion of the site being soaked changes, the proportion of total S&P and evaporation attributable to land soaking will change correspondingly.

Total S&P losses from fields undergoing land soaking were 182 mm with corresponding evaporation losses of 26 mm. Combined with the requirement for soaking, they produced a total water requirement of 318 mm for all components of land soaking (Table 1).



2. Percentage of area soaked and percentage of moisture content plotted against cumulative water supplied during land preparation. Talavera, Nueva Ecija province, Philippines, 1977 wet season.

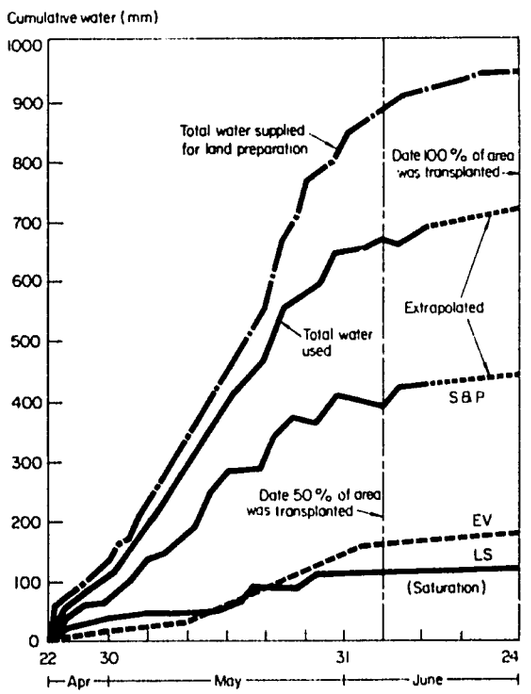
Table 1. Water used at weekly intervals for land soaking, seepage and percolation, and evaporation of unplowed areas. Talavera, Nueva Ecija, Philippines, 1977 dry season.

Week ending	Area fully soaked[a] (%)	Water used for land soaking[b] (mm)	Prorated water used for: Seepage and percolation[d] (mm)	Prorated water used for: Evaporation[e] (mm)	Total water required for land soaking[f] (mm)
22 April	0	8.9	22.9	0	31.8
29 April	10	21.0	34.9	6.3	61.5
6 May	27	6.6	58.8	3.7	69.3
13 May	42	23.4	46.6	4.8	74.8
20 May	62	35.6	18.2	10.4	64.2
26 May	98	14.3	1.8	0.6	16.7
Total	98	110.0	182.5	25.8	318.3

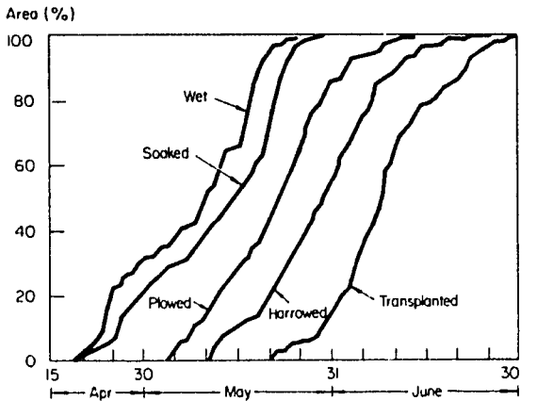
[a]Sample paddies were assumed fully soaked when they reached soil moisture content of 38 to 42% and were soft enough to plow. [b]Computed from change in soil moisture content of sample paddies times 30 cm rooting depth times apparent specific gravity of soil. [c]Total water for each use times the percentage of the area undergoing land soaking. [d]Calculated as a residual from total supply less drainage, land soaking, and evaporation. [e]From a class A evaporation pan. [f]Total of land soaking and prorated seepage, percolation, and evaporation.

Total water use for land preparation. The total water supply during land preparation is used for soaking the top 30-cm layer of soil, S&P beyond that layer, evaporation, and surface drainage. The water required for soaking was computed as 110 mm, and all other components, except S&P, were measured. Evaporation from the field was prorated according to the percentage of the site reached by water. By 4 June, when 50% of the site was transplanted, 656 mm of water had been supplied for land preparation, of which more than 400 mm was lost as S&P and as water absorbed into the soil profile after it was soaked to 38–42% moisture content (Fig. 3). Because total analysis was stopped on 11 June when heavy rains fell, the drainage data were incomplete. Eighty percent of the area had been transplanted by then and relatively little additional water was required for land preparation.

The water-use efficiency — total water required for each component divided by total water supplied — until 80% of the area was transplanted was 54%. It is higher than reported mean efficiencies (1972 Annual Report) and is attributed to the absence of excessive rainfall during most of the period, to the limited irrigation resulting from only four offtakes for the 145-ha area, and to the well-bounded nature of the area, which kept most of the applied water within the site.



3. Cumulative water supplied and water used for land soaking (LS), seepage and percolation (S&P), evaporation (EV), and their total during land preparation (curves for S&P and total water used were extrapolated after 11 June). Talavera, Nueva Ecija province, Philippines, 1977 wet season.



4. Percentage of area wet, soaked, plowed, harrowed, and transplanted by date. Talavera, Nueva Ecija province, Philippines, 1977 wet season.

Duration. The land soaking front moved slowly across the site, especially during the first weeks of irrigation. Once water reached a field, its soaking requirement was usually met within a week, but even after 3 weeks of irrigation less than 50% of the site had been soaked (Fig. 4). Half the area was soaked after 25 days, and all of it, by 40 days after the first irrigation. Land preparation followed the same trend, with a lag of about 26 days between soaking and transplanting of a given field. The mean age of seedlings for the site was 27 days, because farmers planted the seedbeds slightly ahead of the date the fields were ready for plowing, or less than a week after the fields were first wetted.

Two factors that prolong the total period of land preparation are, therefore, the length of time it takes for water to reach the more remote farms, and the age of seedlings. Both constraints can be removed by careful water management. The initial delay was caused by unpredictable and modest flow rates, especially during the first

2 weeks. The mean discharge rate for the area during that period was 9 mm/day, which resulted in land soaking of only 24% of the area (Fig. 2). If water at 22 mm/day (the maximum design rate and near the observed maximum) had been supplied throughout land preparation, the total water required for soaking would have been delivered in 28 days, 12 days earlier than recorded. Furthermore, total water savings for the entire land preparation period could have been estimated, based on reduced evaporation (6 mm/day) and S&P (4.5 mm/day) losses due to the shorter period. Those savings amount to 189 mm, 32% of the recorded total irrigation water supply. The total land preparation time would have been reduced from a mean of 48 days to 30 days.

Improved water management can create conditions conducive to the *dapog* nursery system in which 14-day seedlings are transplanted. The *dapog* system would permit farmers whose land is soaked last to partially catch up with the others. It is unlikely, however, that all farmers would adopt the practice. When the system was tried for the first time on a few farms outside the site, farmers expressed interest in adopting it provided the water supply was reliable. Adoption was retarded, however, by the belief that when 14-day seedlings are ready for planting, the land may not be fully prepared because of insufficient water.

Farmers' views. More than 70% of the farmers in the area cited undependable delivery of water as the chief constraint to rapid land preparation; 23% cited unavailability of cash and 6%, lack of machinery. Farmers expressed skepticism about schedules for water release and instead preferred to plan their operations after an adequate supply of water had reached their farms. Almost 90% of the farmers perceived benefits from simultaneous transplanting by all farmers; the majority cited reduced risk of disease and insect infestations as the main benefit. Three-fourths of the farmers felt that planting a common seedbed would not be a feasible way to speed up land preparation, but many (61%) were willing to try the *dapog* nursery system.

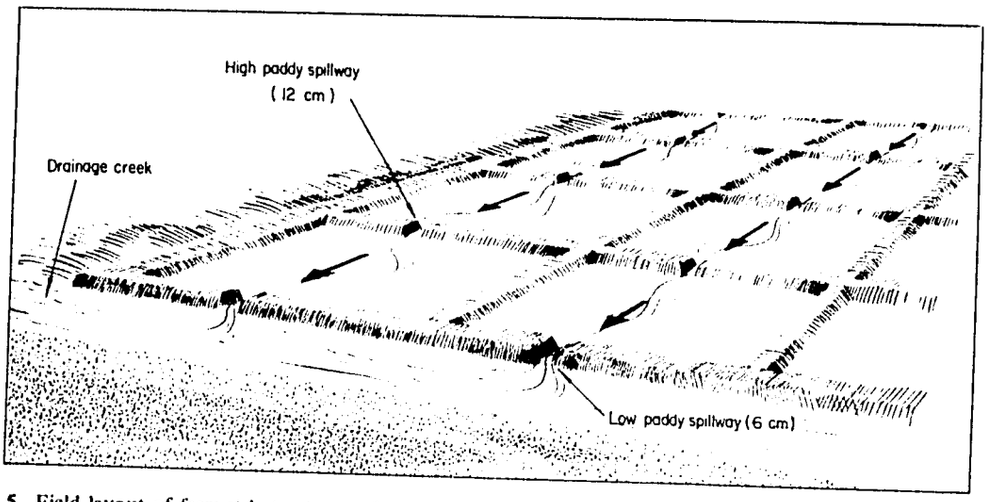
Field studies of effective rainfall for lowland rice. For a rainfed rice crop, more effective use of rainfall can result in earlier dates of planting, shorter and less severe periods of drought, and higher yields. In irrigated areas, effective use of rainfall saves irrigation water, which can be applied to a larger area. A 1976 study determined the effectiveness of rainfall, i.e., the proportion of total rainfall used by the soil-crop system, for rainfed lowland rice paddies of different spillway heights, and for irrigated lowland rice paddies with different spillway heights and irrigation management.

Methodology and computational models. The study was conducted on rainfed farm strips in Nueva Ecija, and on irrigated farm strips in Nueva Ecija and Laguna provinces during the 1976 wet season. The rainfed strips were a series of 5 to 10 paddies draining from one paddy to the next and finally into a creek. Two adjacent series were studied with spillways set at 6 cm above the soil surface in one series and at 12 cm above the surface in the other (Fig. 5). Each pair of treatments was replicated on three nearby farms. Rainfall, surface drainage from each series, and water depth above the soil surface were measured. Evaporation data were collected from a nearby hydrometeorology station.

Irrigated sites were selected in the same manner as the rainfed strips, except that they had six adjacent treatments. The six combinations of spillway management and irrigation management practices follow:

Treatment	*Spillway management*	*Irrigation management*
1	5 to 8 cm (adjustable)	Rotational (5-day cycle)
2	5 to 8 cm (adjustable)	Rotational (5-day cycle)
3	5 to 12 cm (adjustable)	Rotational (5-day cycle)
4	5 cm	Intermittent irrigation
5	5 cm	Rotational (5-day cycle with scheduled suspension)
6	5 cm	Continuous (with suspension)

If the average depth of water in the paddy was less than 5 cm, irrigation for the first three treatments was supplied once every fifth day; if it was greater than 5 cm, irrigation was withheld for another 5 days. Treatments 1 and 2 received irrigation water on different days. Treatment 4 was supplied with about [illegible] cm water whenever the field had no standing water. In treatment 5,



5. Field layout of farm strip treatments for study of effective rainfall for rainfed field. Nueva Ecija province, Philippines, 1976 wet season.

irrigation delivery was postponed 1 day for rainfall of 5-10 mm, 2 days for rainfall of 10-18 mm, and 3 days for rainfall greater than 18 mm. Treatment 6 was initially supplied with 5 cm of irrigation water and continuously supplied with 1 cm per day after that. But when it rained, or rainfall was expected, irrigation was postponed until there was no standing water in the paddy. The 5-cm application was then resumed and followed by daily application of 1 cm of water.

Spillway heights were adjusted by wooden frames with removable gates in the bund. The gates were opened to make low spillways during periods of irrigation, and closed afterwards to make high spillways to trap rainfall.

Three models for calculating effective rainfall were used:

1. *Drainage model.* The drainage model computes the noneffective rainfall by measuring surface drainage (SD) in millimeters from the paddy system (Fig. 6). For rainfed sites, all SD is assumed to be noneffective rainfall, so

$$EFR = 100 \frac{(RF - SD)}{RF}$$

$$= 100 \left(1 - \frac{SD}{RF}\right)$$

where EFR = effective rainfall (%), and RF = rainfall (mm).

In irrigated conditions both rainfall and irrigation water contribute to surface drainage. Therefore, the effective rainfall equation for this condition is

$$EFR = 100 \left(1 - \frac{SD_r}{RF}\right)$$

where SD_r is the amount of surface drainage attributable to rainfall. Assuming that SD_r is in the same proportion of SD as the rainfall amount in the total water supplied ($RF + IR$),

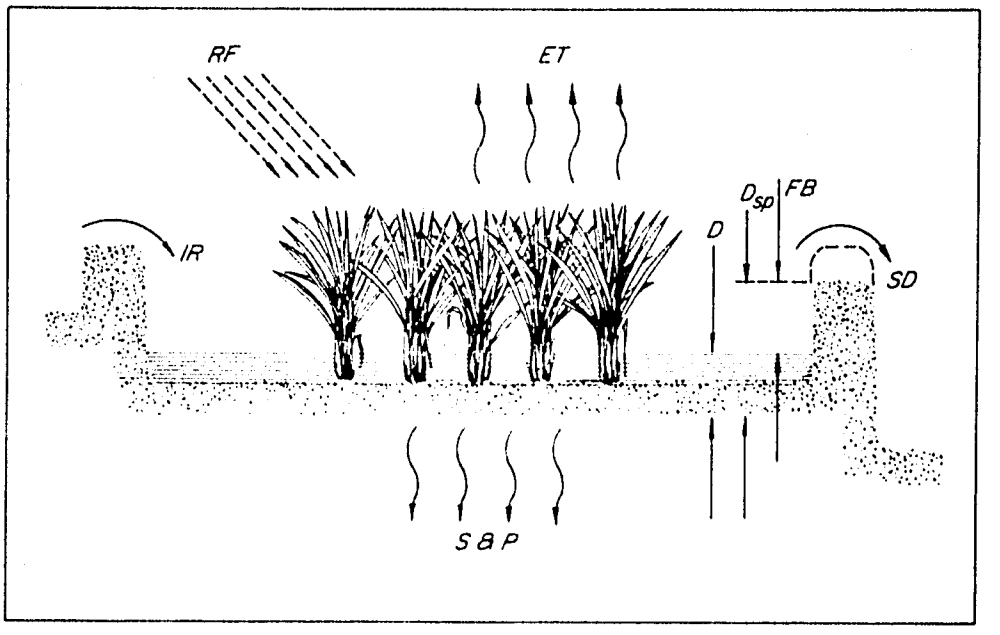
$$SD_r = \frac{SD\ (RF)}{RF + IR},$$

where IR is the depth of irrigation water applied. Substituting this in the equation for effective rainfall yields

$$EFR = 100 \left(1 - \frac{SD}{RF + IR}\right)$$

which is the drainage model used for irrigated conditions.

2. *Freeboard model.* This model assumes that the paddy system can store additional rainfall up to the level of the paddy spillway and no higher (Fig. 6). It uses mean depths of water recorded in the field for the water balance, and the available freeboard (FB) is expressed as



6. Components of the models used for computing effective rainfall. IRRI, 1976. IR = irrigation water, RF = rainfall, ET = evapotranspiration, S&P = water lost to seepage and percolation, D = water depth above soil surface, D_{sp} = height of spillway above paddy surface, FB = available freeboard, SD = surface drainage.

$$FB_t = D_{sp} - D_{t-1} + ET_t + S\&P_t$$

where D_{sp} is the height of the spillway above the paddy surface, D = the water depth above the soil surface, ET = evapotranspiration, $S\&P$ = the water lost to seepage and percolation, all in millimeters, and $t-1$ and t are two consecutive time intervals in days.

For $RF_t \leq FB_t$, $EFR = 100\%$ because all the rainfall is stored within the paddy system; for $RF_t > FB_t$, $EFR = 100\ (FB_t/RF_t)\%$; and for $RF_t = 0$, $EFR = 0\%$.

3. *Simulation model.* This model is similar to the freeboard model (Fig. 6) except that instead of using mean recorded depth of water on the paddy, the values of D_t are computed iteratively by

$$D_t = D_{t-1} + IR_t + RF_t - ET_t - S\&P_t - SD_t$$

Rainfed farm results. Total effective rainfall over the whole season was about the same for the three rainfed farms because of similar rainfall patterns. Mean effective rainfall for the two treatments, three farms, and three models in Gapan, Nueva Ecija, was about 47%, meaning that less than 50% of the 1976 wet season rainfall was utilized in growing the crop.

The simulation model showed little difference in effective rainfall between 12- and 6-cm spillway heights, but the freeboard model showed effective rainfall for the 12-cm spillways to be almost double that for the 6-cm ones (Table 2). The difference was due to S&P

Table 2. Effective rainfall based on three computational models for treatments of 6- and 12-cm-high paddy spillways. Means of three rainfed field sites, Nueva Ecija, Philippines, 1976 wet season.[a]

Spillway ht (cm)	Effective rainfall (% of total rainfall)		
	Freeboard model	Drainage model	Simulation model
6	28 a	45 a	42 a
12	54 b	64 b	47 a

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

Table 3. Mean effective rainfall at different intensities of daily rainfall on three rainfed farms with 6-cm and 12-cm-high paddy spillways. Nueva Ecija, Philippines, 1976 wet season.

Daily rainfall (mm)	Daily observations (no.)	Mean effective rainfall[a] (%)	
		6-cm spillways	12-cm spillways
<10	98	94 a	96 a
10–20	27	59 ab	61 ab
20–40	23	56 ab	64 ab
>40	24	36 b	43 b

[a]In the same column means followed by the same letter are not significantly different at the 5% level. Values for different spillway heights are not significantly different at any rainfall intensity level (5%).

rates, which were estimated by subtracting *SD* and *ET* from *IR* + *RF*. S&P was more than twice as great for the 12-cm as for 6-cm spillways because the greater depth of water stored in the former resulted in greater lateral seepage. Effective rainfall for the higher spillway was therefore biased upward; that for the 6-cm was biased downward because it received some of the seepage. Thus, effective rainfall calculations for both the freeboard and drainage models overestimate the effect of spillway height, and the insignificant difference reflected by the simulation model is probably more accurate.

The most important factor influencing effective rainfall is the intensity of daily rainfall. Rainfall effectiveness was reduced as rainfall intensity increased (Table 3).

Irrigated farm results. None of the three models showed significant difference in mean effective rainfall between the two irrigated Laguna sites, but all three showed rainfall at the Nueva Ecija site to have low effectiveness because of high rainfall during 2 weeks.

Among the six treatments of each site, only treatment 3 (12-cm spillways) had effective rainfall greater than that of some other treatments, and the differences were significant only for the freeboard and drainage models (Table 4). The simulation model produced almost equal mean effectiveness for all six treatments. Factors other than spillway height, e.g. rotational versus continuous irrigation, or suspension practices, did not significantly affect the extent of effective rainfall computed by any model for any site.

Direct comparisons of effective rainfall for the rainfed and irrigated sites were meaningful because the rainfall pattern was not the same for both. But the simulation model can find how irrigation affects effective rainfall by comparing computed effectiveness based on measured irrigation flows and that based on similar data but with no irrigation input (rainfed). By this procedure, the mean rainfall effectiveness in the irrigated trials was about 16% less than that in the rainfall trials (Table 4).

The mean volume of irrigation supply to all three sites was about 200 mm for the season. With soil and crop requirements assumed as 7 mm/day, the 200 mm was about 25% of the total water required for wet-season rice production, which was possible only through effective use of rainfall.

Effective rainfall simulated over 11 years. The simulation model was used to compute effective rainfall over 11 years (1966–76) at Los Baños, Laguna, and at Cabanatuan City, Nueva Ecija. Because irrigation data for those years were not available, the model applied only to rainfed conditions. The analysis used daily rainfall for 122-day cropping period beginning 1 June of each year, and included computations based on paddy spillways of 2, 5, 8, and 12 cm high. Evapotranspiration was assumed as 5.3 mm/day and S&P as 2 mm/day.

The results for Los Baños rainfall, based on 1966–76 records, show close to 100% effectiveness for higher spillways during years of less than the mean rainfall and about 50% effectiveness during 1 year of excessive rainfall

Table 4. Effective rainfall for six water treatments, based on three computation models. Means of three irrigated field sites, Nueva Ecija and Laguna, Philippines, 1976 wet season.

Treatment[a]	Effective rainfall (% of total rainfall)[b]			
			Simulation model	
	Freeboard model	Drainage model	With irrigation	Without irrigation
1	78 ab	75 ab	57 a	78 b
2	73 ab	72 ab	63 a	79 b
3	92 a	88 a	63 a	86 a
4	61 b	60 b	57 a	72 c
5	57 b	60 b	59 a	71 c
6	61 b	65 b	58 a	70 c

[a]See page 247 for description of treatments. [b]In the same column means followed by the same letter are not significantly different at 5% level.

Table 5. Mean effective rainfall, total rainfall, and total stress days for different spillway heights computed by simulation model for rainfed conditions. Rainfall at IRRI (Los Baños, Laguna) and Cabanatuan City (Nueva Ecija), Philippines, 1 June to 30 September 1964–76.

Year	IRRI					Cabanatuan City				
	Rainfall (mm)	Paddy spillway ht (cm)				Rainfall (mm)	Paddy spillway ht (cm)			
		2	5	8	12		2	5	8	12
		Mean effective rainfall (%)					*Mean effective rainfall (%)*			
1964						1343	54	65	70	73
1965						1471	52	58	59	59
1966	831	70	85	91	96	1028	61	69	72	76
1967	976	65	77	83	89	1666	46	52	57	59
1968	835	75	92	98	98	1279	53	59	62	65
1969	475	88	100	100	100	1220	50	57	62	68
1970	921	59	75	85	89	920	64	75	78	82
1971	866	65	73	76	78	1047	60	74	79	83
1972	1676	49	47	49	52	1947	36	41	43	45
1973	822	77	92	100	100	1253	54	65	67	68
1974	1029	51	62	67	75	1355	43	53	58	61
1975	853	66	82	89	96					
1976	1011	54	67	74	82					
Mean[a]	936	65 a	77 b	83 bc	87 c	1321	52 a	61 b	64 c	67 d
		Stress days[b]					*Stress days*[b]			
		22 a	14 ab	11 b	9 b		12 a	7 ab	4 bc	2 c

[a]Total days in excess of 3 when the soil was not flooded for the period between transplanting and 25 days before harvest. [b]In the same row, means followed by the same letter are not significantly different at 5% level. Tests were applied separately for each location.

(Table 5). Effective rainfall was relatively unaffected by spillway height during years of low rainfall (1969) and of high rainfall (1972). High spillways apparently are not sufficient to moderate water use significantly during years of high rainfall, and are not used when rainfall is low. But for years of intermediate rainfall, higher spillways allow more effective use of rainfall. The means for 11 years show that rainfall was significantly less effective with 2-cm spillways than with higher spillways; rainfall was significantly more effective with 12-cm spillways than with 5-cm spillways but there was no significant difference between 8- and 12-cm spillways. The 11-year analysis included computation of the number of stress days as a measure of water shortage for the crop for each year. The mean results show insignificant differences in stress days for paddy spillways 5 to 12 cm high, but larger differences between 2-cm and 8- or 12-cm spillways (Table 5).

Cabanatuan City recorded (1964–74) a mean of 1,321 mm of rainfall for the 122-day period starting 1 June. The yearly data showed that spillway height played an important role in saving rainwater. For years with moderate or high rainfall (1964, 1965, 1967, 1972, and 1973) effective rainfall did not vary much between 8-cm and 12-cm spillways (Table 5). In the high-rainfall year of 1972, more than 50% rainwater was ineffective. The Cabanatuan City record showed more response to spillway height than the Los Baños record because rainfall in Cabanatuan City tended to be greater and less uniform. The 11-year analysis reveals further that stress days vary with paddy spillway height. The number of stress days decreases significantly when spillway heights are increased by at least 6 cm. For years with moderate and high rainfall, the number of stress days was about the same for the 8-cm and 12-cm-high spillways.

Farmers' views on effects of water depth on productivity and problems of rice culture. The height of paddy spillways controls the depth of standing water in lowland rice, and is one of the few water-related factors for which the farmers are responsible. Farmers' views on the preferred depth of standing water for rice were collected through interviews of 40 rainfed-rice

Table 6. Farmers' views[a] of the effects of water depth[b] on tillering, yield, rat damage, insect damage, and diseases of rice. Nueva Ecija, Bulacan, and Laguna, Philippines, 1976 wet season.

Farmers' view	Deep water		Shallow water	
	Irrigated farms (%)	Rainfed farms (%)	Irrigated farms (%)	Rainfed farms (%)
Increases tillering[b]	0 a	3 b	92 a	85 a
Decreases tillering	92 a	72 b	0 a	0 a
Increases yield	0 a	10 b	92 a	78 b
Decreases yield	92 a	65 b	0 a	7 b
Greater damage from rats	2 a	5 b	0 a	5 b
Less damage from rats	52 a	18 b	54 a	18 b
Greater damage from insect pests	5 a	30 b	0 a	3 b
Less damage from insect pests	52 a	23 b	55 a	45 b
Greater damage from diseases	52 a	38 a	0 a	3 b
Less damage from diseases	5 a	15 a	55 a	45 b

[a]Farmers from 40 rainfed farms and 65 irrigated farms were interviewed. [b]Percentages were based on total responses in rainfed or irrigated sample. Sums within a category may not equal 100% because of "don't know" or "no answer" responses. Deep water = greater than 7 cm, shallow water = less than 5 cm. Values in the same row for each water depth followed by the same letter are not significantly different at the 5% level based on chi-square test applied to number of responses.

farmers in Bulacan and Nueva Ecija provinces, and 65 irrigated-rice farmers in Nueva Ecija and Laguna provinces.

The effect of shallow water (less than 5 cm) on rice production was evaluated similarly by farmers growing rainfed and irrigated rice. More than 85% of both samples said that shallow water increased rice yields by promoting tillering (Table 6).

The effect of deep water (greater than 7 cm) was perceived somewhat differently by the two groups of farmers. Sixty-five percent of those growing rainfed rice indicated that deep water decreased their yield, while 92% of irrigated-rice farmers had the same opinion. Farmers with irrigation have stronger reservations about deep water on their paddies because their fields have a more secure water regime. They are thus less inclined to save water and maximize effective use of rainfall through higher spillways than are farmers who depend only on rainfall as their source of water.

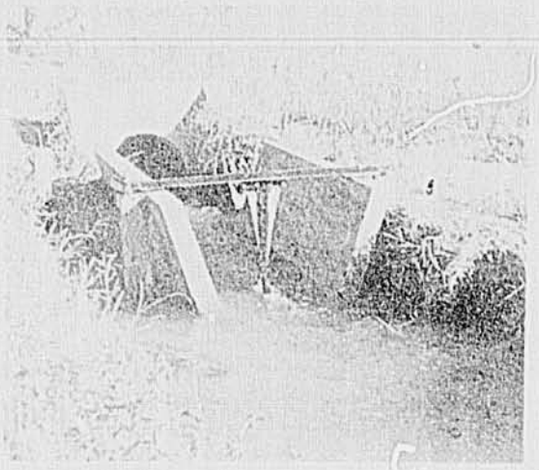
More than half of the farmers growing irrigated rice said that neither shallow nor deep water causes additional crop damage due to rats and insects. Farmers growing rainfed rice feel the same regarding rat damage, but they said that deep water encourages insects and results in greater crop damage. Both groups claimed that deep water leads to more crop damage because of the crop's susceptibility to diseases.

There is some evidence that rainfed-rice farmers are more willing to tolerate deep or shallow water than irrigated-rice farmers, but the difference is relatively small. Neither group was inclined to drain water from their fields more than they now do, or to increase the stored water on the paddy to depths greater than 4 to 6 cm.

Instrumentation in water management. Difficulty in measuring the principal variables, especially water flow rates, is a constraint to improved water management. Two instruments, an automatic water sampler and a vane for measuring discharge, were designed, fabricated, and tested for irrigation water management.

Vane instrument for measuring discharge. Many devices are used to measure water flows in the field. Most, such as weirs, Parshall flumes, and constant head orifices produce a head (increased elevation) of water that can be related to discharge. Current meters are laborious to use and cannot be placed permanently at a measuring point.

Each existing device is satisfactory for measuring flows under certain conditions, but each has disadvantages. The head-producing devices partially block canals, thereby increasing the upstream head and retarding the flow. They need sufficient channel slope or head (0.10-m minimum) to operate efficiently. Cur-



7. Vane-type instrument installed on a trapezoidal concrete channel (RRI, 1977).

rentmeters do not measure the discharge directly and require additional measurement of the cross-sectional area. Almost all the devices commonly used are ineffective when water movement is slow. To overcome most of the disadvantages, a vane instrument was designed and used in irrigation field studies.

The vane instrument determines the amount of water flowing along an open channel by measuring the torque produced by the flowing water, and relating it to discharge. The instrument has two main parts: a vane that is submerged vertically and subjected to the force of the flowing water and a meter, which includes a scale and counterweight, to measure torque required to counteract the drag force acting on the vane (Fig. 7).

When the drag force produced by the flowing water deflects the vane from its vertical position, the shaft rotates and the torque meter is deflected. To counteract the drag force, the counterweight is adjusted along the scale until the torque meter returns to horizontal, which indicates that the vane is also vertical. The product of the distance of the counterweight from the center of the shaft times its weight is the torque acting on the vane.

The critical feature of the instrument is the shape of the vane. The general flow equation is: discharge equals the velocity of the water times the cross-sectional area of the channel filled with water. Because cross-sectional area increases with greater water depth in the channel, the same discharge rate can be achieved with relatively high velocities and shallow water depths, or with low velocities and deep water depths. The vane must be so shaped that the drag force of the moving water would produce equal torque in both conditions. The design can be specified by differential calculus provided the shape of the channel, height of the vane, mass density of water, drag coefficient, location of the point force acting on the vane, and the relative areas of vane and channel section at maximum water depth are known.

With a properly proportioned vane, the discharge Q can be measured by

$$Q = K\sqrt{M}$$

where Q is in liters per second, M is the torque in gram-meters, and K is a constant whose value is determined by design specifications such as vane size relative to channel size, geometry of the channel, and other considerations. K can be determined by field calibration of the instrument, and does not change for vanes of the same shape installed in different sections of the same dimension.

Prototype instruments were designed and fabricated for channels of rectangular and trapezoidal cross sections, but designs for trapezoidal sections were emphasized because they are common in irrigation and drainage canals. The test channel had side slopes of 3:1, a 0.30-m base width, and 1.2-m length. The prototype instrument has an aluminum vane mounted on knife edges 0.15 m upstream from the end of the section. It was calibrated for both fast water velocities (free flow) and sluggish flows (backflow) with a Parshall flume or current meter upstream of the instrument.

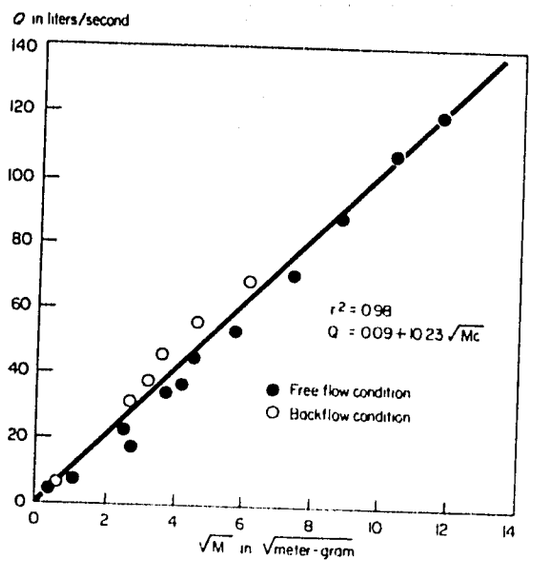
The free-flow relationship was

$$Q = 4.5 + 10.6\sqrt{M}$$
$$(\text{No. obs.} = 12;\ r^2 = 0.99),$$

while the backflow relationship was

$$Q = 1.9 + 11.2\sqrt{M}$$
$$(\text{No. obs.} = 6;\ r^2 = 0.98).$$

Combining the calibration points for both conditions, the general relationship (Fig. 8) was



8. Field test of the vane instrument prototype installed in a trapezoidal channel whose base = 30 m, side slope = 3:1, maximum water depth = 60 cm, and channel length = 120 cm. IRRI, 1977.

$$Q = -0.1 + 10.2\sqrt{M}$$
$$(\text{No. obs.} = 18;\ r^2 = 0.98).$$

The vane instrument has a number of significant advantages. It does not constrict water flow through an open channel and can operate with small or no head loss. It is essentially unaffected by backflow and is sensitive to almost all water levels and velocities. That permits its use in channels with low grade and minimum head loss, such as drains. The vane instrument requires minimum calibration, is inexpensive, and easy to make, install, and maintain. It is read like a beam balance scale, with torque values converted directly to flow with the use of rating tables based on the calibration constant. The total cost of the vane, mount, and torque meter is about US$10 exclusive of the channel.

Although the prototype test section was of field channel dimensions, the vane can be used efficiently in large canals or drains where standard measuring systems would be difficult to construct. In practice, lined channels could serve as control sections. After development of the prototype, eight vane instruments were installed for joint operations and research with the Philippine National Irrigation Administration.

A disadvantage of the vane instrument is that it tends to catch weeds and debris flowing in the water. To avoid that, it can be swung out of the water when not in use. For this reason, it is not well adapted for continuous recording of discharge. The vane is also affected by strong winds, especially when the water elevation is low.

Automatic water sampler. Collecting water samples in the field requires periodic attention on a 24-hour basis. A simple instrument for collecting water samples in a water-measuring device such as a Parshall flume would be useful in pollution and siltation studies. Constraints in designing such an instrument for field use included lack of electric power, lack of security, and extremes of temperature and humidity.

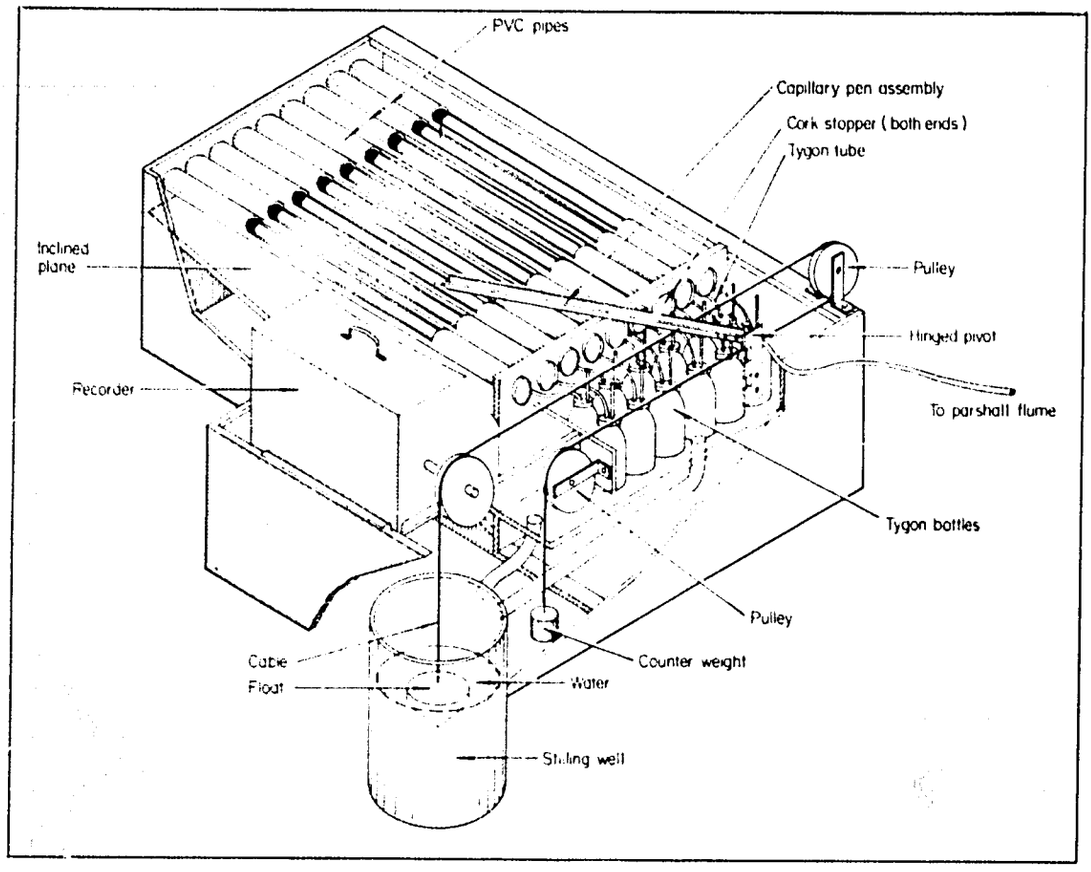
The design for the IRRI automatic sampler is based on a small feeder tube diverting water from a flume into a distribution tube. The tube swings slowly through an arc distributing water into a series of collectors, each of which discharges directly into a sampling bottle (Fig. 9).

Two mechanisms were developed to swing the tube. The first connects the tube to a light cable attached to a capstan run by an 8-day clock. The clock pulls the distribution tube past the set of collectors at speeds predetermined according to the desired sampling frequency, by using pulleys of different sizes.

Another means of moving the distribution tube past the collectors is by float and counterweight (Fig. 9). When a bottle is filled, the additional water spills from the collector into the sump. As the sump fills, the float rises, pulling the distribution tube through its arc by the cable linkage. When a bottle is filling, no water spills and the tube remains stationary. The advantage of the float design is that frequency of sampling is determined by water flow instead of by time unit as is the case with the clock system.

An exhaust line for the bottles allows air to escape as the bottle fills, and acts as a seal to stop the entry and mixing of additional water when the distribution tube is still over a full bottle.

The water sampler is inexpensive to build, install, and maintain. It does not require a pump



9. Automatic water sampling device for collection of sample in the field. IRRI, 1977.

or external power source, but it does require that the water source be higher than the distributor arm so that water flows by gravity to the collectors. The sampler was used in a 1977 study of nutrient movement in surface water flows.

ECONOMIC DIMENSIONS OF IRRIGATION

Agricultural Economics and Irrigation and Water Management Departments

Previous research on economic issues in irrigation included studies of how irrigation affects rice production and how profitability of irrigation investment is influenced by improved rice production technology. Studies in 1977 included an economic evaluation of a special form of irrigation.

Economic evaluation of tube well irrigation in the Philippines. Increasing attention is being focused on groundwater as a plentiful source of irrigation water in many rice-producing areas not suited to canal irrigation. To obtain more information on the costs and benefits associated with groundwater irrigation in the Philippines, a study of a system that included six 60-hp electric pumps in deep tube wells ranging from 200 to 303 m deep was undertaken. The command area included about 300 ha. The wells were constructed in 1975 for distribution canals already in place and formerly supplied by a river diversion system.

The project resulted in higher yields and expansion of the rice area cropped in the dry season (Table 7). There was almost no change in the wet season crop area within the project.

Table 7. Rice production and costs in a pilot groundwater project replacing diversion gravity water, 107 sample farmers, Philippines, 1975–76.

	Wet season			Dry season		
	Area (ha)	Yield (t/ha)	Costs (US$/ha)	Area (ha)	Yield (t/ha)	Costs (US$/ha)
			Within project area			
Before	287	2.37	187	211	1.82	192
After	282	2.91	187	272	2.12	196
			Outside project area			
Before	86	1.95	157	0	0	0
After	86	2.33	187	57	1.48	159

However, because part of the command area was previously served by the diversion system, the benefits of the pump project included both increased production within the project area and production made possible by water not used within the project area, and now available to other parts of the canal system.

The annual flow of benefits was computed by multiplying the increased quantity of production by the price of rice and subtracting the increased costs of production. All costs were computed at 1975–76 prices. About 86 ha outside the command area of the pumps benefited from the project.

One hundred and seven farmers were interviewed in 1977 to determine their production practices, costs, yields, and water-related problems. Data were obtained for the wet and dry seasons preceding the installation of the pumps, and the two seasons following activation of the system. Costs of system installation and operation were obtained from the records maintained by the irrigation agency (Table 8). Because the sample covered 64% of the rice production area, the farm survey data were inflated to represent the entire command area.

Performance was poor during the first year of operation. Yields increased by 0.5 t/ha during the wet season and 0.7 t/ha during the dry season of the first year, and the area of dry season rice increased by 61 ha. Assuming that those benefits continue for the 15-year life of the project, that all costs and value of benefits are discounted to a common point in time, and a discount rate of 12%, the benefit: cost ratio is less than one (Table 9).

However, a break-even situation would result 9 years after, if the project's target yield of 3.86 t/ha is achieved in 1983 without additional costs (Table 9). That yield has been achieved in other Philippine irrigation systems, and an even

Table 8. Costs and benefits computations for pilot groundwater project under three yield levels. Data from 107 sample farmers were adjusted to reflect total irrigated area. Philippines, 1977.

	Costs and benefits (US$)						
Year	Capital cost	O&M[a]	Production cost change	Gross cost	PV[b] at 12%	Production value (change)	PV[b] at 12%
			Within project area, 1976–77 actual yields				
1975	516,737	0	0	516,737	461,446	0	0
1976–1990	0	19,181	11,574	30,755	186,990	41,403	251,730
Total					648,436		251,730
			Within project area, inflated yields[c]				
1976–1990	0	19,181	11,574	30,755	186,990	53,835	327,316
			Within project area, target yields[d]				
1976–1990	0	19,181	11,574	30,755	186,990	130,502	633,002
			Outside project area[e]				
1976–1990	0	0	11,692	11,692	71,087	14,689	89,309

[a]Operation and maintenance (O&M) costs were reduced by 11% assumed to cover the cost of testing the capacity of the aquifer. [b]Present value. [c]Inflated by 30% to account for possible under-reporting by farmers during interview (1973 Annual Report). [d]Yields are projected to increase from 2.35 to 3.86 t/ha in 1983, remaining constant thereafter. [e]Assumed yields of 2.3 t/ha in the wet season and 1.4 t/ha in the dry season.

Table 9. Benefit-to-cost ratio (B:C) for pilot groundwater project under three alternative yield levels.[a] Philippines, 1977.

Yield level	Discounted value (US$) of Costs	Benefits	B:C
1976–77, actual[b]	719,523	341,039	0.47
1976–77, inflated[c]	719,523	416,625	0.58
1983 targets[d]	719,523	722,311	1.00

[a]Pooled change in yield and cost within and outside the project area was used in computing the B:C. [b]Actual yields averaged 2.5 t/ha (wet and dry seasons) in the first year after the project started. [c]Yields were inflated by 30% to account for possible under-reporting by farmers during interview (1973 Annual Report). [d]Yield level of 3.86 t/ha was the project target for 1983.

higher rate of yield increase over time could be projected for the area if complementary agricultural technology is also adopted. A study similar to the one reported here is therefore planned for 1980 or thereabout to evaluate the trend of change in benefits and costs.

Private benefits to farmers within the command area were reflected in their returns. On the basis of their yields and costs, farmers had an increased return of US$67/ha in the wet season and US$34/ha in the dry season (Table 10). These increases exceeded the increase in the annual water fee of about US$22/ha. If one assumes that land and family labor are paid the opportunity cost, the returns to capital and water supplied are those shown in the last line of Table 10. Clearly, the project improved the capacity of the farmers to pay for irrigation, although in the dry season total cost still exceeded total returns.

Despite the benefits, farmers still report considerable problems of water shortage. Nineteen percent reported insufficient water before and after the project in the wet season, while the proportion reporting water shortage during the dry season dropped from 65% to 50%.

SOILS, WATER, AND YIELD RELATIONSHIPS

Irrigation and Water Management Department

Studies completed in 1977 covered S&P losses in flooded soils, nitrogen losses in drainage from rice fields, and water use and yield studies for chili, soybean, and rice crops.

Seepage and percolation through flooded soils. Previous research documented typical rates of S&P through puddled lowland soils of the Philippines (1972, 1975 annual reports). Research in 1977 focused on relating the S&P rates to soils and environmental parameters,

Table 10. Alternative measures of income per hectare (1975–76 constant prices) before and after the project, sample of 107 rice farmers, pilot groundwater project, Philippines.

Item	Wet season Before	After	Change	Dry season Before	After	Change
1. Value of production (US$/ha)	299.3	366.9	67.6	229.7	267.2	37.5
2. Cost of production (US$/ha)	187.1	187.9	.8	192.8	196.0	3.2
3. Returns to land, capital, family labor and water (US$/ha; 1–2)	112.2	179.0	66.8	36.9	71.2	34.3
4. Land cost[a] (US$/ha)	37.1	40.4		32.4	35.6	
5. Returns to farm family labor, capital and water (US$/ha)	75.1	138.6	63.5	4.5	35.6	31.1
6. Water fees (US$/ha)	5.4	13.8		7.8	21.2	
7. Returns to farm family labor and capital (5–6)	69.7	124.8	55.1	–3.3	14.4	17.7
8. Family labor[b] (man-days)	33.0	34.0		34.0	35.0	
9. Returns per man-day family labor (US$/m-d; 7 ÷ 8)	2.1	3.6	1.5	–.10	0.41	0.51
10. Imputed value of family labor[c]	40.5	42.8		42.3	41.9	
11. Returns to capital and water supplied (US$/ha, 5–10)	34.6	95.8	61.2	–37.8	–6.3	44.1

[a]Average rental paid by lessees; 35% of sample were owners or part-owners, others were tenants or lessees. [b]Includes exchange labor. [c]Imputed at market wage rate paid per man-day for specified jobs.

Table 11. Mean and potential[a] rates of seepage and percolation for 19 field sites stratified by season, area, drainage density, and stress days, Central and southern Luzon, Philippines. Based on data for 1969–70 wet and dry seasons.

Factor	Sites (no.)	Seepage and percolation[b] (mm/day)	
		Mean	Potential
Seasons[c]			
Wet	8	2.2 (−1.0 to 6.0)	1.9 (−2.0 to 6.9)
Dry	8	3.9 (−0.3 to 10.1)	4.5 (−0.2 to 21.2)
Area per site			
1.2 to 20.3 ha	10	6.9*(0.8 to 17.2)	11.1*(0.0 to 26.3)
20.4 to 74.0 ha	9	2.0 (−1.0 to 6.3)	0.9 (−2.0 to 3.7)
Drainage density			
0– 50 m/ha	10	3.3 (−1.0 to 15.7)	3.5 (−2.0 to 26.3)
51–317 m/ha	9	6.0 (1.3 to 17.2)	9.4*(0.9 to 25.8)
Stress days (no.)			
0–10	12	2.2 (−1.0 to 6 0)	1.6 (−2.0 to 6.9)
11–71	7	8.8*(2.1 to 17.2)	14.3*(0.2 to 26.3)

[a]Mean is based on water balance over entire cropping season; potential is modeled, and excludes data for the days water was not available to the site. [b]Within a factor, a value marked with an asterisk is significantly greater than the other at 5% level. Tested by paired *t*-test for seasons and *F*-test for others. Numbers within parentheses show range of values. [c]Only the eight sites studied in both seasons are included.

and on determining representative rates for selected soils of Bangladesh.

In a study conducted by the University of the Philippines at Los Baños College of Agriculture (UPLBCA) using the water balance method, mean S&P rates ranged from −1.0 to 17.2 mm/day for 19 field sites (25 ha) in Central and southern Luzon (1972 Annual Report). Mean S&P rates for sites that suffered water shortages were abnormally low, so a potential rate was computed based only on those periods when the sites were fully flooded. Mean and potential S&P rates were then computed for sites stratified according to season, area, drainage density, and the number of days water was limiting during crop growth.

The mean S&P rates for 8 sites were 2.2 mm/day in the wet season and 3.9 mm/day in the dry (Table 11). The high S&P rate was associated with small sites because seepage from their edges was greater. Ten sites with drains between 0 and 50 m/ha had mean S&P of less than 3.3 mm/day, while 9 others had mean S&P of 6.0 mm/day because they had a higher capacity to remove seepage. The mean S&P rate was 2.2 mm/day for sites with less than 10 stress days/season, but 8.8 mm/day for those with water shortages resulting in more than 10 stress days. The cracking of soils that have been drained for long periods causes higher S&P when irrigation is resumed. That is partially offset, however, by negligible S&P during the stress periods. Potential S&P rates computed only for those periods with standing water show average S&P of only 1.6 mm/day for sites with up to 10 stress days, and almost 9 times greater S&P (14.3 mm/day) for sites with more than 10 stress days. The factors studied affected potential S&P rates more than they did mean S&P rates.

Data from a 1972 dry season experiment at IRRI were also analyzed to determine S&P differences due to prolonged water shortages midway through crop growth. The experiment had 144-m^2 plots surrounded by metal levees to minimize lateral seepage and regular larger plots to which the same water treatments were applied. Treatments included continuous flooding throughout crop growth, drainage with no irrigation for 38 days beginning 22 days after transplanting (early stress), and drainage with no irrigation for 39 days beginning 43 days after transplanting (late stress).

All water used in the plots was accounted for as ET, S&P, and water used to restore partially dried soils to their saturated state. ET for fully flooded plots was assumed equal to Class A open pan evaporation data taken from the same site, and water stored in the soil following the stress periods was calculated as 117 mm based on the increase in moisture content (30%, dry basis), rooting depth (30 cm), and bulk density

Table 12. Mean daily rates of water use for evapotranspiration (ET), soil saturation, and seepage and percolation (S&P) from a continually flooded treatment, and from treatments subjected to stress in the 1972 dry season. IRRI, 1977.

Treatment	Total water use (mm/day)	Resaturation requirement (mm/day)	ET[a] (mm/day)	S&P[b] (mm/day)	Time period (days)
Continually flooded	8.1	0.0	5.3	2.8	95
Early stress					
Before	5.8	0.0	5.1	0.7	22
After	18.0	3.3	6.0	8.7	35
Late stress[d]					
Before	6.5	0.0	4.6	1.9	43
After	37.6	9.0	5.9	22.7	13

[a]Estimated as equal to evaporation data from nearby station. [b]S&P = total water use-resaturation and evapotranspiration requirements. There was no surface drainage. [c]Drained and not irrigated from 22 to 60 days after transplanting (DT). [d]Drained and not irrigated from 43 to 82 DT.

Table 13. Analysis of seepage and percolation for four soil texture classes and two water-table regimes at field sites in Central and southern Luzon, Philippines, in the 1969 wet season. IRRI, 1977.

	Seepage and percolation[a] (mm/day)				
	Shallow water table		Deep water table		
Textural class	Observations (no.)	S&P rate (mm/day)	Observations (no.)	S&P rate (mm/day)	Weighted av. S&P rate (mm/day)
Clay and silty clay	8	0.6 a	6	1.8 a	1.0 a
Silty clay loam and clay loam	21	1.3 a	5	2.9 ab	1.6 a
Loam	10	1.0 a	2	2.5 ab	1.2 ab
Sandy clay loam and sandy loam	7	2.7 b	3	3.6 b	2.9 b
Mean	46	1.3	16	2.6	1.6

[a]In any column means followed by the same letter are not significantly different at the 5% level. Differences in S&P rates between the shallow and the deep water table are significant at the 5% level for all soil classes and their means.

(1.3 g/cm^3). Mean S&P rates for the flooded periods of all three treatments were computed by subtracting the estimates of ET and the resaturation requirement from the total water supplied.

The results were a mean S&P rate of 2.8 mm/day for the continuously flooded treatment, and rates of 0.7 and 1.9 mm/day for the prestress periods of the two other treatments (Table 12). In both cases the rates increased more than tenfold after the stress period.

The study also showed that mean S&P rates for plots flooded for 22 days after transplanting (DT), 43 DT, and for full crop growth increased by about 1 mm/day each, supporting the hypothesis that S&P tends to increase slightly with crop growth.

Soil texture is often considered an important determinant of S&P rates, so the 19 UPLBCA field sites (discussed earlier) were stratified into groups with similar topsoil textures. S&P varied little among the groups, however, because all sites had relatively heavy texture.

Another UPLBCA study of S&P from 73 dry season field sites in Central and southern Luzon was analyzed for S&P differences due to soil texture and depth to water table. S&P for the sites was estimated as a residual in water balance accounting using about 10-day measurements per site. The total sample was divided into a matrix of four soil types and two water table depths (from 0.5 to 2 m, and greater than 2 m), and mean S&P rates were computed for each cell of the matrix. For each water table regime, S&P through both sandy clay loam and sandy loam was significantly greater than that through the finer textured soils, but there was no significant difference among the heavier textured soils (Table 13). The influence of water table on S&P was substantiated: S&P rates for

sites over deep water tables were about twice the corresponding rates for shallow water tables for all soils.

For elastic alluvial soils, texture appears to affect S&P rates much less than do other factors such as depth to water table, drainage density, size of continuous area, and drought resulting in cracked soils. Soils with more than 50% sand have significantly greater S&P than typical Philippine lowland soils, however.

Rates of S&P through Bangladesh soils were studied jointly with the Bangladesh Rice Research Institute. The soils were alluvial clay loams in all four sites about 30 km north of Dacca. They contained from 30 to 38% sand, from 26 to 33% silt, and from 30 to 42% clay; their water tables were between 0.5 and 2.5 m. During the 1977 dry season S&P was measured by the rate of subsidence of the water level in selected paddies, from which ET (estimated by Class A pan evaporation data) was subtracted. This technique, applicable only for periods with no surface flow in or out of the sample paddies, was used previously in the Philippines (1975 Annual Report). Twenty-three paddies selected for measurement in the four sites yielded an average of 25 daily estimates of S&P.

The mean S&P rates during the dry season ranged from 1.3 to 2 mm/day; they were more uniform and slightly lower than the mean dry season rates for the Philippines. Mean S&P rates for different depths of water up to 6 cm did not differ significantly, but losses were significantly greater when water was stored at depths greater than 6 cm (Table 14). The increase in S&P rates was attributed to tunnels made by insects and animals in the paddy bunds at the higher elevations.

Although the physical properties of the Bangladesh soils appear to preclude the thorough soil puddling commonly done on Philippine rice soils, mean S&P rates were about the same for both.

Nitrogen losses in water draining from lowland rice fields. More than half the total rainfall frequently runs off as surface drainage from rainfed lowland fields. For irrigated land, about two-thirds of the total applied water runs off in the wet season, one-third in the dry season. Considerable quantities of agricultural nutrients and chemicals are lost with this water under certain conditions.

Table 14. Mean rates of seepage and percolation (S&P) by depth of water in the paddy at four field sites in Bangladesh. 1977 dry season.

Water depth[a] (cm)	Observations (no.)	Mean S&P rate[b] (mm/day)
0 – 2	230	1.1 a
2 – 4	124	1.5 a
4 – 6	132	1.7 a
6 and above	90	2.6 b

[a]Reference is the minimum water elevation required to completely submerge each sample paddy. [b]Means followed by the same letter are not significantly different at the 5% level. Tests based on variation among the four sites.

A study of nitrogen losses in water draining from lowland rice fields was conducted jointly with the Laguna Lake Development Authority. Four field sites were selected around Laguna Lake in Laguna province, Philippines. The higher end of the sites received water from an irrigation canal, while the lower end drained into a creek. Irrigation water entering the first paddy carried no drainage from upstream, and that leaving the last paddy collected in a natural creek discharging into Laguna Lake.

Six treatments of fertilizer and water management were applied at each stie. Two fertilizer management practices — topdressing and incorporation — were combined with each of three water management practices — continuous flow, impounded water, and temporary drainage (Table 15, Fig. 10). A total of 60 kg N/ha was applied through two applications, 20 kg basal and 40 kg at 45 DT. The second application was incorporated by rotary weeders. Continuous water flow involved continuous (simultaneous) irrigation and drainage throughout crop growth, and both periods of fertilizer application; the impounded water treatments involved application of fertilizer on standing water, which was then allowed to soak into the paddy for 5 days with neither irrigation nor drainage; and temporary drainage treatments involved draining the field 1 day before applying nitrogen, and then withholding irrigation for 2 days. Except for the periods of fertilizer application, the supply of water to all treatments was about the same, as were other input and management levels.

Table 15. Mean nitrogen in the inflow and outflow water, and net nitrogen for six treatments in four field sites, Laguna province, Philippines, 1976–77 wet and dry seasons.

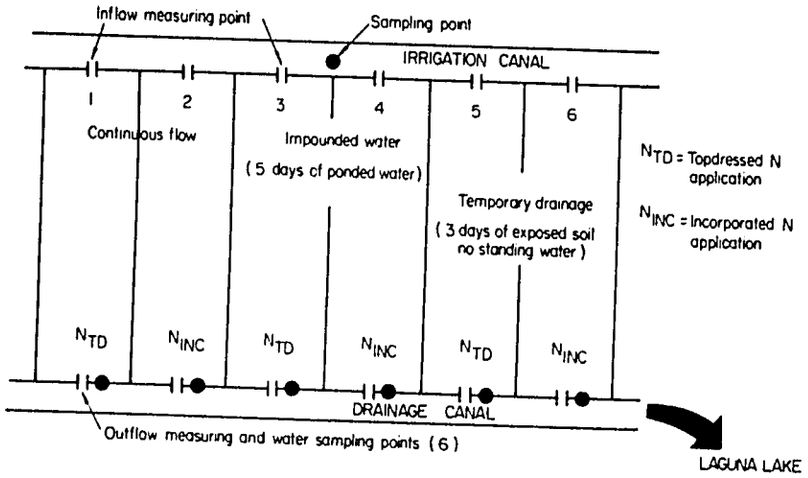
	Nitrogen (kg/ha)									
	Biñan		Calamba		Calauan		Pila		Mean	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
					Topdressed, continuous flow					
Inflow	2.1	2.8	2.9	2.0	2.3	1.2	1.3	1.4	2.1	1.9
Outflow	2.9	3.9	5.5	7.1	7.0	8.3	6.9	5.0	5.6	6.1
Net	-0.8	-1.1	-2.6	-5.1	-4.7	-7.1	-5.6	-3.6	-3.4	-4.2
					Incorporated, continuous flow					
Inflow	2.6	4.5	3.7	2.0	2.2	1.0	1.6	1.7	2.5	2.3
Outflow	1.5	1.3	4.0	3.5	5.1	3.8	4.3	4.0	3.7	3.1
Net	1.1	3.2	-0.3	-1.5	-2.9	-2.8	-2.7	-2.3	-1.2	-0.8
					Topdressed, impounded water					
Inflow	2.5	17.9	3.3	2.6	1.9	1.0	1.1	0.4	2.2	5.5
Outflow	0.0	0.1	1.6	0.9	2.3	0.3	0.8	0.4	1.2	0.4
Net	2.5	17.8	1.7	1.7	-0.4	0.7	0.3	0.0	1.0	5.1
					Incorporated, impounded water					
Inflow	1.6	14.9	2.9	3.2	2.6	1.0	0.9	0.7	2.0	4.9
Outflow	0.0	0.1	1.9	1.2	2.1	0.5	0.3	0.5	1.1	0.6
Net	1.6	14.8	1.0	2.0	0.5	0.5	0.6	0.2	0.9	4.3
					Topdressed, temporary drainage					
Inflow	3.3	12.9	1.4	1.9	2.9	1.0	0.7	1.0	2.1	4.2
Outflow	0.7	0.3	0.7	1.5	4.6	8.3	3.7	3.6	2.4	3.4
Net	2.6	12.6	0.7	0.4	-1.7	-7.3	-3.0	-2.7	-0.3	0.8
					Incorporated, temporary drainage					
Inflow	2.4	19.3	3.0	3.9	2.8	1.0	1.0	0.7	2.3	6.2
Outflow	0.4	0.3	1.0	5.8	3.3	1.0	2.5	2.6	1.8	2.4
Net	2.0	19.0	2.0	-1.9	-0.5	0.0	-1.5	-1.9	0.5	3.8
					Mean					
Inflow	2.4	12.0	2.9	2.6	2.4	1.0	1.1	1.0	2.2	4.1
Outflow	0.9	1.0	2.4	3.3	4.1	3.7	3.1	2.7	2.5	2.7
Net	1.5	11.0	0.5	-0.7	-1.7	-2.7	-2.0	-1.7	-0.4	1.4

[a]Negative values reflect net losses; positive values, net gains.

Water flowing into and out of fields for each treatment was measured and water samples were taken daily. Sampling at the drainage outlet was done separately for each treatment. Samples from the inflow were taken only at one point for each site because the nitrogen content of the water along the irrigation canal showed little variation. The samples for analysis were collected with the automatic sampler. Nitrogen gained or lost daily in each treatment was computed.

The total nitrogen added to the system by irrigation water inflow, the nitrogen in drainage, and the net balance varied considerably among sites (Table 15). For Biñan, the source of nitrogen inflow was the municipal sewage, which drained into the irrigation canal about 200 m from the site. For Calamba, nitrogen flowed in from commercial livestock farms 6 km upstream. Calauan and Pila had relatively little incoming nitrogen. Most incoming nitrogen was in the form of ammonium, except that in Calamba, where nitrate was predominant because the ammoniacal wastes entering the river were nitrified while being carried 6 km to the study site.

Nitrogen concentration in the drainage water increased markedly after fertilization, but concentrations from the topdressed treatment were more than twice those of incorporated treatments (Fig. 11). Peak nitrogen concentrations were about 12,400, 1,500 and 1,200 μg/liter for topdressed plots with continuous flow, temporary drainage, and impounded water, respectively (Fig. 12). Continous-flow treatments had less nitrogen outflows after basal application

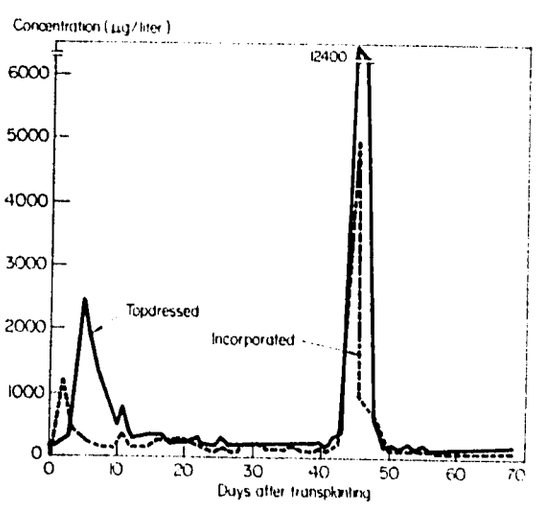


10. Illustrated treatment layout of site showing the nitrogen and irrigation treatments, nutrient movement study. TD = topdressed, INC = incorporated.

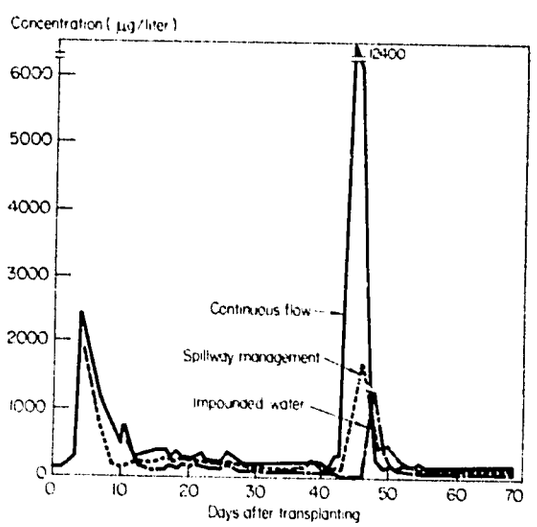
than after post-transplanting application because water supply was delayed for 2 days, and because the basal application was half that of the second application.

Almost all outflows of nitrogen were in the form of ammonium. Since the Biñan and Calamba sites received larger amounts of nitrogen from irrigation water, they showed net gains of nitrogen. Those of Calauan and Pila, which received relatively less, showed net losses for both seasons (Table 15), but the losses were less than 2 kg N/ha.

Mean net gains or losses of nitrogen were computed and tested for significance. In the wet



11. Concentration of outflow ammonium (NH_4^+) in water with two fertilizer management treatments and continuous flow. Calauan, Philippines, 1976 wet season.



12. Concentration of outflow ammonium (NH_4^+) in water with three water management treatments and topdressed nitrogen. Calauan, Philippines, 1976 wet season.

Table 16. Mean grain yield and net nitrogen flow for six nitrogen and water management treatments, Laguna province, Philippines, 1976–77 wet and dry seasons.

Water management treatment	Mean grain yield[a] (t/ha)			Net nitrogen flow[a] (kg/ha)		
	Topdressed nitrogen	Incorporated nitrogen	Difference[b]	Topdressed nitrogen	Incorporated nitrogen	Difference[b]
			Wet season			
Continuous flow	3.74 a	3.97 a	-0.23*	-3.40 a	-1.20 a	-2.20 *
Impounded water	4.04 a	4.66 a	-0.62*	1.00 b	0.90 b	0.10
Temporary drainage	3.79 a	4.03 a	-0.24*	-0.30 ab	0.50 ab	-0.80
Mean	3.86	4.22	-0.36*	-0.90	0.10	-1.00
			Dry season[d]			
Continuous flow	3.93 a	4.16 a	-0.23	-5.23 a	-2.21 a	-3.03
Impounded water	4.30 a	4.59 b	-0.29*	0.79 b	0.86 b	-0.07
Temporary drainage	4.22 a	4.32 ab	-0.10	-3.23 ab	-1.22 ab	-2.01
Mean	4.15	4.35	-0.21*	-2.56	-0.86	-1.70

[a]In the same column, means followed by the same letter are not significantly different at the 5% level. [b]Difference = topdressed less incorporated. Asterisk (*) indicates significant difference between fertilizer treatments. Means of four field locations. [d]Means of three field locations; data exclude yield at one location affected by severe lodging.

Table 17. Concentrations and total amounts of carbofuran[a] from the outflow of 3 treatment combinations. Biñan, Laguna, Philippines, 1977 dry season.

Treatment	Observations (no.)	Water flow (liter/s)	Carbofuran concn (ppm)	Time (h)	Amount of carbofuran drained (g)	Mean rate of carbofuran drained (g/ha)
Continuous flow, topdressed[b]	1	0.4	0.36	2.0	1.037	
	2	0.4	0.07	0.5	0.050	
	3	0.3	0.19	1.0	0.205	
	4	0.3	0.26	2.0	0.562	
				5.5	1.854	0.34
Continuous flow, incorporated[c]	1	0.1	0.15	2.0	0.108	
	2	0.2	0.17	0.5	0.061	
	3	0.2	0.13	1.0	0.094	
				3.5	0.263	0.08
Impounded water, incorporated[c]	1	0.2	0.03	2.0	0.043	
	2	0.2	0.008	2.0	0.012	
				4.0	0.055	0.01

[a]Applied at the rate of 0.480 kg a.i./ha. [b]Sampling started 2 hours after insecticide application. [c]Sampling started 4 days after insecticide application; no water flow was allowed before that.

season, incorporated nitrogen showed a 0.1 kg N/ha net gain, and topdressed nitrogen, a mean net loss of 0.9 kg N/ha (Table 16). In the dry season net losses for both treatments followed a similar trend.

Among the water management practices, impounded water gave a small net yield gain with both nitrogen management practices and for both seasons. Continuous flow resulted in lowest yields and temporary drainage was intermediate (Table 16).

The significantly higher yields with incorporated than with topdressed nitrogen under each water management practice in both seasons were attributed to overall higher nitrogen use, and not to the small differences in nitrogen net losses. Water management practices also affected yields but differences among them were generally small.

Gas chromatograph analyses of carbofuran in drainage water from selected treatments at one site showed trends similar to those for nitrogen (Table 17). With continuous water flow, incorporation of carbofuran resulted in losses only 25% of those recorded for topdressing.

The water management treatments of the

Table 18. Nitrogen and water management beliefs and practices of 100 farmers. Laguna province, Philippines, 1977.

Practice	Farmers (%)
Applied nitrogen in standing water	99
Maintained the water depth during fertilizer application by closing the spillways	95
Applied water in their field from paddy to paddy	70
Believed separate canal to irrigate each field would be beneficial	57
Believed impounding water during fertilizer application would be useful	32
Believed fertilizer loss occurs in paddy-to-paddy movement of water	18
Reported fertilizer inputs from irrigation water from different sources, such as municipal and agricultural wastes	63
Reported higher yield in uppermost paddy in a strip of paddies	23
Reported higher yield in middle and lower paddies in a strip of paddies	2
Were willing to use sewage water	66
Were willing to practice deep placement of nitrogen fertilizer in mudballs and pellets	78
Were willing to incorporate fertilizer by mechanical weeder	68

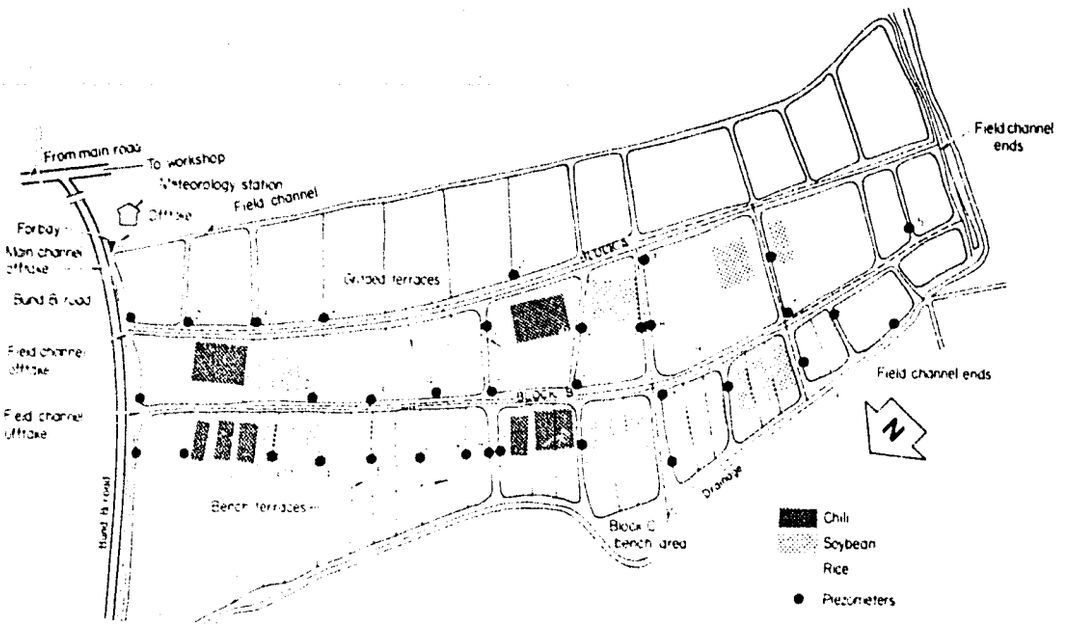
study were also used to compare the relative populations of nitrogen-fixing and non-nitrogen-fixing algae by water regime. Continuous flow flushed out the algae and prevented their growth; in this treatment, only the nitrogen-consuming algae prospered. Impounded water and incorporated nitrogen provided the best medium for nitrogen-fixing algae.

Farmers' nitrogen and water management practices. A total of 100 farmers near the 4 sites were interviewed about their nitrogen fertilizer and water management practices. Almost all closed their paddy spillways and applied nitrogen in standing water (Table 18). After a mean of 7 days when no irrigation was applied, the spillways were reopened. Seventy percent of the farmers reported that their fields received irrigation water from another paddy, and not from a canal, and about 80% of those farmers perceived benefits from individual supply canals. Most of the farmers expressed their willingness to use recycled sewage water, and nitrogen deep placement and incorporation techniques.

Yields and water use for chili, soybean, and rice in Sri Lanka. More than 60% of Sri Lanka's area is in a dry zone. Agricultural production is limited because of infertile soils and a mean annual rainfall of 1,870 mm distributed in pronounced wet and dry seasons. A massive program of irrigation expansion, now under way, will bring dry season irrigation to most of the zone, but information about on-farm use of the water in the area or the relative benefits of irrigating different crops is limited. A 1977 study was organized jointly with the University of Sri Lanka's Faculty of Agriculture, the Department of Agriculture, and the Asian Institute of Technology, to determine the effect of different forms of land shaping on irrigation and the relative yields and water use of chili, soybean, and rice grown on such landforms in the dry season.

The study was carried out in Catchment C of the Maha Illuppallama Agriculture Research Station, an 11-ha watershed similar to the microcatchments that abound in the dry zone Within the catchment, experiments were on soils that were well, imperfectly, and poorly drained, corresponding to positions near the top, middle, and lower regimes, respectively, of a toposequence. For each drainage class, plots were on graded and bench terraces. Graded terraces were furrowed landforms with lengthwise slopes between 0.4 and 0.8% to facilitate water movement to the ends of the furrows. Bench terraces were level basins similar to lowland rice paddies except that the land was prepared in short furrows with slopes not exceeding 0.2%. For each combination of drainage class and terrace type, chili, soybean, and upland rice were planted — chili in 30- × 12-m plots, and the other crops in 30- × 30-m plots. Data for each crop-and-treatment combination were collected separately from three replicates that were laid out adjacent to each other (Fig. 13).

Irrigation schedules that would permit high yields from three crops essentially unconstrained by water shortage were adopted. Earlier research on the soils had determined field capacity and the permanent wilting point at about 20 and 11% soil moisture, respectively; irrigation for chili and soybean was therefore scheduled at about 15 to 16% moisture content. Irrigation for rice was scheduled at 18% soil moisture. Starting 2 days after the irrigation of each replicate, soil moisture was sampled daily at depths of 30 cm for chili and soybean and 23 cm for rice. Irrigation flow to each replicate was



13. Plot layout for yield and water use studies on three drainage classes and two terrace types at Maha Illuppallama, Sri Lanka, 1977.

measured separately by Parshall flumes. Water was distributed within replicates to three or four furrows at a time at rates designed to avoid any surface drainage losses.

Areas for studying rice on a lowland puddled soil were not available within Catchment C. Two nearby field sites, each about 0.8 ha, were used. Their soils were similar to those of the poorly drained class of Catchment C, except that they had been puddled for two annual crops of lowland rice for more than 40 years. The rice variety BG-34-8 was dry-seeded in the upland plots and wet-seeded in the lowland sites. Irrigation to the lowland sites was continuous, with paddy-to-paddy on-farm distribution.

Yields. Yield differences among the drainage classes and between the terrace types were generally not significant for any crop (Table 19). Grain yield in the lowland field sites averaged 4.16 t/ha, about 0.5 t/ha less than that in upland rice plots.

Water use. Water use of the crops was defined as the total water used for evapotranspiration (ET) plus S&P into the soil. Water use was essentially equal to the water supplied to the plots, because surface drainage after irrigation was negligible, and the change in water stored in the soil was insignificant during the whole season. Occasional light rains during crop growth were added to data as irrigation; for heavier rains only that portion considered as effective rainfall was included. Ineffective rainfall was calculated separately for each plot as rainfall in excess of total water use, which was estimated from earlier and later periods without rainfall.

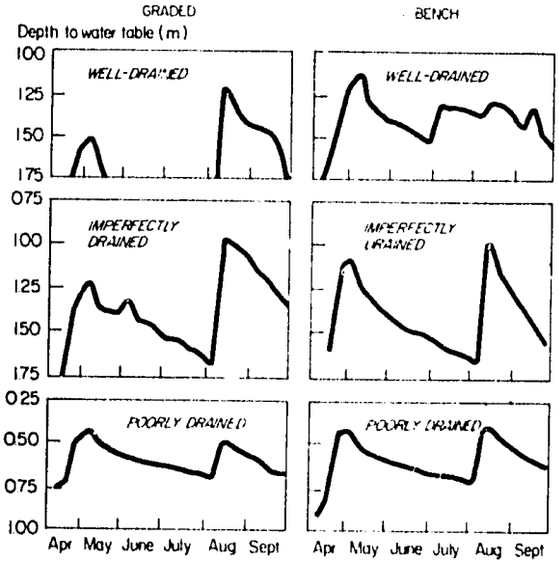
Mean water use, including effective rainfall, was the same for corresponding bench and graded terraces for each crop (Table 19). Well-drained soils used significantly more water than poorly drained soils, as expected. Water use was about the same between the imperfectly and poorly drained classes, despite the deeper water table for the former (Fig. 14). One reason is that the surface horizons of the poorly drained soils were somewhat lighter in texture than that of the better drained classes. Mean total water use for all treatment combinations was almost 1 m for rice and chili, and almost 0.5 m for soybean.

Table 19. Mean yields and water use of chili, soybean, and rice in three drainage classes and two terrace types. Catchment C, Maha Illuppallama, Sri Lanka, 1977 dry season.[a]

Drainage class, terrace type	Chili		Soybean		Rice	
	Yield (t/ha)	Water use (mm)	Yield (t/ha)	Water use (mm)	Yield (t/ha)	Water use (mm)
Well drained						
Bench	2.78 a	908 a	2.61 b	472 a	3.73 b	1045 a
Graded	2.79 a	920 a	2.88 ab	451 a	4.59 ab	1070 a
Imperfectly drained						
Bench	3.22 a	808 b	2.69 ab	410 a	5.71 a	939 b
Graded	2.85 a	821 b	3.34 ab	447 a	4.38 ab	998 ab
Poorly drained						
Bench	[b]		2.44 b	467 a	4.73 ab	924 b
Graded	[b]		3.58 a	449 a	4.61 ab	932 b
Mean	2.91	864	2.92	449	4.63	985

[a]In any one column means followed by a common letter are not significantly different at 5% level (LSD). [b]Omitted in the layout.

S&P was estimated by two methods to confirm the assumption that differences in water use among drainage classes should be attributed to greater S&P in the well-drained class, and not to ET, which is about the same for all three classes. In the first method, irrigation applications in amounts greater than what the root zone can store were assumed lost as S&P; in the second, S&P was estimated as a residual after Penman estimates of ET computed from weather data from the meteorological station within Catchment C were subtracted from water use. The two methods produced results that closely agreed, and showed S&P losses of 0.6 to 2.2 mm/day for the treatment combinations for chili, 0 to 1.0 mm/day for soybean, and 4.3 to 7.3 mm/day for rice. Losses were higher for rice because it received more irrigation. The soybean plots had minimal S&P losses for all drainage classes; thus its water use did not vary by drainage class (Table 19).



14. Depth to water table at weekly intervals for three drainage classes and two terrace types. Catchment C, Maha Illuppallama, Sri Lanka, 1977 dry season.

Although the water use (ET + S&P) of two lowland sites was about the same, the total water supplied to them after seeding was more than twice that supplied to the upland rice plots. The lowland sites had surface drainage losses greater than their water use, while the Catchment C plots had negligible surface drainage. Furthermore, during land preparation the lowland sites required additional water. Because the upland plots were dry-seeded, they did not need much moisture before the start of the study.

Comparisons of water use between the two types of rice culture are difficult, because water management for the upland plots aimed to preclude surface drainage for experimental reasons, and because some of the water drained from the field sites irrigated downstream areas, and therefore was not completely lost.

Productivity of water. Yields per unit of water use ranged from a low of 3.4 kg/ha per mm for chili to a high of 6.5 kg/ha per mm for soybean. Upland and lowland rice productivities were

Table 20. Productive efficiencies[a] for chili, soybean, and rice. Catchment C, Maha Illuppallama, Sri Lanka, 1977 dry season.

	Productive efficiency (kg/ha per mm)	Gross productive[b] efficiency (US$/ha per mm)	Net productive[c] efficiency (US$/ha per mm)
Chili	3.4	3.76	3.00
Soybean	6.5	2.01	1.28
Upland rice	4.7	0.34	(-0.01)
Lowland rice[d]	4.4	0.31	0.13

[a]Means of all replicates, terrace types, and drainage classes for each crop. [b]Gross returns. [c]Net returns after costs of production were subtracted. [d]Based on mean of two field sites.

Table 21. Mean[a] irrigation intervals, number of irrigations, labor per irrigation, and labor per season used for chili, soybean, and upland rice. Catchment C, Maha Illuppallama, Sri Lanka, 1977 dry season.

	Irrigation interval (days)	Irrigations (no.)	Labor: Per[b] irrigation (man-h/ha)	Labor: Total[c] (man-d/ha)
Chili	5.8	28	20	68
Soybean	4.4	20	19	49
Rice (upland)	2.6	39	22	105

[a]Means of 3 replicates, 3 drainage classes, and 2 terrace types. [b]Mean time required to irrigate 3 replicate plots of approximately 0.1 ha, expressed on per-hectare basis. [c]Total labor = number of irrigations times man-hours/ha per irrigation, assuming 8 man-hours/man-day.

intermediate (Table 20). In economic terms, however, the high prices received for chili gave it the highest gross value per unit of water supplied, followed by soybean and then rice. The same trend is observed in net income per millimeter of water use after production costs are subtracted from gross income. Upland rice showed negative returns because the labor costs associated with its water management were high. Because of its low price, lowland rice generally showed low returns. Expressed on a volume basis, dry season irrigation produced net farm income of about $0.30 for chili, $0.13 for soybean, and $0.00 for upland rice per cubic meter of water used.

The low productivity of water used for rice was due in part to its large S&P losses. Calculations of grain yield per unit of water used solely for ET show that rice was the most efficient crop physiologically, producing 9.8 kg/ha for each millimeter of water, compared with 7.7 kg/ha for soybean and 4.9 kg/ha for chili.

Irrigation labor requirements. Records show that upland rice required more labor than the other crops primarily because of its high frequency of irrigation (Table 21). About 105 man-days of labor/ha was needed to irrigate the upland rice plots for the 105 days of crop growth, or 1 man-day/day of crop growth. Graded terraces required slightly less labor because they could be irrigated more quickly than benches. Labor used in irrigating soybean was half that used in irrigating upland rice, although soybean was in the ground almost as long as rice. Because of the long interval between irrigations, chili also used much less labor than rice, despite a 50% longer season.

Comparisons of labor used for the upland rice plots and that used for the lowland field sites are not exact because of the experimental nature of the former. Nevertheless, field observations for the two lowland sites showed only 14 farmer visits to control water after seeding in one site, and 45 visits in the other. The site with a shared water source required the greater number of visits. For both sites, two-thirds of the visits were for controlling irrigation and one-third for drainage. Assuming 2 man-hours per field visit, the total attention to water control from seeding to harvesting was about 10 man-days/ha, or about 10% of that in the upland plots. Thus, lowland rice requires substantially less attention to managing water than does upland rice, but at the cost of greater water wastage. Yields and productivities per unit of water use for the two systems are roughly comparable, which explains why farmers with good supplies of water do not readily adopt upland rice culture.

Soil and crop management

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SOIL CHARACTERIZATION

Salt injury in the 20,000 ha of coastal saline soils under rice in the Philippines depends on the complex interaction of tides, rainfall, and freshwater discharge from rivers. Farmers grow their main rice crop after the salt is washed away by rain. Their use of salt-tolerant varieties has increased yields.

On a zinc-deficient calcareous soil, 0.2% salt benefited rice; 0.4% salt affected rice more adversely in acid soils than in neutral or alkaline soils.

Hydrological and chemical studies of an iron-toxic rice field in Sri Lanka suggest that interflow and severe nutrient deficiencies may cause iron toxicity at water-soluble iron concentrations of 20–50 ppm.

Soil and plant analyses revealed that aluminum toxicity and phosphorus deficiency severely retard the growth of rice, especially dry-sown rice, on the acid sulfate soils of Thailand.

Zinc deficiency in the Philippines is associated with high soil pH or with prolonged wetness due to artesian or phreatic activity. Wet zinc-deficient soils may be classified as Tropaquents or Hydraquents.

A study of 37 wetland rice soils revealed that the 0.05 *N* HCl method for available zinc is more precise, simpler, more convenient, and less expensive than the 0.1 *N* HCl, EDTA, and DTPA methods.

Laboratory, greenhouse, and field experiments revealed that most Philippine Histosols are deficient in available nitrogen, phosphorus, potassium, zinc, copper, and molybdenum.

Studies of nitrogen transformation in rice soils gave the following results:

- Alternate flooding and drying did not depress yield or nitrogen uptake in unfertilized fields carrying a rice crop.
- The nitrogen-supplying capacity correlated strongly with organic matter content, nitrogen content, and the ammonia released by four chemical methods.
- Putting rice fields in flood fallow between crops led to a marked accumulation of nitrogen and organic matter.
- Urease activity was lowest in acid sulfate soils and highest in a sodic soil.
- Photosynthetic nitrogen fixation in the greenhouse was 9.2 mg N/kg soil per month in a neutral soil and 12.5 mg N/kg soil per month in an acid soil.

SOIL FERTILITY MANAGEMENT: MICROBIOLOGICAL STUDIES

Nitrogen balance sheet studies and acetylene reduction assays revealed greater autotrophic nitrogen fixation activity than heterotrophic nitrogen fixation associated with wetland rice plants. *Azolla pinnata* in the field produced 330 kg N/ha in 220 days. Inoculation of *Azolla* before and after the transplanting of dry season rice increased rice yield by 36%, or 1.8 t/ha, over the control. The collection of *Azolla* species and strains was started.

Nitrogen transformation studies using ^{15}N in rainfed rice soils revealed the possibility of denitrification in dryland conditions and the greater effect of soil moisture conditions during the dry season on nitrogen supply of wet season rice.

SOIL FERTILITY AND FERTILIZER MANAGEMENT

The magnitude of direct volatilization losses was determined in field and greenhouse experiments. Maximum ammonia volatilization losses amounted to 18% of the urea nitrogen and to 15% of the ammonium sulfate nitrogen when both fertilizers were entirely broadcast during the period of high sunlight and active algae growth. Even when surface applied, slow-release fertilizers, particularly IBDU, substantially minimized ammonia volatilization losses.

In situ release patterns of nitrogen from placement sites of prilled urea, supergranule urea, sulfur-coated urea (SCU), and urea in mudballs were compared in field studies. The rate of nitrogen release was considerably slower in the placement site of SCU than in that of prilled urea, supergranule urea, or mudball urea.

Placement of nitrogen using the IRRI-

designed plow-sole applicator and placement as urea briquets gave similar yields, but use of the former method gave a significantly higher yield than split application of nitrogen.

In another field study, the rice yield increased as the plant density was increased. Beyond a certain point, the yield increase with an increase in plant density was modest.

For correcting zinc deficiency in direct-seeded rice, coating the pregerminated rice seeds with zinc oxide at 2 kg/ha and spraying the plants with 0.5% $ZnSO_4$ at 5–7 days before panicle initiation appeared promising.

SOIL AND CROP CULTURE

In both rainfed wetland and dryland rice fields, where the land preparation was completed at the end of the previous wet season, shallow tillage (10 cm), deep tillage (20 cm), and straw incorporation conserved moisture through the dry season and made land preparation and stand establishment for the first crop of rainfed dry-seeded rice possible during the beginning of the rainy season.

Soil and crop management

Soil characterization

Soil Chemistry Department

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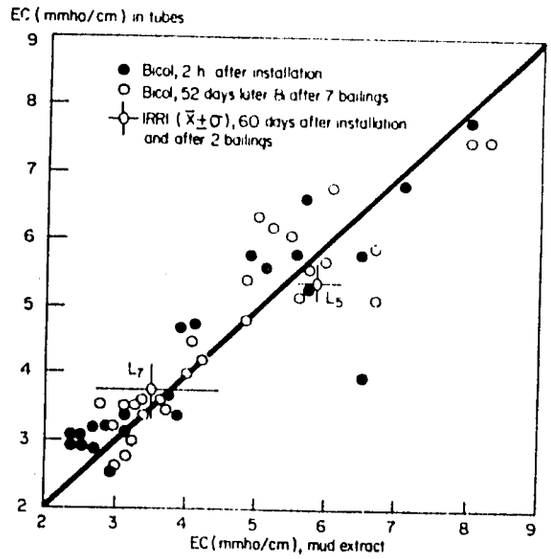
COASTAL SALINE SOILS IN THE PHILIPPINES

Occurrence and use. More than half of the 400,000 ha of tidal saline soils in the Philippines is under natural mangrove. Rice is grown on only less than 20,000 ha of these soils.

High tides cause flooding of rice fields by salt water, but the damage depends on the complex interaction of tides, rainfall, and freshwater discharge from rivers. Because of high rainfall, most of the flooding, which occurs from June to September, is caused by fresh water backed up by ocean tides. When high tides precede the rainfall peak, however, soil salinity may increase to 10 mmho/cm in the dry season. This was observed from March to May 1977 at Lubao, Pampanga, where desalinization started in August. In similar areas, farmers grow their main rice crop after the salt has been washed away. The second crop is harvested before inundation by salt water during spring tides.

Where salinity and flooding are not severe, improved salt-tolerant varieties have increased yields. In other areas, reclamation combined with varietal tolerance is necessary.



1. Relationship between electrical conductivity (EC) values in piezometer tubes and in mud extracts from tube sites. Philippines, 1977.

Monitoring salinity in experimental fields. Electrical conductivity (EC) values of the water in piezometers were similar to those of the interstitial water at the same depth in an artificially salinized field at IRRI (Fig. 1) and in four coastal saline soils. The EC values correlated well with the degree of salt injury, except at two sites where the surface salt water was diluted by fresh water.

Where the EC values of the surface water and the piezometer water are within a 5-mmho/cm range, piezometer readings provide a rapid and reliable estimate of the soil salinity to which rice plants are exposed.

Forty piezometers were used to monitor salinity in a 0.25-ha field in Sabang, Camarines Sur, used for mass-screening of rices for salt tolerance. The salinity varied from 4–5 mmho/cm in the two southern corners to 9–11 mmho/cm in the north-central part of the field. The mean salinity reached a maximum in August and then declined. The reactions of Pokkali, the resistant check, reflected salinity as measured by the piezometers.

Chemical kinetics of saline soils and rice growth. The chemical kinetics of saline soils differ. In a study of how soil properties influence salt injury, IR26 rice was grown in the greenhouse on four submerged soils at four salt concentrations.

As the salt concentration increased, the EC increased, the pH decreased, and the peak soil solution concentrations of sodium potassium, calcium, magnesium, and manganese increased (Table 1).

Salt (NaCl) at 0.2% increased the growth and yield of rice on Lipa clay loam but not on Maahas clay and Luisiana clay. At 0.4% salt, the yield reduction was highest in Luisiana clay and least in Maahas clay. The plants on the acid sulfate clay at all salt levels died (Table 2). Iron toxicity, which killed the plants in the acid sulfate soil, also killed those at 0.4% in Luisiana clay.

Salt of up to 0.2% benefited rice, apparently because it increased the concentration of plant nutrients in the soil solution. The adverse effects of excess salt were more severe in the strongly acid soil than in the nearly neutral soil.

Table 1. Effect of 4 salt concentrations on the cation concentration in the soil solution of 4 soils growing IR26 rice, 8 weeks after submergence. Philippines, 1977.

Added salt (%)	Concn (ppm)					
	Sodium	Potassium	Magnesium	Calcium	Iron	Manganese
			Lipa clay loam (pH: 8.1; O.M.: 11.0%)			
0	128	21	403	93	0.4	1.2
0.1	353	24	501	143	1.0	1.5
0.2	413	29	640	243	1.4	1.9
0.4	827	36	841	297	1.1	2.1
			Maahas clay (pH: 6.8, O.M.: 2.5%)			
0	118	7	76	140	18	22
0.1	387	10	187	277	18	35
0.2	347	14	246	337	20	28
0.4	777	22	302	393	11	44
			Luisiana clay (pH: 5.0; O.M.: 3.8%)			
0	34	2	60	73	129	12
0.1	160	7	97	77	180	28
0.2	500	17	104	162	[illegible]	50
0.4	820	23	126	208	484	60
			Acid sulfate soil (pH: 3.8, O.M.: 3.1%)			
0	102	42	88	496	2017	7
0.1	347	50	121	638	2377	11
0.2	500	56	114	654	2350	9
0.4	1923	65	147	704	2137	10

IRON-TOXIC SOILS IN SRI LANKA

Soil, hydrological, and plant observations were made on acid soils of the wet zone of Sri Lanka to ascertain whether interflow from adjacent highlands was causing the iron toxicity on the acid soils in Sri Lanka. Additionally, soil and water from iron-toxic fields were analyzed and greenhouse studies were undertaken (Fig. 2). The results of the investigation suggest that:

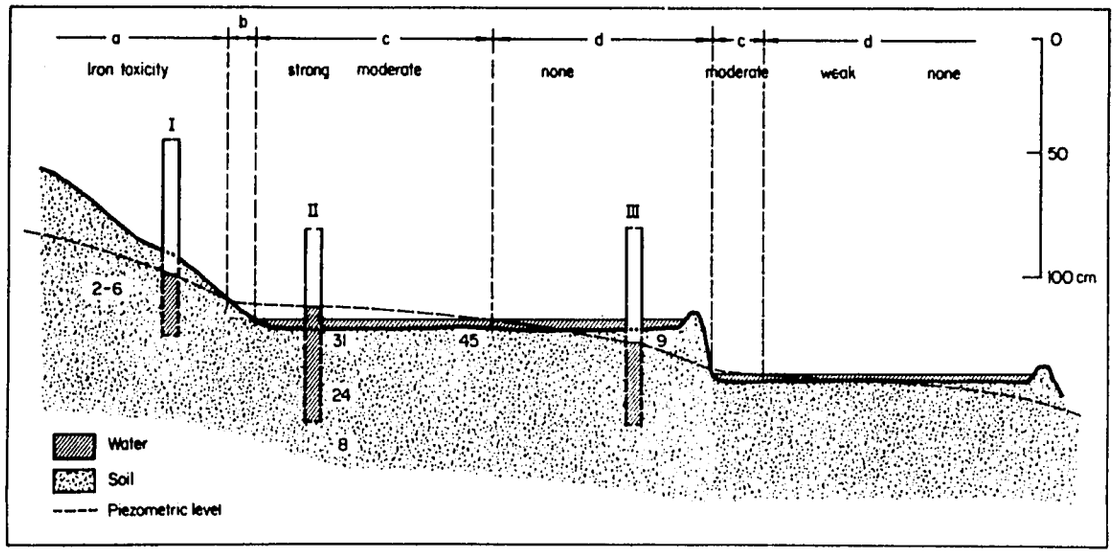
- Upwelling of water from adjacent highlands (due to interflow) aggravates iron toxicity.
- Interception of interflow does not eliminate the deleterious effects.
- The concentrations (20–50 ppm) of dissolved iron in the root zone are not excessive.
- The concentrations of iron and other nutrients in the interflow are lower than those in the soil solution.
- Nutrient deficiencies probably induce iron toxicity in some acid submerged soils.

ACID SULFATE SOILS IN THAILAND

In Thailand, 250,000 ha of acid sulfate soils are sown dry in June-July. Rice grows as a dryland crop for 2 months without the benefit of the pH increase brought about by flooding. The growth of rice sown in June as a dryland crop

Table 2. Effect of 4 concentrations of salt on the yield of IR26 rice on 4 flooded soils. Philippines, 1977.

Added salt (%)	Yield (g/pot)	
	Straw	Grain
	Lipa clay loam (pH: 8.1; O.M.: 11.0%)	
0	0	0
0.1	41	5.2
0.2	50	18.7
0.4	24	2.6
	Maahas clay (pH: 6.8; O.M.: 2.5%)	
0	62	23.8
0.1	63	22.0
0.2	64	24.2
0.4	53	18.5
	Luisiana clay (pH: 5.0; O.M.:3.8 %)	
0	84	59.3
0.1	84	60.5
0.2	42	23.0
0.4	0	
	Acid sulfate soil (pH: 3.8; O.M.: 3.1%)	
0	0	0
0.1	0	0
0.2	0	0
0.4	0	0



2. Hydrology of rice paddies in valleys in the low country wet zone of Sri Lanka, illustrated by piezometer levels (June–July 1977). a) upland, b) lateral seepage, c) upwelling zone, d) percolation zone. Figures indicate concentrations of dissolved Fe^{2+} (ppm) in interstitial water at various depths.

on acid sulfate soils between Pathum Thani and Nakhon Nayok in Thailand was retarded. It was poorest on strongly acid soils (pH 4.0 to 4.3). Chemical analysis of rice plants grown on such soils indicated that phosphorus deficiency and aluminum toxicity may have caused the poor growth. The phosphorus content of retarded rice plants was 0.031%, that of healthy plants was 0.069%, and that of normal plants, > 0.1%. The aluminum content of retarded rice plants was 911 ppm, while that of healthy plants was 177 ppm and that of normal plants was < 300 ppm.

At the Acid Sulfate Research Station in Ongkharak, Thailand, the pH of the surface water of acid soils was 0.5 to 1.0 unit lower than that of the reduced soil (4.5–5.0). Apparently, aluminum toxicity and phosphorus deficiency can retard rice growth, even in flooded acid sulfate soils. When caused by surface acidity, these two conditions can be alleviated by split applications of lime as topdressing.

ZINC DEFICIENCY IN THE PHILIPPINES

Role of hydrology and pH. A survey of zinc-deficient soils in the Philippines showed that zinc deficiency was associated with high pH or prolonged wetness due to artesian activity or shallow aquifers in gently sloping either alluvial or colluvial areas adjoining mountains (phreatic rice lands). It was less common in flat areas or depressions (fluvial rice lands). The zinc-deficient soils studied were high in organic matter, unmottled, and greenish gray throughout the profile. The wet zinc-deficient soils may be classified as Tropaquents or Hydraquents (Table 3).

In soils where zinc deficiency was observed, the pH ranged from 5.2 to 8.0 and the organic matter content, from 2.3 to 48% (Table 4).

The influence of landform on the severity of zinc deficiency is shown for a toposequence at Tiaong, Quezon (Fig. 3).

Zinc deficiency at Tiaong, Quezon. The standard remedy of dipping rice seedlings in a 2% aqueous suspension of zinc oxide before transplanting was ineffective with susceptible varieties on a strongly zinc-deficient Lipa clay loam at Tiaong (pH: 8.2; O.M.: 9.0%; available zinc: 0.04 ppm). Thus, alternative methods were tested in the 1977 wet season using IR34 a moderately resistant variety. Growth and yield were nearly normal whether the seed was coated with zinc oxide and broadcast (3.9 t/ha), the seedlings were dipped in zinc oxide before transplanting (3.5 t/ha), or zinc sulfate was applied to the soil (3.5–4.2 t/ha).

Table 3. Landscape and hydrological characteristics of some zinc-deficient rice lands in the Philippines.

Location	Area (ha)	Landform	Slope (%)	Artesian activity		Soil classification
				Shallow upwelling	Deep wells	
Banaue, Ifugao	>500	Rice terraces	5–20	Yes	No	Hydraquents
Bugallon, Pangasinan	>500	Alluvial-colluvial footslopes	1/2	Yes	No	Tropaquents and Hydraquents
Calapan, Mindoro	>500	Marine plain	0	No	Yes	Tropaquents
Calauan, Laguna	< 50	Lacustrine plain and hanging mires[a] in old crater	0–2	Yes	No	Histic Fluvaquents, Hydraquents and Tropohemists
Canaway, Agusan del Norte	> 500	Alluvial-colluvial footslopes	1/4	Yes	No	Tropaquents
Capudlosan, Agusan del Norte	>500	Alluvial-colluvial footslopes	1/4	No	Yes	Tropaquents, Hydraquents
Kalayaan, Laguna	50	Hanging mire[a]	0–2	Yes	No	(Histic) Hydraquents
Morong, Rizal	< 50	Spring mire[a]	0	Yes	No	Hydraquents
Palsabangon, Quezon	> 50	Alluvial fan	3–6	Yes	No	Tropaquents
Pangil, Laguna	> 50	Spring mire[a]	0	Yes	No	Tropohemists
Sabang, Camarines Sur	> 500	Marine plain	0	No	No	Tropaquents
Taal, Batangas	> 50	Alluvial-colluvial footslope	2	No	No	Andaquepts
Tayug, Pangasinan	>500	Alluvial-colluvial footslopes	1/4	?	Yes	Tropaquents
Tiaong, Quezon	< 50	Alluvial-colluvial footslope	1–2	Yes	Yes	Tropaquents and Hydraquents

[a]Spring mires are peaty spots developed over artesian spring heads; hanging mires are of similar origin but are formed on slopes.

Available zinc in rice soils. Available zinc in 37 soils (pH: 3.7 to 8.5; O.M.: 0.6 to 66%; total zinc: 33 to 161 ppm) was measured by four methods using air-dried soil samples. IR26 was grown on the same soils, flooded. The severity of zinc deficiency was scored on a 0 to 9 scale. The plants were harvested 6 weeks after transplanting and their zinc content was determined.

The amounts of zinc extracted by the solvents were in the order 0.05 *N* HCl < DTPA < EDTA < 0.1 *N* HCl (Table 5). The 0.05 *N* HCl method gave the best correlation (r = 0.88**) with the zinc content of the plants, followed by the extraction methods of 0.1 *N* HCl (r = 0.55**) and EDTA–$(NH_4)_2CO_3$ (r = 0.43). The correlation of r = 0.31 for the DTPA method was not significant. IR26 rice showed zinc deficiency symptoms on 11 of the 37 soils. Using the Katyal and Ponnamperuma method of analysis, all except two Histosols had less than 1.0 ppm zinc.

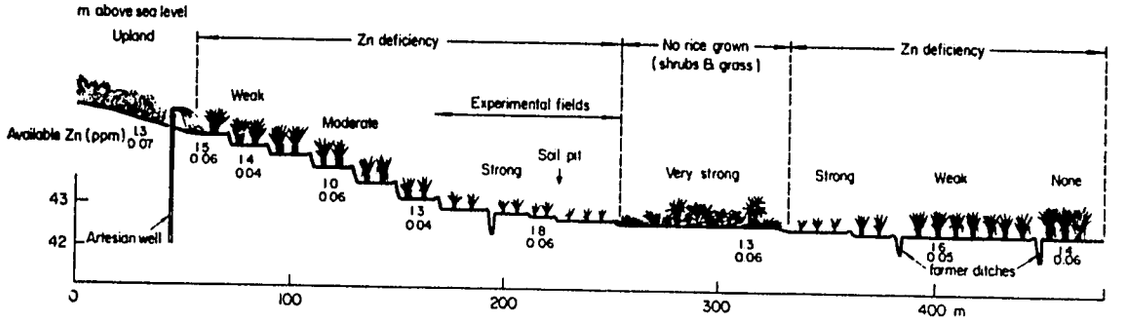
The 0.05 *N* HCl method for zinc extraction appears to be a good method of analysis for available zinc in wetland rice soils because it is precise, simple, convenient, and inexpensive.

NUTRITIONAL PROBLEMS OF RICE GROWN ON HISTOSOLS

Deficiencies of macronutrients and micronutrients. Laboratory tests and greenhouse experiments revealed that most Histosols are deficient in available nitrogen, phosphorus,

Table 4. Properties of soils at Philippine sites where zinc deficiency was observed in 1977.

Location	pH	Organic matter (%)	Available zinc (ppm)
San Isidro, Santa Fe, Leyte	5.2	48.0	0.98
Morong, Rizal	5.5	25.5	1.20
Kalayaan, Laguna	5.6	20.5	0.56
Halang, Pangil, Laguna	5.8	33.0	0.47
Famy, Laguna	5.8	35.0	0.45
Plaridel, Bulacan	6.0	2.3	0.47
Infanta, Quezon	6.0	57.5	0.84
Paete, Laguna	6.2	19.3	0.20
Libon, Albay	6.5	10.7	0.26
Calauan, Laguna	6.5	35.8	0.24
Calauan, Laguna	6.6	44.0	0.16
Sinacaban, Misamis Oriental	6.6	15.0	0.14
Calapan, Mindoro	6.7	6.9	0.50
Bilar, Bohol	7.5	15.1	0.09
Pila, Laguna	7.5	3.3	0.18
Taal, Batangas	8.0	3.0	0.80



3. NE-SW cross section of the Tiaong, Quezon, Philippines, toposequence. Upper figures of available zinc represent EDTA; lower figures, HCl 0.05 N.

Table 5. Soil properties, available zinc determined by 4 methods of analysis, and zinc content of 6-week-old IR26 rice grown on 37 submerged soils. Philippines, 1977.

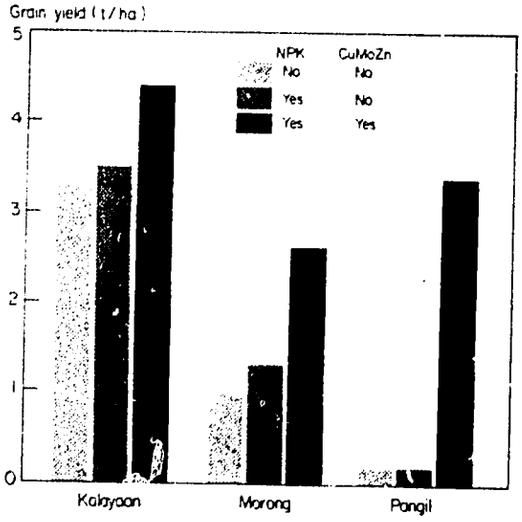
Soil	pH	Organic matter (%)	Total zinc (ppm)	Available zinc[a] (ppm)				Plant zinc (ppm)
				1	2	3	4	
Aggaie clay loam	7.9	1.4	38	0.4	1.1	0.5	2.5	19
Taal sandy loam	6.9	0.56	71	13.0	14.0	8.4	22.0	28
Antipolo clay	5.8	3.0	126	3.1	6.7	2.2	6.3	34
Bani clay	6.3	2.1	62	0.7	2.7	2.0	4.2	n.a.
Calumpang clay loam	5.0	3.8	85	1.6	7.6	2.9	7.0	25
Acid sulfate soil (San Jose, Camarines Sur)	3.7	2.3	48	3.4	4.6	.3	4.1	n.a.
Histosol (Calauan)	6.1	50.0	47	0.3	14.0	5.5	11.0	16
Acid sulfate soil (Castañas, Sariaya)	3.8	4.0	132	40.0	42.0	18.0	62.0	102
Histosol (Famy)	5.7	48.0	45	0.3	11.0	3.7	10.0	22
Histosol (Infanta)	6.0	57.0	80	0.8	11.0	7.9	13.0	27
Histosol (Kalayaan)	5.6	25.0	98	2.8	15.0	6.7	16.0	27
Sandy loam (Korea)	4.9	2.2	91	2.3	2.4	1.2	2.7	39
Lipa clay loam	6.9	5.6	79	0.2	6.6	5.6	13.0	19
Pangasinan sandy loam	7.3	0.68	64	0.6	0.7	0.4	2.8	29
Taal silt loam	7.1	0.56	40	1.9	3.3	1.1	4.3	27
Libon sandy loam	6.8	1.7	49	0.6	3.2	1.6	6.5	17
Luisiana clay	4.7	2.7	142	6.4	15.0	3.1	15.0	37
Luna clay	7.5	1.7	161	0.4	10.0	5.0	32.0	30
Maahas clay	6.2	1.9	128	0.5	5.4	2.3	7.5	32
Alkalinized Maahas clay	8.5	2.4	128	0.	8.7	7.8	16.0	20
Luna clay	6.7	3.0	86	0.1	2.3	1.2	7.0	18
Malinao sandy loam	4.1	2.2	33	3.6	5.6	1.4	5.0	n.a.
Bigaa clay loam	5.3	1.7	52	3.8	6.8	4.2	11.0	32
Histosol (Morong)	5.5	25.0	52	1.2	5.6	1.9	18.0	17
Buenavista clay	6.5	2.1	81	2.5	10.0	5.2	15.0	39
Acid sulfate soil (Thailand)	4.1	1.4	52	2.0	3.7	1.0	2.5	39
Histosol (Luisiana)	5.9	66.0	69	0.3	17.0	4.7	12.0	19
Pila clay	7.0	3.6	101	0.7	10.0	6.5	20.0	25
Guadalupe clay	5.9	3.0	98	0.8	2.2	2.2	9.0	35
La Paz silt loam	6.2	1.7	71	1.8	3.8	1.9	7.0	29
Lipa clay	6.8	4.3	79	0.7	4.9	2.9	11.0	27
San Fernando clay	4.5	4.4	100	5.0	9.4	5.3	13.0	n.a.
Lipa sandy loam (Sariaya, Quezon)	5.4	4.0	122	3.5	12.0	4.0	12.0	26
Silc silt loam	7.8	1.8	139	0	4.4	5.5	12.0	28
Tungshan silt loam	6.6	2.8	132	4.8	7.6	3.2	12.0	33
Angeles sandy loam	5.9	3.4	54	1.8	3.8	2.1	4.0	31
Histosol (Camp Eldridge)	6.7	24.0	126	2.0	38.0	21.0	39.0	12

[a]1 = 0.05 N HCl (Katyal and Ponnamperuma), 2 = EDTA- $(NH_4)_2CO_3$ (Trierweiler and Lindsay), 3 = DTPA (Lindsey and Norvell), 4 = 0.1 N HCl (Nelson et al.).

potassium, zinc, copper, and molybdenum (Table 6). Histosols are more deficient in nutrients than analyses of the dry soils indicate, because when the field is wet, the soils absorb several times their weight of water and dilute the nutrients. Replicated experiments in 1977 at six locations in the Philippine provinces of Laguna, Rizal, and Leyte confirmed those findings.

The response of IR26 to two levels of NPK fertilizers, and the trace elements copper, molybdenum, and zinc was investigated in a 2^4 factorial experiment with NPK fertilizer levels as main plots and the factorial combinations of the trace elements as subplots replicated four times. A zero level of all factors was compared with 50 kg N/ha + 25 kg P/ha + 50 kg K/ha, 20 kg Cu/ha (copper sulfate), 2 kg of Mo/ha (ammonium molybdate), and 20 kg Zn/ha (zinc sulfate). Three-week-old IR26 seedlings were transplanted after the NPK fertilizers and microelements were incorporated into the soil.

The yields at three locations differed markedly in response to NPK fertilizers and to the combined micronutrient treatments (Fig. 4). The response to NPK was significant only when micronutrients were added. The response to zinc was significant at three locations; the



4. Response of IR26 to nitrogen, phosphorus, and potassium and to copper, molybdenum, and zinc on Histosols at 3 locations in Laguna, 1977 dry season.

Table 6. Chemical characteristics of the 4 Histosols used in a greenhouse study of varietal reactions, Philippines, 1977 dry season.

	Pangil	Lamau	Morong	Calauan
pH	5.9	6.1	5.7	6.3
Organic matter (%)	41.9	38.9	15.0	36.7
CEC[a] (meq/100 g)	165.0	157.0	115.0	211.0
Total nitrogen (%)	1.39	1.19	0.55	1.48
Available phosphorus (ppm)	2.2	13.2	0	9.0
Available potassium (ppm)	32.0	18.5	11.0	34.0
Available zinc (ppm)	0.52	0.56	1.66	0.42
Available copper (ppm)	5.5	7.1	15.9	0.45
Available boron (ppm)	31.0	24.0	18.0	52.0
Active iron (%)	0.512	0.412	0.662	0.731
Active manganese (%)	0.014	0.010	0.031	0.078

[a]Cation exchange capacity.

responses to copper and to molybdenum were significant at Pangil, Laguna (Table 7).

The responses of IR26 to molybdenum on the Histosols at Morong, Rizal, and at Pangil are the first reports on the benefits of applied molybdenum to rice soils.

Effects of drying Histosols. To ascertain whether drying Histosols before flooding will destroy toxins and improve the growth of rice, IR26 was grown on four Histosols with two water management schemes — continuously submerged and well-drained — with a basal dressing of nitrogen, phosphorus, potassium, copper, molybdenum, and zinc in a replicated greenhouse experiment.

Table 7. Mean grain yields of IR26 rice at 2 rates of copper, molybdenum, and zinc application in the presence of nitrogen, phosphorus, and potassium (50, 25, 50 kg/ha) on Histosols at 3 locations in the Philippines, 1977 dry season.

Element	Application rate (kg/ha)	Grain yield (t/ha)		
		Kalayaan	Morong	Pangil
Copper	0	3.7	1.5	1.6
	20	3.6	1.8	2.7
Difference		−0.1ns	0.3ns	1.1**
Molybdenum	0	3.6	1.4	1.5
	2	3.8	1.9	2.7
Difference		0.2ns	0.5*	1.2**
Zinc	0	3.2	1.3	1.5
	20	4.1	2.0	2.7
Difference		0.9**	0.7**	1.2**

The soils were placed in 16-liter pots and treated with complete macronutrient and micronutrient fertilizer. In the drainage treatment the soils were allowed to drain freely and the drainage water was recycled.

Drainage depressed straw production and decreased grain yield severely. The plants in all four well-drained soils were chlorotic and contained more zinc (214 vs 41 ppm) and manganese (964 vs 161 ppm), but less iron (55 vs 68 ppm) than plants grown in submerged soils.

NITROGEN TRANSFORMATIONS IN RICE SOILS

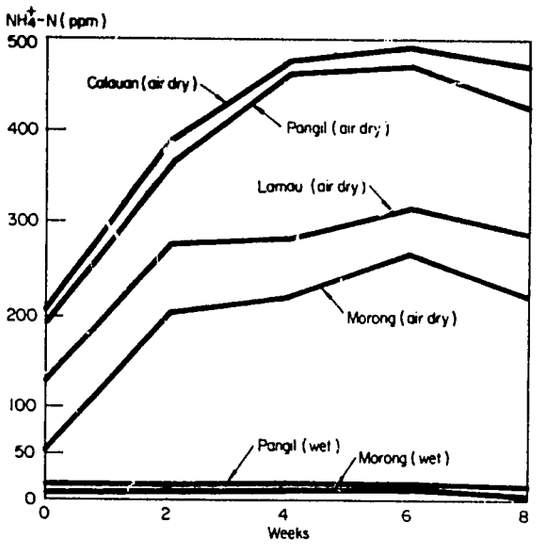
Ammonification. Ammonia released by anaerobic incubation at 30°C for 2 weeks ranged from < 50 to > 200 ppm for 39 Philippine lowland rice soils. The amount of ammonia in parts per million of dry soils was highly correlated positively with the percentage of organic carbon (r = +0.91) and with the percentage of nitrogen (r = +0.94), but negatively with the carbon-to-nitrogen (C:N) ratio (r = −0.46).

The fraction of total nitrogen ammonified ranged from 1.9 to 10.7%. A previous study of 380 Philippine wetland rice soils revealed that 20 to 640 ppm was released by anaerobic incubation at 35°C for 2 weeks. The amount of ammonia was highly correlated (r = +0.79) with the percentage of total nitrogen of the soils. The fraction of total nitrogen released ranged from 3.5 to 26.0%.

When four Histosols containing 22 to 42% organic matter were incubated anaerobically without previous drying, they released only a small amount of ammonia. Drying the soil before submergence and anaerobic incubation caused a surge of ammonia release (Fig. 5). The moisture regime in Histosols is crucial in the release and conservation of nitrogen.

Nitrification. No nitrate was found in two strongly acid soils (Luisiana clay, pH 4.4; and Calalahan sandy loam, pH 3.4) incubated anaerobically at 30°C for 4 weeks. Apparently, there is no denitrification normally in strongly acid soils.

Denitrification. To study the influence of water regime on nitrogen losses, dry matter production and nitrogen uptake by IR32 rice were determined on seven soils subjected to two moisture regimes — continuous flooding and flooding with soil drying between successive crops in the greenhouse. The water regimes appeared to have no effect on dry matter production and nitrogen uptake.

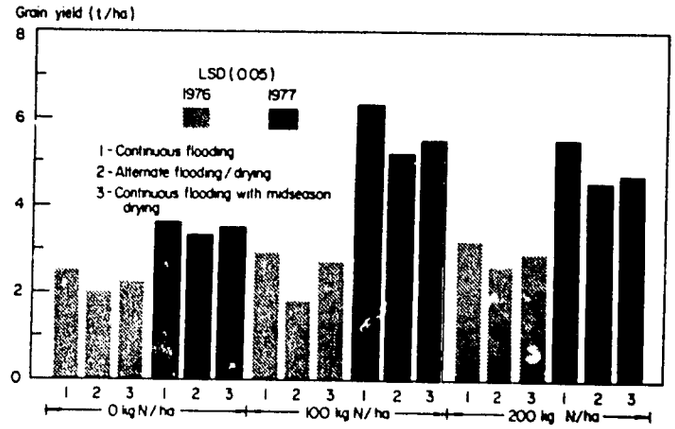


5. Influence of previous moisture conditions on the release of ammonia during anaerobic incubation of 4 Histosols at 30°C. Philippines, 1977.

A field experiment showed that the effect of alternate wetting and drying on nitrogen uptake and the depressing effect on yield were insignificant in unfertilized fields with a rice crop (Fig. 6), but when fertilizer nitrogen was applied at high levels, the adverse effect on grain yield was substantial.

Urea hydrolysis. Urea is rapidly replacing ammonium sulfate as the most important nitrogen fertilizer for rice. Most of the urea nitrogen absorbed by rice is the hydrolysis product $(NH_4)_2CO_3$.

The urease activity (Table 8) in eight different soils and their flood water was least in strongly acid soils (acid sulfate soils, pH 3.4–3.8) and greatest in the alkali soil (Maahas clay, alkalized, pH 8.6). Sodium chloride at 0.5% by weight of the soil (Maahas clay,



6. Effect of different moisture regimes and nitrogen levels on the grain yield of IR32 rice. IRRI. 1977.

salinized, pH 6.9) had no effect on the rate of urea hydrolysis.

Ammonia volatilization. Five days after 100 kg N/ha, as ammonium sulfate, was applied to the surface of four soils, 5 kg N/ha was lost in Luisiana clay (pH 5.7) and 47 kg N/ha in the alkalized Maahas clay (pH 8.6). Maahas clay (pH 6.6) and Lipa clay loam (pH 7.5) lost 11 and 15 kg N/ha, respectively. The loss of ammonia nitrogen increased as the pH of the soil increased.

Nitrogen-supplying capacity of submerged soils. Because the nitrogen-supplying capacity of submerged soils is important to the efficient use of nitrogen fertilizers in rice production, the dry matter production and nitrogen uptake by rice were studied on 39 Philippine wetland rice soils. Organic carbon, total nitrogen, and ammonia released by anaerobic incubation and oxidation with alkaline potassium permanganate were found to be good indexes of the nitrogen-supplying capacity of submerged soils (Table 9).

The level of available nitrogen in 13 provinces in the Philippines ranged between 54 and 477 ppm — values obtained by anaerobic incubation at 30°C for 1 week. Although the number of samples per province varied from 4 to 129, the level of available nitrogen in the soils of Nueva Vizcaya, Bulacan, Pangasinan Rizal, and Tarlac appeared to be lower than that in the soils of Agusan del Norte, Albay, Laguna, and Sorsogon. It varied from 76 to 274 ppm in the province of Laguna.

Water regime and nitrogen status. The results of a long-term experiment on the influence of water management on nitrogen content in the 23rd and 24th season confirmed the earlier finding that flood fallow promotes nitrogen accumulation. The percentage of nitrogen in soils subjected to flood fallow was 0.183–0.185; that in dry fallow soils was 0.118–0.126.

About 100 kg N/ha more nitrogen is accumulated annually in flood fallow soil than in dry fallow soil. In the 23rd season (no fertilizer had been added since the 13th season), rice grown on flood fallow soils yielded more

Table 8. Urease activity of some flooded rice soils.

Kind of soil	pH	Organic carbon (%)	Urease activity (μg NH_4^+ formed/ g soil per hour)
Acid sulfate soil	3.4	1.57	8.8
Acid sulfate soil	3.7	1.22	8.0
Saline soil	6.1	1.20	8.4
Histosol	6.1	22.70	20.1
Luisiana clay	4.3	1.94	20.0
Maahas clay	6.3	1.50	12.0
Maahas clay, salinized	6.9	1.50	12.0
Maahas clay, alkalized	8.6	1.50	32.0

Table 9. Correlation of values of available soil nitrogen by different methods with dry matter yield and uptake of nitrogen by rice (n = 39).

Method	Correlation coefficient (r)	
	Dry matter wt	Nitrogen content
Organic carbon %	0.45**	0.82**
Total nitrogen	0.46**	0.84**
Incubation, 30°C (2 wk)	0.40*	0.84**
Incubation, 40°C (1 wk)	0.46**	0.82**
Alkaline $KMnO_4$	0.40*	0.81**
H_2O_2 oxidation	0.46**	0.82**
Acid $KMnO_4$	0.39*	0.75**
Acid $K_2Cr_2O_7$	0.39*	0.74**
1 *N* H_2SO_4	0.10ns	0.42**

(112–140 g/drum) than rice grown on dry-fallow soils (77–93 g/drum). These data are averages for three soils.

Effects of straw incorporation. Straw incorporation significantly increased the organic matter content, but not the nitrogen content of the soil.

Algal nitrogen fixation. To study the effect of surface application of lime and phosphate on algal nitrogen fixation, two submerged soils were treated with 600 kg calcium carbonate/ha and 5 kg phosphorus/ha in pots in the greenhouse. Half of the pots were covered with black cloth. Every 8 weeks, the soil in each pot was thoroughly mixed and a sample was taken from it for analysis.

Light caused significant increases in both the nitrogen content and the carbon content of the soils (Table 10). The monthly accretion of nitrogen was lower in the nearly neutral Maahas clay (9.2 mg N/kg soil) than in the acid Luisiana clay (12.5 mg N/kg soil), apparently because of greater nitrification-denitrification. Although the application of lime did not affect the nitrogen and carbon contents of the soils, applied phosphorus increased them.

The net nitrogen fixation in acid soils may be greater than that occurring in neutral soils, probably because there is less denitrification in acid soils.

Table 10. Nitrogen content and organic carbon content at the 5th sampling of 2 soils subjected to the factorial combinations of 2 levels of lime ($CaCO_3$), phosphate, and light in the greenhouse. IRRI, 1977.

Soil	$CaCO_3$	P	No light[a]	Light[a]	Diff.[a]
			Nitrogen content (%)		
Luisiana clay	0	0	0.163 a	0.177 ab	0.014**
	0	+	0.163 a	0.181 a	0.018**
	+	0	0.163 a	0.175 bc	0.012**
	+	+	0.165 a	0.171 c	0.006*
Maahas clay	0	0	0.099 b	0.110 d	0.011**
	0	+	0.102 b	0.109 d	0.007**
	+	0	0.099 b	0.107 d	0.008**
	+	+	0.100 b	0.111 d	0.011**
			Organic carbon (%)		
Luisiana clay	0	0	2.37 b	2.51 b	0.14**
	0	+	2.47 a	2.62 a	0.15**
	+	0	2.51 a	2.66 a	0.15**
	+	+	2.51 a	2.67 a	0.16**
Maahas clay	0	0	1.52 d	1.88 c	0.36**
	0	+	1.65 c	1.91 c	0.26**
	+	0	1.62 c	1.86 c	0.24**
	+	+	1.69 c	1.88 c	0.19**

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

Soil and crop management

Soil fertility management: microbiological studies

Agronomy and Soil Microbiology Departments

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NITROGEN FIXATION ASSOCIATED WITH WETLAND RICE

Agronomy and Soil Microbiology Departments

A collaborative research project to increase the nitrogen-fixing activity of the rice rhizosphere was initiated in March 1976 with the Boyce Thompson Institute and Cornell University, USA. The relative contribution of nitrogen-fixing microorganisms associated with the roots of lowland rice was studied and compared with that of other known nitrogen-fixing agents in lowland rice.

Nitrogen balance studies *(Agronomy and Soil Microbiology). Field studies.* The soil-nitrogen values of plots (sampled to the plow-pan depth) to which no nitrogen had been added for 24 crops at IRRI and 17 crops at Maligaya, Nueva Ecija, Philippines, were similar to or only slightly higher than the original analytical values (original Kjeldahl assays).

Using values of 0.6% for straw (about two-thirds removed from field) and 1.1% for grain, the crop removed from the soil an estimated 1,392 kg N/ha at IRRI and 778 kg N/ha at Maligaya. The nitrogen input in rain and irrigation water can also be estimated. Thus, assuming no nitrogen input other than that from rain and irrigation water, the amount of nitrogen that may be fixed annually is about 100 kg N/ha for IRRI and about 75 kg N/ha for Maligaya. If this amount of nitrogen had been removed from the soil, the expected nitrogen value of the Maligaya soil would be 0.048% N and that of the IRRI soil 0.118% N. Both values are substantially below the experimental values.

The data suggest a sizable input of nitrogen (37 to 50 kg/ha per crop) into flooded rice paddies in the tropics.

Greenhouse studies. To obtain quantitative data on the net amount of nitrogen fixed in flooded rice, a preliminary greenhouse pot experiment using a rice soil from Maligaya was established for 4 successive crops of IR28 rice with 2-week intervals between crops.

In the standard treatment, rice was grown in continuously flooded soil. In another treatment, some pots were covered to preclude light from the soil surface. In two other treatments, the soil was inoculated with *Azolla pinnata* or with blue-green algae (with phosphorus and iron fertilization). The fifth treatment was flood fallow pots. The algal inoculant was taken from the field and, depending on the crop, contained *Nostoc, Gloeotrichia,* or *Anabaena.*

The amount of nitrogen removed by each crop decreased substantially after the first crop, and stabilized by the fourth crop. The nitrogen uptake per crop was significantly greater than that of the standard treatment only with *Azolla* inoculation. Nitrogen equal to 50% of that removed by the crop was fixed in the standard treatment. All the nitrogen removed by the crop in the covered treatment can be accounted for by the decrease in soil nitrogen (Table 1).

The flooded-fallow pots did not fix a significant amount of nitrogen. This suggests that the rice plant must be present to stimulate nitrogen fixation. The *Azolla* and the algae inoculation stimulated nitrogen fixation. All the net nitrogen fixation was due to the phototrophic microorganisms.

The final soil nitrogen content was higher when the net nitrogen fixation was significant, as

Table 1. Nitrogen (N) balance sheet for 4 crops of IR28 rice. IRRI, 1977.

Treatment	Debit			Credit		Balance	
	Decrease in soil N (mg/pot)	Miscellaneous N input (mg/pot)	Total N (mg/pot)	N in 4 crops (mg/pot)	Increase in soil N (mg/pot)	N unaccounted for[a] (mg/pot)	N unaccounted for[a] Crop N (%)
Standard	469	25	494	967	—	473* b	49
Covered	895	25	920	915	—	-5 c	—
+ algae (+ P, Fe)	252	70	322	1,093	—	771* ab	71
+ *Azolla* (+ P, Fe)	260	78	338	1,316	—	978 a	74
Fallow	—	22	22	—	177	155 c	—

*Significant at 1% level. [a]Values followed by a common letter are not significantly different at the 5% level.

Table 2. Changes in soil nitrogen and amount of fixed nitrogen after 4 consecutive crops of IR28 rice. IRRI greenhouse pot experiment, 1977.

Treatment	Soil nitrogen[a] (mg/pot)		Nitrogen fixed (mg/pot)
	Original	Final	
Covered	7213 a	6317a	0 a
Standard	7134 a	6665 b	474 b
Algae (+ P + Fe)	7103 a	6851 c	771 bc
Azolla (+ P + Fe)	7024 a	6764 bc	978 c

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

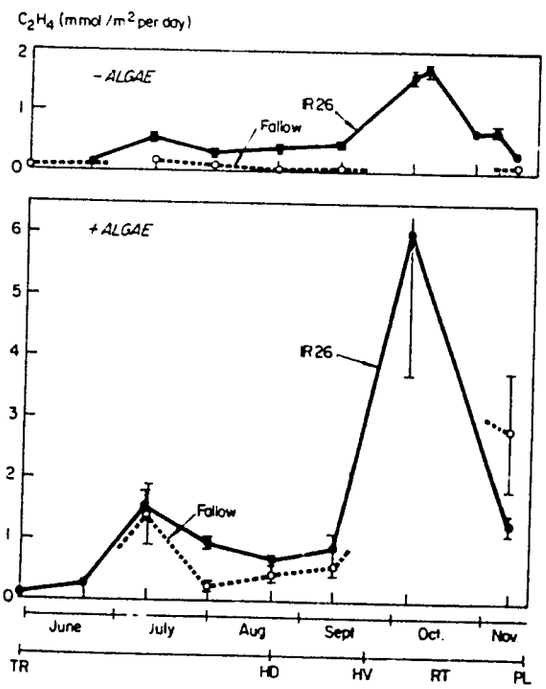
in the *Azolla* and algae treatments (Table 2). All the recently fixed nitrogen may not be immediately available to the plant.

Acetylene reduction assays *(Soil Microbiology)*. Acetylene reduction activity (ARA) assays were conducted in an IRRI field, a farmer's field in the Philippines, and experimental plots in Thailand to estimate the extent of nitrogen fixed in the flood water of a rice field and that of nitrogen fixed in association with the rice plant. The water replacement technique (1975 Annual Report) was used to eliminate the algal nitrogen-fixing activity (NFA) in flood water and the surface soil.

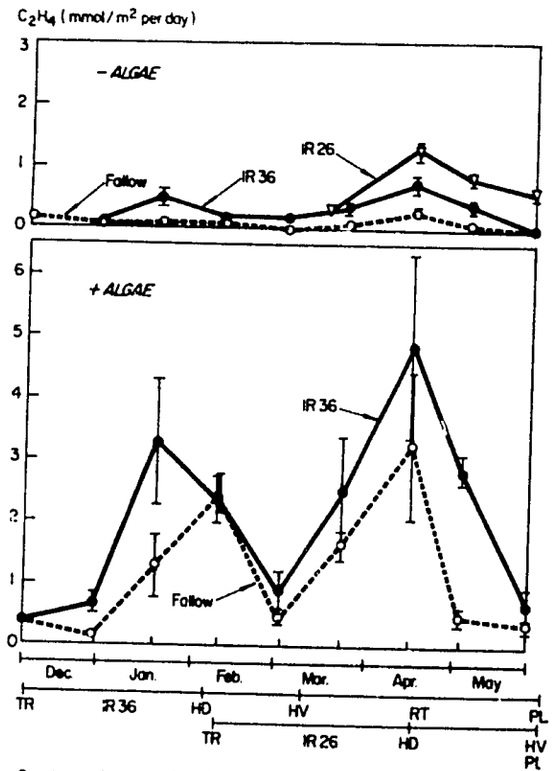
The NFA was measured in IRRI's continuously flooded field planted to IR26 rice in the 1976 wet season and IR26 and IR36 in the 1977 dry season. The NFA of fallow plots was also measured. In both seasons, the removal of algal activity greatly reduced the NFA (Fig. 1,2); concomitantly, the ARA was higher in the planted soils than in the fallow soils. NFA appears to be associated with the presence of the rice plant. With IR26, the NFA was higher in the dry season than in the wet.

High temperature and solar radiation appear to favor nitrogen fixation; the period from March to May is the hottest period of the year in Los Baños, Philippines. In both the 1976 wet and 1977 dry seasons, algal NFA had two peaks: one at the early stage of rice growth and the other at the ratoon stage.

By extrapolating ARA assays, algal ARA was estimated to be 200 mmol C_2H_4/m^2 in the



1. Acetylene reduction rate at IRRI, with and without algae in the wet season of 1976. TR = transplanting, HD = heading, HV = harvesting, RT = ratoon, PL = plowing.



2. Acetylene reduction rate at IRRI with and without algae in the dry season of 1977. TR = transplanting, HD = heading, HV = harvesting, RT = ratoon, PL = plowing.

Table 3. Acetylene-reducing activity (ARA) of IR26 and IR36 rice plants.[a] IRRI, 1977 wet season.

Days after transplanting	IR26			IR36		
	ARA (μmol C_2H_4/hill daily)		Dry root (g)	ARA (μmol C_2H_4/hill daily)		Dry root (g)
	In situ	In water culture		In situ	In water culture	
21	12.3 ± 0.7[b]	11.5 ± 3.2	3.15 ± 0.5	14.8 ± 0.7	15.8 ± 3.9	1.1 ± 0.14
43	30.6 ± 2.6	48.4 ± 7.9	5.0 ± 0.5	21.3 ± 1.6	35.5 ± 5.0	4.6 ± 0.5
64	49.9 ± 4.9	50.8 ± 5.9	6.1 ± 0.9	38.7 ± 5.5	34.2 ± 2.8	3.1 ± 2.0
84	18.9 ± 1.8	22.0 ± 3.7	3.2 ± 0.25	26.4 ± 3.3	31.7 ± 9.3	2.3 ± 0.4
106	15.8 ± 1.1	21.0 ± 3.3	2.8 ± 0.35	—	—	—
Ratoon[c]	7.8 ± 1.0	24.5 ± 4.8	2.1 ± 0.3	9.[illegible] ± 1.0	17.8 ± 2.9	1.3 ± 0.2

[a]Roots of plants from the field were washed under running water bubbled continuously with nitrogen gas, then transferred to a culture solution where the assay was made 24 hours later. [b]Average ± standard error of the mean. [c]IR26, 24 days after cutting; IR36, 37 days after cutting.

wet season (163 days) and 300 mmol C_2H_4/m^2 in the dry season (168 days). ARA associated with the rice plant was calculated to be 90 mmol C_2H_4/m^2 in the wet season (163 days, IR26) and 50 mmol C_2H_4/m^2 in the dry season (168 days, IR36).

To demonstrate the role of roots in nitrogen fixation associated with the rice plant, the NFA of the top part of the rice plant separated from the roots was measured in the field. Some ARA remains associated with the top part of the rice plant after its separation from the roots, indicating that the ARA associated with the plant is not confined to the rhizosphere. The relative contribution of the rhizosphere and stems to the total NFA associated with the rice plant varied. This factor complicates the monitoring of the NFA of the rice rhizosphere.

In the 1977 wet season, the ARA associated with IR26 rice and that associated with IR36 rice were compared at IRRI by field ARA and water-culture assays. The population of the heterotrophic bacteria and aerobic nitrogen fixers grown on either malate or glucose medium was determined. At the early stages of growth, the ARA of IR26 was higher than that of IR36, but the reverse was true during the later stages (Table 3). For both rice varieties, the ARA activity was highest at the heading stage, and lower at the ratoon stage because the algal activity on the stem was eliminated. The extrapolation of the measured ARA up to harvest time showed 66 mmol C_2H_4/m^2 for IR26 (105 days) and 51 mmol C_2H_4/m^2 for IR36 (95 days). Therefore, the daily average ARA values for IR26 and IR36 were similar.

The population of aerobic nitrogen fixers at the root surface (rhizoplane) and within the washed root tended to increase as the plants grew, and reached 10^8/g fresh root (Table 4). The population count of the nitrogen fixers grown on a glucose-yeast extract medium was consistently higher than that of the nitrogen fixers grown on malate-yeast extract medium. Most of the bacteria grown on malate medium were of the *Spirillum* type, which was also found within the internode tissue.

The plants were taken on the day when the field assays were conducted. The water-culture pots with the rice plants were enclosed in a plastic assay bag. Assays were conducted for 24 hours in the greenhouse. This assay eliminates problems of gas transfer.

The field-assay ARA almost paralleled water-culture ARA (r = 0.88) (Table 3), and ARA by the water-culture assay was higher by 20% than ARA by the field assay. Perhaps the acetylene was transported quickly to the root zone and became accessible to nitrogenase located in the plant and to the root. The almost parallel values from both methods suggest the validity of the field assays. The slightly lower ARA measured by the field assay, however, suggests that the field assay values might still be low estimates, probably because of the limitation of gas transfer.

The ARA was measured in a farmer's field (Puro clay loam) in Albay province, Philip-

Table 4. Population of the heterotrophs and aerobic nitrogen fixers per gram of fresh root of 2 rice varieties.[a] IRRI, 1977.

Days after transplanting	Heterotrophs[b] (× 10^3/g fresh root)		Aerobic nitrogen fixers (× 10^3/g fresh root)			
			Rhizoplane		Within plant[c]	
	Rhizoplane	Within plant[c]	Glucose[d]	Malate[e]	Glucose[d]	Malate[e]
			IR26			
43	134	874	160	4	125	3
64	234	875	200	23	740	72
84	300	870	205	2	1000	21
Ratoon[f]			180	4	1400	34
			IR36			
43	189	682	140	14	230	16
64	467	1670	220	15	920	31
84	720	1650	600	13	1000	22
Ratoon[f]			240	4	1800	53

[a]Based on av. of 3 replicates. [b]Plate count on 3% tryptic soy agar (Difco). [c]Washed root was macerated. [d]Most probable number in glucose medium. [e]Most probable number in malate medium. [f]10 days after cutting.

pines, three times from August to October. The field was planted to IR26 and Malagkit, a local cultivar of glutinous rice. In all cases, the water replacement treatment reduced the ARA only slightly, because of limited algae growth. The NFA values associated with rice were similar to those usually found in IRRI fields and were slightly higher for Malagkit rice than for IR26.

In cooperation with the Department of Agriculture in Thailand, field ARA was determined in the 1976 wet season and the 1977 dry and wet seasons at three experiment stations in Thailand — Klong Luang (least fertile), Supanburi (medium), and Chainat (the most fertile). Both unfertilized plots and plots that received potassium and phosphorus were used. The removal of algae also greatly reduced the ARA values. The ARA values associated with RD9 rice were similar to or slightly less than those recorded at IRRI. The effect of adding phosphorus to the soil on the NFA associated with the rice plant was evident in Supanburi and Klong Luang where soils were deficient in phosphorus. The NFA of the flood water was lowest in Klong Luang (acid sulfate soils) but high in the dry season crop at Supanburi and Chainat.

Varietal differences in nitrogen fixation ability. Screening for rice varieties that have a high NFA capacity was continued in the laboratory, greenhouse, and field. Among 15 varieties tested in the greenhouse, 5 varieties of *Oryza sativa* (JBS236, IR26, Pokkali, PeBiHun, and DV20), *O. australiensis*, and *O. punctata* had higher ARA values. These rices were also grown in the field at IRRI, where their NFA was compared with that of IR26 by the field assay technique and by the water-culture technique.

The ARA values and the population counts of aerobic nitrogen fixers of the root were much smaller than those of the rices grown in the field. The population counts of N_2-fixers were not related to the ARA values.

In field assays, the NFA of Latisail, JBS236, and one clone of *O. australiensis* was slightly higher than that of IR26. The ARA values determined by water culture were slightly higher than those obtained through field assays. The highest value (water-culture) was 180 g N/ha per day for *O. australiensis*.

It is too premature to identify any rice whose consistently higher ARA value compares with that of IR26. The variability of NFA in different growth stages of rice complicates screening for a high capacity for NFA.

NITROGEN FIXATION BY *AZOLLA-ANABAENA* ASSOCIATION

Soil Microbiology Department

Field experiments. Field trials to test the effect of *Azolla* inoculation on rice growth was continued on the same treatment plots as those reported in 1976, but the method was modified.

Table 5. Effect of *Azolla* inoculation on rice growth. IRRI, 1977.

Treatment[a] P W A	1977 dry season[b] Straw (t/ha)	Grain t/ha	Grain Index	Panicles (no./hill)	1977 wet season[c] Straw (t/ha)	Grain t/ha	Grain Index	Panicles (no./hill)	Both seasons' grain yield (t/ha)
– – –	3.8	4.5	100	12	3.0	3.1	100	12	7.6
– – +	5.6	5.8	130	13	3.4	3.5	111	11	9.3
– + –	4.2	4.7	100	12	3.4	3.4	100	13	8.1
– + +	4.8	5.4	114	13	3.0	2.9	85	12	8.3
+ – –	4.6	5.0	100	13	3.7	3.5	100	13	8.5
+ – +	7.0	6.9	136	18	4.4	4.3	123	14	11.2
+ + –	4.5	4.9	100	13	3.7	3.6	100	14	8.5
+ + +	6.9	6.3	128	16	4.3	4.0	109	12	10.3

[a]P = phosphorus, W = puddling to incorporate *Azolla*, A = *Azolla* inoculation. [b]Four inoculations of *Azolla* before the rice was transplanted and two after transplanting. [c]Two inoculations of *Azolla* before transplanting and three after transplanting.

Azolla was grown and inoculated both before and after transplanting. Because *Azolla* decomposes slowly in soil, the medium-maturing IR26 was used in place of IR30. The amount of phosphorus was decreased to 15 kg P_2O_5/ha.

For the 1977 dry season rice, 4 crops of *Azolla* (from October to December) were grown for 80 days before the land was prepared for transplanting. In plots that were puddled, *Azolla* was incorporated into the soil before new inoculation. After the rice was transplanted, *Azolla* was inoculated twice. Without added phosphorus and puddling, a 1.3-t grain increase was obtained with *Azolla* inoculation (Table 5). Puddling tended to reduce the grain yield response to *Azolla* inoculation.

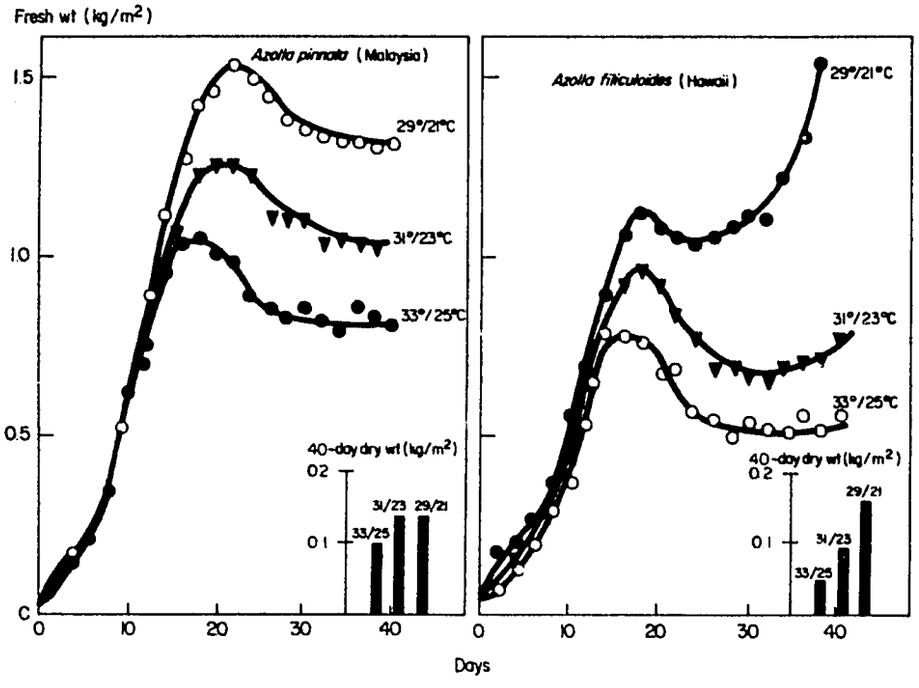
In the wet season rice, two crops of *Azolla* were grown for 1 month (May-June) before the rice was transplanted. After the rice was transplanted, *Azolla* was inoculated three times. Because of high temperature, the growth of *Azolla* before transplanting was poor, particularly in plots without phosphorus. After transplanting, its growth was more vigorous. Without added phosphorus, a 12% or 0.4-t increase in rice yield was obtained with *Azolla* inoculation.

***Azolla* inoculum preparation.** In the field plots (25 m²) where the *Azolla* inoculum was grown, *Azolla* production continued for more than 8 months. The first half of the total superphosphate (15 kg P_2O_5/ha) and carbofuran (3 kg a.i./ha) added was applied when half of the plot was inoculated with *Azolla*. The other half was added when *Azolla* was transferred to the other half of the plot. Because mixing both compounds with *Azolla* was deleterious to its initial growth, both the superphosphate and carbofuran were broadcast over the inoculated *Azolla*. Half of the plots were shaded to 20% of the light intensity in the open area, as measured at 1200 hours. *Azolla* was harvested when it had covered the surface of the plot or when it started to decompose.

In the open area in the plot, 330 kg N/ha was accumulated in 220 days. The growth rate was depressed from April through June probably because of high temperature and strong solar radiation.

***Azolla* species and clones collection.** *Azolla pinnata* collected from the Philippines, Malaysia, Indonesia, and Thailand, and *A. filiculoides* collected from Hawaii were grown in the greenhouse and in the phytotron at 5 klux 30°C. Their tolerance for high temperature and their phosphorus requirements were tested. At 29°/21°C (day/night), *A. filiculoides* had a higher population density than *A. pinnata* (Fig. 3); at 33°/25°, this higher density did not occur and the result was less biomass. Although temperature did not greatly affect the rate of growth, it markedly affected the maximum biomass. It appeared that the higher temperature regime accelerated the decomposition and death of *Azolla*.

The variability in the pH of the water-culture solution from pH 4, 6, and 8 did not appear to significantly affect the growth of the 3 clones of *A. pinnata* and *A. filiculoides*. Among the *Azolla* species tested at 7 temperature regimes — 23°/15°C, 26°/18°C, 29°/21°C, 32°/24°C,



3. Temperature response of *A. pinnata* and *A. filiculoides*. IRRI, 1977.

35°/27°C, 38°/30°C, and 41°/33°C — *A. filiculoides* was most sensitive to high temperature. *Azolla* clones from Banaue, located in the cool mountain area of Luzon, Philippines, showed no special tolerance for low temperatures.

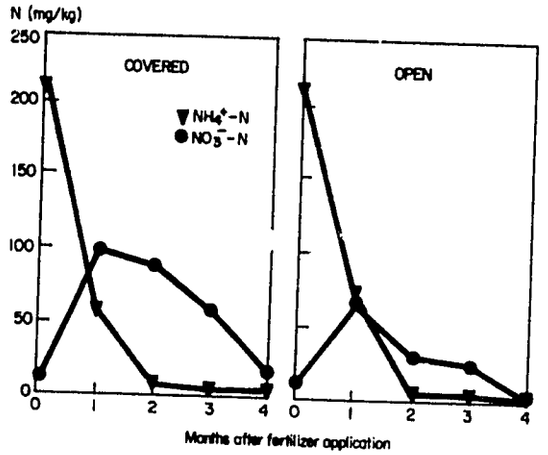
NITROGEN TRANSFORMATION IN RICE SOILS

Soil Microbiology Department

Nitrogen transformation in rainfed and upland rice soils. The loss of applied ammonium was studied at two sites: IRRI upland field with poor drainage, and Cale, Batangas, Philippines, with good drainage. In the study, ^{15}N-labeled ammonium (50 kg N/ha) was applied in metal cylinders (18.5 cm in diameter) inserted in the furrows. To prevent leaching, half of the cylinders were covered with plastic film. At 0, 1, 2, 3, 4, and 5 months after application of fertilizer, the soil from covered and uncovered cylinders was sampled at depths of 15 to 75 cm.

Ammonium nitrogen in the surface soil layer (0-15 cm) of the poorly drained soil decreased rapidly during the first month after application, and decreased further during the second month to the level before fertilizer was applied (Fig. 4). The decrease in ammonia was accompanied by an increase in nitrate nitrogen. Nitrification was faster in the covered cylinders than in the open ones. Nitrate movement occurred in both open cylinders — where the soil was exposed to rainfall — and covered cylinders. Little nitrate accumulated at 50 cm in both types of cylinders (Fig. 5), probably because the water table frequently rose and the soil surface was sometimes submerged after heavy rains. That could have created anaerobic conditions and, thus, the low nitrate accumulation at this depth may have been caused by denitrification loss.

In open cylinders and 5 months after the ^{15}N-labeled ammonium was applied, nitrate and

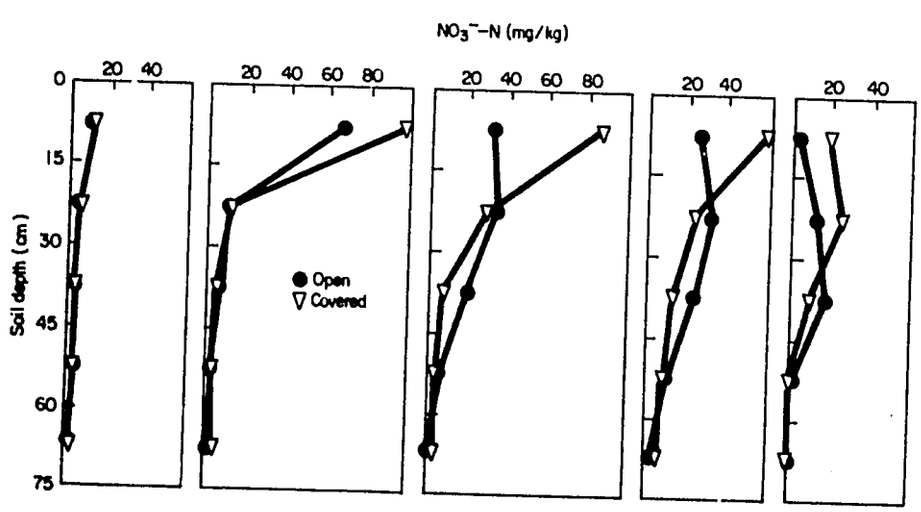


4. Changes in the contents of ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) in the surface (0–15 cm) soil layer. IRRI, 1976 wet season.

ammonium accumulated at the 30-45 cm depth, but were negligible at the surface layer (Table 6). In the covered cylinders, however, they accumulated at the 0-15 and 15-30 cm depths and were negligible at depths below 45 cm. The nitrogen losses may have occurred at the lower depths (45-75 cm). The recovery of the applied ^{15}N was 19% in the open cylinders and 35% in the closed cylinders, suggesting that leaching may have caused part of the nitrogen loss. The 65% loss in the covered cylinders was considerable, and may have been caused by the frequent rise of the water table (cylinder depth was 25 cm). Denitrification may be the major cause of nitrogen loss in poorly drained soils.

In Cale, where drainage is good, ammonium nitrogen disappeared very rapidly from the surface soil layer (0-15 cm) 1 month after fertilizer was applied in both the planted (IR5 rice) and unplanted plots (Fig. 6). In the unplanted plots the level of nitrate increased during the first month, then decreased. At harvest (5 months after), it was about the same as that in the no-nitrogen plot at the start. The disappearance of ammonium nitrogen in the first soil layer (0-15 cm) of the unplanted plots was followed by the appearance of nitrate in all of the 5 soil layers 1 month after the application. The total amount of nitrate occurring between 15 and 75 cm was equal to the amount of ammonium that disappeared in the 0-15 cm surface layer (Fig. 7). No similar findings were noted in the IRRI upland field.

The nitrate that appeared in the different soil layers during the first month decreased gradually with time; at harvest it was almost equal to that found at the start of the experiments. No peak of nitrate accumulation within the soil layers to a depth of 75 cm was observed. The nitrate might have been leached below 75 cm.



5. Vertical distribution of nitrate nitrogen in the soil profile (0–75 cm). IRRI, 1976 wet season.

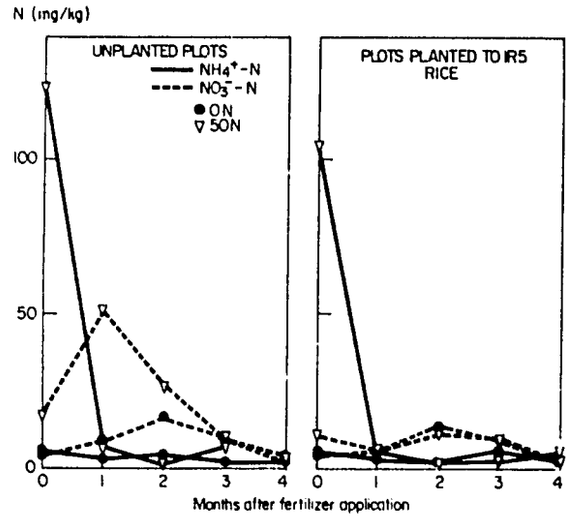
Table 6. Recovery of fertilizer nitrogen (^{15}N-labeled ammonium) 5 months after its application in poorly drained soil.[a] IRRI, 1976 wet season.

Soil depth (cm)	Mineral $NH_4^+ + NO_3^- - N$ (mg/kg)		^{15}N (mg/kg)	
	Total	^{15}N	Immobilized N	Total N
	Open cylinders			
0 - 15	5.86	0.716	19.70	20.42
15 - 30	13.4	5.04	1.08	6.12
30 - 45	10.12	9.24	0.135	9.38
45 - 60	NG	-	-	
60 - 75	NG	-	-	
	Covered cylinders			
0 - 15	23.96	12.58	28.87	41.45
15 - 30	28.22	15.87	4.10	19.97
30 - 45	13.43	3.96	2.48	6.44
45 - 60	NG	-	-	
60 - 75	NG	-	-	

[a] = <0.4% ^{15}N. NG = negligible.

In the open cylinders, 5 months after fertilizer application, the soil nitrate to a depth of 75 cm was almost equal to the amount before the nitrogen was applied.

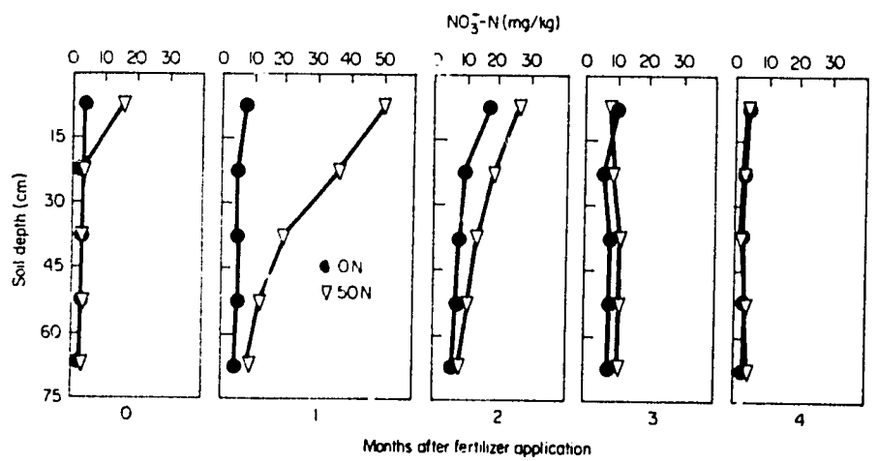
In covered cylinders, however, nitrate accumulated only in the first layer (0-15 cm), in contrast with its movement in IRRI field plots. Nitrate diffuses faster at higher soil moisture contents. Thus, its slow downward movement in covered cylinders in Cale may have been due to a lower soil moisture content in the lower layers (15-75 cm).



6. Changes in the contents of ammonium and nitrate nitrogen in the surface soil layer (0–15 cm). Cale, Batangas, Philippines, 1976 wet season.

In contrast to that in the poorly drained field at IRRI, the applied nitrogen in Cale was found at depths beyond 45 cm (Table 7). Recovery of ^{15}N in the soil layer up to 75 cm was 25% in open cylinders and 65% in covered cylinders.

Assuming that the loss of nitrogen in covered cylinders was caused by denitrification, the loss of nitrogen by leaching in open cylinders was 40% in Cale and 15% in the IRRI field. Deni-



7. Vertical distribution of nitrate nitrogen in the soil profile (0–75 cm). Cale, Batangas, Philippines, 1976 wet season.

Table 7. Recovery of fertilizer nitrogen (^{15}N-labeled ammonium) 5 months after its application in upland soil. Cale, Batangas, Philippines, 1976 wet season.

Soil depth (cm)	Mineral $NH_4^+ + NO_3^-$-N (mg/kg)		^{15}N (mg/kg)	
	Total	^{15}N	Immobilized N	Total N
	Open cylinders			
0 - 15	3.66	0.648	18.09	18.74
15 - 30	5.59	0.589	7.21	7.80
30 - 45	6.19	1.23	3.98	5.21
45 - 60	7.10	2.82	2.97	5.79
60 - 75	7.68	2.00	2.67	4.67
	Covered cylinders			
0 - 15	77.43	56.03	30.69	86.72
15 - 30	9.79	3.96	4.61	8.57
30 - 45	5.99	2.39	2.38	4.77
45 - 60	8.46	2.58	2.28	4.86
60 - 75	6.02	1.32	0.69	2.02

trification losses appear to be greater in poorly drained upland soils.

Effect of soil condition during the dry season on nitrogen availability during the wet season. In rainfed rice fields the condition of the soil during the dry season may affect the availability of soil nitrogen and the growth of rice during the wet season. The design of greenhouse experiments and the yield of wet season lowland rice were discussed in the 1976 Annual Report.

Submerging dried soil for 9 days before transplanting effected the release of available nitrogen, especially in soils that were air-dried during the entire dry season and in the dry soil prepared by alternate wetting and drying. The active ammonification process, however, was accompanied by nitrification when the flooded soil was subsequently dried. Fallowing the flooded or moist upland soil did not promote the storage of a large amount of exchangeable ammonium nitrogen. The release of immobilized ^{15}N from the previous year's wet season was about proportional to the mineralization of soil nitrogen.

In spite of the sufficient amount of available soil nitrogen and the application of 350 mg N/pot, the growth of plants in the previously moist upland and dried soils was inhibited. It improved with age, however, and was vigorous during the middle and late stages.

Use of fertilizer nitrogen was best in continuously flooded soils and lower in previously moist upland and dried treatments (Table 8). One cycle of alternate wetting and drying of the soil for 20 days, however, improved plant uptake of applied nitrogen.

The total amount of tagged nitrogen recovered in plant and soil revealed losses of 4.1% in the continuously flooded soils. The nitrogen loss was greatest (23%) from soils subjected to air-drying. High nitrogen losses from soils subjected to the wetting and drying treatment may be associated with the inhibition of growth during early plant development, when fertilizer nitrogen can be lost.

Although the air-drying treatment caused more losses of fertilizer nitrogen, the losses were compensated for by a greater availability of soil nitrogen at the later stages of rice growth, even greater than that in continuously flooded soils (Table 9). The grain yield was comparable with that of rice grown on continuously flooded soils. The practice of alternate wetting and drying appears to improve use of nitrogen from both the soil and fertilizer sources.

The percentage of soil nitrogen in the total nitrogen uptake was proportional to the amount of ammonium nitrogen that was present before transplanting. Increased mineralized nitrogen and inhibited rice growth, which occur after flooding of moist and dried soils, may explain the availability of fertilizer nitrogen and soil nitrogen. They are partly overcome by alternate wetting and drying.

The fate of applied nitrogen was followed in

Table 8. Balance sheet of ^{15}N-labeled fertilizer in lowland rice as affected by soil conditions during previous dry season.[a] IRRI greenhouse, 1976 wet season.

Soil condition[b] in previous dry season	Recovered (%)			Unaccounted for (%)
	Crop	Soil	Total	
Flooded, planted	55.1 a	40.8 ab	95.9 a	4.1 c
Flooded, fallow	58.5 a	35.9 bc	94.4 a	5.6 c
FMC, planted	38.2 d	45.5 a	83.7 bc	16.3 ab
FMC, fallow	46.0 bc	35.4 bc	81.4 bcd	18.6 ab
Air-dried	43.0 cd	34.2 c	77.2 d	22.8 a
Dry, with rain	40.3		bc	18.6 ab
Dry, with rain (AWD)	49.3 b	37.0 bc	86.3 b	13.7 b

[a]Based on the amount of ^{15}N applied (350 mg/pot). In a column, any 2 means followed by a common letter are not significantly different at the 5% level. [b]FMC = field moisture capacity; AWD = alternate wetting and drying for the wet season.

Table 9. Effect on soil nitrogen (N) uptake of soil conditions during previous dry season.[a] IRRI greenhouse, 1976 wet season.

Soil condition[b] in dry season	Total N uptake (mg/pot)	Soil N uptake (mg/pot)	Residual tagged N in soil N uptake (%)	Soil N in total N uptake (%)
Flooded, planted	320.8 c	128.1 d	6.3 ab	39.9 e
Flooded, fallow	380.3 b	175.4 c	7.1 a	46.1 d
FMC, planted	240.1 d	106.5 e	5.9 b	45.1 d
FMC, fallow	254.7 d	93.6 f	6.0 b	36.8 e
Air-dried	417.8 a	267.3 a	6.2 ab	64.0 a
Dry, with rain	305.0 c	163.6 c	5.6 b	53.7 c
Dry, with rain (AWD)	406.1 ab	233.5 b	6.3 ab	57.5 b

[a]In a column, any 2 means followed by a common letter are not significantly different at the 5% level. [b]FMC = field moisture capacity, AWD = alternate wet and dry preparation for wet season.

three cropping seasons. Of the 180 mg N/pot applied, 44% of the applied nitrogen was taken up by the first crop and 50% remained in the soil as immobilized nitrogen. Remineralization of immobilized nitrogen was slow; 7% was released in the second crop of lowland rice and 5% was released in the second crop of upland rice. Soil conditions during the dry season affected the availability of immobilized nitrogen to the subsequent lowland rice crop. Mineralization activity appears to improve after soil drying. Regardless of the difference in uptake of soil nitrogen among plants in different treatments, nitrogen from the residual fertilizer was almost constant at 6% of the total soil nitrogen uptake. At the end of the third crop, 35% of the applied nitrogen still remained immobilized in soil.

Appropriate manipulation of the soil before and during land preparation can markedly improve the amount of available soil nitrogen that can be released after a prolonged dry period in rainfed fields.

Soil and crop management

Soil fertility and fertilizer management

Agronomy Department

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Ammonia volatilization losses. The magnitude of direct ammonia volatilization losses, determined by nitrogen source and by time and method of nitrogen application, was measured in outdoor drums and in the field using a neutral and an acid rice soils.

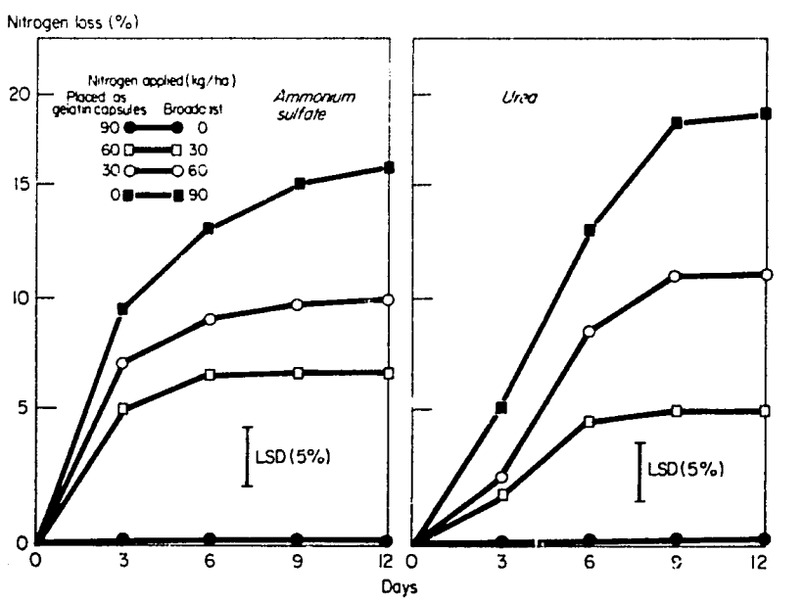
In one experiment, drums were filled with neutral Maahas and acid Luisiana soils, and flooded with water. Variable proportions — 100, 66, 33, and 0% — of 90 kg N/ha from ammonium sulfate and urea were placed 10-12 cm deep in the reduced soil layer as gelatin capsules; the remaining portions were broadcast on the flood water. Solar radiation and temperature were high during the experiment.

Ammonia volatilization losses from urea were generally greater than those from ammonium sulfate during a 12-day period. Maximum ammonia volatilization losses amounted to 18% urea nitrogen and 15% ammonium sulfate nitrogen when both nitrogen sources were entirely broadcast during periods of high light intensity and active algae growth (Fig. 1). The rate of ammonia volatilization from ammonium sulfate was initially faster than that from urea. Ammonia volatilization losses were nearly eliminated when all urea and ammonium sulfate were placed 10-12 cm deep in the soil.

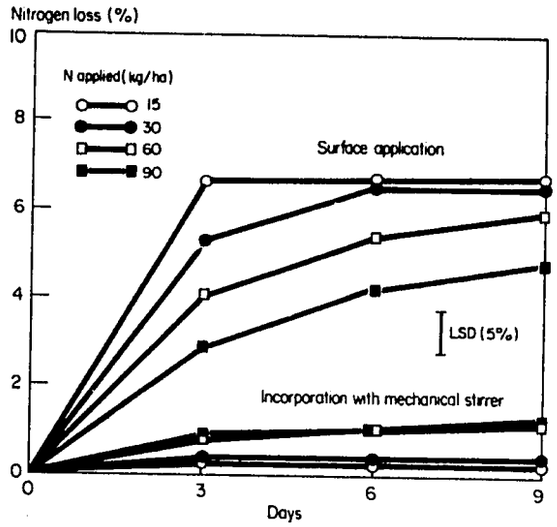
In a second experiment, ammonium sulfate at 15, 30, 60, and 90 kg N/ha was broadcast over the 5-8 cm of water contained in 2.5-liter glass bottles pressed into the mud of each drum. For mechanical incorporation, the soil in each bottle was stirred for 30 seconds with an electric stirrer. Stirring completely mixed the soil and water in each bottle to a depth of about 10-12 cm. The degree of incorporation was superior to what farmers achieved by harrowing.

In 9 days, volatilization losses with surface application of nitrogen ranged from 4.5 to 6.5% (Fig. 2). In contrast, mechanical incorporation of broadcast nitrogen reduced the losses to less than 1% for all rates of nitrogen. The levels of soil retention of nitrogen were similar to those achieved by placement as gelatin capsules (Fig. 1). Complete field incorporation of applied nitrogen fertilizer conserved considerable quantities of the fertilizer nitrogen.

A third experiment to determine the effects of rate and method of ammonium sulfate application on ammonia volatilization losses was car-



1. Effect of nitrogen source and placement on nitrogen loss through ammonia volatilization (as percentage of total application). Large pot experiment (Maahas clay). IRRI, 1977 dry season.



2. Effect of method of application on loss of nitrogen in Maahas clay. Large pot experiment. IRRI, 1977 dry season.

ried out at two field sites (Luisiana clay and Maahas clay) during the 1977 dry season. Preplant (basal) nitrogen (at rates 20, 30, 40, and 90 kg N/ha) was broadcast over 5-8 cm of water and incorporated; 30 kg N/ha was applied as topdressing 10 days after transplanting; and mudballs (60, 90, and 120 kg/ha) were placed 10-12 cm deep between rows of rice planted on a 20- × 20-cm grid.

The nitrogen loss from water on Luisiana soil was about 1% of the 20 kg N/ha of basal application and significantly higher than that from the topdressed 30 kg N/ha. Losses from mudball placement application were negligible (Fig. 3).

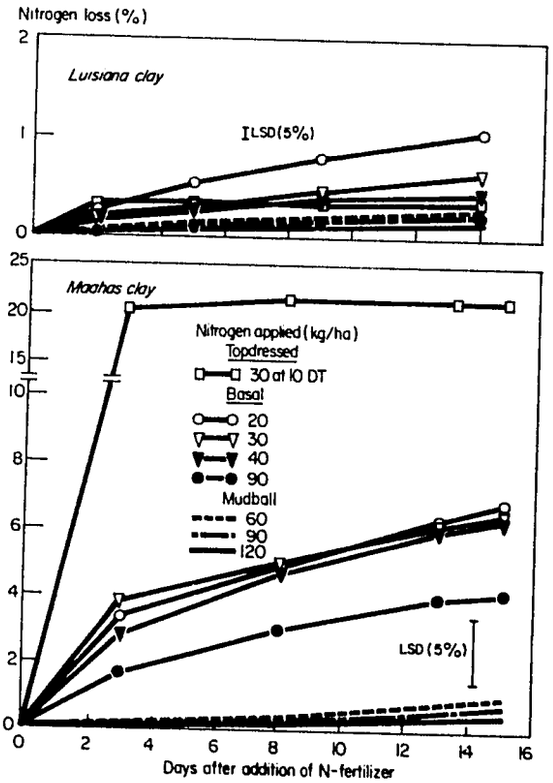
Maahas clay had the largest volatilization losses because the pH of the water ranged from 7.2 to 10 in diurnal fluctuations. Losses of nitrogen from topdressed fertilizer applied 10 days after transplanting totaled about 20%, with most of the ammonia lost during the first 3 days after application. Less than 1% of the total nitrogen placed as mudballs was lost through ammonia volatilization (Fig. 3).

In a fourth experiment in drums during the 1977 wet season, two conventional fertilizers — ammonium sulfate and urea — were compared with two slow-release nitrogen sources — sulfur-coated urea (SCU 21) and isobutylidene diurea (IBDU). Three methods of application were used — surface, incorporation into a 5-7 cm soil layer, and placement at a depth of 10–12 cm.

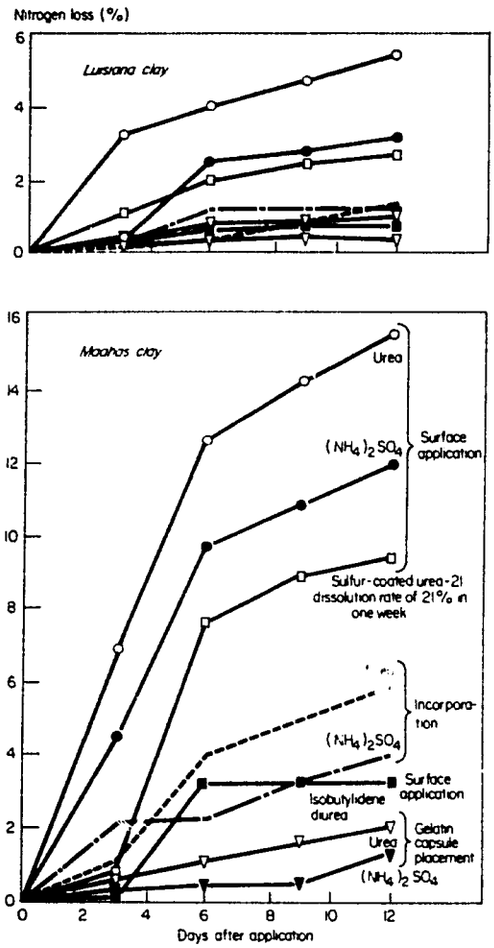
In Luisiana clay, the maximum loss of nitrogen through ammonia volatilization was from surface-applied urea (about 5%). With surface application in Maahas clay, nitrogen losses were 15.4% for urea, and 11.9% for ammonium sulfate. For the slow-release fertilizers SCU 21 and IBDU, nitrogen losses were 9.4 and 3.2%, respectively (Fig. 4).

In a subsequent study, also during the wet season, incorporation of SCU 21 and IBDU minimized ammonia volatilization losses in Maahas clay to a negligible level similar to that which resulted from deep placement of conventional fertilizer. In Luisiana clay, the maximum loss of volatilized ammonia was less than 1% regardless of the method of application (Fig. 5).

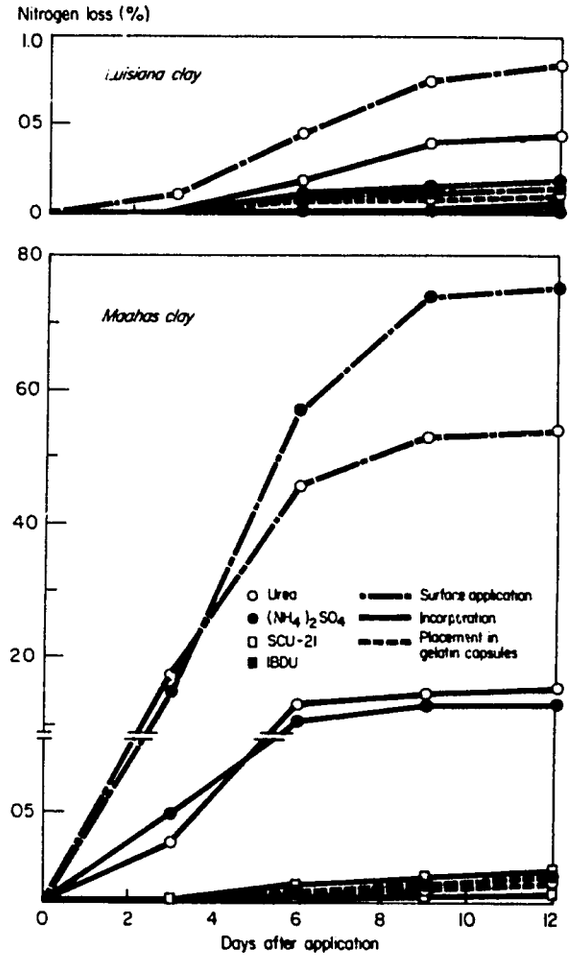
Ammonia volatilization losses appear to be greatly minimized by placement of nitrogen fer-



3. Effect of time and method of application on nitrogen loss (percentage of total application) through ammonia volatilization. IRRI, 1977 dry season.



4. Effect of source and method of application on nitrogen loss through ammonia volatilization. Large pot experiment. IRRI, 1977 wet season.



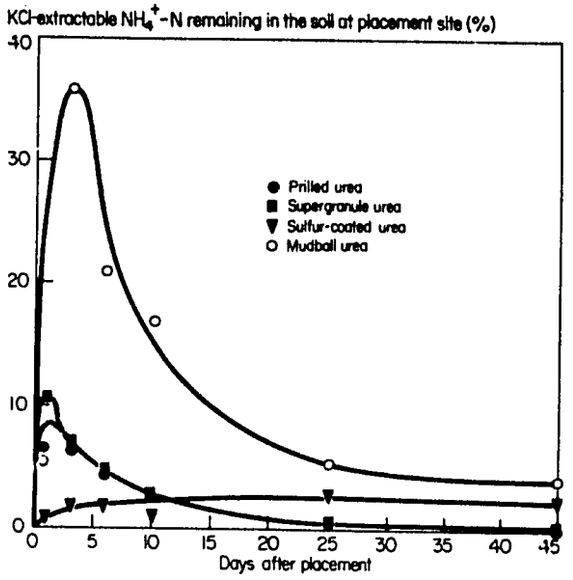
5. Effect of source and method of application on nitrogen loss through ammonia volatilization. Large pot experiment. IRRI, 1977 wet season.

tilizer 10–12 cm deep in the soil. They are minimum with slow-release fertilizers, particularly IBDU, even when these are surface applied. Incorporation of slow-release fertilizer and deep placement of conventional fertilizer nitrogen resulted in the lowest losses of ammonia.

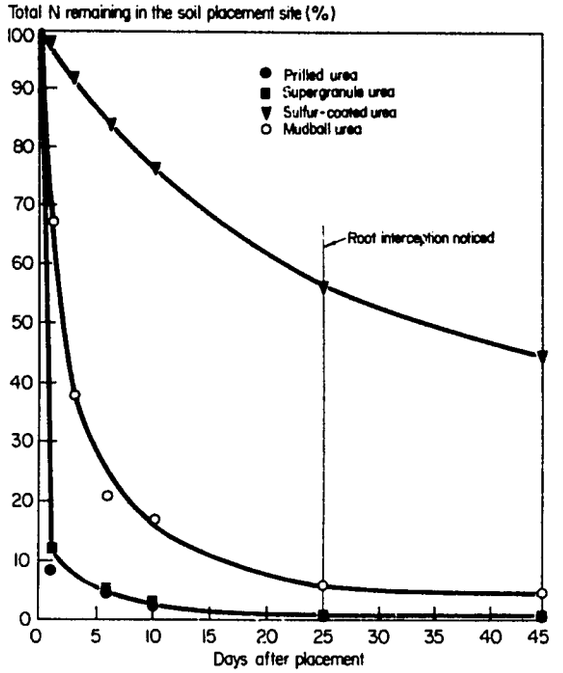
The pH of the flood water affects the losses of fertilizer nitrogen applied in water or on the soil surface.

In situ release patterns of nitrogen from deep-placed urea in flooded soils. During the 1977 wet season, in situ release patterns of nitrogen from deep-placement sites (later referred to as placement sites) of prilled urea (PU), supergranule urea (SGU), sulfur-coated urea (SCU), and urea in mudballs (MBU) were studied in flooded Maahas clay. In a small nylon screen bag, nitrogen (450 mg) as PU, SGU, or SCU was sandwiched between two layers of wet soil freshly collected from the field. A mudball containing the same quantity of nitrogen as PU was also placed in a nylon screen bag. A sufficient number of nylon bags containing PU, SGU, SCU, and MBU were placed at a 10- to 15-cm depth in the reduced soil layer in 30-m^2 plots. Placements were made at random between rows of transplanted IR36 rice spaced 20 × 20 cm.

Urea nitrogen decreased rapidly at the



6. Changes in potassium chloride-extractable ammonium nitrogen at deep-placement sites after the application of different forms of urea in flooded soil. IRRI, 1977.



7. Changes in the total nitrogen [urea-nitrogen + potassium chloride - extractable ammonium nitrogen (NH_4^+-N) + fixed NH_4^+-N] remaining at deep placement sites after urea was applied in different forms in flooded soil. IRRI, 1977.

placement sites of PU, SGU, and MBU and almost disappeared within 3 days after placement. At the placement site of SCU, it decreased gradually over 45 days. Apparently, the urea in the flooded rice soils was rapidly hydrolyzed.

Ammonium nitrogen resulting from urea hydrolysis reached peak values between 1 and 3 days after the placement of PU, SGU, and MBU, and then slowly decreased (Fig. 6). The ammonium nitrogen fixation by soils was negligible (< 0.2% of nitrogen placed) at all placement sites.

The nitrogen released from the placement sites of PU, SGU, SCU, and MBU was assumed to be the difference between urea nitrogen placed and the total nitrogen (urea nitrogen + potassium chloride-extractable ammonium nitrogen + fixed ammonium nitrogen) recovered by analyzing soil in the nylon bags, which were sampled periodically (Fig. 7). Nitrogen release from placement sites of PU and SGU was rapid during the first day after placement and then declined gradually. The pattern of nitrogen release from the placement site of MBU was similar to but slower than that from placement sites of PU or SGU. Nitrogen release from the placement site of SCU was considerably slower, but more constant, than that from the PU, SGU, and MBU sites.

PLACEMENT OF FERTILIZER NITROGEN

Experiments with IR36 and IR26 rices were conducted during the 1977 dry and wet seasons at IRRI (Alfisol) and in three farmers' fields (Ultisol and Vertisol) in the Philippines to evaluate placement techniques on different soils. The texture and chemical characteristics of the soils in farmers' fields are given in Table 1. Treatments evaluated the effect of placement of urea mudballs and supergranules on fertilizer nitrogen efficiency. Another treatment consisted of SCU broadcast and incorporated during land preparation.

Dry season. At IRRI, the grain yields from 56 kg N/ha placed as mudballs or as supergranules were comparable. At 56 kg N/ha, SCU gave significantly higher yields than commercial urea in split applications. At 84 kg N/ha, both mudball placement and SCU gave significantly higher yields of both IR26 and IR36 than did a

Table 1. Characteristics of soils in farmers' fields in Luisiana (Laguna) and Teresa and Tanay (Rizal), Philippines. Experiments on increasing nitrogen fertilizer efficiency in rice, 1977.

Criterion	Luisiana	Tanay	Teresa
pH (1:1)	4.8	6.5	6.7
CEC (meq/100 g)	28	31	37
Total N (%)	0.19	0.14	0.09
Available P (ppm Bray)	8.0	10.0	8.0
Exchangeable K (meq/100 g)	0.4	0.2	0.4
Soil texture	Silty clay	Clay	Clay
Soil taxonomy	Ultisol	Vertisol	Vertisol

split application. SCU was distinctly superior to all other treatments at the same nitrogen rate; at 84 kg N/ha, it gave a yield comparable with that obtained with split doses of urea at 120 kg N/ha (Table 2).

SCU gave the highest grain yield in all three trials in farmers' fields. At Luisiana, Laguna (silty clay, Ultisol, pH 4.8), placement of MBU and SG, and broadcast and incorporation of SCU gave comparable yields at 56 kg N/ha. At 84 kg N/ha, urea in mudballs and as supergranules, and incorporated SCU gave significantly higher grain yield than split-applied urea. At Teresa, Rizal (clay, Vertisol, pH 6.7), the yield obtained with SCU at 84 kg N/ha was higher than the yields obtained with all other sources and methods of application.

In Tanay, Rizal (clay, Vertisol, pH 6.5), placement of MBU and SGU at 84 kg N/ha gave comparable yields that were significantly lower than those obtained with SCU from IR36 rice but not from IR26.

In all sites, SCU had consistently high fertilizer nitrogen efficiency, calculated as kilograms of rice obtained per kilogram of applied nitrogen.

Wet season. At IRRI, split application at 28 kg N/ha and an unfertilized control gave similar yields (Table 3). Grain yields with three placement techniques — mudballs, supergranules, and in a band — were also similar. At the same rate of nitrogen, the placement techniques gave significantly higher grain yields than split application. At 56 kg N/ha, sources, and methods and time of nitrogen application did not significantly affect grain yields.

At Luisiana, Laguna, the yield with mudball placement of 28 kg N/ha was significantly higher than that with split application and was comparable with the yield with split application of 56 kg N/ha (Table 3).

Table 2. Effects of sources and methods of nitrogen application on the grain yield of rice at IRRI and in 3 farmers' fields in the Philippines. The Second Internationa Trial on Nitrogen Fertilizer Efficiency in Rice, 1977 dry season.

Treatment	Yield[a] (t/ha)						
	Neutral Alfisol		Acid Ultisol	Neutral Vertisol			Mean
	IRRI		Luisiana, Laguna	Teresa, Rizal	Tanay, Rizal		
	IR26	IR36	IR36	IR36	IR36	IR26	
No fertilizer nitrogen	2.8 f	3.2 g	3.5 e	3.0 h	4.0 e	4.2 d	3.4
56 kg N/ha							
Split application	4.8 e	5.6 f	5.3 cd	5.3 cde	5.5 d	5.9 c	5.4
Band placement	5.3 de	6.0 ef	4.9 d	4.4 g	5.7 cd	5.9 c	5.4
Mudball placement	5.7 cd	6.2 def	5.8 bc	5.2 cdef	6.3 ab	6.3 abc	5.9
Supergranule placement	6.9 ab	5.7 f	5.5 c	4.6 fg	5.6 cd	6.1 bc	5.7
Sulfur-coated urea	5.9 cd	6.8 bcde	5.7 bc	5.0 def	6.3 ab	6.4 ab	6.0
84 kg N/ha							
Split application	5.4 de	6.3 cdef	5.6 c	5.5 bcde	5.7 cd	6.1 bc	5.8
Band placement	6.2 bc	7.0 abc	5.0 cd	4.9 efg	6.2 ab	6.3 abc	5.9
Mudball placement	6.9 ab	6.9 abcd	6.1 ab	5.6 bc	6.1 b	6.3 abc	6.3
Supergranule placement	6.2 abc	6.4 cdef	6.1 ab	5.5 bcd	6.0 bc	6.3 abc	6.1
Sulfur-coated urea	7.0 a	7.6 a	6.4 a	6.3 a	6.6 a	6.6 a	6.7
120 kg N/ha							
Split application	6.3 abc	7.3 ab	6.3 a	6.0 ab	6.3 ab	6.5 ab	6.4

[a]In a column, any 2 means followed by a common letter are not significantly different from each other at the 5% level.

Table 3. Effects of sources and methods of nitrogen application on the grain yield of rice at IRRI and in 2 farmers' fields in the Philippines. The Second International Trial on Nitrogen Fertilizer Efficiency in Rice, 1977 wet season.

Treatment	Yield[a] (t/ha)				
	Neutral Alfisol		Acid Ultisol	Vertisol	Mean
	IRRI		Luisiana, Laguna	Teresa, Rizal	
	IR26	IR36	IR36	IR36	
No fertilizer N	2.8 c	3.7 d	3.3 e	3.5 f	3.3
			28 kg N/ha		
Split application	3.2 bc	3.8 d	3.8 de	4.2 e	3.7
Band placement	3.9 a	4.9 bc	3.8 de	4.2 e	4.2
Mudball placement	3.9 a	4.9 bc	4.6 bc	5.0 bcd	4.6
Supergranule placement	4.0 a	4.3 cd	4.3 cd	4.8 d	4.3
Sulfur-coated urea	4.0 a	5.0 ab	4.5 bcd	4.9 cd	4.6
			56 kg N/ha		
Split application	3.8 ab	5.1 ab	4.7 bc	5.0 bcd	4.7
Band placement	3.8 ab	5.2 ab	4.6 bc	5.2 abcd	4.7
Mudball placement	4.1 a	5.4 ab	5.5 a	5.4 abc	5.1
Supergranule placement	4.0 a	5.1 ab	5.0 abc	5.5 ab	4.9
Sulfur-coated urea	4.1 a	5.6 a	5.2 ab	5.4 abc	5.1
			80 kg N/ha		
Split application	4.3 a	5.4 ab	4.9 abc	5.6 a	5.1

[a]In a column, any 2 means followed by a common letter are not significantly different from each other at the 5% level.

At Teresa, Rizal, the highest yield among the 28 kg N/ha treatments was obtained with mudball placement; that among the 56 kg N/ha treatments, with placement of urea supergranules (Table 3). At 28 kg N/ha, the nitrogen fertilizer efficiency of mudball placement was highest; that of SCU was second highest.

Machines for placement of fertilizer nitrogen. An IRRI-developed plow-sole applicator and an applicator developed by a Japanese company were evaluated at IRRI during the 1977 wet season. The evaluation used 2 nitrogen rates (28 and 56 kg N/ha), a standard control of 80 kg N/ha, and the early maturing rices IR36 and IR40.

At 28 kg N/ha, the yield of IR36 was significantly higher with the use of the plow-sole applicator than with the best split application (Table 4). At 56 kg N/ha, the grain yields of both IR36 and IR40 were significantly higher with the use of the plow-sole applicator than with the best split application. Results with the plow-sole applicator were comparable with those obtained with placement of urea briquets (Table 4).

Conceptually, the plow-sole applicator

Table 4. Effect of placement methods using 2 machines on the grain yield of IR36 and IR40. IRRI, 1977 wet season.

Method of nitrogen application	Grain yield[a] (t/ha)	
	IR36	IR40
No nitrogen fertilizer	3.1 f	3.4 e
	28 kg N/ha	
Urea briquets	4.4 bc	4.2 cd
Liquid band placement (IRRI design)	3.9 de	3.9 cde
Plow-sole applicator (IRRI design)	4.8 ab	4.4 bcd
Split application of urea	3.8 de	4.3 bcd
Topdressing 10 and 40 DT[b]	3.7 e	3.9 cde
Japanese applicator	4.0 cde	3.9 cde
	56 kg N/ha	
Urea briquets	5.1 a	4.7 ab
Liquid band placement	4.5 bc	4.2 cd
Plow-sole applicator	5.2 a	5.1 a
Split application of urea	4.2 cd	4.2 cd
Topdressing 10 and 40 DT[b]	4.1 cd	4.3 bcd
Japanese applicator	4.4 bc	4.3 bcd
	80 kg N/ha	
Split application of urea	4.8 ab	4.6 ab
Split application of ammonium sulfate	4.4 bc	4.4 bc
Mean	4.3	4.2

[a]In a column, any 2 means followed by the same letter are not significantly different from each other at the 5% level. [b]Days after transplanting.

Table 5. Effect of different methods of fertilizer application on grain yield of IR40 rice.[a] 1977 wet season.

Method of application	Yield[b] (t/ha)
Mudball	4.5 a
Capsule	4.4 a
Fertilizer tape[c]	4.1 b

[a]Av. of 4 depths of placement. [b]Any 2 means followed by the same letter are not significantly different from each other at the 5% level. [c]Band placement.

appeared highly promising as an alternative to the placement of supergranules.

Concentrated vs band placement. In the 1977 wet season, IR40 was used in comparing the effect of concentrated placement (mudballs and capsules) with that of band placement on the efficiency of fertilizer nitrogen at IRRI.

Urea, at 56 kg N/ha, was placed in mudballs or in capsules. In one treatment, urea nitrogen was put evenly in tape before it was inserted in the soil shortly after rice was transplanted. The fertilizer was applied at 1 of 4 depths in the soil — 2.5, 5.0, 7.5, and 15 cm. Averaged over the 4 depths of application, the grain yield of rice with urea applied in the concentrated form as mudballs (4.5 t/ha) or in capsules (4.4 t/ha) was significantly higher than that obtained with band placement with tape (4.1 t/ha) (Table 5). Depth of placement of fertilizer nitrogen at 56 kg N/ha did not appear to affect grain yield; however, deep placement of urea as mudballs and in capsules consistently gave a higher grain yield (4.2 to 4.8 t/ha) than split application (3.8–3.9 t/ha).

EFFECT OF PLANTING DATE, PLANT DENSITY, AND GEOMETRY ON NITROGEN RESPONSE IN RICE

The effects of planting date (crop environment), rate and time of nitrogen fertilizer application, plant density, and plant geometry (plant spacing and row orientation) on rice yield were studied in field experiments at IRRI during the 1976 wet and 1977 dry seasons.

A split-split-split-plot design with three replications was used with planting date on the main plots, variety on the subplots, nitrogen fertilizer on the sub-subplots, and plant density and plant geometry on the sub-sub-subplots. The early maturing IR36 rice and the intermediate maturing IR26 rice were planted on 18 August and 18 October 1976 and on 20 January and 20 March 1977. Six combinations of nitrogen fertilizer (ammonium sulfate) rates and times of application with five combinations of plant density and

Table 6. Effect of nitrogen fertilizer treatments on grain yield and efficiency of nitrogen fertilizer use in IR36 and IR26 rices planted in the 1976 wet season and 1977 dry season, IRRI.

N fertilizer rate (kg/ha)	Time of application[a]	Grain yield[b] (t/ha)		N efficiency (kg rough rice/kg N)	
		IR36	IR26	IR36	IR26
		1976 wet season[c]			
0	—	2.6 c	2.6 d	—	—
60	B	4.4 a	4.2 bc	30	27
60	1/2 B + 1/2 5–7 DBPI	4.2 ab	4.3 ab	27	28
60	1/3 B + 1/3 T + 1/3 5–7 DBPI	4.2 ab	4.3 ab	26	28
60	1/2 T + 1/2 5–7 DBPI	4.1 b	4.0 c	24	24
60	1/3 10 DT + 1/3 T + 1/3 5–7 DBPI	4.2 b	4.2 bc	26	27
90	1/3 B + 1/3 T + 1/3 5–7 DBPI	4.4 a	4.5 a	20	22
		1977 dry season[d]			
0	—	4.3 d	4.4 c	—	—
120	B	7.8 a	6.9 a	29	20
120	1/2 B + 1/2 5–7 DBPI	7.0 bc	6.7 ab	22	19
120	1/3 B + 1/3 T + 1/3 5–7 DBPI	7.5 ab	7.0 a	27	22
120	1/2 T + 1/2 5–7 DBPI	6.4 c	6.0 b	17	13
120	1/3 10 DT + 1/3 T + 1/3 5–7 DBPI	6.7 c	6.7 ab	20	19
150	1/3 B + 1/3 T + 1/3 5–7 DBPI	7.0 bc	6.5 ab	18	14

[a]B = basal; T = tillering stage (about 20 and 30 days after transplanting (DT) for IR36 and IR26, respectively); DBPI = days before panicle initiation. [b]Any 2 means in 1 column of a season followed by the same letter are not significantly different from each other at the 5% level. [c]Av. from 2 planting dates and 5 combinations of plant density and plant geometry. [d]Only from the 20 January 1977 planting; av. from 5 combinations of plant density and plant geometry.

plant geometry were evaluated. Superphosphate and muriate of potash at rates of 40 kg P_2O_5/ha and 40 kg K_2O/ha were applied 1 day before planting. A basal dose of fertilizers was broadcast and incorporated before planting, and a topdressing was made in paddy water.

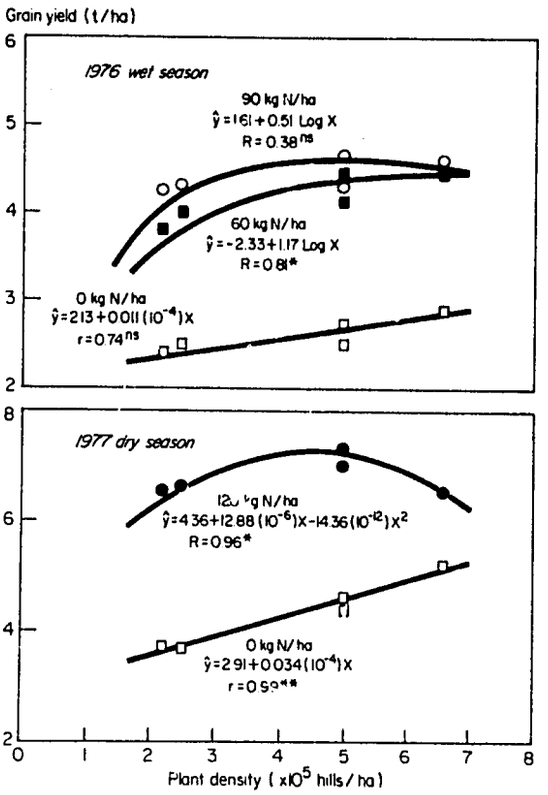
Rate and time of nitrogen fertilizer application. During the 1976 wet season, 60 kg N/ha, one-third basally applied and incorporated, one-third as topdressing at 30 days after transplanting (tillering), and one-third as topdressing at 5 to 7 days before panicle initiation (DBPI), gave the highest nitrogen fertilizer efficiency for IR26 rice (Table 6). Similar nitrogen efficiency was obtained when the same amount of nitrogen was applied in split does — one-half dose at tillering, one-half at 5 to 7 DBPI. For IR36, the application of 60 kg N/ha basal and incorporated gave the highest yield and nitrogen fertilizer efficiency.

During the 1977 dry season, IR26 rice had similar high yields with several nitrogen treatments. For IR36, the basal application of 120 kg N/ha gave the highest grain yield and highest nitrogen fertilizer efficiency (Table 6).

Planting date. Topdressing of nitrogen fertilizer at 6–7 DBPI produced late tillers, which were unproductive at harvest. The production of late tillers appeared to be affected by date of planting, fertilizer rate, and rice variety. The soil analyses showed that with fertilizer application, the ammonium nitrogen content of the soil was much greater (20–30 ppm) at 5–7 DBPI with IR36 rice than at 5–7 DBPI with IR26 rice (10–15 ppm).

Plant density and geometry. Rice yield was increased by increasing plant density and selection of appropriate plant geometry. The rice yield increased as the plant density increased to a certain point. Beyond this "ceiling," the yield increase with an increase in plant density was modest when a low level of nitrogen fertilizer was used and the yield decreased when a high level of nitrogen fertilizer was applied (Fig. 8).

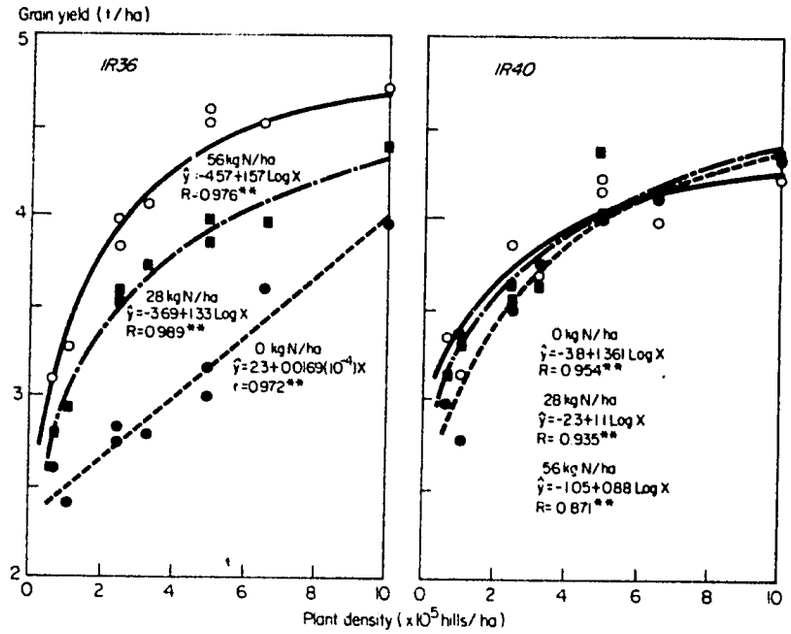
In the first crop of the 1977 dry season, when the solar energy was high and sunshine duration was long during the last 50 days of crop growth, the yield of IR36 rice planted at 500,000 hills/ha and at a 40- × 5-cm spacing with a north-to-south row orientation (7.1 t/ha) was



8. Effect of rates of nitrogen fertilizer on yield response to plant density of rices planted in 1976 wet season (av. of IR36 and IR26 rices and two planting dates) and in 1977 dry season (av. of IR36 and IR26 rices). IRRI.

significantly greater than that of rice planted at the same density but at 20- × 10-cm spacing with the same row orientation (6.7 t/ha) (Table 7). No such significant difference in grain yield due to plant spacing was recorded in IR26 in the same period. But in both crops of IR26 and IR36 in the 1976 wet season, when the solar energy was low and sunshine duration was short during the last 50 days of crop growth, the plant spacing of 20 × 10 cm gave significantly higher rice yield (4.2 t/ha) than the 40- × 5-cm spacing (3.8 t/ha) (Table 7).

In the 1977 wet season, the contribution of plant density and plant geometry to rice yield was again examined. Nine combinations of plant density and plant geometry were evaluated with seven nitrogen fertilizer treatments and the early maturing varieties IR36 and IR40. Plant density varied from 67,000 to 1 million hills/ha. Rice was planted at either



9. Effect of rates of nitrogen fertilizer on yield response to plant density of IR36 and IR40 rices. IRRI, 1977 wet season.

square, or short or long rectangular spacings with north-to-south row orientation.

IR36 rice responded to nitrogen fertilizer treatments but IR40 did not (Fig. 9). At 28 kg N/ha, the grain yield of IR36 increased with increasing plant density even up to 1 million hills/ha (20- × 5-cm plant spacing). But the increase in grain yield of IR36 rice at 56 kg N/ha and of IR40 rice at all levels of nitrogen fertilizers with increasing plant density plateaued at a plant density of 500,000 hills/ha (average of 20- × 10-cm and 40- × 5-cm spacings) (Fig. 9).

Plant geometry had no significant effect on rice yield in this trial. The sunshine duration was short and solar energy was low during the reproductive stage (from panicle initiation to flowering) and vice versa during ripening (from flowering to maturity) (Table 8). Solar radiation at the two stages counteracted each other, removing any beneficial effects of plant geometry.

Light distribution in rice communities varied with plant geometry, and time and place of measurement. When the sunshine duration was relatively long, the light distribution in the canopy of rice grown at 40- × 10-cm (rectangular) spacing with north-to-south row orientation was presumably more favorable than that in the canopy of rice spaced 20 cm apart (square spacing).

Table 7. Effect of plant geometry on grain yield of IR36 and IR26 rices planted at 500,000 hills/ha in August 1976, October 1976, and January 1977.[a]

Plant geometry[b] (cm)	Grain yield (t/ha) 1976	1976	1977
		IR36	
20 × 10	4.4	4.2	6.7
40 × 5	4.1	3.8	7.1
Difference	0.3**	0.4**	-0.4**
		IR26	
20 × 10	4.2	4.2	6.7
40 × 5	3.8	3.9	6.6
Difference	0.4**	0.3**	0.1ns

[a]Av. of 7 nitrogen-fertilizer treatments. [b]With north-to-south row orientation.

LONG-TERM FERTILITY EXPERIMENT

IRRI. The 26th and 27th crops in the long-term fertility experiment were grown at IRRI in 1977. In the dry season, each of the 3 varieties used — IR8, IR26, and IR36 — yielded significantly more in treatments containing 140 kg N/ha than in those without it (Table 9). While

Table 8. Climatological data during the reproductive and ripening stages, and grain yield of IR36 and IR40 rices at 2 plant densities and different plant spacings in rows oriented north to south.[a] IRRI, 1977 wet season.

Plant spacing (cm)	Grain yield[b] (t/ha) IR36	IR40	Mean	Date	Solar radiation (g/cal per cm² per wk)	Sunshine duration (h:min/wk)	Growth stage[c]
	250,000 hills/ha			29 Aug. – 4 Sept.	2,464	24:37	PI (IR36)
20 × 20	3.6	3.5	3.6 b	5 Sept. – 11 Sept.	1,974	32:05	PI (IR40)
40 × 10	3.7	3.6	3.6 b	12 Sept. – 18 Sept.	1,722	25:47	
				19 Sept. – 25 Sept.	1,323	16:30	F (IR36)
	500,000 hills/ha			26 Sept. – 2 Oct.	2,394	51:41	F (IR40)
20 × 10	4.1	4.1	4.1 a	3 Oct. – 9 Oct.	2,408	54:15	
40 × 5	4.3	4.1	4.2 a	10 Oct. – 16 Oct.	2,030	44:20	
				17 Oct. – 23 Oct.	2,128	4[illegible]:15	H (IR36)
				24 Oct. – 30 Oct.	1,568	47:15	H (IR40)

[a]Av. of 7 N-fertilizer treatments. [b]Any 2 means followed by the same letter are not significantly different from each other at 5% level. [c]PI = panicle initiation, F = flowering, H = harvest.

the yield response to complete fertilizer was higher than that to nitrogen alone, the response to the treatment in which part of the nitrogen was applied as compost was significant.

During the wet season, the response to 30 kg P_2O_5/ha or to 30 kg K_2O/ha was not significant. The yields of IR36 were higher than those of IR8 and IR26, because of the heavy incidence of brown planthopper. Zinc sulfate (20 kg/ha) had to be applied in both seasons to correct zinc deficiency.

Philippine Bureau of Plant Industry (BPI) stations. In 1976, the 19th (dry season) and 20th (wet season) crops (IR8, IR26, and IR36) were harvested from long-term fertility experiments — begun in 1968 — at the BPI stations at Maligaya, Bicol, and the Visayas. In the dry season the yield of IR36 was poor in Maligaya; in Bicol, the yields of IR36 and IR8 were similar. The 1977 dry season data, averaged for the three rice varieties at Bicol and Maligaya, showed that the response to complete fertilizer

Table 9. Effects of NPK fertilization on the grain yields of IR8, IR26, and IR36 rice in the 26th (dry season) and 27th (wet season) consecutive crops. IRRI, 1977.

Fertilizer treatment[a] (kg/ha) N	P_2O_5	K_2O	Yield (t/ha) IR8	IR26	IR36	Mean[b]
			Dry season			
0	0	0	3.7	4.1	5.0	4.3 c
140[a]	0	0	5.9	6.4	6.9	6.4 b
0	30	0	3.8	4.1	5.4	4.5 c
0	0	30	3.9	4.5	5.0	4.5 c
140[a]	30	0	6.5	6.2	6.9	6.5 b
140[a]	0	30	6.4	6.9	6.8	6.7 ab
140[a]	30	30	6.4	6.4	7.4	6.7 ab
140[a,c]	30	30	6.8	6.9	7.3	7.0 a
			Wet season			
0	0	0	1.5	2.3	4.4	2.7 b
60[a]	0	0	2.4	3.9	5.5	3.9 a
0	30	0	1.5	2.5	4.2	2.7 b
0	0	30	1.6	2.4	4.1	2.7 b
60[a]	30	0	2.6	3.8	5.4	3.9 a
60[a]		30	2.2	3.8	5.6	3.9 a
60[a]		30	2.5	4.1	5.8	4.1 a
60[a,c]	30	30	2.6	4.2	5.6	4.2 a

[a]Includes 40 kg N/ha topdressed at panicle initiation in the dry season and 20 kg N/ha in the wet season. [b]In the column, any 2 means followed by a common letter are not significantly different from each other at the 5% level; av. of 4 replicates. [c]Compost (10 t/ha) plus inorganic 24 kg N/ha compost + 116 kg N/ha inorganic for the dry season; 24 kg N/ha compost + 36 kg N/ha inorganic for the wet season.

Table 10. Effect of NPK fertilization on the mean grain yields of IR8, IR26, and IR36 rices in the 19th (dry season) and 20th (wet season) crops in the long-term fertility experiments at 3 sites (av. of 3 replications): Maligaya Rice Research and Training Center, Bicol Rice and Corn Experiment Station, and Visayas Rice Experiment Station, Philippines. IRRI-BPI cooperative experiments, 1977.

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	2.1 d	3.4 d	3.6 d	3.0 d	—	2.5 b
140/70	0	0	3.2 cd	3.7 cd	4.5 c	3.7 c	—	2.7 b
140/70	60	0	3.3 c	4.5 b	4.5 c	4.3 bc	—	5.2 a
140/70	0	60	3.5 bc	3.9 c	5.9 b	3.9 c	—	2.5 b
140/70	60	60	5.4 a	5.0 a	6.3 a	5.2 a	—	5.1 a
140/70	60	60 + 30[d]	5.2 a	5.1 a	6.8 a	4.8 ab	—	4.8 a

[a]For the dry season, 140 kg N/ha; for the wet season, 70 kg N/ha, 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 3 varieties. Any 2 means followed by the same letter are not significantly different from each other at 5% level. [c]The experiment was discontinued because of severe water shortage. [d]Applied in 2 doses: basal and at panicle initiation.

(NPK) (5.4–6.3 t/ha) was more marked than that to nitrogen alone (3.2–4.5 t/ha) or to NP treatments (3.3–4.5 t/ha). Response to phosphorus and to potassium was significant at both stations (Table 10).

During the wet season, IR8 and IR26 gave a significant yield response to applied potassium, while IR36 did not. The yield response to phosphorus, averaged for three varieties, was significant in the three stations; the response to potassium was significant at the Maligaya and Bicol stations but not at the Visayas station.

In any station or season, the split application of potassium did not give a significant yield difference (5.1–6.8 t/ha) from the application of all potassium as a basal dose (5.0–6.3 t/ha).

Long-term fertility experiments on different soils. The second and third crops in the long-term fertility experiment were grown in farmers' fields in Tanay (Rizal) and Luisiana (Laguna) on an Ultisol and a Vertisol (Table 11).

In both the wet and dry seasons, 0 and 40 kg P_2O_5/ha, and 0 and 40 kg K_2O/ha were used.

In Tanay (Vertisol, clay, pH 7.4), the interaction between variety and fertilizer was significant (Table 12). In the second crop (dry season), the yields of both rice varieties, obtained with both NP (6.8–7.1 t/ha) and NPK (7.1–7.4 t/ha) treatments, were similar and significantly

Table 11. Characteristics of soils in farmers' fields in Luisiana (Laguna) and Tanay (Rizal), Philippines. Long-term fertility trials, International Network on Fertilizer Efficiency in Rice program, 1977.

Criterion	Luisiana	Tanay
pH (1:1)	4.7	7.4
CEC[a] (meq/100 g)	24.0	40.0
Total N (%)	0.18	0.17
Available P (ppm Bray)	8.0	7.0
Exchangeable K (meq/100 g)	0.4	0.1
Soil texture	Silty clay	Clay
Soil taxonomy	Ultisol	Vertisol

[a]Cation exchange capacity.

Table 12. Effects of NPK on the grain yields of IR36 and IR26 rices in the second (dry season) and third (wet season) consecutive crops. Tanay, Rizal, Philippines, 1977.

Fertilizer treatment (kg/ha)			Yield[a] (t/ha)	
N	P_2O_5	K_2O	IR36	IR26
			Dry season	
0	0	0	3.9 g	4.1 efg
120	0	0	6.4 d	6.5 cd
0	40	0	4.2 efg	4.4 e
0	0	40	3.9 fg	4.2 efg
120	40	0	6.8 bc	7.1 ab
0	40	40	4.4 ef	4.4 ef
120	0	40	6.7 bcd	7.0 ab
120	40	40	7.1 ab	7.4 a
			Wet season	
0	0	0	2.9 ef	3.2 def
60	0	0	4.2 bc	4.2 bc
0	40	0	3.4 de	3.6 d
0	0	40	2.7 f	2.9 ef
60	40	0	4.7 ab	4.5 ab
0	40	40	2.9 ef	3.6 d
60	0	40	4.3 ab	3.7 cd
60	40	40	4.7 ab	4.8 a

[a]In a column any 2 means followed by a common letter are not significantly different from each other at the 5% level; av. of 4 replications. CV = 9.7% for wet season and 5.3% for dry season.

higher than the grain yields obtained when only nitrogen was applied (6.4–6.5 t/ha).

In Luisiana (acid Ultisol, pH 4.7), the interaction between variety and fertilizer treatments was significant. In the dry and wet seasons, only the response to nitrogen was significant in both IR26 and IR36.

PHOSPHORUS SOURCES ON DIFFERENT SOILS

A series of experiments on four Philippine farmers' fields were started during the 1977 wet season to evaluate the effect of phosphorus sources on the yield of IR36 rice growing on three acid Ultisols (Table 13) (2 silty clays, 1 clay) (Luisiana, Laguna; Lucban, Quezon; and Tanay, Rizal) and on one Vertisol (clay) (Teresa, Rizal). Four sources of phosphorus were used: guano (16.8% P_2O_5), Phosmak (30.0% P_2O_5), North Carolina rock phosphate (31.3% P_2O_5), and Phospal (34.9% P_2O_5).

At Lucban (pH 5.0, 5 ppm available P), the grain yield response to applied phosphorus was significant only at 40 and 60 kg P_2O_5/ha as superphosphate and at 60 kg P_2O_5/ha as Phosmak, and 120 kg P_2O_5/ha as local guano fertilizer (Table 14).

In Teresa (pH 6.5, 3.0 ppm available P) the grain yield with added phosphorus was 4.9 t/ha, which was significantly higher than the 4.1 t/ha achieved with the no-phosphorus fertilizer control (Table 14). At 20 kg P_2O_5/ha, superphosphate and Phospal (HRP) each gave yields of 4.9 t/ha. The grain yields obtained with 40 and 60 kg P_2O_5/ha as superphosphate (5.9 and 6.1 t/ha, respectively) were significantly better than those obtained with 40 and 60 kg P_2O_5 as Phospal (5.2 and 4.9 t/ha, respectively). The grain yield obtained with less reactive guano at 80 kg P_2O_5/ha was similar to that obtained with 20 kg P_2O_5/ha as superphosphate (Table 14).

At the Luisiana and Tanay sites, there was no significant yield response to the applied phosphorus (Table 14). The crop at Luisiana badly lodged because of typhoons, which might have affected crop response to applied phosphorus.

Table 13. Analysis of flooded soils in experiments on sources of fertilizer phosphorus. Farmers' fields in Luisiana (Laguna), Lucban (Quezon), and Teresa and Tanay (Rizal), Philippines, 1977 wet season.

Criterion	Luisiana	Lucban	Teresa	Tanay
pH (1:1)	4.8	5.0	6.5	5.1
CEC[a] (meq/100 g)	24.0	16.0	25.0	21.0
Total nitrogen (%)	0.17	0.14	0.08	0.16
Available phosphorus (ppm)	6.0	5.0	3.0	5.0
Exchangeable potassium (meq/100 g)	0.20	0.40	0.04	0.04
Soil texture	Silty clay	Silty clay	Clay	Clay
Soil classification	Ultisol	Ultisol	Vertisol	Ultisol

[a]Cation exchange capacity.

Table 14. Effects of different sources of fertilizer phosphorus on the grain yield of IR36 rice. Farmers' fields in Luisiana (Laguna), Lucban (Quezon), and Teresa and Tanay (Rizal), Philippines, 1977 wet season.

Source of fertilizer phosphorus	Rate (kg P_2O_5/ha)	Grain yield[a] (t/ha)			
		Luisiana	Lucban	Teresa	Tanay
No phosphorus	—	2.6 a	4.5 b	4.1 e	4.8 a
Superphosphate	20	2.7 a	5.1 ab	4.9 cd	4.7 a
	40	2.6 a	5.2 a	5.9 ab	4.7 a
	60	3.2 a	5.3 a	6.1 a	4.9 a
HRP[b]	20	2.6 a	4.8 ab	4.9 cd	4.9 a
	40	3.0 a	5.0 ab	5.2 c	4.5 a
	60	3.2 a	5.2 a	4.9 cd	4.8 a
Guano (LRP[c])	40	2.7 a	4.9 ab	5.4 bc	4.8 a
	80	3.3 a	4.9 ab	4.6 d	4.8 a
	120	3.0 a	5.2 a	5.0 cd	4.8 a

[a]In the same column, any 2 means followed by a common letter are not significantly different from each other at the 5% level. [b]Highly reactive phosphate (North Carolina rock phosphate in Luisiana, Phosmak in Lucban and Tanay, and Phospal in Teresa). [c]Less reactive phosphate.

ZINC RESPONSE OF LOWLAND RICE ON A CALCAREOUS SOIL

During the 1977 crop seasons, six fertilizer materials containing zinc at different levels were tested on transplanted and on direct-seeded IR28 (early maturing) rice on a calcareous soil in Tiaong, Quezon. The transplanted experiment had 12 treatments, and the direct-seeded experiment, 10. Transplanted rice was spaced at 15 × 15 cm. For the direct-seeded experiment, seeding rate was 80 kg/ha.

During the dry season, both experiments were continuously flooded. In the wet season, the transplanted experiment was continuously flooded and the direct-seeded trial was rainfed. Weed and insect control, and fertilizer were optimum.

In the dry season, no grain yield was obtained when no zinc was applied, when 50 kg $ZnSO_4$·

Table 15. Zinc response of lowland transplanted rice on a calcareous soil. Tiaong, Quezon, Philippines, 1977 dry and wet seasons.

Zinc source	Rate of application	Method of application	Grain yield[a] (t/ha)		
			Dry season	Wet season	Av.
Zinc oxide + $ZnSO_4 \cdot 7H_2O$	2% + 0.5%	Seedling dip + foliar spray	5.4 a	4.3 a	4.9
Zinc oxide	2%	Seedling dip	5.5 a	4.1 a	4.8
$ZnSO_4 \cdot 7H_2O$	50 kg /ha	Broadcast and incorporated	4.9 a	3.5 ab	4.2
Zinc-Ke-Min	4 kg Zn/ha	"	3.1 b	3.4 ab	3.3
Zinc-coated ammonium sulfate	4 kg Zn/ha	"	2.3 bc	2.3 cd	2.3
Zinc-Ke-Min	2 kg Zn/ha	"	2.0 bc	2.6 bc	2.3
Zinc-coated urea-ammonium sulfate	2 kg Zn/ha	"	0.8 cd	1.1 e	1.0
Zinc-coated ammonium sulfate	2 kg Zn/ha	"	0.6 cd	1.1 e	0.9
$ZnSO_4 \cdot 7 H_2O$	0.5%	3 foliar sprays	0.2 d	1.4 de	0.8
$ZnSO_4 \cdot 7 H_2O$	50 kg/ha	Broadcast (seedbed)	0.0 d	0.6 e	0.3
Zinc-coated urea	2 kg Zn/ha	Broadcast and incorporated	0.0 d	0.6 e	0.3
No zinc	—	—	0.0 d	0.5 e	0.3

[a]In a column, any 2 means followed by a common letter are not significantly different from each other at the 5% level.

Table 16. Zinc response of lowland direct-seeded rice on a calcareous soil. Tiaong, Quezon, Philippines, 1977 dry and wet seasons.

Zinc source	Rate of application	Method of application	Grain yield[a] (t/ha)		
			Dry season	Wet season	Av.
Zinc oxide + $ZnSO_4 \cdot 7H_2O$	2 kg Zn/ha + 0.5%	Seed coating + foliar spray	2.6 a	3.4 a	3.0
Zinc-Ke-Min	2 kg Zn/ha	Surface-applied before seeding	3.0 a	2.2 abc	2.6
Zinc oxide	2 kg Zn/ha	Seed coating	1.8 abc	3.1 ab	2.5
Zinc-Ke-Min	4 kg Zn/ha	Surface-applied before seeding	2.2 ab	2.4 abc	2.3
Zinc-coated ammonium sulfate	4 kg Zn/ha	"	2.4 ab	1.8 bc	2.1
Zinc-coated urea-ammonium sulfate	2 kg Zn/ha	"	2.1 ab	1.8 bc	2.0
Zinc-coated ammonium sulfate	2 kg Zn/ha	"	1.5 abc	1.7 c	1.6
Zinc-coated urea	2 kg Zn/ha	"	1.5 abc	1.3 cd	1.4
$ZnSO_4 \cdot 7H_2O$	0.5%	3 foliar sprays	0.0 c	0.4 d	0.2
No zinc	—	—	0.7 bc	0.3 d	0.5

[a]In a column, any 2 means followed by a common letter are not significantly different from each other at the 5% level.

$7H_2O$/ha was applied in the seedbed, and when 2 kg Zn/ha as zinc-coated urea was broadcast and incorporated into the soil (Table 15). The highest grain yield of 5.5 t/ha in the transplanted experiment during the dry season was obtained when the seedlings were dipped in 2% ZnO suspension before transplanting. The grain yield obtained when a seedling dip with 2% ZnO was later followed with foliar spray with 0.5% $ZnSO_4 \cdot 7H_2O$ 5 days before panicle initiation (5.4 t/ha) was similar to the yield (4.9 t/ha) noted when 50 kg/ha $ZnSO_4 \cdot 7H_2O$ was applied basally. The three yields did not differ significantly.

In the wet season, the yield without zinc was only 0.5 t/ha. It was highest (4.3 t/ha) when the seedlings were dipped in a 2% ZnO suspension and then given a foliar spray of 0.5% $ZnSO_4$. Seedling dip alone produced 4.1 t/ha, while 50 kg $ZnSO_4$ $7H_2O$/ha, broadcast and incorporated, produced 3.5 t/ha. These yields were not significantly different from each other (Table 15).

Table 16 shows the grain yield of the direct-seeded rice experiment.

During the dry season, the no-zinc treatment yielded 0.7 t/ha of grain, but the yield obtained with 3 foliar sprays with 0.5% $ZnSO_4 \cdot 7H_2O$

was nil. The difference was not statistically significant, however. The highest grain yield was 3.0 t/ha, produced when Zn-Ke-Min was surface applied just before the pregerminated seeds were sown (Table 16). It was similar to the yield of 2.6 t/ha that was obtained when pregerminated seeds were coated with 2% ZnO and later sprayed with 0.5% $ZnSO_4 \cdot 7H_2O$.

The generally low yield in the direct-seeded experiment was due to poor stand establishment. The first seeding was severely damaged by rats despite rat control measures. Therefore, reseeding was done 2 weeks after the first seeding. The delayed rice establishment gave a head start to the weeds, particularly *Scirpus maritimus*. The sedge population was very high, but it was controlled much later with two foliar sprays of bentazon.

In the wet season, the grain yield was only 0.3 t/ha when no zinc was applied. The highest yield (3.4 t/ha) was obtained when pregerminated seeds were coated with ZnO, and later sprayed with 0.5% $ZnSO_4 \cdot 7H_2O$. A grain yield of 3.1 t/ha was obtained when pregerminated seeds were coated with ZnO (Table 16).

Dipping seedlings in 2% suspension of ZnO appears to be an effective method of correcting zinc deficiency in transplanted rice. For direct-seeded rice, coating the pregerminated rice seeds with ZnO at 2 kg/ha appeared to be the best procedure for correcting zinc deficiency in a soil highly deficient in zinc.

Soil and crop management

Soil and crop culture

Agronomy Department

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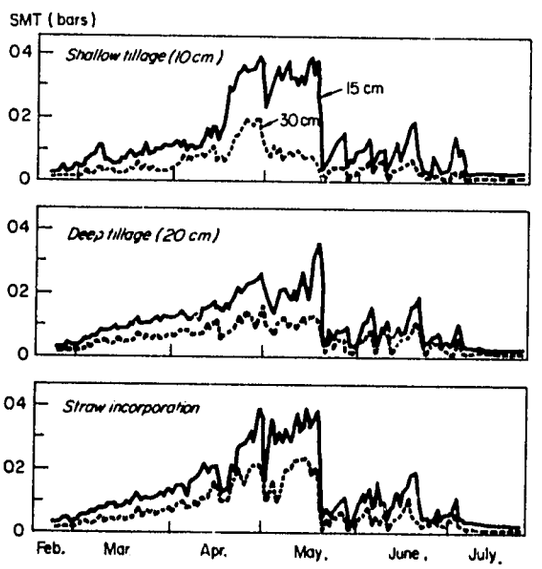
EFFECT OF DRY SOIL MULCH AND STRAW MULCH ON MOISTURE CONSERVATION

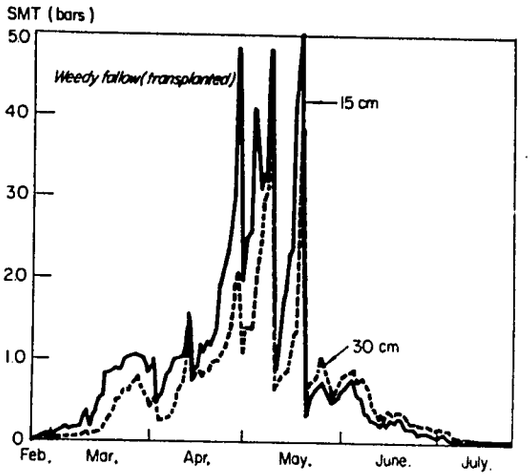
Field experiments at IRRI during the 1976 crop season suggested that a dry soil mulch conserved soil moisture and that planting an early seeded crop after the dry soil mulch saved considerable time.

During the 1977 crop seasons, the experiments were repeated in rainfed-lowland rice. A new study of the benefits of dry soil mulch in upland rice was begun.

Rainfed-lowland rice. The six treatments in the dry season experiments included two tillage treatments [shallow tillage (10 cm deep) and deep tillage (20 cm deep)], 5 t rice straw/ha incorporated to a 10-cm soil depth, spreading of 5 t/ha rice straw/ha without incorporation, weed-free fallow using herbicides, and weedy fallow. All treatments were followed by a dry-seeded crop during the wet season. One additional control was the practice of most rainfed rice farmers in Asia: weedy fallow followed by soil puddling and transplanting. The drought-tolerant rices



1. Effect on soil moisture tension (SMT) of a dry soil mulch generated by shallow tillage (10 cm deep) and deep tillage (20 cm deep) and straw incorporation (10 cm deep) at 5 t/ha during the dry season followed by (fb) a dry-seeded rice crop. Tillage consisted of 3 rotovations in January–February fb 1 rotovation in April. Rices were dry-seeded on 30 April. IRRI, 1977 dry and wet seasons.



2. Effect on soil moisture tension (SMT) of a dry season weedy fallow followed by a transplanted rice crop. Tillage consisted of 2 plowings and 2 harrowings. The seedbed was sown 22 June and seedlings were transplanted 20 July. IRRI, 1977 dry and wet seasons.

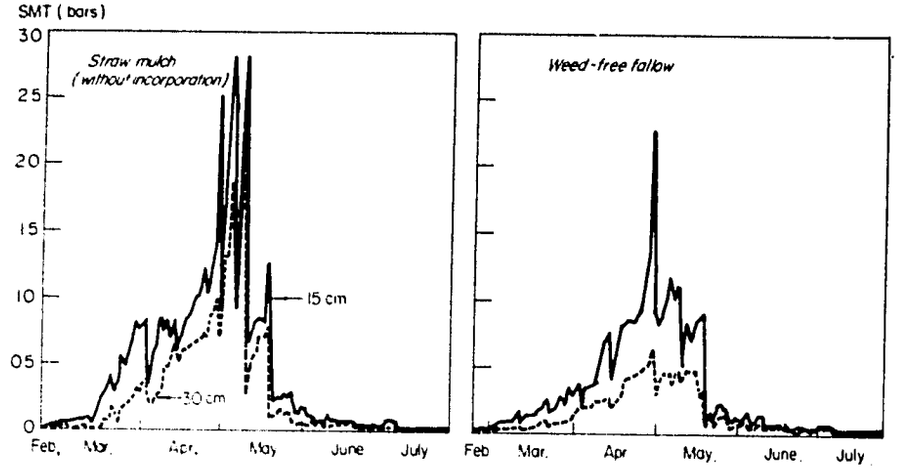
IR1529-430-3, IR2035-117-3, and IR9575, and the drought-susceptible variety IR20 were used.

In all the main plots, the four varieties or IRRI lines were either dry-seeded at 80 kg/ha or transplanted at 20- × 20-cm spacing, with 2–3 seedlings/hill. The soil moisture tension (SMT) was measured with a tensiometer and gypsum block daily, or as weather conditions permitted.

In plots where land preparation at the end of the previous wet season was completed with shallow tillage, deep tillage, and straw incorporation, the SMT did not exceed 40 centibars (cb) (Fig. 1). The SMT in the weedy-fallow plots at the end of the dry season reached 5 bars at a depth of 15 cm (Fig. 2).

The SMT values of the weed-free fallow and straw mulch treatments (Fig. 3), which had no tillage operations during the dry season, were lower than the SMT values of the weedy fallow (Fig. 2). By the end of the dry season, the SMT at 15 cm rose between 2 and 3 bars, indicating that moisture was conserved through the elimination or reduction of weeds.

Weed control also conserved soil moisture at 30 cm. Maintaining weed-free sites and



3. Effect on soil moisture tension (SMT) of straw mulch at 5 t/ha (without incorporation) and weed-free fallow treatment during the dry season followed by a dry-seeded rice crop. Tillage consisted of 3 rotovations in straw mulch and 2 rotovations in weed-free fallow plots. Rices were dry-seeded in straw mulch on 10 May and in weed-free fallow plots on 2 May. IRRI, 1977 dry and wet seasons.

covering the soil with a straw mulch during the dry season conserved some soil moisture, but to a lesser extent than that achieved through shallow tillage, deep tillage, and straw incorporation. These three treatments saved 2 days more than weed-free fallow, 10 days more than straw mulch, and 24 days more than weedy-fallow treatments.

Land preparation for the transplanted crop was delayed until the beginning of July when sufficient rainwater accumulated to make thorough puddling possible. Transplanting therefore took place 1 month later than in the dry-seeded crop. Thus, only one crop of transplanted rice was grown on puddled soil, while a second crop of transplanted rice was established on the dry-seeded plots.

The average yields obtained with straw incorporation, deep tillage, shallow tillage, and straw mulch treatments were similar (Table 1). The weedy fallow that was dry seeded at the beginning of the wet season gave the lowest yield.

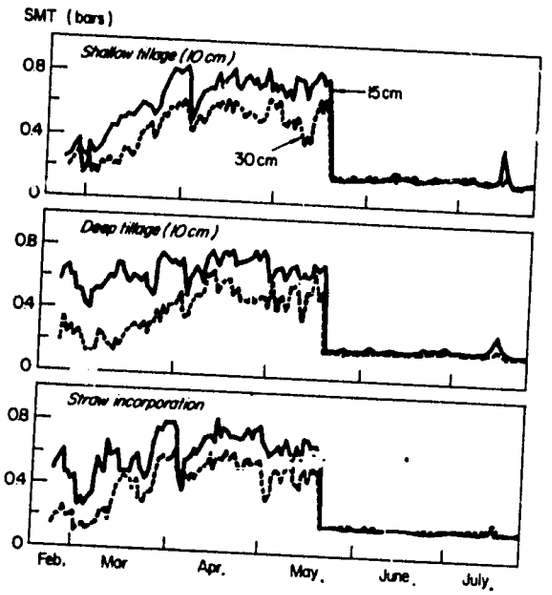
Varietal differences were also apparent. IR9575 gave the best yield followed by IR2035-117-3. The yields of IR1529-430-3 and IR20 were similar and lower than those of the two other lines (Table 1).

Upland rice. During the 1977 dry season, 6 treatments were used: shallow tillage (10 cm

Table 1. Effect of different dry soil mulch and straw mulch treatments on the grain yield of rainfed bunded rice. IRRI, 1977 wet season.

Variety[a]	Grain yield[b] (t/ha)							
	Shallow tillage (10 cm deep)	Deep tillage (20 cm deep)	Straw incorporation (5 t/ha)	Straw mulch (5 t/ha)	Weed-free fallow	Weedy fallow (dry-seeded rice)	Weedy fallow (transplanted rice)	Mean
IR1529-430-3	2.5 b	2.5 c	2.6 c	2.5 c	2.3 b	2.0 c	2.2 d	2.4
IR2035-117-3	4.4 a	4.2 b	4.3 b	3.9 b	4.1 a	3.3 a	4.0 a	4.0
IR9575	4.7 a	5.2 a	5.5 a	4.5 a	4.0 a	2.7 b	3.4 b	4.3
IR20	2.6 b	2.5 c	2.4 c	2.7 c	2.3 b	1.9 c	2.9 c	2.5
Mulching[a] (mean)	3.6	3.6	3.7	3.4	3.2	2.5	3.1	

[a]Av. of 4 replicates. [b]In a column, any 2 means followed by the same letter are not significantly different from each other at the 5% level. [a]cv for mulching: 5.4%; cv for varieties: 9.5%

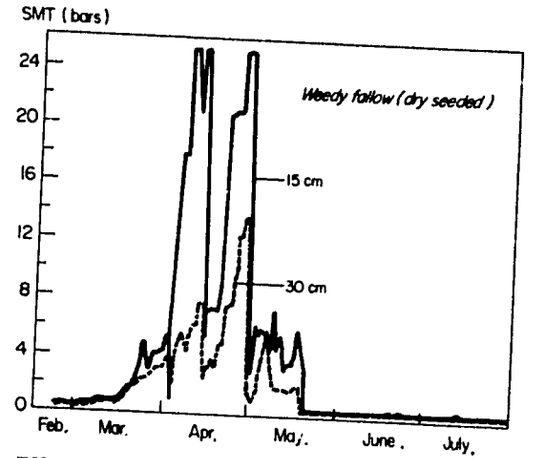


4. Effect on soil moisture tension (SMT) of a dry soil mulch generated by shallow tillage (10 cm deep) and deep tillage (20 cm deep) and straw incorporation of 3 t/ha (10 cm deep) during the dry season followed by a dry-seeded upland rice crop. Tillage consisted of 3 rotovations in January–February followed by 1 rotovation in April. Rices were dry-seeded on 30 April. IRRI, 1977 dry and wet seasons.

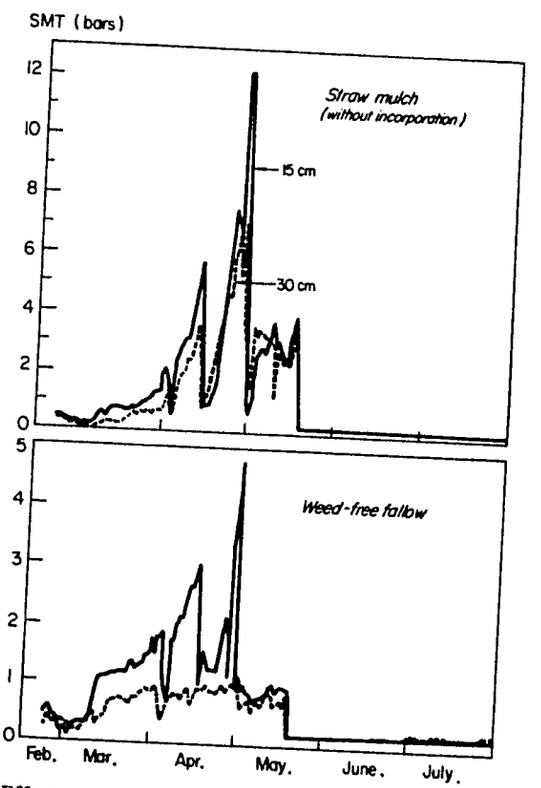
deep), deep tillage (20 cm deep), incorporation (10 cm deep) of 3 t rice straw/ha, spreading 3 t rice straw mulch/ha on the soil surface, a weed-free (with herbicide) fallow, and a weedy fallow. The four rices grown in the rainfed-lowland trial were used.

The soil at the upland site was drier than that at the lowland site. But because its texture was lighter, the straw-mulch and weedy-fallow, dry-seeded plots were seeded 5 and 15 days earlier at the upland site than at the lowland-rainfed site. The shallow-tillage, deep-tillage, and straw-incorporation plots were dry seeded 2 to 9 days earlier than the weed-free fallow, straw-mulch, and weedy-fallow dry-seeded plots. The seed, fertilizer rates, methods and times of nitrogen application, and SMT measurement methods were the same as those in the lowland-rainfed dry-seeded treatments.

In plots where land preparation — shallow tillage, deep tillage, and straw incorporation — was completed at the end of the previous wet season, the SMT did not exceed 85 cen-



5. Effect on soil moisture tension (SMT) of a dry-season weedy fallow followed by a dry-seeded upland rice crop. Tillage consisted of 1 plowing and 3 rotovations. Rices were dry-seeded on 9 May. IRRI, 1977 dry and wet seasons.



6. Effect on soil moisture tension (SMT) of straw mulch of 3 t/ha (without incorporation) and weed-free fallow treatments during the dry season followed by a dry-seeded upland rice crop. Tillage consisted of 3 rotovations in straw mulch and 2 rotovations in weed-free fallow plots. Rices were dry-seeded in straw mulch plots on 5 May and in weed-free fallow plots on 2 May. IRRI, 1977 dry and wet seasons.

Table 2. Effect of different dry-soil-mulch and straw-mulch treatments on grain yield of upland rice. IRRI, 1977 wet season.

Variety[a]	Grain yield[b] (t/ha)						
	Shallow tillage (10 cm deep)	Deep tillage (20 cm deep)	Straw incorporation (3 t/ha)	Straw mulch (3 t/ha)	Weed-free fallow	Weedy fallow (dry-seeded rice)	Mean
IR1529-430-3	2.8 a	4.1 a	3.6 a	3.6 a	3.1 a	2.6 a	3.3
IR2035-117-3	2.6 a	3.0 b	3.0 b	3.0 b	2.4 b	2.2 b	2.7
IR9575	2.3 b	2.5 c	2.5 c	2.3 c	2.3 b	2.3 ab	2.4
IR20	1.8 c	1.8 d	2.4 c	1.9 d	1.7 c	1.5 c	1.8
Mulching[c] (mean)	2.4	2.8	2.9	2.7	2.4	2.2	

[a]Av. of 4 replicates. [b]In a column, any 2 means followed by the same letter are not significantly different from each other at the 5% level. [c]cv for mulching: 4.5%; cv for varieties: 6.5%

tibars (Fig. 4); in the weedy-fallow plots the SMT reached 25 bars at 15 cm at the end of the dry season (Fig. 5).

During the early part of the dry season, the SMT values for both weed-free fallow and straw-mulch sites were lower than those for the weedy fallow (Fig. 6). By the end of the dry season, the weeds began to emerge through the straw mulch and the SMT reached 12 bars at 15 cm. In weed-free fallow, the highest SMT recorded at 15 cm was 5 bars; that at 30 cm, 84 centibars. Maintaining sites weed free appears to conserve some soil moisture. Straw mulch (unincorporated) at 3 t/ha does not seem to provide an adequately thick mulch layer to suppress weeds.

Straw incorporation gave the highest average yield, followed by deep tillage and straw mulch; the weedy fallow gave the lowest (Table 2). The yields of the shallow-tillage and weed-free plots were similar and lower than those of the straw-incorporation, deep-tillage, and straw-mulch treatments and higher than the yield of the weedy fallow plot. Among the four rices tested, IR1529-430-3 gave the highest yield and IR20 the lowest (Table 2). Grain yield results (2.2 to 2.9 t/ha) were consistent with those in other trials in the Philippines and other countries growing upland rice. As in rainfed-lowland rice, dry-soil mulch in upland rice conserved soil moisture through the dry season for a rainfed crop.

Climatic environment and its influence

Plant Physiology Department

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SUMMARY

Studies on the effect of such climatic variables as temperature, solar radiation, and water on rice growth and yields continued in 1977.

Relatively lower temperatures during the reproductive stage favored an increased number of spikelets (grains) and thereby affected crop yield. The effective grain-filling period was 22 days at Los Baños, Philippines, and 32 days at Suweon, Korea. This 10-day differential was attributed to the difference in temperature between the two locations.

The interaction between temperature and humidity as it affects the incidence of unfertilized grains was found to be complex. At 29°C and 32°C, decreased humidity increased the number of unfertilized grains, but at 35°C, the number declined.

The paddy field model was described and applied to 10 years of agrometeorological records at Los Baños to estimate the total water consumption (evapotranspiration plus percolation and seepage) in rice fields. The effective rooting depth of paddy fields at three locations in the Philippines, determined by measuring root penetration and penetration resistance of the rice soils, varied markedly. The rate of rice root elongation into the soil was closely correlated with soil penetration resistance in water-saturated soils. The soil's water regime had a marked effect on vertical root distribution.

Investigation of the microclimate of two rice canopies with contrasting plant types indicated that a tall, droopy rice canopy does not necessarily have a higher humidity than a short, erect canopy. Tall plant stature appears to improve ventilation within the canopy, compensating for leaf droopiness, thereby preventing increased humidity inside the leaf canopy.

TEMPERATURE

Effect of temperature on spikelet number per square meter. In a study to determine whether relatively low temperatures during the reproductive stage of rice increase the number of spikelets, IR747B2-6 rice plants were grown in pots, as a minicrop at 20- × 20-cm spacing in a glasshouse of the IRRI phytotron. Four temperature regimes were superimposed on three levels of applied nitrogen (Table 1). The number of spikelets increased with decreasing temperature at all nitrogen levels studied. The increase was most marked at the highest level of applied nitrogen (150 kg/ha). At each of the four temperature regimes, the number of spikelets increased as the level of applied nitrogen increased.

The number of spikelets was greater at 50 kg N/ha and a day/night temperature regime of 26°/18°C than at 150 kg N/ha and temperature regimes of 35°/27°C and 32°/24°C.

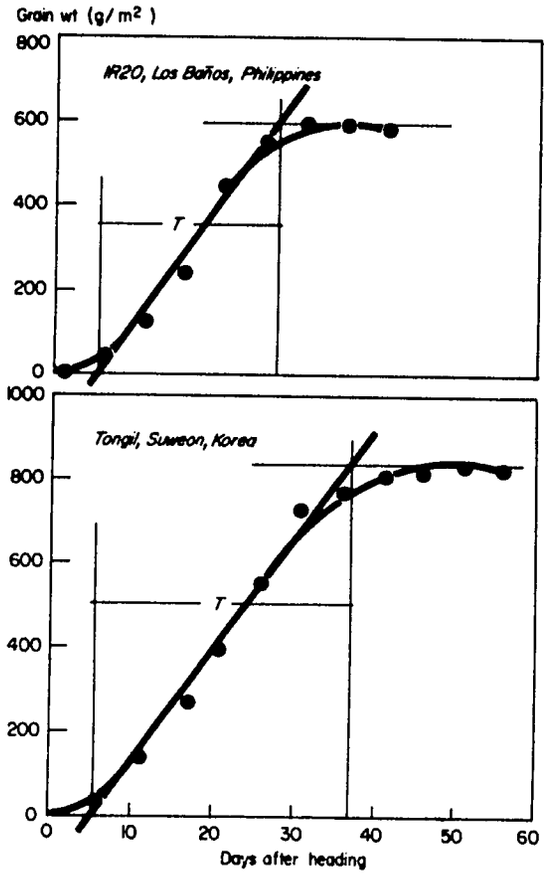
Absorbed nitrogen produced spikelets more efficiently at the lower temperatures and at the lower nitrogen levels.

Effective grain-filling period at Los Baños, Philippines, and Suweon, Korea. The effect of temperature on the duration of the grain-filling period (GFP) of rice in the field was investigated in a cooperative experiment conducted at Suweon, Korea, and Los Baños, Philippines. The effective GFP was 22 days for IR20 rice in Los Baños and 32 days for Tongil rice at Suweon (Fig. 1). The grain growth rates (increases in grain weight per square meter per day) were similar at the two sites — about 26-27 g/m² daily, or 0.26–0.27 t/ha daily.

The grain growth rate is determined by both the growth rate per grain and the number of grains per square meter. At Suweon, the growth

Table 1. Effect of temperature on the number of spikelets and the efficiency of nitrogen to produce spikelets. Minicrop experiment, IRRI phytotron.

Day/night temperature (°C)	Spikelets (no./m²) at			Spikelets (no./mg N absorbed) at		
	150 kg N/ha	100 kg N/ha	50 kg N/ha	150 kg N/ha	100 kg N/ha	50 kg N/ha
35/27	27,800	28,000	24,400	1.4	2.0	2.9
32/24	29,900	30,800	27,500	1.6	2.2	3.0
29/21	37,600	31,300	28,800	2.1	2.3	3.3
26/18	48,200	40,900	32,600	2.2	2.5	3.2



1. Grain growth of rice at two locations. *T* is the effective grain-filling period.

rate of a single grain was slower because of lower temperatures, but the grain number per square meter was greater than that at Los Baños. Thus, the grain growth rates in Suweon and Los Baños were similar.

Effect of temperature and vapor pressure deficit on the occurrence of unfertilized grains. The effect of temperature and vapor pressure deficit (VPD) on the occurrence of unfertilized grains was studied by growing N22 rice plants in a phytotron glasshouse at day/night temperatures of 29°/21°C until near flowering time. The plants were then transferred to artificially lighted cabinets and subjected to one of three day temperatures (29, 32, 35°C) with a constant night temperature of 21°C and three vapor pressure deficits (12, 24, 36 millibars [mb]). At maturity, the filled and empty grains were separated, and the number of unfertilized grains was determined. The percentage of unfertilized grains increased sharply as the temperature increased from 32 to 35°C (14 to 78% at VPD 12 mb and 25 to 47% at VPD 24 mb).

The effect of VPD on the incidence of unfertilized grains was complex. At 29 and 32°C, when the VPD increased from 12 to 24 mb, unfertilized grains increased by 5 and 10%, respectively. At 35°C, however, the percentage of unfertilized grains declined when the VPD increased — 78, 47, and 41% at the respective VPD levels of 12, 24, and 36 mb. This was probably because within the range of this experiment drier air prevented excessive elongation of filaments at 35°C. Hence, when the anthers dehisced, an adequate number of pollen grains were shed on the stigma. At high VPD levels, however, a considerable fraction of fertilized grains stopped growing at an early stage of grain filling and became empty. Thus, at 35°C, the percentage of empty grains at the three VPD levels used was high, ranging from 62 to 86%.

SOLAR RADIATION AND WATER BALANCE

The amount of water available to the roots of rice plants depends on meteorological factors (the balance between rainfall and evaporation) and on soil factors (the relation among soil water content, water potential, effective rooting depth, water conductivity, and water table).

The maximum rate of evaporation from a crop or from the soil during a certain period can be estimated from the net income of radiant energy throughout that period. Thus, water loss from a crop can be related to incident solar energy. The difference between precipitation and evaporation gives a measure of the deficit or surplus of the water balance.

The paddy field model. The following model is based on the results — published elsewhere — of agrometeorological studies on paddy fields.

Continuous measurements of net radiation in a paddy field during the whole rice-growing period indicate that the ratio of net radiation to the total incoming shortwave radiation varies from 0.70 at the early stage of growth to 0.55 at the ripening period, with a mean value of 0.62. On the average, about 18% of incoming radia-

tion is reflected at the surface of the paddy field and 20% is lost as outgoing longwave radiation.

Thus, the relationship between net radiation and incoming shortwave radiation is:

$$R_n = 0.62\ (Q + q) = 0.62 \cdot S \qquad (1)$$

where R_n is net radiation, Q = direct solar radiation, q = diffuse solar radiation, and S = total incoming solar radiation.

Net radiation is used for evapotranspiration (E), sensible heat (H), soil heat flux (G), and photosynthesis (Ph):

$$R_n = E + H + G + Ph \qquad (2)$$

Generally, the net storage of heat by soil and the energy captured by photosynthesis are negligible, and (2) can be simplified to:

$$R_n = E + H \qquad (3)$$

For freely transpiring, well-covered surfaces with no shortage of water in the root zone, evapotranspiration may utilize most of the net radiation and sensible heat may approach zero. This evapotranspiration rate gives the maximum rate, which may be similar to Penman's potential transpiration or Thornthwaite's potential evapotranspiration. The potential evapotranspiration is given by:

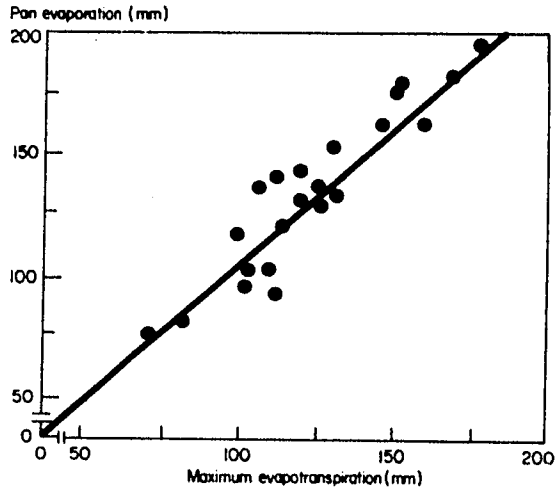
$$E = \frac{R_n}{L} \qquad (4)$$

where L is the latent heat of vaporization (590 cal/g). Combining equation (4) with equation (1) gives the complete equation for average potential evapotranspiration (millimeters per unit time):

$$E = \frac{R_n}{L} = \frac{0.62 \cdot S}{L} = 0.017\ (0.62 \cdot S)$$
$$= 0.0105 \cdot S\ (\text{mm}/T) \qquad (5)$$

where S is expressed in calories per square centimeter per unit of time (T), which can be day or week or month.

Equation (5) estimates the average potential evapotranspiration of a paddy field if no significant advection (oasis effect) affects evapotranspiration in the paddy fields being considered. Advection may occur where a moist area is surrounded by or is adjacent to drier land. The above assumption is likely to be valid during the wet season in monsoon Asia. The potential evapotranspiration computed from equation (5) agrees with the observed US class A pan evaporation rate in an IRRI field (Fig. 2). In this example, data for April and May, when advection might exist, were also included. On the average, the potential evapotranspiration is related to the pan evaporation as:



2. Relationship between maximum evapotranspiration and pan evaporation for 1972 and 1973. IRRI.

$$E = 0.93 \times \text{pan evaporation} \qquad (6)$$

Thus, the estimated average potential evapotranspiration of a paddy field is slightly lower than the observed pan evaporation. In rice-growing areas in monsoon Asia, the monthly average solar radiation ranges from 300 to 650 cal/cm² daily. The corresponding range of average potential evapotranspiration is approximately 3 to 7 mm/day.

Even under flooded conditions, however, sensible heat is not negligible. Continuous measurements of consumption of net radiation by a paddy field indicated that 82% is used for evapotranspiration, and 18% for sensible heat. This proportion is considered independent of the rice growth stage. Taking loss of energy by

sensible heat into account, equation (5) can be modified to:

$$E_R = \frac{0.82 \cdot R_n}{L} = 0.0086 \cdot S \text{ (mm/}T\text{)} \quad (7)$$

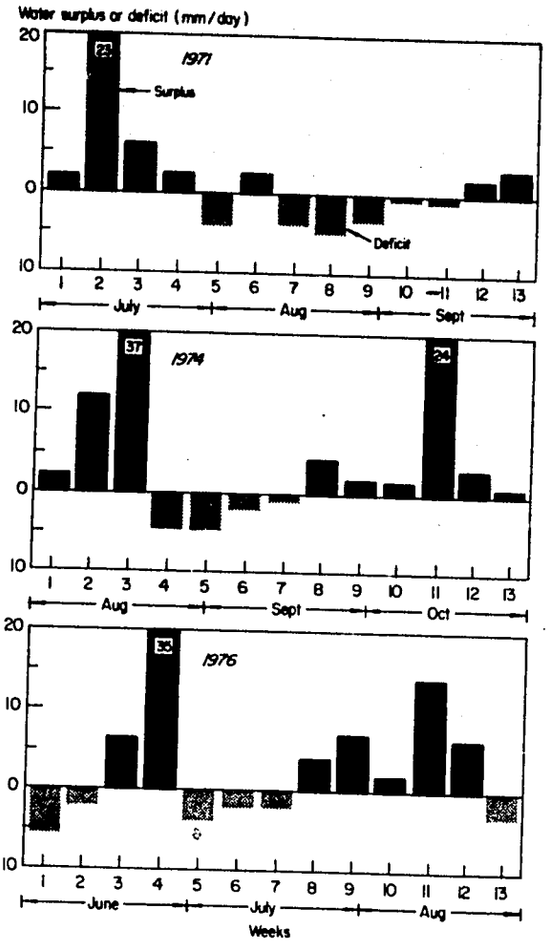
Equation (7) can estimate the evapotranspiration from a paddy field after the crop is established. About 7 mm/day has been reported as necessary for maximum yields in IRRI fields during the dry season (IRRI, 1970). The same conclusion can be obtained from estimates of evapotranspiration and percolation and seepage in the following way.

Given a value of 14,964 cal/cm² for April 1970, the daily evapotranspiration according to equation (7) is

$$E_R = \frac{0.0086 \times 14{,}964}{30} = 4.3 \text{ (mm/day)}$$

About 3 mm is the best estimate of the daily percolation and seepage in IRRI fields during the dry season. Thus, the total water consumption in IRRI fields is 4.3 mm/day (evapotranspiration) plus 3 mm/day (percolation and seepage), or 7.3 mm/day.

Water balance at Los Baños, Philippines. A review of the water balance (P-E) between precipitation (P) and potential evapotranspiration (E) at Los Baños for 1967 to 1976 indicates that the annual precipitation normally exceeds the annual potential evapotranspiration by 400 to 1,000 mm, except in 1968 and 1969 when the annual potential evapotranspiration exceeded the annual precipitation. At Los Baños, dry months (when E exceeds P) are normally January to April and wet months (when P exceeds E) are June to December. May is transition period from the dry to the wet months. Dry spells, however, occur sometime during the wet season. A marked water deficit occurred in 3 of the 10 years surveyed during the regular rice-growing season. The average water deficit in dry spells during the wet season of 1971, 1974, and 1976 was about 50 to 60% of the potential evapotranspiration (Fig. 3). When such water deficits occur during the reproductive stage to the flowering stage, the rice yield can be markedly impaired (1969 Annual Report).



3. Weekly balance of precipitation minus evaporation before, during, and after drought periods at Los Baños, Philippines.

Effective depth in soil water balance. Under drought conditions, soil moisture is the major source of water for plants. Thus, evapotranspiration (E) is equal to a decrease in soil moisture ($-\Delta M$).

$$E = -\Delta M \quad (8)$$

When moisture is adequate, evapotranspiration is determined largely by the incident solar energy (equation 7). When the soil moisture drops below a level adequate for good plant growth, stomates may be closed partially or totally to minimize water loss, photosynthesis is impaired, and growth may slow or stop. Under

Table 2. Bulk density and penetration resistance of rice soils at four locations in the Philippines.

Depth (cm)	Texture[a]	Bulk density (g/cm³)	Penetration resistance (kg/cm²)	Moisture content (%)
	Rainfed paddy – Manaoag, Pangasinan			
0–11	LiC	1.34	0.7	31.6
11–25	LiC	1.57	22.3	23.5
25–50	LiC	1.53	23.0	25.7
	Rainfed paddy – Oton, Iloilo			
0–29	HC	1.20	3.5	43.3
29–40	HC	1.35	16.3	33.2
40–50	HC	1.23	12.1	41.7
	Rainfed paddy – Tigbauan, Iloilo			
0–17	LiC	1.37	2.7	32.6
17–27	LiC	1.47	8.0	28.5
27–60	HC	1.23	10.7	41.1
	Upland – San Felipe, Cuenca, Batangas			
0–14	SC-LiC	1.22	3.3	34.2
14–32	LiC	1.09	26.5	49.8
32–63	LiC	1.06	29.1	54.0
63–	LiC-HC	0.93	18.5	66.6

[a] LiC = light clay; HV = heavy clay; SC = sandy clay.

these conditions, excess heat will be lost as sensible heat.

The soil moisture provides a buffer against periods of limited rainfall and can prolong the growing period beyond the time when rainfall ceases.

Total moisture storage capacity of soil (M) is:

$$M = \text{effective rooting depth (cm)} \times \text{available soil moisture content (mm/cm)} \quad (9)$$

The effective rooting depth (ERD) is known to range from 10 cm to 100 cm, depending on the crop. The physical properties of a soil and the rooting characteristics of a crop affect the ERD. An ERD of 50 cm was reported for paddy soils in Bangkok, Thailand.

As the first step towards determining the ERD, a survey of rice soils in four locations in the Philippines measured four soil physical properties along the soil profile (Table 2). Penetration resistance was used as a measure of mechanical impedance to root growth.

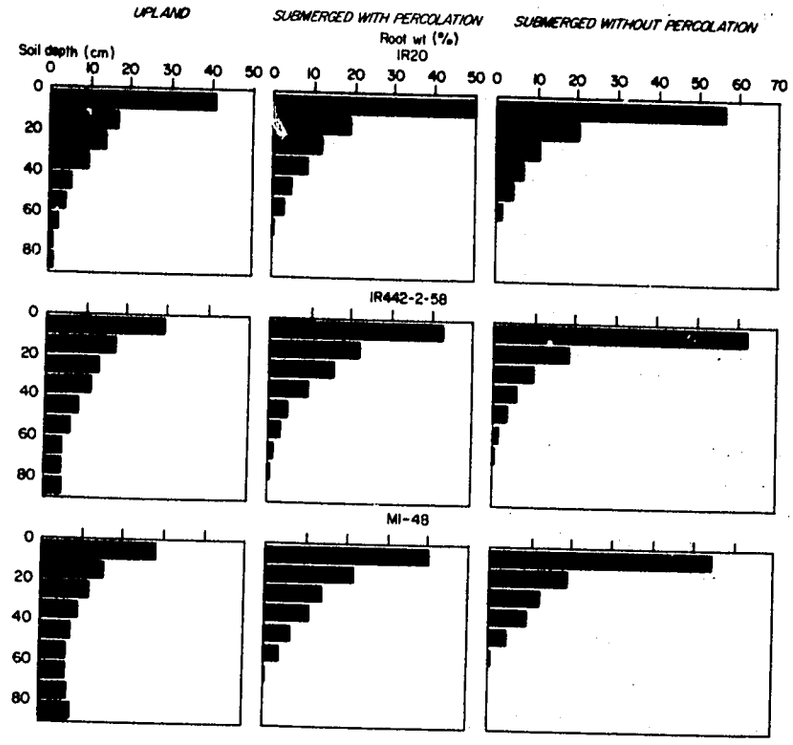
The ERD varied among the fields investigated. At Manaoag, Pangasinan (rainfed paddy), and San Felipe, Batangas (upland), low values of soil penetration resistance (SPR) were recorded only for surface soils (11-14 cm). SPR values of subsoils at these locations were quite high and no rice roots were detected in the subsoil. On the other hand, at Tigbauan, Iloilo, SPR values of both surface and subsoils were low. Roots were easily detected even at the 50-cm depth.

Relationship between root penetration and penetration resistance of soil. Plant roots penetrate into soil 1) through pore spaces and 2) between soil aggregates by working against an external force. The ability of a root to penetrate into the soil can be related to the SPR of a given soil. Soil was compacted to predetermined bulk density values in a steel core sampler, 50 mm in diameter and 51 mm deep. Five pregerminated seeds were placed on the surface and the core was placed in a growth chamber maintained at 29°/21°C day/night temperatures. The roots that penetrated to the bottom of the core were counted.

The root penetration rate was closely correlated with soil bulk density and penetration resistance under water saturation (Table 3). The lower the SPR value, the faster the roots penetrated the soil. Rice roots appear to have the ability to penetrate with relative ease soils having SPR values of up to about 10 kg/cm². At a bulk density of 1.4 and with the SPR of about 26 kg/cm², roots elongated only 1.2 cm over a period of 140 hours after seeding.

Table 3. Relationship among soil bulk density, soil penetration resistance, and root penetration under water saturation from 44 to 140 hours after seeding.

Bulk density (g/cm³)	Soil penetration resistance (kg/cm²)	Root penetration (%)								
		44 h	53 h	68 h	77 h	92 h	101 h	117 h	125 h	140 h
1.0	Negligibly small	22	100	100	100	100	100	100	100	100
1.1	Negligibly small	4	100	100	100	100	100	100	100	100
1.2	2.8	0	48	87	100	100	100	100	100	100
1.3	9.9	0	0	5	9	64	82	86	95	95
1.4	25.7	No roots reached the bottom								



4. Effect of water regimes on vertical root distribution of three rice varieties.

Effect of water regimes on root development. An oxygen transport model for the rice plant suggests that the partial pressure of oxygen in the root tip would decrease with increasing root length. The partial pressure of oxygen at the tip of a 40-cm-long root would be about 20% of the partial pressure at the base. To determine whether a limited supply of oxygen associated with different soil water regimes affects the depth of root growth, three rice varieties planted in root boxes were subjected to three water regimes: 1) flooded with no vertical water movement, 2) flooded with a percolation rate of 5 cm/day, and 3) upland with an adequate supply of water. Among the water regimes tested, upland-grown plants had the deepest root systems; the root systems of rice grown under flooded conditions with no percolation were the shallowest, and the root systems of those grown under flooded conditions with percolation were intermediate (Fig. 4). Apparently a limited external supply of oxygen restricts the development of rice roots in flooded soils.

MICROCLIMATE OF TWO RICE CANOPIES WITH CONTRASTING PLANT TYPES

Improved rice varieties with short stature and compact tiller arrangement may create a microclimate different from that of tall varieties with a loose tiller arrangement. To examine the effect of different plant types on temperature and humidity within canopies, IR747B2-6 (short and compact tiller) and Dular (tall and loose tiller) were planted at 20- × 20-cm and 30- × 30-cm spacing at IRRI during the 1977 dry season.

The two varieties differed in crop height and in leaf area index (LAI) at different spacings. Crop height is the distance from the ground level to the highest point of the canopy. The crop height of Dular was greater by 20 to 30 cm than that of IR747B2-6.

Relative humidity (RH) was always higher inside the canopy than outside (Table 4), and generally higher inside the canopy at a close plant spacing than at a wide spacing. Spacing

Table 4. Temperature and relative humidity of crop canopies of two contrasting plant types at flowering, IRRI, 19 and 22 March 1977 dry season.

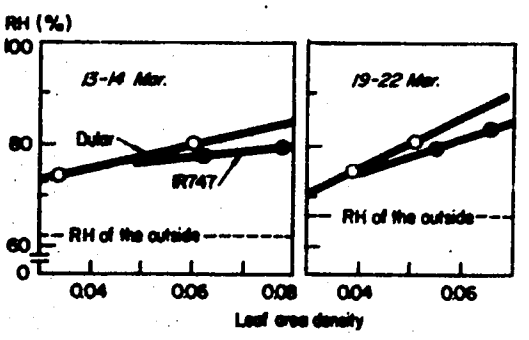
Av. of observations on 19 and 22 March	Inside the leaf canopy[a] of				
	Dular		IR747B2-6		
	20 x 20 cm	30 x 30 cm	20 x 20 cm	30 x 30 cm	Outside[b] canopy
Day[c]					
Temperature (°C)	28.1	28.5	28.7	28.7	28.3
Relative humidity (%)	80.4	74.6	82.6	79.0	66.3
Night[d]					
Temperature (°C)	24.3	24.4	24.6	24.9	24.5
Relative humidity (%)	92.7	86.5	88.3	86.4	82.3

[a]20 cm above water level. [b]190 cm above water level. [c]Mean value of observations at 1000, 1200, and 1400 hours. [d]Mean value of observations at 2200, 2400, and 0200 hours.

had a more pronounced effect on RH than did plant type. The canopy of IR747B2-6 had a slightly higher RH than that of Dular rice during the daytime. To examine the influence of plant type on the RH inside the crop canopy, the leaf area density (LAD) was calculated accordingly:

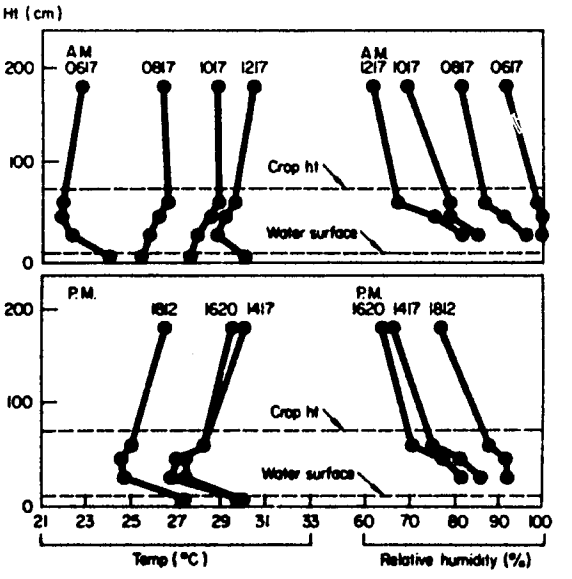
$$LAD = \frac{LAI}{\text{Crop height}}$$

LAD implies the density of the leaf area per unit of volume, while the LAI is the density of leaf area per unit of ground surface. LAD values ranged from 0.039 to 0.078. The RH of Dular was higher at high LAD values than was that of IR747B2-6 (Fig. 5). The high RH of the Dular canopy may be attributed to the variety's droopy leaf habit. However, the tall crop height counteracts the droopiness effect, because the tall plant stature improves ventilation within the canopy. Thus, the RH of a droopy canopy may not necessarily be higher than that of an erect-leaved canopy.



5. Relative humidity (RH) values inside the canopies of two rice varieties with different leaf habits.

The temperature inside the canopy of the IR747B2-6 rice was generally lower than that outside the canopy (Fig. 6). A temperature difference as large as 1.4°C was observed between a point 20 cm above water level and above the canopy. The water temperature varied from 24°C at 0610 hours to 30°C at 1410 hours. This fluctuation was smaller than that of air temperature. The RH inside the canopy was always higher than outside and its diurnal changes followed a pattern similar to that outside the canopy. The RH declined in a clear gradient from near the surface of the water to the maximum height of the crop.



6. Vertical distribution of temperature and humidity of a rice canopy (IR747B2-6, 30- x 30-cm spacing, 1 April 1977).

Postproduction technology and management

Agricultural Engineering and Agricultural Economics Departments

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SUMMARY

Farm-level evaluation trials and surveys in the Philippines reveal that a strong institutional and economic relationship conditions the adoption of improved postproduction equipment. Loss-assessment levels indicate that adoption of improved threshing equipment would be profitable. Economic analysis shows mechanical dryers are unjustified at present high machine-cost levels.

Rice-milling evaluation studies show a significant difference in milling returns between rubber roll-type technology and existing techniques in villages. Improved technology can increase recovery and significantly improve quality. Profiles of small-scale milling units indicate that the close proximity of these units to customers, the ability to handle small lot sizes, and the relatively low investment and operating costs characterized the technology at the village level.

FARM-LEVEL SYSTEMS

Farm-level applied research and demonstration trials were conducted at three sites in the Bicol River Basin area during the 1976 wet and 1977 dry seasons (Table 1). The technical evaluation trials involved 17 farmer-cooperators with a total of 150 plots and 5 varieties.

Farm-level research had two components: 1) a survey of farmers at each site to develop a profile of the postproduction practices used in the area; 2) a technical evaluation of alternative postproduction systems.

Field survey sites. One hundred thirty-seven farmers at three survey sites were interviewed. All respondents planted two crops a year. Average farm size was 1.7 ha, and 82% of the farms were irrigated.

Farmers used several guidelines to determine crop maturity and suitability for harvesting. Sixty percent usually harvested when 90 to 100% of the grains were ripe, 21% at the dates recommended for the varieties planted, and 11% when 70 to 90% of the grains were ripe. A large percentage of the farmers managed to harvest on or near the maturity dates determined by the guidelines. Forty-eight percent experienced delays resulting from lack of available labor or adverse weather conditions.

All farmers used manual methods of harvesting, primarily the sickle. During the wet season, 74% of the respondents cut stalks less than 80 cm below the panicle base. Most preferred intermediate straw length to facilitate handling and manual threshing. Fifty-one percent of the respondents indicated their paddy was handled three times; 30% said the crop was handled four or more times before threshing.

Thirty-eight percent of the farmers used mechanical threshers. No differences in use patterns were observed between the wet and dry season, primarily because the threshers used were small and portable. Most farmers (89% for the wet season and 93% for the dry) at one site continued to use some type of traditional threshing method, such as flailing, treading, or beating.

Sun drying was the most prevalent technique used to reduce moisture. Over 40% of the

Table 1. Characteristics of three sites of postproduction pilot trials, Bicol River Basin area, Philippines, 1976–77.

Location	Season	Cooperators (no.)	Plots (no.)	Av. plot area (m^2)	Av. yield[a] (t/ha)	Variety planted
Libon, Albay	Wet	3	25	1209.20	1.84	C4 C4 IR26
	Dry	5	32	1739.39	3.38	Peta C4 IR20 IR26
San Jose, Camarines Sur	Dry	5	54	1069.40	4.25	IR30
Buhi, Camarines Sur	Dry	4	39	1017.04	4.06	IR26
All 3 locations		17	150	1222.00	3.58	

[a]Final weight of paddy after being dried to 14% moisture content; weight was adjusted according to purity.

respondents used some type of mat, plastic sheet, or canvas as underlay for drying. Others used cemented roads, highways, or local public cemented areas.

Most of the farmers interviewed indicated that the modern varieties had increased problems in postproduction operations. Lack of labor, the additional handling required by higher yields, and increased drying and storage requirements were most frequently mentioned.

Technical evaluation trials. Four systems involving alternative combinations of technology and management were used in the farm-level trials. All four used the sickle in harvesting. System I used a series of traditional techniques for harvesting, threshing, and drying. System II employed traditional harvesting and threshing but incorporated a mechanical batch-type dryer for moisture control. In system III, the mechanical thresher was used for threshing, but the paddy was sun dried. System IV combined mechanical threshing and drying with traditional harvesting.

Crop-cut samples from each system were used to measure potential yield in the field. For actual area yields, plots were measured and the grain was weighed twice — after threshing and after drying. All yield and weight measurements were corrected for moisture content and impurities. To determine the effects of paddy quality on milled rice, 750-g paddy samples for each system were taken after each operation and dried, milled, and analyzed in the laboratory. Labor records were kept for each operation within individual systems, the cost incurred for each operation, and the total time required to complete the entire sequence of operations. In addition, the quantitative and qualitative measurements necessary to impute relative benefits and costs to each system were compiled.

Quantitative losses were measured at each stage in the system. Harvesting loss was determined with a 2-m^2 sample frame. At harvest, the paddy was bundled and stacked, and grain that had fallen on the ground or remained unharvested within the sample was gathered manually and weighed. This process was replicated two or more times per plot, depending on the total area involved in a system. To measure losses from stacking, harvested materials were placed on sheets. After stacking, grain remaining on the sheets was weighed. Losses in the traditional system of threshing were determined by weighing paddy recovered in the cleaning operation after threshing. In mechanical threshing, canvas and mats were used to recover paddy.

Detailed labor data for each operation in each system are shown in Table 2. The labor requirement was highest for the traditional system I and lowest for system IV. The two other systems embodying both traditional and improved technologies had lower labor requirements per hectare than the traditional system. Labor inputs for harvesting in systems III and IV, which use the mechanical thresher and required additional handling of unthreshed paddy, are often greater than those in systems that use traditional methods.

Mechanical threshing requires that paddy be carried to the road or levee, particularly during the wet season when the machines cannot operate in the field. Cleaning is normally performed with winnowing baskets, manually operated sieves, or manually operated semimechanized winnowing machines. Table 2 shows that improved technology in systems III and IV reduced the labor requirements for the threshing operation.

Mechanical drying reduces labor inputs for drying compared with sun drying (Table 2). Many farmers indicated a preference for the mechanical dryer but felt its high initial cost was beyond the reach of the ordinary farmer. Further drawbacks were high operation and maintenance costs, particularly the escalating price of fuel and difficulty in management of

Table 2. Comparative labor requirements for alternative rice postproduction systems (I-IV).[a] Bicol River Basin area, Philippines, 1976–77.

Operation	Mean value (man-hours/ha) of labor requirements			
	I	II	III	IV
Harvesting	139	147	174	142
Threshing	151	158	45	49
Drying	27	14	47	14
Total	317	318	266	205

[a]System I = traditional threshing and sun drying; II = traditional threshing and mechanical drying; III = mechanical threshing and sun drying; IV = mechanical threshing and drying.

Table 3. Laboratory results of comparative recovery rates for alternative postproduction systems (I-IV).[a] Bicol River Basin area, Philippines, 1976–77.

Item	Comparative recovery rate[b] (%)			
	I	II	III	IV
Brown rice	74.78	74.88	74.92	74.66
Milled rice	67.98	68.34	67.95	68.62
Head rice	79.45	80.26	80.25	84.09
Broken	19.07	18.08	18.73	14.50

[a]System I = traditional threshing and sun drying; II = traditional threshing and mechanical drying; III = mechanical threshing and sun drying; IV = mechanical threshing and drying. [b]Results from laboratory analysis of 400 paddy samples collected during field trials (av. for all postproduction operations).

the drying system. The reasons cited for the use of a mechanical dryer included a growing lack of drying space, increased yields, and the potential for deterioration of paddy harvested during rainy periods. The mechanical dryer also improves potential head rice recovery, compared with sun drying (Table 3).

Grain losses from harvesting through subsequent handling steps were recorded. Table 4 shows the harvesting and threshing losses for improved and traditional systems. Improved systems incurred higher harvest losses than traditional systems, apparently because of the more numerous handling steps required in using the mechanical thresher.

Paddy samples from each system were analyzed for total milling recovery and head rice. Systems with combinations of traditional and improved technologies showed significantly higher recovery rates. A similar trend for head rice recovery was also noted. Broken and cracked kernels decreased when improved technology was introduced.

Table 4. Comparative grain losses from harvesting through threshing using traditional and improved methods, Bicol River Basin area, Philippines, 1976–77.[a]

Handling step	Grain loss (%)	
	Traditional[b]	Improved[c]
Harvesting	2.86	2.72
Stacking	0.21	0.41
Threshing	1.56	0.48
Total	4.63	3.61

[a]Composite data from 125 plots. [b]Traditional systems (av. of systems I and II) involve use of traditional methods of threshing. [c]Improved systems (av. of systems III and IV) involve use of axial flow mechanical thresher.

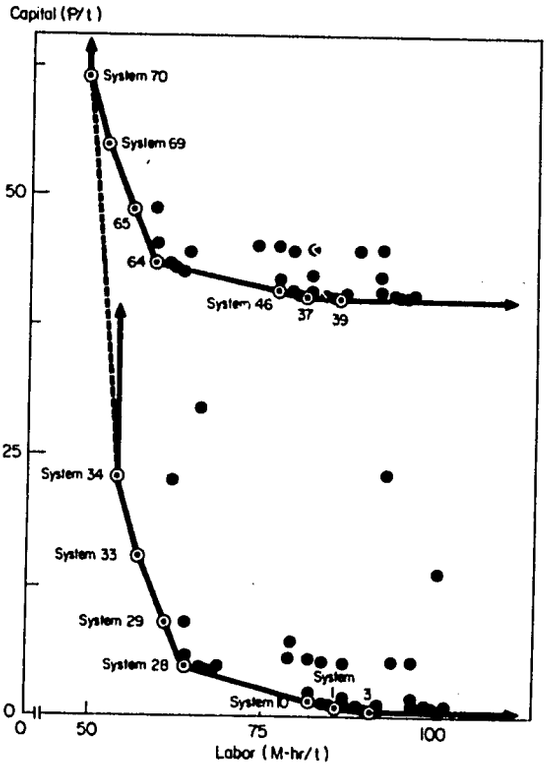
Table 5. Combinations of techniques for farm-level postproduction systems for rice harvested by sickle.

System no.	Combinations of techniques for given tasks		
	Threshing	Cleaning	Drying
1	Threshing frame	Win-Basket[a]	Solar
2	Treading	-do-	
3	Flailing	-do-	
4	Threshing frame	WB+Man Fan[b]	
5	Treading	-do-	
6	Flailing	-do-	
7	Threshing frame	WB+Mech Fan[c]	
8	Treading	-do-	
9	Flailing	-do-	
10	Threshing frame	S-ManB-Sim[d]	
11	Treading	-do-	
12	Flailing	-do-	
13	Threshing frame	S-MechB-Sim[e]	
14	Treading	-do-	
15	Flailing	-do-	
16	Threshing frame	S-ElecF-Sim[f]	
17	Treading	-do-	
18	Flailing	-do-	
19	Threshing frame	S-ManW-Sep[g]	
20	Treading	-do-	
21	Flailing	-do-	
22	Threshing frame	S-MechW-Sep[h]	
23	Treading	-do-	
24	Flailing	-do-	
25	Bicol type thresher	Win-Basket	
26	-do-	WB-Man Fan	
27	-do-	WB-Mech Fan	
28	-do-	S-ManB-Sim	
29	-do-	S-MechB-Sim	
30	-do-	S-ElecF-Sim	
31	-do-	S-ManW-Sep	
32	-do-	S-MechW-Sep	
33	Mini axial flow[i]	—	
34	IRRI axial flow[i]	—	
35	Cotabato thresher[i]	—	
36	McCormick thresher[i]	—	
37 to 72	Same as 1 through 36 with mechanical drying		Mechanical

[a]Using winnowing basket with natural aspiration. [b]Using winnowing basket with a manually operated fan. [c]Using winnowing basket with a mechanical blower. [d]Using sieve with a manually operated fan. [e]Using sieve with a mechanical blower. [f]Using sieve with an electric fan. [g]Using sieve followed by a manually operated winnower. [h]Using sieve followed by a mechanical winnower. [i]These threshers all have complete or partial cleaning systems that minimize or eliminate the need for subsequent cleaning.

Economic analysis of farm-level systems. A detailed economic study was undertaken to determine the most efficient combination of techniques available for farm level postproduction systems. With the use of data from the pilot sites, a set of synthetic systems was developed. It had 72 combinations of harvesting, threshing, cleaning, and drying techniques (Table 5).

By combining the alternative capital and labor inputs associated with each system, a series of points was established (Fig. 1). The factor proportions indicated a wide degree of var-



1. Frontier isoquants bounding the 72 combinations of harvesting, threshing, cleaning, and drying techniques.

iability. Points combining minimal levels of both labor and capital were joined to create a frontier isoquant curve. Points that fall inside this curve are relatively less efficient in the use of both resources.

Introduction of the mechanical dryer elevates the capital component of all combinations of harvesting, threshing, and cleaning equipment. Figure 1 (systems 37-70) shows that the high cost of drying equipment is a major constraint to its widespread use in the area.

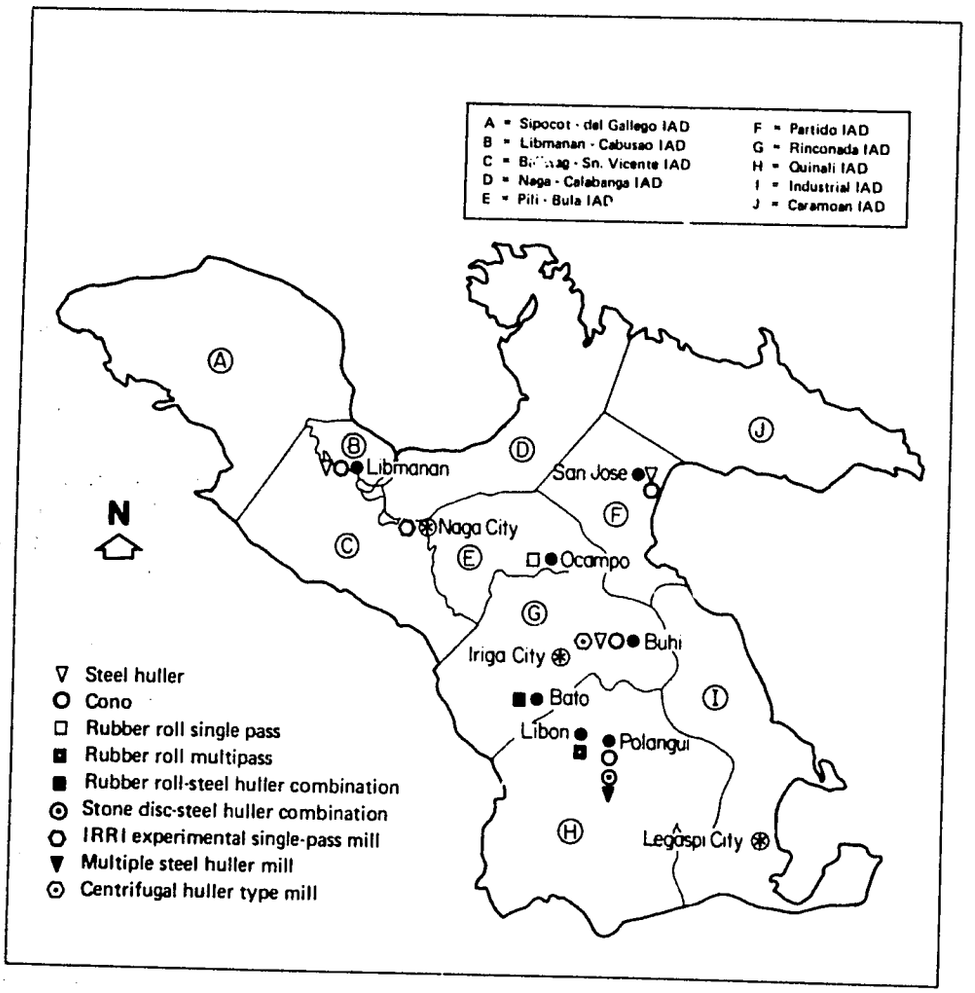
MILLING SYSTEMS

An attempt was made to quantify the comparative performance of village processing systems and of potential alternatives. A field study was undertaken to develop a set of empirically derived data describing the technical and economic characteristics of a range of operational and potentially operational rice-processing systems. Technical information describing in detail the composition and configuration of each alternative system was assembled. Complementary data on the use of labor, capital, and mill-use patterns were also collected.

The performance of each milling system was assessed in the field and the laboratory. Empirical data were collected during the 1976 wet and 1977 dry seasons in the Bicol River Basin region from: 1) a technical assessment of the existing rice milling systems, 2) a series of milling tests using existing systems to mill paddy from alternative farm-level systems with a range of threshing and drying techniques, 3) a continuous monitoring schedule for rice mills included in the technical assessment study, and 4) an engineering-economic survey involving 59 rice mills.

Table. Alternative milling systems included in the technical assessment study. Bicol River Basin area, Philippines, 1976–77 wet and dry seasons.

System	Precleaning	Hulling	Husk aspiration	Whitening
Steel huller mill ("kiskisan" or local Engelberg)	None	Steel huller	None	Steel huller
Cone-type mill	Sieve	Stone disc	Air trap/aspirator	Abrasive
Rubber roll multipass mill	Scalper-sieve	Rubber roll	Aspirator	Abrasive-friction
Rubber roll-steel huller combination mill	None	Rubber roll	Air trap	Friction
Stone disc-steel huller combination mill	Sieve	Stone disc	Air trap	Friction
Rubber roll single-pass mill	None	Rubber roll	Aspirator	Friction
IRRI experimental single-pass steel huller mill	None	Steel huller	None	Steel huller
Multiple steel huller mill	None	Steel huller	None	Steel huller
Centrifugal huller mill (dry season only)	None	Centrifugal	Air trap	Friction



2. Location of nine alternative milling technologies included in the technical assessment and monitoring activities. Bicol River Basin, Philippines, 1976–77. IAD = Integrated Area Development.

Technical assessment. Nine milling systems were identified for technical evaluation (Table 6). An evaluation trial involving 13 cooperators at several alternative locations in the Bicol area was included in the study (Fig. 2).

A homogenous 35-t sample of IR36 was procured, ...shed, and dried under controlled conditions. The sample was segregated into lot sizes large enough for replicated test runs through each milling system. Four replicated samples were used for each milling trial. Samples were measured at different points in the milling system and analyzed.

Among village-level mills, the rubber roll single-pass mill, the rubber roll-steel huller combination, and the centrifugal huller type performed best (Table 7). Two steel huller mills showed milling recoveries comparable to those of the rubber hullers. A multiple-pass steel huller mill also gave significantly higher recovery than the single-pass steel huller units.

Statistical analysis showed the rubber roll single-pass mill, the centrifugal huller, and the rubber roll-steel huller combination had significantly better performance than the other village mills. The rubber roll-steel huller combination was notably better than the single-pass steel huller unit.

A number of commercial-level mills were included in the trials for comparison. Qualitatively, the commercial mills performed well. Tests on both commercial and village mills, in

Table 7. Total milled and head rice recoveries[a] for nine milling systems, wet and dry seasons. Bicol River Basin area, Philippines, 1976–77.

System	Milling recovery (%)		Head rice (%)		Broken rice[b] (%)
Rubber roll single-pass	70.31	ab	62.51	bc	36.34
Rubber roll multipass	68.98	bc	77.09	a	22.37
Rubber roll-steel huller combination	69.24	bc	71.25	ab	28.02
Cone type rice mill (av.)	(69.00)		(75.76)		(23.26)
Concina RM	71.53	a	75.55	a	23.41
Gonzales RM	67.60	cde	75.19	a	23.67
Libmanan RM	70.63	ab	76.75	a	22.32
Nazarrea RM	66.25	efg	75.55	a	23.65
Steel huller rice mill (av.)	(66.23)		(41.70)		(56.40)
Dycoco RM	65.45	fg	42.14	f	56.78
Olaño RM	67.62	cde	48.07	def	49.83
Ruta RM	63.13	h	31.96	g	65.63
Torres RM	68.74	bcd	44.66	ef	53.36
Stone disc-steel huller combination	66.99	def	55.40	cd	41.36
Multiple-pass steel huller mill	68.15	cde	51.45	def	46.48
IRRI experimental single-pass steel huller mill	64.76	gh	54.45	cde	41.53
Centrifugal huller mill	70.33	ab	73.76	a	25.53

[a]Treatment means with at least one common letter are not significantly different at the 5% level. [b]Brewer's rice excluded.

which disaggregated milling systems were used, show that multiple-pass milling produces higher head rice recovery, particularly for units that use rubber roll multiple-pass systems and cone-type technology (Table 7).

In summary, mills with combination steel hullers and rubber roll hullers increase milling yields quantitatively and qualitatively. With this combination, the system remains simple without an accompanying paddy separator. Hulling efficiency is high. The head rice obtained is 6% lower than, but not statistically different from, the best produced by the rubber roll multiple-pass mill. With a stone-disc huller, the results were less impressive. Because of lower hulling efficiency, this system requires a paddy separator to remove unhulled paddy that is mixed with the brown rice as it leaves the husking unit. Thus, it requires additional cost, space, and power.

Milling with farm-level systems. Effects of combining alternative techniques of harvesting, threshing, handling, and drying on milling efficiency were examined. Paddy samples from both traditional and improved farm-level systems were used in tests of commercial and village-level milling systems. The tests were restricted to disc cone and steel huller mills.

Unmilled paddy samples were gathered from three sites in the Bicol River Basin. There were no significant differences in total milling recovery between traditional and improved farm-level systems. The improved system of threshing and drying had higher head-rice recovery rates, however (Table 8).

Monitoring activities. Weekly visits over a

Table 8. Head rice recoveries of cono and steel huller mills as affected by alternate methods of handling, threshing, and drying. Three pilot areas, Bicol River Basin area, Philippines, 1976–77.

System	Head rice recovery (%)							
	Cono				Steel huller			
	San Jose	Buhi	Libon	All areas	San Jose	Buhi	Libon	All areas
I[a]	85.19	71.69	71.92	76.27	37.75	34.49	26.99	33.08
IV[b]	86.49	78.88	79.13	81.5	40.85	34.68	47.44	40.99
Difference	1.30	7.19	7.21	5.23	3.1	.19	20.45	7.91
Av.	85.84	75.29	75.53	78.89	39.3	34.59	37.22	37.04

[a]Traditional method of handling, threshing, and drying. [b]Improved method using mechanical thresher and dryer.

Table 9. Potential milled and head rice recoveries of 32 samples classified according to grade. Bicol River Basin area, Philippines, 1976–77.

Grade	Samples[a]		Cracked kernel (%)	Potential recovery (%)	
	No.	%		Milled rice recovery	Head rice recovery
Premium	0	0	—	—	—
1	8	25	4	69.56	81.49
2	9	28	5	68.92	77.25
3	4	13	2	68.91	77.81
Substandard	11	34	4	66.42	72.75

[a]Collected during monitoring tour of rice mills.

Table 10. Potential total and head rice recoveries of 32 samples classified according to variety. Bicol River Basin, Philippines, 1976–77.

Variety	Samples[a] (no.)	Cracked kernels (%)	Milling potential (%)	
			Milled rice	Head rice
75-day japonica variety	9	3	69.89	78.85
C-4	4	7	65.27	79.82
IR8	1	4	67.37	81.35
IR26	8	5	68.14	75.85
IR28	1	8	68.05	55.04
IR30	2	3	68.17	87.76
IR36	2	1	67.79	88.13
BPI-76	1	5	68.61	75.87
Peta	1	4	67.37	81.35
Wagwag	1	0	66.91	66.34
Mixed	2	2	65.27	81.35

[a]Collected from nine mills included in the monitoring schedule.

1-year period were made to determine the quality and characteristics of paddy entering the milling systems of each site and the utilization pattern of each milling system, and to develop a profile of customer demand for milling services.

A laboratory analysis of paddy samples collected during the monitoring tour showed 34% were substandard, 41% of low quality, and only 25% of high grade (Table 9).

Table 9 also indicates a relationship between the grade of paddy entering the milling system and potential total and head rice recovery rates to be expected. A difference of 3% in potential milling recovery was observed between grade 1 and substandard paddy. A difference of 9% in head rice recovery was also found between the two grades. The findings strongly suggest that the efficiency of the processing system is a function of both the milling technology and the quality of the paddy entering the system.

Table 10 indicates potential total milled rice and head rice recovery expected from the range of varieties grown in the study area. A short-grain japonica variety had the highest total milling yield, while the long-grain indica type C-4 gave the lowest recovery rates.

Comparison of actual milling yields and potential recovery rates obtained in the laboratory showed that huller mills gave the lowest efficiency. A difference of 6% total milled rice and 23% head rice recovery was observed from samples procured during monitoring checks (Table 11).

Economics of milling systems. A series of synthetic budgets were constructed to compare the costs of alternative milling systems. The budgets were based on the results of interviews regarding utilization, initial investment costs, and input requirements. Table 12 shows that the rubber roll-steel huller combination rubber-roll single-pass, and centrifugal huller

Table 11. Comparative milling performance of mills included in monitoring schedule. Bicol River Basin area, Philippines, 1976–77.

Milling system	Commercial milling		Laboratory milling[c]		Difference between commercial and laboratory milling	
	Milled rice[a] (%)	Head rice[b] (%)	Milled rice (%)	Head rice (%)	Milled rice(%)	Head rice (%)
Cone-type mill	65.22	77.35	67.12	79.77	1.90	2.42
Steel huller	62.70	50.97	68.86	73.93	6.16	22.96
Rubber roll single-pass	67.0	67.63	71.53	81.82	3.73	14.19
Rubber roll-steel huller combination	67.49	64.17	69.51	74.73	2.02	10.56
Disc-huller combination	63.68	[d]	[d]	[d]		

[a]Based on daily records. [b]Based on analysis of samples collected from mill output. [c]Milling potential from paddy sample. [d]No samples collected.

Table 12. Cost, revenue, and profit per ton for alternative milling systems at 25% utilization rate. Bicol River Basin area, Philippines, 1976–77.

Milling system	Paddy input[a] (t/mo)	Price of paddy[b] (US$/t)	Operating cost of paddy[c] (US$/t)	Total cost (US$/t)	Milling recovery (%)	Milled-rice output (t/mo)	Price of milled rice[d] (US$/t)	Total sale of milled rice (US$/mo)	Revenue paddy (US$/t)	Profit (US$/t)
Cone-type mill	125.65	148.6	7.46	156.11	69.00	87.60	270.27	23432.00	186.49	30.38
Steel huller mill	32.36	148.6	2.81	151.46	66.23	21.43	270.27	5792.43	179.00	27.54
Rubber roll single-pass	18.35	148.6	6.24	154.89	70.31	12.90	270.27	3487.00	190.03	35.14
Rubber roll-steel huller combination	56.25	148.6	4.99	153.64	69.24	38.95	270.27	10526.35	187.13	33.49
Stone disc-steel huller combination	41.22	148.6	3.59	152.24	66.90	27.58	270.27	7452.97	180.81	28.57
Multiple steel huller mill	40.02	148.6	4.14	152.79	68.15	27.27	270.27	7371.22	184.19	31.39
Centrifugal huller mill	40.08	148.6	4.36	153.01	70.39	28.21	270.27	7625.00	190.24	37.24

[a]Actual input observed from monitoring activities. [b]Price of paddy is set at US$0.1486/kg. [c]Operating cost per ton is set at 25% utilization level. [d]Price of milled rice is set at US$0.2702/kg.

Table 13. General information for 39 steel huller mills. Bicol River Basin area, Philippines, 1976.

	Av. capacity			
	180 kg/h	280 kg/h	400 kg/h	All rates
Size classification	3–4	7–8	1–2	
Mills (total no.)	120	270	54	444
Sample mills (no.)	10	15	14	39
Av. operating days per year	279	272	247	256
Av. operating hours per day	2.79	1.92	3.86	2.8
Quantity of paddy milled per year	142.3	149.85	383.7	230.9
Average size of power units (hp)	7	10	16	11
Average years in operation	14	12	11	12.33
Average distance of mill from main road (km)	4	0.4	0.1	1.3
Average distance of mill from paddy source (km)	0.25	3.13	4.17	2.75
Smallest lot size accepted for milling (kg)	25	25	25	25
Average milling fee (US%/t)	12.32	13.01	10.95	12.05
Customer profile (%)				
Farmer	94	98	91	95
Landlord	6	1	4	3
Retailer or wholesaler	0	1	3	1

mill have the highest profit per ton. The higher recovery rates for the rubber roll huller more than offset the higher maintenance and replacement cost incurred and make this mill more efficient than the steel huller unit. But the degree to which higher profitability is realized will be heavily conditioned by the willingness of consumers to pay an additional premium for high-quality milled rice.

Survey of village milling units. An engineering-economic survey was conducted on 59 milling plants in the Bicol area. The focus was on the village-level mill.

Table 13 indicates the characteristics of three steel-huller size groupings. Of particular interest is the ability of these units to operate at relatively low utilization rates on a daily and annual basis. The ability to handle lot sizes of 25 kg or less and easy accessibility to households within their demand area are features of this technology. The greatest demand for milling services comes from farmer households and the villages surrounding the mill. Mills operate a large number of days per year, but average daily operating time is low. Most are part-time businesses operated by farmers or small businessmen in conjunction with other economic activities.

Constraints on rice yields

Agricultural Economics, Agronomy, and Statistics Departments

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SUMMARY

Results in 1977 continued to confirm findings that the dry season yield gap between farmers' level and high level of inputs was about 2 t/ha, the range being from 1.4 t/ha in Iloilo to 2.4 t/ha in Camarines Sur. Fertilizer accounted for approximately 1 t/ha of the yield gap at all four sites. Insect control also accounted for close to a ton in all sites except Iloilo, but weed control accounted for 0.3 t/ha or less in each site.

The wet season yield gap was approximately 1 t/ha in all sites except in Camarines Sur where it was zero. Factors contributing most to the yield gap were insecticide in Laguna and Nueva Ecija and fertilizer in Iloilo. High levels of fertilizer caused severe lodging on many Laguna farms and on some farms at other sites, particularly where IR36 was grown.

An experiment measuring yield in relation to age of seedlings under optimum management practices in Nueva Ecija showed that yields were not significantly affected by transplanting seedlings with ages ranging from 20 to 45 days.

An experiment was conducted in Laguna to determine whether farmers can increase yields by applying fertilizer at the correct time. The results showed that yields with farmers' timing and with recommended timing did not significantly differ.

Economic analysis of experiments showed that the high input level of fertilizer gave consistently higher profit over farmers' level at all four sites in the dry season. For insecticide and weed control in the dry season and for all three inputs in the wet season, the pattern was mixed, with some sites showing lower profit at high than at farmers' level. Intermediate levels of fertilizer included in the experimental design in three locations gave higher profits in the wet season. But intermediate levels of insecticide did not raise profits above the farmers' level. Farmers interviewed perceived drought, insects, and rats to be the major dry season constraints to high yield, and typhoons and insects the major wet season constraints.

Further analysis of experimental data using a production function approach suggests that the apparently large but economically recoverable dry season season gap due to fertilizer cannot be easily reduced because of the inefficiencies in farmers' use of fertilizer.

Analysis of farm survey records in Laguna, Nueva Ecija, and Camarines Sur indicates that farmers obtaining loans under the government Masagana 99 program tended to use higher levels of fertilizer. Yields of Masagana 99 farmers were higher but, in general, not significantly higher than those of farmers borrowing from other sources or not borrowing. Thus, the implications in terms of the impact of credit on yield are unclear.

An experimental design combining complete factorial, minifactorial, and supplemental trials was successfully tested in 1977. The main feature is the ability to maintain a small number of treatments even with a large number of test factors, and thus to allow the experiments to cover a wider geographic area with a fixed set of resources.

Results of measurements on 10 farmers' fields in Laguna during the 1977 wet season indicated that the farmers' level of fertilizer input, weed control practice, and yield were quite similar among paddies on the same farm. But the rate of fertilizer input and yield for the whole farm determined by interview differed from those determined by physical measurement of individual paddies, although no consistent bias existed from farm to farm.

A much higher degree of rat damage occurred in plots that were highly fertilized and protected from insect pests but had no weed control. The finding indicates the need to closely monitor and read rat damage in yield constraints trials ar[illegible] properly adjust yields.

BIOLOGICAL CONSTRAINTS

Agronomy and Statistics Departments

Four types of experiments were conducted in 1977 to identify with greater precision the magnitude of the yield gap and the contribution of test inputs in a given area without a large increase in the workload: 1) complete factorial, 2) minifactorial, 3) supplemental trials, and 4) management package.

The *complete factorial* experiment has all possible combinations of test factors (fertilizer, insect control, and weed control), each

at two levels — farmer and high (2^n treatments where n = 3, the number of test factors). In some cases, intermediate levels of test factors were also included.

The minifactorial trial has the number of treatments equal to two more than the number of factors being tested. With three test factors, there are five treatments: one with all factors high; one with all factors at farmer level; and each of the three others having all but one factor at the high level.

The *supplemental* trial has a minimum of one plot with all test factors at the high level. Farmer's yield is measured by crop-cutting the farmer's field.

In the *management package*, treatments are designed to represent intermediate levels between the farmer's practices and the high level of inputs. The incremental steps between treatments usually involve a simultaneous change in more than one input.

All experiments are used in identifying the yield gap. In addition, complete and minifactorial trials examine the contribution of the test factors to the yield gap. The economic analysis relies more heavily on the intermediate level of inputs from either the factorial or management package experiments.

The above experiments continued to be conducted in farmers' fields in four Philippine provinces (1975, 1976 annual reports). Farmers' and high levels of inputs, averaged over all test sites in each province, are shown in Table 1. The dominant interactions found in the complete factorial were between fertilizer and insecticides.

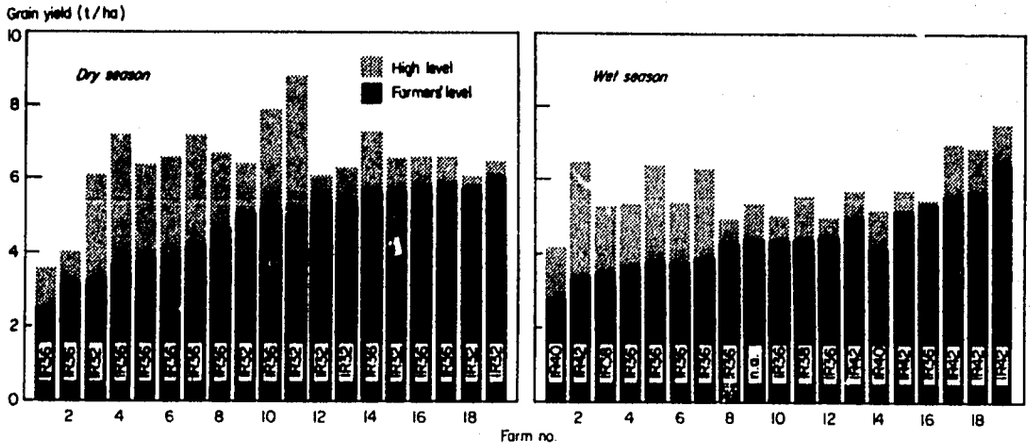
However, interactions for all 4 locations were significant on only 4 out of 21 farms in the dry season and on 3 out of 30 in the wet season. Furthermore, the direction of the interaction was not consistent. Therefore, the contributions to the yield gap (Table 2) were measured by combining data for the complete and minifactorial experiments: the contribution of the test factor to the yield gap is measured as a yield decrease from the high input due to the reduction from high to farmers' level of each input.

Laguna sites *(Statistics). Dry season.* Dry season experiments were on 19 farms — 4 used complete factorial trial; 3, minifactorial trial; and 12, supplemental trial. Ten farms were canal irrigated, six pump irrigated, two irrigated by a pump-canal combination, and one through a spring. The farmer-applied fertilizers, averaging 72 kg N/ha, 4 kg P_2O_5/ha, and 3 kg K_2O/ha, were split into two or three applications, with one farm having a single application and another four. All farmers, except one, controlled weeds by one or two rotary weedings followed by one hand weeding. Only one hand weeding was practiced on one farm. To control insects, all farmers but two used one to three foliar sprays. Six farmers supplemented spraying with granular insecticide. Two farmers used only granular insecticide. Eleven farmers planted IR36 and eight planted IR32.

Farmers' yields varied from 2.5 to 6.1 t/ha (Fig. 1), averaging 4.8 t/ha. The high levels of insect control, fertilizer, and weed control (Table 1) produced yields that ranged from 3.6 to 8.8 t/ha, averaging 6.5 t/ha. Yield gaps ranged from 0.6 to 3.5 t/ha; one farm exhibited no yield increase. Of the average yield gap of 1.8 t/ha, about half was contributed by improved insect control and half by improved fertilizer use (Table 2). Improved weed control did not contribute to the yield gap.

Wet season. Wet season experiments were on 19 farms; 17 were the same farms on which dry season experiments were carried out. On the average, the farmers' rates of fertilizer application were the same as those for the dry season. However, 6 of the 17 farmers increased their fertilizer rates, 5 decreased theirs, and 7 used the same rates as those in the dry season. While the mechanical weed control practices were similar to those in the dry season, the number of farmers using chemical control increased from four to eight. Farmers' insecticide use was slightly higher than that in the dry season, with increase in the use of granular insecticides. Varieties grown were predominantly IR36 and IR42, with two farms each planting IR38 or IR40.

Farmers' yields ranged from 2.8 to 6.5 t/ha, averaging 4.5 t/ha (Fig. 1). With high inputs, yields ranged from 4.2 to 7.5 t/ha, averaging 5.7 t/ha. Yield gaps ranged from 0.5 to 3.1 t/ha, with one farm showing no gap and another showing a yield decrease of 1 t/ha with high inputs. Lodg-



1. Yields at high and at farmers' level of inputs from farm yield-constraints studies. Laguna, Philippines, 1977 dry and wet seasons.

Table 1. Farmers' (F) and high level (H) of test factors, yield-constraints experiments. Four provinces, Philippines, 1977.

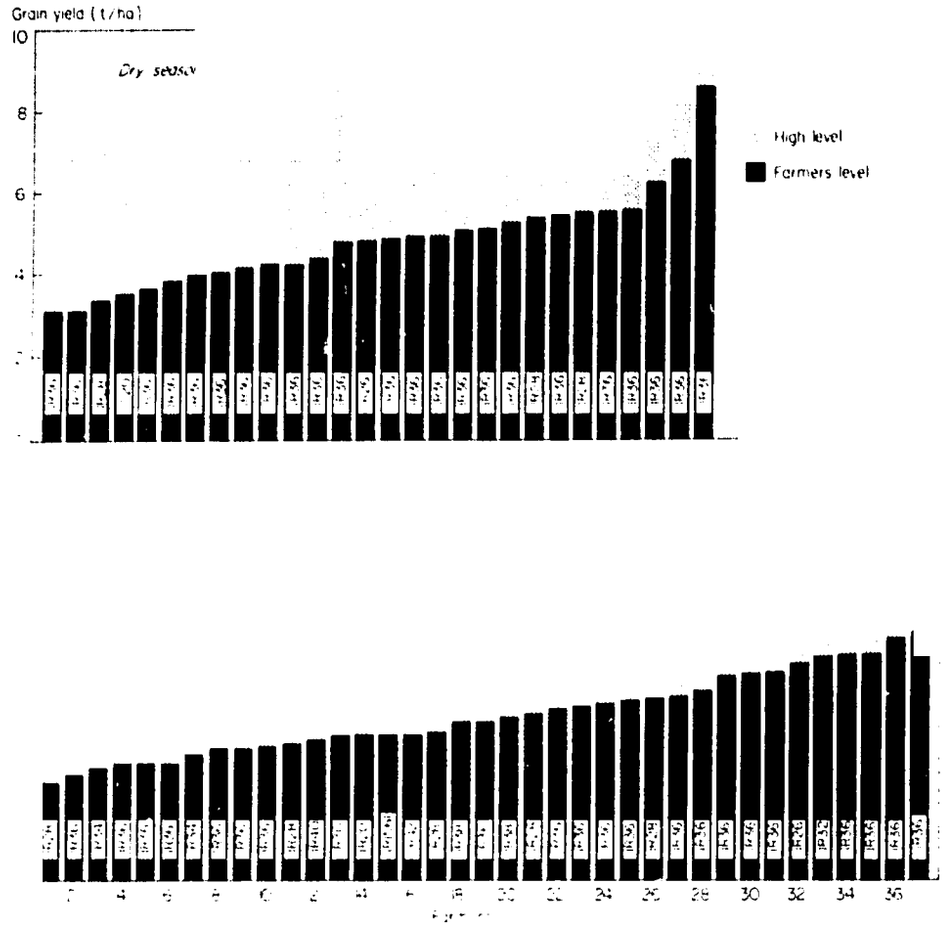
Province	Sites (no.)	Fertilizer (kg/ha)						Weed control[a]				Insect control[b]			
		N		P_2O_5		K_2O		Mechanical		Chemical		Foliar		Granular	
		F	H	F	H	F	H	F	H	F	H	F	H	F	H
								Dry season							
Laguna	19	73	120	5	30	3	0	2.4	1.3	0.2	1.0	1.4	4.8	0.3	4.4
Nueva Ecija	28	93	150	41	40	4	30	0.8	1.0	0.5	1.0	1.9	1.0	0.6	4.0
Camarines Sur	20	58	150	24	40	5	30	1.0	1.0	0.9	1.0	3.0	1.0	0.0	4.0
Iloilo	17	66	150	11	40	3	30	1.3	0.8	0.7	1.0	1.8	2.3	0.2	3.6
								Wet season							
Laguna	19	73	90	7	0	2	0	2.5	1.7	0.4	1.0	1.5	1.9	0.7	4.9
Nueva Ecija	37	64	100	30	40	8	30	0.4	1.0	0.4	1.0	2.3	2.3	0.7	3.0
Camarines Sur	27	55	100	13	40	11	30	0.8	1.0	0.5	1.0	2.8	1.0	0.1	3.0
Iloilo	23	55	100	12	40	5	30	0.9	0.9	0.3	1.2	2.3	2.0	0.0	3.5

[a]Av. no. of weeding operations. [b]Av. no. of insecticide applications.

Table 2. Relative contribution of three inputs (insect control, fertilizer, and weed control) toward the improvement of rice yields in farmers' fields, International Rice Agro-Economic Network (IRAEN), Philippines, 1977 (complete factorial and minifactorial combined).

Province	Sites (no.)		Grain yield (t/ha)			Contribution[a] (t/ha)			
	Irrigated	Rainfed	Farmers' input	High input	Difference	Fertilizer	Weed control	Insect control	Residual
				Dry season					
Laguna	6	0	4.9	6.7	1.8	0.9	−0.2	0.8	0.3
Nueva Ecija	16	0	5.2	7.3	2.1	0.9	0.2	1.0	0.0
Camarines Sur	12	0	3.5	5.9	2.4	1.2	0.3	1.0	−0.1
Iloilo	9	0	4.0	5.4	1.4	1.1	0.2	0.3	−0.2
				Wet season					
Laguna	6	0	4.5	5.6	1.1	0.2	0.2	0.9	−0.2
Nueva Ecija	18	6	4.2	5.3	1.1	0.4	0.0	0.5	0.2
Camarines Sur	11	5	3.6	3.8	0.2	0	−0.1	−0.3	0.6
Iloilo	13	3	3.6	4.6	1.0	0.6	0.3	0.4	−0.3

[a]Measured as yield decrease from high input due to a reduction from high to farmers' level of each input.



2. Yields at high and at farmers' level of inputs from farm yield-constraints studies, Nueva Ecija province, Philippines, 1977 dry and wet seasons

ing was a serious problem on most farms, especially in plots receiving high fertilizer rates. The result was no yield gap and even a loss in yield at high fertilizer levels on some farms.

Of the average yield gap of 1.1 t/ha, the major portion of about 70% was from improved insect control and the rest was equally divided between fertilizer and weed control (Table 2). The relatively small contribution of fertilizer was primarily caused by lodging.

Nueva Ecija sites (*Agronomy*). *Dry season.* Dry season experiments were conducted on 28 pump-irrigated farms — 7 with complete factorial, 9 with minifactorial, and 12 with supplemental trials. The average levels of fertilizer nutrients applied by cooperating farmers were 93 kg N/ha, 41 kg P_2O_5/ha, and 4 kg K_2O/ha (Table 1). Farmers typically applied two foliar sprays of insecticide, but one farmer applied none. Twelve of the 28 farmers supplemented foliar spray with granular insecticides. The majority of the farmers used hand weeding, and about half combined it with chemical or mechanical weed control. Herbicides were used more commonly than rotary weeders, as most farmers did not practice straight-row planting.

Yields at the farmers' level of inputs ranged from 3.2 to 8.6 t/ha (Fig. 2), averaging 4.8 t/ha. At the high level of fertilizer, insect control, and weed control, yields ranged from 4.7 to 8.9 t/ha, averaging 7 t/ha. Yield gaps ranged from 0.3 to 3.8 t/ha, averaging 2.2 t/ha. Considering only the complete and minifactorial experiments, the yield gap averaged 2.1 t/ha, with approxi-

Table 3. Intermediate[a] levels of fertilizer and insect control used in three provinces, Philippines, 1977.

Season	Fertilizer (kg/ha)						Intermediate insect control[b]	
	Intermediate 1			Intermediate 2				
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	Foliar	Granular
Dry	50	20	10	100	30	20	0.7	1.7
Wet	40	20	10	70	30	20	1.2	1.8

[a]Between farmers' and high levels. [b]Av. no. of insecticide applications.

mately 1 t/ha contributed each by fertilizer and by insect control (Table 2). Improved weed control did not appreciably increase yields on most farms.

The complete factorial experiments included two levels of fertilizer and one level of insecticide intermediate between the farmers' and high level (Table 3). Grain yield at a specific input level was averaged over all other inputs (Table 4). Farmers applied fertilizer at a level higher than intermediate 2 (I-2), but the yields they obtained were not significantly higher than those at intermediate 1 (I-1). The intermediate level of insect control contained more granular and less foliar insecticides than what farmers were currently using, but it did not increase yield.

One management package experiment was conducted on a pump-irrigated farm. The M_1 level used a higher rate of nitrogen than the M_4 level and about the same rate of phosphate. Farmers' insect and weed control measures were at the M_2 level (Table 5). The farmers' variety was compared with the test variety IR26. No varietal differences were noted (Table 6).

Wet season. Wet season experiments were conducted on 28 irrigated and 9 rainfed farms during the wet season. There were 10 complete trials, 14 minifactorial, and 13 supplemental. The average level of fertilizer nutrients applied by cooperating farmers was 64 kg N/ha, 30 kg P_2O_5/ha, and 8 kg K_2O/ha (Table 1). The level of insect and weed control was similar to that in the dry season, with most farmers applying foliar insecticide twice and hand weeding. One farmer applied no insecticide, while 6 of the 37 farmers did no hand weeding.

Yields at the farmers' level of inputs ranged from 2.4 to 6 t/ha (Fig. 2), averaging 4 t/ha. At the high level of inputs, yields ranged from 3.2 to 6.9 t/ha (5.3 t/ha). Yield gaps ranged from 0.1 to 2.9 t/ha (av. 1.3 t/ha). Considering only the complete and minifactorial experiments, the yield gap averaged 1.1 t/ha, with fertilizer and insecticide each contributing approximately 0.5 t (Table 2). A high level of weed control did not contribute significantly to an increase in yields.

As in the dry season, yields at farmers' and I-1 levels of fertilizer were similar, despite the higher level of N and P_2O_5 (approximating I-2) applied by the farmers (Table 4).

Management package experiments were conducted on two irrigated farms. The average level of fertilizer nutrients applied by the farmers were 43 kg N/ha, 27 kg P_2O_5/ha, and 11 kg

Table 4. Grain yield under farmers' (F), intermediate (I), and high (H) levels of inputs. Project areas in three provinces in the Philippines, 1977 (complete factorial).

Province	Farms (no.)	Grain yield[a] (t/ha)								
		Fertilizer				Insect control			Weed control	
		F	I-1	I-2	H	F	I	H	F	H
						Dry season				
Nueva Ecija	7	5.8	5.5ns	6.4ns	6.7*	5.8	5.6ns	6.9**	6.1	6.2ns
Camarines Sur	6	4.1	4.5ns	5.4**	5.3**	4.4	4.8ns	5.4**	4.7	4.9ns
Iloilo	4	3.8	3.6ns	4.4ns	4.6ns	4.0	4.1ns	4.2ns	4.1	4.1ns
						Wet season				
Nueva Ecija	10	4.8	4.9ns	5.2ns	5.2ns	4.8	4.8ns	5.4*	5.0	5.0ns
Camarines Sur	8	3.2	3.6ns	3.5ns	3.4ns	3.4	3.5ns	3.4ns	3.4	3.4ns
Iloilo	9	3.9	4.1ns	4.2ns	4.3*	4.0	4.1ns	4.3ns	4.0	4.2*

[a]Value of a specific input level is averaged over all other inputs. *, ** indicate significantly different from the F level at 5% and 1% level, respectively. ns indicates no significant difference from F at the 5% level.

K_2O/ha, approximately equivalent to N at M_2 level, P_2O_5 at M_1 level, and K_2O at half that of M_3 level (Table 5). Average levels of farmers' insect and weed control were equivalent to those for the M_2 package. The farmers planted IR36 and the test variety was IR42, a recent release of the Philippine Government. Yields increased as inputs were raised from the M_2 to

Table 5. Average levels of inputs used by farmers and levels of four input management packages. Project areas in three provinces, Philippines, 1977.

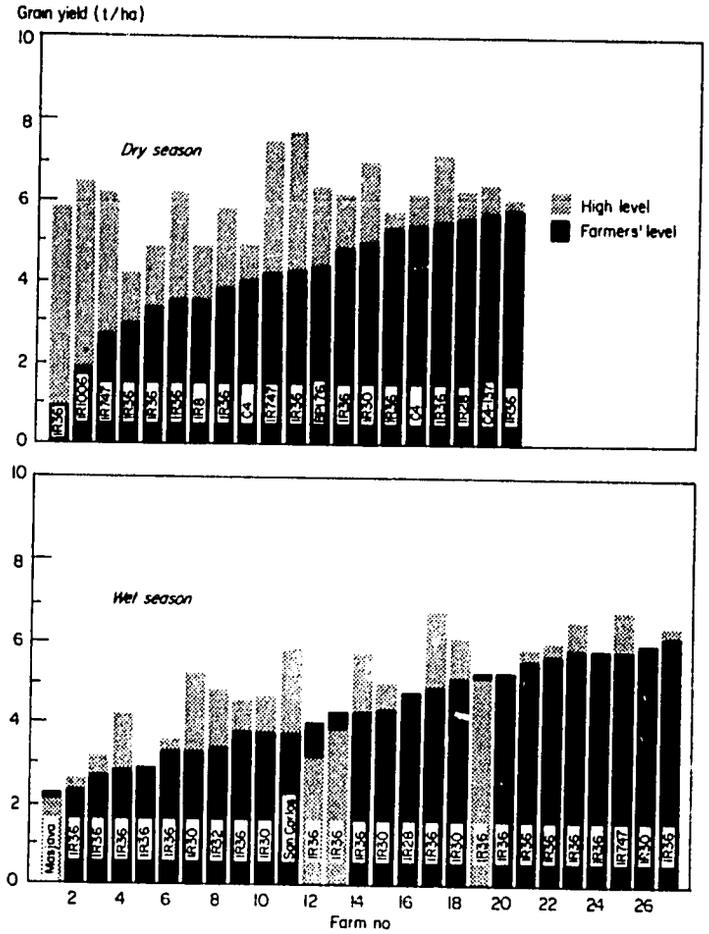
Province	Sites (no.)	Package level[a]	Fertilizer (kg/ha)			Insect control[b] (av. no. of applications)					Weed control[c] (av. no. of treatments)	
						Seedbed		Field				
			N	P_2O_5	K_2O	F	G	R	F	G	M	C
					Dry season							
Nueva Ecija	1	M_1	132	27	0	0	0	0	3	0	1	0
Camarines Sur	1	M_1	64	0	0	0	0	0	4	0	1	1
Iloilo	1	M_1	174	0	0	0	0	0	4	0	1	1
All three	All	M_2	40	10	0	0	0	0	2	0	1	0
All three	All	M_3	80	20	20	0	1	1	0	0	0	1
All three	All	M_4	130	30	30	1	1	1	0.3	0	0	1
All three	All	M_5	160	40	40	0	2	0	1	4	1	1
					Wet season							
Nueva Ecija	2	M_1	43	27	11	0	0	0	3	0	1	0
Camarines Sur	2	M_1	30	7	7	0	0	0	2.5	0.5	0.5	0
Iloilo	3	M_1	78	25	7	0.3	0	0	2.7	0	1	0
All three	All	M_2	40	10	0	0	0	0	2.3	0	1	0
All three	All	M_3	60	20	20	0	1	1	0.7	0	0	1
All three	All	M_4	80	30	30	0	2	1	0.9	1.0	0	1
All three	All	M_5	100	40	40	0	2	0	1.6	4.0	1	1

[a]M_1 = farmers' levels of application of the three inputs by site. M_2 – M_5 have levels of fertilizer, insect control, and weed control as listed in this table. [b]F = foliar, G = granular, R = root zone placement of liquid carbofuran. [c]M = mechanical weeding either by hand or by rotary weeder. C = chemical weedicide

Table 6. Average yield of farmers' varieties and test varieties compared at farmers' and four input management packages and grown under high levels of cultural practices. Project areas in three provinces, Philippines, 1977.

Province	Sites (no.)	Variety[a]	Grain yield[b] (t/ha)										
			M_1[c]		M_2		M_3		M_4		M_5		Av.
					Dry season								
Nueva Ecija	1	IR36 F	5.4	c	4.4	d	5.7	bc	6.1	b	7.8	a	5.9
		IR26 T	5.6	c	4.2	d	5.7	c	6.4	b	7.3	a	5.9
Camarines Sur	1	IR36 F	2.3	a	3.1	a	4.6	a	4.2	a	5.0	a	3.8
		IR26 T	4.4	a	5.0	a	5.1	a	3.7	a	5.1	a	4.7
Iloilo	1	IR30 F	4.1	bc	3.4	c	4.7	ab	5.6	a	5.1	a	4.6
		IR36 T	4.5	bc	3.6	c	4.2	bc	5.7	a	5.0	ab	4.6
					Wet season								
Nueva Ecija	2	IR36 F	4.6	a	4.3	a	5.1	a	5.3	a	5.4	a	4.9
		IR42 T	4.8	b	4.8	b	5.2	ab	5.6	a	6.5	a	5.3
Camarines Sur	2	IR36 F	2.9	a	2.8	a	3.0	a	3.3	a	3.7	a	3.1
		IR42 T	2.8	a	2.5	a	3.4	a	3.2	a	3.6	a	3.1
Iloilo	3	[d]	3.9	ab	3.6	b	4.2	ab	4.3	ab	4.6	a	4.1
		IR42 T	4.1	b	4.2	b	4.6	ab	5.0	a	5.0	a	4.6

[a]F = farmers' variety, T = test variety. [b]Management packages (M_2, M_3, M_4, and M_5) contain varying levels of fertilizer, insect control, and weed control as shown in Table 5. In a row, means followed by a common letter are not significantly different at 5% level. An underline indicates significant difference from farmers' variety under the same management package. [c]Farmers' level. [d]IR30, IR36, and IR42.



3. Yields at high and at farmers' level of inputs from farm yield-constraints studies. Camarines Sur province, Philippines, 1977 dry and wet seasons.

the M_5 level (Table 6). Except at M_5, where IR36 lodged severely, the difference in performance between IR36 and IR42 was not significant. In fact, IR36 tended to perform better one one farm, while IR42 performed better on the other.

Camarines Sur sites (*Agronomy*). *Dry season.* The dry season complete factorial trials were conducted on 6 pump-irrigated and 14 canal-irrigated farms. Six complete factorial, six minifactorial, and eight supplemental experiments were conducted. The average levels of fertilizer nutrients applied by cooperating farmers were 58 kg N/ha, 24 kg P_2O_5/ha, and 5 kg K_2O/ha (Table 1). The N and P_2O_5 levels were almost half of those applied by Nueva Ecija farmers. The level of foliar insecticide use was somewhat higher than in Nueva Ecija with many farmers spraying up to four times. But no farmer used granular insecticide. Most cooperators used a combination of hand weeding and herbicides to control weeds.

Yields at the farmers' level of inputs ranged from 1 to 5.8 t/ha (Fig. 3), and averaged 4 t/ha. At the high level of fertilizer and insect and weed control, yields ranged from 4.2 to 7.8 t/ha, averaging 6 t/ha. Yield gaps ranged from 0.2 to 4.8 t/ha (av. 2 t/ha). Considering only the complete and minifactorial experiments, the yield gap averaged 2.4 t/ha with fertilizer and insect control each contributing about 1 t/ha to the gap (Table 2). The findings were surprisingly consis-

tent with those for Laguna and Nueva Ecija in the dry season.

The value of a specific input level is averaged over all other inputs (Table 4). In the case of fertilizer, farmers applied nitrogen at a level approximately equal to I-1 and obtained a somewhat lower yield. Applying fertilizer beyond the I-2 level did not increase yield. As previously noted, farmers depended entirely on foliar spray for insect control. The yields at the intermediate level of insect control increased by 0.4 t/ha over the farmers' level.

A management package experiment was conducted on one canal- and one pump-irrigated farm, but yield data were obtained only for the canal-irrigated farm. The farmers' level (M_1) of inputs was between M_2 and M_3 (Table 5). The farmers' variety was IR36, the test variety was IR26. Yield increases were progressively higher from M_2 to M_5, except at M_4 when the crop lodged and was damaged by rats (Table 6). The average of all management levels showed that the test variety IR26 outyielded IR36 by 0.9 t/ha.

Wet season. Wet season experiments were conducted on 27 farms: 13 pump-irrigated, 5 canal-irrigated, and 9 rainfed. There were 8 complete factorial trials, 7 minifactorial, and 12 supplemental. The average level of fertilizer used by the cooperating farmers was 55 kg N/ha, 13 kg P_2O_5/ha, and 11 kg K_2O/ha (Table 1). Farmers typically applied two to four foliar sprays for insect control, somewhat less than in the dry season. Most farmers did not use herbicides. Considering only complete and minifactorial trials, the yield gap was 0.1 t/ha. The yield gap was virtually zero because plots of IR36 with high inputs lodged severely after a typhoon.

Yields were approximately 3.5 t/ha at all levels of fertilizer and insecticide (Table 4) with farmers applying more nitrogen than that in I-1 but substantially less insecticide than that in the intermediate level.

Management package experiments were conducted on two farms, one irrigated and one rainfed. Farmers (M_1) applied a level of input equivalent to M_2 (Table 5). The farmers planted IR36; the test variety was IR42. Yields increased from M_2 to the M_5 level, but differences between varieties were not significant (Table 6).

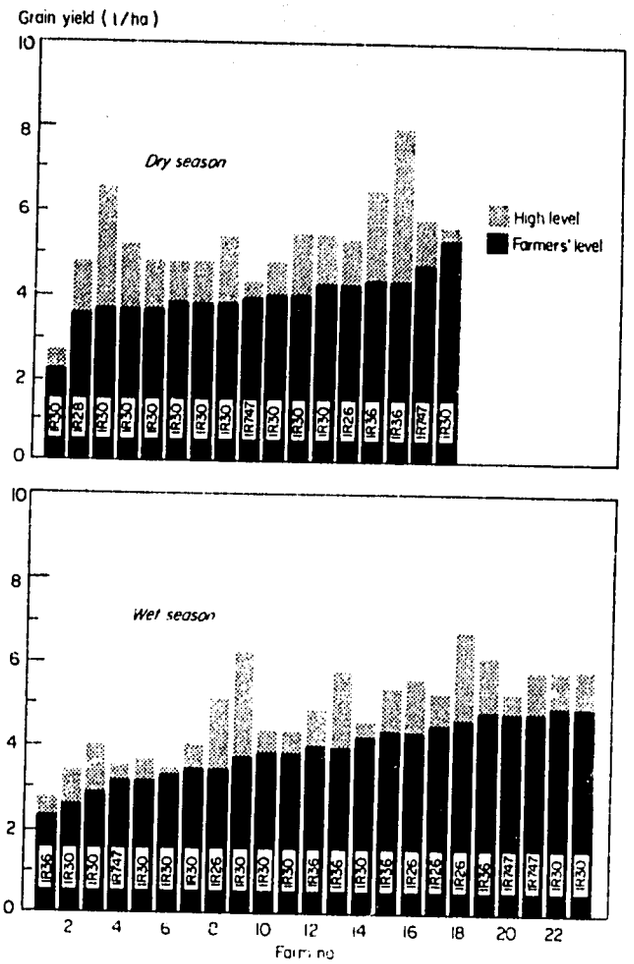
Iloilo sites (*Agronomy*). *Dry season.* Experiments were conducted on 17 canal-irrigated farms: 4 complete factorial, 5 minifactorial, and 8 supplemental trials. The average levels of fertilizer nutrients applied by the cooperating farmers were 66 kg N/ha, 11 kg P_2O_5/ha, and 3 kg K_2O/ha (Table 1). Fifteen of the 17 farmers direct seeded on puddled soils. To control insects, farmers applied two foliar sprays on the average. Granular insecticide was not used. Weeding was done principally by hand with a number of farmers combining hand weeding with mechanical and chemical controls.

Grain yields at the farmers' level of inputs ranged from 2.3 to 5.5 t/ha (Fig. 4), averaging 4 t/ha. At the high level of fertilizer, insect control, and weed control, yields ranged from 2.7 to 8 t/ha (av. 5.3 t/ha). Yield gaps ranged from 0.2 to 3.6 t/ha (av. 1.3 t/ha). Considering only the complete and minifactorial experiments, the yield gap averaged 1.4 t/ha with more than 1 t/ha contributed by fertilizer, 0.5 t/ha by insect control, and 0.3 t/ha by weed control (Table 2).

Farmers applied a level of fertilizer approximating that of I-1 and obtained about the same yield (Table 4). Higher fertilizer input resulted in higher yields. Intermediate and high levels of insecticide application did not increase yields significantly.

A management package experiment was conducted on a canal-irrigated farm at the same site where one complete factorial was conducted. The farmers' input level (M_1) of nitrogen exceeded the M_5 level but no P_2O_5 or K_2O was applied (Table 5). Carbofuran (EC) was placed in the root zone in the M_3 and M_4 packages. The farmers' variety IR30 was compared with the test variety IR36. Yields increased from M_2 to the M_4 level, and were higher at M_4 than at M_5, which could have been related to root zone placement of insecticides (Table 6). There was no discernible difference in yield due to varieties.

Wet season. Wet season experiments were conducted on 19 canal-irrigated and 4 rainfed farms. There were nine complete factorial, seven minifactorial, and seven supplemental trials. At 17 of 23 sites, rice was direct seeded on



4. Yields at high and at farmers' level of inputs from farm yield-constraints studies. Iloilo, Philippines, 1977 dry and wet seasons.

puddled soils. The average levels of fertilizer nutrients applied by the cooperating farmers were 55 kg N/ha, 12 kg P_2O_5/ha, and 5 kg K_2O/ha (Table 1). On the average, farmers applied about two foliar sprays and used hand weeding occasionally in combination with mechanical or chemical control measures.

Yields at farmers' level of inputs ranged from 2.3 to 4.9 t/ha (Fig. 4), averaging 3.9 t/ha. At the high level of test inputs, yields ranged from 2.7 to 6.7 t/ha (av. 4.9 t/ha). Yield gaps ranged from 0.3 to 2.4 t/ha (av. 1 t/ha). Considering only the complete and minifactorial experiments, about half of the 1 t/ha yield gap average can be attributed to fertilizer, and the remainder divided between insect and weed control (Table 2).

The complete factorial experiments included two levels of fertilizer and one level of insecticide, intermediate between the farmers' and high levels (Table 3). The intermediate level of fertilizer and insecticide did not raise yields significantly above the farmers' yield (Table 4).

Management package experiments were conducted on two irrigated farms, and one rainfed farm. The farmers' input level (M_1) approximated the M_4 level of fertilizer and the M_2 level of insect and weed control (Table 5). The farmer in the rainfed area grew IR26, while one in the irrigated area increased from M_2 to

M_3 level, with IR42 giving somewhat higher yields than the farmers' varieties (Table 6).

ADDITIONAL EXPERIMENTS

Agronomy and Statistics Departments

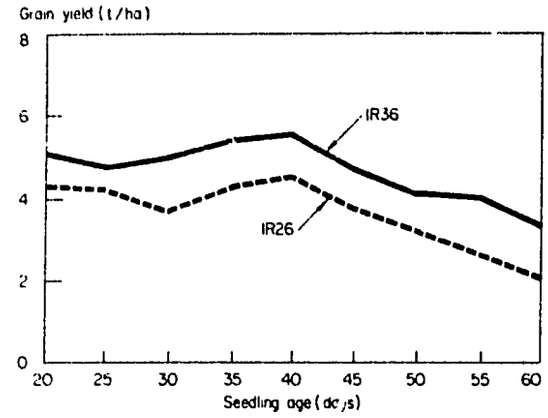
In addition to the experiments discussed, others were designed to 1) determine the relationship between yield and age of seedlings (Nueva Ecija, 2) examine the effect of time of fertilizer application on yields (Laguna), and 3) examine the variability in yield among experiments conducted at the experiment station and to compare it with that in farmers' fields (all four sites).

Age of seedlings, Nueva Ecija sites (*Agronomy*). Experiments were conducted on one irrigated and two rainfed farms during the 1977 wet season to determine how age of seedlings influences grain yield of transplanted rice in farmers' fields. Inputs and cultural practices other than seedling age were at high level.

The varieties IR26 and IR36 were transplanted at different seedling ages — 20 days up to 60 days — with an interval of 5 days. Intermediate levels of fertilizer were used — 70 kg N/ha, 30 kg P_2O_5/ha, and 20 kg K_2O/ha. For seedling ages of 20 to 50 days, nitrogen was applied in two equal split doses — basal and at 5–7 days before panicle initiation. For 55- and 60-day seedlings, the entire nitrogen fertilizer was applied as a basal dose. Phosphorus and potassium were applied basally and uniformly on all plots. Insect control, weed control, and other cultural practices were kept at optimum level. All farms received one or two additional foliar sprays with insecticide to control leaf rollers and other rice pests.

On all farms and with seedlings of all ages, the early maturing IR36 produced significantly higher yields than the medium- to late-maturing IR26 (Fig. 5). Typhoon damage contributed largely to serious grain losses of IR26; IR36 was also affected by a typhoon at one rainfed and one irrigated site. Moisture stress at the reproductive stage aggravated the problem on the rainfed farms.

Average data for two varieties under irrigation show that grain yields were not significantly different when 20- to 45-day-old seedlings were transplanted (Table 7). On rainfed farm 1, yield differences were not significant among the 20- and 40-day-old seedlings. On rainfed farm 2, age of seedlings produced greater variability in grain yields. The grain yield difference between 20- and 60-day-old seedlings was significant.



5. Grain yields of IR26 and IR36 rices as influenced by seedling age at transplanting (av. of 1 irrigated and 2 rainfed farms). Farmers' fields, Nueva Ecija, Philippines, 1977 wet season.

The results suggest that in the wet season, farmers can use up to 40-day-old seedlings provided that management practices are optimum and water level will not drown the seedlings.

Fertilizer timing, Laguna sites (*Statistics*). To evaluate experimentally whether farmers can increase rice yields by applying fertilizer at the optimum time, we conducted experiments on

Table 7. Combined average grain yields[a] of IR26 and IR36 as influenced[b] by seedling age at transplanting. Supplementary studies, Nueva Ecija, Philippines, 1977 wet season.

Seedling age (DS[b]) at transplanting	Yield (t/ha) Irrigated farm	Rainfed farm 1	Rainfed farm 2	Av.
20	5.4 ab	4.5 a	4.1 abc	4.7
25	5.7 a	4.8 a	2.9 e	4.5
30	5.5 a	4.9 a	2.7 e	4.4
35	5.3 ab	4.7 a	4.5 ab	4.8
40	5.7 a	4.7 a	4.7 a	5.0
45	5.3 ab	3.7 b	3.8 bc	4.3
50	4.9 bc	2.6 c	3.6 cd	3.7
55	4.6 cd	2.3 c	3.0 de	3.3
60	4.2 d	1.8 d	1.9 f	2.6

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]Days after seeding.

Table 8. Farmers' time of nitrogen application on seven farms, Laguna, 1977 wet season.

Time of application (DT)[a]	Nitrogen applied (kg/ha)						
	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7
0	—	—	—	—	64	—	7
1–10	—	—	41	—	—	37	—
11–20	22	29	—	36	—	—	—
21–30	22	—	41	36	—	—	20
31–40	—	29	—	—	—	37	—
41–50	—	20	—	—	—	—	20
51–60	—	20	41	36	38	—	—
61–70	22	—	—	—	—	—	—
Total	66	98	123	108	102	74	47

[a]As indicated by farmers before the start of the experiments. DT = days after transplanting.

seven farms in Laguna in the 1977 wet season. We compared rice yields at the farmers' time of fertilizer application (Table 8) with those using the recommended practice of three equal splits applied as basal incorporated, at 30 days after transplanting, and at 5–7 days before panicle initiation. Comparisons were made under the farmers' and high level of insect and weed control. Under the farmers' condition, both rate and timing of fertilizer application varied from farm to farm, while under the high level, the nitrogen rate was fixed at 90 kg N/ha.

Table 9. Effects of proper timing of fertilizer application under two input levels[a] tested in farmers' fields. Laguna, 1977 wet season.

Farm no.	Variety planted	Grain yield[b] (t/ha)			
		Farmers' inputs		High inputs	
		Farmers'[c] timing	Recommended[d] timing	Farmers'[c] timing	Recommended[d] timing
1	IR36	3.1	3.2	6.6	6.3
2	IR36	4.6	5.0	5.2	5.0
3	IR36	5.0	4.8	4.9	5.0
4	CA-137/ IR36	4.3	3.8	5.8	5.4
5	IR42	5.2	5.1	6.6	6.9
6	IR36	5.4	5.2	6.3	5.4
7	IR38	3.2	3.4	5.2	5.3
		Av. 4.4	4.4	5.8	5.6

[a]Involving insect control and weed control; nitrogen rates at farmers' input levels varied from farm to farm; rate at high inputs is 90 kg N/ha. [b]Data are av. of 2 replications. [c]See Table 8. [d]Three equal splits applied as basal, at 30 days after transplanting, and 5–7 days before panicle initiation.

While most farmers applied fertilizer in splits, only two used basal application (Table 8). Differences in yield between the recommended and the farmers' timing of fertilizer application were neither appreciable nor consistent (Table 9) under both levels of inputs. On farm 6 lodging in the high-input plots at the recommended timing was more severe, resulting in a yield difference of almost 1 t/ha in favor of farmers' timing; but in no other case was the yield difference higher than 0.5 t/ha, nor was the direction of the difference consistent.

The present results give no experimental evidence to indicate that the farmers' timing of fertilizer application is a constraint to high rice yield in the wet season crop in Laguna. The present findings do not confirm our previous report, based on survey data, that without increasing the cost of applied fertilizer, farmers can increase rice yields by applying fertilizer at the optimum time (1976 Annual Report). Further investigation including the dry season and a wider range of farmers' nitrogen rates is, however, needed.

Variability in yield among experimental sites at four locations (*Agronomy*). Until now, little attention has been given to measuring the magnitude of the variance in yield among experimental sites at a given location and identifying the source of that variance. In the 1977 wet season, experiments were conducted at several sites within each of four experiment stations at two levels of inputs, high (Table 1) and "average" farmers' level. The mean yield, standard deviation, and range were compared for experiment station and farmers' field experiments. At the farmers' level of inputs, however, input levels varied from farm to farm.

The results show that the range in yield covered 2 to 3 t/ha in most locations, both at the experiment station and in the farmers' fields (Table 10). The range is significantly less only at the Bicol Rice and Corn Experiment Station farmers' level, where the experimental sites tended to be clustered rather than scattered throughout the experiment station.

Because production practices are carried out

Table 10. Mean, standard deviation, and range of yields among experimental sites in the experiment station compared with those in farmers' fields at high and farmers' level of inputs. Four provinces, Philippines, 1977 wet season.

Location	Sites (no.)	Grain yield (t/ha)		
		Mean	s.d.	Range
		High inputs		
IRRI experiment station	10	6.0	1.2	4.1 — 7.7
Laguna farmers' fields	19	5.7	0.9	4.2 — 7.5
Maligaya Rice Research & Training Center	7	5.6	0.6	4.3 — 6.2
Nueva Ecija farmers' fields	28	5.2	0.9	3.4 — 6.5
Bicol Rice & Corn Experiment Station	8	3.1	0.6	2.5 — 4.3
Camarines Sur farmers' fields	20	3.3	0.8	2.4 — 4.5
Visayas Rice Experiment Station	4	5.4	0.8	3.5 — 5.0
Iloilo farmers' fields	17	4.6	1.1	2.7 — 6.7
		Farmers' inputs[a]		
Maligaya Rice Research & Training Center	7	3.6	1.1	2.1 — 5.0
Nueva Ecija farmers' fields	28	4.1	1.1	2.4 — 6.0
Bicol Rice & Corn Experiment Station	8	2.9	0.4	2.2 — 3.2
Camarines Sur farmers' fields	20	3.3	0.7	2.2 — 4.2
Visayas Rice Experiment Station	4	4.2	0.6	3.5 — 5.0
Iloilo farmers' fields	17	3.6	0.8	2.3 — 4.8

[a]For experiment station, an "average" farmers' level at each location was used.

fairly uniformly and input levels are the same at the experiment station, variance in management is not likely to be a factor. However, despite the similarity in magnitude of variability among experimental sites and in farmers' fields, one cannot conclude that the sources of variance are the same. These sources will have to be identified separately. From a practical point of view, we would like to identify those sources of variance that have a degree of commonality among farms to find economically efficient practices that can raise the yield level of the lowest sites.

SOCIOECONOMIC CONSTRAINTS

Agricultural Economics Department

Profitability of high inputs. The high-yield input levels tested in the constraints experiments were analyzed to determine the extent to which they would have provided farmers with a profit higher than that from existing practices (Table 11). The anticipated maximum yields from the three inputs combined gave higher average profits in the dry season but lower profits in the wet season, except in Nueva Ecija. In Laguna, Camarines Sur, and Iloilo, the increased output value did not offset the increased input cost.

The separate effects of the three inputs provide a useful basis for judging the relative benefits attainable by increasing each input (Table 12). The high fertilizer level was highly profitable in the dry season in each location, raising profits by over US $100/ha on the average. In the wet season, it was much less profitable in Laguna, Nueva Ecija, and Iloilo, and resulted in lower profits in Camarines Sur.

The farmers' level of insect control cost much less — on the average, less than US$15/ha — while the high level of insect control cost over US$125/ha. The high level therefore gave less profit than the farmers' level in many cases. Only in Nueva Ecija did the high level increase profits in both the wet and the dry seasons. In the three other provinces, the farmers' level was more profitable in either one or both seasons. Except in Laguna, the high level of insect control gave a greater increased value of output in the dry season than in the wet season.

The high level of weed control cost, on the average, US $27/ha while the farmers' level cost about US$18/ha. In the dry season, high weed control raised profits in Nueva Ecija, Camarines

Table 11. Economic performance of the anticipated-maximum-yield level of a combination of three inputs[a] and of farmers' levels of those inputs in constraints experiments in farmers' fields, Philippines, 1977.

Province	Sites (no.)	Input cost (US$/ha)		Increase (US$/ha) from high inputs			Sites (%) where profits	
		Farmers' level	High level	Input cost	Output value	Profit	Increased	Decreased
				Dry season				
Laguna	7	94	292	198	307	109	57	43
Nueva Ecija	16	117	269	152	346	194	94	6
Camarines Sur	12	56	263	207	324	117	67	33
Iloilo	9	62	246	184	208	24	44	56
				Wet season				
Laguna	7	85	250	165	162	−3	43	57
Nueva Ecija	23	92	197	105	146	41	61	39
Camarines Sur	15	50	137	87	23	−64	13	87
Iloilo	16	54	214	160	144	−16	25	75

[a]As specified in the section on biological constraints.

Sur, and Iloilo. But in Laguna, the farmers' level gave higher profits than the researchers' treatment. In the wet season, profitable increases were achieved in Laguna and Iloilo, but not in the two other locations.

Intermediate levels of fertilizer and insect control, tested in three of the locations, gave results similar to those obtained with high levels (Table 13). In Nueva Ecija and Iloilo the intermediate 1 fertilizer level cost less than the farmers' current practice in both seasons. The intermediate 2 level increased profits substantially in the wet season, and nearly doubled them in the dry season. In Nueva Ecija, the farmers' level cost more than the intermediate 2 levels but again the intermediate level gave higher return than the farmers', indicating the substantial inefficiency of fertilizer use there.

The intermediate level of insect control was generally not effective in raising yields enough to offset costs. Only in the dry season sites in Camarines Sur was the intermediate level more profitable than farmers' practices.

Variability and risk in Nueva Ecija. Experiments similar to those described above have been conducted since the 1974 wet season in several locations in the Philippines. Yield results and their economic analyses have been reported in the 1974, 1975, and 1976 annual reports. They show considerable year-to-year

Table 12. Economic performance of anticipated-maximum-yield levels of three separate inputs and of farmers' current practices in yield-constraints experiments in farmers' fields, Philippines, 1977.

Province	Sites (no.)	Fertilizer			Insect control			Weed control		
		Cost (US$/ha)		Increase (US$/ha) over farmers' profit	Cost (US$/ha)		Increase (US$/ha) over farmers' profit	Cost (US$/ha)		Increase (US$/ha) over farmers' profit
		Farmers'	High		Farmers'	High		Farmers'	High	
				Dry season						
Laguna	8	42	78	114	11	165	−26	35	41	−44
Nueva Ecija	16	77	107	139	21	129	87	19	32	[illegible]
Camarines Sur	12	29	112	71	12	129	8	15	22	24
Iloilo	9	42	103	118	9	123	−40	11	20	29
				Wet season						
Laguna	7	43	45	32	11	166	−18	32	38	20
Nueva Ecija	23	51	80	48	30	91	35	12	26	[illegible]
Camarines Sur	15	31	85	−69	10	31	−99	[illegible]	21	−38
Iloilo	16	38	78	46	8	116	−20	8	19	−31

Table 13. Intermediate levels of fertilizer and insect control compared with farmers' current practices in yield-constraints experiments in farmers' fields, Philippines, 1977.

Province	Sites (no.)	Increase (decrease) (US$/ha) over farmers' level								
		Fertilizer level						Intermediate insect control		
		Intermediate 1			Intermediate 2					
		Output value	Input cost	Profit	Output value	Input cost	Profit	Output value	Input cost	Profit
					Dry season					
Nueva Ecija	7	−54	−50	−4	92	−16	108	−43	20	−63
Camarines Sur	6	56	3	53	166	38	128	51	21	30
Iloilo	4	−24	−12	−12	87	20	67	7	29	−22
					Wet season					
Nueva Ecija	9	−34	−32	−2	49	−9	58	−58	1	−59
Camarines Sur	8	53	12	41	47	36	11	11	22	−11
Iloilo	9	18	−16	34	35	6	29	20	71	−51

Table 14. Comparison of high level of inputs with farmers' input level in constraints experiments.[a] Nueva, Ecija, Philippines, 1974-77.

Year	Sites (no.)	Cost of inputs (US$/ha)		Yield (t/ha)		Net return[b] (US$/ha)		Sites (%) where maximum inputs	
		Farmers' level	High level	Farmers' level	High level	Farmers' level	High level	Increased returns	Increased returns by > US$25/ha
					Dry season				
1975	3	119	240	4.3	5.2	466	459	67	33
1976	9	99	230	4.0	6.5	543	605	67	66
1977	7	123	267	5.4	7.9	761	1027	86	57
All	19	111	245	4.6	6.8	611	737	74	58
					Wet season				
1974	10	42	226	1.9	2.3	216	87	0	0
1975	11	56	162	3.2	3.9	379	369	27	27
1976	9	67	178	2.8	4.4	350	475	88	88
1977	9	101	197	4.6	5.7	531	579	67	44
All	39	64	190	3.1	4.1	369	375	44	39

[a]Experiments conducted by IRRI Agronomy Department (complete factorial). [b]Value of output minus cost of inputs used for insect control, weed control, and fertilizer.

and site-to-site variability. It is hypothesized that the variable performance of the technology may deter farmers from using technologies that appear profitable in a single year. The data reported below examine the variability in economic performance of input levels higher than farmers' in Nueva Ecija, the area for which the largest data base exists.

Table 14 shows the performance of the high level of inputs for anticipated maximum yield and farmers' level for seven seasons. Farmers used roughly one-third of the high level of inputs in the wet season. Both farmers and researchers use lower input levels in the wet season than in the dry. In addition, farmers' inputs tended to reflect changes in the farms where experiments were placed. Differences in the anticipated-maximum-yield input cost across years reflect changes in researchers' ideas of the levels of inputs needed to give maximum yields. Input prices were relatively constant over the seasons shown, so prices do not account for much of the cost variability.

The last two columns of the table indicate that the high level of inputs gives more variable returns and hence is more risky in the wet sea-

Table 15. Economic risk of anticipated-maximum-yield level of inputs compared with farmers' current practices as evaluated in constraints experiments[a] in farmers' fields, Nueva Ecija, Philippines.

Year	Fertilizer			Insect control			Weed control		
	Sites (%) with profit change		B:C ratio with increased fertilizer	Sites (%) with profit change		B:C ratio with increased inputs	Sites (%) with profit change		B:C ratio with increased inputs
	Increase > US$10/ha	Decrease		Increase > US$10/ha	Decrease		Increase > US$10/ha	Decrease	
				Dry season					
1975	67	33	1.0	0	100	0.3	67	33	12.1
1976	89	0	4.6	67	34	1.5	67	33	5.7
1977	86	14	4.5	71	14	1.7	43	57	1.6
All years	84	10	4.3	58	37	1.4	58	42	4.8
				Wet season					
1974	0	90	neg	20	80	0.5	60	40	1.9
1975	55	27	2.0	18	82	0.4	44	27	1.6
1976	56	22	2.1	89	11	2.4	22	67	0
1977	56	33	3.1	56	33	1.2	22	56	0
All years	41	43	1.3	44	54	1.1	44	46	0.9

[a]Experiments conducted by IRRI Agronomy Department. B = benefit, C = cost.

son than in the dry. The high inputs increased net returns at most sites in the favorable 1976 wet season, but considering all wet season experiments, the maximum input level gave lower profits than the farmers' level in 56% of the cases. In only 39% of the experiments were net returns increased by at least US$25/ha. In contrast, in three-quarters of the dry season experiments, the high input level gave higher yields than the farmers' level, and net returns were raised by more than US$25/ha in more than half the cases.

Examining the average costs and returns for the three separate inputs provides some insights into why the high input levels are more profitable in the dry than in the wet season.

In the dry season, high weed control increased yields greatly and gave an average benefit:cost (B:C) ratio of 4.8 (Table 15). Absolute increases in net returns averaged US$33/ha, exceeding farmers' levels by US$10 or more per ha in 58% of the cases. However, in 42% of the cases net returns were reduced. In the wet season, the anticipated-maximum-yield level of weed control had only a modest impact on yields giving a low average B:C ratio (Table 15). In 46% of the cases, net returns were lower with high weed control level than with farmers' level. It appears that there is relatively little economic incentive for farmers to use the high level of weed control in the wet season, and that results are uncertain in the dry season.

The anticipated-maximum-yield level of insect control was set too high in the first wet season of research (1974) to give a profitable return. It was subsequently reduced (Table 15). Results in the 1975 wet season were similar to those in the dry season, even though input levels were lower. In over 80% of the cases in both seasons, net returns were lower with high insect control inputs than with low, even though average yields increased. In 1976, the situation reversed: the B:C ratio was 2.4 and net returns increased by more than 10% in two-thirds of the cases. In 1977, the situation was intermediate. On the average the benefits barely exceeded the costs, and profits were decreased with slightly greater frequency than they were increased.

In the dry season, although yield increases from the high insect control levels averaged 0.8 t/ha, the costs of achieving increases were such that B:C ratios on the increased inputs were less than 1.8 each season. The average chance of increasing net returns by more than US$10/ha was about 60%, judging from the three seasons' results.

Because the yield contribution of improved insect control was large but often uneconomic, a lower-cost intermediate level of insect control was tested in 1976 and 1977 (Table 16). The intermediate level gave yields nearly the same as those of the farmers' level in two of the four

Table 16. Economic risk of intermediate levels of inputs compared with farmers' current practices as evaluated in constraints experiments[a] in farmers' fields. Nueva Ecija, Philippines.

Year	Sites (no.)	Fertilizer			Insect control		
		Sites (%) with profit change		B:C ratio of increased input	Sites (%) with profit change		B:C ratio of increased input
		Increase > US$10/ha	Decrease		Increase > US$10/ha	Decrease	
				Dry season			
1976	9	89	0	12.4	56	44	n.a.
1977	7	86	14	98.0	14	86	neg
Both	16	88	6	19.0	38	62	0
				Wet season			
1976	9	44	34	3.4	89	11	8.5
1977	9	67	33	n.a.[b]	22	44	neg
Both	18	55	33	n.a.	56	28	1.6

[a]Corresponds to intermediate 2 level in Table 3. B = benefit, C = cost, n.a. = not available. [b]Intermediate level costs less than farmers' inputs, so increased input cost is negative and hence, B:C ratio concept does not apply.

seasons. Consequently, little benefit from intermediate insect control could be consistently obtained in either season. One concludes, therefore, that in the wet season there is relatively little incentive for farmers to change from their present methods and levels of pest control to the levels tested in the experiments. There is slightly greater incentive to change to the high level in the dry season, although the probability of income losses is nearly 40%.

The seven typhoons that hit the experimental area during the 1974 wet season caused lodging in the plots with high fertilizer; as a result, plots with farmers' inputs had higher yields than the high-input plots that season. The high fertilizer level was somewhat reduced the next year, but was raised even higher than the original in 1976 and 1977. The high fertilizer level was marginally profitable in the 1975 and 1976 wet seasons (Table 15). Considering all seasons, the high level raised net returns by more than US$10/ha in 40% of the cases, but reduced net returns in about the same percentage of cases. Despite the unusually bad typhoons, the high fertilizer level increased profits in 50% of the cases in the wet season and decreased them in about 25%.

In each of the three dry seasons, on the other hand, average yields and net returns were substantially increased by the application of the maximum level of fertilizer. There was an 84% chance of net returns increasing by more than US$10/ha, an average B:C ratio of 4.3 and only a 10% chance of experiencing losses.

Two intermediate fertilizer levels were tested in 1976 and 1977. The higher of these was only slightly higher than farmers' dry season levels and was somewhat lower than the farmers' level in one wet season. Despite the relatively small difference in fertilizer level, the experimental treatment proved clearly superior to farmers' treatments, increasing profits by an average of US$60/ha in the wet season and US$133/ha in the dry. The intermediate fertilizer level was just as risky as the high level in the wet season, and somewhat less risky in the dry season (Table 16). As expected, the B:C ratio of the intermediate level was higher than that of the high level.

Thus, the high levels of insect and weed control in the experiments either were not more profitable than the levels used by farmers on whose fields they were tested, or resulted in profit reductions in 40% or more of the tested cases. High fertilizer levels were risky in the wet season. Intermediate levels of insect control were somewhat less risky in the wet season, but still had highly variable performance with a low average profit increase.

The evidence suggests that farmers could spend up to 50% more on fertilizer in the dry season and have a relatively small chance of loss

Table 17. Constraints identified by farmers in constraints survey, Philippines, 1977.

Constraint	Times (%) identified					
	Dry season			Wet season		
	Laguna	Nueva Ecija	Camarines Sur	Laguna	Nueva Ecija	Camarines Sur
Lack of fertilizer	3	8	11	0	3	0
Drought	22	27	20	2	8	5
Flood	0	0	0	2	8	3
Typhoon	3	6	13	12	37	25
Insects	19	27	25	10	23	27
Diseases	3	1	0	4	0	1
Weeds	0	12	2	0	0	1
Rats and birds	17	7	22	4	1	1
Others	2	4	0	6	2	0
No problem	31	8	10	67	18	36

and a good chance of reasonable profit increase. This conclusion may, however, be subject to modification because of the apparent substantially lower fertilizer efficiency level achieved by farmers (Table 13), discussed in a subsequent section.

Perceived constraints. Farmers were interviewed to determine the factors that they perceived as yield limiting. The sample of 60 respondents for each province consisted of all farmers with constraints experiments plus farmers chosen at random from the same and nearby barrios. In the dry season, drought and insect damage were perceived as the most important constraints (Table 17). They were cited by about 25% of all farmers interviewed. Rats or birds were the next most frequently cited dry season constraint.

The analysis in the preceding section suggests that applying higher rates of fertilizer during the dry season has a significant potential for profitably increasing yields in the areas represented by the experiments in Nueva Ecija (Table 12). Farmers were asked specifically why they were not using higher fertilizer rates (Table 18). Many farmers stated they believed they had "used enough" in the wet season when, as shown by analysis, there is little opportunity for profit. Two reasons dominated the responses for the dry season: lack of capital and the belief that the level of fertilizer used was "high enough."

The expenditures for inputs reported by the farmers citing the last two reasons were compared (Table 19). Except in Laguna during the wet season, farmers who said they used enough spent slightly more on purchased inputs than those who lacked capital, but in most cases the difference was quite small. Total input costs were substantially lower than the cost of maximum input package and slightly lower than the cost of the intermediate packages. The relatively small difference in cost of inputs between the two groups weakens the two cited reasons. Our questions may not have elicited the true reasons that underlie farmers' actions, perhaps because farmers themselves cannot formalize those reasons. A normative model to help explain farmers' level of input use was formulated and fitted to experimental data from Nueva Ecija.

Profitability and input efficiency in Nueva Ecija. Previous constraints research has indicated that farmers apply fertilizer inefficiently (p. 287, 1976 Annual Report). One illustration

Table 18. Reasons given by farmers for not applying higher rates of fertilizer. One hundred eighty sample farmers in 1977 constraints survey, Philippines.

Reasons given	Farmers (%) giving reasons					
	Dry season			Wet season		
	Laguna	Nueva Ecija	Camarines Sur	Laguna	Nueva Ecija	Camarines Sur
Lack of capital	45	43	46	17	49	16
Used enough	43	45	44	61	39	51
Plants may lodge	7	0	2	17	4	3
Lack of water	3	2	0	0	3	11
No response	2	10	8	2	1	14
Others	0	0	0	3	4	5
Total	100	100	100	100	100	100

Table 19. Expenditures on fertilizer, weed control, and insect control of 180 farmers giving two responses to the question, "Why didn't you apply more fertilizer to your rice?" Three provinces, Philippines, 1977 wet season.

Response	Wet season expenditures on inputs (US$/ha)		
	Nueva Ecija	Laguna	Camarines Sur
Lack of capital	64	82	59
Used enough	70	76	79

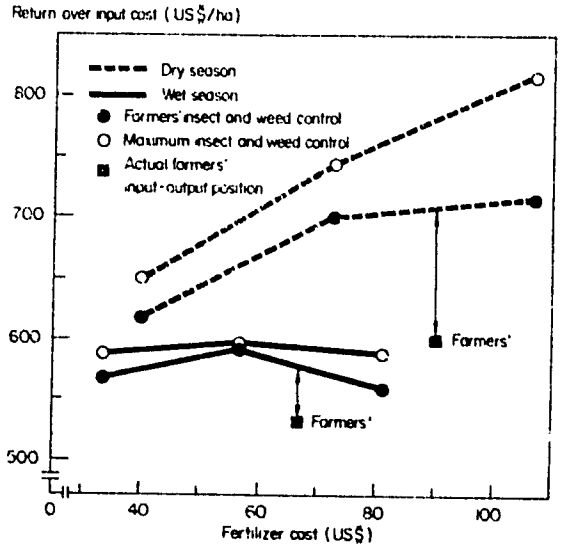
from the Nueva Ecija experiments (Fig. 6) shows the average return over costs of fertilizer, insect control, and weed control for four fertilizer test levels at farmers' and at maximum levels of insect and weed control. In both wet and dry seasons, the farmers' fertilizer level cost considerably more than the middle fertilizer level, but returns were substantially lower than those achieved with the experimental levels. This inefficiency was examined to determine whether it explains why farmers use less fertilizer than what the experiments indicate is optimal.

To determine the level of fertilizer and insect control inputs that would maximize net returns, a response function was estimated from the data from the 1976 and 1977 Nueva Ecija experiments. The general form of the function is:

$$Y = a + b_1 F + b_2 I + b_3 F^2 + b_4 I^2 + b_5 I \cdot F + b_6 DY + b_7 DF \cdot F + b_8 DI \cdot I + b_9 DF \cdot F^2 + b_{10} DI \cdot I^2$$

where F stands for kilograms of fertilizer nutrient (N + P + K), I stands for expenditures for insect and weed control, DY is a dummy variable equal to 0 for 1976 and to 1 for 1977, DF is a dummy variable equal to 0 for farmers' fertilizer practices and to 1 for the test fertilizer treatments, DI is a dummy variable equal to 0 for farmers' insect control practices and to 1 for the two experimental insect control treatments. Selected dummy variables were included in various equations. The treatment yields were averaged across farms for 1976 and 1977 and fit separately to the wet and dry season data (Table 20).

Equations W1 and D1 (Table 20), which include only the input terms, provide relatively



6. Return over cost of variable inputs for four levels of fertilizer inputs and two levels of weed and insect control inputs. Av. of nine experiments in farmers' fields. Nueva Ecija, Philippines, 1977.

poor explanations for the observed yield variability, but when the dummy variables reflecting year and farmers' input treatment are added, the explanatory power of the equations increases substantially. The signs of the insect control coefficients are reversed from that which is expected in equation D1. That is, when both linear and quadratic terms are included in the equation for the dry season, higher insect control is associated with lower yield. When the quadratic term is dropped, the sign of insect control changes from negative to positive (equation D2).

When the same equation was fitted to individual site data, there was a range of coefficients, with experiments at some sites showing that farmers have the same efficiency as the researchers. In four of seven dry season sites and in four out of nine wet season sites fertilizer was inefficiently used.

Profit-maximizing levels of fertilizer and insect control can be calculated for equation W4 by equating the marginal value products of the two inputs with their respective prices. One cannot perform the same analysis with any of the dry season equations, however, because the

Table 20. Estimated relationships of tested inputs to yield in constraints experiments,[a] Nueva Ecija, Philippines 1976 and 1977.

Equation no.	Constant	Estimated coefficients and standard errors[b] of F	F^2	I	I^2	FxI	DY	DF.F	DI.I	$DF.F^2$	$DI.I^2$	R^2	F
						Wet season equations							
W1	1583	31.71	−0.1072	1.030	0.0009	0.0005						0.32	5.35
		(20.30)	(0.0829)	(03.638)	(0.0035)	(0.0125)							
W2	2212	9.794	−0.0514	2.537	−0.0037	0.0018	1350			0.0222	0.0022	0.94	100.70
		(6.290)	(0.0281)	(1.042)	(0.0013)	(0.0036)	(62.13)			(0.0054)	(0.0007)		
						Dry season equations							
D1	3576	11.14	−0.0068	−0.3132	0.0013	0.0015						0.76	30.67
		(6.628)	(0.0270)	(1.338)	(0.0009)	(0.0040)							
D2	2154	21.29	−0.0613	1.516		0.0029	591.3	4.561	−0.3471			0.94	101.95
		(4.731)	(0.0160)	(0.4400)		(0.0020)	(71.99)	(0.6135)	(0.2297)				

[a]Experiments conducted by IRRI Agronomy Department. F = kilograms of fertilizer nutrient (N + P + K); I = expenditures for insect and weed control; DV = dummy variable for year (0 for 1976, 1 for 1977); DF = dummy variable for fertilizer (0 for farmers' fertilizer practices, 1 for the test fertilizer treatments; DI = dummy variable for insect control (0 for farmers' insect control practices, 1 for the two experimental insect control treatments. [b]Figures in parentheses are the estimated standard errors of the coefficients.

second order conditions for maximum profit are violated either because of the "reversed" signs of I and I^2 in equations that included both, or because of the absence of an I^2 term in equation D2. Comparison of the coefficient of I and $DI \cdot I$ in equation D3 indicates that for every US $1 spent on insect control by farmers US$1.52 was returned, but for US$1 spent by researchers, the net return was only US$1.17. Since the high level of insect control was three to four times higher than the farmers' level, the coefficient of $DI \cdot I$ indicates the presence of diminishing returns, even though it was not reflected in the coefficients of D1, D2, and D4.

To estimate a maximum profit level of fertilizer in the dry season, the average farmers' insect control level is assumed to be economically optimal. The profit-maximizing levels of fertilizer and insect control and the yield implied by those levels were calculated with the use of equation W2 for the wet season, and equation D2 for the dry season. The results are shown in Table 21.

Table 21. Profit-maximizing levels of fertilizer and insect control inputs at two efficiencies, and resulting yields estimated from quadratic response function fit to constraints experiments[a] data. Nueva Ecija, Philippines, 1976 and 1977.

Season	Rice price assumption	Efficiency level	Profit-maximizing input level: Fertilizer (kg/ha)	Insect control (US$/ha)	Yield (t/ha)
Wet	Current	Researchers'	117	80	5.4
Wet	Current	Farmers'	60	30	4.4
Dry	Current	Researchers'	179	25	5.7
Dry	Current	Farmers'	142	25	4.9

[a]Conducted by IRRI Agronomy Department.

The yields and input levels that were optimal at farmers' level of efficiency were much lower than those optimal at researchers' level. In the wet season, optimal fertilizer and insect control levels at farmers' efficiency were half the levels optimal at researchers' efficiency. In the dry season the effect was in the same direction. The yield reduction due to farmers' lack of technical efficiency was about 1 t/ha in both seasons.

Table 22 summarizes the socioeconomic constraints as analyzed earlier. The potential and actual farm yields, as calculated from the response function and as derived from the experiment directly (Table 2), are similar. The effect of any lack of credit the cooperating farmers may have suffered was calculated by substituting the actual level of inputs those farmers used into the response function and comparing the predicted yield with the yield predicted by the equation assuming actual prices, farmers' efficiency, and profit-maximizing behavior.

In the dry season, economizing behavior was the most important socioeconomic factor that accounted for 62% of the 1977 yield gap (1.3 t/ha of the 2.1 t/ha), while lack of technical efficiency contributed 38%. In the wet season, the importance of the two factors was reversed —

Table 22. Estimated yield gap and contribution of socioeconomic factors to the yield gap. Nueva Ecija, Philippines, 1977.

Season	Source	Grain yield (t/ha)			Av. contribution (t/ha)			
		Farmers' behavior[a]	High[b] input and efficiency	Yield gap	Economizing behavior	Technical[c] inefficiency	Credit[d] lack	Residual
Wet	Experiments	4.2	5.3	1.1	—	—	—	—
Wet	Function	4.4	5.8	1.4	0.3	1.1	0.1	-0.1
Dry	Experiments	5.2	7.3	2.1	—	—	—	—
Dry	Function	4.9	7.0	2.1	1.3	0.8	0.0	0.0

[a]For the experiments, the farmers' input plots; for the function, the profit maximum with farmers' efficiency. [b]Maximum yield, disregarding input costs, researchers' efficiency. [c]Averaged over high and low level of the other contributing factors. [d]Calculated by comparing the yield from input levels of farmers with experiments with the yield predicted by the equation, assuming actual prices and farmers' efficiency.

economizing behavior accounted for 21% of the gap, while lack of efficiency accounted for 78%. This group of farmers had adequate credit. The potential contribution of additional knowledge by farmers was substantial, averaging nearly 1 t/ha for both wet and dry seasons.

This analysis also indicates that because of the farmers' inefficient use of fertilizer, the apparent large, economically recoverable dry season gap due to fertilizer (Table 12) cannot easily be reduced. The precise reason for such inefficiency is not known, but the method, timing, and type of fertilizer seem important.

Lack of credit as a constraint to high input use. It is widely believed that small farmers who do not have access to institutional credit will apply lower levels of purchased inputs than if they had access to it. Two studies were designed to test that hypothesis.

The Philippine Government began an institutional credit program to provide small rice farmers noncollateral credit in the 1973 wet season. The program provides an opportunity to empirically study the impact of institutional credit.

Impact of institutional credit in three Philippine locations. Data from farmers in three areas where constraints experiments were conducted during the past 3 years were analyzed for three wet (1975, 1976, and 1977) and two dry seasons (1976 and 1977). The objective was to determine whether farmers with institutional credit used higher levels of fertilizer, weed control, or insect control inputs than farmers without such credit. The sample farms included those on which constraints experiments were located during the respective seasons and additional farms chosen at random from the same and adjacent barrios to give a total of about 60 farms per province in the wet season and 40 in the dry season. Table 23 shows the proportion of farmers in each province with the three types of loans each season.

Data on input expenditures and yields were obtained by interviewing the sample farmers each season. The amount spent on each input by farmers with Masagana 99 loans was compared with the amounts spent by farmers with other sources of credit and those without credit for the wet and dry seasons.

In the dry season, the farm sizes of the three groups did not significantly differ (Table 24). Non-Masagana 99 farmers in three compari-

Table 23. Proportion of farmers in constraints project survey with Masagana 99 credit, other loans, or no loans. Three Philippine research areas, 1975–77.

Type of loan	Farmers (%) with each type of loan[a]					
	Dry 1975	Wet 1975	Dry 1976	Wet 1976	Dry 1977	Wet 1977
Nueva Ecija						
Masagana 99	67	43	24	22	17	46
Others	12	40	6	52	47	31
None	21	17	69	26	37	23
Laguna						
Masagana 99	na	68	62	74	60	66
Others	na	15	5	10	22	17
None	na	17	33	16	18	17
Camarines Sur						
Masagana 99	na	38	21	45	44	46
Others	na	36	30	27	12	22
None	na	26	48	27	44	31

[a]Totals may not add up to 100 because of rounding.

Table 24. Expenditures on inputs and yields of sample farmers with Masagana 99 (M99) loans, other sources of credit, and no loans. Philippines, 1977 dry season.[a]

Variable	Nueva Ecija			Laguna			Camarines Sur		
	M99 loan	Other loans	No loan	M99 loan	Other loans	No loan	M99 loan	Other loans	No loan
Farmers (no.)	10	28	22	36	13	11	26	7	26
Farm size (ha)	1.6	1.3	1.5	2.3	2.3	2.4	1.8	1.3	1.6
Fertilizer (US$/ha)	110	78**	71**	54	38**	46	44	21	42
Insecticide (US$/ha)	32	18	18	15	8	8	10	12	14
Herbicide (US$/ha)	3	5	9	2	1	2	5	2	4
Weed control labor (US$/ha)	9	11	9	25	44	17	6	7	13
Yield (t/ha)	4.2	3.8	3.7	4.7	3.6**	4.4	4.0	3.5	3.8

[a]* and ** indicate significantly different from the corresponding M99 data at the 5% and at the 10% level, respectively, using a t-test. All variables except farm numbers were tested.

sons spent significantly less on fertilizer; Camarines Sur farmers without loans spent almost as much, however, as the Masagana farmers. Masagana farmers in Nueva Ecija and Laguna spent more on insecticides than non-Masagana 99 farmers, but the difference was not significant.

Weed control expenditures were not related to source of capital. Laguna farmers spent substantially more on weed control than did the others, but the source of their capital had no significant effect on the level of expenditures. That may have resulted from the use of the *gama* system, in which weeders also contract to harvest — a service for which they receive a share of the crop as payment.

In all three provinces, Masagana 99 farmers had the highest yields, which ranged from 0.2 t/ha to 1.1 t/ha more than those of non-Masagana 99 farmers. But in Laguna they had significantly higher yields than farmers with other loans.

In the wet season, there was no consistent or significant difference in farm size among farmers with Masagana 99 loans, other loans, and no loans (Table 25). Masagana 99 farmers used more fertilizer than farmers in the two other groups, but the difference was significant in only two of the six comparisons. Insect control expenditure was one-third to one-fourth that of fertilizer. The Masagana 99 farmers spent slightly more for insect control than the others; the differences were significant in half of the comparisons. Weed control inputs were substantially higher in Laguna than in the two other areas, and substantially higher in Camarines Sur than in Nueva Ecija. However, in none of the areas did Masagana 99 farmers have the highest yields. In Camarines Sur the group without loans had the highest yield, and the group with other loans had the lowest.

A model of farmer decision making with credit. A model was developed to generalize about the effect of lower interest rates and liber-

Table 25. Expenditures on inputs and yields of sample farmers with Masagana 99 (M99) loans, other sources of credit, and no loans. Philippines, 1977 wet season.[a]

Variable	Nueva Ecija			Laguna			Camarines Sur		
	M99 loan	Other loan	No loan	M99 loan	Other loan	No loan	M99 loan	Other loan	No loan
Farmers (no.)	32	22	16	40	10	10	31	15	21
Farm size (ha)	2.9	3.1	2.6	2.3	1.8	2.4	2.4	2.2	1.9
Fertilizer (US$/ha)	48	40	35*	48	4[illegible]	42	50	14**	46
Insecticide (US$/ha)	22	14*	14*	14	9	6*	12	8	13
Herbicide (US$/ha)	4	1	2	2	2	3	5	2	14
Weed control labor (US$/ha)	2	3	6	27	19	21	12	9	14
Yield (t/ha)	3.3	2.8	2.6	4.6	3.7	3.4	3.6	2.1*	

[a]Data subject to revision when sample completes crop production. * and ** indicate significantly different from the corre. M99 data at the 5% and at the 1% level, respectively, using a t-test. All variables except farm numbers were tested.

Table 26. Response function, estimated from experiments conducted in farmers' fields in Nueva Ecija, Philippines, in 1972, 1973, and 1974, used in the farmer decision-making model.

Variable	Definition	Coefficient
Intercept		1079.83**
N × SR	Nitrogen (kg/ha) times solar radiation 45 days before harvest (kcal/cm²)	0.91**
N^2	Nitrogen (kg/ha) squared	-0.06**
SD	Stress days — days in excess of 3 for which paddy is without standing water	110.68**
P	Phosphorus (kg/ha)	3.81**
WC1	Weed control using one application of herbicide	160.11**
WC2	Weed control using one hand weeding plus herbicide	297.94**
ID	Insect damage measured as % of plants infested	-7.87**
IC	Expenditure on insecticide (₱/ha)	1.47*
%C	% clay content of soil	28.40**
N × SD	Nitrogen times stress days	-0.39**
SR × SD	Solar radiation times stress days	-8.95**
R^2		0.72

al credit limits, such as those introduced by the Masagana 99 program. The model simulates farm production and farmer response to credit policies in a risky environment like that existing in Nueva Ecija. It uses an estimate of the rice production function, which incorporates weather and insect risks with management inputs (Table 26). The model stimulates farmer choice among production technologies as affected by savings-consumption behavior and alternative lending conditions.

Frequency distributions of solar radiation, insect infestation, and typhoon damage were derived from available sources. Solar radiation data were obtained from 1966–75 records at the Maligaya Rice Research and Training Center. Insect infestation distributions were based on 650 observations in constraints experiments in Nueva Ecija in 1974 and 1975. Typhoon damage data were based on subjective responses of farmers interviewed in constraints surveys. A water-balance model was used to generate frequency distributions of stress days for sites with good, average, and poor irrigation and for various soils. Frequency distributions of yield were computed by randomly selecting, from each distribution, levels of environmental factors for each water regime for levels of nitrogen inputs ranging from zero to 196 kg/ha. One thousand samples were used to generate each yield distribution. In this response function, the complementary management inputs of insecticide, phosphorus, and weed control do not interact with environmental variables except for typhoon damage in the wet season, which enters the computation exogenously to the equation. The yield distributions were adjusted to reflect this interaction in the wet season.

Maximum yield, the level of nitrogen required for maximum yield, and its standard deviation are shown in Table 27 for seven season-water regime combinations, as determined by the model. Nitrogen levels for maximum yield ranged from 101 kg/ha for rainfed situations to 151 kg/ha for the dry season conditions with high quality irrigation. Yields ranged from 2.4 t/ha to 3.6 t/ha. Yield variability was greatest for wet season conditions — reflecting typhoons — and lowest for high-quality irrigation in the dry season.

The farmer decision model distinguishes between farms operating with share tenancy and those with fixed land payments, accommodates farms of various sizes, permits choice among the management variables in the production function according to various decision rules, and evaluates a range of interest rates and loan limits.

Given alternative technologies each with a distribution of yields, costs, and returns, the model evaluates the outcome of choices under both risk-neutral and risk-averse decision rules. Only results of the risk-neutral decision rules are presented here.

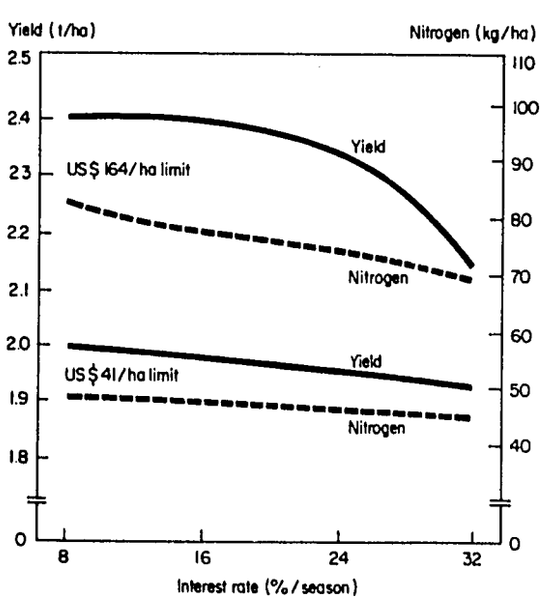
Table 27. Maximum expected yield, standard deviation of maximum yield, and nitrogen required to obtain maximum yield derived from simulation of production from response function with random weather and insect attacks for seven water regimes.

Season	Irrigation quality	Nitrogen at yield maximum (kg/ha)	Maximum expected yield (kg/ha)	Standard deviation of yield (kg/ha)
Dry	High	151	3572	524
Dry	Medium	137	2977	684
Dry	Low	111	2417	675
Wet	High	123	2908	813
Wet	Medium	119	2824	777
Wet	Low	117	2764	769
Wet	Rainfed	101	2414	723

Table 28. Average simulated farmers' borrowings, input use, and production results from farmer decision-making model with two interest rates and three loan limits.

Financial market						
Interest rate (%/season)	Loan limit (US$/ha)	Nitrogen (kg/ha)	Complementary inputs (US$/ha)	Loan (US$/ha)	Yield (kg/ha)	Income (US$/ha)
8	164	80	28	66	2402	116
8	82	78	24	61	2350	115
8	41	49	10	40	1971	101
24	164	75	28	65	2374	104
24	82	73	24	61	2320	103
24	41	47	9	40	1951	94

The maximum level of productive inputs used is implicitly set by the choice of technologies available. That level may be reduced by capital constraint: total spending on fixed and variable costs in season $t + 1$ cannot exceed total savings from production in season t plus new borrowings in season $t + 1$. The maximum amount and cost of credit to any farm are set within the model to reflect credit policy. Total savings in season t are the difference between net returns and consumption, which is a positive linear function of income.



7. Simulated impact of various interest rates and two loan limits on fertilizer use and rice yield under risk-neutral decision-making.

The financial market has an institutional and informal sector. All farms begin in season one with access to the institutional market at a specified interest rate and with credit available up to maximum loan limit per hectare. The farm borrows from the institutional market. When crop failure at some period prevents a farm from both meeting subsistence requirements and repaying the loan, the farm defaults on the loan, and uses the funds to supplement consumption and increase savings. In subsequent seasons, it obtains production loans from the informal market, which differs from the institutional market in interest rates and loan limits.

It was determined that it would be impossible to simulate enough sets of outcomes to generate stable distribution of inputs and yields for all possible combinations of farm types, environments, and policies at reasonable cost. Therefore, a Markov chain process was used to represent the decision process over several seasons. The key variable in the Markov chain process is the season-to-season level of savings determined internally as a function of input choice, yields, incomes, and income allocation behavior. A choice of technology is determined when a savings level is specified, the decision rule is chosen, and all necessary parameters are set. The technology choice in turn determines a yield distribution, which determines distribution of net returns, income, and savings for the subsequent period. The distribution of savings is then the basis for computation of the probabilities of moving to any savings state in the next period.

The average results of the model with financial parameters set to reflect typical institutional interest rates of 8%/season were compared with the results for informal financial markets of 24%/season for three loan limits (Table 28).

The high interest rate reduced expenditure for nitrogen between US$2 and US$7/ha, and expenditure on complementary inputs by up to US$7/ha. The lending limit had a more restricting impact, as expected. At the low credit limit fertilizer and complementary inputs used were roughly half those at the high loan limit. Figure 7 shows the effect of interest rates on nitrogen use and yield predicted by the model. The impact of the highest interest rate is greater with

the US$164/ha limit because at the high interest rate complementary inputs are sharply reduced, while at low interest rates they are not used at the lower loan limit.

The results of the model illustrate the potential benefits of an institutional credit program. Releasing the credit constraint by lowering interest rates from 32% to 8%/season and raising loan limits from US$41 to US$164/ha increased yields by about 0.5 t/ha, or 25%, under the environmental and technological conditions simulated. This yield difference used an additional 34 kg/ha of nitrogen and additional complementary inputs costing US$20/ha to generate an additional net income of US $26/ha.

Raising the loan limit, even at a high interest rate of 24%/season, would have increased yields by 0.5 t/ha with 28 kg/ha additional fertilizer and US$19/ha additional complementary inputs. Additional net income would have been only US$10/ha, however. Thus, the incentive to apply high level of inputs is less with high interest rate than with the rate that would prevail under institutional credit.

EVALUATION OF EXPERIMENTAL TECHNIQUES

Statistics Department

In yield constraints studies where field experiments are conducted in farmers' fields, it is necessary to keep the size of the experiments small to simplify operations and to increase the number of samples and the area covered. Since yield-constraints experiments in farmers' fields are set up primarily to estimate the yield gap and the relative contribution to the yield gap of individual production inputs, this section elaborates on how to get these estimates with the minimum size of experiment.

Two yield levels — potential farm yield and actual farm yield — are needed to estimate the yield gap. Since actual farm yield can be obtained through crop-cutting of farmers' fields, all that needs to be done is to grow a high-input level plot that will estimate potential farm yield on each farm. Such a trial, which we call supplemental trial, is simple to conduct and, therefore, can be done with a much larger number of farms than would be possible with the factorial trials.

Table 29. Comparison between grain yields of leveed and nonleveed plots receiving high levels of fertilizer, insect control, and weed control. Laguna, Philippines, 1977.

Location of plots[a]	Farms (no.)	Grain yield[b] (t/ha)		
		Leveed plot	Nonleveed plot	Difference
		Dry season		
A	6	5.49	5.48	0.01[ns]
B	6	6.85	6.28	0.57**
		Wet season		
A	5	6.37	5.98	0.39*
B	7	5.32	5.16	0.16[ns]

[a]"A" refers to plots at the end of the field opposite the flow of irrigation water and "B" to plots in the middle of the field. All plots are 10 x 10 m. [b]Harvested from 10-m² areas in the center of the plot.

For assessing the relative contribution of individual test inputs, either a complete or an incomplete factorial experiment can be conducted. A complete factorial experiment usually requires a large number of treatments and, hence, a large experiment. Its use is necessary, however, when interaction effects among test factors are to be assessed. For cases where interaction effects will not be appreciable, the minifactorial treatment combination is suggested (1976 Annual Report). Its main feature is the ability to maintain a small number of treatments even with a large number of test factors.

In 1977, the minifactorial trial and the supplemental trial were used in all test sites. A few questions concerning their implication were examined.

Supplemental trial. A major question raised in the conduct of a supplemental trial concerns the type and placement in a farm of the single plot receiving the high level of all test inputs. Should the plot receiving the plot be leveed or nonleveed? What size should it be? And where in the test paddy should such a plot be located?

Our investigations show the following results:

1. Leveed plots tend to give a slightly higher yield than nonleveed plots (Table 29), perhaps because of the researcher's inability to maintain the same water level out-

Table 30. Grain yields of plants along the perimeters of nonleveed plots receiving high levels of three inputs. Laguna, Philippines, 1977.

Harvest position[a]	Grain yield[b] (t/ha)			
	Dry season		Wet season	
	Outside plot	Inside plot	Outside plot	Inside plot
1	5.13 a	5.82 a	5.16 a	5.43 b
2	4.81 b	5.88 a	4.88 b	5.58 ab
3	4.77 b	5.84 a	4.75 b	5.64 a
4	4.91 b	5.88 a	4.82 b	5.56 ab
5	4.73 b	5.90 a	5.94 b	5.59 ab
6	4.82 b	5.93 a	4.87 b	5.53 ab

[a]Each harvest position consists of 2 rows 3.5 m long; position 1 refers to the area nearest the perimeter of the plot. [b]Av. of 12 farms each with 2–3 subcuts. In a column, means followed by a common letter are not significantly different at the 5% level.

side and inside the leveed plot. There is usually more water inside the leveed plot.

The difference between leveed and non-leveed plots was affected by their location. In the dry season, throughout which irrigation water was used, no difference was observed between leveed and nonleveed plots at the end of the field opposite the flow of irrigation water, but there was a large difference between plots placed in the middle of the field. Such differential effects were in the opposite direction and much less in magnitude in the wet season, when crops depended more on rainfall.

2. While yields of plants along the perimeter of a nonleveed plot differed slightly, the difference was confined primarily to the two rows, about 0.5 m wide of the perimeter (Table 30). Comparison between yields obtained from crop-cuts made at the corners (0.5 m away from the edge of the plot) and at the center of the nonleveed plot showed no appreciable difference (Table 31). It seems that while some "diffusion of chemicals" does occur in nonleveed plots, the affected areas are rather restricted. Hence, a relatively large nonleveed plot (80-100 m²) can be safely used in supplemental trials. Large plots not only require no costly levee-building process, but also ensure that the water level in them is the same as that in the farmers' plot.

Table 31. Grain yield under high levels of three inputs[a] determined from different positions in plots 10 × 10 m, Laguna, Philippines, 1977.

Crop season	Farms (no.)	Grain yield (t/ha)	
		Center cut[b]	Perimeter cut[c]
Dry	12	5.9	5.8
Wet	12	5.6	5.4
Dry and wet	24	5.8	5.6

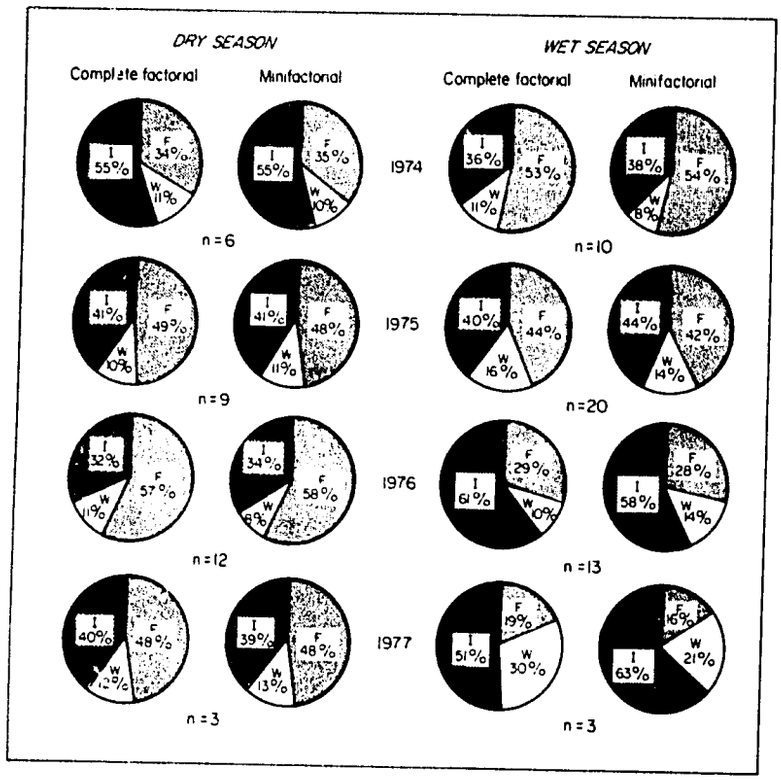
[a]Fertilizer, insect control, and weed control. [b]From a 10-m² cut. [c]From 4 corner cuts, each 5 m² and 0.5 m away from the edge of the plot.

Minifactorial trial. For a minifactorial trial, the number of treatments is two more than the test factors. These treatments consist of one treatment with all test factors at the high level, another at the farmers' level, and one treatment each corresponding to all but one test factor at the high level.

Contributions in percentages of individual test factors to the yield gap obtained from the minifactorial trial were compared with those from the complete factorial trial using 4-year data from Laguna farms. No marked difference between the two methods was observed (Fig. 8). Results suggest the usefulness of minifactorial trials in yield-constraints studies.

Variation among paddies on a farm. During the 1977 wet season, the farmer's rate of nitrogen fertilization was measured in from 2 to 3 paddies and for the whole farm in each of 10 farms. To measure the rate for the whole farm, data on the amount and type of fertilizer used were obtained from farmer interviews and those on farm size, by actual measurement. For the paddy estimate, the farmer was requested to report on the amount used in that particular paddy each time he made the application. To improve the accuracy of the farmer's estimate, the method of the "marked container" was used — the farmer's container was marked and numbered along its height at 2-cm intervals. The amount of fertilizer the farmer used was determined based on the level at which he filled his container each time he applied fertilizer.

We also monitored the farmers' weed control practices in 2 to 3 paddies for the whole growing season of the same 10 farms. For each selected paddy, records were kept on number of times



8. Comparison between relative contributions of test inputs to the yield gap, estimated from complete factorial and minifactorial trials, yield-constraints study. Laguna farms, Philippines, 1974–77. I = insect control, F = fertilizer, W = weed control.

that either mechanical weeding (hand weeding or rotary weeding) or herbicide was applied.

In addition, grain yields were determined by crop-cutting from each of the 2 to 3 paddies on the same 10 farms. From each paddy, 3 crop-cuts of 10 m^2 each were harvested.

The weed control practices showed close agreement across paddies on the same farm (Table 32). If herbicide was used, it was likely to be used in all paddies. On a few farms, the number of hand weedings or rotary weedings among paddies slightly differed. Weeding was less frequent in paddies with less weeds.

Nitrogen rate differences among paddies were also relatively small. But rates determined on the whole-farm and on the paddy bases showed relatively larger differences. The differences seem to indicate differences in the techniques used in determining fertilizer usage rather than variations among paddies.

In no case did either fertilizer use or weed control practice vary appreciably between the comparable paddy (1976 Annual Report) and the other paddies. There was no evidence that, because of the presence of the researchers, the farmer applied different input levels in the comparable paddy relative to the rest of the farm. This result confirms the representativeness of the comparable paddy for use in identifying input use of the farm where a yield constraints trial is located.

Grain yields were quite similar among paddies on the same farm (Table 33). Except on one farm where a yield difference of 1 t/ha was observed, paddies in the rest of the farms had differences of 1/2 t/ha or less. A much larger difference was observed when comparison was made with the yields obtained from interviews based on the whole farm, although no distinct bias could be seen. This result emphasizes the

Table 32. Variation in farmers' nitrogen rate and weed control, among and within farms.[a] Laguna, Philippines, 1977 wet season.

Farm no.	N rates (kg/ha)				Weed control treatment (av. no.)					
	Whole farm	CP	Paddy 1	Paddy 2[b]	CP		Paddy 1		Paddy 2[b]	
					M	C	M	C	M	C
1	74	92	99	96	3	1	3	1	3	1
2	31	23	16	20	3	—	1	—	3	—
3	93	73	72	66	2	1	3	1	3	1
4	118	98	116	110	3	1	3	1	3	1
5	54	96	109	90	3	—	3	—	4	—
6	70	87	78		3	1	3	1		
7	55	64	61		2	—	3	—		
8	62	109	89		2	—	3	—		
9	81	97	94		3	—	3	—		
10	90	89	82		1	1	1	1		
Av.	73	83	82	—	2.5	0.5	2.6	0.5	—	—

[a]CP = comparable paddy, M = mechanical weeding either by hand or rotary weeder, C = chemical weedicide. [b]Data not collected on farms 6 thru 10.

Table 33. Yield variation among farms and among paddies within farms based on interview and crop-cutting. Laguna, 1977 wet season.

Farm no.	Variety planted	Grain yield (t/ha)				
		Interview (whole-farm basis)	Crop-cutting			
			CP[a]	Paddy 1	Paddy 2[b]	Av.
1	IR42	4.7	4.9	5.0	5.0	5.0
2	IR40	1.8	2.8	1.8	2.4	2.3
3	—[c]	5.4	4.4	4.7	4.2	4.4
4	IR36	3.9	5.0	5.3	5.3	5.2
5	IR42	6.8	6.4	6.5	5.9	6.3
6	IR36	4.8	4.6	4.2		4.4
7	IR38	2.6	3.5	3.3		3.4
8	IR36	4.4	4.5	4.6		4.6
9	IR42	5.5	5.2	5.4		5.3
10	IR42	4.1	5.6	5.4		5.5
	Av.	4.4	4.7	4.6	—	4.6

[a]Comparable paddy. [b]Data not collected on farms 6 thru 10. [c]Unidentified.

importance of using the proper technique for yield determination in farmers' fields.

The yield of the comparable paddy did not differ appreciably from yields of other paddies on the same farm. That confirms the findings based on input use regarding the representativeness of the comparable paddy.

Adjustment for rat damage. One hazard of conducting controlled experiments in farmers' fields is the damage caused by rats. Rat problems are generally well- controlled in trials conducted at experiment stations but not in trials in farmers' fields. Rat incidence is usually not uniform over plots receiving different input levels. Our data indicated a much higher degree of rat damage in plots receiving high input level on all test factors than in plots receiving the farmer input level (Table 34). Rat damage

Table 34. Degrees of rat damage, measured at harvest, as affected by the level of input use in trials conducted in farmers' fields. Laguna, Philippines, 1977 dry season.

Input level[a]			Rat damage (% of damaged tillers)				
Insect control	Fertilizer	Weed control	Farm 1	Farm 2	Farm 3	Farm 4	Av.
F	F	F	0.0	0.0	0.0	0.2	0.1
F	H	H	—[b]	7.0	0.0	0.9	2.6
H	F	H	0.0	0.0	0.0	0.2	0.1
H	H	F	11.9	34.6	14.0	14.4	18.7
H	H	H	10.8	5.9	9.9	5.2	5.7

[a]F = farmers' level, H = high level. [b]Data not available.

became most serious when only the high level of fertilizer and high level of insect control were used but without the benefit of better weed control.

In yield-constraints trials in farmers' fields, the levels of the test inputs vary simultaneously. The nonuniform rat incidences in the various treatment levels could, therefore, result in a negative bias in the assessment of the effects of applying input levels higher than the farmers'.

It is essential that rat incidence in yield-constraints trials be closely monitored and recorded and yields properly adjusted. The following procedure for yield adjustments has been used in our trials:

1. If rat damage affects less than 30% of the plants in the plot, only undamaged hills are harvested for yield determination. Otherwise, that plot is excluded.
2. If too many plots lack yield determination because of severe damage, the degree of rat damage for each plot is measured and all hills (damaged and undamaged) are harvested for yield determination. Degrees of rat damage are used as a covariate for data adjustment through the analysis of covariance.

Consequences of new technology

Agricultural Economics Department

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SUMMARY

Intensive investigation of the economic structure of a single village in Pila, Laguna province, Philippines, continued over the past year. Analysis of 11 household accounts — income, expenditure, and savings — was completed. A complete enumeration of a village was also undertaken to ascertain historical changes in population growth, production, and institutions.

The village studies brought to light important relationships and trends. The income of village dwellers came almost exclusively from rice. Savings have not been used to improve land infrastructure nor has surplus labor been used for capital investment other than in the construction of private homes. Growth in production due to expansion of the irrigation system and modern rice technology was accompanied by rapid population growth and a rapid increase in the proportion of landless workers. As a result, economic and social pressures have encouraged 1) growth in subleasing of tenanted plots, and 2) change in the harvest labor contract by which laborers agree to do the weeding in return for the right to harvest the plot and obtain one-sixth share of the crop. The implications of these changes for the long-term viability of the village economy are uncertain.

Sources of rice output growth in Asia were assessed and a model was developed to estimate output growth up to 1985. Over the past 10 years, there has been an increasing reliance on irrigation and fertilizer (together with modern varieties and other modern inputs) as the principal sources of output growth. Projections to 1985 suggest that continued reliance on irrigation and fertilizer is likely to be extremely costly unless steps can be taken to increase the productivity of these inputs.

ANATOMY OF RICE VILLAGE ECONOMY

The 1977 Annual Report provides basic information on the characteristics of an irrigated rice village in Laguna based on an intensive study of 11 households (4 large farmers, 3 small farmers, and 4 landless workers) for a 1-year period ending 31 May 1976. This year's report summarizes the household income and expenditures for the 11 households and outlines the overall structure of the village economy.

Household income and expenditures. The sources of funds (income) were 1) rice production, 2) duck and hog enterprise, 3) earnings from employment, and 4) other sources of income including nonfarm enterprises. Funds were used for 1) food consumption, 2) nonfood consumption, 3) capital investment, 4) savings (or deficits), and 5) other expenditures.

Earnings from employment were largely wages paid in cash or in kind for transplanting, weeding, or harvesting the rice crop. Since such employment was primarily for rice work within the village, as much as 70% of the income of an average household in the village was generated by rice production.

Other sources of income included remittance from family members living in the city as well as grants from parents or relatives living in the barrio. Nonfarm enterprises, which were limited, included tricycle operation for commercial transportation on one of the large farms.

Capital investment included the purchase of equipment for agricultural production, such as tractors or pumps, and the construction of homes. *Other expenditures* included interests on consumption loans, grants, and payment of fees and taxes.

The average value of rice production was US$2,213 per farm household. The value for the four large farmers (3.2 ha) was about twice as large as that for the three small farmers (1.3 ha) (Table 1). The output per hectare was lower for large than for small farmers, but the profit per hectare was larger.

Disposal of rice was principally for cash or for payments in kind (Fig. 1). On the large farms, 45% of the rice was sold for cash and 37% was used as payment in kind. Cash sales made up 24% of rice output on small farms, while the payment in kind was 59%. Landless workers acquired rice largely as payment in kind and sold 42% of their rice for cash. Thus, the village is highly monetized, with all elements of the population engaged in cash transactions.

For all households, 42% of farm income was from rice production, but this ranged from 59% on large farms to less than zero for landless work-

Table 1. Costs and returns of rice production in seven farm households, in a barrio in Laguna, Philippines, 1974–75.[a]

Item	Costs and returns of rice production (US$)					
	Per farm household			Per hectare		
	All farmers	Large farmers	Small farmers	All farmers	Large farmers	Small farmers
Payments to external inputs	1366	1571	1095	569	491	842
Wage	414	519	273	172	162	210
Rent	569	523	629	237	164	484
Interest and rental	75	105	34	31	33	26
Current inputs	309	422	159	129	132	122
Seed use of rice	49	69	22	20	22	17
Imputed income of family factors	798	1124	362	332	351	279
Family labor wage	276	385	132	115	120	101
Owned land rent	0	0	0	0	0	0
Farm profit	521	739	231	217	231	178
Total output	2213	2764	1479	922	864	1138

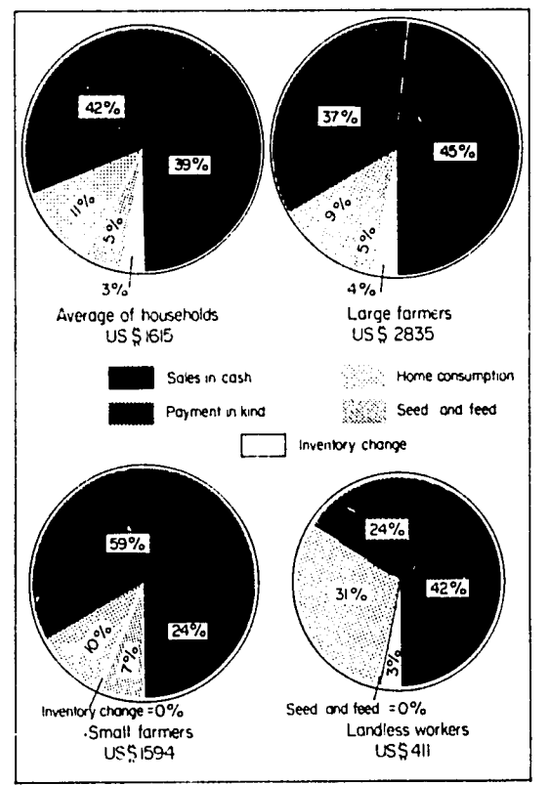
[a]Philippine P7 = US$1.

ers, who temporarily leased a small parcel of land (Fig. 2). Duck and hog enterprises provided over a quarter of the total income on small farms, while labor earnings provided 61% of the income for landless workers. Labor earnings represented principally the wages and payment in kind for employment in various tasks of rice production. All households raised incomes by 20 to 30% with earnings outside of farming.

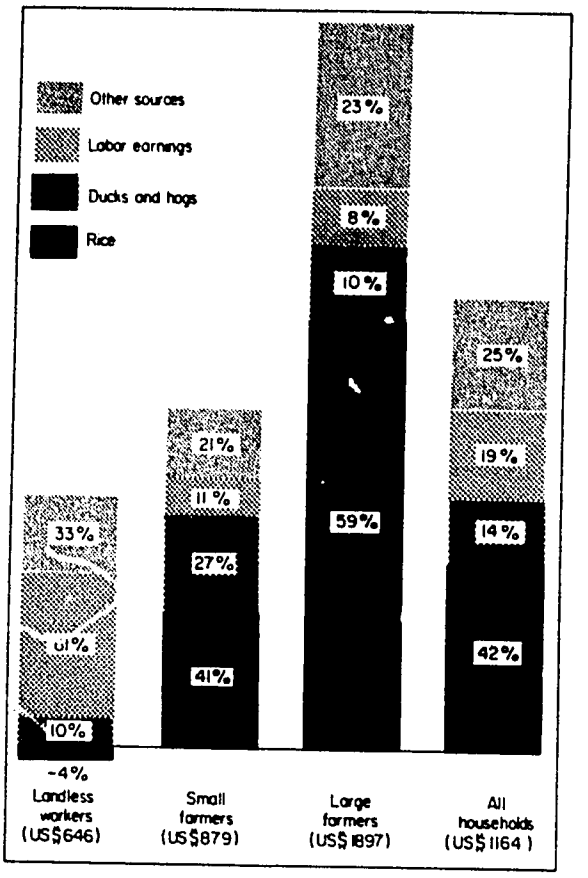
Close to 50% of household income was used for food consumption (Fig. 3). A substantial portion of the food consumption in the households of small farmers and landless workers came from home produce (including payments in kind). Household surplus was available for investment. While 25% of total income remained as household surplus on large farms, the figure was only 12% for small farms and 7% for households of landless workers.

Investments are made not only from household surplus but also through the contribution of family factors, especially by landless workers (Table 2), but there is a sharp contrast between farmers and landless workers. Both large and small farmers depended 100% on the household surplus for investment. The household surplus of the landless workers was relatively small, and a significant source of their capital formation was their own labor used principally in household construction. The total input represents less than 3 weeks of labor per landless family.

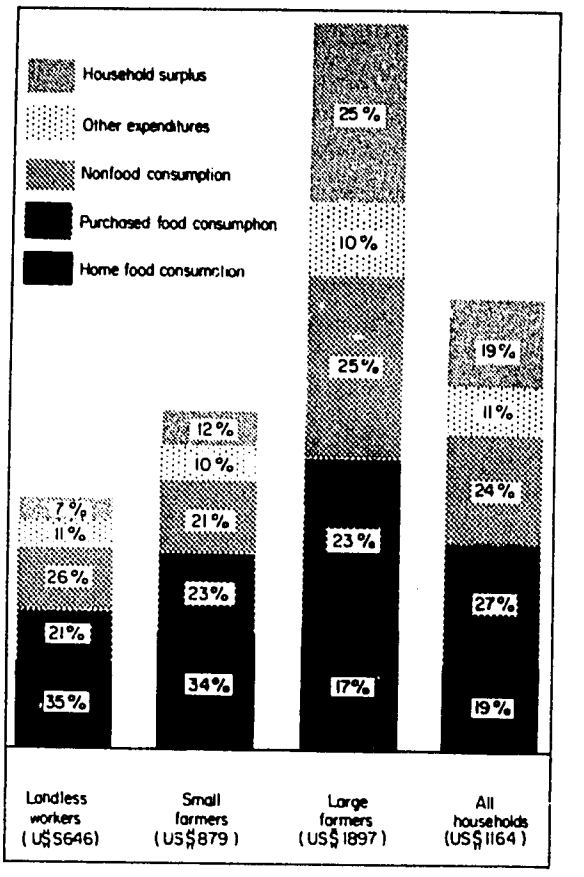
Agricultural capital formation accounted for a small portion of total capital formation and consisted of the purchase of machinery, implements, and working animals principally by the



1. Total disposition (%) of rice output in a barrio in Laguna, Philippines, 1974–75.



2. Structure of household income of 11 farm households in a barrio in Laguna, Philippines, 1974–75.



3. Household expenditures by 11 farm households in a barrio in Laguna, Philippines, 1974–75.

large farmers. There was essentially no investment in land improvement.

Social accounts of the village. The social accounts of the village were constructed by aggregating the accounts of the individual households after deducting the transactions among households within the village. The procedures follow:

1. The individual accounts (11 farms) adjusted for the within-village transactions and claims were averaged into the average accounts of large farmers, small farmers, and landless workers.
2. The average accounts for large farmers, small farmers, and landless workers were multiplied by the number of households in the respective categories in the village and aggregated into village totals.
3. Infrastructure subsidies for irrigation, schools, agricultural extension, and roads were added to the aggregates of income and investment in private accounts.

The village economic system can be viewed in terms of the production and distribution of income (Fig. 4). The returns to the various factors of production from farm activities, such as rice production and duck and pig raising, are generated in the proportions shown in the large pie.

"Operators' surplus" of farm and nonfarm production is measured as the residual of output after deducting both paid-out and computed family labor costs. This surplus is supposed to represent a return to capital including human capital owned by farmers. But it included a part of land rent, because the rents actually paid to landlords were substantially lower than the

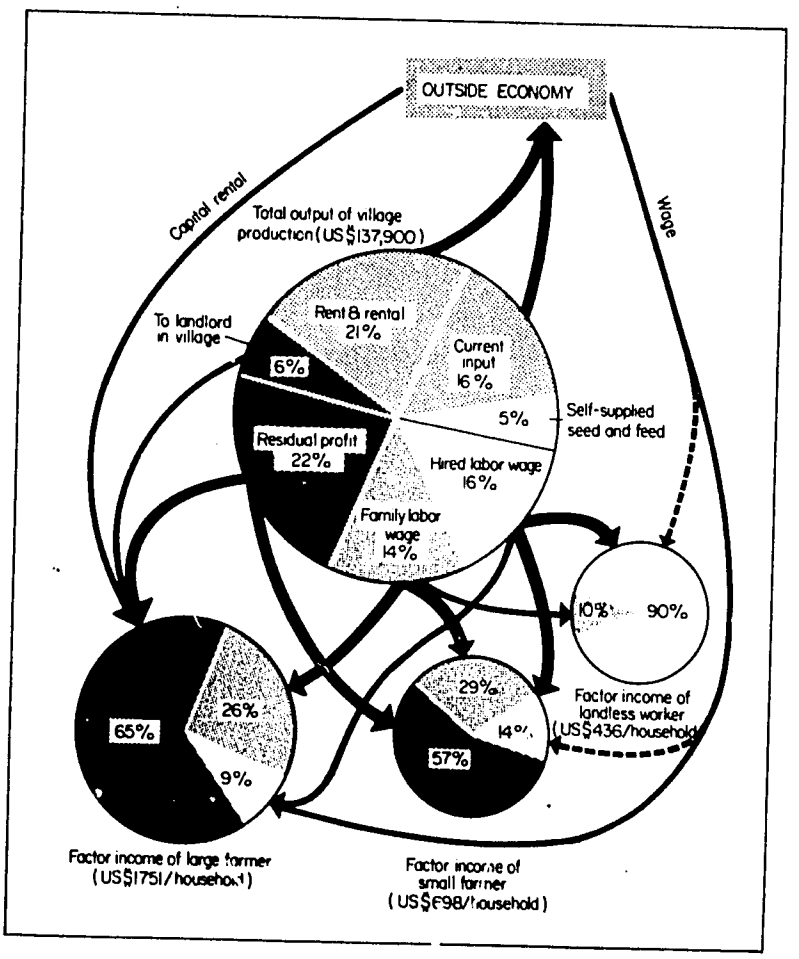
economic rent on the functional share of land under the land reform regulations. Sixty-five percent of the factor income of the large farmer is a return to his capital, while 100% of the income of the landless worker is a return to his labor.

Village income is divided between consumption and savings (Fig. 5). The three upper pies represent the average disposable incomes of the three classes of households in the village. The two lower pies represent the capital formation in the village as a whole. Half or more of disposable income in each class of households was spent for consumption purchases. Consumption of village produce, mainly rice, was only about one-third of total consumption.

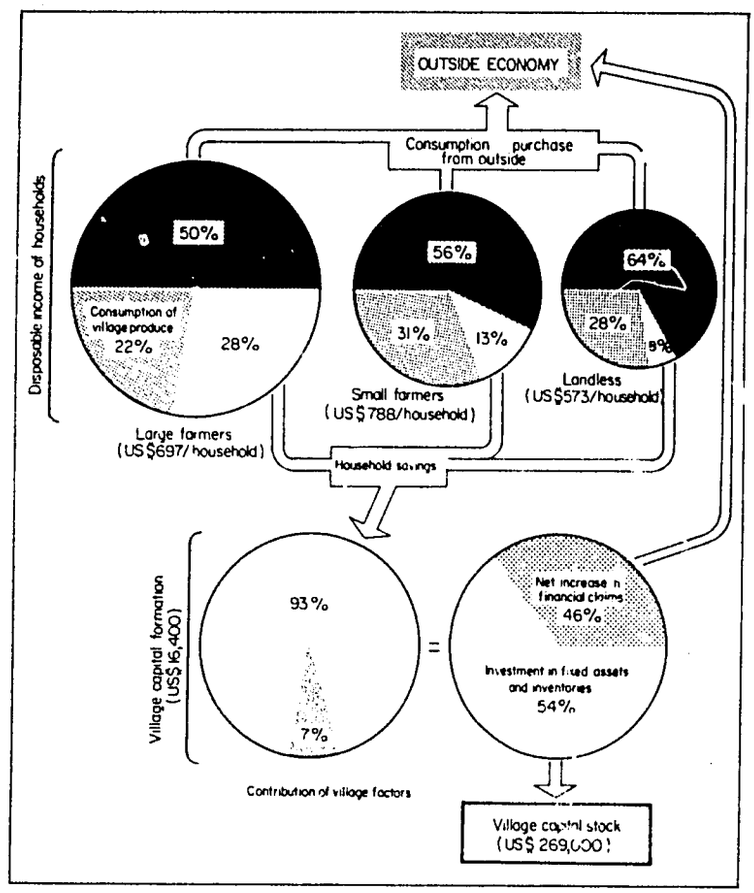
Household savings were the major source of financing for capital formation in the village.

Table 2. Sources and outlets of investments in all farm households, in a barrio in Laguna, Philippines, 1974–75.

Item	Investment (US$/household)			
	All households	Large farmers	Small farmers	Landless farmers
Sources				
Household surplus	217	474	105	45
Contribution of family factors	10	8	1	20
Gross investible fund	227	482	106	65
Outlets				
Agricultural fixed capital formation	43	44	6	71
Nonagricultural fixed capital formation	47	64	35	38
Inventory change	49	119	4	14
Acquisition of financial assets	88	255	61	-58
Gross investment	227	482	106	65



4. Generation and distribution of village income in a barrio in Laguna, Philippines, 1974–75.



5. Disposition of village income in a barrio in Laguna, Philippines, 1974–75.

The proportion of total investment that became a new addition to capital stock in the village was 54%; close to half of all savings flowed out of the village, primarily as repayments of past debts.

DYNAMICS OF AGRARIAN CHANGE

The study of the dynamics of agrarian change analyzes the interaction between demographic, technological, and institutional changes. The research reported here deals specifically with changes in land tenure arrangements and in labor contracts.

A survey was conducted from November 1976 to January 1977 in a village in the province of Laguna, Philippines. Similar surveys had been conducted in 1966 and again in 1974. These previous studies plus additional census material provide the benchmark information by which historical trends can be ascertained. The latest survey was a complete enumeration, based on interview with the heads of all households in the barrio. Data collected are primarily for 1976.

Demographic problem and landholdings. The population growth rate in the barrio accelerated from 2.3% between 1963 and 1966 to 5.3% between 1966 and 1976 (Table 3). Part of this acceleration reflects the rapid increase in agricultural production after the national irrigation system was extended to the barrio in 1958 and modern rice technology was introduced after 1966.

The recent rapid population growth reflects substantial migration into the village. Out of 36 households formed in the barrio from 1970 to 1976, 17 were formed through migration

Table 3. Changes in the population of a barrio in Laguna, Philippines, 1903-76.

Year	Data source	Barrio		Whole municipality	
		Number	1960 =100[a]	Number	1960 =100[a]
1903	Census	94	27	6,040	54
1960	Census	349	100	11,156	100
1966	Umehara survey (as of 1 Dec.)	383	110		
1974	IRRI survey (as of Nov.)	549	157		
1975	Census (as of 1 May)	571	164	18,356	165
1976	This survey (as of Dec.)	644	185		

[a]The column gives the index numbers when 1960 = 100.

(Table 4). Landless workers headed 27 of the new households. Most migrated to the village to marry or to find employment.

Such trends reflect the growing scarcity of land for cultivation. They also point out the growing opportunities for agricultural employment in this barrio due to the intensification of rice farming with the improved irrigation system and diffusion of the seed-fertilizer technology.

The class demarcation between farmers (generally tenants) and landless workers was not fixed. Landless workers frequently became farmers and vice versa. Twenty-three of the 55 farmers in the village in 1976 had moved up from the landless class, while 26 out of 54 landless workers had been farmers. This movement back and forth seems to have accelerated in recent years as growing population pressure has intensified the competition for farmland through various leasing arrangements.

In 1966, 46 farmers cultivated 104 ha of paddy fields owned by 41 landlords. In 1976, 54 farmers residing in the barrio cultivated 108 ha owned by 66 landlords. The ownership distribution had become more dispersed during the decade. Only three barrio residents owned rice land and none of them owned more than 1 ha.

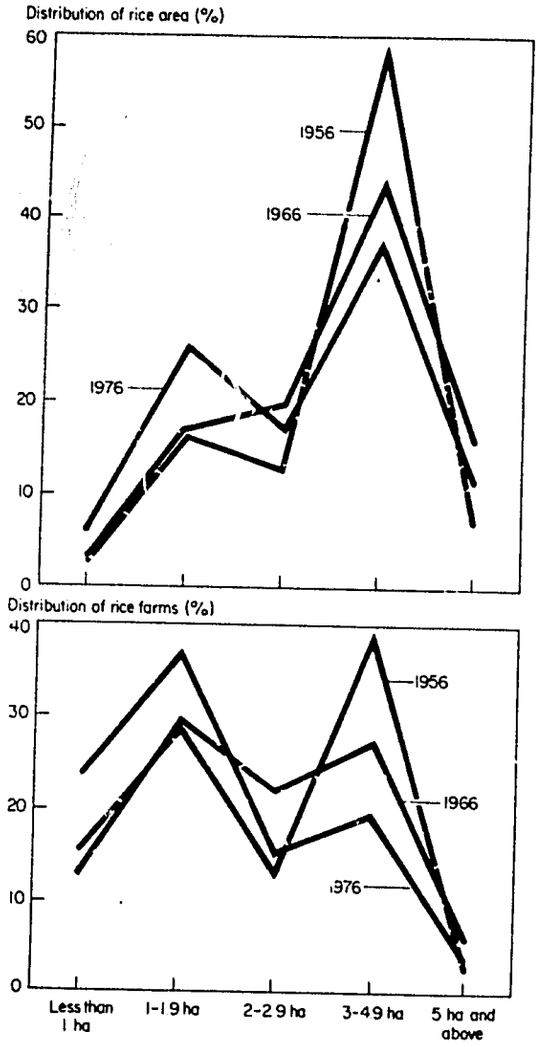
The average paddy field area per farm operator was stable at 2.3 ha between 1956 and 1966, but declined to 2 ha by 1976. The process by which population pressure reduced the average operational holding can be inferred from the changes in farm size distribution (Fig. 6). From 1956 to 1966, the share of farms belonging to the class of 3–5 ha declined with a corresponding increase in the class of 2–3 ha. From 1966 to 1976, the percentage in classes of 3–5 and 2–3 ha declined and the share in the class of 1–2 ha increased.

Land tenure system. In this village, all of the farmers are tenants of some sort. Traditionally, share-tenancy was the most common; about 70% of the farmers belonged to this category in both 1956 and 1966. From 1966 to 1976, land tenancy distribution experienced a major change. The conversion from share to leasehold tenancy since 1968 under the Agricultural Land Reform Code (R.A. 3844) and the Code of Agrarian Reform (R.A. 6389) markedly reduced the number of share-tenants. In 1976, over 50% of the farmers were leasehold tenants (paying a fixed rent) and only about 25% remained as share-tenants.

Another significant change was an increase in the land under "subtenancy" (Table 5). The

Table 4. Causes of the formation of households during selected periods in a barrio in Laguna, Philippines, 1939-76.

Period of household formation	Migration			Independence			Total for both causes
	Farmer households (no.)	Landless worker households (no.)	Total	Farmer households (no.)	Landless worker households (no.)	Total	
Before 1939	2	—	2	9	2	11	13
1940-49	4	1	5	5	3	8	13
1950-59	2	1	3	9	6	15	18
1960-69	5	2	7	10	12	22	29
1970-76	6	11	17	3	16	19	36
Total	19	15	34	36	39	75	109



6. Changes in farm-size distribution in a barrio in Laguna, Philippines, 1956–76.

contract is usually made without formal consent of the landowner. Subtenancy can be classified into three categories: 1) the sublessor and the sublessee share the output and cost 50:50 (9 out of 16 plots, Table 6), 2) the sublessor receives a fixed rent from the sublessee (2 out of 16 plots), and 3) the subrenting takes a form in which the sublessor puts his land in pawn to the sublessee (5 out of 16 plots). In other words, the sublessee advances credit to the sublessor to establish the right to cultivate the land until the loan is paid back. This type can be subdivided into three

Table 5. Distribution of parcels by tenure status in a barrio in Laguna, Philippines, 1956-76.[a]

	Owned		Leased		Shared-rented		Subrented	
Year	Parcels (no.)	Area (ha)	Parcels (no.)	Area (ha)	Parcels (no.)	Area (ha)	Parcels (no.)	Area (ha)
1956	2	1.3	11	26.9	25	42.1	1	1.2
1966	2	1.3	12	29.9	44	66.1	5	6.9
1976	3	1.7	44	67.7	30	29.7	16	9.1

[a]Average number of parcels per farm = 1.3 in 1956, 1.4 in 1966, and 1.7 in 1976.

categories, where the sublessor receives 1) share-rent, 2) a fixed rent, or 3) no rent.

Land under subtenancy has been increasing, indicating that the rent actually paid by tenants to landlords increased less than the economic rent or the functional share of the land, producing a substantial surplus to be captured by the tenants. Partly because of social inertia and partly because of land reform regulations, it has been difficult to raise the rates of rent under leasehold tenancy even if land productivity has increased. Thus, the opportunity has increased for the leasehold tenants to transform themselves into intermediate landlords.

The hypothesis that the gap between the functional share of the land and the actual rent provided a condition for the emergence of subtenancy was tested. Factor shares of rice output for the 1976 wet season for different tenure types were estimated with market prices imputed to unpaid factor inputs. The results show that the share of land was lowest and the operator's surplus highest for land under leasehold tenancy in both absolute and relative terms (Table 7). In contrast, the share of land was highest and no surplus was left for farm operators under subtenancy. The substantial surplus for leasehold tenant operators provided

Table 6. Distribution of parcels under subtenancy contracts in a barrio in Laguna, Philippines, 1956-76.

	With share-rent		With fixed rent		By pledging		Total	
Year	Parcels (no.)	Area (ha/parcel)	Parcels (no.)	Area (ha/parcel)	Parcels (no.)	Area (ha/parcel)	Parcels (no.)	Area (ha/parcel)
1956	1	1.2	—	—	—	—	1	1.2
1966	4	1.6	—	—	1	0.5	5	1.4
1976	9	0.8	2	0.4	5	0.3	16	0.6

Table 7. Factor shares of rice output per hectare in a barrio in Laguna, Philippines, 1976 wet season.

	Plots (no.)	Area (ha)	Rice yield[a] (cavan/ha)	Factor shares (cavan/ha): Current inputs	Land: Landlords' share	Land: Sublessees' share	Land: Total	Labor	Capital[b]	Operators' surplus
Leasehold land[c]	31	60.4	70.1	12.9	12.6	0	12.6	22.6	9.8	12.2
Share-tenancy land[c]	17	26.7	58.1	15.2	14.4	0	14.4	18.4	6.3	3.8
Subtenancy land	9	6.3	78.1	18.9	11.3	18.0[d]	29.3	22.4	6.6	0.9

[a]One cavan = 44 kg rough rice. [b]Sum of irrigation fee and paid or imputed rentals of carabao, tractor, and other machines. [c]Excludes the plots of which the yield per hectare were below 60% of the average for 1974–76. [d]Rents to sublessors in the case of pledged plots are imputed by applying the interest rate of 40% per annum.

them an opportunity to become intermediate landlords; the surplus represents a basic force underlying the emergence of multistage landlordism.

Changes in tenure status often take place through land transactions. Increasing numbers of transactions in tenancy rights corresponding to the acceleration in population growth have occurred since 1959 (Table 8). The price of tenancy rights also shows an increasing trend; in contrast, the price of the land ownership title shows a decreasing trend. By 1976, the value of the tenancy right was almost half the value of land.

Labor contracts. The economic forces that have induced changes in land tenure have had a pervasive effect on the employment relations between farmers and landless workers. The forms of labor used for rice production in this area are 1) family labor, 2) exchange labor, 3) daily hired wage labor *(upahan)*, and 4) labor employed to harvest and thresh the crop in return for one-sixth share of the harvest (*gama*). While the rice transplanting labor was supplied

Table 8. Transfer of land ownership and tenancy right in a barrio in Laguna, Philippines, 1959-76.

Year	Transfer of land ownership: No.	Area (ha)	Current value (US$/ha)	Value deflated by rice price index[a] (US$/ha)	Transfer of tenancy right: No.	Area (ha)	Current value (US$/ha)	Value deflated by rice price index[a] (US$/ha)
1959	—	—	—	—	1	1.0	21	117
1960	—	—	—	—	1	2.4	18	94
1961	—	—	—	—	—	—	—	—
1962	1	3.0	905	4112	—	—	—	—
1963	1	1.3	1099	4070	1	2.0	214	794
1964	1	3.5	776	2425	—	—	—	—
1965	—	—	—	—	1	3.0	62	206
1966	1	1.0	1571	5238	—	—	—	—
1967	—	—	—	—	1	1.5	67	222
1968	1	1.5	2571	8571	3	3.9	87	265
1969	1	0.8	2095	5820	3	2.5	140	389
1970	1	2.0	1357	3878	4	6.4	300	816
1971	1	2.0	1429	3322	—	—	—	—
1972	2	1.4	1735	3098	4	5.0	186	332
1973	1	1.0	2143	2551	2	3.5	441	525
1974	—	—	—	—	2	3.1	588	612
1975	1	0.4	2229	2229	4	5.1	581	581
1976	—	—	—	—	1	1.2	952	952

[a]The rice price index used is that of southern Tagalog area, 1975 = 1.00. No change in price is assumed from 1975-76, based on the survey data. Philippine ₱7 = US$1.

Table 9. Diffusion of *gama* system in a barrio in Laguna, Philippines, 1959–76.

Year	Employers' side: Farmers adopting *gama* (no.) (1)	Farmers (total no.) (2)	(1)÷(2)	Employees' side: *Gama* workers (no.) (3)	Landless workers (total no.) (4)	(3)÷(4)
1959				1		
1960	1			1		
1962	2			5		
1964	6			11		
1966	14	46	0.30	21	20	1.05
1968	15			23		
1970	24			26		
1972	33			40		
1974	43	54	0.80	52	40	1.30
1976	45	54	0.83	66	54	1.22

by a team of daily wage workers (*upahan*) organized by a leader called a *kabisilya*, harvesting and threshing were done largely under *gama* or *hunusan*. Other tasks for which the share of hired labor was high were land preparation based on *upahan* and weeding based on *gama*.

Gama is the dominant form of labor contract for harvesting and threshing, as shown in the data for the 1976 wet season (Table 9). From 1966 to 1976, the number of farmers who have adopted the *gama* system, and the area under *gama* contracts increased almost four times. The minimum unit of contract is a paddy field (*pilapil*). Average size of paddy fields was a little under 0.1 ha. The contracts per farm averaged about eight or nine, and the area per contract was 0.2 ha. Employer-farmers made 413 contracts in the barrio in 1976. Contracts with landless workers totaled 342 (83%); with other farmers, 71 (17%). Contracts with people who lived in the barrio totaled 323 (78%); with those outside the barrio, 90 (22%).

When rice yield per hectare was low and labor was more scarce, the one-sixth share of output under the *hunusan* system might have represented a wage rate equal to the marginal product of the harvesters' labor. As productivity of farming and the labor supply increased, one-sixth of the output has become substantially larger than the marginal product of labor for harvesting and threshing.

The *gama* system offers an alternative to simply lowering the harvesters' share as output rises. It appears the *gama* system has been adopted rapidly because it allows the adopters to equate the cost of the harvesters' share of the output to the marginal productivity of labor. Market wage rates were imputed to labor inputs applied to rice production under the *gama* system, and the imputed wage costs (based on actual hours worked) were compared with the actual wages of the *gama* harvester (Table 10). The close proximity between the imputed wages and the actual harvesters' shares tends to support the hypothesis, assuming that the marginal value of labor is approximately equal to the market wage rate.

Implications of village studies.

1. Village dwellers' earnings came almost exclusively from production within the village; 80% came from rice. Employment opportunities outside the village are limited.
2. Expansion of the irrigation system and introduction of modern rice technology have provided gains in income and production, but

Table 10. Comparison between the imputed value of harvester's share and the imputed cost of *gama* labor, in a barrio in Laguna, Philippines, 1976 wet season.

	Based on employers' data	Based on employees' data
No. of working days of *gama* labor[a] (days/ha):		
Weeding	21	18
Harvesting and threshing	34	34
Imputed cost of *gama* labor[b] (US$/ha):		
Weeding	24	21
Harvesting and threshing	53	53
Total	77	74
Actual share of harvesters:		
In kind[c] (cavan/ha)	11.2	12.2
Imputed value[d] (US$/ha)	72	78
Total imputed cost of *gama* labor minus imputed value of harvesters' share (US$)	−5	4

[a]Includes the labor of family members who worked as *gama* laborers. [b]Imputation using market wage rates (daily wage = ₱8 for weeding, ₱11 for harvesting. US$1 = ₱7. [c]One-sixth of output/ha. One cavan = 44 kg rough rice. [d]Imputation using market prices (1 cavan = ₱45).

the population has expanded rapidly and the proportion of landless laborers has been growing.

3. Land reform has increased the total income in the village, but large tenants seem to have captured the major benefits. A patron-client relationship has developed through both the subleasing arrangements and through the contracts between tenants and landless laborers. In the short run, this may have assisted the landless in receiving some share of rice productivity gains.
4. In the long run, if present trends continue, farm size will decline further and landless laborers will continue to increase in number relative to farmers. Real wages will decline and the value of tenancy rights will rise, widening the income gap between farmers and landless workers.
5. There are few opportunities for employment outside the village. Employment within the village must be encouraged through the intensification of both rice and nonrice production.
6. There seems to be ample opportunity for increasing both rice and nonrice production. But it requires capital investment to improve irrigation and drainage and to improve land and facilities for vegetables and livestock. A large potential for building such capital seems to exist: village labor, which remains idle during the slack months of rice farming, can be mobilized. Indeed, a critical question for the development of the village economy is how to organize village labor for capital formation.

PROSPECTS FOR ASIAN RICE PRODUCTION

There have been a number of attempts to determine whether future food grain availability in Asia will meet demand. The projections of the International Food Policy Research Institute, the Asian Development Bank, and the World Bank differ somewhat in absolute levels because of differences in countries and crops included and different production and income projections. Yet, all the studies indicate that by 1985, production in the region will fall short of demand by 25 to 40 million t of food grains.

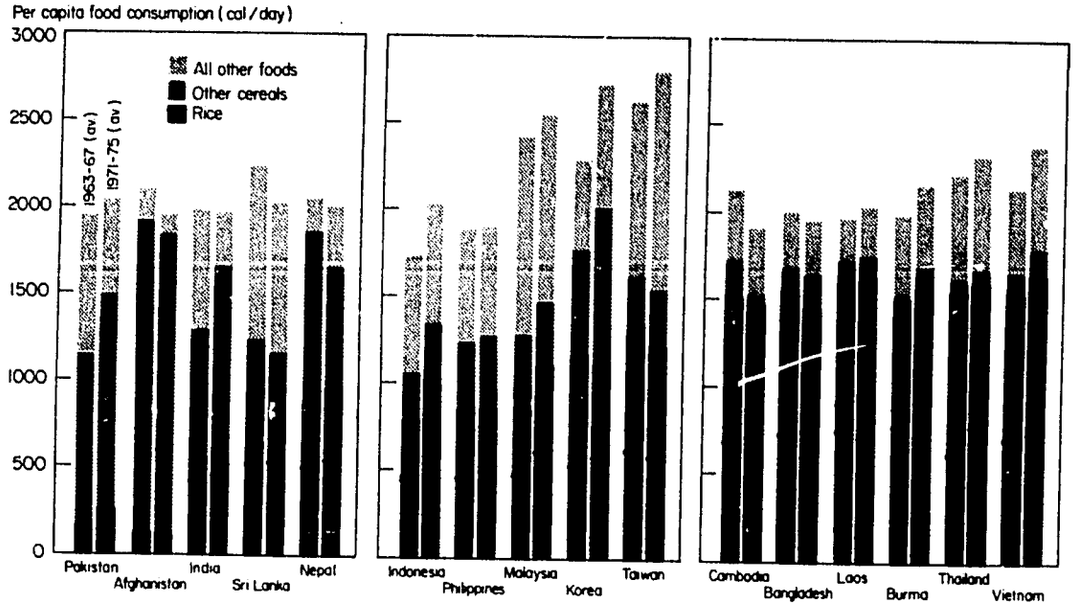
Research on prospects for Asian rice production focuses on steps needed to ensure a sufficiently rapid growth in food grain production 1) for the region as a whole, and 2) for individual countries within the region. This year's results are based on the analysis of prospects for growth in rice production for the region as a whole. Past trends are assessed and a model is developed to estimate output growth up to 1985 at specified levels of input availability.

Current food adequacy and recent trends. The average per capita consumption of food, measured in calories per day, changed relatively little between 1963–67 and 1971–75 for 15 countries in Asia (Fig. 7). Cereals dominate the consumption patterns in most of the countries, but noncereals are particularly important in Sri Lanka, Malaysia, and Taiwan. Rice contributes an appreciable fraction of total calories in all countries, and makes up an especially large portion of total calories in Bangladesh, Burma, Thailand, Laos, Cambodia, and Vietnam. Per capita rice consumption over the past 10 years appears to have risen most sharply in Indonesia.

Growth in per capita consumption of food is related to the growth in per capita income (Fig. 8). Per capita food consumption increases at a slower rate as incomes rise. The availability of food at approximately 2,000 calories per capita in many Asian countries approaches the FAO's estimated requirements of 2,200 calories. However, such a comparison grossly understates the skewed distribution in food consumption within a country, which tends to follow the skewed distribution of income.

Three groups of countries can be distinguished based on present growth rates in food production relative to population and food demand: 1) those where food production has grown more slowly than population (Nepal, Bangladesh, Indonesia), 2) those where the food production growth rate has exceeded the population growth rate but failed to equal the growth in domestic demand (Burma, India, Pakistan, Philippines), and 3) those whose production growth has exceeded the growth in domestic demand (Sri Lanka, Korea, Malaysia, Thailand).

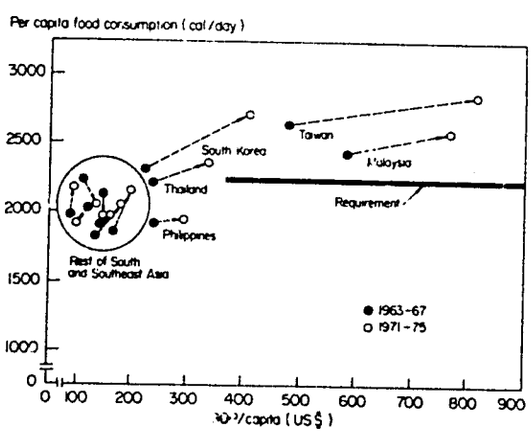
While food production has increased from 1.6 to 5% per year in various countries, with substantial increases in rice, only in a few coun-



7. Apparent per capita daily food consumption in some Asian countries, 1963–67 and 1971–75.

tries have the increases been rapid enough to keep pace with demand. It is, thus, important to examine the growth that has occurred, to determine its source, and to ask whether it can be enhanced in the future.

Sources of output growth. Agricultural output can be increased through the expansion of cultivated area or through an increase in the productivity of existing land. Crop area changes arise from changes in total land area or from changes in the double-cropped area. Yield



8. Growth in per capita consumption and in gross domestic product (GDP) per capita at 1975 constant prices. Selected Asian countries, 1963–67 to 1971–75.

increases are partitioned into increases due to irrigation of a bigger portion of the cropped area and to greater use of yield-increasing inputs, such as new seed and fertilizer. In calculating the contribution of fertilizer, it is assumed that 1 kg of fertilizer nutrient produced 10 kg of paddy (rough rice). The contribution of new varieties is assumed to be embodied in the added fertilizer that made their adoption profitable.

Following the above method, the sources of output growth in the Philippines for the past 20 years were disaggregated (Table 11). In the earlier period, the major contribution to increased production was from irrigation, as reflected in double-cropping and improved average land quality (type of land in Table 11), which accounted for 1.82% of a total 2.41% annual growth. Land area expansion and fertilizer were not important. In the later period, the contribution of land area became negative, principally because of a decline in upland rice area. The contribution of irrigation became even more important, with the area double-cropped more than offsetting the decline in net area. Fertilizer accounted for an output increase of 1.5% per year.

Similar analytical procedures and assumptions were used to estimate the contribution of

Table 11. Growth rates of production, area and yield of rice and their components, Philippines, 1955-73.[a]

	1955–73	1955–65	1965–73
	Annual growth rates (%)		
Production	2.86	[illegible]	[illegible]
Area	1.07	1.24	0.86
Yield	[illegible]	1.10	2.52
	Percentage points attributed		
Area			
Physical area	−0.17	0.30	−0.83
Double-cropping	1.24	0.94	1.69
Yield			
Type of rice land[b]	0.84	0.88	0.52
Fertilizer[c]	0.91	0.29	1.51
Residual	−0.02	−0.07	0.49

[a]Data are from the Philippines Bureau of Agricultural Economics, Fertilizer Industry Authority. [b]Reflects changes in the proportion of land in irrigated, rainfed, or upland palay. Computed with the following formula:

$$\left[Y_{2t} - \frac{(Y_{2a}A_{1a} + Y_{2b}A_{1b} + Y_{2c}A_{1c} + Y_{2d}A_{1d})}{A_{1a} + A_{1b} + A_{1c} + A_{1d}}\right] \div (Y_{2t} - Y_{1t}) \times G_y$$

where Y = yield, A = area. The first subscript refers to time period (e.g. 1965–73 = 2), while the second subscript indicates type of rice, namely: t = total, a = upland, b = rainfed, c = irrigated first crop, d = irrigated second crop, and G_y = annual growth rate of yield. [c]Calculated on the basis of 10 kg of yield for 1 kg of fertilizer.

land, irrigation, and fertilizer inputs to growth in production in six other Asian countries that had experienced a growth in rice production in excess of 2% per year since 1965 (Table 12). The countries have been ranked by their annual rate of production growth. Area change is divided into irrigated and unirrigated. Unfortunately, available data were not robust enough to permit a breakdown of the double-cropped area. Yield growth is attributed to fertilizer and a residual.

In five of the seven countries — Pakistan, Sri Lanka, Indonesia, the Philippines, and India — the major source of output growth is an increase in yield per cropped hectare. In four of these five countries (all but Sri Lanka), the level of fertilizer input tripled from about 7 to 8 kg NPK/ha to 20 to 25 kg NPK/ha. In Sri Lanka, the fertilizer level also tripled from 25 to 72 kg/ha, but the absolute increase in the amount of fertilizer applied was almost 50 kg/ha, or more than double that in the four other countries, and caused the especially large contribution of fertilizer to output growth in Sri Lanka.

The procedure shows a large residual for Pakistan, perhaps because drainage and desalinization are ignored except as reflected in increased irrigated rice area. The contribution of such investments and other factors is included in the residual, indicating their importance for Pakistan.

The sources of growth in Malaysia and Thailand sharply contrast with those in the five other countries. The most significant development in Malaysia was the expansion of irrigated land, which accounted for almost two-thirds of the added production. The expansion was a principal result of the development of the Muda River irrigation system, which increased the area of double-cropped rice. In contrast, Thailand is the only country that followed the traditional pattern of increasing output by expanding the

Table 12. Estimated proportion of growth in rice output attributed to components of area and yield for selected Asian countries, mid-1960's to early 1970's.[a]

Country	Period	Annual rate of production growth (%)	Percentage points attributed to			
			Area		Yield	
			Irrigated	Unirrigated	Fertilizer[b]	Residual[c]
Pakistan	1965-73	7.9	1.4	0	1.7	4.8
Malaysia	1965-73	5.7	3.7	0.1	1.4	0.5
Sri Lanka	1965-72	5.6	0.5	0.1	3.5	1.5
Indonesia	1965-72	4.8	2.2	−0.3	1.1	1.8
Philippines	1965-73	3.4	1.2	−0.3	1.5	1.0
India	1965-70	3.2	0.6	0.2	1.5	0.9
Thailand	1965-72	2.1	0.2	1.7	0.3	−0.1

[a]Production, total area, and yield data are from the US Dep. of Agriculture (USDA), except those for Indonesia and Thailand, which use national sources. Irrigation data come from national sources. Fertilizer data are estimated from the FAO *Annual Fertilizer Review*, national sources, and special studies. For more detailed explanation on sources of irrigation and fertilizer data, see Palacpac, "World rice statistics" (IRRI Agricultural Economics Dep., April 1977). [b]Calculated on the basis of 10 kg yield for 1 kg of fertilizer. [c]Includes the contribution to yield of improved quality of land due to higher proportion of irrigated area.

Table 13. Growth rates in rice yields in South and Southeast Asia, 1963-67 to 1973-77.[a]

Country	Rice yield (t/ha)			Annual compound growth rates (%)	
	1963-67	1968-72	1973-77	1965-70	1970-75
Bangladesh	1.69	1.67	1.77	−0.24	1.17
Burma	1.54	1.60	1.77	0.77	2.04
India	1.46	1.65	1.73	2.48	0.95
Indonesia	1.77	2.33	2.65	5.65	2.61
Malaysia (West)	2.54	2.76	2.94	1.68	1.27
Pakistan	1.47	2.20	2.27	8.40	0.63
Philippines	1.30	1.54	1.69[b]	3.45	2.07
Sri Lanka	1.65	2.26	2.32	6.49	0.52
South Korea	4.26	4.47	5.47	0.97	4.10
Taiwan	4.03	4.31	4.36	1.35	0.23
Thailand	1.93	1.90	1.79	−0.31	−1.19

[a]Source of basic data: US Department of Agriculture (USDA), except those for the Philippines, which use national sources.
[b]1973-76 average only.

rainfed rice area. The low rate of change in unirrigated areas in the six other countries suggests that expansion of irrigated area — hence double-cropping — is the principal source of additional production.

The annual growth in yield for a number of Asian countries was estimated to examine the possibility that the trend in production slackened after an initial spurt caused by the introduction of new technology in the late 1960's. Yields for the 5-year periods 1963-67 to 1968-72 and 1968-72 to 1973-77 were averaged.

Most countries seem to have experienced more rapid growth in yield from 1965 to 1970 than from 1970 to 1975 (Table 13). Some notable exceptions are Bangladesh, Burma, and South Korea, where yields increased little until after 1970. The introduction of a new generation of high yielding varieties has boosted Korean yields substantially since 1973.

Yield growth seems to have leveled off significantly in Indonesia, Pakistan, and Sri Lanka, the countries that showed the most rapid gain in the 1965-1970 period. In Thailand, there has been a rapid expansion of the rainfed rice area over the past 10 years. The increased proportion of rainfed to irrigated lands results in a decrease in aggregate national yields.

For yields, the pattern of growth in production and in specified inputs shows considerable variability from country to country (Table 14). Data for the past 10 years are shown separately for the period 1968-70 and 1970-74 to identify possible changes in the growth of outputs and inputs. Rice production and change in the irrigated area are reported in the table in terms of annual compound growth over the designated periods; growth in fertilizer and in area in modern varieties (MV) is reported in annual increments since the level of both was close to zero in 1965.

The reasons for the increase or decrease in growth seem to vary considerably from country to country and suggest that the decline in production and yield growth that was observed in the early 1970's — compared with that in the late 1960's — may be due to temporary fluctua-

Table 14. Annual growth in production, irrigated area, fertilizer per hectare, and area in modern varieties 1965-70 and 1970-74.[a]

Country	Annual compound growth rates (%)						Average annual increment			
	Production		Irrigated land		Other land		Fertilizer (kg NPK/ha)		Area in MV (% of rice area)	
	1965-70	1970-74	1965-70	1970-74	1965-70	1970-74	1965-70	1970-74	1965-70	1970-74
Pakistan	10.65	1.66	2.10[b]	0.65[b]	0	0	2.73	1.33	7.32	0.92
Sri Lanka	7.39	0.94	2.93[c]	n.a.[d]	2.72	n.a.	5.50	20.40	1.67	12.55
India	3.20	0.83	1.56	n.a	0.33	n.a.	2.28	1.05	2.42[e]	3.75
Thailand	2.61	0.93	0.85	0.62	3.02	0.04	0.78	−0.23	0.20[f]	1.52
Indonesia	4.92	4.71	2.89[g]	2.53[h]	−0.64	−4.36	2.37	4.41	3.70[h]	7.35
Philippines	3.59	3.99	4.51	1.30	−2.54	1.45	2.31	1.66	10.06	1.80
Bangladesh	0.73	1.73	12.72[i]	5.73	0.05	−0.49	0.45	0.20	0.92	2.50
Burma	0.49	2.28	2.02	3.87	−0.61	0.40	0.61	0.40	1.0[j]	0.65

[a]Sources of production, irrigation and fertilizer data are the same as in Table 12. Modern varieties data are from D. Dalrymple, *Development and spread of high yielding varieties of wheat and rice in the less developed nations* (USDA, August 1976). [b]Assume 100% of rice area is irrigated. [c]This refers to time period 1965-69. [d]Data not available. [e]1964-70. [f]1968-70. [g]This includes rainfed area. [h]1967-70. [i]This refers to boro crop area. [j]1966-70.

tions rather than to long-term trends. The favorable supply-demand situation prevailing in Asia during 1976 and 1977 lends further credence to this view.

A model of rice output growth. Rice output has grown at somewhat more than 2.5% yearly over the past 10 years, but as previously noted, doubts have been raised as to whether this rate can continue. To shed light on this question, a simple aggregate model of rice output growth for South and Southeast Asia has been developed. The model incorporates the input-output relationships for land, labor, fertilizer, irrigation, and technological change. The investment cost associated with each source of growth is developed. The model begins from the base year 1974 and projects to 1985.

The model is not intended to realistically represent the situation in each country, rather the country data are used as components of regional totals. Results of this analysis suggest the magnitude of regional investment that would be required to obtain alternative rates of output increase.

The model works as follows: 1) input-output relationships are specified, 2) inputs are projected to 1985 and the implied growth in output calculated, 3) an estimate is made of the annual investment cost for inputs. By varying the rate of input growth and the assumed rate of technological change, alternative solutions can be generated.

Input-output relationships. In this model, output is assumed to grow either through an increase in yield or intensification of production per hectare. This is in keeping with our earlier observation that rice output growth over the past 10 years has been accomplished previously in this manner (Tables 11 and 12).

Rice yields can be increased through the adoption of modern varieties (MV), application of fertilizer (F), and expansion of irrigation. The complementary relationship among these modern inputs is captured in four fertilizer response functions for irrigated (I) and rainfed (R), modern (MV), and traditional (TV) varieties, which form the core of the model:

$$\text{MVI}: \quad Y_1 = 2200 + 18F_1 - 0.09F_1^2 \qquad (1)$$

$$\text{MVR}: \quad Y_2 = 1400 + 15F_2 - 0.11F_2^2 \qquad (2)$$

$$\text{TVI}: \quad Y_3 = 2000 + 11F_3 - 0.13F_3^2 \qquad (3)$$

$$\text{TVR}: \quad Y_4 = 1400 + 9F_4 - 0.16F_4^2 \qquad (4)$$

The functions are based on national farm survey data in the Philippines and experiment station data adjusted by observed differences between survey and experimental data. Upland and deep-water rice are assumed to be unresponsive to fertilizer application under present technology.

When the levels of fertilizer, modern varieties, and irrigation for a particular year are known, the resulting production is calculated using these functions. Assuming market equilibrium, the marginal productivity of fertilizer applied to each type of rice will be equal to the ratio of the price of fertilizer to the price of rice. If available fertilizer is not enough to permit this, then the available supply will be allocated in some way. The maximum possible production from the available fertilizer would be obtained if the fertilizer is applied so that its marginal product is equal on each type of rice. The model uses this approach as follows. If one unexploited source of growth is from higher rates of fertilizer application, this implies that the present rates do not equate the marginal productivity to the price ratio. Thus, the marginal products will be equated to a constant, say a, which is the shadow price of fertilizer in terms of rice — the real marginal value of fertilizer applied to rice.

The rice areas devoted to modern varieties (equations 1 and 2) and to irrigation (equations 1 and 3) are increasing over time. Irrigation adds to increased production through both yield increase and increased cropping intensity. It is assumed that irrigation increases the area devoted to rice through double-cropping equal to 30% of the net area irrigated.

Technological change is also occurring gradually, further increasing the yield response. From data on expenditures for research and extension in Asia over the past 10 years, it is estimated that an investment of US$350 million has been required to generate and spread the present modern varieties that produced a

response function with a two-thirds greater slope (equation 1 vs equation 3). The conservative estimate is that an additional US$100 million investment in research and extension over the next 10 years would increase the slope (marginal productivity) by 15%. This is the assumption made for those solutions that incorporate technological changes.

Labor will continue to grow through the projection period. The impact of added labor input on output is not incorporated explicitly into the model. However, it is assumed to contribute 0.3% growth in rice output per year, the difference between the rate of output growth observed in the 1963-74 period and the rate projected on the basis of other inputs.

The assumptions of the model are summarized as follows:

- Land in rice
  - Geographic area for 1975-85 is constant.
  - Upland and deep-water areas are constant.
- Irrigation
  - Irrigated area depends on investment.
  - 30% of irrigated land is double-cropped.
- Varieties
  - MV are planted on 90% of irrigated land by 1985.
  - MV are planted on 30% of rainfed land by 1985.
- Fertilizer
  - 20 kg/ha nutrients were used in 1974.
  - Demand grew by 12% in 1975, will grow by 8% in 1985.
  - Fertilizers may be imported or domestically produced.
  - Yield response depends on irrigation and fertilizer type.
- Fertilizer rates per hectare
  - Fertilizer rates depend on total amount available and economic behavior of users.
- Research
  - Research changes the response to fertilizer, raising the response functions by 15%.
- Labor
  - Labor contributes 0.3% annual rice output growth.

Input projections. Input projections for modern varieties, fertilizer, and irrigation were based to a large degree on recent trends (Table 14). Modern varieties were projected to cover 90% of the irrigated area and 30% of the rainfed area by 1985. On the basis of projections of fertilizer use by the international fertilizer division of the Tennessee Valley Authority (TVA), fertilizer consumption was projected to be 12% in 1975 and to decline to 8% by 1985. An alternative projection using a 12% rate that declines to 9.5% in 1985 was also tested.

Gross irrigated rice area grew 2 to 3% over the past 10 years (Table 14). Alternative projections of output are derived from the model using a projected growth in irrigation that ranges from 1.5% to 3%.

Investment costs. The investment cost of the agricultural growth actually achieved between 1963-67 and 1968-72 is calculated in Table 15. All costs are shown in US dollars at constant 1975 prices. Investments are for fertilizer production, irrigation expansion, and research-extension. Because of the considerable range in investment costs that exists in the sources used, a low and a high estimate for fertilizer and irrigation are shown.

Fertilizer can be either produced domestically or imported. Under a perfect market and equilibrium, the cost of domestically produced and imported fertilizer would be equal. But because of market imperfections, it is likely that fertilizer can be produced within the region at a cost lower than the import price. TVA projection of fertilizer prices and costs leads to the assumption that urea can be produced domestically for US$100 to US$109/t and imported for US$150 to US$250. Triple superphosphate can be produced domestically at US$138 to US$253/t or imported for US$250 to US$350.

The cost of additional irrigated land is assumed to range from a low of US$1,000/ha to a high of US$1,300 according to information from the Asian Development Bank and the World Bank. The cost is expected to be higher in the next 10 years than in the past 10 because

Table 15. Estimation of costs associated with increased input use for increased rice production achieved, nine Asian countries, 1963–67 to 1968–72.[a]

Input	Cost range	Av. annual increase	Unit cost (US$)		Annual investment (million US$)		Annual additional current costs[b] (million US$)		Five-year costs (million US$)		
			Capital invest-ment	Current cost	Domestic	Foreign	Domestic	Foreign	Total	Domestic	Foreign
Irrigated land	Low	638,000 ha	1,000	10	319	319	6	0	3,280	1,685	1,595
Irrigated land	High	638,000 ha	1,300	20	415	415	12	0	4,330	2,255	2,075
Fertilizer, urea	Low	232,000 t[c]	0	150[d]	0	0	0	35	525	0	525
Fertilizer, TSP	Low	77,000 t	0	250[d]	0	0	0	19	285	0	285
Fertilizer, urea	High	232,000 t	0	250[d]	0	0	0	58	870	0	870
Fertilizer, TSP	High	77,000 t	0	350[d]	0	0	0	27	405	0	405
Fertilizer, urea	Low	0.47 units[e]	187 M	60[f]	0	87	7	7	649	105	544
Fertilizer, TSP	Low	0.23 units[g]	78 M	132[f]	0	18	5	5	190	75	165
Fertilizer, urea	High	0.47 units	190 M	70[f]	0	89	8	8	685	120	565
Fertilizer, TSP	High	0.23 units	133 M	243[f]	0	30	9	9	435	150	285
Research-extension	·		43 M	0[h]	33[i]	10	0	0	215	165	50

[a]Source: Fertilizer data — Tennessee Valley Authority, National Fertilizer Development Center, *An Appraisal of the Fertilizer Market and Trends in Asia*, Muscle Shoals, Alabama, June 1975. [b]The additional amount must be cumulated so that the 5-year total of the additional costs equals, in the first year, the first year addition; in the second year, the second year addition plus the first year addition, etc. [c]Annual increase of 139,000 nutrient tons converted to urea and triple superphosphate (TSP) assuming ⅔ of fertilizer is urea, ⅓ is TSP. [d]All fertilizer is imported in these cases. [e]One ammonia-urea production unit will produce 495,000 t urea/year. About 1 unit every 2 years would meet the needs. [f]Cost per ton of producing the fertilizer, excluding capital depreciation and interest, assumed half domestic, half foreign. [g]One TSP production complex with phosphate rock grinding and sulfuric acid plant will produce 340,000 t TSP/year with investment cost ranging from 78 to 133 million (TVA, p. 99). [h]Assumed to be entirely an investment. Arbitrary breakdown between domestic and foreign.

most of the lower cost sites are already developed.

It has been noted that research-extension investment will increase by about 30% over that in the previous decade. The annual investment is assumed to be US$43 million.

Model verification. To test the reasonableness of the model, the actual levels of inputs in the countries of the region for the 5-year average periods 1963-67 and 1968-72 were used for estimating production in the model (Table 16). Data on land, irrigation, modern varieties, and fertilizer on rice were derived for the 5-year average periods centered on 1965, 1970, and the 2-year average of 1973-74. It was assumed that in 1963-67, the modern varieties were planted only on irrigated land; and that by 1973-74, 90% of the area in modern varieties was irrigated. The areas of upland and deep-water rice were assumed to remain constant. In the 7 countries for which irrigation data were available, the irrigated rice area grew 75% as rapidly between 1968-72 and 1973-74 as it had in the previous 5-year period. Assuming the same proportional rate for all countries gave the 1.8% rate of irrigation growth used for the second validation period.

Under these assumptions and using the data in Table 16, the model estimates an average annual level of output of 112.1 million t of rice (paddy) production compared to reported average actual production — as estimated by the US Department of Agriculture — of 111.1 for 1963-67. The model estimates the 1968-72 output as 130.2 as against the reported output of 129.5; the 1973-74 estimate is 143.4 as against the reported output of 142.9.

The shadow price ratio of fertilizer (nutrient) and rice (paddy) implied by the model exceeds 6.5 for both verification periods. Market price ratios in most countries were 4 or lower during the period. This suggests that, on the average, for the region the rate of fertilizer applied to rice was below the equilibrium level and that profitable scope existed for further output increases from higher rates of fertilizer.

Investment levels for the 4-year period 1963-67 to 1968-72 are reported in Table 15. Annual growth in inputs, annual growth in production, the implied N to rice price ratio, and annual investment requirements are shown for the two verification runs in the first two rows of Table 17.

Table16. Area, irrigation, modern varieties and fertilizer used in rice production in South and Southeast Asia, 1973 to 1974.[a]

Country	Total rice area (thousand ha)			Irrigated rice area (thousand ha)			Modern varieties area (thousand ha)			Fertilizer applied to rice (thousand nutrient tons)		
	1963–67	1968–72	1973–74	1963–67	1968–72	1973–74	1963–67	1968–72	1973–74	1963–67	1968–72	1973–74
India	35,886	37,333	38,302	13,413	14,498		894	5,539	10,249	279	715	869
Bangladesh	9,311	9,745	9,900	500[b]	910[b]	1,106[b]	34	513	1,515	20[c]	43[c]	50[c]
Indonesia	7,249	8,078	8,625	5,739	6,616	7,220	0	1,039	3,270	64	167	285
Thailand	6,153	6,941	7,398	1,706	1,780	1,819	0	108	425	22	52	49
Burma	5,019	4,958	5,143	667	737	858[d]	3	177	292	6	21	29
Philippines	3,159	3,183	3,544	1,102	1,374	1,447	392	1,556	2,217	24	61	83
Pakistan	1,373	1,523	1,624	1,373[d]	1,523[d]	1,624[d]	2	547	634	11	33	41
Malaysia	399	515	587	167	375	442[d]	65	161	219	19	32	49[f]
Sri Lanka	597	627	574	359	403		0	73	360	15	33	65
Total	69,146	72,903	75,697	25,026	28,216	30,035[e]	1,390	9,713	19,181	460	1,157	1,520
Growth rate	—	1.1%	1.1%	—	2.4%	1.8%[e]	—	38.9%	19.4%	—	18.5%	7.8%
Seven-country total[h]	32,663	34,943	36,821	11,254	13,315	14,516	496	4,101	8,572	166	409	586
Growth rate		1.3%	1.5%	—	3.4%	2.5%	—	42.4%	21.1%	—	18.0%	10.3%

[a]Sources of data are the same as for Tables 12 and 14. [b]Data are for the area planted to boro rice, which is irrigated. [c]Assumed equal to 32% of total fertilizer, the corresponding figure for India. [d]All rice area in Pakistan is assumed to be irrigated. [e]Based on an estimate of the growth in net irrigated area. [f]Projected at 20% of total fertilizer for the country, projected from two previous periods when it was 30% and 23%. [g]Projection based on growth rate of 9% in countries for which data are available, compared to 18% in previous 5-year period. [h]Bangladesh through Malaysia.

Table 17. Projected rates of increase of irrigation, fertilizer and technology,[a] and associated output growth and investment required, South and Southeast Asia, 1974–85.

Run[b] no.	Inputs to the model		Outputs of the model					
					Annual investment (million US$)			
					Low costs		High costs	
	Irrigated area (%/yr)	Fertilizer (%/yr)	Production (%/yr)	Implied N: rice shadow price	Imported fertilizer	Domestic fertilizer	Imported fertilizer	Domestic fertilizer
				Verification				
V1	2.4	18.5	3.0	6.6	861	866	1164	1133
V2	1.8	7.8	2.8	6.9	715	742	768	773
				Projections with inputs increased				
1	1.5	12-8[c]	1.6	1.4	1072	960	1530	1237
2	2.0	12-8	1.8	1.8	1252	1140	1768	1475
3	3.0	12-8	2.3	2.6	1641	1529	2256	1963
4	3.0	12-9.5	2.4	0.8	1754	1619	2435	2080
				Projections with improved technology and inputs				
5	1.5	12-8	2.5	5.5	1272	1160	1730	1437
6	3.0	12-8	3.0	6.3	1841	1729	2456	1963

[a]MV covered 6% of irrigated rice land in 1963-67, 33% in 1968-72, and 57% in 1973-74. They are assumed to cover 90% of irrigated and 30% of rainfed land by 1985. [b]V = verification run. V1 covers the 5-year period 1963-67 to 1968-72; V2 covers the 3½-year period 1968-72 to 1973-74. [c]Fertilizer applied to rice was at 12%/year in 1974; that rate will have gradually declined to 8%/year by 1985.

Projections to 1985. In runs 1, 2, and 3, the irrigated area was assumed to increase at 1.5, 2, and 3% annually (Table 17). Fertilizer use grew at 12% in 1974, then would gradually decline to a rate of 8% annual growth in 1985, as projected by TVA. In run 4, irrigated area grows at 3% and fertilizer demand grows slightly more rapidly than projected by TVA. Runs 5 and 6 assume that farmers' fertilizer productivity is increased 30% through research and extension.

Runs 1 through 3 show the effect of different rates of irrigation expansion with the base rate of fertilizer growth and constant technology. With a 1.5% annual rate of increase in irrigation, output grows at 1.6%. A 2% annual increase in irrigation pushes output growth to 1.8%/year, while a 3% growth rate of irrigation increases output growth to 2.3%. All three rates are below the observed rates of output growth during the verification periods, and all entail substantially higher rates of annual investment for irrigation and fertilizer.

Because of the large investments and scarce real resources (engineering talent and appropriate sites) needed for irrigation construction, it is unlikely that irrigated area could grow much more rapidly than 3%/year. At these rates, the increased irrigated area and the accompanying double-cropping together with fertilizer will not be adequate to meet the projected demand for rice.

Use of fertilizer in the first three runs makes a substantial contribution to output, but additional fertilizer pushes the per hectare rates to levels where the marginal productivity of fertilizer is low. In fact, the implied fertilizer:rice shadow price ratio is 2.6 or below, a level lower than that which has prevailed historically in most Asian countries.

Run 4, which has higher growth rates of fertilizer use, shows the futility of trying to push rice growth only through that route. The marginal productivity of fertilizer falls below the levels of the first three runs and so the price necessary to induce farmers to use all the available fertilizer is about half the level of the previous runs. Such a price would entail large fertilizer price subsidies.

Technological change is expected to increase the productivity of conventional inputs like irrigation and fertilizer, but the exact relationship and mechanism are uncertain. In runs 5 and 6, it is assumed that an additional US$100 million investment in research and extension per year will raise productivity as discussed above. This assumption, while based on the best available data, is highly tentative.

Implications. The implications of this set of projections are sobering. The model's projections imply that in the absence of technology change, it will be impossible for production to grow fast enough to meet demand even with the level of annual investment twice as high as that of the past decade. Added investment in research and extension does accelerate the growth in output, but a high level of investment is still required.

The results suggest that continued reliance on fertilizer and irrigation as major sources of output growth is likely to be extremely costly unless steps can be taken to increase the productivity of these inputs. This can be accomplished only through further emphasis on research and extension that will 1) close the gap between potential and actual yields with present technology, and 2) raise the potential by developing and disseminating better technology.

Cropping systems program

Summary

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ENVIRONMENTAL DESCRIPTION

Landscape-related field hydrology. The time a field retains standing water determines its potential for growing two lowland rice crops. Within a given rainfall class, landform and soil texture — and irrigation — modify water regimes. In an exploratory analysis, the flooded status day (FSD), any day on which there is standing water on the field, was used to indicate the duration when standing water could be kept on fields in several important land units within the Pangasinan and Iloilo land systems.

For Pangasinan and Iloilo, 15 and 15 separate models, respectively, were computed, using classification data to explain variations in observed FSD. For Iloilo rainfed land units, a trend toward decreased frequency of FSD when progressing from waterway position to high side slope positions was apparent. The major differences between rainfed units occurred after the 16th week. There was little difference between the medium and high side slope regimes, or between the plateau and low side slope regimes. Irrigation, when used, greatly increased the frequency of FSD after the 16th week. FSD estimates for fields with medium- or light-textured soils were much lower than those for fields with heavy-textured soils.

Land-related factors that modified the effect of rainfall distribution on FSD regimes in Pangasinan were water table depth class, irrigation class, and surface drainage class. Water table depth was the major factor differentiating land units. Land units with shallow water table had earlier increases in FSD frequencies and broader intervals of peak FSD frequencies than units with deep water table. Fields located within relative depressions (broad, natural surface drainageways) did not have greatly prolonged FSD regimes, as previously assumed. Irrigation differences were expressed more clearly. Within the shallow-water-table sector, the major irrigation difference arose between land units near free-flowing wells and the rainfed or partially irrigated units.

Plant protection. Study of current pest management practices of farmers identified the main obstacles to adequate control of insects and diseases as a general lack of awareness of pest problems, leading to inappropriate timing or pest control practices, and use of a sublethal dosage of pesticides.

The important insects and diseases recorded for nine crops were 1) tungro, yellow and white stem borers, rice caseworm, rice bug, rice leaf folder, and green-horned caterpillar for *rainfed lowland rice*; 2) no serious pest problems for *upland rice*; 3) Asian corn borer for *corn;* 4) corn earworm for *sorghum;* 5) powdery mildew, bean fly, flea beetle, corn earworm, black bean aphid, leafhopper, and bean pod borer for *mung bean;* 6) bean fly, flea beetle, corn earworm, black bean aphid, leafhopper, and bean pod borer for *cowpea;* 7) bean fly, flea beetle, lima bean pod borer, and soil-borne diseases for *soybean;* 8) black bean aphid and soil-borne diseases for *peanut;* and 9) sweet potato weevil for *sweet potato.*

Labor conditions and pattern performance. Cropping intensity and, hence, higher incomes in South Sumatra were found to be constrained by insufficient family labor for conducting all the crop work during peak seasons. *The gotong royong* labor exchange system partly relieved the labor constraint but labor hiring was still necessary. Labor hiring was so constrained by cash availability that an improved production credit system would allow substantial increase in income, especially in lowland rice systems where labor requirements were concentrated in short periods. New multiple cropping technology for lowland rice land in South Sumatra appeared promising, but the upland patterns needed improvement. Experiments also showed that yields of present patterns can be increased by more efficient application of present levels of input.

A method of computing seasonal labor opportunity costs based upon cash and in-kind payments to crop laborers was developed for use in routine cost and returns analysis. A wage schedule based on data from Cale, Batangas, Philippines, was significantly correlated with total labor use.

Baseline conditions for measuring research impact. To measure the impact of developing and introducing new cropping patterns, a baseline survey of farmers in Manaoag, Pangasinan, a cropping systems research site,

was analyzed to identify the levels of farm income, income distribution, cropping intensity, and other factors in target sites before research takes place. Net incomes were found to be lower in cropping systems where land and water conditions imposed difficulty for tillage between successive crops. Farmers tilled the poorly drained lowland soils only once a year and planted a single rice crop or a single rice crop followed by mung bean rice broadcast on top of the soil.

DESIGN OF CROPPING PATTERNS

After 2 years of research, the proposed cropping patterns were reduced to 11 for Iloilo and 8 for Pangasinan. In Pangasinan the wet season sets in gradually, and many soils require heavy rainfall accumulation before they retain standing water. To determine the feasibility of early rice crop establishment in that situation and any resulting advantage for the second rice crop, dry seeding was given priority as the establishment method for the first crop in rice-rice-upland crop patterns. Wet-seeded rice was emphasized in Iloilo because onset of rainfall was less predictable but more abrupt, and the heavy-textured soils easily retained water.

Designing rice-based patterns for production complexes. The expected field durations of the rice portions of patterns with two rice crops or a main rice crop plus a ratoon crop were compared against crop year (CY) 1976–77 flooded-status-day regimes estimated for three Iloilo land units. The results suggested that for the rainfed plateau and plain units, patterns containing two 100-day rice crops would be more risky and no more rewarding than patterns containing a main crop plus ratoon. For partially irrigated plateau units, a pattern with two crops of 125-day rice crops clearly appeared more productive and profitable than patterns with either two 100-day varieties or a long-duration main crop plus ratoon.

Determining insect and disease pest control recommendations. Insect and disease control recommendations for preproduction trials were determined by a process of selection, adaptation, and evaluation of national recommendations at each Philippine cropping systems site. The final pest control recommendations were tailored to farmer resource availabilities and managerial capabilities as determined from data compiled.

Turnaround in rice-rice cropping patterns. Case studies of farmers' power and labor utilization during turnaround periods between rice crops indicated that adequately irrigated areas can practice triple rice cropping with present resources. Long turnaround times in one irrigated area were related to the farmers' reluctance to grow three crops of rice per year because of high irrigation cost or undependable water supply. In a rainfed Iloilo site, long turnaround times reduced rice yields of the second crop on high elevation sites by as much as 700 kg for every 10 days of delay.

TESTING OF CROPPING PATTERNS

Iloilo tests. In CY 76–77, 17 alternative cropping patterns were designed for Iloilo land units. The patterns fell into six general groups. Two groups were designed for unflooded land units and four for land units with various durations of submergence. Early heavy rains caused shifts in many of the proposed cropping patterns. However, the shifts that occurred were mainly in the method of establishment of the first rice crop, although accumulation of excessive water precluded corn establishment. Because rice seedlings were not available, 17 of the 26 proposed patterns containing transplanted rice (TPR) were shifted to wet-seeded rice (WSR) to take advantage of the early rain.

Yield comparisons between land units showed little difference in the first rice crop, regardless of landform, irrigation class, or pattern group. However, yields of the second rice crop were influenced by water regimes, as governed by either landform or irrigation class. Upland crops following two rice crops generally suffered from drought.

The material costs of rice-rice-upland crop (R-R-UC) and rice-upland crop (R-UC) patterns were comparable across land units but those of R-UC averaged only US$17.89/ha less than those of R-R-UC. Across land units, the total returns and returns above variable costs for the same pattern group generally increased

as the moisture regime became more favorable.

Within heavy-textured, rainfed, high and medium side slope land units, farmers could not satisfactorily grow two rice crops and an upland crop, but were generally able to meet R-UC pattern requirements. Moreover, the R-UC pattern was more profitable than the R-R-UC.

Within heavy-textured, rainfed, low side slopes and plateau units, farmers were unable to successfully grow the R-R-UC patterns. The second rice crop in those units was very sensitive to moisture regimes. Of the 23 second rice crops attempted, 5 were total failures, while the top 5 yielders averaged 4 t/ha. The outcomes from pattern trials on heavy-textured, rainfed, plateau and low side slope units showed that farmers were able to cope with R-R requirements in the more favorable fields and with the R-UC requirements in the less favorable fields, but not with those of full R-R-UC patterns.

Within the plain and waterway land units, only R-R-UC patterns were attempted. Pattern performance indicated that farmers in such units could cope with the requirements of two rice crops, but not with those of the upland crops that followed.

In heavy-textured plateau and plain units receiving irrigation for less than 2 months beyond the normal end of the wet season (Irrigation I), farmers easily coped with the R-R portion of the R-R-UC pattern. The abbreviated R-R pattern group was more profitable than the R-UC.

For heavy-textured plateau positions receiving irrigation for more than 2 months beyond the normal end of the wet season, farmers also easily produced two rice crops, but the upland crops were often affected by seepage water from nearby fields where rice was still growing.

Of the upland patterns, the corn-upland crop-upland crop (C-UC-UC) pattern obtained the highest return over variable costs followed by C-UC and C + R-UC. Material inputs for upland patterns were higher than those for lowland patterns, reflecting slightly higher seed and fertilizer costs and preharvest labor requirements. All three upland pattern groups were satisfactorily grown in the trials. However, the C-UC-UC pattern, which had the highest return over variable cost, required the highest material cost and the most labor, leading to lower returns per unit of cash and labor.

Several management components that modify basic pattern group performance were compared with the use of cropping pattern trial data. These modifiers included methods of first and second rice crop establishment and upland crop performance at different tillage levels. Results clearly indicate that the farmer-cooperators could cope with WSR cultural requirements for the first crop, and that WSR resulted in higher yields and returns. For the second rice crop, the TPR method was better than the WSR method with respect to yields and returns over variable costs. There was little difference in upland crop yields regardless of tillage level, but lower costs made less intensive tillage procedures more profitable.

Pangasinan tests. In CY 76-77, 52 Pangasinan farmer-cooperators agreed to test cropping patterns on a total of 79 fields. The patterns tested were more intensive than the farmers' normal patterns. Pattern intensification was derived from the introduction of one additional crop in production complexes where only one or two crops had been traditionally grown, or from increased production in complexes where two crops had been grown but at a low level of management. The patterns tested belonged to four groups:

- green corn-rice-upland crops (GC-R-UC),
- rice-rice-upland crop (R-R-UC) or fallow,
- rice-upland crop (R-UC), and
- rice-rice-rice (R-R-R).

The patterns introduced were selected on the basis of performance in identified production complexes during CY 75-76. Thirty-seven patterns were located in the deep water-table sector and 42 in the shallow water-table sector of the research area.

As the CY 76-77 season started and the factors that control pattern adaptation in the deep water-table sector became more obvious, there was a shift to more R-UC patterns and less GC-R-UC and R-R-UC. But in the shallow water-table sector, the shift was toward more R-R-UC patterns. In many strictly rainfed fields, R-R-UC patterns were shifted to R-UC.

Average yields of single rice crop patterns in both deep water-table and shallow water-table

units were about 3.4 t/ha. Between water table sectors, no distinct differences in the yields of first rice crops in R-R-UC patterns were observed. However, the second rice crop was affected by drought in the later growth stage, yielding an average of 3 t/ha across the rainfed and partially irrigated units of the deep water-table sector, and 3.6 t/ha in the partially irrigated shallow water-table units. No R-R-UC patterns were attempted on rainfed shallow water-table land units.

Crop failures were common on green corn preceding rice because of heavy early rain. Only on the partially irrigated units where internal and surface drainage were adequate did the corn component approach satisfactory performance on more than half of the fields tested.

No land unit or pattern group gave a decided advantage to upland crops — average relative yields ranged from 38% for crops grown after a single rice crop in the shallow water-table sector to 48% for crops grown after 2 rice crops in the deep water-table sector.

On partially irrigated, shallow water-table land units, a R-R pattern was found most profitable in CY 76–77, and was also manageable for farmers. In the deep water-table sector, the green corn component of GC-R-UC patterns was more profitable than R-UC on the partially irrigated units. The performance of R-R-UC patterns in the deep water-table sector was moderately successful. Farmers attempting to grow the pattern were able to produce profitable rice crops and, in some cases, a profitable upland crop. However, a comparison of R-R-UC and R-R shows that returns to the upland crop were only 1.21 times that in the deep water-table sector.

A comparison of planting dates showed that dry-seeded rice (DSR) patterns were planted 11 days earlier than WSR, and 1 month earlier than TPR. Average yields of the DSR crops were higher than those of either WSR or TPR. The second rice crops, all of which were transplanted, yielded lowest when preceded by TPR, reflecting the late drought stress of the second crop. Material costs were highest for DSR, but labor costs were higher for TPR. DSR patterns had higher returns over variable costs than either WSR or TPR.

The performance of upland crops in the pattern trials showed that in CY 76–77, the traditional mung bean crop, and cowpea and sorghum, which are not commercially grown in the area, were moderately well adapted to the postrice-crop environment in the Pangasinan area, but showed potential for yield increases. Reduced tillage methods were adequate to produce profitable upland crops in most cases. In farmers' present systems, low tillage for mung bean resulted in as high yields and profit as high tillage. Controlling the bean fly with proper insecticides increased mung bean yields and profit threefold.

Batangas tests. Batangas cropping pattern trials showed that the upland rice C171–136 reduced harvest labor requirements by two-thirds. C171–136 yielded 1.5 t/ha higher than Dagge as a sole crop and 1.3 t/ha higher than Dagge on a corn-rice intercrop. Opportunity budgeting of labor costs substantially changed the evaluation of the performance of C171–136 compared with that of the long-used local Dagge.

Continuous rice cropping. A model for continuous rice production completed 1 year of operation. Crop yields of 23.7 t/ha gave an annual net income per hectare of US$1,811 (a monthly income of US$151.00). Rice production varied throughout the year but was closely related to solar radiation.

COMPONENT TECHNOLOGY DEVELOPMENT AND EVALUATION

Soil and crop management. Flooding for 7 days at different growth stages reduced yields of mung bean, soybean, and peanut more than those of corn and sorghum. The effects of flooding on grain legumes differed among the three crops studied. The soybean stand and seed weight were reduced, the mung bean stand and number of pods were decreased, and the peanut crop was particularly sensitive to flooding at the pod-filling stage.

A toposequence study showed that zero tillage reduced the turnaround times between rice and 6 upland crops by 2 weeks in low-lying paddy fields. Peanut yielded less in lower paddies than in higher fields and less in zero-tillage

than in high-tillage fields. Weed numbers and weed weights at time of first weeding were significantly influenced by topographic position and tillage.

Clark 63 soybean showed a more stable yield than TK5 and L114 when planted at 14-day intervals in a period of shortening day length and reduced soil moisture. The growth duration of those varieties was reduced by 17 days as a result of adverse growing conditions. Yield component analyses showed that average seed weight and number of pods per square meter accounted for 66% of the yield differences.

Yield responses of transplanted IR30 to complete (NPK) fertilizer differed substantially between the shallow and deep water-table sectors of Pangasinan. Available soil nitrogen was much greater in the soil with shallow water table and additions of phosphorus or potassium did not modify crop response to 60 kg N/ha. In the soil with deep water table, however, a basal application of 30 kg K/ha plus 60 kg N/ha significantly increased rice yields over a nitrogen application alone.

From experiments in which three levels of nitrogen and three zinc treatments were applied to a transplanted crop, no zinc response was obtained at the shallow water table site. However, the deep water table site showed a slight depression due to zinc. Nevertheless, the rice crop responded extremely well to nitrogen applications with or without zinc at both sites. Those responses differed from previous responses in the same vicinity.

The time of cassava planting in the cassava + [(corn + rice) cowpea-soybean] cropping pattern was critical for the performance of most crops involved in the pattern. The study indicated that it is best to plant the cassava 20 to 40 days after the establishment of the corn + rice intercrop. Cowpea yields were reduced by 80% by competition from cassava mainly because of poor shade tolerance.

Row pairing of corn in a corn-rice intercrop increased the land equivalent ratios (LER) of plots in which corn was planted at a distance of 40 cm or less between paired rows. High corn populations reduced rice yields and favored corn yields more than they did in previous trials with lower corn plant populations.

Three-and-a-half years of continuous monoculture cropping established varied patterns of growth that had inhibitory effects on upland rice and mung bean. Grain yields were consistently low after the second crop of upland rice, while the growth of mung bean was partly affected by season of planting. The sick mung bean soil tended to recover, however, after several poor croppings. Preceding crops of cowpea and sorghum had no detrimental effects on upland rice and mung bean, respectively.

Weed science. *Effect of dry-season land preparation on weed growth in the succeeding crop.* When neither fertilizer nor herbicide was applied to corn, significantly more but smaller weeds grew in the plot that was previously maintained as weedy fallow than in all the other plots, except those that were maintained weed free by cultivation. When basal nitrogen was applied, more weeds grew in the weedy fallow than in all other plots, except those that were maintained weed free with herbicides.

When herbicides were applied, weeds were fewer in the plot in which sweet potato had been planted. Plots that had previously been left as a weedy fallow had more weed species.

One week after crop emergence in the second trial, weeds were significantly fewer in the plots that were left weedy during the dry seasons than in those that were plowed once at the start of the experiment. Significantly more *Amaranthus spinosus* and *Portulaca oleracea* and significantly fewer *Dactyloctenium aegyptium* plants grew in the plot that had been plowed during the dry season than in the plots that had received no treatment.

In Pangasinan, land preparation during the dry season had different effects. In three fields, weeds were significantly fewer in the plots that had been kept weed free by tillage during the dry season. In one field, previous treatments had no effect on total number of weeds; in another, significantly more weeds grew in the plots that had been kept weed free.

Upland rice. The method of land preparation (stable seedbed vs conventional tillage) resulted in different proportions of the various species in the weed flora, but weed growth in the unweeded plots was so great there was no crop yield. Plots that were weeded once yielded sig-

nificantly less than the other plots that had been weeded and which used the stale seedbed technique but no difference was observed when the crop was planted immediately after initial land preparation.

Dry-seeded rainfed bunded rice. In unweeded plots, delay in date of planting from 5 to 27 May increased the weed weight. In most instances, the effect of initial weed control with herbicides could not be detected at crop harvest because the weeds rapidly grew as soon as the residual toxicity of the herbicide had disappeared.

Wet-seeded rice. In a trial in which wet-seeded rice was subjected to four different water regimes, the weed weight in the unweeded plots was highest in the plots that were not irrigated until 28 days after seeding and lowest in the plots that were continuously flooded. Of the herbicides used, thiobencarb followed by 2, 4-D, propanil, and propanil-fenoprop performed well under all water regimes. The yields obtained from each of the plots generally reflected the degree of weed control achieved with a particular treatment.

Soybean. In a herbicide trial conducted during the wet season when weed counts were made 15 days after soybean emergence, weeds were significantly fewer in the metribuzin-treated plots than in the butachlor-treated plots. Weeds were significantly fewer in the butachlor-treated plots than in the unweeded check. Neither herbicide had a detrimental effect on crop growth.

Effect of method of land preparation on weed growth in upland crops. In upland crops planted after rice in Pangasinan, tillage techniques, mulching methods, or weeding treatments had no significant effects on the yields of cowpea and mung bean. For sorghum, however, the unweeded plot always yielded significantly less than the weeded plots.

Competitiveness of upland crops against weeds. On the basis of weed weight at harvest, cowpea was the most competitive of seven crops against weeds, and rice was the least competitive. The percentage of yield reduction due to weeds did not necessarily reflect the competitiveness of the crop against weeds.

Advanced screening of herbicides for upland crops. Pendimethalin was the most promising of the herbicides tested for weed control in Batangas and at IRRI. Initially the compound was highly toxic to sorghum and soybean and moderately toxic to rice and corn. Sorghum and corn recovered and yielded almost as well as the hand-weeded check, but soybean and rice never recovered from the initial setback and yielded less than the hand-weeded check.

None of the herbicides tested gave consistently good results for all crops at the two sites. The best that can be expected from those available is a herbicide that is selective to only two or three crops.

Sorghum. Yield losses due to weeds were greatest when no nitrogen was applied and least when 120 kg N/ha was applied. The weight of weeds growing in association with the crop was less at close row spacing and high seeding rate than at wide row spacing and low seeding rate. However, neither plant spacing nor seeding rate affected crop yield.

In a herbicide trial on sorghum, most of the herbicides caused stand reduction and burning of the leaves. The herbicides gave good initial control of grasses and broadleaf weeds but failed to control sedges and volunteer rice seedlings. The herbicide-treated plots yielded less than the hand-weeded plots.

Intercropping. The amount of weeding needed to ensure optimum yields is dependent on the crops that are grown in the intercrop and the spatial relationship of one to the other.

Effect of crop rotation on crop and weed growth. Among plots that were planted to mung bean after sorghum, those that had previously been treated with atrazine had significantly fewer mung bean plants, indicating a residual carry-over of a lethal concentration of the herbicide. There was no indication that good weed control in the first crop resulted in fewer weeds in the unweeded second crop. But there were significantly more sedges in the plots that had been treated previously with atrazine and butachlor, reflecting the results obtained in the previous sorghum crop.

The effect of different degrees of weeding in one transplanted rice crop on weeds growing in association with the subsequent crop was examined in two trials. In the first trial, plots in which weeds were adequately controlled in the

first crop had fewer weeds in the second crop than plots in which weeds were poorly controlled. In the second trial, no significant differences in weed number or weight at harvest were observed as a result of previous weeding treatments. In both trials, the highest yields were obtained from the plots that were previously well weeded and the lowest, from those that had not been weeded.

In a trial in which the effect of soil and water management on weed growth and crop yield was studied, the population of *Scirpus maritimus* was considerably lower when lowland rice was rotated with an upland crop than when lowland rice was planted continuously. In the crop rotation, the population of *Cyperus rotundus* was reduced to 33% of that which occurred where upland rice was rotated with dry-seeded rainfed bunded rice.

In the wet season, the rice in an upland crop-lowland rice rotation yielded 1 t/ha in the unweeded plots, but the rice crop in the other cropping systems yielded nothing.

Plant protection. Double-cropped rainfed lowland rice developed insect pest problems only on the second crop in Iloilo. One prophylactic treatment using a systemic granular insecticide incorporated into the soil followed by foliar sprays at 30 and 40 days after transplanting gave the highest return.

There were indications that carbofuran insecticide directly stimulated the plant growth of dry-seeded rice, which achieved significant yield gains in the apparent absence of pests in Pangasinan.

Reducing the fertilizer input for corn is as effective as intercropping in controlling the Asian corn borer.

A well-timed insecticide application using high dosages is necessary to counteract the high populations of corn earworm attacking developing grains of sorghum planted after rice in rainfed-lowland environments. The same insect caused significant yield losses (as a pod borer) on mung bean in Pangasinan and likewise required high insecticide dosages for adequate control.

The presence of rice stubble substantially reduced bean fly attack on cowpea following lowland rice. This cultural method of insect control has been traditionally used by farmers who broadcast cowpeas into rice stubble.

For mung bean, insect control should receive a higher priority than powdery mildew control.

Fungicide seed treatment or foliar insecticide protection on peanut produces an equal but nonadditive yield response.

In all landforms except river levees, flooding during lowland rice culture is an effective cultural method in the control of *Meloidogyne* and *Rotylenchulus* nematodes attacking grain legumes.

Increasing the number of insecticide applications to a corn + mung bean intercrop under moisture stress resulted in higher mung bean yields at the expense of corn yields. Highest corn yields were in an untreated control.

Surveys of upland rice cropping pattern trials showed light infections of leaf blast in Iloilo and of bacterial leaf streak in Pangasinan. In upland crops after rice, damping-off (*Sclerotium rolfsii*) was associated with poorly drained areas and was more common in plots with zero or minimum tillage.

Varietal testing. Dry seeding of upland rice and Farmers' Evaluation of New Selections Applied Research Trials (FENSART) yield trials were conducted at IRRI, Batangas, Iloilo, and Pangasinan. Dry-seeding IR26 under rainfed-lowland conditions gave the highest yield (5.01 t/ha) at IRRI. In the upland rice trial in Batangas, IR3830-1 gave the highest yield (5.64 t/ha) with insect control. C171–136, a new variety for cropping pattern testing, gave the highest yield (5.48 t/ha) without insect control. C166–133 and IR2058-78-1-3-2-3 were the highest yielders in the FENSART yield trials at Pangasinan and Iloilo.

Several varieties of upland crops were evaluated under upland conditions with high tillage, and under lowland conditions with high and zero tillage. The most outstanding entries were sorghum D67–4, D67–1, and UPLB-SG 5; soybean Clark 63, UPLB-SY-2, and Kuro Daizu; peanut M10, Moket, and BPI P9; cowpea EG #3 and V59-41; sweet potato Jewel; and corn TC #1 DMR (TC #1 Early × Phil. DMR 1) F_3, Philippine DMR Comp. #1, TC #1 DMR × Penjalinan F_3, and Early DMR Comp. #1.

PREPRODUCTION EVALUATION

Results of preproduction evaluation in 1977 indicated that the rice-rice pattern grown under rainfed conditions in the Philippines is better adapted to the Visayas and Mindanao than to Central Luzon. A method for multilocation testing of new cropping patterns was developed. It used nonreplicated 1,000-m production plots in selected land types. Results indicated that yields from research sites were similar to those from production plots in farmers' fields of similar land types.

Pilot production programs were completed in Batangas and Iloilo. In Batangas, 100 ha of sorghum was planted in a pilot area. Yields were 1.4 t/ha in open fields and 0.90 t/ha under coconut palms. Only a few farmers grew ratoon crops, which were deemed essential for a profitable pattern. As a result, only a few farmers continued to plant sorghum in 1977, indicating that the new technology, as introduced, was not acceptable.

In Iloilo a pilot project named *Kabsaka* brought farmers from 9 barrios into a 2 rice crop system on 262 ha. First-crop yields (harvested September-October 1977) ranged from 3.5 to 7.75 t/ha.

CROPPING SYSTEMS NETWORK

The operational cropping systems network research sites numbered three in the Philippines, four in Thailand, two in Indonesia, two in Sri Lanka, two in Nepal, and one in Bangladesh. The two Nepal sites were added to the network in 1977. The network concentrated on design and testing of cropping patterns in different environments. Component technology research was conducted at each site. Different varieties of upland crops (sorghum, soybean, mung bean, peanut, and sweet potato) were evaluated (see reports in Cropping systems component technology section). Other major activities of the network were training of research and extension workers, sharing of research information, and varietal testing. Training was expanded in 1977 with 14 M.S. students, 4 Ph.D. students, 38 trainees in the 6-month cropping systems course, and 22 on-the-job trainees.

The cropping systems working group met twice in 1977. There were 28 participants in Bangladesh and 26 in Sri Lanka.

Cropping systems program

Environmental description

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LANDSCAPE-RELATED HYDROLOGY

Multiple Cropping Department

A land unit is a physical area that is homogeneous with respect to soil characteristics, landform type, and hydrologic regime. Land units generally found closely associated with each other comprise a land system. Within a given rainfall class, several land-related factors affect the duration of standing water on land units within land systems. The factors are landform, relative elevation of the land unit, soil texture, extent and nature of the watershed above the land units, and the gravity irrigation regime. The gravity irrigation network is conditioned by landform and relative elevation.

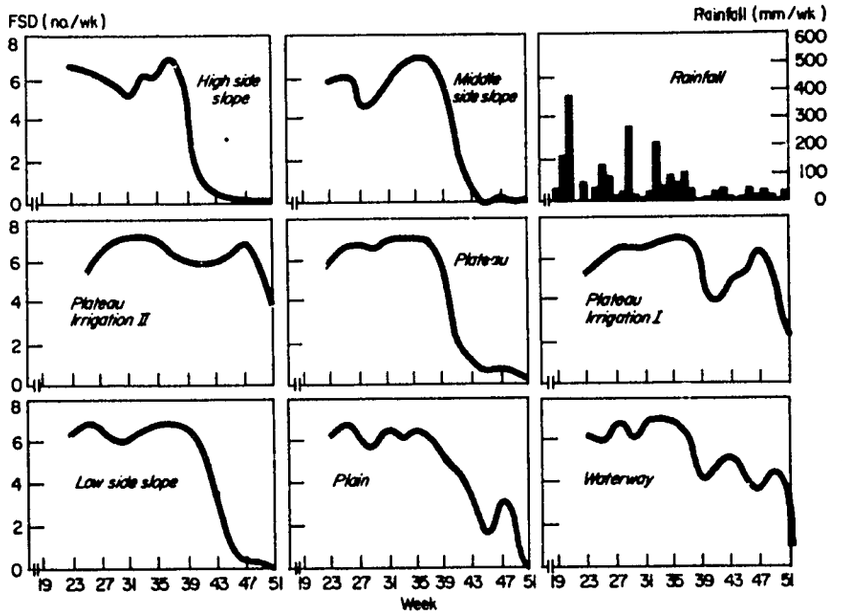
The stress day (SD) concept has been used by IRRI scientists as an indicator of water availability for lowland rice (1972, 1976 annual reports). In an analysis of factors affecting the duration of standing water on a field, the flooded status day (FSD) concept — essentially the reverse of SD — was used in 1976–77. The FSD is any day during which there is standing water on a field, whereas the SD is any day beyond 3 successive days during which there is no standing water on a field. Another difference is in the application of the two concepts. For the 1976–77 analysis, the FSD were counted during a period of about 7 months, whether or not a crop was in the field; SD were counted only during a period of crop growth.

Thus, the FSD concept indicated the period that standing water could be kept on the field in several important land units within the Pangasinan and Iloilo, Philippines, land systems. The rapidity of FSD increase at the beginning of the season, the reliability of FSD over the season, and the rate of FSD decline at the end of the season should affect pattern performance and thereby influence the domain of pattern adaptation.

The relationships between daily observations of FSD and several independent land factors were analyzed using the crop year (CY) 1976–77 monitoring data taken from Pangasinan and Iloilo cropping patterns. In the Pangasinan analysis, the numbers of FSD observed in 13 3-week periods were used as 13 dependent variables for a single model containing land-related classification factors appropriate for Pangasinan as independent variables. In the Iloilo analysis, 15 3-week periods were used as 15 dependent variables for a single model containing land-related classification factors appropriate for Iloilo as independent variables. For both the Pangasinan and the Iloilo models, the dependent variables were obtained from the number of observed FSD in weeks 1 to 3, in weeks 3 to 5, in weeks 5 to 7, and so forth, starting 26 May 1976. A 1-week overlap in the procedure was incorporated to reduce the effect of farmers' field operations, such as drainage before harvesting, on the number of FSD observed. Therefore, of the 31 weeks of Iloilo FSD data, 14 weeks were used twice; of the 27 weeks of Pangasinan FSD data, 12 weeks were used twice.

The actual CY 76–77 weekly rainfall distribution for Iloilo is superimposed over the diagram of the plateau position with estimated FSD in Figure 1. Although rainfall distribution has a major influence on the observed FSD regimes, the other diagrams indicate that regimes are modified by landform, soil texture, and irrigation class within landforms. In the analysis, soil texture was the texture of the horizon between 12 and 30 cm deep. It was used instead of the surface horizon because it was thought to have a greater effect on the establishment of a perched water table. Texture classes were heavy (c, sic, sc), medium (cl, sicl), and light (scl, l, sil, ls, sl).

Bund position or relative elevation within a landform class was found important only for side slopes. Estimated FSD frequencies per week were plotted in Figure 1 for six heavy-textured rainfed landforms. For these rainfed land units, a trend toward decreased FSD frequency is apparent, when progressing from waterways positions to high side slopes. The major differences between units occurred after week 16, reflecting greater decline in frequency for the higher landforms. There was little difference between the medium and high side slope regimes, and between the plateau and low side slope regimes. For the Iloilo rainfed units, all estimates of FSD began with high frequencies because heavy rains preceded the start of data recording. In the lower landforms FSD beyond



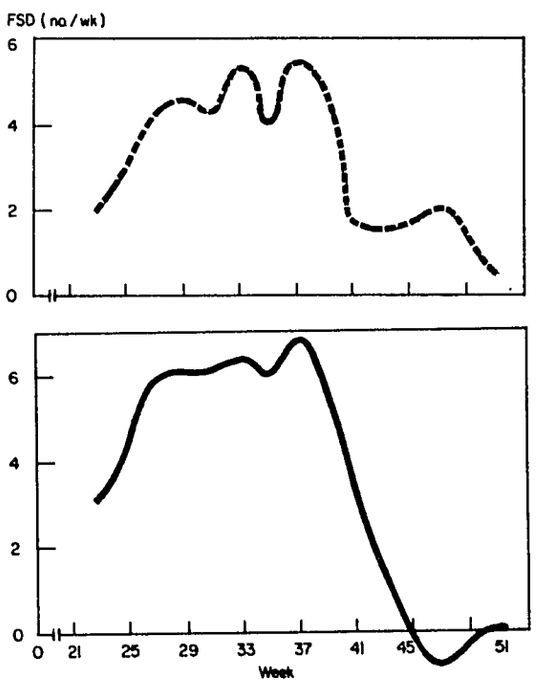
1. Weekly total rainfall and estimated flooded status days (FSD) for eight heavy-textured rainfed and irrigated Iloilo land units, 1976. The rainfall is the same for all units.

the end of the peak rainy period resulted because of the surface and base flow from higher elevations.

For heavy-textured plateau units, irrigation greatly increased the frequency of FSD after week 40. Irrigation I means partial irrigation 2 months or less beyond the end of the wet season, and Irrigation II means partial irrigation more than 2 months beyond the end of the wet season.

Composite estimates of FSD frequency from 4 rainfed fields located on a plateau with medium- or light-textured soils and from 4 fields with light-textured soils and coarse subsoil strata at least 10 cm thick are in Figure 2. The data indicated that

- a medium- or light-textured soil hampers the formation of a perched water table, which, for a land unit with a heavy-textured soil, causes a rapid and early increase in FSD;
- for a land unit with coarse substrata, rapid and deep percolation is a major factor causing lower than average FSD frequencies, even when rainfall sufficient to recharge coarse substrata has accumulated and is



2. Estimated flooded status days (FSD) for irrigated, light-textured side slope and plateau land units with coarse substrata (upper diagram) and rainfed, medium- and light-textured plateau land units. Iloilo, Philippines.

frequent enough to maintain near-maximum frequencies of FSD on land units with medium- and light-textured soils over heavy material; and

- although irrigation water increases the frequency of FSD on a land unit with coarse substrata, it is also subject to high percolation losses.

Statistics for the 15 Iloilo FSD periods are presented in Table 1. The data indicate the dynamic role of factors over the periods analyzed. A decreasing trend in total sum of squares (SS) occurred up to the sixth period; after the eighth period, the total SS increased rapidly. As indicated by the R^2, less variation is explained by the first 10 periods than by the remaining 4. The intercept started at moderate values, increased to high values toward the middle of the series, and then rapidly dropped to negative values. The changes in total SS, R^2, and intercept values reflect the dominance of rainfall at the peak of the wet season.

The extra SS for model variables (the contribution of the denoted variables to the model SS, after all other variables are present in the model) indicates that the role of landscape was moderate over all intervals. The relative elevation of side slope positions was moderately important during a few dry intervals toward the middle of the wet season and again at the end of the wet season. Irrigation played a moderate role up to the eighth period and from then onward played the dominant role in explaining the differences in FSD observed among the land units. The influence of a landscape-texture interaction was moderated in a few periods but was not considered important.

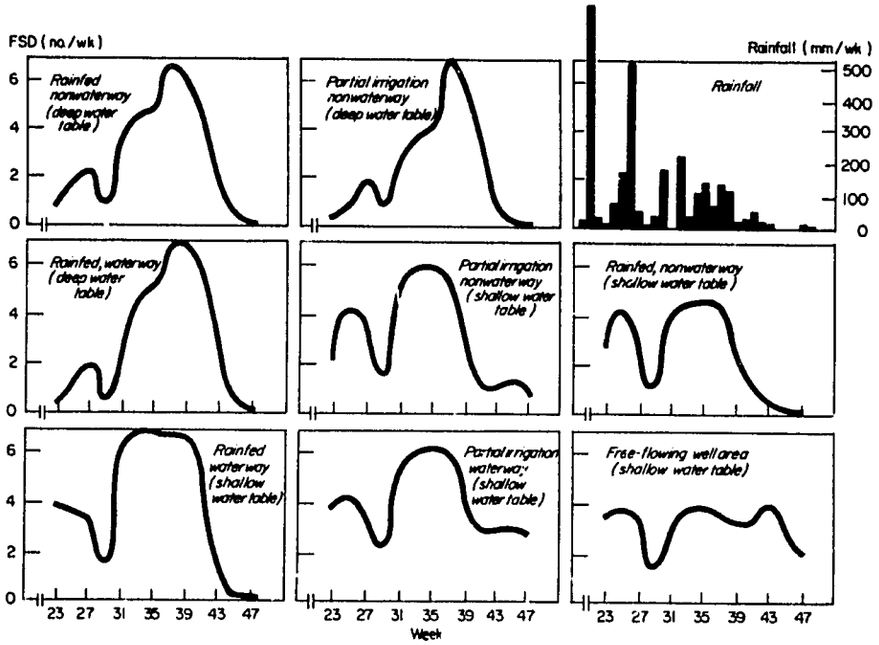
The actual CY 76–77 weekly rainfall distribution for Pangasinan is superimposed in Figure 3. The land-related factors that modify the effect of this distribution on FSD regimes are water-table depth class, irrigation class within the water table depth class, and depressions (or broad, natural drainageways) within the water table depth and irrigation classes. Figure 3 presents estimated FSD frequencies for 9 land units during a 27-week period. Water table depth was the major factor differentiating land units; it divided the area into two sectors—deep water table (Lipit-Pao) and shallow water table (Caaringayan).

On the basis of FSD regimes, the major differences between shallow and deep water-table land units are 1) an early increase in FSD, and 2) a broader interval of peak frequencies of FSD in the shallow than in the deep units. In the shallow units much less rainfall is required to recharge the subsoil, and the saturated substratum retards deep percolation losses. In comparison, a substantial portion of early rain-

Table 1. Iloilo flooded status day statistics for periods 1 to 15, crop year 76–77.

			Extra SS[b]																	
3-wk period	Total SS[a]	Model SS	LNDSCP		BNDPOS/ LNDSCP		IRRI BNDPOS/ LNDSCP		TEXT2		LNDSCP & TEXT2		Error SS	R^2	Intercept
1	4012	1625	109	(7.0)	12	(0.7)	280	(17.2)	485	(29.8)	25	(1.5)	2387	0.41	13.1
2	2364	1097	125	(11.4)	36	(3.3)	297	(27.1)	294	(26.8)	47	(4.3)	1267	0.46	13.7
3	1793	723	133	(18.4)	151	(20.8)	131	(18.1)	118	(16.3)	164	(22.7)	1070	0.40	11.3
4	1628	569	83	(14.6)	93	(16.3)	65	(11.4)	181	(31.8)	140	(24.6)	1059	0.35	10.2
5	1235	458	104	(22.7)	38	(8.3)	77	(16.8)	54	(11.8)	46	(10.0)	777	0.37	15.1
6	358	156	24	(15.3)	4	(2.5)	27	(17.3)	7	(4.5)	24	(15.3)	202	0.44	18.7
7	919	640	61	(9.5)	11	(1.7)	114	(17.8)	23	(3.6)	20	(3.1)	279	0.70	19.7
8	552	235	7	(3.0)	3	(1.3)	60	(25.5)	2	(0.8)	3	(1.3)	316	0.43	20.7
9	2016	470	10	(2.1)	57	(12.1)	298	(63.4)	25	(5.3)	67	(14.3)	1546	0.23	17.1
10	5156	2667	228	(8.5)	205	(7.7)	1895	(71.1)	33	(1.2)	141	(5.3)	2490	0.52	4.2
11	6588	3963	261	(6.6)	329	(8.3)	3114	(78.6)	86	(2.2)	6	(0.1)	2624	0.60	—1.5
12	7558	5793	281	(4.8)	195	(3.4)	4944	(85.3)	92	(1.6)	4	(0.1)	1765	0.77	—3.9
13	8805	6833	692	(10.)	88	(1.3)	5753	(84.2)	86	(1.3)	35	(0.5)	1937	0.78	—4.6
14	7085	4983	298	(5.9)	108	(2.2)	4278	(85.8)	29	(0.6)	190	(3.8)	2102	0.70	—4.3
15	4894	2914	40	(1.4)	3	(0.0)	2683	(92.1)	37	(1.3)	25	(0.9)	1980	0.60	—3.2
							Degrees of freedom								
	93	21	3		2		10		2		3		72		

[a]Sum of squares. [b]Figures in parentheses represent the percentage of SS explained by the extra SS due to inclusion of the variable in the model. LNDSCP is landscape, BNDPOS is bund position, TEXT is texture.



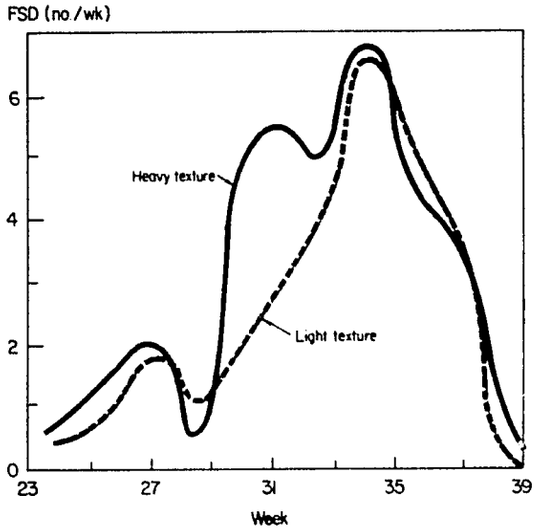
3. Weekly total rainfall and estimated flooded status days (FSD) for nine Pangasinan land units. Weeks 19 to 47, 1976.

fall is used to recharge the deep water-table units. The soils in the deep water-table sector are permeable, and rainfall rapidly infiltrates and percolates to deep soil layers. It is apparent that the local irrigation system had no significant impact on FSD regimes, either early or late in the wet season. The main irrigation canal runs along a river levee. Therefore, fields close to the irrigation canal, which are generally partially irrigated, tend to have deeper water tables and faster percolation than the lower lying fields further from the canal. Furthermore, the lower fields also receive run-on from higher fields. These two factors help to explain the slightly higher frequencies of FSD in nonirrigated fields than in partially irrigated fields.

Fields located within relative depressions or waterways did not have greatly modified FSD regimes as had been postulated, although rainfed depression units appeared to have slightly prolonged FSD regimes as rainfall declined.

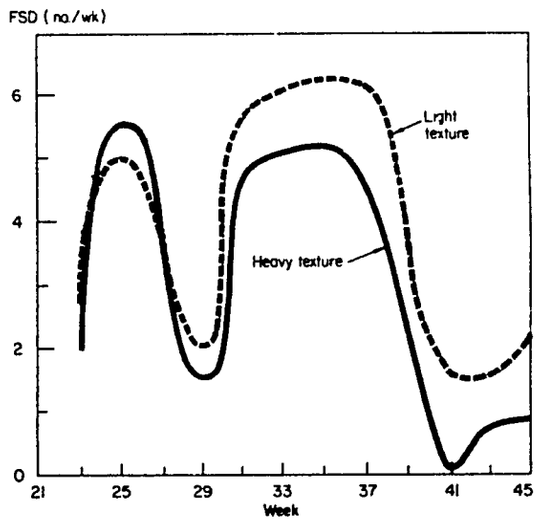
In contrast, within the shallow water-table sector, irrigation differences were expressed more clearly. The major irrigation difference arises between land units near free-flowing wells and rainfed or partially irrigated units. The partially irrigated units had higher FSD frequencies than rainfed units toward the end of the wet season. A comparison of the FSD regimes of nonwaterway land units indicates that the lower positions had higher FSD frequencies, especially when they are rainfed, as was noted in deep water-table fields. In partially irrigated fields, the FSD regimes were more favorable as the dry season started, although the frequencies were far from ideal.

Soil texture has also been postulated as a factor modifying FSD regimes. However, early models indicated that texture was less important overall than landform differences (waterway vs nonwaterway). Therefore, soil texture was abandoned as an explanatory variable so that the model's degrees of freedom would be reduced. Nevertheless, composited FSD estimates from an early model, which included the textural class of the second soil horizon as an independent variable, are presented in Figures



4. Estimated flooded status days (FSD) for heavy- and light-textured rainfed, nonwaterway, deep water-table land units. Pangasinan, Philippines, weeks 23 to 39, 1976.

4 and 5 for the two land units having the greatest number of observations. The estimates in Figure 4 are from nonirrigated, nonwaterway, deep water-table land units; those in Figure 5 from partially irrigated, nonwaterway, shallow water-table land units. A comparison of the estimates indicates that soil texture altered the regimes as expected, e.g., the heavier soils had



5. Estimated flooded status days (FSD) for heavy- and light-textured partially irrigated, nonwaterway, shallow water table land units. Pangasinan, Philippines, weeks 23 to 45, 1976.

greater average FSD frequencies over the season. However, the major difference among the deep water-table units occurred during the rise to maximum FSD frequency, while the effect on the shallow land units was more general over the period analyzed.

Statistics for the 13 Pangasinan periods are presented in Table 2. R^2 started at a high level and decreased with minor variation through periods 4 to 8, which correspond to the interval of maximum FSD frequencies. It again increased over the last six periods. Except in period 4, intercept values steadily increased to a maximum in period 8. Total SS decreased to period 8, then increased. Period 4, whose R^2 was lower than expected, corresponds to the reduction of FSD frequencies at week 29, which was preceded by an interval of low rainfall. The general behavior of total SS, model SS, and intercept values reflects the influence of rainfall distribution on FSD, especially after land units have been recharged. The extra SS indicates that water table depth was the dominant factor explaining the differences between land units, and that it was most important during the first three quarters of the period examined. Irrigation played a moderate role in the early weeks, (see periods 1–4), minor in the middle weeks (see periods 5-8), and major in the last weeks (see periods 9-13). However, its impact was important only in the shallow water-table sector. Landform played a moderate role as rainfall declined (see periods 7–10).

Undoubtedly, there are important land-related factors, other than those examined, that modify FSD regimes but have been ignored or incorrectly characterized for this analysis. The role of the watershed above the land units, with regard to its extent, landforms, soils, and vegetation, should be a major factor. The farmer's management of his water resources is undoubtedly another important factor.

A better understanding of FSD regime dynamics within a land system can provide an improved base for defining the domain of rice-based cropping patterns. Documentation of the regimes on different land units and of the roles played by factors at different stages of the season forms an important basis for a convincing communication of site-related research results.

Table 2. Pangasinan flooded status day statistics for periods 1 to 13, crop year 76–77.

3-wk period	Total SS	Model SS	Extra SS[a] WT	Extra SS[a] IRRI/WT	Extra SS[a] LNDSCP IRRI/WT	Error SS	R^2	Intercept
1	2503	1917	1207 (63.0)	579 (30.2)	131 (6.8)	587	0.77	0.9
2	3624	2466	2121 (86.0)	337 (13.7)	8 (0.3)	158	0.68	0.9
3	1961	934	546 (58.5)	366 (39.2)	21 (2.2)	1027	0.48	3.6
4	1685	563	227 (40.3)	308 (54.7)	28 (5.0)	1122	0.33	2.3
5	2442	1371	1133 (82.6)	104 (7.6)	134 (9.8)	1071	0.56	4.6
6	2297	834	563 (67.5)	130 (15.6)	142 (17.0)	1462	0.36	9.8
7	1503	630	425 (67.5)	60 (9.5)	145 (23.0)	873	0.42	12.4
8	913	316	136 (43.0)	54 (17.1)	126 (40.0)	598	0.35	20.6
9	2609	1165	451 (38.7)	378 (32.4)	336 (28.8)	1444	0.45	17.8
10	4343	1781	470 (26.4)	838 (47.0)	474 (26.6)	2562	0.41	11.9
11	3455	1589	58 (3.7)	1339 (84.3)	192 (12.1)	1866	0.46	2.4
12	2995	1656	482 (29.1)	1084 (65.5)	89 (5.4)	1339	0.55	0.0
13	2310	1256	357 (28.4)	763 (60.7)	135 (10.7)	1054	0.54	0.0

[a]Figures in parentheses represent the percentage of model SS explained by the extra SS due to inclusion of the variable in the model. LNDSCP is landscape, BNDPOS is bund position, WT is water table.

The performance of introduced cropping patterns on the Iloilo and Pangasinan land units is discussed in the section Testing of cropping patterns.

FARMERS' INSECT AND DISEASE CONTROL PRACTICES

Cropping Systems Components of Entomology and Agricultural Economics Departments

Traditional beliefs and other sociological factors may influence farmers' adoption of pest control practices. A study was designed to determine current farmer awareness of pest problems and the resources used to control them, farmers' awareness of various pest control methods in terms of acceptance of recommendations made, and possible new pest control techniques or pest problems from the farmers themselves. A random sample of 36 farmers was interviewed at each of 3 Philippine sites — Iloilo, Pangasinan, and Batangas.

Most of the 108 farmers (73%) were aware of the concept of plant resistance to pests. Their enumeration of resistant varieties mirrored the present status of plant pest resistance in the Philippines. Rice headed the resistance awareness list at each site — Iloilo (14 varieties), Pangasinan (25 varieties), and Batangas (4 varieties). One variety of corn — but no mung bean or cowpea varieties — was mentioned.

Farmers were also aware of cultural practices to control pests; 96% of them cited at least 1 method they used. Most frequently cited were increasing seeding rate (58%), intercropping (45%), crop rotation (34%), and time of planting (22%).

Farmers, however, were not aware of many biological-control organisms that parasitize or prey on the insect pests. No farmer mentioned parasites, and few knew the role of insect predators such as lady beetles. In fact, lady beetles were considered defoliators. Most farmers (70%) recognized birds, spiders, frogs, or dragonflies as important predators.

The farmers used a wide range of mechanical and physical control methods. Hand picking of insects from plants was mentioned by 84%. Several methods of rodent and bird control were also cited — scarecrows (55%), flags (57%), tin cans (29%), and crosses (28%). Other more conventional methods of bird control included suspending twine above the crop, clapping split bamboo sticks together, and placing bamboo propellers in the fields.

A high percentage (60%) said they practiced at least one of the traditional pest control methods listed below.

Pest control method	Pest
Plant parts as repellants or attractants	
Gliricidia sepium (Leguminosae) (madre	Rice army-

de cacao) branches and leaves, repellant	worm, rice caseworm
Cordia dichotoma (Borganinaceae) (anonang) branches and leaves, attractant, repellant	Termite, corn downy mildew
Traditional pesticides	
Ash	Aphids
Sand	Rice *Cercospora* leaf spot
Smoke from burning rubber tire	General
Rock salt	White grub
Kerosene	General
Soap	Aphids
Unfavorable planting dates	
Full moon	General
August	General
Dates with the number seven	General
Alarm mechanisms	
Riding a horse or carabao around a rice field at twilight	Rice bug
Circling the field with a burning bamboo pole	General
Magical or religious	
Invoking spirits that control pests	General
Offering food (rice, eggs, chicken) to appease spirits	General
Avoiding becoming angry with pests (spirits may become vengeful)	General
Making trial plantings to appease spirits	General
Blessing seed for planting on Holy Saturday	General
Reciting prayers while circling the field	General

Many farmers still invoke spirits that control or reside in pests. The most creditable methods, however, were the use of parts of plants as attractants or repellants, and the use of traditional pesticides. The most frequently mentioned plants were *Gliricidia sepium* and *Cordia dichotoma*.

Farmers, however, commonly used commercial insecticides to control insects. All farmers interviewed had used insecticides at least once during the year. Less than 15%, however, used fungicides to control diseases and only 2% used rodenticides. Most farmers (98%) believed pesticides increase crop yield but 51% expected yield gains of less than 25% from usage. Pesticides were considered readily available (91% responded affirmatively) but expensive (only 18% said pesticides were reasonably priced).

According to 97% of the respondents, the farmer-operator rather than the landlord made decisions on pesticide usage. Cash to purchase pesticides came from personal savings (63%) and bank loans (62%) more than from neighbors (16%), relatives (12%), or private moneylenders (3%). Most farmers (73%) said they purchased pesticides at least 1 week before usage and 66% indicated that pesticides were specific against a range of pest species.

All farmers interviewed said they had access to knapsack sprayers through either ownership (65%) or borrowing from neighbors or relatives (33%) or from village cooperatives (11%). The majority of farmers (59%) had used sprayers for more than 10 years. The availability of water for sprayers was a problem for 31% of the respondents; within sites, the rainfed-lowland farmers of Iloilo (44%) and Pangasinan (25%) expressed greater difficulty than upland farmers in Batangas (22%). Water for spraying was normally hauled to fields on animal-drawn sleds, and high bunds, as in Iloilo, hindered access to fields.

Sprayer sizes ranged from 11 to 19 liters, but the 15-liter size was most common (54%). The farmer-operator provided his own labor for spraying (94% of respondents); however, 31% said they had hired help from time to time. Most farmers (87%) said that no special skills were required to spray pesticides properly.

Safety considerations during pesticide usage appeared to be lacking. No farmer knew that pesticides could enter the body through the skin, but most (69%) took precautions not to inhale pesticide spray. The interval from time of spraying to safe consumption of the crop was more than 5 days, according to 61% of the respondents. Only 28% of the farmers stated that they feared using certain pesticides, par-

ticularly the insecticides endrin (27% of respondents), carbofuran (10%), and methyl parathion (4%).

For decisions on pesticide use, farmers depended mainly on their own initiative (51%). In addition, they relied on the advice of extension workers (32%) rather than on that of neighbors (4%), advertisements (4%), pesticide dealers (1%), or radio (1%). To determine pesticide dosage, most farmers (77%) relied on the written directions on the package rather than on guesses (13%). They preferred bottle caps (69%) to spoons (26%), graduated cups (10%), or guesses (5%) for measuring pesticide into sprayer.

Most farmers (81%) sprayed in the morning, and 90% believed it was necessary to spray all the plants in a field. Eighty percent knew that pesticides are washed off after heavy rains and most (81%) said they increased dosages in response to higher pest numbers.

Farmers applied pesticides in the presence of pests, pest damage, or at a certain plant growth stage (prophylactic) (Table 3). In rice, applications were equally divided among the three conditions, but in legumes, most (77%) were prophylactic.

Daily farmer records for CY 75–76 were studied for a detailed account of insecticide usage on each crop in the three Philippine provinces. The discussion centers on the rainfed lowland areas, Iloilo and Pangasinan, because no farmer in the Batangas upland sample applied insecticides to corn or rice and the area planted to grain legumes was too small to allow reliable conclusions. No farmer surveyed in either Iloilo or Pangasinan used insecticides on corn.

Rice. Insecticide usage on rainfed rice was low in terms of the number of fields in Pangasinan (27%) and Iloilo (54%). Most of the treated fields received only one application — Pangasinan (70%) and Iloilo (59%) — with a maximum of three and five applications for the two sites, respectively. The mean retail price of the insecticide used on treated fields was US$4.35/ha for Pangasinan and US$2.86/ha for Iloilo.

Timing of insecticide applications to rice differed between the two provinces. Insecticides were applied from 3 to 7 weeks after seeding in Iloilo, but from 6 to 10 weeks after seeding in Pangasinan, where insecticides were more frequently applied.

Table 3. Signs 108 farmers interviewed commonly follow to decide when to apply pesticide to rice and grain legumes. Batangas, Iloilo, and Pangasinan, Philippines, 1977.

Sign	Farmers (%)	
	Subtotal	Total
Rice		
Plant damage		37
Leaf damage or color change	24	
Floating leaves (caseworm)	9	
Deadheart	2	
Prophylactic		33
Panicle initiation	15	
Flowering	7	
After transplanting	7	
Presence of pests		29
Mung bean and cowpea		
Prophylactic		77
Flowering stage	60	
After rainfall	10	
Green pod stage	5	
Presence of pests		16
Plant damage		7

The most commonly used insecticides at each location were cheap, broad-spectrum sprays such as methyl parathion, azinphos-ethyl, MIPC, chlorpyrifos, malathion, monocrotophos, and carbaryl. Less than 5% of farmers chose granular formulations. Mean dosages per application were low, averaging between 0.07 and 0.16 kg active ingredient (a.i.)/ha.

Grain legumes. Because less than 6% of mung bean and cowpea fields in Iloilo received insecticide, data are from Pangasinan where 40% of mung bean and 44% of cowpea fields received insecticide. One application per field was most common for mung bean (45%) and cowpea (43%); the maximum number per field was four for mung bean and six for cowpea. The mean value of insecticide used on treated fields was US$5.17/ha for mung bean and US$11.02/ha for cowpea. Insecticide was applied after the flowering stage (5 weeks) for both cowpea and mung bean.

Farmer concepts and practices. For all crops, farmers generally used appropriate insecticides,

but they did not achieve good control because they used sublethal dosages, generally applied at the wrong time. In rice, applications of less than 0.5 kg a.i./ha are sublethal against any of the pests attacking the crop. The recommended dosage for sprayables is 0.75 kg a.i./ha. Farmers interviewed applied mean dosages far below that level.

In legumes, the problem of dosage was not as critical as that of timing. Research has shown that dosages of 0.25 kg a.i./ha are effective at the preflowering stage. Most farmers interviewed, however, did not begin to spray until after flowering, concentrating their efforts against the more difficult to control pod borers. Thus they could not get good control.

Farmers were correct in not using insecticides against corn pests because research has shown that insecticides are generally ineffective on corn.

The problem of inadequate dosages apparently did not result from putting insufficient insecticide into sprayers. Farmers interviewed generally followed the directions on labels. Low dosages arose from low spray volume per hectare. The farmers sprayed an average of 135 liters/ha although the dosages recommended on container labels, in tablespoons per sprayer load, were based on spray volumes from 350 to 1,000 liters/ha, depending on crop age.

The problem of timing stemmed from a lack of pest recognition. Although farmers interviewed in the three provinces have names in local dialects for most of the crop pests, many of the names translated into fly, worm, hopper, bug, or beetle. Few names identified plant diseases. The lack of a vocabulary to distinguish pest species indicated a general lack of perception. In some cases, pest organisms had local names but either were not considered pests (bean fly, whorl maggot, powdery mildew), or the type of damage was not appreciated (hoppers were commonly said to be defoliators).

The farmers were asked to rank, in order of importance, the three worst pests of rice, corn, and grain legumes. Their responses were compared with those determined from 2 years of testing in each of the 3 provinces. Degree of correlation was high in corn, low in rice, and lowest in legumes.

Farmers were asked to describe the pest problem in each of 17 color photographs depicting a wide range of pests and associated damage symptoms. They scored high in their perception of corn insect pests. For rice, the farmers recognized the large defoliators, the rice bug, and stem borer whiteheads, but not brown planthopper burn, stem borer deadhearts, or whorl maggot damage. Few farmers recognized the main preflowering legume insects — bean fly, flea beetle, or *Empoasca* leafhopper — or their symptoms. Farmers knew pod borers and the large defoliating larvae, but considered powdery mildew symptoms to be derived from factors other than living organisms.

The conclusions from this study follow:

1. Farmers are not achieving adequate control of pests, particularly through pesticide use.
2. A general lack of awareness of pest problems is a roadblock to proper timing of control practices.
3. Farmers generally apply sprayable pesticides at sublethal dosages because they use insufficient spray volumes for the amount of pesticides they put into sprayers.
4. The traditional methods of pest control are not a hindrance to adoption of modern pest control practices.

PESTS IN UPLAND RICE-BASED CROPPING SYSTEMS

Cropping Systems Components of Entomology and Plant Pathology Departments

Monitoring of disease and insect problems in upland rice-based cropping systems continued at sites in Batangas, Philippines.

Rice. Planting synchronized with the first rains in May or early June, after the 3-month dry fallow, prevents pest buildup in the single-rice crop systems. Farmers plant early to achieve older plants before the midmonsoon drought, which occurs usually in August. All farmers establish their rice crops quickly by direct seeding.

Intensive monitoring of insects and diseases over a 3-year period has not revealed a major pest problem in upland rice although the white grub problem remains a threat. Farmers claim that termites cause significant yield losses, but that has not been substantiated. Other soil pests are insignificant. Potential reduction in stands

due to ants is offset by high seeding rates (120 kg/ha). Armyworm outbreaks have been reported by farmers in the past. Rice blast or other diseases have not been observed in the Batangas area.

Corn. The Asian corn borer *Ostrinia furnacalis* (Guenee) is held in check by the earwigs *Proreus simulas* Stal and *Euborellia stali* (Dohrn) Fabricius, which are prevalent as predators in the upland environment. Ants cause significant loss of corn stand, but are not recognized as pests.

The corn seedling maggot *Atherigona oryzae* (Malloch) causes severe stand reduction only in August and early September plantings. Farmers have learned to avoid planting corn during those months. The timing of the corn-after-rice pattern prevents the seedling maggot problem. No disease problems have been observed.

Grain legumes. Mung bean, cowpea, and bush sitao planted after rice are damaged at preflowering by bean fly *Ophiomyia phaseoli* (Tryon), flea beetle *Medythia* prob. *suturalis* (Motschulsky) [formerly referred to as *Longitarsus manilensis* (Weise)], and leafhopper *Empoasca biguttula* (Shiraki), which can only be controlled by insecticides. Pod borers — *Cathochyrysops cnejus* Fabricius, *Maruca testulalis* (Geyer), and *Heliothis armigera* Hubner — are less important than the preflowering pests. The aphids *Aphis craccivora* Koch is normally held in check by heavy rains. Powdery mildew *Erysiphe polygoni* DC of mung bean is the only serious disease. Nematodes of the genera *Rotylenchulus* and *Meloidogyne* are important grain legume pests in upland soils.

Sorghum. The only serious pest problems of sorghum are the sporadic occurrences of *Mythimna separata* (Walker) and two insects that attack developing grains — *H. armigera* and the rice weevil *Sitophilus* spp. No serious sorghum disease has been observed.

PESTS IN LOWLAND RICE-BASED CROPPING SYSTEMS

Cropping Systems Components of Entomology and Plant Pathology Departments

Monitoring of diseases and insects in lowland rice-based cropping systems continued at sites in Iloilo and Pangasinan, Philippines.

Single-cropped rice. The rice whorl maggot *Hydrellia philippina* Ferino, yellow stem borer *Tryporyza incertulas* (Walker), rice caseworm *Nymphula depunctalis* Guenee, rice green-horned caterpillar *Melanitis leda ismene* Cramer, and rice bug *Leptocorisa* spp. were the important insect pests at Pangasinan. Tungro disease was destructive on susceptible varieties.

Less serious problems occurred at Iloilo. Rice whorl maggot and tungro were not a problem, but rice stem borers, rice caseworm, green-horned caterpillar, and rice bug consistently reduced yields. The white stem borer *Tryporyza innotata* (Walker) replaced the yellow stem borer as the dominant borer species.

Double-cropped rice. The first rice crop, planted with the early rains, generally escapes major pest damage. Only in Pangasinan did the rice leaf folder *Cnaphalocrosis medinalis* (Guenee) increase to significant numbers on direct-seeded first-crop rice.

The second crop of rice had the same pest problems as the single-cropped rice at both sites.

Green corn before rice. At both sites the Asian corn borer was a significant pest on green corn planted before rice. Downy mildew disease *Sclerospora philippinensis* Weston was important on early plantings (March and April) only at Pangasinan.

Sorghum. The corn earworm attacking the developing grains occurred in significant numbers at both sites. The Asian corn borer infested sorghum, although less intensively than it did corn. An unidentified lepidopterous webworm present in the panicles also caused losses. No major disease problems were noticed.

Grain legumes. Mung bean and cowpea were under intensive pressure from several preflowering insects. The most important was bean fly, followed by a flea beetle and leafhopper. At Pangasinan, a pod borer (the corn earworm) became abundant during the postflowering period.

Soybean in Iloilo was under severe attack by the lima bean pod borer *Etiella zinckenella* (Treitsche), which alone caused 79% yield loss. It caused damage mainly by boring into developing seeds, but it also defoliated plants during the vegetative stages. This insect was also recorded but was not a serious pest in the

pods of mung bean, cowpea, and peanut.

The principal disease problems were powdery mildew of mung bean and *Sclerotium* fungus infestation of the seeds and seedlings of all legumes, which slightly reduced stand. The parasitic nematodes *Rotylenchulus* spp. and *Meloidogyne* were checked by soil flooding during the rice crop.

Sweet potato. Damaging infestations of the sweet potato weevil *Cylas formicarius* (Fabricius) were recorded in Pangasinan. The attack started from infested planting material. No disease problems were found.

LABOR CONDITIONS AND PATTERN PERFORMANCE

Cropping Systems Component of Agricultural Economics Department

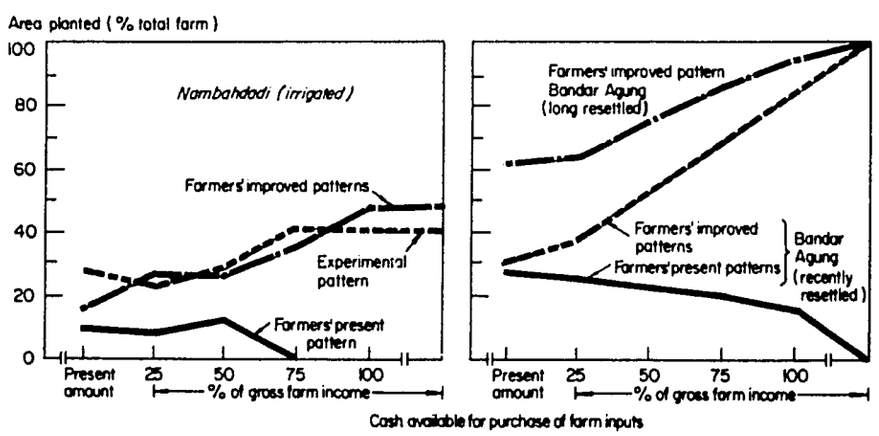
To examine the suitability of multiple cropping technology to economic conditions not found at Philippine sites, IRRI collaborates with researchers in the Cropping Systems Program of the Indonesian Central Research Institute for Agriculture (CRIA). After 2 years of research by CRIA on farmers' fields around Bandarajaya, Lampung, cropping systems research will expand to additional sites in Sumatra in 1978.

The Bandarajaya work included trials of experimental cropping patterns as well as documentation of present systems through a baseline survey and daily recording of crop operations on 36 farms. With those data, the collaborative project studied suitability of the multiple cropping patterns being developed and, particularly, the effect of scarcity of labor and cash in the area on crop intensification.

Profitability of new cropping patterns and higher input levels. Linear programming models were constructed for three farm types — one for irrigated lowland (typical of farms in the village of Nambahdadi), one where long-settled transmigrants farm only upland (the village of Bandar Agung), and one where new transmigrants farm upland (the village of Komering Putih). Each model gave, for a given set of farm resources, the most profitable combination of crop activities, including experimental cropping patterns and those currently used. Farm resources were weekly levels of cash and labor availability, and seasonal land availability. To determine why certain patterns are better suited than others, levels of farm resource and their prices can be repeatedly altered in the models and each new optimum combination of cropping patterns compared with other solutions.

Figure 6 represents the most profitable combinations of several types of cropping patterns as projected by the three farm models. The pattern types are:

- farmers' pattern where management and performance were reported by farmers and not observed by researchers;
- the most common farmers' pattern at each



6. Projected changes in area of land planted to various cropping patterns as the amount of cash available for purchase of inputs increases. Lampung, Sumatra, Indonesia, 1975–76.

Table 4. Relation of income and resource use to institutional factors on lowland and upland farms in Lampung, Indonesia. 1976.

Institutional factor and farm type	Changes[a] (%) in response to 1% change in level of institutional factors					
	Gross income	Net income[b]	Land use	Total labor use	Hired labor use	Family labor use
Wage rate						
Lowland farms	-0.14	-0.19	-0.11	-0.11	-0.57	-0.04
Upland farms	-0.15	-0.17	-0.13	-0.04	-0.95	+0.04
Labor repayment period						
Lowland farms	0.15	0.28	0.16	0.20	-1.02	0.35
Upland farms	0.08	0.18	0.13	0.14	-0.06	0.16
Available cash						
Lowland farms	0.72	0.29	1.33	0.73	2.16	0.33
Upland farms	0.27	0.19	0.27	0.36	1.16	0.10

[a]Percentage of change was computed when each institutional factor increased from present levels, when the wage rate increased about 15%, when the period allowed for returning labor services was extended from 4 to 6 weeks, and when cash operating capital was doubled. [b]Computed as gross income less the cost of chemicals, seeds, and hired labor.

site with improved management, and

- experimental patterns managed by researchers.

The most profitable combination of cropping patterns grown under the present labor and cash conditions of Lampung farmers is shown by points on Figure 6 above "present amount" on the horizontal scales. Presently it is profitable to use 52% of all land in Nambahdadi, distributed to all three pattern types. In Nambahdadi, the experimental rice-rice pattern is a promising alternative for farmers. The projected use of improved farmers' patterns under present conditions indicates that higher levels of input use are also profitable. Unusually dry weather in 1975–76 caused the late crops in experimental pattern trials to have low yields on rainfed upland in Bandar Agung and Komering Putih. Data from 1976–77 trials are being incorporated into new models to better assess these patterns. Nevertheless, the projected use of improved farmers' patterns indicates higher rates of input are profitable on uplands.

To further identify factors relevant to research priorities that constrain cropping intensity and other measures of benefit, various response elasticities were computed, assuming changes in underlying economic conditions. The elasticities shown in Table 4 show the percentages of change in income, labor use, and land use for a 1% change in each of 3 economic conditions: wage rate, available cash, and the period of time allowed for repayment of borrowed labor through the labor exchange system called *gotong-royong*.

Wage rates. When wage increased from present levels, farm income, land use, labor use — especially hired labor use — all declined, as expected. These responses were generally less than 20% of the magnitude of wage changes. That indicates that the returns to labor under present conditions were well above market wages, that present wage levels were not a strong deterrent to additional labor use, and that some other factors were likely to be more influential in determining present and potential cropping systems. Furthermore, the mix of cropping patterns (not shown) remained about the same at all wage levels, indicating that the productivity of labor used in experimental and in farmers' patterns was not sufficiently different to favor the adoption of either type of pattern.

Exchange labor. In Indonesia, *gotong royong* means helping one another. It can take the form of exchanging labor — borrowing or lending labor that is later repaid within an agreed time period, usually 4 weeks in Lampung. As exchange labor constituted a third of crop labor in Lampung, it was necessary to consider it in the analysis of wage and cash effects on crop activities. It was modeled as a bank; an amount of *gotong royong* labor could be used on a farm in a given week if an equal amount of labor was deducted from the farm family's work capacity within 4 weeks before or after the week

Table 5. Effect on income of increasing the amount of cash available for crop production by US$75/farm in Lampung, Indonesia, 1975–76.

Village name and type	Present cash input (US$/farm)	Net income (US$/farm)			Change in profit/US$1 more input (US$/US$1)
		At present level	With additional input	Change	
Nambahdadi, partly irrigated	102	292	343	50	0.66
Bandar Agung, long-settled	26	205	259	54	0.71
Komering Putih, newly settled	17	160	236	76	0.99

when *gotong royong* labor was to be used.

The results were compared with those when no labor exchange was permitted. The system of *gotong royong* was worth US$102/irrigated farm (35% of net income), US$104/long-settled upland farm (51% of its net income), and US$52/upland farm of new transmigrants (33% of net income). To earn these additional net incomes, the irrigated farm expended 533 additional man-hours of family labor for a return of US$0.19/man-hour; the long-settled upland farms, 897 additional man-hours for US$0.12/man-hour; and the new transmigrant farms, 589 additional man-hours for US$0.09/man-hour. The additional family labor expended was wholly channeled through the exchange system; in fact, the use of family labor directly on family-owned farms declined with the institution of *gotong royong*. Labor exchange increased employment and also improved its efficiency.

The elasticities of income, land use, and labor use as the labor repayment period is extended beyond 4 weeks are shown in Table 5. Lowland farms tended to respond more sharply to the extension of the labor repayment period, reflecting the greater concentration over time of their labor requirements compared with that of upland farms, and hence greater gains from spreading of labor demand over more weeks.

Because research cannot change the operation of the labor exchange system, the implications of the model for labor-spreading through labor exchange are less pertinent than those for labor-spreading through pattern design. The development of substitutable cultural practices for lowland rice, which has diverse characteristics with respect to timing and level of labor requirements should increase the capacity of the farm family for growing it. Techniques, such as direct seeding and minimum tillage, will complement, rather than replace, present technology on farms.

Cash availability. The relatively high elasticities of response to increases in available cash for farm operating expenses shown in Table 5 indicated it as the most important factor directly affecting income, and land and labor use in Lampung. However, most of the additional cash was spent for hiring labor, indicating that family labor availability, or the concentration of crop labor requirements was the underlying problem. The elasticities were computed for a range of cash use exceeding the levels currently used by farmers and, therefore, represented the possible response to improved credit facilities in Lampung.

Because labor constrains crop activities more on lowland farms than on upland farms, the response to greater operating cash reserves was higher there. Some of the gains from higher cash use were transferred off the farm — to hired labor, and perhaps to consumers in the form of more produce for sale. In fact the farmer himself would have been about as well-off from a 1% increase in the labor repayment period discussed earlier, where net income and family labor use increased comparably.

As different amounts of cash were spent on crop production in the 3 farm types, a 1% increase represented a different absolute amount on each type. The models were also used to find the effect of spending an equal addi-

tional amount (US$75) on each farm type, and the results are shown in Table 5. The US$75 was 75% of the irrigated farmers' present expense, but was more than 4 times that of the new transmigrants.

Additional expenditures increased income most, absolutely and proportionately, on the new transmigrants' upland farms and brought their net incomes close to those of the older transmigrants. Each additional US$1 spent on the newly settled — the poorest — farm returned US$0.99 profit; it returned US$0.71 on the older upland farm, and US$0.66 on the lowland farm.

The results imply that credit facilities should be increased in Lampung, farmers should be permitted to use production loans for hiring labor, and increased cash availability to the new transmigrants should be emphasized. Figure 6 shows that the projected increase in upland crop production with greater cash availability came from both expansion of area and use of more inputs. On lowland, more cash permitted area expansion, higher rates of inputs, and more crops per year through double rice cropping. With respect to area expansion, however, the results can alternatively be interpreted to indicate that more animal or mechanical power should be introduced. In the present models, most land preparation is done by hand. The projected area expansion as cash increases is associated with hiring more workers for tillage. The possibility that the same can be accomplished through investment in animals or tractors is being investigated.

Seasonal wages. The 1977 labor study in Indonesia and results of other labor analysis reported in 1975 and 1976 suggest that new cropping patterns should be designed to use farm labor resources more evenly through the year. Three techniques for assessing the gains from redistribution of labor requirements have been reported: a labor redistribution index (1975), a computer simulation of the impact of new patterns on system labor variance (1976), and the 1977 linear programming analysis of labor-spreading through *gotong royong*. Each approach was based on the principle of pricing labor resources at the level they would earn in the next best opportunity for employment.

A simpler, less accurate technique for designing and testing new cropping patterns based upon opportunity cost pricing of resources, was developed in 1977. For each week of the year when hiring was observed, a wage was computed by dividing the total value of worker compensation, in cash and kind, by the observed hours worked. Wages were interpolated for weeks when no hiring was observed, and the series was smoothed by taking a 5-week moving average. Figure 7 shows weekly imputed wages in Cale, Batangas, charted with weekly labor use in the village for all crop activities. The correlation at the 99% level of probability ($r = +0.38$) indicates that the total labor requirements in a village influence the labor wage rate for all activities. A similar result was obtained using wage data from an Indramayu, Indonesia, site.

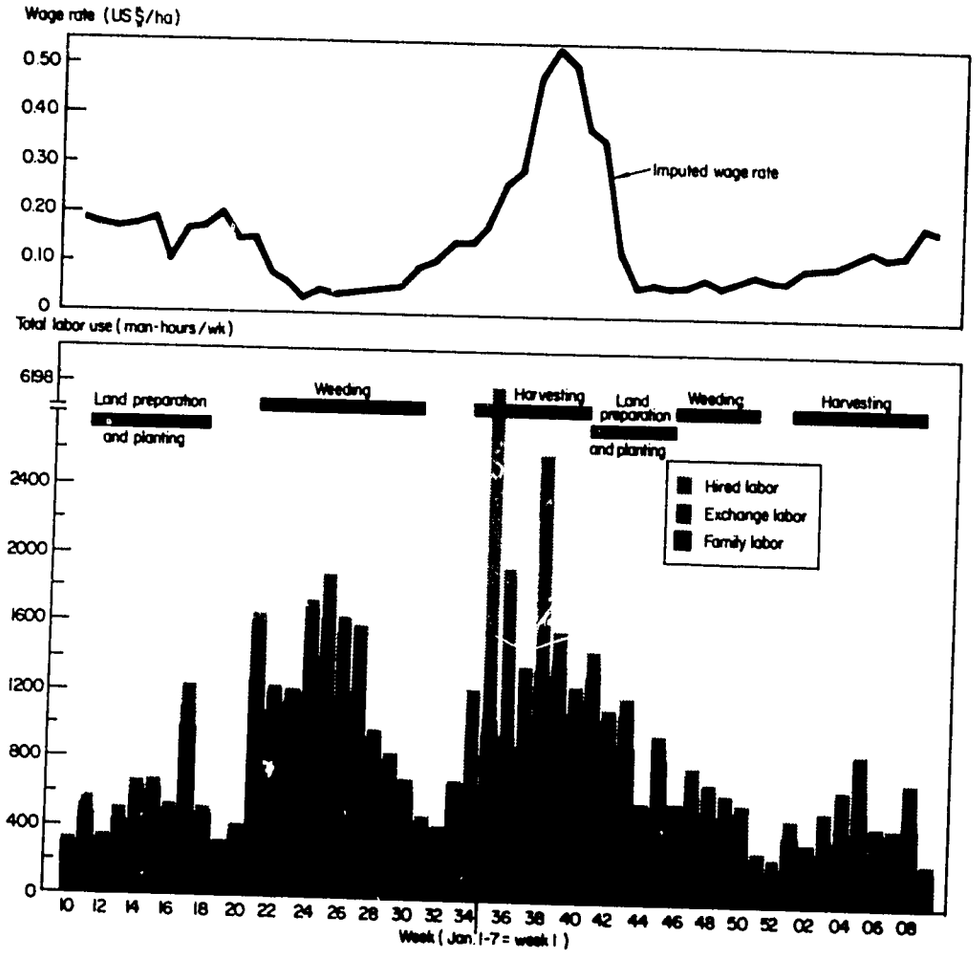
The imputed wage schedule can be regarded as the opportunity cost of labor and used to price the entire labor input into new cropping patterns according to the week labor is used. In designing new patterns, the lower labor costs resulting from following an early crop schedule — for example, using direct-seeding methods and early maturing varieties — can be estimated and compared with the expected yield effects. A more precise evaluation of pattern acceptability is possible after field trials have been carried out, and timing and levels of labor requirements, and yields have been observed.

The imputed wage schedule in Figure 7 was used to evaluate the profitability of C171-136, a new upland rice variety in Cale, Batangas. The new variety was 19% more profitable with opportunity-cost pricing of labor than with constant wage rates. A simple procedure for computing schedules of labor opportunity costs was included in a prototype handbook for economic analysis of cropping systems, for the use of researchers testing new cropping patterns.

BASELINE CONDITIONS FOR MEASURING RESEARCH IMPACT

Cropping Systems Component of Agricultural Economics Department

Description of a research site is required for efficient cropping pattern design and testing.



7. Weekly labor use and imputed weekly wage rates on 36 farms in Cale, Batangas, Philippines, 1975–76.

Eventually the impact of research at a site will be assessed by measuring changes that reflect farmer welfare or societal benefits. Present land use, farm income, and farm income distribution are likely to measure the impact of IRRI research at Philippines sites; they are therefore characterized at the early stage of research. Studies at Manaoag, Pangasinan, were particularly revealing of relationships between cropping systems, the land types where they occurred, and relative income levels.

A baseline survey of 103 Manaoag farmers indicated that the average farm was 1.58 ha, of which 76% was lowland growing an average 1.8 rice crops/year. The upland remainder was planted to 1.1 crops/year per farm. Seventy percent of land was sharecropped, 23% owned, 3% mortgaged, and 4% leased or rented. Twenty-eight different cropping patterns using 15 crops were grown in 1975–76. The cropping patterns and the land area of each follow: rice-mung bean, 54.3%; rice-fallow, 9.7%; sugarcane, 8.5%; rice-mung bean-corn, 7.5%; rice-rice, 5.7%; rice-squash, 3.2%; rice-tomato, 2.6%; rice-tobacco, 1.4%; rice-corn, 1.1%; mung bean, 1.0%; and 18 other patterns, 5.0%. Each farm grew an average of 2 patterns, and rice occupied 53% of the area planted.

Rice gave 47% of the gross farm income, but only 4% of that was cash sales. All crops together contributed 71% of the gross farm household income (18% of it in cash sales);

Table 6. Profitability of four cropping systems observed on a random sample of farms at Manaoag, Pangasinan, Philippines, 1974–75.

Measures of profitability	Profitability per farm[a]				
	Type I Rainfed lowland, poorly drained (40)	Type II Rainfed lowland, well-drained (20)	Type III Rainfed lowland, + upland (27)	Type IV Irrigated lowland + upland (76)	All systems (103)
Farm receipts					
Cash (US$)	223	268	392	419	306
Noncash (US$)	321	372	355	388	349
Total (US$)	543	640	746	808	655
Farm expenses					
Cash (US$)	112	138	144	139	130
Noncash (US$)	191	209	214	237	208
Total (US$)	304	347	358	376	338
Earnings					
Net farm (US$)	239	293	381	432	317
On farm capital[b] (US$)	207	249	340	368	275
Rate on farm capital (%)[c]	8.3	8.3	8.8	7.7	8.3
Operators' farm labor[d] (US$)	82	118	128	174	115
Household farm labor (US$)[e]	101	132	153	202	136
Household farm labor and capital[f]	161	182	250	278	207
Household, from all sources[g] (US$)	335	206	548	284	358

[a]Figures in parentheses are number of farms. [b]Net farm earnings less unpaid operator labor. [c]Earnings on capital less capital investment x 100. [d]Net farm earnings less interest on capital investment. [e]Operator farm labor earnings + unpaid household labor. [f]Household farm labor earnings + interest on capital investment. [g]Household farm labor and capital earnings + off-farm and nonfarm income.

livestock, 12%; and nonfarm jobs, 17%. In half of the farm households someone received outside income; half of the earners were the operators themselves.

The cropping systems of the 103 randomly chosen farmers were differentiated into 4 types by the degree to which the quality of their land favored cropping intensity. Forty farms were classed as rainfed lowland with heavy, poorly drained soils. All 40 farms grew only one cropping pattern — either rice-fallow (34 farmers) or rice-mung bean. The mung bean was usually broadcast into the standing rice crop a week before harvest and grown with a low level of management. The low level of cropping intensity on the rainfed farms resulted primarily from insufficiency of rainfall for two crops of lowland rice and the difficulty of tilling the heavy, poorly drained soils to a condition suitable for upland crops after rice. Only one land preparation per year was conducted.

Twenty farms were classed as rainfed lowland with well-drained soils. They used one to four patterns — corn-rice-mung bean, rice-mung bean, rice-vegetables, or rice-tobacco — each with an upland and a lowland crop. Every farm grew at least one pattern requiring two land preparations, one of which converted soil from the lowland to upland condition, or vice versa.

The third farm type (27 sample farms) had both rainfed-lowland and upland soils. On these farms the patterns were rice-mung bean, corn-fallow, root crop-fallow, and sugarcane. Every farm grew the rice-mung bean pattern plus one or more of the single upland crops.

The fourth farm type (16 farms) had irrigated lowland where rice-rice was grown, plus upland where either a grain legume followed by corn, or a root crop followed by mung bean was grown. All land on farms in this class grew either two lowland crops or two upland crops, with no conversion of lowland to upland or vice versa.

Incomes were lowest in those systems where land quality least favored multiple cropping, and highest where multiple cropping was possible without restructuring the soil between crops. Some data are given in Table 6, and are reflected in the ratios of total farm receipts to total farm expenses: 1.8 for farm type I, 1.9 for II, 2.1 for III, and 2.2 for IV. The data suggest that with present technology, farm incomes are positively related to the degree to which land

quality favors cropping intensification. Development of double-rice patterns for rainfed lowland where single rice crops are now grown will benefit the poorest of Manaoag farmers in terms of farm income alone, and create more equal income distribution in the area.

Cropping systems program

Design of cropping patterns

Multiple Cropping Department and Cropping Systems Program and Cropping Systems Components of Entomology, Plant Pathology, and Agricultural Economics Departments

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RICE-BASED PATTERNS FOR CROP YEAR 1977–78.

Multiple Cropping Department and Cropping Systems Program

After 2 years of research, the number of cropping patterns was reduced to 11 for Iloilo and 8 for Pangasinan. The distribution of the proposed patterns is given in Table 1. For Iloilo, research on improved patterns for knolls and other unflooded land units was discontinued because results showed little improvement over farmers' present patterns, and the area covered by those units was relatively small. Iloilo land units receiving partial irrigation were also excluded, and the project resources were concentrated on the more widely distributed rainfed land units.

For Pangasinan, the onset of the wet season is relatively gradual and many soils require heavy rainfall accumulation before they retain standing water. In a test to determine if early planting of the first rice crop would be feasible and result in an advantage for the second crop, dry seeding was given priority as the establishment method for the first crop in a rice-rice-upland crop (R-R-UC) pattern. Because improved rice-upland crop (R-UC) patterns previously tested were found adapted and competitive with existing ones, no new patterns were designed for crop year (CY) 1977–78. Fertilizer and tillage studies were outlined to investigate possible reduction in production costs of upland crops in R-UC patterns without substantial yield sacrifices.

Proposed cropping patterns for Pangasinan were also allocated so that the flooding hazard to an early green corn crop on shallow water table units was eliminated.

Designing rice-based patterns for production complexes (*Multiple Cropping*). Rice varieties in several maturity classes are critical in the design of improved rice-based patterns for the major production complexes in Iloilo. During the 1976 wet season, a transplanted rice yield trial at Iloilo provided information on varietal performance on which to base future pattern designs. The selections formed two groups: one with 10 early-maturing cultivars, and another with 12 medium-maturing cultivars. Both groups received high levels of pest protection and had adequate water management. The coefficient of variation was 9.8% for the early group and 7.7% for the medium group. A quadratic regression analysis was computed for yield means (Y) against maturity (M) and maturity squared (M^2). The resultant equation and data points are plotted in Figure 1. Assuming other factors constant and equal, 79% of the yield difference in this set of data was explained by differences in cultivar maturities.

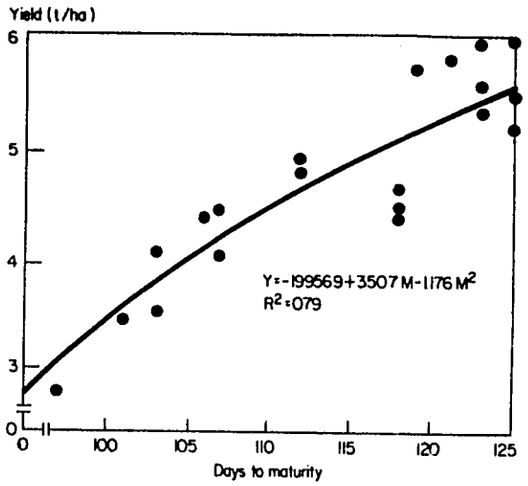
As a design activity, the rice portion of patterns containing two rice crops or a main rice crop and a ratoon crop were superimposed on flooded status day (FSD) regimes measured in

Table 1. Planned distribution of proposed rice-based patterns to landform classes in Iloilo, and water table classes in Pangasinan, for crop year 77–78.

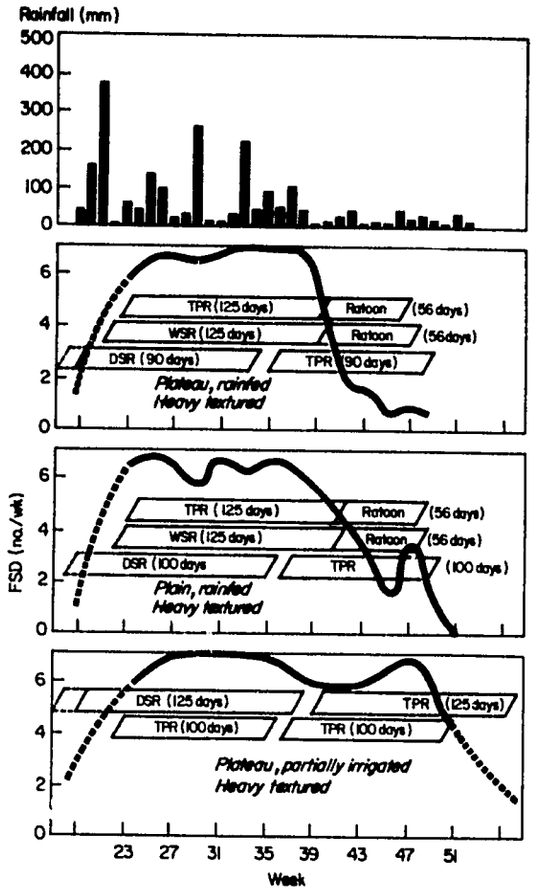
Pattern[a]	Planned distribution (no.)			
	Landform class			
	Plain	Plateau	Side slope	Bottom-land
Iloilo				
I Rice-Rice-Upland crop				
DSR-WSR-M, CP	4	2	2	—
WSR-TPR-M, CP	8	2	2	8
WSR-WSR-M,CP	—	—	—	4
II Rice-Upland crop				
WSR,TPR-SOR	1	2	2	—
WSR, TPR-P	1	2	2	—
WSR,TPR-M	1	2	2	—
WSR,TPR-CP	1	2	2	—
WSR,TPR-SP	1	2	2	—
WSR,TPR-SB	1	2	2	—
III Green corn-Rice- Upland crop				
GC-WSR,TPR-M	2	6	6	—
GC-WSR,TPR-CP	2	6	6	—

Pangasinan	Water table class	
	Deep	Shallow
I Rice-Rice-Upland Crop		
DSR,WSR-TPR-M	7	7
DSR,WSR-TPR-SOR	5	9
DSR,WSR-TPR-CP,BS	5	9
DSR,WSR-TPR-P	5	6
II Green corn-Rice-Upland Crop		
Corn-TPR-R-M	6	—
Corn TPR-R-SOR	6	—
Corn-TPR-R-CP	6	—
III Rice-Rice-Rice	—	9 (free-flowing wells)

[a]DSR = dry-seeded rice, WSR = wet-seeded rice, TPR = transplanted rice. M = mung bean, CP = cowpea, SOR = sorghum, P = peanuts, SP = sweet potato, SB = soybean, and GC = green corn.



1. Relationship between yield and maturity of transplanted early and medium-maturing rice selections during the 1976 wet season, Iloilo, Philippines.



2. Possible rice components of patterns designed for three Iloilo land units, versus flooded status day (FSD) regimes based on crop year 76–77 results. Broken lines indicate projections of model input. TPR = transplanted rice, WSR = wet-seeded rice, DSR = dry-seeded rice.

CY 1976–77 for three Iloilo land units (Fig. 2). Assumed field durations, yields, costs and returns, and labor incomes are presented in Table 2 for the rice portion of five selected combinations from Figure 2. The combinations used only selections of either 100- or 125-day maturity. Yield estimates are based on the relationship in Figure 1, and no depressions due to establishment method or drought stress were assumed in the computation of returns. Ratoon crop yields of 900 kg/ha following transplanted rice (TPR) and 800 kg/ha following wet-seeded rice (WSR) main crops were assumed.

In designing the patterns, it was necessary to make many assumptions relative to crop performance, weather, farmer's management, and production costs. Of these, major assumptions were in crop performance and the variability of weather.

The results of this design activity suggest that

Table 2. Assumed field duration, yields, and costs and returns of five potential rice components designed for Iloilo land units, crop year 76–77.

Pattern[a]	Field duration (wk)	Total yield (t/ha)	Total returns (US$)	Total variable cost (US$)	Returns above variable cost (US$)	Labor income (US$)	Returns above material costs[b] (US$)
TPR_{125}–ratoon	24	6.4	964	521	444	370	814
WSR_{125}–ratoon	26	6.2	934	445	489	253	742
DSR_{100}–TPR_{100}	28	6.8	1,118	808	310	466	775
DSR_{125}–TPR_{125}	36	11.0	1,733	925	808	582	1,390
TPR_{100}–TPR_{100}	26	6.8	1,071	890	181	630	811

[a]TPR = transplanted rice, WSR = wet-seeded rice, DSR = dry-seeded rice. Subscript numbers indicate days to maturity. [b]Returns above variable cost plus labor income.

on the dominant rainfed plateau units, patterns containing two 100-day rice crops are more risky and no more rewarding than patterns containing a main crop followed by ratoon. Furthermore, once a second rice crop is established, the flexibility of forgoing a ratoon in favor of an upland crop, should the weather become dry, is lost.

Although rainfed plain units are less drought prone than plateau units for the second crop, additional cost is necessary to produce the two-rice-crop pattern, and the returns above variable cash costs (labor income plus returns above variable costs) are about the same as that expected from the pattern of a main crop followed by ratoon. Moreover the extra water needed to produce the second rice crop, much of which must come from stored soil water as the crop matures, may leave the soil too dry for optimum growth of a subsequent upland crop. For partially irrigated plateau units, patterns with two crops of 125-day rice varieties are clearly more profitable than patterns with two 100-day varieties. However, patterns with varieties of about 115 days maturity and with a WSR first crop could be only slightly less productive than the longer DSR-started pattern and would be much less risky in the partially irrigated environment.

DETERMINATION OF INSECT AND DISEASE CONTROL RECOMMENDATIONS

Cropping Systems Components of Entomology and Plant Pathology Departments

Pest control recommendations for preproduction testing of cropping patterns were determined by a process of selection, adaption, and evaluation of national recommendations during a 3-year testing period of each at three Philippine sites. They will be further evaluated during the preproduction phase of the program.

The recommendations were designed to minimize difficulty of choice on the part of the farmer. Prophylactic methods against significant pests that occur year after year were specified.

The operational process is schematically presented in Figure 3. It begins with scrutiny of national pest control recommendations and results from other cropping systems sites.

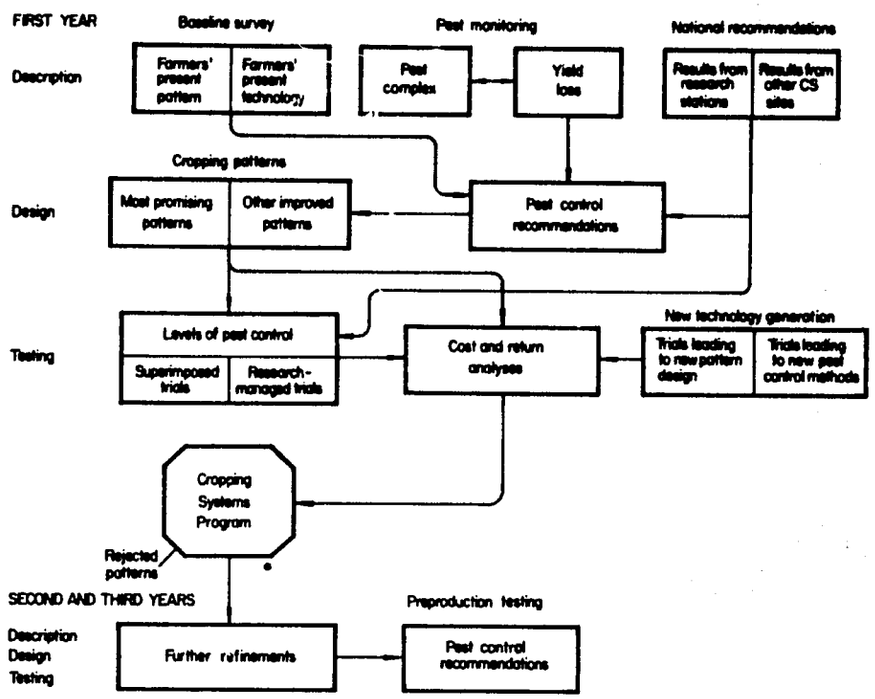
- The number of cropping patterns that can be studied during the first year is limited to manpower availability, and preference is given to the most promising patterns.
- Yield losses, calculated from the difference between completely protected and untreated plots, are transformed into monetary terms and, if significant, the pest species causing such losses become the target of the following year's trials.
- Pest control research priorities carried out at cropping systems sites differ from those of experiment station-oriented research.

Varietal resistance. Methods of pest control tested at the cropping systems sites should stress pest-resistant varieties that meet agronomic specifications. Entomologists and plant pathologists cooperate with the trial agronomists to monitor pests.

Pesticides follow varietal resistance in importance as a pest control method of cropping systems sites. Screening should be limited to pesticides for controlling pests whose distribution is restricted to certain sites and for which little information is available.

Testing at a site should stress timing, frequency, and method of application — factors known to vary locally, depending upon pest complexes, rainfall patterns, soil characteristics, and crop establishment methods.

- Cultural control methods tend to be site specific and generally are less proven at the national level. Planting time would be the most important cultural factor to test; however, intercropping, tillage method, plant density, crop residue management, and fertility levels can also be important. Cultural methods need to be compatible with results being found by the other team members.
- Biological control of insect pests would be last in importance as a method to test at cropping systems sites because of the limited information available. Conservation of natural enemies, however, would receive first priority. Extensive monitoring of arthropod populations is necessary. Predator populations can be sampled along with pests, and parasites can be reared from insects at the site. If a predator or a



3. Scheme of the 3-year process of adapting national pest control recommendations for cropping patterns at cropping systems sites. IRRI, 1977.

parasite were found to be a limiting factor for a pest, then methods should be found to conserve its numbers.

The pest control recommendations for the three Philippine sites are summarized in Table 3.

Feedback to national and international research centers. During the testing phase (Fig. 3) at each of three Philippine cropping systems sites, problems developed, which, if solved (new technology generation), can lower the cost of pest control and make more cropping patterns economically attractive to farmers.

- There is a need for more insect-resistant varieties for several crops, including an early maturing lowland rice resistant to whorl maggot; a corn variety with good eating quality resistant to both downy mildew and Asian corn borer; a sorghum variety resistant to corn earworm; mung beans and cowpeas resistant to corn earworm, bean fly, flea beetle, leafhopper, and aphids (in that order); and soybeans resistant to the lima bean pod borer, bean fly, and flea beetle (in that order).
- There is a general need to find a more efficient pesticide delivery system to replace the knapsack sprayer.
- In-depth studies are essential to identify effective biocontrol agents for all crops.

TURNAROUND IN RICE-RICE CROPPING PATTERNS

Multiple Cropping Department and Cropping Systems Component of Agricultural Economics Department

Delay between harvesting of one rice crop and planting of the next is a serious constraint to intensification of cropping patterns. The turnaround period was studied at two small irrigated rice areas in Laguna Province as well as at a rainfed Iloilo research site.

In one area in Laguna, which had a private pump scheme, farmers had year-round control over water supply. The dominant cropping pat-

Table 3. Insect and disease pest control recommendations designed for pre-production testing of cropping patterns at Batangas, Iloilo, and Pangasinan sites, Philippines,[a] 1977.

Crop	Cropping pattern	Upland environment		Lowland rainfed environment			
		Batangas		Iloilo		Pangasinan	
		Recommendation	Target pest	Recommendation	Target pest	Recommendation	Target pest
Rice	Single crop Double crop (second crop) Third crop	None necessary		1. Resistant variety 2. Soil incorporated 1.5 kg a.i. carbofuran/ha at planting	Tungro Stem borer caseworm, greenhorned caterpillar	1. Resistant variety 2. Soil incorporated 1.5 kg a.i. carbofuran/ha	Tungro Whorl maggot, stem borer, caseworm
	Double crop (first crop) Dry-seeded	—		1. Resistant variety 2. 0.5 kg a.i. carbofuran/ha in seed furrow	Tungro	1. Resistant variety 2. 0.5 kg a.i. carbofuran/ha in seed furrow	Tungro None
	Wet seeded	—		None necessary		1. Resistant variety 2. Soil incorporated 1.0 kg a.i. carbofuran/ha at planting	Tungro Whorl maggot
Corn	Green corn before rice	—	60 kg N or intercrop		Asian corn borer	1. 60 kg N or intercrop 2. Avoid planting in late May or June	Asian corn borer Downy mildew
	Corn after rice	1. Diazinon WP or carbaryl WP seed treatment (Oct.-Nov. plantings)	Ants	—		—	
		2. 0.5 kg a.i. carbofuran/ha with seed (Sept. planting)	Seedling maggot	—		—	
		3. Use no foliar insecticide to conserve earwig predator	Asian corn borer	—		—	

continued on opposite page

Sorghum	After rice	Apply 1.0 kg a.i. carbaryl/ha when 0.5 larva/grain head threshold is surpassed	Corn earworm	Apply 1.0 kg a.i. carbaryl/ha when 0.5 larva/grain head threshold is surpassed.	Corn earworm	Apply 1.0 kg a.i. carbaryl/ha when 0.5 larva/grain head threshold is surpassed.	Corn earworm
Mung bean	After 1 or 2 rice crops, zero or high tillage	1. Resistant variety 2. 0.5 kg a.i. carbofuran/ha in seed furrow	Powdery mildew Bean fly, flea beetle, leafhopper	1. Resistant variety 2. Spray 0.25 kg a.i. monocrotophos/ha at 2 and 12 DE 3. Spray 0.75 kg a.i. carbaryl/ha at 25 DE	Powdery mildew Bean fly, flea beetle, leafhopper Pod borers	1. Resistant variety 2. Spray 0.25 kg a.i. monocrotophos/ha at 2 and 12 DE 3. Spray 0.75 kg a.i. carbaryl/ha at 25 DE	Powdery mildew Bean fly, flea beetle, leafhopper Corn earworm
Cowpea	After 1 or 2 rice crops, zero or high tillage	0.5 kg a.i. carbofuran/ha in seed furrow	Bean fly, flea beetle, leafhopper	1. Spray 0.25 kg a.i. monocrotophos/ha at 2 and 12 DE 2. Spray 0.75 kg a.i. carbaryl/ha at 35 DE	Bean fly, flea beetle, leafhopper Pod borers	1. Spray 0.25 kg monocrotophos/ha at 2 and 12 DE 2. Spray 0.75 kg a.i. carbaryl/ha at 35 DE	Bean fly, flea beetle, leafhopper Corn earworm
Soybean	After 1 rice crop, zero or high tillage	1. Maneb treatment 2. 0.5 kg a.i. carbofuran/ha in seed furrow	*Sclerotium* Bean fly, flea beetle	Do not plant	Lima bean pod borer	1. Maneb seed treatment 2. Spray 0.25 kg a.i. monocrotophos/ha at 2 and 12 DE	*Sclerotium* Bean fly, flea beetle
Peanut	After 1 or 2 rice crops	Maneb seed treatment	*Sclerotium*	Maneb seed treatment	*Sclerotium*	Maneb seed treatment	*Sclerotium*
Sweet potato	After 1 or 2 rice crops	Clean planting material	Sweet potato weevil	Clean planting material	Sweet potato weevil	Clean planting material	Sweet potato weevil

[a]WP = wettable powder, DE = days after emergence.

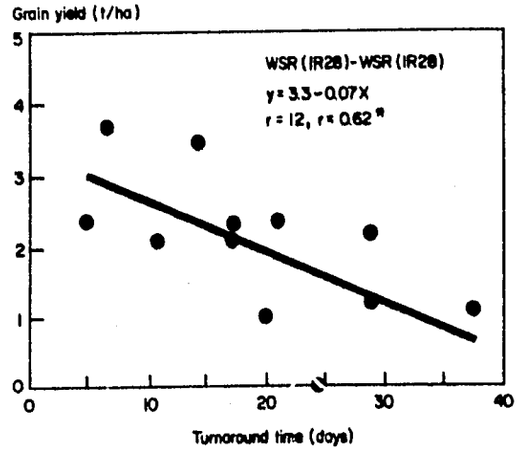
tern was rice-rice, but some fields were planted to rice-rice-watermelon. The work activities and field operations of 10 farms were recorded throughout the turnaround periods after harvest of the second rice crop.

The average turnaround period was 74 days/ha (range of 52 to 116 days). The fields required only 5 days/ha for harvest, 10 days for land preparation, and 1 day for transplanting. Farmers and laborers worked an average of 35 man-hours/week during the turnaround period; however, the amount ranged from 48 man-hours/week and 54 man-hours/week at harvest and land preparation and dropped to 20 man-hours/week between turnaround times. A three-rice-crop farmer in the same area averaged 56 man-hours/week with no dip in workload during turnaround, suggesting that farmer-labor is not a constraint to shifting to triple cropping. Farmers confirmed the lack of a labor constraint. Labor for harvesting, land preparation, and planting came from almost completely separate pools.

There was likewise no evidence of a draft-power constraint. Land preparation used a combination of carabao plowing and hand-tractor harrowing, mostly hired. With current land preparation times, a three-rice-crop pattern is possible.

Although irrigation water was available, the cost of fuel and availability of pumps restricted its use. The cost of irrigation was estimated to be 135% higher than that for government-managed schemes. Benefit:cost (B:C) ratios averaged 1.7 for the share-tenant. Farmers were reluctant to grow a third rice crop, because it was almost completely dependent on irrigation water.

The second Laguna area received irrigation from a government-managed source that also provides year-round irrigation. Three crops were grown each year with turnaround periods of about 30 days. Harvesting and land preparation times were the same as those for the first study area. The irrigation was low cost and sufficient for high yields; therefore farmers used additional cash for fertilizer and pesticides. The result was a B:C ratio of 2.4 to the share-tenant — an incentive to intensify the cropping pattern. An additional incentive was the favorable



4. Relationship between yield of second rainfed rice crop and turnaround time. Iloilo, Philippines, 1976. WSR = wet-seeded rice.

contractual arrangement between share-tenants and the landlords. The share-tenants received half the produce after deducting 1/8 share for harvesters and only paid 1/5 of production costs. Seventy percent of the gain to the farmer in the second study was due to these favorable contractual arrangements, with only 27% due to the lower costs and higher production. The conclusion was that the cropping pattern in the area intensified to three rice crops because of reliable and cheap irrigation water.

At the rainfed Iloilo site the constraints on turnaround were more numerous. Research in 1975 indicated a constraint on both draft power and labor. The 1976 research was focused on water adequacy, the major physical constraint.

Although the average turnaround time was 21 days between the first and second rainfed rice crop, the range was from 4 to 37 days. The wet-seeded second crop was established in only 16 days, but with more thorough land preparation, the transplanted second crop took 26 days. However, with seedlings 20 days old or older, the transplanted crop was harvested earlier than the wet-seeded crop and therefore escaped drought stress. This late drought stress was the main reason for low yields of the second crop.

Because of the compounding effects of landscape position, supplemental irrigation, variety, and times and methods of rice establishment, there was no simple relationship between turnaround time and yield of the second rice crop.

However, a significant relationship was found between turnaround time and yield for the WSR-WSR pattern using IR28 for high-elevation sites (Fig. 4). Because the first crop on all sites was seeded in the same week, yield reduction was effectively a function of second-crop planting date. A delay of 20 days would cause a 1.4 t yield reduction (Fig. 4). This alone would justify increased expenditures on turn-around operations to ensure early establishment of the second rice crop. In addition, where the second rice crop was harvested early, a third upland crop could be grown on the residual moisture.

Cropping systems program

Testing of cropping patterns

Multiple Cropping Department and Cropping Systems Components of Agronomy, Agricultural Economics, and Entomology Departments and Office of Rice Production Training and Research

ILOILO TESTS 424
Method of rice establishment 428
Upland crops and their management 428
PANGASINAN TESTS 429
Establishment of first crop in R-R-UC 433
BATANGAS TESTS 434
CONTINUOUS RICE PRODUCTION MODEL 435

ILOILO TESTS

Multiple Cropping Department and Cropping Systems Components of Agronomy, Agricultural Economics, and Entomology Departments

The IRRI-Bureau of Plant Industry (BPI) cropping systems research area in Iloilo falls in a 2.3 climate pattern (1976 Annual Report) of 5–6 consecutive wet months with 200 mm rain and 2–4 consecutive dry months with 100 mm rain. The soils and associated land systems are common and widespread in other rice-growing areas. Taxonomically, the predominant soils are Pelluderts, Eutropepts, and Tropofluvents. Soil surface materials are generally moderate to slightly acid clay or silty clay material. The land system was derived by erosion of an old terrace; the result is a landscape sequence of beach ridges, to marine plains, to dissected low terraces, to colluvial intermediate terraces, to high relict terraces, and to foothills. Although the Iloilo research area is essentially rainfed, an increasing number of land units receive partial irrigation of varying duration.

On the basis of crop year (CY) 1975–76 field tests, landscape and soil texture were considered in the CY 76–77 cropping pattern design phase. Seventeen alternative cropping patterns were designed, based on landscape, soil texture, and average rainfall distribution (1976 Annual Report). These patterns fall in 6 general groups, as shown in Table 1. Groups E and F were designed for unflooded land units within the land system. Groups A, B, C, and D were designed for land units with various durations of submergence. To visualize the cropping patterns in relation to the expected rainfall distribution, the proposed patterns are plotted against average monthly rainfall in Figure 1.

The actual rainfall pattern deviated greatly from the 20-year average (Fig. 2). In CY 76–77, early typhoon during May caused a monthly rainfall total for that month three times the long-term average. At the end of the wet season, October received less than half its long-term average rainfall, and November and December were also below average.

As a result of the heavy rains during May, most of the proposed cropping patterns were not followed. The pattern shifts were mainly in the method of establishment of the first rice crop, although excessive water either precluded corn establishment if it had not been planted before the typhoon or resulted in crop failure if corn had been planted (Table 2). Taking advantage of the heavy rain, farmer-cooperators established more rice by the wet-seeded rice (WSR) method. Of the 36 proposed patterns containing a dry-seeded rice (DSR) first crop, 33 were shifted to WSR. Seventeen of the 26 proposed patterns containing TPR were shifted to WSR because rice seedlings were not available. All corn proposed to precede a lowland rice crop either was shifted to WSR or failed because of excessive moisture, thereby eliminating pattern group D (C-R-UC).

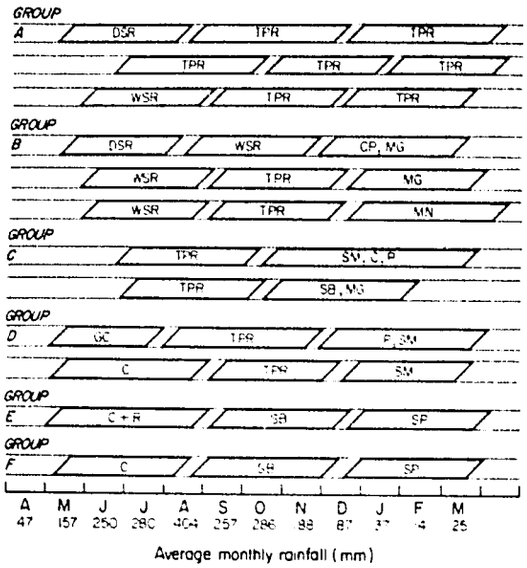
Because of the similarities in flooded status day (FSD) regimes (see Environmental description section), the cropping pattern results were combined by pattern groups over the following land units:

- high and medium side slopes, rainfed, heavy textured,

Table 1. Distribution of fields for proposed cropping patterns. Iloilo, Philippines, crop year 76–77.

	Cropping pattern[a]	Fields (no.)
A.	Rice-rice-rice (R-R-R)	
	1. DSR-TPR-TPR	10
	2. TPR-TPR-TPR	2
	3. WSR-TPR-TPR	1
B.	Rice-rice-upland crops (R-R-UC)	
	1. DSR-WSR-cowpea	24
	2. DSR-TPR-WSR-mung bean	2
	3. WSR-TPR, WSR-mung bean	32
	4. WSR-TPR-melon	1
C.	Rice-upland crops (R-UC)	
	1. TPR-sorghum	11
	2. TPR-soybean	9
	3. TPR-mung bean	2
	4. TPR-corn	1
	5. TPR-peanut	1
D.	Corn-rice-upland crops (C-R-UC)	
	1. Green corn-TPR, WSR-peanut	1
	2. Green corn-TPR, WSR-sorghum	1
	3. Corn-rice-cowpea	8
E.	Corn + rice-upland crop-upland crop (C +R-UC-UC)	4
F.	Corn-soybean-sweet potato (C-UC-UC)	6
	Total	116

[a]DSR = dry-seeded rice, WSR = wet seeded rice; TPR = transplanted rice, C+R = corn + upland rice intercrop, R = rice, UC = upland crop.



1. Proposed cropping patterns and 20-year average monthly rainfall, crop year 76–77, Iloilo, Philippines. DSR = dry-seeded rice, TPR = transplanted rice, WSR = wet-seeded rice, CP = cowpea, MG = mung bean, MN = melon, SM = sorghum, C = corn, P = peanut, SB = soybean, GC = green corn, C+R = corn and rice intercrop, SP = sweet potato.

- low side slopes and plateaus, rainfed, heavy textured;
- plains and waterways, rainfed, heavy textured;
- plateaus and plains, irrigation I, heavy textured;
- plateaus, irrigation II and III, heavy textured, and
- summit (upland) positions.

Data from a group of medium- and light-textured soils, some with coarse-textured substrata and partial irrigation, were interpreted separately. Salient agronomic and economic characteristics of patterns grown on heavy-textured lowland units are presented in Table 3.

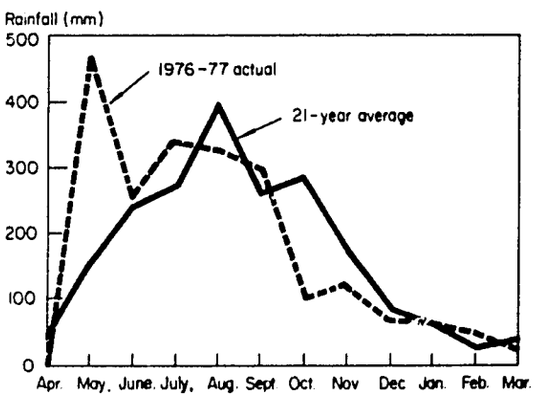
Between land units there was little difference in the yield of the first rice crop. However, yields of the second rice crop were influenced by water availability as governed either by landform or irrigation class. Upland crops generally suffered from drought following two rice crops, although in areas covered by irrigation (II and III) lateral seepage caused poor performance of many upland crops planted while adjacent fields were

Table 2. Summary of the cropping pattern components distributed among proposed, shifted, actual, cancelled, and failed during the first crop. Iloilo, Philippines, crop year 76–77.

Pattern components	Fields (no.)				
	Proposed	Shifted	Actual	Cancelled	Failed
DSR	36	33 WSR	3	—	2
WSR	34	1 TPR	89	—	—
TPR	26	17 WSR	8	1	—
Corn	16	6 WSR	9	1	2
Corn + rice	4	0	4	—	1 corn 1 rice

flooded for the rice crop. Material costs of R-R-UC varied little over land units. Although based on fewer observations, the material costs of R-UC patterns were also about the same over land units, and only slightly less than those of R-R-UC. The minor cost difference was explained partly by slightly higher material costs for the earlier upland crop; moreover, the extremely dry conditions prevented 30% of the farmers from planting the UC portion of a proposed R-R-UC pattern, thereby reducing the average material cost of the pattern. When data for the farmers who skipped the UC in an R-R-UC pattern were excluded, the difference in material costs came to US$50.27/ha. Labor costs were generally lowest for the least productive patterns because harvesting and threshing costs, which constitute a major share of the total labor cost, are closely proportional to pattern productivity.

Across land units, the total returns, returns above variable costs, returns to cash, and



2. Crop year 76–77 monthly rainfall and the 21-year average rainfall. Iloilo, Philippines.

Table 3. Summary of cropping pattern performance on heavy-textured land units and pattern groups. Iloilo, crop year 76–77.

Land units	Pattern group	Observations (no.)	Yield[a] 1	Yield[a] 2	Yield[a] 3	Cost (US$/ha) Material	Cost (US$/ha) Labor	Cost (US$/ha) Variable	Cost (US$/ha) Total	Returns[b] Above variable cost (US$)	Returns[b] To cash (US$/$1)	Returns[b] To labor (US$/h)
High and medium side slopes, rainfed	R-R-UC	5	5.2	1.3	21%(1)[c]	258	348	605	1108	503	4.3	.29
	R-UC	6	5.4	64%	—	213	280	493	1220	727	5.7	.42
Low side slopes and plateaus, rainfed	R-R-UC	23	5.3	2.0	13%(9)	214	314	529	1177	648	5.5	.36
	R-UC	2	5.2	57%	—	228	340	628	1416	788	6.2	.41
Plains and waterways, rainfed	R-R-UC	6	6.1	4.7	1% (1)	258	403	661	1536	875	5.9	.37
Plateau and plains irrigation I[d]	R-R-UC	11	5.7	4.6	13%(4)	237	369	605	1566	961	6.6	.42
	R-UC	2	4.5	64%	—	185	305	488	1189	701	6.4	.38
Plateaus, irrigation II and III[d]	R-R-R	7	5.4	4.7	3.3	244	462	707	1936	1229	8.0	.43
	R-R-UC	9	5.1	4.6	2% (1)	218	367	585	1472	887	7.1	.40

[a]Numbers 1, 2, and 3 refer to crop in pattern. Rice (R) yields are in t/ha, yield of upland crops (UC) is on a relative yield basis, with cowpea = 1.72 t/ha = 100; sorghum = 8.33 t/ha = 100; mung bean = 1.20 t/ha = 100. These were the highest yields obtained in any of the cropping pattern trials, and are believed to reflect the maximum performance obtainable by farmer-cooperators. Data from patterns which included soybean were not included in the relative yield computation because it is not locally adapted due to uncontrollable levels of insects. [b]Returns to cash = total return ÷ material cost. Returns to labor = (total returns – material cost) ÷ man-hours. [c]Number in parentheses is number of patterns in which no UC was attempted. [d]Irrigation I — partially irrigated. With supplemental irrigation at least 1 month after the end of the rainy season. II — Partially irrigated. With supplemental irrigation 1 to 2 months after the end of the rainy season. III — Fully irrigated. Has available water 11 or more months of the year.

returns to labor within each pattern group generally increased as the moisture regime became more favorable. The lack of major differences between pattern groups within each land unit reflected the farmers' ability to cope with pattern requirements.

Within heavy-textured, rainfed units with high and medium side slopes, farmers could not satisfactorily grow two rice crops and an upland crop: the yield of the second rice crop was low and the following crop showed poor performance. However, farmers were generally able to meet R-UC pattern requirements. Furthermore, the R-UC pattern group was more profitable than the R-R-UC.

Within heavy-textured, rainfed low side slopes and plateau units, farmers were unable to successfully grow the R-R-UC pattern. Among the 14 that did grow a UC, 6 experienced complete crop failure. Thus, the relative crop yield average was only 13% for the pattern group. Furthermore, the second rice crop in those units was sensitive to moisture regimes as affected by planting date and slight positional differences within land units. Of 23 second rice crops attempted, 5 were total failures, while the top 5 yields averaged 4 t/ha. Nine cooperators who grew only R-R patterns either were delayed in their plantings or were on less favorable fields within the land units; therefore the second rice crop yields were only 0.8 t/ha, compared with the 2.8 t/ha of the 14 farmers who attempted the UC.

When the cost and returns of the UC portion of the R-R-UC patterns were removed and combined with the R-R cost and returns data, total variable costs decreased to US$438/ha, returns over variable costs increased to US$672/ha, and returns to cash increased to 6.5. On the basis of two R-UC observations, therefore, the R-UC patterns were more profitable than the abbreviated R-R patterns. Moreover, average material and labor costs of the R-UC patterns were higher than those for the R-R-UC, indicating exceptional cases. The outcome of trials of these pattern groups on heavy-textured rainfed, plateau and low side slope units indicates that farmers can cope with R-R requirements in the more favorable fields and R-UC requirements in the less favorable fields, but not with the full R-R-UC requirements.

In the plain and waterway land units, only R-R-UC patterns were attempted. However, 1 farmer did not attempt the UC portion; of the 5 who did, 4 experienced total UC failures because of drought and 1 harvested only 75 kg mung beans/ha. Thus, farmers in those units could cope with requirements of two rice crops, but not with those of the UC that followed.

In heavy-textured plateau and plain units receiving irrigation for less than 2 months beyond the normal end of the wet season (Irrigation I), farmers easily coped with the R-R portion of an R-R-UC pattern. However, 4 of the 11 farmers did not plant a UC, and for the 7 cooperators who did, performance of the UC was generally poor. The average cost of the 2 R-UC patterns was lower than those of the 11 R-R-UC patterns by US$117/ha, and returns were lower by US$273/ha. Deducting the costs and returns of the UC component from the R-R-UC made the abbreviated R-R pattern group even more profitable than the R-UC group.

In heavy-textured plateau positions receiving irrigation for more than 2 months beyond the normal end of the wet season (Irrigation II and III), farmers also easily coped with at least 2 rice crops. Yields were reduced on the third rice crop of the R-R-R patterns, but they were still substantial. The R-R-R patterns were located primarily in Irrigation III units. Upland crops performed poorly in Irrigation II units, partly because of seepage from adjacent fields, which farmers kept flooded for late rice crops.

Land units having medium- and light-textured soils, as expected, were generally poorer than the heavy-textured units, especially for either the second rice crop or the upland crops. The average yield of the first rice crop over all medium- and light-textured units was 4.9 t/ha, which was 0.5 t/ha less than the weighted average over all heavy-textured rainfed units. Furthermore, UC yields after one or two rice crops were much lower. Where partial irrigation existed, farmers produced second rice-crop yields sufficient to make an R-R pattern more profitable than an R-UC, although the per-hectare return over variable costs was only US$550 for the R-R versus US$358 for R-UC.

Of the upland pattern groups, the corn-UC-UC gave the highest return over variable costs, followed by corn-UC and corn + rice-UC (Table 4). In those pattern groups, the corn crop or the corn + rice intercrop was grown during about the same period when single rice crops are traditionally grown in lowland fields. Although the upland patterns were not extensively tested, they fitted well into the Iloilo land system on the better drained knoll (or summit) positions.

Compared with lowland patterns, upland patterns had higher material inputs, reflecting slightly higher seed and fertilizer costs and preharvest labor requirements. All three patterns were satisfactorily grown in the trials. However, the corn-UC-UC pattern, which gave the highest return over variable cost, required the highest material cost and most labor, leading to lower returns per unit cash and per unit labor. Furthermore, the additional return for the corn-UC-UC pattern (US$722) was only 1.4 times the additional expense (US$524), indicating a much lower return for the additional expense of using the more intensive cropping pattern.

Within pattern groups, several management alternatives can be used for higher total crop

Table 4. Summary of costs and returns of three experimental upland cropping patterns, Iloilo, Philippines, crop year 76–77.

Pattern	Fields reported (no.)	Costs (US$/ha)			Returns			
		Material	Labor	Total variable	Total (US$)	Above variable cost (US$)	To labor (US$/h)	To cash (US$/$1)
Corn-UC	12	225	288	513	1003	490	.29	4.6
Corn + rice-UC	4	325	375	700	1075	375	.18	3.2
Corn-UC-UC	2	429	608	1037	1725	688	.22	4.0

Table 5. Comparative yields and costs and returns of wet-seeded rice (WSR) and transplanted rice (TPR), first and second crops. Iloilo, Philippines, crop year 76–77.

Crop position	No. reported	Yield (t/ha)	Costs (US$/ha)			Returns (US$)	
			Material	Labor	Total variable	Total	Over variable cost
WSR first	84	5.3	97	178	274	782	508
TPR first	13	4.6	112	188	301	614	313
WSR second	51	3.0	78	117	195	454	259
TPR second	21	4.4	103	189	281	661	380

output, reduced production costs, or reduced risks. The suitability of some is briefly discussed here. For further discussion of other alternatives, see the section Component technology.

Method of rice establishment. The yields, and costs and returns associated with different methods of rice establishment for both first and second crops are in Table 5. For the first crop, both yields and returns over variable costs favored WSR. The averages over all land units and pattern groups were taken. Because R-UC patterns were often planted later than WSR patterns, and therefore suffered higher levels of pest incidence, TPR yields were expected to be lower than WSR yields. The time difference was not sufficient, however, to explain the yield difference or the higher returns. Furthermore, the earlier harvested WSR commanded a higher market value. The results clearly indicate that farmers can cope with WSR cultural requirements in the first crop.

For establishing the second rice crop, the TPR method was favored, with respect to both yields and returns over variable costs. One main reason for the difference is the greater drought stress from the longer duration WSR crop.

Because of the early typhoon, only five DSR were attempted; two failed. The average yield for the 3 successful crops, 5.4 t/ha, suggested the potential of DSR, but the failures and many switches to WSR indicate that the technique must undergo further refinements to make it acceptable.

Upland crops and their management. Upland crops following either one or two rice crops generally did not perform well. The puddled soil from the preceding rice crop created an unfavorable physical environment for the upland crops. Furthermore, thorough tillage required high energy inputs and was costly and time consuming. Both are undesirable characteristics for a crop that must rely on later sporadic rains and residual soil moisture for growth. If a farmer chose to grow a crop following rice, his strategy was an extremely low-input one, mainly broadcasting mung bean or cowpea on the rice crop shortly before, or soon after, harvest.

To examine the effect of higher tillage levels on the performance of UC in R-R-UC and R-UC patterns, two tillage levels were examined. In Table 6, these levels are referred to as

Table 6. Economic analysis[a] for some upland crops planted after lowland rice at high and zero tillage levels. Iloilo, Philippines, crop year 76–77.

Crop	Yield[b] (kg/ha)		Labor cost (US$/ha)		Net returns (US$/ha)	
	High	Zero	High	Zero	High	Zero
Cowpea[c]	817 (5)	1033 (5)	74	13	45	233
Cowpea[d]	136 (3)	290 (5)	43	8	-40	13
Mung bean[d]	255 (2)	260 (13)	50	20	9	85
Soybean[c]	565 (4)	342 (2)	90	16	8	9
Sorghum[c]	4343 (2)	8326 (1)	63	19	471	952

[a]Costs and prices were based on the prevailing value during the production season. [b]Numbers in parentheses indicate number of fields. [c]Grown after one rice crop. [d]Grown after two rice crops.

zero and high tillage and are defined as follows:

- Zero tillage consists of spraying rice stubble and weeds with paraquat, opening a furrow at the desired row width with a native plow, placing seed and fertilizer in the furrow, and covering the furrow by pulling a spike-tooth harrow diagonally over the furrows.
- High tillage consists of plowing once with a carabao-drawn native plow to a depth of 10–15 cm, then harrowing once or twice, opening a furrow and placing seeds and fertilizer in it, and covering the seeds by drawing a spike-tooth harrow diagonally over the field.

Data in Table 6 indicate several points related to tillage level, crop species, and sequence of planting in the pattern. Zero tillage was more profitable than high tillage. Crop yields were generally slightly higher at zero tillage than at high tillage. Moreover, zero-tillage labor costs amounted to only 23% of high-tillage labor costs.

A comparison of cowpea yields and net returns following one and two rice crops indicates that cowpea after a single rice crop should be higher yielding and more profitable at zero tillage. However, mung bean grown after two rice crops was profitable at zero tillage, despite low yields. The productivity of sorghum following one rice crop was promising. From three observations, soybean performed poorly in patterns because of uncontrollable pod-borer damage.

Because of the generally low yield levels of UC in the patterns, investigation of the currently recommended levels of nitrogen, phosphorus, and potassium fertilizers, which range from 20 to 60 kg/ha per nutrient per crop was started for CY 77–78. However, in two cases of R-UC pattern grown in CY 76–77, where mung bean and sorghum intercrops and monocrops were superimposed, a sorghum yield response of 0.6 t/ha was obtained by increasing basal nitrogen from 30 to 40 kg N/ha; a further increase of 0.8 t/ha was obtained from an additional 40 kg N/ha topdressed. By increasing basal nitrogen from 20 to 40 kg/ha, a mung bean yield response of 230 kg/ha was obtained.

Additional crop management subjects related to cropping patterns are discussed in the section Component technology.

PANGASINAN TESTS

Multiple Cropping Department, and Cropping Systems Components of Agricultural Economics, Agronomy, and Entomology Departments

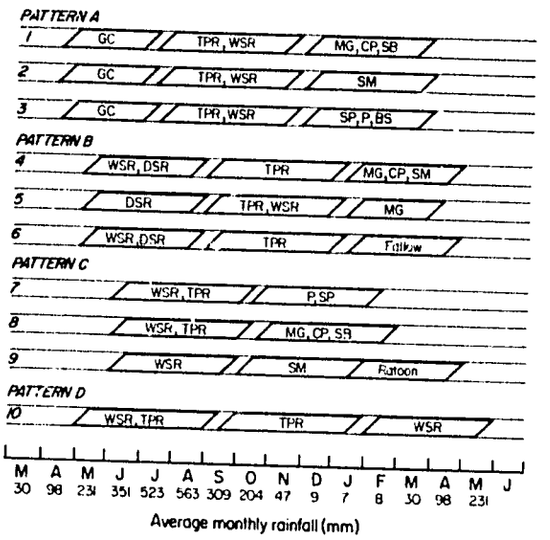
The IRRI-Bureau of Plant Industry (BPI) cropping systems research area in Pangasinan has a 3.6 rainfall pattern of 3–4 consecutive wet months, with 1 or more monthly totals exceeding 500 mm, and 5–6 consecutive dry months. One sector of the Pangasinan research area (Caaringayan) has a shallow water table, and the other (Lipit-Pao) has a deep water table. Taxonomically, most soils in both sectors are Eutropepts. Their pH ranges from 6.7 to 7.9. Clay loam is the modal surface soil texture in both sectors. Average soil organic matter is 2.4% in Caaringayan and only 1.8% in Lipit-Pao, the difference apparently resulting from soil moisture differences. The water table difference is the major factor that divides the research area into different production complexes.

In CY 76–77, 52 farmer-cooperators tried 1 to 3 cropping patterns in 79 test fields: 37 in Lipit Pao and 42 in Caaringayan. The patterns introduced were more intensive farmers' patterns with intensification derived from the introduction of one additional crop or from increased production in complexes where two crops were grown by farmers but at a low level of management. The patterns tested in CY 76–77 belong to four groups:

- green corn-rice-upland crop (GC-R-UC)
- rice-rice-upland crop or fallow (R-R-UC)
- rice-upland crop (R-UC)
- continuous rice (R-R-R)

The patterns are graphically described in Figure 3. The mean monthly total rainfall is included to orient the patterns to seasonality. The patterns were selected on the basis of their performance during CY 75–76. Patterns 1 to 3, designed for fields with deep soils with rapid surface and internal drainage, were assigned to the Lipit-Pao sector.

Patterns 4 and 10 were designed for the Caaringayan sector, the former for fields with coarse-textured, deep soils, and the latter for fields near free-flowing wells.



3. Proposed cropping patterns and 25-year average monthly rainfall. Pangasinan, Philippines, crop year 76--77. TPR = transplanted rice, WSR = wet-seeded rice, DSR = dry-seeded rice, GC = green corn, MG = mung bean, CP = cowpea, SB = soybean, SM = sorghum, SP = sweet potato, P = peanut, BS = bush sitao.

Patterns consisting of two rice crops and an upland crop or fallow (4 to 6) were designed for the wetter fields in both sectors. Either the DSR or the WSR establishment technique was used for the first crop depending on water availability. Patterns 7 to 9 were designed for both sectors on the basis of 1975 performance. They had been used to test intensification in fields likely to have insufficient water for two rice crops, in fields where only a single rice crop was grown, and in fields where a low management level UC followed a single rice crop.

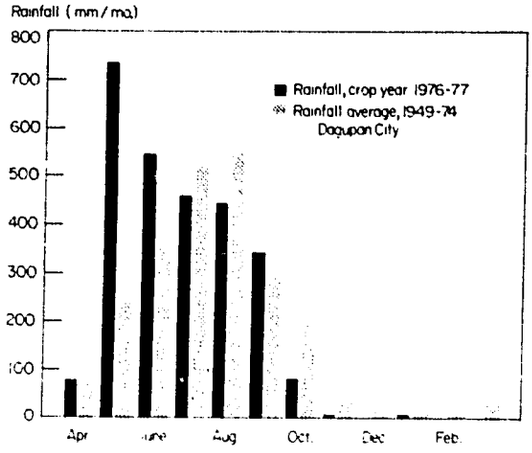
The distribution of the patterns in pattern groups A, B, and C (Fig. 3) is shown in Table 7. As CY 76–77 started and the factors that controlled pattern adaptation in Lipit-Pao became more obvious, there was a shift to more R-UC and less GC-R-UC and R-R-UC patterns, but in Caaringayan, the shift was toward more intensive patterns. The pattern shifts reflected the farmers' and researchers' realization that water would be a less limiting factor in Caaringayan. In rainfed conditions across both water table classes, fields with R-R-UC were shifted to the R-UC patterns. Initially, 46% of the R-R-UC patterns were designated for rainfed fields, but only 24% were implemented. For the R-UC group, the shift was reversed — 41% were designed for rainfed fields and 52% were implemented.

As Figure 4 indicates, the CY 76–77 rainfall deviated in two characteristics from the long-term average. The onset of the wet season was abrupt and early rains were heavy, and late-season rainfall declined more sharply than normal. Those deviations affected the performance of cropping patterns.

Table 7. Distribution of proposed and implemented patterns by pattern group[a], irrigation, and location. Pangasinan, crop year 76–77.

Cropping pattern group, sector	Proposed (no.)			Implemented (no.)		
	Total	Rainfed	Partially irrigated	Total	Rainfed	Partially irrigated
A. GC-R-UC						
Lipit-Pao (deep)	15	8	7	11	6	5
Caaringayan (shallow)	8	5	3	9	7	2
Total	23	13	10	20	13	7
B. R-UC						
Lipit-Pao (deep)	7	4	3	17	10	7
Caaringayan (shallow)	15	5	10	12	5	7
Total	22	9	13	29	15	14
C. R-R-UC						
Lipit-Pao (deep)	12	9	3	6	5	1
Caaringayan (shallow)	12	2	10	15	0	15
Total	24	11	13	21	5	16

[a]A fourth group, R-R-R, was also designed. Seven R-R-R plots were proposed for Caaringayan (near free-flowing wells), none for Lipit Pao. Six of the seven were implemented in Caaringayan.



4. Monthly rainfall distribution at Manaoag, Pangasinan, Philippines, during crop year 76–77 compared with data for the 25-year average at Dagupan City, Philippines.

As indicated in the section Environmental description, FSD regimes differed little between waterway and nonwaterway positions within the same water table and irrigated rainfed class. Crop yields, and costs and returns data from the pattern groups were separated according to water table and partially irrigated-rainfed classifications, ignoring the distinction between waterway and nonwaterway. Yield, and cost and return means for the pattern groups are in Table 8.

Average yields of the patterns with single rice crops (R-UC and GC-R-UC) were not greatly different between rainfed and partially irrigated land units. The rice component of both patterns coincided with maximum FSD intervals, as depicted in FSD frequency diagrams for Pangasinan. The single rice pattern yield averages for the deep water table units were 3.6 t/ha for rainfed and 3.2 t/ha for partially irrigated units. In the shallow water-table sector, the averages for the same crops were 3.1 t/ha for rainfed and 3.4 t/ha for partially irrigated units.

Yields of first rice crops in R-R-UC patterns showed no distinct differences between deep and shallow sectors. Within the deep water-table sector, however, partially irrigated units had an advantage over rainfed units, but observations in both cases were limited. The first rice crop yield from R-R-UC patterns was 1.4 t/ha higher than rice yields of the later planted single rice patterns, reflecting in part greater buildup of pests and crop stress from late drought. The second rice crop was affected by later drought, yielding an average of 3 t/ha in rainfed and partially irrigated units of the deep water-table sector and 3.6 t/ha in the partially irrigated, shallow water-table units. No R-R-UC was attempted on rainfed land units with shallow water table.

In fields near free-flowing wells, the first two

Table 8. Mean yields, and costs and returns for pattern groups, according to land units. Pangasinan, crop year 76–77.

Land unit	Pattern group	Observations[a] (no.)	Yield[b] 1	Yield[b] 2	Yield[b] 3	Costs (US$/ha) Material	Costs (US$/ha) Labor	Costs (US$/ha) Variable	Returns Total (US$)	Returns Above variable cost (US$)	Returns To cash (US$/$1)	Returns To labor (US$/h)
Deep												
Rainfed	GC-R-UC	6	2.1	3.4	47(5)	357	243	682	897	215	2.5	.19
	R-R-UC	5 (2)	4.7	2.8	54(3)	447	522	924	1614	690	4.0	.19
	R-UC	11	3.7	39(10)		266	338	615	1016	401	4.1	.26
Partially irrigated	GC-R-UC	7	11.2	3.6	41(5)	379	359	739	1178	439	3.1	.27
	R-R-UC	2 (0)	5.2	3.5	38(2)	496	538	1035	1636	601	3.3	.29
	R-UC	8	2.8	56(8)		306	322	628	1008	380	3.3	.26
Shallow												
Rainfed	GC-R-UC	9	0.3	3.1	34(9)	315	353	668	779	111	2.5	.15
	R-UC	4	3.0	26(1)	—	219	231	451	599	148	2.7	.21
Partially irrigated	GC-R-UC	2	0	4.6	—	414	351	765	883	118	2.1	.16
	R-R-UC	13 (7)	4.7	3.6	40(4)	345	459	804	1595	791	4.8	.32
	R-UC	7	3.0	46(7)	—	195	302	497	796	299	4.1	.26

[a]Numbers in parentheses represent cooperators not planting UC. [b]Numbers 1, 2, 3 refer to crops in the pattern. Yields are in t/ha for rice; thousand green ears for corn; and relative yield for UC, where yields of 1.53, 1.29, and 4.50 t/ha were the bases for the relative yield computation. These were the maximum yields obtained by farmer-cooperators. Numbers in parentheses are number of observations in computation of UC relative yield.

crops of R-R-R patterns were readily grown by the seven farmers. The average yields for the first and second crops were 4.7 and 4 t/ha, respectively. One cooperator failed to complete the first two crops in time to start the third crop, and three farmers planted the third crop but had failures because their wells ran dry. The average third-crop yield of the 3 farmers who grew the full R-R-R pattern was 4.4 t/ha. The results suggest that most farmers could cope with cultural requirements of three 100- to 110-day-duration rice crops on at least part of their land if there are no water limitations.

Failures with green corn (GC) were common because of the early typhoon. All but one of the GC crops in the shallow water-table area were total failures. Only on the partially irrigated units, where internal and surface drainage were adequate, did the GC component approach satisfactory performance on more than half of the units tested. On that land unit, 4 of 7 cooperators grew crops averaging 19,600 marketable ears; the others had total crop failures.

There was no decided advantage to UC from any land unit or pattern groups as indicated by average relative yields, which ranged from 38% for UC grown after a single rice crop in the shallow water-table sector to 48% for that grown after two rice crops in the deep water-table sector. UC yields were somewhat dependent on planting date in relation to the abrupt decline in rainfall. UC yield range and variability suggested a good potential for UC yield increases on deep soils with substantial water-holding capacity.

In the shallow water-table sector, R-R-UC patterns were attempted only in the partially irrigated land units. However, 7 of the 13 farmer-cooperators did not grow UC, indicating that its cultural requirements were too much for many. The 6 farmers who grew UC spent an extra US$428/ha to produce the R-R-UC pattern, but the additional return of US$436/ha merely covered costs. A comparison of R-UC costs and returns with those of the R-R-UC pattern shows that the additional cost to produce the extra rice crop was US$307/ha and the added output was US$799/ha. When the UC component of R-R-UC is ignored (i.e. assuming an abbreviated R-R pattern by removing UC costs), returns over variable costs were about the same (US$7/ha more) but costs were greatly reduced (US$137/ha less). Thus, on the partially irrigated, shallow water-table land units, an R-R pattern was most profitable in CY 76–77, and was also manageable for the farmers.

As reported earlier, within the rainfed and partially irrigated shallow water-table units, farmers could not obtain field drainage necessary to grow green corn in GC-R-UC patterns. The presence of a shallow water-table suggests that early flooding would likely occur in many years, except on the highest and coarsest-textured land units. Therefore, the GC-R-UC was not adapted to most fields in the shallow water-table sector.

The GC failure rate was also high in the deep water-table sector, amounting to three of seven on the partially irrigated units and five of six on the rainfed units. Where yields were obtained, they were much lower than usual. Consequently, GC-R-UC patterns gave returns lower than R-R-UC patterns. However, the GC component was more profitable on the partially irrigated units than the R-UC crop, even when the computation included the cost of failures. The additional cost of the GC-R-UC pattern was US$111/ha and the additional return US$170/ha.

The R-R-UC patterns were moderately successful in the deep water-table sector. Farmers attempting to grow the pattern produced profitable rice crops and, in some cases, a UC. However, because of the few R-R-UC observations in that sector, data for the rainfed and partially irrigated units were combined. Compared with R-UC patterns, R-R-UC patterns cost an extra US$335/ha and gave an extra return of US$607/ha. Furthermore, the extra cost of growing the abbreviated R-R pattern was US$103/ha and the extra return was US$308/ha. A comparison of R-R-UC and R-R, in which the UC costs and returns were excluded from R-R-UC to derive R-R costs, showed that R-R returns were 1.21 times those of UC. Although the comparison was based on only five cases in which UC was attempted, the results indicated that UC can be profitably grown after two rice crops in some fields in the

Table 9. Average yields, costs, and returns of R-R-UC patterns started by three alternative first crop establishment methods. Pangasinan, crop year 76–77.

First crop establishment methods[a]	Planting date	Yield (t/ha)		Costs (US$)				Returns (US$)		
				1st crop		Pattern				
		1	2	Material	Labor	Material	Labor	Total over pattern	Over variable cost	To cash (US$/$1)
DSR (5)	8 June	5.9	3.4	203	215	432	563	1891	896	2.1
WSR (8)	19 June	4.1	3.5	180	195	385	462	1570	722	1.9
TPR (6)	8 July	4.6	3.1	136	327	285	429	1401	687	2.4

[a]Figures in parentheses are number of observations.

deep water-table area but at a high cost.

Establishment of first crop in R-R-UC. In the rainfall regime found in Pangasinan, improved methods of establishment are advantageous for early planting of R-R-UC patterns. Therefore, rice yields, and pattern costs and returns from 19 cropping patterns test fields where farmer-cooperators had grown R-R-UC were separated on the basis of first rice crop establishment methods. Means of selected characteristics are in Table 9. DSR-established patterns were planted 11 days earlier than WSR-established patterns, and 1 month earlier than TPR-established patterns. DSR crops had higher average yields than either WSR or TPR crops. The second rice crops, all transplanted, gave the lowest yields when preceded by a TPR crop, which reflected drought stress on the second crop, despite the high proportion of DSR patterns grown in the deep water-table sector.

Material costs were highest for the DSR method, but labor costs were higher for the TPR method, partly because of transplanting requirements. Although DSR patterns had higher costs, they had higher returns over variable costs than either WSR or TPR. An important portion of the cost difference was due to labor and material for planting the UC. However, UC yields were low and often did not cover production costs. Compared with TPR-started patterns, the DSR-started patterns had a 1.7 return for the additional variable input cost.

Upland crops after rice. Of the upland crops originally considered, corn was susceptible to drought, sweet potato was seriously attacked by weevils, and soybean was heavily attacked by pod-borers and was susceptible to drought. In contrast, the farmer's traditional mung bean crop, and cowpea and sorghum, which are not commercially grown in the area, are better adapted to the crop environment after rice. For the dry soil conditions often prevailing after two rice crops, additional research is necessary to reduce tillage and fertilizer costs without sacrificing moderate yield levels. For wet soil conditions prevailing after one rice crop, tillage systems that protect young plants from late but heavy rains require further development, and optimum fertilizer rates need to be defined.

Rice-mung bean pattern. The rice-mung bean pattern is grown on half the land in Pangasinan, and is the only crop activity of a third of the farmers. The mung bean hectarage has since 1973 continually increased to a present level of 2.7 times that of rice. But farmers' mung bean yields are extraordinarily low — 0.25 t/ha compared to a minimum achievable yield of 0.75 t/ha with moderate management. Because of the crop's value, popularity, and ability to grow immediately after rice on heavy soils, research on improvement of techniques for multiple cropping mung bean after rice received emphasis.

Farmers' management practices were identified as a basis for developing and evaluating new techniques. Seeding rates and insecticide applications on 67 farms averaged a value of US$19/ha and US$7/ha, respectively, but no fertilizer was applied. Tillage varied from none to two plowings and two harrowings. While yields and net returns were low, the level of returns to labor — average US$0.33/man-hour — was good for the period of year when mung bean was grown.

In Table 10, 37 farmers' plots of rice-mung bean are compared with 9 experimental plots.

Table 10. Comparison of costs and returns for rice-mung bean pattern (experimental vs farmers' plots). Manaoag, Pangasinan, crop year 76–77.

Crop	Plots reported (no.)	Yield (t/ha)	Labor input (man-h/ha)	Costs (US$/ha)		Returns			
				Material	Total variable	Gross (US$/ha)	Above variable costs (US$/ha)	To labor (US$/man-h)	To cash (US$/US$1)
				Experimental plots					
1st crop, rice	9	3.76	1723	133	364	701	338	2.3	5.3
2nd crop, mung bean	9	0.73	400	163	241	444	203	4.9	2.7
Total			2123	296	605	1145	531		
Av.	9							3.6	4.0
				Farmers' plots					
1st crop, rice	37	1.65	504	44	173	308	136	3.2	7.0
2nd crop, mung bean	37	0.22	344	26	73	138	60	2.2	5.1
Total			848	70	246	446	196		
Av.	37							2.7	6.05

The gains in mung bean production resulted mainly from better control of bean fly. Higher rates of insecticide application, reflected in higher material costs, were partly responsible for better bean fly control but applying insecticides too late was the farmers' biggest mistake. Bean fly control was best accomplished 10 days after plant emergence when the pest and its damage were hardly visible.

BATANGAS TESTS

Multiple Cropping Department and Cropping Systems Components of Agricultural Economics, Agronomy, and Entomology Departments

For years, cropping systems researchers have sought a better upland rice variety than Dagge, the one grown at an upland rice-based research site in Cale, Batangas province. Until 1976, all varieties tested in farmers' fields failed, often because they could not withstand the farmers' weeding practices, which involved passing a spike-toothed harrow diagonally across the rows from 10 to 20 days after emergence, followed by 1 or 2 interrow cultivations with a wooden furrower and repeated hand weeding. The spike-toothed harrow usually uprooted improved upland varieties. Also, their shorter stature often intensified weed problems later in the growing season and increased labor requirements.

In 1976 variety trials, C171-136 and C166-135 outyielded Dagge. The more promising C171-136 was compared with Dagge in 1977 cropping pattern trials in split fields under farmers' management.

When both varieties were planted as sole crops, C171-136 averaged 1.5 t/ha more than Dagge; when both intercropped with corn that was harvested green, C171-136 produced 1.3 t/ha more (Table 11). C171-136 and Dagge did not differ significantly in their effect on corn yields, but both yielded slightly higher when intercopped, probably because of nitrogen applied to the corn. When both were intercropped, the labor required to weed C171-136 was substantially lower than that for Dagge (Table 12). Because C171-136 has even maturity, the labor required to harvest it was much less than that for Dagge. Dagge is harvested by removing individual panicles or cutting the entire plant. Farmers must harvest it two or three times because it matures unevenly. Farmers harvested the entire C171-136 crop at once by sickle. C171-136 also produced more tillers per square meter. Although its early growth is slightly slower than that of Dagge, the higher tiller number reduced weed competition. Combined with the increased gross returns, the lower labor requirement of C171-136 resulted in an average increase in net returns over Dagge of 143% for the sole crop and 80% for the intercrop. That assumed a cost of US$0.34/hour

Table 11. Performance of C171-136 and Dagge as sole crops and intercropped with corn, at constant and variable labor prices for weeding and harvest. Cale, Batangas, Philippines, 1977.

	Dagge alone	C171-136 alone	Dagge + corn	C171-136 + corn
Rice				
Yield (t/ha)	2.76	4.30	3.26	4.57
Tillers (no./m²)	185	244	182	193
Gross returns[a] (US$/ha)	525.03	818.50	620.54	869.66
Corn				
Yield (marketable ears)	—	—	12,466	13,400
Gross return[b] (US$/ha)	—	—	144.22	154.97
Total return (US$/ha)	525.03	818.50	764.76	1024.63
Input costs[c] (US$/ha)	77.55	77.55	157.82	157.82
Assuming constant wages for weeding and harvest (US$0.17/ha)[d]				
Labor costs (US$/ha)	179.73	89.39	203.13	140.82
Total cost (US$/ha)	257.28	166.94	361.90	298.78
Net return (US$/ha)	267.76	651.56	403.67	693.76
Return to cash (US$/ha)	0.60	1.28	0.48	0.75
Weeding labor at US$0.17/hour, harvest labor at US$0.39/hour[e]				
Labor cost (US$/ha)	271.70	109.93	337.41	171.70
Total cost (US$/ha)	349.25	187.48	495.24	359.52
Net return (US$/ha)	175.78	631.02	269.52	694.97
Return to cash (US$/ha)	0.44	1.24	0.37	0.73
Return to labor (US$/ha)[f]	0.48	1.86	0.57	1.25

[a]Palay at US$0.19/kg. [b]Green ears of corn at US$0.01/ear. [c]Seeds and fertilizer: seeds at US$0.19/kg; fertilizer (ammonium sulfate) at US$8.23/50-kg bag. [d]Cultivation and land preparation at US$0.34/h. [f](Total return – input costs) ÷ labor (man-hours).

for any activity requiring animals and a constant US$0.17/hour for all other labor inputs.

It is more appropriate to value labor for hand weeding at US$0.07/hour and that for harvesting at US$0.34/hour on the basis of the imputed labor wage in Cale, Batangas (see section Environmental description, Fig. 7). At those wage rates, C171-136 increased average net return over that for Dagge by 290% for the sole crop and 158% for the intercrop. It also gave higher average returns to labor and cash; however, the introduction of corn reduced returns to cash for both C171-136 and C166-135, and reduced returns to labor for C171-136. The application rate of 90 kg N/ha to the corn intercrop, in addition to the 75 kg N/ha applied to the rice, may have been too high.

The reduced labor for harvest of C171-136 also may reduce turnaround time between rice and corn, which would allow earlier planting and give higher corn yields.

CONTINUOUS RICE PRODUCTION MODEL

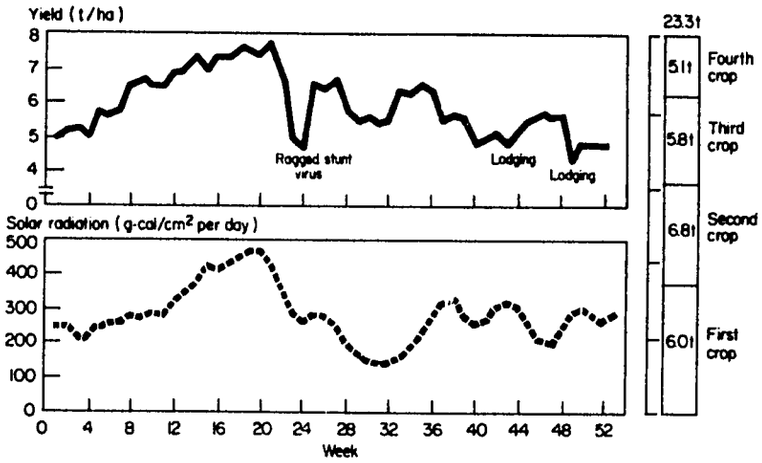
Cropping Systems Components of Office of Rice Production Training and Research and Agricultural Economics Department

Preliminary data were given in 1976 for a continuous rice production model (CRPM) for areas with year-round irrigation (1976 Annual

Table 12. Labor requirements for production of C171-136 and Dagge as sole crops and intercropped with corn. Cale, Batangas, Philippines, 1977.

	Labor required (man-h/ha)				
Crop(s)	Land preparation and seeding[a]	Weeding	Cultural practices[a]	Harvest	Total
Dagge alone[b]	95	163	35	636	929
C171-136[b]	95	95	35	174	399
Dagge + corn[c]	95	90	54	825	1064
C171-136 + corn[c]	95	234	64	299[d]	692

[a]Includes thinning, replanting, fertilizer application, and cultivation. [b]Av. of 6 plots. [c]Av. of 3 plots. [d]Only 1 plot for corn.



5. Average weekly yield of IR36 and solar radiation at 23 days after heading. Continuous rice production model. IRRI, 1977.

Report). In the model, rice was planted and harvested 3 times a week from 40- × 250-m plots. The total production was 23.7 t/ha (a daily production of 64 kg) (Fig. 5).

Rice production varied from plot to plot on a daily basis, which could not be completely accounted for. However, solar radiation during the entire year had a dramatic effect on yields as seen in Figure 5. During weeks 22–24, solar radiation and production dropped drastically but the drop was not entirely an effect of solar radiation — an attack of ragged stunt virus caused an additional reduction in yields. Lodging in weeks 40–43 also accounted for reduced yields. Variability of production from the four crops appeared to be influenced more by solar radiation than by any other factor observed. Damage by a typhoon occurred in week 49.

Table 13. Cost of production (labor and materials) to produce rice from 250-m² plot. IRRI, 1977.

Activity	Time (ha)[a]	Cost (US$/plot)		
		Labor	Material	Total
Land preparation	3.62	0.62	0.46	1.08
Seeds and seed bedding	1.37	0.23	0.06	0.29
Fertilizer	1.18	0.20	4.10	4.30[b]
Weed control	0.33	0.06	0.22	0.28
Insect control	0.45	0.08	1.54	1.62
Planting	3.35	0.57	—	0.57
Irrigation	0.40	0.07	0.51	0.58
Harvesting (hauling, threshing, cleaning)	8.09	1.38	—	1.38
Total	18.79	3.21	6.89	10.01

[a]Field operation time excluding job preparation. [b]Cost of fertilizer includes that of chicken manure at 5 t/ha.

Costs of production per plot are shown in Table 13. About 19 hours was required to produce rice from a 250-m² plot. The total cost of production was US$10.01/plot, or a labor and material cost per hectare of US$400 and a yearly cost of US$1,600 for four crops. Price of palay used was US$0.135/kg. Based on that price, 23,400 kg would bring a total income of US$3,160/ha or a net yearly income of US$1,530.

The benefits of the CRPM were that with 1-day turnaround, more crops could be grown in 1 year than in other systems. All tasks were performed by 1 worker, each working 40 hours a week. That eliminated the high levels of hired labor required at transplanting and harvest time. Disadvantages of the system were that land preparation costs were about 25% higher on the small plots than on plots of about 1,000 m². Also, with 40 crops at different stages of growth, labor overhead costs of about 250 hours/crop were required in preparation for each day's diverse activities; the usual overhead time is 35 hours/crop.

On a per-crop basis, resources were less productive in continuous rice cropping than in a

Table 14. Comparison of labor requirements of continuous rice cropping and other multiple rice cropping patterns. IRRI, 1977.

Cropping pattern[a]	Labor (man-hours/ha per crop)					
	Land preparation	Nursery and planting	Weeding and other care	Harvesting and threshing	Overhead	Total
Farmers' double rice crop	145	250	85	210	20	710
Research-cooperators' double rice crop	250	340	95	215	35	935
CRPM, 40 plots 3.96 times/yr	145	190	95	325	250	1005
CRPM, 10 plots 3.76 times/yr	115	290	95	325	35	760

[a]CRPM = continuous rice production model.

Table 15. Comparison of costs and returns of continuous rice cropping and other multiple rice cropping patterns (US$/ha). IRRI, 1977.

Cropping pattern[a]	Variable costs/crop (US$/ha)			Total returns (US$/ha)		Net returns above variable costs (US$/ha)	
	Labor	Materials	Total	One crop	All crops	One crop	All crops
Farmers' double rice crop	141	61	202	325	650	127	246
Research-cooperators' double rice crop	226	111	337	568	1136	231	262
CRPM, 40 plots 3.96 times/yr	136	274	409	800	3162	391	1544
CRPM, 10 plots 3.76 times/yr	103	274	376	798	3000	422	1587

[a]CRPM = continuous rice production model.

single-crop system because in the latter, a farmer plants a single crop at a time to obtain higher yield. An average yield of 5.9 t/crop was realized in the CRPM, and a maximum yield of about 7 t/ha was obtained for a February planting.

Nevertheless, the CRPM is profitable compared with alternatives. Table 14 compares labor requirements of alternative systems and Table 15 shows the comparative returns. Late in 1977 the model was shifted to a 10 plot/ha system of 1,000 m^2, giving 3.76 crops/year. Reduced labor overhead and land preparation costs were offset by lower total production, and the systems were about equally profitable.

Cropping systems program

Component technology development and evaluation

Multiple Cropping Department and Cropping Systems Components of Agronomy, Entomology, Plant Pathology, and Soil Microbiology Departments

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SOIL AND CROP MANAGEMENT

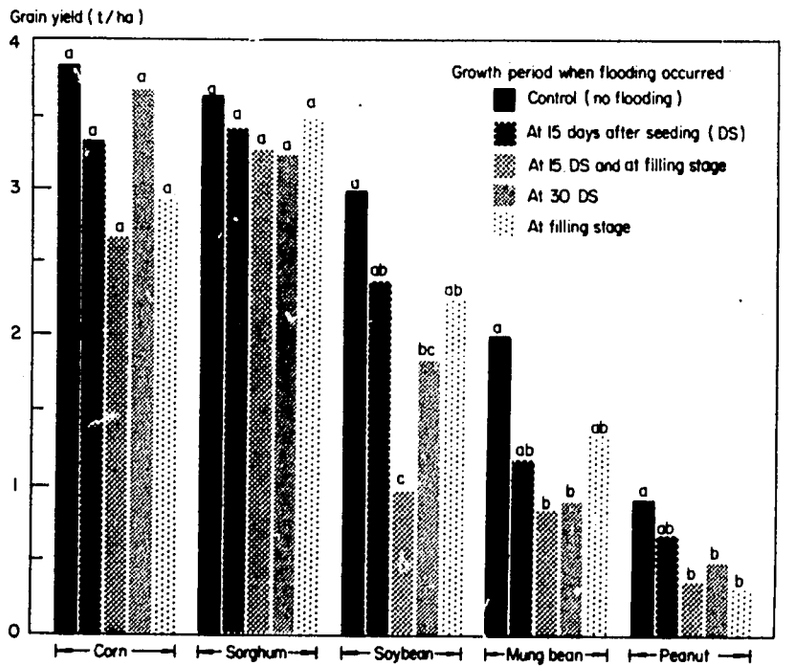
Multiple Cropping Department and Soil Microbiology Department Cropping Systems Component

Susceptibility of six upland crops to periodic flooding. A field experiment conducted in Maahas clay soil at IRRI from January to April 1977 determined the response of corn (DMR-2), sorghum (Cosor 3), peanut (CES 101), mung bean (CES 55), and soybean (Multivar 80) to waterlogging of the soils at different growth stages. All crops were planted without furrowing in a level seedbed and received 5 flooding treatments: flooding at 15 days after seeding (DS), at 15 DS and at the early grain-filling stage, at 30 DS, at the early grain-filling stage, and a control (no flooding).

The plots were completely submerged during the designated flooding periods from heavy surface irrigation for 7 continuous days. Relative damage to crops caused by excessive soil moisture differed, with the cereals being generally more tolerant than the legumes (Fig. 1). The grain yield, total dry matter, ear and panicle length, and seed weight of corn and sorghum were only slightly affected. The lack of effect on corn yields was partially explained by lateral seepage from adjacent treated plots, which depressed the yield of the control plot. Peanut yields were depressed because of severe *Cercospora* leaf spot attack in all treatments.

For each crop, the effect of flooding varied with stage of crop growth. When flooded at 30 DS, mung bean, peanut, and soybean suffered 56, 49, and 37% reduction in yield, respectively. The cumulative effects of flooding at 15 DS and again at the grain-filling stage were even more severe (57, 60, and 64%, respectively). Because its pods are submerged, peanut was more sensitive to flooding at the pod-filling stage than either mung bean and soybean. All the crops became stunted when flooded at the vegetative stage.

Although flooding reduced the yields of all legumes, it affected different yield components in each legume studied. When soybean was flooded at 15 DS, yield reduction was caused by an average 22% reduction in stand. The weight of 100 seeds was reduced by 21% from the



1. Effect of flooding (1-week duration) at different growth periods on the grain yields of 5 upland crops. IRRI, 1977. For each crop, bars with a common letter are not significantly different at the 5% level.

check weight of 18.5 g in treatments flooded at the pod-filling stage, but the number of pods per plant and of seeds per pod were only slightly reduced in the treatment flooded at 14 DS and at pod-filling. The stand of mung bean was significantly reduced (by 33%) only in the 15 DS flooding treatments although a 13% reduction resulted from flooding at 30 DS. The weight of 100 seeds did not change, but the number of pods per plant averaged 11 in the 3 treatments flooded at or after 30 DS, compared with the average 19.2 for the check. The number of seeds per pod was significantly lower by 18% only in the 30 DS treatment. In contrast with their effect on soybean and mung bean, flooding treatments did not affect peanut stand and dry matter production. Besides those on yield, the only other effects were on plant height and the 100-seed weight, which was reduced by an average 36% in treatments flooded at the pod-filling stage.

Effect of toposequence position and establishment method on weeds and upland crops after rice. Six upland crops (corn, soybean, cowpea, mung bean, sorghum, and peanut) were planted after a high level of tillage (hand-tractor rotovation plus butachlor spray) and zero tillage (row planting with no land preparation, plus a rice straw mulch) to determine the effects of field position in a toposequence and of establishment method on each crop's performance after rainfed rice. The high field had dry-seeded rice and the medium and low fields had transplanted rice as a first crop.

Differences in the dates of upland crop establishment indicated that the turnaround period was influenced more by field position than by tillage level. The crops in the high field were established a week earlier than those in the medium field, and 30–35 days earlier than those in the low field. The time difference was due mainly to excessive soil moisture in the lower fields, which hampered planting operations.

The advantage of zero tillage in reducing turnaround increased in the lower fields. Crop establishment was 5 days earlier after zero tillage than after high tillage in the high field, but 2 weeks earlier in the low field.

Field position generally had little effect on grain yields (Table 1), except in peanut, which had significantly lower yields in the lower fields. Tillage at a given field position had no appreciable effect on yields. The significant yield reduction in peanut with zero tillage at all field positions was probably caused by a poorer condition for pod development. Tillage method did not influence plant height, but corn, sorghum, soybean, and peanut were stunted in the low field.

Weed density and the dry weight of weeds differed across tillage levels and previous rice planting methods. Weed numbers were higher but weed weight was lower with a previous transplanted crop than with a previously dry-seeded crop. Despite the mulch, low-tillage plots had more weeds than high-tillage plots in the dry-seeded fields. With low tillage, weed weight was lower in the puddled field, however, than in the dry-seeded field (Table 2). In general, the grasses (including volunteer rice) were more dominant than the broadleaf weeds and the sedges: the weed ratio was 65:30:5 in the high field position, and 58:40:2 in the low field. Those ratios were 64:30:6 for the high-tillage plots and 59:40:1 for the low-tillage plots.

Dry season planting of soybean. Soybean was evaluated for planting after rainfed rice at the end of the rainy season. In northern Philippines

Table 1. Yields of 6 upland crops after 2 levels of tillage and for 3 positions in a toposequence.[a] IRRI, 1977.

Crop	Yield (t/ha)				
	High tillage	Zero tillage	High bund	Medium bund	Low bund
Field corn	2.27 a	1.97 a	2.87 a	1.59 b	1.90 ab
Sorghum	2.53 a	3.14 a	3.40 a	1.62 b[b]	3.48 a
Cowpea	1.66 a	1.53 a	1.45 a	1.60 a	1.73 a
Peanut	1.38 a	0.77 b	1.43 a	1.06 b	0.75 c
Mung bean	0.83 a	0.79 a	0.87 ab	0.94 a	0.62 b
Soybean	0.61 a	0.66 a	0.61 a	0.69 a	0.59 a

[a]In a row, any 2 means followed by a common letter are not significantly different from each other at the 5% level. [b]Head worm damage.

Table 2. Effect of tillage and previous rice culture[a] on average weed count and weight at first weeding in stands of 6 upland crops.[b] IRRI, December 1976 — April 1977.

Previous rice culture	Weed count (no./m²) High tillage	Weed count (no./m²) Low tillage	Weed count (no./m²) Mean[c]	Weed wt (g/m²) High tillage	Weed wt (g/m²) Low tillage	Weed wt (g/m²) Mean[c]
Dry-seeded	36.7	75.8	56.3 a	12.7	72.7	42.7 b
Transplanted	77.0	79.5	78.3 b	13.5	41.7	27.6 a
Mean[c]	56.8 a	77.7 b		13.1 a	57.2 b	

[a]Interaction was significant between weed count and weed weight. [b]Av. of 3 replications and 6 crops. [c]Any 2 means followed by the same letter are not significantly different from each other at the 5% level.

Table 3. Grain yield and growth duration of 3 soybean varieties planted biweekly after rainfed rice. IRRI, 1977.

Soybean variety	Planting date 21 Oct.	4 Nov.	18 Nov.	2 Dec.	16 Dec.	30 Dec.	Mean
			Grain yield[a] (t/ha)				
Clark 63	1.57 a	1.47 a	1.07 a	0.79 a	0.19 a	0.30 a	0.90
TK5	0.88 b	0.61 c	0.77 b	0.62 b	0.09 a	0.10 b	0.51
L114	0.85 b	0.82 b	0.61 b	0.44 c	0.06 a	0.04 b	0.47
Mean	1.10	0.97	0.82	0.62	0.11	0.15	
			Growth duration[b] (days)				
Clark 63	88	98	86	82	78	70	83
TK5	83	92	75	77	72	70	78
L114	100	102	91	89	82	79	90
Mean	90	97	84	82	77	73	

[a]In a column, any 2 means followed by a common letter are not significantly different from each other at the 5% level. [b]Growth duration denotes days from seeding to harvest.

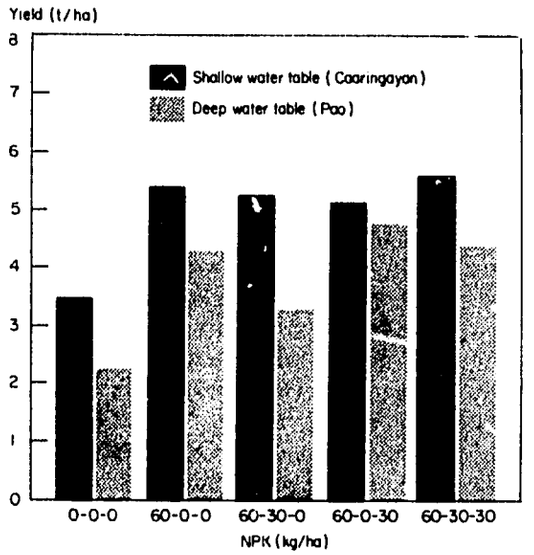
that period coincides with reduced day length (to 11 hours 20 minutes), a mean daily temperature drop from 30 to 25°C, and monthly rainfall that rapidly diminishes in December and January and nearly stops in February. All those factors limit soybean yields. The soybean varieties TK 5 (early), Clark 63 (medium), and L114 (late) were planted every 2 weeks from October until the end of December in a rainfed well-drained area at IRRI.

Clark 63 was consistently the highest yielder (Table 3). Grain yield, total dry matter, plant height, and the other agronomic characteristics of the three varieties decline from the early-season planting to the late-season planting as a result of shortened day and decreased soil moisture (particularly for the last two seeding dates). The reduced yields were strongly related to rainfall. Growth duration also decreased by an average of 17 days from the early and the late planting.

Regression analyses of grain yield with the number of pods per square meter (P), the number of seeds per pod (S), and seed weight (W) showed that the number of pods per square meter explained most of the yield variation in Clark 63 and L114. For L114 the number of seeds per pod was more important in this respect. In a combined analysis of the three varieties, S and P were closely correlated (r = 0.73). The average W (in g/seed) was not, however, correlated with S (r = 0.03). For the three varieties combined, the model Y (kg/ha) = 0.79 $P \times S$ explained 87% of the yield variation. Inclusion of the seed weight into the model did not significantly increase the regression sums of squares.

Fertilizer on transplanted rice, Pangasinan. Fertilizer experiments with transplanted IR30 on land with shallow and deep water tables in the Pangasinan research area examined general responses to moderate fertilizer levels (Fig. 2). Available soil nitrogen was much greater in the soil with the shallow water table: additions of phosphorus or potassium did not greatly modify crop response to 60 kg N/ha in the soil with shallow water table.

In areas with deep water table, however, the basal application of 30 kg K_2O/ha significantly increased rice yields. The possibility that the



2. Effect of NPK and water table depths on the yield of transplanted IR30. Manaoag, Pangasinan, Philippines 1976.

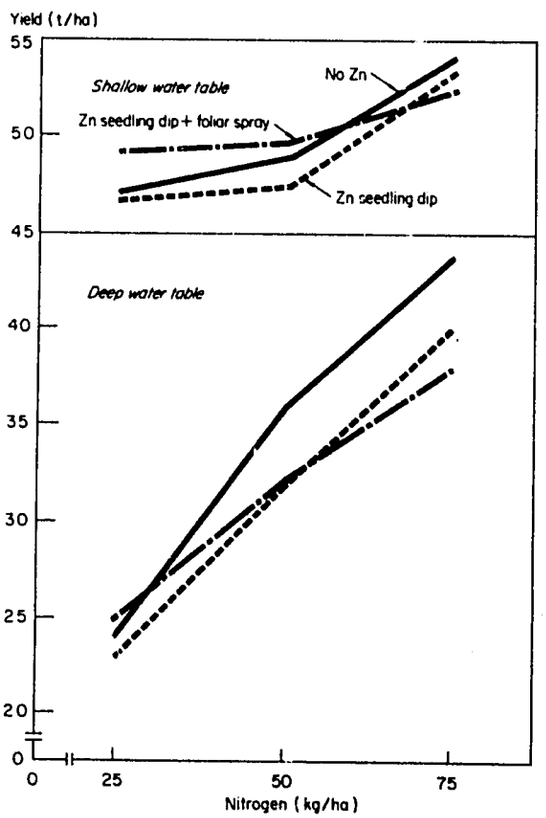
availability of soil potassium may be limited by a high level of calcium, and that the depression caused by phosphorus application may be a phosphate reaction with zinc and ammonium to further reduce zinc availability when high calcium levels are present is being investigated.

Figure 3 summarizes an experiment in which 3 levels of nitrogen (20, 50, and 75 kg/ha) and 3 zinc treatments (none, seedling dip, and seedling dip plus foliar spray) were applied to a transplanted IR28 crop on land with shallow (Caaringayan) and deep (Pao) water tables. A minor but significant response to nitrogen levels beyond 25 kg N/ha was observed for the shallow water table. As in the previous experiment (Fig. 2), yield levels in this locality exceeded 3.5 t/ha with no nitrogen fertilizer added. No response to zinc applications was observed. The area with a deep water table, however, had a slight but statistically significant yield depression due to zinc. The crop in this area responded well to nitrogen with or without zinc, a response opposite to that observed previously in the same vicinity (1975 Annual Report).

Sorghum and mung bean intercrop, Pangasinan. To determine the suitability of sorghum as a monocrop, mung bean as a monocrop, and mung bean and sorghum as intercrops after rice, trials were held in seven farmers' fields. Equal areas were devoted to sorghum and mung bean as intercrops. Nitrogen fertilizer treatments for sorghum were 0, 30 kg/ha basal, and 30 kg/ha basal plus 40 kg/ha topdressed. Mung bean had inoculum plus 0 kg N/ha, inoculum plus 30 kg N/ha, and 30 kg N/ha with no inoculum. The results are summarized in Table 4.

Because of a wide range of moisture conditions following rice crops, yield levels greatly varied among the seven fields. As both monocrop and intercrop, sorghum responded to nitrogen; however, a major portion of the nitrogen response was lost in the intercrop. Mung bean did not respond to combinations of inoculum and fertilizer nitrogen, and its yields were strongly depressed by intercropping with sorghum.

The results indicate that a sorghum and mung bean intercrop can be satisfactorily grown in



3. Effect of nitrogen, zinc, and water table depth on yield of transplanted IR28. Manaoag, Pangasinan, Philippines, 1976 wet season.

Table 4. Grain yields of monocrops and intercrops of sorghum and mung bean after rice, as affected by fertilizer and inoculum treatments. Av. of 7 farmers' fields, Pangasinan, Philippines, crop year 1976–77.

Crop, yield range	Yield (kg/ha)		
	Sorghum fertilization		
	0-60-60	30-60-60	(30+40)-60-60
Sorghum alone	1179	1540	2234
Minimum	376	742	953
Maximum	3006	3062	4159
Sorghum intercrop	775	1006	1185
Minimum	240	462	304
Maximum	2115	2169	2282
	Mung bean fertilization		
	0 kg N/ ha + inoculum	30 kg N/ ha + inoculum	30 kg N/ ha
Mung bean alone	565	580	539
Minimum	54	100	74
Maximum	1435	1060	1045
Mung bean intercrop	430	376	342
Minimum	51	99	41
Maximum	1035	712	756
Land equivalent ratio	1.42	1.30	1.16

farmers' fields after a rice crop. The reduction in land equivalent ratio (LER) — from 1.42 to 1.16 — as more nitrogen fertilizer was added suggests that at high fertilizer input levels there is no substantial advantage in intercropping sorghum and mung bean, especially at the prevailing low price for sorghum. The response of sorghum to fertilizers and of mung bean to improved inoculum is examined in more detail in crop year 1977–78.

Effect of time of planting cassava on upland cropping pattern performance. In areas in Indonesia with less than 2 dry months, a 5-crop pattern for upland rice-growing areas had shown promise. The pattern consisted of a cassava crop relay-planted into every other corn row of a corn-upland rice intercrop, in which corn harvest was followed by rice harvest. The area remaining between the rows was planted to soybean followed by cowpea. Because of the shading effects of cassava, its planting time is critical.

An experiment at IRRI was conducted under rainfed conditions from June 1976 to April 1977. Data on the crops planted, variety, planting and harvesting dates, spacing, and fertilizing rates of the respective crops are in Table 5. Cassava was planted at 20-day intervals, and 1 cropping pattern without cassava was added to make 7 treatments. One-third of all fertilizer for corn was dibbled as basal and two-thirds of the nitrogen was side-dressed. One-third of the nitrogen and all phosphorus and potassium for rice were placed in band at planting time; one-third was side-dressed 30 days after planting, and the remainder at 70 days after planting. For cassava one-half of the nitrogen and all phosphorus and potassium were dibbled at planting time; the other half of the nitrogen was side-dressed 60 days after planting. One-half of the fertilizer for soybean and cowpea was placed in band at planting time and one-half 35 days after emergence. Azodrin was applied to soybean and cowpea at the rate of 2 liters/ha at 3-week intervals until pod-filling. The plots were weeded 1 month after the planting of upland rice and 1 month after the planting of cowpea.

The yield of corn was higher in rows without cassava than in rows in which corn was combined with cassava. Cassava planted within 60 days of the date of corn planting reduced the yields only of corn grown in the same row with cassava (Table 6). Because of a typhoon at the seed-filling stage of the rice crop, rice planted without cassava lodged and the tall cassava from the first planting date lodged and reduced the

Table 5. Crop, variety, date of planting and harvesting, fertilizer rate, and spatial arrangement of a rainfed cassava planting-date experiment. IRRI, crop year 1976–77.

Crop	Variety	Planting date	Harvest date	Spacing (cm)	Plants or seeds (no./hill)[a]	Fertilizer (kg/ha)		
						N	P_2O_5	K_2O
Corn	DMR-2	15 June	3 Oct.	150 x 50	2	48.6	15.2	15.2
Upland rice	C-22	15 June	13 Oct.	25 x row	—	54.8	24.6	24.6
Cassava	Malagkit	[b]	14 April	300 x 50	1	58.3	28.1	28.1
Soybean	TK 5	16 Oct	14 Jan.	50 x 10	2	24.6	24.6	24.6
Cowpea	EG #2	16 Jan	24 April	50 x 20	2	24.6	24.6	24.6

[a]Plant populations are percentages of the normal: corn (54), upland rice (88), cassava (67) soybean (88), and cowpea (88). [b]Cassava planting at 20-day intervals starting 15 June.

Table 6. Yield of corn from rows with and without cassava, and the average of both as affected by cassava planting date. IRRI, crop year 1976–77.

Cassava planting date	Corn yield[a] (kg/ha)		
	Without cassava	With cassava	Total
Same date as rice and corn	2481 a	2015 b	4496 b
20 days after rice and corn	2398 a	2069 b	4467 b
40 days after rice and corn	2425 a	2327 ab	4752 ab
60 days after rice and corn	2414 a	2418 a	4832 ab
80 days after rice and corn	2420 a	2495 a	4915 ab
No cassava	2435 a	2546 a	4981 a

[a]In a column, any 2 yields followed by a common letter are not significantly different from each other at the 5% level.

yield of rice (Table 7). In the other treatments, cassava did not lodge and so acted as a windbreak for rice. In those treatments early planting of cassava did not reduce rice yields. Yields of intercrop soybean were lower than those of soybean not intercropped with cassava. The early planting of cassava reduced soybean yield significantly more than later plantings did. Cowpea yields were strongly reduced by intercrops. Late planting of cassava reduced yields because of a shorter growing period and greater competition from corn and rice. After rice harvest the late cassava plantings were weak and did not completely recover.

The general conclusions were that the best planting date for cassava is between 20 days after the corn planting and 40 days after the rice planting, and that a more shade-tolerant cowpea is required for intercropping.

Effect of row pairing on corn competition with intercropped rice. Late-maturing corn strongly reduces the yields of intercropped upland rice (1976 Annual Report). Row pairing of corn was evaluated as a means of reducing its competitive effect on rice, but without reducing its yields. DMR 2, a tall, competitive corn variety, was seeded at the high population of 60,000 plants/ha. C-22 rice was sown at 200 kg/ha into 20-cm spaced furrows. Row spacings started at an equidistant 1 m and increasingly narrowed until the paired row merged to give an equidistant 2-m row spacing (Table 8). High inputs of fertilizer, and insect and disease control were provided and all plots were irrigated.

The high corn population within rows produced a rapidly growing tall stand that reduced the sole-crop rice yields of 2.33 t/ha to intercrop

Table 7. Yield[a] of upland rice, soybean, cowpea, and cassava as affected by cassava planting date. IRRI, crop year 1976–77.

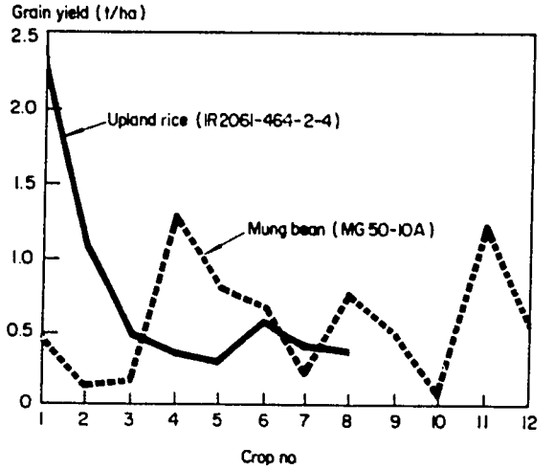
Cassava planting date	Yield (kg/ha)			
	Upland rice	Soybean	Cowpea	Cassava
Same date as rice and corn	1957 c	636 c	825 b[b]	339 a[c]
20 days after rice and corn	2416 ab	963 b	146 c	294 a
40 days after rice and corn	2407 ab	941 b	140 c	260 b
60 days after rice and corn	2495 a	969 b	141 c	211 c
80 days after rice and corn	2516 a	955 b	142 c	169 d
No cassava	2248 b	1461 a	875 a	—

[a]In the same column any 2 yields followed by a common letter are not significantly different from each other at the 5% level. [b]Unreliable data. The cassava from the treatment was stolen at the early stage of cowpea. [c]Estimated from remaining plots.

Table 8. Grain yields of corn and rice as affected by row pairing of corn (corn population 60,000 plants/ha).[a] IRRI, 1977.

Spacing (cm) between		Intercrop yield (t/ha)		Sole-crop corn yields	LER[b]	LER[c]
Corn rows	Rice and corn rows	Corn	Rice			
0	200	4.48 c	0.98 a	4.86 b	1.24	1.11
20	180	4.74 bc	0.71 a	5.91 a	1.10	1.03
40	160	4.97 abc	0.52 ab	5.97 a	1.05	0.99
60	140	5.26 ab	0.41 ab	6.50 a	0.98	0.99
80	120	5.10 abc	0.33 b	6.46 a	0.93	1.00
100	100	5.39 a	0.22 b	6.48 a	0.92	0.92

[a]In a column, yields followed by the same letter are not significantly different from each other at the 5% level. [b]Land equivalent ratio. Compared with sole crop corn at same spacing, sole crop rice yield was 2.33 t/ha. [c]Land equivalent ratio. Compared with sole crop corn at 100 cm spacing, sole crop rice yield was 2.33 t/ha.



4. Grain yields in continuous cropping sequences. IRRI, 1977.

rice yields of 0.98 t/ha for the 2-m row spacing and 0.22 t/ha for the 1-m row spacing. Intercrop rice yields decreased steadily as corn row spacing increased. Sole-crop corn yields were highest (6.48 t/ha) in the 1-m spacing and increasingly reduced as the distance between the paired rows decreased. The minimum corn yield was 4.8 t/ha for the 2-m row spacing. The reduction in corn yield due to rice intercropping was higher for the treatments with increased corn row spacings. That, combined with the higher rice yields, led to LER values greater than one for the treatments in which corn rows were paired at 40 cm or less distance. LER is the total land required for monocultures 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. The high plant population used to increase competition in the experiment would not normally be considered for corn and rice intercropping. In previous trials the DMR 2/C-22 intercrop at 30,000 plants/ha in 1.5-m rows had yields of 3.63 t corn/ha and 1.54 t rice/ha with LER of 1.14. Row pairing at such populations is expected to lead to higher LER values.

Continuous cropping of upland rice and other upland crops. After 3.5 years of continuous cropping, the patterns of grain yield reduction in upland rice (IR2061-464-2-4) and mung bean (MG50-10A) were confirmed (Fig. 4). For upland rice there was sharp decline in grain yield until the third crop; after that a low level of production was maintained. Growth appeared unaffected by season.

Continuous cropping was repeatedly compared with first crops in the mung bean rotation or with the fallow plots. Grain yields were reduced by at least 60% (Table 9). The second rice crop was greatly inhibited. Keeping the field fallow for 5 months improved plant growth but was not enough to remove all harmful effects. Two cropping seasons without rice apparently removed the cause of growth inhibition.

In mung bean, grain yield reduction usually occurred in the second and third crops. After a poor crop of less than 0.2 t/ha, a next crop tended to improve. Because the inhibitory effects occurred during seed germination or seedling growth, the reduction in plant population apparently allowed the soil to recover. In some cases the plants completely recovered at late growth stages. Higher dry season yields indicated that mung bean is affected by seasonal changes. When continuous cropping was compared with first cropping or with crop rotation patterns, grain yield in the one-crop system was always lower by at least 35% during any season of the year (Table 9). As with upland rice, grain yield reduction occurred in the second crop and the chances of failure in a third crop were great. One season of fallow invariably reduced growth inhibition for mung bean.

Short-duration (2-week) flooding or drying of monoculture soil before planting did not improve growth or yields of upland rice or mung bean. Steam sterilization of the soil had varied effects. It favored the growth of upland rice; however, the effect may not have been entirely biological because soil fumigation also affects the chemical properties of soil and the release of plant nutrients. Soil sterilization decreased mung bean growth and yield because it controlled the beneficial organisms like *Rhizobium sp.*

The trials were conducted on Maahas clay. Before the first crop, the pH was 6.2 and total nitrogen content, 0.13%. With adequate fertilization, the values remained after 6 continuous crops of upland rice; but the pH dropped to 5.7

Table 9. Occurrence and persistence of growth inhibitory effects with continuous cropping of upland rice and mung bean. IRRI, 1976–77.

Cropping period (variety)	Cropping history[a]	Plant ht[b] (cm)	Grain wt[b] (kg/ha)	Index
	Upland rice			
June-Sept. 1976 (IR2061-464-4)	7 cowpea	83 a	3,024 a	100
	4 rice/5-mo fallow	61 b	1,589 b	53
	5 rice	54 c	669 c	22
June-Oct. 1976 (IR5)[c]	4 rice/1 sorghum/1 season fallow	80 a	2,119 a	100
	6 rice	68 b	866 b	41
Jan.-June 1977 (IR5)[c]	2 1/2 years continuous fallow	63 a	1,058	100
	4 rice/1 sorghum/1 season fallow/1 rice	44 b	0	0
	7 rice	47 b	0	0
	Mung bean			
June-Sept. 1976	6 sorghum	81 a	1,208 a	100
	7 mung/5-mo fallow	60 b	1,109 a	92
	8 mung	39 c	530 b	44
Oct. 1976-Feb. 1977	7 sorghum	78 a	450 a	100
	6 sorghum/1 mung	58 a	230 b	51
	7 mung/5-mo fallow/1 mung	39 b	160 bc	36
	9 mung	37 b	90 c	20
July-Oct. 1977	8 seasons fallow	73 a	1,037 a	100
	7 sorghum/1 mung/1 sorghum	73 a	901 ab	87
	7 sorghum/2 mung	57 b	797 ab	77
	10 mung/1 season fallow	50 bc	761 ab	73
	11 mung	42 c	661 b	53

[a]Since June 1974. [b]In a column for each cropping period, any 2 means followed by a common letter are not significantly different from each other at the 5% level. [c]First 6 crops were IR747-B_2-6-3; 7th and 8th crops were IR5.

and the nitrogen level rose to 0.14% after 9 continuous crops of mung bean. After the eighth crop of IR5 as upland rice, the nutrient status of the soil did not distinctly differ among plots of continuous rice, 2.5 years continuous fallow, or continuous rice with a short fallow period. The observation indicated that plant nutrition is not the primary factor in the reduction of growth.

WEED SCIENCE

Agronomy Department Cropping Systems Component and Multiple Cropping Department

Effect of dry season land preparation on weed growth in succeeding crops. (*Agronomy and Multiple Cropping*). *Upland crops.* Several trials were conducted to examine the effect of various dry season practices on weeds growing in association with the succeeding wet season upland crops.

In the first trials at IRRI, half of an area was planted to upland crops (sweet potato, sorghum, and mung bean) in January 1977 and the other half was left fallow. One part of the fallow area was kept weed free by cultivation, another by application of herbicide (paraquat + butachlor); a third was left weedy. With the onset of rains (in May), the whole field was rotovated and corn was planted. Nitrogen at 40 kg/ha was applied basally to half the field, and butachlor at 1.2 kg active ingredient (a.i.)/ha was applied to half of the area that received nitrogen and half of that with no nitrogen. Because of a severe attack of downy mildew, the corn was plowed under about 3 weeks after emergence and rice (IR36) was planted in its place. Nitrogen at 40 kg/ha was applied basally to those plots which, in the preceding corn crop, received a basal application of nitrogen.

In corn plots that received neither fertilizer nor herbicide, previous land use had no effect on total weed weight (Table 10). However, with basal nitrogen but no herbicide, weed weight was significantly lower in plots previously planted to sweet potato than in those kept weed free with herbicides.

Table 10. Effect of previous land use on weight of weeds growing in association with sweet corn. IRRI, 1977 wet season.

Previous land use	Weed wt[a] (g/0.5 m²)			
	With 40 kg basal N/ha		Without basal N	
	Herbicide[b]	No herbicide	Herbicide[b]	No herbicide
Weed-free fallow (herbicide)	5.1 ab	14.1 b	7.6 bc	7.4 a
Sorghum planted	4.0 ab	6.7 ab	3.1 abc	5.1 a
Weedy fallow	7.7 b	9.7 ab	7.6 c	7.4 a
Weed-free fallow (tillage)	4.7 ab	6.2 ab	2.8 ab	9.5 a
Mung bean planted	7.2 b	9.4 ab	4.7 abc	6.9 a
Sweet potato planted	2.0 a	5.3 a	1.7 a	5.2 a

[a]In a column, any 2 means followed by the same letter are not significantly different at the 5% level. [b]Butachlor 1.2 kg active ingredient/ha.

Results differed with weed counts. When no fertilizer or herbicide was applied to the corn, significantly more but smaller weeds occurred in the weedy fallow than in any other plots except the one kept weed free by tillage. Where basal nitrogen was applied to no-herbicide plots, more weeds occurred in the weedy fallow than in all plots except those kept weed free with herbicides.

When herbicide was applied, the trend was the same whether weed weight or weed number was used as a basis for comparing treatments. Fewer broadleaf weeds and sedges — the weeds poorly controlled by butachlor — tended to grow in plots that had previously been planted to sweet potato than in the other plots. Plots that received basal nitrogen had neither more nor heavier weeds than the unfertilized plots.

In the rice crop that was planted after sweet corn, previous land preparation treatments caused no significant difference among the total weed weights (Table 11). But when no basal nitrogen was applied, weeds were significantly fewer in the plots previously planted to sorghum, mung bean, or sweet potato than in the weedy fallow and the plot kept weed free with herbicides. Where basal nitrogen had previously been applied, weeds were significantly fewer in the plot kept weed free by cultivation and in those where sorghum or sweet potato had been planted than in the plots kept weed free with herbicides and in the weedy fallow.

Previous land preparation methods caused no significant differences in number and weight of grasses and sedges. However, they produced differences in weed weight and weed number in broadleaf weeds. When no basal nitrogen was applied to rice, the weight of broadleaf weeds was significantly lower in the plot previously planted to sorghum than in the fallow plots kept weed free with herbicides and tillage (Table 11). There were fewer broadleaf weeds in the plots in which sorghum, mung bean, and sweet potato had been planted than in the weedy fallow and in the area kept weed free with herbicides. Where basal nitrogen had been applied, broadleaf weeds had significantly lower weight and number in the plot previously planted to sweet potato than in the herbicide-treated fallow or the weedy fallow. Weeds in plots that

Table 11. Effect of previous land use on weight of weeds growing in association with rice. IRRI, 1977 wet season.

Previous land use	Weed wt[a] (g/0.5 m²)			
	With 40 kg basal N/ha		Without basal N	
	B	T	B	T
Weed-free fallow (herbicide)	16.8 b	31.2 a	10.5 b	17.8 a
Sorghum planted	10.9 ab	14.9 a	0.9 a	8.5 a
Weedy fallow	16.1 b	22.8 a	16.0 b	24.4 a
Weed-free fallow (tillage)	6.6 ab	11.4 a	9.4 b	12.2 a
Mung bean planted	6.4 ab	13.9 a	7.9 ab	13.8 a
Sweet potato planted	3.4 a	7.7 a	3.6 ab	8.6 a

[a]In a column, any 2 means followed by the same letter are not significantly different at the 5% level. B = broadleaf weeds; T = total of all weeds.

Table 12. Effect of methods of controlling weeds during the dry season on weeds growing in the wet season in association with upland rice and corn 1 week after crop emergence. IRRI, 1977.

Preplanting treatment	Weeds[a]	
	No./0.5 m²	Wt (g/0.5 m²)
Plowing at start of experiment	90 a	18.4 a
Paraquat[b] (0.5 kg a.i./ha) as needed	72 ab	20.7 a
Mowing weeds at start of experiment	67 ab	15.9 a
Plowing followed by harrowing	58 ab	10.8 a
Mowing weeds as needed	52 ab	15.9 a
None	31 b	11.7 a

[a]Av. of 2 crops. In a column, any 2 means followed by the same letter are not significantly different at the 5% level. [b]a.i. = active ingredient.

received basal nitrogen were neither more numerous nor heavier than those in the unfertilized plots.

The different land preparation methods had an effect on the number of weed species and the major weeds growing in association with rice. Fourteen weed species were found in the plots that had previously been left as a weedy fallow, but only six were found in the plots that had been kept weed free by herbicide. The major weed species varied slightly. *Cyperus rotundus* was common to all plots. Slightly fewer *Portulaca oleracea* and slightly more *Euphorbia hirta* and *Celosia argentea* grew in the plots that had previously been weedy.

In a second upland trial at IRRI, either the weeds were controlled by different methods during the dry season or the land was left in weedy fallow. No crop was planted. At the start of the rainy season, rice and corn were seeded separately in each plot.

One week after crop emergence, weed weights and numbers were averaged for the two crops (Table 12). Weeds were significantly fewer in the plots that were left weedy during the dry season than in the plots that received a single plowing at the start of the experiment, but there was no significant difference between weed weights. Fewer but larger weeds grew in the plots that were left weedy during the dry season.

There were significantly more *Amaranthus spinosus* and *P. oleracea* plants and significantly fewer *Dactyloctenium aegyptium* plants in the plots that had been plowed during the dry season than in those that had received no treatment (Table 13). Differences in the other species or between the other preplanting treatments were not as marked.

Dry-seeded bunded rice. The effect of previous land use on weeds growing in association with dry-seeded, rainfed, bunded rice was examined in five farmers' fields in three barrios in Pangasinan province, Philippines. In three fields, weeds were significantly fewer in the plots that had been kept weed free by tillage during the dry season than in the other plots (Table 14). In one field in Lipit, the previous treatments had no effect on the total number of weeds, while in Caaringayan the plots that had been kept weed free had significantly more weeds than those that had been weeded.

A similar relationship was observed for grasses and sedges in all fields except in Caaringayan, where plots previously planted to mung bean had the greatest number of sedges while the number of grasses that grew in association with rice was not affected by the previous treatments. Broadleaf weeds tended to be more numerous in the plots previously kept weed free by tillage, especially in Caaringayan (Table 15).

Table 13. Effect of methods of controlling weeds during the dry season on the number of individual weeds growing in the wet season in association with upland rice and corn 1 week after crop emergence. IRRI, 1977.

Preplanting treatment	Weeds[a] (no./0.5 m²)					
	Cyperus rotundus	*Amaranthus spinosus*	*Portulaca oleracea*	*Dactyloctenium aegyptium*	*Digitaria sanguinalis*	Others
Plowing at start of experiment	23 a	28 b	22 d	1 a	6 c	10
Paraquat[b] (0.5 kg a.i./ha) as needed	36 a	20 ab	6 bc	2 ab	2 abc	6
Mowing weeds at start of experiment	36 a	16 ab	4 ab	4 b	3 bc	4
Plowing followed by harrowing	15 a	22 b	11 cd	2 b	1 a	7
Mowing weeds as needed	37 a	4 a	2 a	6 b	1 a	2
None	16 a	4 a	1 a	4 b	3 bc	3

[a]Av. of 2 crops. In a column, any 2 means followed by the same letter are not significantly different at the 5% level. [b]a.i. = active ingredient.

Table 14. Effect of previous treatments on the total number of weeds growing in association with dry-seeded, rainfed, bunded rice 5 weeks after seeding in 5 fields in 3 barrios in Pangasinan, Philippines. 1977 wet season.

Previous treatment or crop	Weeds[a] (no.)				
	Pao		Lipit		Caaringayan
	Field 1	Field 2	Field 1	Field 2	Field 1
Unweeded mung bean	647 b	415 b	192 b	81 a	87 ab
Mung bean — weeded once	469 b	480 b	221 b	66 a	122 bc
Weedy fallow	720 b	347 b	200 b	68 a	71 a
Weed-free fallow	197 a	98 a	48 a	90 a	140 c

[a]In a column, any 2 means followed by the same letter are not significantly different at the 5% level.

Table 15. Effect of previous treatments on number of broadleaf weeds growing in association with dry-seeded, rainfed, bunded rice 5 weeks after seeding in 5 farmers' fields in 3 barrios in Pangasinan, Philippines. 1977 wet season.

Previous treatment or crop	Broadleaf weeds[a] (no.)				
	Pao		Lipit		Caaringayan
	Field 1	Field 2	Field 1	Field 2	Field 1
Unweeded mung bean	26 bc	4 ab	6 a	3 ab	5 a
Mung bean — weeded once	18 ab	2 a	9 ab	2 a	8 a
Weedy fallow	11 a	6 ab	17 b	4 ab	9 a
Weed-free fallow	35 c	7 b	11 ab	8 b	49 b

[a]In a column, any 2 means followed by the same letter are not significantly different at the 5% level.

In such plots, there were significantly more *Echinochloa colona* and significantly fewer *C. rotundus* and *Cynodon dactylon*.

Postplanting weeding treatments consisted of no weeding, 1 hand weeding 35 days after seeding, and application of herbicide (dinitramine, butachlor, or pendimethalin) alone or followed by 1 hand weeding 35 days after seeding.

In two fields in Pao and in one in Lipit, the growth of weeds, especially *C. rotundus* and *C. dactylon*, was so heavy that none of the postplanting weed control treatments provided adequate weed control. No yield was obtained except in the plots that had been kept weed free by tillage. In all fields, the use of herbicides alone did not provide adequate weed control, and yields were generally not significantly higher than those from the unweeded checks. Less time was required to hand weed the herbicide-treated plots than the untreated plots. It is unlikely, however, that the reduction in weeding time could compensate for the cost of the herbicide.

Interrow cultivation and preemergence herbicides for weed control in corn (*Agronomy*). Weed control by three preemergence herbicides applied alone or followed by an interrow cultivation 28 days after seeding was compared with interrow cultivation alone and with no weeding in corn planted at the start of the rainy season in Pangasinan. The predominant weed species was *E. colona*. The weight of grasses was significantly lower in atrazine-treated plots than in plots that received butachlor followed by an interrow cultivation, those that received an interrow cultivation, and the unweeded check (Table 16). All treated plots had significantly lower grass weight and total weed weight than the untreated check. The plots treated with atrazine had the lowest total weed weight.

Corn yield (ears harvested green, husked, and weighed) did not reflect the degree of weed control. The yield from plots treated with atrazine followed by interrow cultivation was significantly higher than that from plots treated with atrazine alone. Interrow cultivation, however, did not significantly increase the yield of plots treated with butachlor or butralin.

Stale-seedbed technique for weed control in upland rice (*Agronomy*). The stale-seedbed technique was compared with conventional land preparation at IRRI as a means of reducing weeds in upland rice. One portion of a field was planted immediately after conventional land

Table 16. Effect of different weed control practices on weed weight and yield of corn. Pangasinan, Philippines, 1977 wet season.

Treatment[a]	Herbicide rate[b] (kg a.i./ha)	Weed wt[c] (g/0.5 m²)		Ear yield[c] (t/ha)
		Grasses	Total	
Atrazine fb interrow cultivation	1.5	49.7 ab	66.9 b	7.7 a
Butralin fb interrow cultivation	2.0	47.1 ab	72.7 b	5.9 ab
Butachlor	2.0	54.2 ab	62.9 b	5.9 ab
Atrazine	1.5	31.4 a	44.2 a	5.5 b
Butachlor fb interrow cultivation	2.0	68.1 b	73.1 b	5.2 b
Butralin	2.0	46.6 ab	80.5 b	4.7 bc
Interrow cultivation	—	83.7 b	94.8 b	3.9 bc
Untreated	—	194.2 c	214.5 c	3.1 c

[a]fb = followed by. [b]a.i. = active ingredient. [c]In a column, any 2 means followed by the same letter are not significantly different at the 5% level.

Table 17. Weight of weeds growing in association with unweeded upland rice 6 weeks after crop emergence as affected by method of land preparation. IRRI, 1977 wet season.

Treatment	Weed wt[a] (g/0.5 m²)			
	Broadleaf weeds	Grasses	Sedges	Total
Immediate seeding	48.7 a	70.0 b	42.3 c	161.0 a
Paraquat application[b]	66.3 a	33.0 a	62.7 c	161.9 a
Glyphosate application[b]	152.7 b	131.7 c	2.2 a	286.6 b
Plowing[b]	141.9 b	79.2 b	13.5 b	234.6 b

[a]In a column, any 2 means followed by the same letter are not significantly different at the 5% level. [b]Weeds were allowed to grow for 2 weeks before chemical application or plowing.

preparation. In the other portion, weeds were allowed to grow for 2 weeks and were killed either by chemicals — paraquat at 0.75 kg a.i./ha or glyphosate at 2 kg a.i./ha — or by plowing. After planting, weed control treatments were superimposed on both portions.

Weed weights were taken 6 weeks after crop emergence. Weeds were significantly fewer in the plots that were seeded immediately after land preparation and in those that were sprayed with paraquat (Table 17). The use of the stale-seedbed technique was not advantageous in weed control.

The broadleaf weeds growing in the plot that was seeded immediately after land preparation were exclusively *A. spinosus*, while those in the other plots were a mixture of *A. spinosus* and *P. oleracea*. Glyphosate almost completely eliminated *C. rotundus*, and the second plowing — compared with the other treatments — reduced it substantially. The grasses *Eleusine indica* and *Digitaria ciliaris* were significantly fewer in the paraquat-treated plots than in the other plots.

Even though method of land preparation changed the proportion of the various weed species in the weed flora considerably, weeds in the unweeded plots grew so vigorously that no yield was obtained. Yields did not differ statistically among the plots that were kept weed free, weeded two or three times, or treated with butachlor and hand weeded. Of the plots where the stale-seedbed technique was used, plots weeded only once yielded significantly less; but when the crop was planted immediately after initial land preparation, there was no significant difference between weeding treatments.

Date of planting and weeds of dry-seeded, rainfed, bunded rice (*Agronomy*). The effect of planting date on weeds growing with dry-seeded, bunded rice was studied at IRRI. IR36 was sown at 100 kg/ha on 5, 17, and 27 May. Six weeding treatments were superimposed across each weeding treatment.

Table 18. Effect of date of planting and weed control practices on weed weight and yield of dry-seeded, rainfed, bunded IR36. IRRI, 1977 wet season.

Treatment[a]	Weed wt[b] (g/0.5 m²)			Yield[b] (t/ha)		
	5 May	17 May	27 May	5 May	17 May	27 May
Weed free	0 a	0	0	2.5 a	2.2 a	1.5 a
Hand weeding 21 and 35 DE	19 b	33 b	63 bc	2.0 a	1.1 bc	1.0 ab
Butachlor (2 kg a.i./ha)	109 c	35 b	90 c	1.8 ab	1.6 ab	0.9 abc
Dinitramine (1.5 kg a.i./ha)	90 c	42 b	44 b	0.5 c	1.0 bc	1.3 ab
Thiobencarb (3 kg a.i./ha)	118 c	40 b	89 c	0.7 bc	0.8 cd	0.5 bc
No weeding	119 c	145 c	205 d	0 c	0.1 d	0.1 d

[a]DE = days after emergence; a.i. = active ingredient. [b]In a column, any 2 means followed by the same letter are not significantly different at the 5% level.

In the unweeded plots, weed weight increased as the date of planting was delayed from 5 to 27 May (Table 18). In the first planting, the weight of weeds at harvest in the herbicide-treated plots was not significantly different from that in the unweeded check. In the second planting (17 May), there were no significant differences among the weights of weeds harvested from the weed-control treatments, but the weeds in those treatments were significantly fewer than those in the unweeded check. In the trial, the initial weed control achieved with herbicides, particularly butachlor, could not be detected at harvest because weeds grew rapidly after the herbicide lost its toxicity. In the third planting, weeds were significantly fewer in the hand-weeded and the dinitramine-treated plots than in the plots treated with butachlor and thiobencarb. The yields were low in all plots at all dates of planting (Table 18).

Water regime and weeds of wet-seeded rainfed rice (*Agronomy*). Weeds are more difficult to control in wet-seeded rainfed rice than in continuously irrigated rice because flooding suppresses weed growth. A 1977 trial examined control of weeds in wet-seeded rice grown in different water regimes.

Pregerminated IR36 seeds were broadcast at 150 kg/ha on a well-puddled soil. After planting, 4 water regimes were imposed: continuous flooding from crop establishment until harvest

Table 19. Weed weight at harvest of wet-seeded, rainfed rice as affected by water regimes and weed control practices.[a] IRRI, 1977 wet season.

Weed control practice	Herbicide application rate[b] (kg a.i./ha)	Date of application[c] (DS)	Weed wt[d] (t/ha) as affected by			
			Soil saturation for first 2/3 of crop life cycle	Soil flooding at 3-week intervals	Soil drying for 28 DS and saturation	Continuous flooding
Thiobencarb fb 2, 4-D	1.0 fb 0.5	6 fb 28	0.7 a	0.3 a	0.5 a	0.3 a
Propanil	2.5	12	0.4 a	0.4 ab	0.8 ab	0.5 a
Propanil – fenoprop	0.7 — 1.3	12	1.3 a	0.6 ab	1.9 ab	0.5 a
Hand weeding	—	28	1.2 a	0.7 b	2.7 ab	0.4 a
Amiprofos-methyl 2, 4-D	1.4 — 0.3	6	1.6 a	0.8 b	2.7 ab	0.3 a
Thiobencarb – 2, 4-D	0.7 — 0.3	6	1.6 a	0.5 ab	3.4 ab	0.4 a
One-way rotary weeding	—	28	1.8 a	1.0 b	4.3 b	0.8 a
Two-way rotary weeding	—	28	1.8 a	1.1 b	4.6 b	0.9 a
No weeding	—	—	3.2 a	3.2 b	5.1 b	0.7 a

[a]fb = followed by. A spaced dash (–) between 2 herbicide names indicates that the chemicals were formulated as a proprietary mixture. [b]a.i. = active ingredient. [c]DS = days after seeding. [d]In a column, any 2 means followed by the same letter are not significantly different at the 5% level.

Table 20. Yield of IR36 as affected by water regimes and weed control practices.[a] IRRI, 1977 wet season.

Weed control practice	Herbicide application rate[b] (kg a.i./ha)	Date of application[c] (DS)	Yield[d] (t/ha) as affected by			
			Soil saturation for first 2/3 of crop life cycle	Soil flooding at 3-week intervals	Soil drying for 28 DS and saturation	Continuous flooding
Thiobencarb fb 2, 4-D	1.0 fb 0.5	6 fb 28	3.0 a	4.5 abc	4.9 a	5.6 ab
Propanil	2.5	12	2.2 ab	5.1 a	4.3 ab	4.9 abc
Propanil – fenoprop	0.7–0.3	12	3.2 a	4.8 ab	4.0 abc	5.7 a
Hand weeding	–	28	2.6 ab	4.6 abc	2.1 de	4.8 abc
Amiprofos-methyl –2, 4-D	1.4–0.3	6	2.8 ab	4.0 abcd	3.6 bc	5.3 abc
Thiobencarb – 2, 4-D	0.7 — 0.3	6	2.1 ab	3.4 cd	2.9 cd	5.2 abc
One-way rotary weeding	—	28	2.1 ab	3.7 bcd	1.9 de	4.3 bc
Two-way rotary weeding	—	28	1.6 b	3.7 bcd	1.3 e	4.2 c
No weeding	—	—	2.3 ab	2.8 d	2.1 de	4.4 bc

[a]fb = followed by. A spaced dash (–) between 2 herbicide names indicates that the chemicals were formulated as a proprietary mixture. [b]a.i. = active ingredient. [c]DS = days after seeding. [d]In a column, any 2 means followed by the same letter are not significantly different at the 5% level.

to irrigation until 28 days after seeding and soil saturation thereafter until harvest, soil saturation for the first two-thirds of the life cycle of the crop, and soil flooding at 3-week intervals after planting. Eight weed control treatments were superimposed on each water regime.

Weed weights differed markedly among the four water regimes at harvest. Among the unweeded plots those not irrigated until 28 days after seeding had the highest weed weight and those continuously flooded had the lowest. When the soil was flooded continuously or kept saturated during the first two-thirds of crop growth, weed weights among the treatments did not significantly differ. But under the two other water regimes weed weights differed markedly (Table 19).

Thiobencarb followed by 2,4-D, propanil, and propanil – fenoprop gave good weed control under all water regimes, while thiobencarb – 2,4-D and amiprofos-methyl – 2,4-D tended to give better weed control when the soil was wet during the initial growth of the crop. Weed control by hand weeding was slightly inferior to that by the best herbicide treatments. In the two rotary weeding treatments, weeds within the crop rows and adjacent to the hills were not controlled; at harvest, weed weights between these plots and the unweeded check were not significantly different.

The grain yield from each of the plots generally reflected the degree of weed control achieved with a particular treatment (Table 20).

Except when the soil was kept dry for 28 days after seeding, the yields from rice plots hand weeded once were not significantly lower than those obtained from the highest yielding treatments. The yields from the plots that were rotary weeded reflected poor weed control

Weed growth in upland crops. *Competitiveness of upland crops (Agronomy).* Seven crops grown in upland field plots varied considerably in the ability to compete with weeds. On the basis of weed weight at harvest, cowpea was most competitive against weeds, and rice least competitive (Table 21). The percentage of yield reduction due to weeds was not necessarily related to weed weight. The lowest yield reduction caused by weeds was in cowpea, the most competitive crop, and the highest yield reduction, in the rice cultivar IR661-170-1-3, which was slightly more competitive against weeds than IR1746-88-1-2-1. Also, yield losses caused by weeds in mung bean were less than those that occurred in sweet potato and soybean, even though more weeds competed against mung bean (Table 21).

The reason for the differing competitive ability of crops and cultivars is not known, but it cannot be plant height. The shortest rice cul-

Table 21. Competitive ability of 7 crops grown in upland field plots. IRRI, 1977 wet season.

Crop (cultivar)	Weed wt (t/ha)	Yield (t/ha)		Yield reduction (%) due to weeds
		Weed-free plot	Unweeded plot	
Cowpea (EC #1)	0.6	1.3	1.1	15
Corn (DMR 2)	1.6	7.3[a]	4.2[a]	42
Sorghum (Cosor 3)	1.9	3.2	1.7	47
Mung bean (CES 55)	2.9	0.47	0.23	55
Sweet potato (BNAS 51)	1.9	19.6	6.7	66
Soybean (Multivar 80)	2.4	0.36	0.10	72
Rice (BPI 76/9 x Dawn)	3.2	3.1	1.2	61
Rice (IR1746-88- 1-2-1)	5.6	2.6	0.7	73
Rice (IR661-170- 1-3)	5.3	3.8	0.0	100

[a]Wt of green corn on the cob.

tivar suffered the greatest yield losses; however, BPI 76/9 × Dawn — a medium-statured cultivar — was more competitive and had less yield reduction due to weeds than IR1746-88-1-2-1, which is a taller cultivar. Cowpea was also more competitive against weeds than corn or sorghum. Further trials are planned.

Effect of land preparation and mulching. Different methods of land preparation (zero and minimum tillage), plus mulching (mulching and no mulching) and weeding treatments (no weeding, weeded once, and weed free) were compared for weed control in mung bean, cowpea, and sorghum planted after a lowland rice crop.

For sorghum and cowpea, there were no significant differences in weed weight at harvest between tillage treatments and mulching methods. For mung bean, weed weight at harvest of the unmulched zero-tillage plot was significantly higher than that in the mulched plot. But there was no significant difference between mulching and no mulching on the minimum tillage plot.

For cowpea and mung bean, there were no significant differences in yield among tillage techniques, mulching methods, or weeding treatments. For sorghum, however, the unweeded plot always yielded significantly less than the weeded plots (Table 22).

Advanced screening of herbicides. During the 1977 wet season, 10 herbicides were compared with hand-weeded and untreated checks for weed control in 6 upland crops at IRRI and in a farmer's field. The major weed species at IRRI were *A. spinosus, C. rotundus, Digitaria sanguinalis, E. indica,* and *Rottboellia exaltata. C. rotundus* had a much heavier stand than the other weeds during the early growth stages of the crops.

During the early stages of crop growth, the farmer's field was heavily infested with *Bidens pilosa, Commelina benghalensis, Cyperus iria, E. colona,* and *E. indica.* During the later stages

Table 22. Effect of degree of land preparation and mulching or weeds and yield of sorghum.[a] Pangasinan, Philippines, 1977 wet season.

Weeding treatment	Land preparation method[b]				Mulching method[c]			
	Zero tillage[c]		Minimum tillage[d]		No mulch		With mulch	
	Weed wt at harvest (g/0.5 m²)	Yield (t/ha)	Weed wt at harvest (g/0.5 m²)	Yield (t/ha)	Weed wt at harvest (g/0.5 m²)	Yield (t/ha)	Weed wt at harvest (g/0.5 m²)	Yield (t/ha)
Weed free	0 a	2.3 a	0 a	2.2 a	0 a	2.1 a	0 a	2.3 a
One weeding at 21 DE[f]	20.9 b	2.3 a	16.9 b	2.2 a	19.6 b	2.0 a	12.2 b	2.5 a
No weeding	95.0 c	1.7 b	83.9 c	1.6 b	77.9 c	1.6 b	100.9 c	1.8 b

[a]In a column, any 2 means followed by the same letter are not significantly different at the 5% level. [b]Yields are averaged for land preparation methods. [c]Field sprayed with paraquat at 0.75 kg/ha. Furrow opened for seed placement. [d]One plowing followed by 2 or 3 harrowings. [e]Yields are averaged for mulching methods. [f]DE = days after crop emergence.

Table 23. Yields of upland crops as affected by preemergence herbicides at IRRI and Batangas province, Philippines, 1977 wet season.

Treatment	Rate[a] (kg a.i./ha)	Yield[b] (t/ha)					
		Rice	Corn	Sorghum	Soybean	Mung bean	Peanut
				IRRI			
Two hand weedings[c]	—	1.4 a	3.4 a	3.5 a	0.8 a	0.40 abc	1.1 a
Pendimethalin	2.0	1.5 a	3.3 a	2.5 abcd	0.5 b	0.40 abc	1.0 a
Butralin	2.0	0.9 a	2.3 a	3.5 a	0.6 ab	0.38 abcde	0.4 cd
EXP 3316	0.4	0.9 a	3.4 a	2.5 abcd	0.6 ab	0.28 de	0.4 cd
Dinitramine	1.5	1.4 a	2.7 a	3.4 ab	0.7 ab	0.26 e	0.6 bc
Oxadiazon	1.0	1.1 a	2.1 a	3.2 abc	0.8 a	0.47 a	0.8 ab
Oxyfluorfen	0.5	1.2 a	1.8 a	2.3 cd	0.8 a	0.36 abcde	0.8 ab
Hercules 22234	1.0	0.6 a	2.4 a	2.5 abcd	0.7 ab	0.43 ab	0.3 cd
Butachlor	2.0	1.0 a	2.0 a	3.1 abc	0.8 a	0.29 cde	0.4 cd
X-150	4.0	1.0 a	3.0 a	1.6 d	0.6 ab	0.39 abcd	0.4 cd
Piperophos – dimethametryn	1.6 – 0.4	0.8 a	2.6 a	2.5 abcd	0.6 ab	0.27 e	0.2 d
Untreated	—	0.6 a	1.7 a	2.0 d	0.6 ab	0.34 bcde	0.2 d
				Batangas			
Two hand weedings[c]	—	3.3 a	4.4 ab	3.4 a	1.2 bc	0.54 a	1.0 a
Pendimethalin	2.0	2.2 b	4.6 ab	2.6 abc	0.4 ef	0.49 ab	0.6 bc
Butralin	2.0	2.0 bc	4.6 ab	2.8 ab	1.1 bcd	0.31 bcde	0.6 bc
EXP 3316	0.4	1.9 bcd	4.5 ab	2.2 abc	1.8 a	0.32 bcd	0.5 bc
Dinitramine	1.5	1.6 bcd	4.4 ab	2.4 abc	0.6 def	0.37 abc	0.7 b
Oxadiazon	1.0	1.8 bcd	3.9 b	2.4 abc	1.1 bcd	0.27 cdef	0.5 bc
Oxyfluorfen	0.5	2.5 ab	5.4 a	1.4 c	1.1 bcd	0.17 def	0.5 bc
Hercules 22234	1.0	1.1 cd	3.7 b	3.3 ab	1.5 ab	0.46 ab	0.5 bc
Butachlor	2.0	0 e	3.4 b	2.9 ab	0.8 cde	0.14 def	0.5 bc
X-150	4.0	1.0 d	3.4 b	2.1 abc	0.7 cdef	0.10 f	0.4 bc
Piperophos – dimethametryn	1.6 – 0.4	0 e	3.6 b	1.3 c	0.5 ef	0.12 ef	0.5 bc
Untreated	—	0 e	1.6 c	2.0 bc	0.3 f	0.11 f	0.3 c

[a]a.i. = active ingredient. A spaced dash (–) between 2 herbicide names indicates that the chemicals were formulated as a proprietary mixture. [b]Av. of 3 replications. For each crop, any 2 means followed by the same letter are not significantly different at the 5% level. [c]Weeded 15 and 30 days after crop emergence.

of growth *Aeschynomene indica, Celosia argentea, Cyperus compressus, D. aegyptium,* and *D. sanguinalis* became important. Absence of rain for more than 1 month after planting and herbicide application delayed the emergence of both crops and weeds and reduced the effectiveness of some of the herbicides.

Pendimethalin was the most promising of the herbicides tested for weed control at both sites. Yields from pendimethalin-treated plots generally were almost as high as those from the hand-weeded check plots (Table 23). However, pendimethalin initially was highly toxic to sorghum and soybean and moderately toxic to rice and corn at Batangas. Sorghum and corn recovered and yielded almost as well as the hand-weeded check, but soybean and rice never recovered and yielded less in the herbicide-treated plots than in the hand-weeded check. Oxyfluorfen was initially toxic to all crops. The crops were ranked according to tolerance for the tested herbicides as follows: peanut > rice > corn > soybean > mung bean > sorghum.

In dinitramine- and pendimethalin-treated plots at IRRI, control of *R. exaltata* and *A. spinosus* in rice was excellent and yields were equal to those from the hand-weeded check. The untreated rice plots at Batangas had no yield because of the heavy infestation of *E. colona.*

The most promising herbicides for corn were pendimethalin and EXP 3316 in both locations, and oxyfluorfen, butralin, and dinitramine at Batangas. Butralin and butachlor gave adequate initial control of weeds and caused only slight injury to sorghum at both locations.

For soybean, oxadiazon and oxyfluorfen appeared promising at IRRI, and EXP 3316 and Hercules 22234 at Batangas. Oxadiazon was the most promising herbicide for weed control in mung bean at IRRI and pendimethalin, Hercules 22234, and dinitramine were the best

in Batangas. Pendimethalin, oxadiazon, and oxyfluorfen performed well in peanut at IRRI. None of the herbicide-treated peanut plots yielded as well as the hand-weeded check in Batangas but dinitramine looked the most promising of the compounds tested on this crop.

Effect of crop rotation. Sorghum was planted at three seeding rates — 150,000, 250,000, and 350,000 plants/ha. Row spacing was constant at 50 cm, but in-row distance between plants was varied. Four postplanting weeding treatments were superimposed on each seeding rate — atrazine and butachlor applied at 2 kg a.i./ha preemergence, hand weeding, and interrow cultivation 17 and 30 days after seeding. After harvest, each plot was divided and the sorghum in one half of the plot was allowed to ratoon. The other half-plot was plowed and planted to mung bean. The ratooned sorghum and the mung bean crops were not weeded.

In the first crop of sorghum, the plots that were weeded by hand yielded significantly more than the other treatments. At the two low plant populations, interrow cultivation gave a significantly lower yield than the other treatments, but at the highest plant population it gave a yield as high as that in the plots treated with atrazine and butachlor (Table 24).

As the plant population increased, yield increased and the percentage of the difference in yield between the hand-weeded treatment and the other treatments decreased. The atrazine-treated plots and the plots with interrow cultivation had significantly more grasses than the other plots. The herbicides used encouraged the growth of sedges. The total weed weight was significantly lower in the hand-weeded plots than in the plots with atrazine or interrow cultivation.

Table 24. Yield of sorghum as affected by plant population and postplanting weed control treatments. IRRI, 1976 dry season.

Treatment[a]	Yield[b] (t/ha) from plant populations of		
	150,000 plants/ha	250,000 plants/ha	350,000 plants/ha
Hand weeding 17 and 30 DS	4.0 a	6.3 a	6.9 a
Atrazine (2 kg a.i./ha)	3.3 b	5.2 b	6.0 b
Butachlor (2 kg a.i./ha)	3.1 b	5.1 b	5.9 b
Interrow cultivation 17 and 30 DS	2.3 c	4.1 c	6.1 b

[a]a.i. = active ingredient, DS = days after seeding. [b]In a column, any 2 means followed by the same letter are not significantly different at the 5% level.

Plant population also affected weed weight. Grasses dominated the weed flora. Grasses harvested from plots with 350,000 plants/ha had significantly lower weight than those harvested from plots with 250,000 plants/ha. The latter, in turn, had significantly lower weight than grasses from 150,000 plants/ha. Most broadleaf weeds grew in association with the highest plant population.

Plots treated previously with atrazine at 2 kg a.i./ha had significantly fewer mung bean plants and the yields were significantly lower, indicating a lethal residual carry-over of herbicide.

There was no indication that good weed control in the first crop resulted in fewer weeds in the unweeded second crop since the total weights of weeds harvested from the mung bean plots were not significantly different. However, the significantly larger number of sedges in the plots treated previously with atrazine and butachlor reflected the results obtained in the sorghum crop.

The level of postplanting weed control achieved in the first crop of sorghum had no effect on the weeds growing in association with the unweeded ratoon crop. There was no significant difference in the total weight of weeds harvested from any of the plots. Sedges, which are sensitive to shade, were much fewer in the sorghum ratoon crop than in the mung bean crop, especially in the plots previously treated with butachlor and atrazine. The significantly greater number of broadleaf weeds in the plots previously treated with butachlor than in the hand-weeded plot is relatively unimportant because broadleaf weeds comprised an average of only 1% of the weed population. The yield of the ratoon crop was unaffected by the previous postplanting weed control treatments.

Plant population in the first sorghum crop affected both yield and degree of weed control in the ratoon crop. The differences were not as marked as in the first crop, but the yield was significantly lower and the total weight of weeds — and the weight of grasses — was significantly

higher where the plant population had been 150,000 plants/ha than where it had been 350,000 plants/ha.

Weed control treatments and sorghum yield (*Agronomy*). Weed control obtained with six herbicide treatments was compared with weed control obtained with two hand-weeding treatments and weed growth in an unweeded check in two experiments. Sorghum yields were also compared.

All the herbicides gave good initial control of grasses and broadleaf weeds but failed to control the sedges (primarily *C. rotundus*) and volunteer rice from the previous crop. Again, the duration of the residual effect of the herbicides was short. Within a month after treatment, broadleaf weeds and grasses that emerged were unaffected by the herbicide. At harvest the weight of weeds from the herbicide-treated plots did not differ significantly from that of weeds harvested from the untreated plots (Table 25).

Table 25. Effect of various weed control treatments on weed control in sorghum.[a] IRRI, 1977 dry season.

Treatment[b]	Experiment 1		Experiment 2	
	Weed wt (t/ha)	Yield (t/ha)	Weed wt (t/ha)	Yield (t/ha)
Three weedings	0.2 a	3.8 a	0.1 a	4.7 a
Two weedings	0.3 b	3.6 a	0.2 b	4.3 ab
Butralin (2 kg a.i./ha)	3.0 c	2.4 b	1.8 bc	3.8 abc
Butachlor (2 kg a.i./ha)	2.2 c	2.6 b	1.9 bc	3.5 bcd
Piperophos - dimethametryn (1.6 - 0.4 kg a.i./ha)	2.8 c	2.4 b	1.2 bc	3.3 cd
Terbuchlor (1 kg a.i./ha)	—	—	1.8 bc	3.0 cd
Pendimethalin (2 kg a.i./ha)	3.4 c	2.2 b	1.9 bc	2.6 d
Untreated	4.5 c	1.8 bc	4.7 c	1.5 e
Oxadiazon (1 kg a.i./ha)	3.0 c	1.1 c	—	—

[a]In a column, any 2 means followed by the same letter are not significantly different at the 5% level. [b]a.i. = active ingredient. A spaced dash (-) between 2 herbicide names indicates that the chemicals were formulated as a proprietary mixture.

Nitrogen levels and number of weedings. The effect of different levels of nitrogen and weeding on sorghum yield and weed growth was studied at IRRI. Increasing the nitrogen applied from 0 to 120 kg/ha resulted in no increase in weed weight at all levels of weeding — no weeding, one weeding 28 days after emergence (DE), and weeding at 21 and at 35 DE. Increasing the level of weeding generally resulted in a significant decrease in weed weight at all nitrogen levels.

The yield losses caused by weeds were greatest when no nitrogen was applied and least when 120 kg nitrogen/ha was applied. Without nitrogen, the yield from the unweeded plots was significantly lower than that from the plots that had been weeded twice, but with 120 kg nitrogen/ha, no significant difference was observed. Increasing the weedings from one to two did not significantly increase the yield at any nitrogen level.

Spacing, seeding rate, and weeding methods. Weed weight and sorghum yield as affected by spacing, seeding rate, and weed control practices were studied at IRRI. The weight of weeds that grew in association with the crop was lower at the closer row spacing (25 cm) than at the wider row spacing (50 cm); it was also lower at a high seeding rate (70 kg/ha) than at a low seeding rate (30 kg/ha). Neither row spacing nor seeding rate affected crop yield.

At harvest there was no significant difference in weed weight among weeding treatments (Table 26). Because of the closeness of the rows and wet soil, interrow cultivation was difficult and gave poor weed control. Butachlor gave good initial control of broadleaf weeds and grasses, but its residual effect was of short duration. Within a month after butachlor treatment weeds grew rapidly in the plots; at 42 DE the weight of weeds harvested from those plots was

Table 26. Weed weights 42 days after crop emergence (DE) and at harvest, and sorghum yield as affected by various weed control treatments.[a] IRRI, 1977 wet season.

Treatment	Weed wt (t/ha)		Sorghum yield (t/ha)
	42 DE	At harvest	
Butachlor[b] (2 kg a.i./ha)	0.6 a	0.7 a	2.8 a
Interrow cultivation 20 and 35 DE	0.6 a	1.5 a	2.4 ab
Interrow cultivation 28 DE	0.6 a	1.0 a	2.3 ab
No weeding	0.9 a	1.3 a	2.0 b

[a]Av. of 3 seeding rates and 2 row spacings. In a column, any 2 means followed by the same letter are not significantly different at the 5% level. [b]a.i. = active ingredient.

not significantly different from that of weeds from the unweeded plot (Table 26).

Most of the herbicides reduced sorghum stand and burned the leaves of seedlings. Oxadiazon was the most toxic and drastically reduced the crop stand. Pendimethalin reduced stand by more than 40% while the other herbicides reduced it by 14% (butachlor) to 27% (piperophos - dimethametryn).

In both experiments, increasing the number of hand weedings from two to three did not significantly increase yield (Table 25). The herbicide-treated plots yielded less than the hand-weeded plots.

Weeding requirements of intercrops (*Agronomy*). The amount of weeding needed depends on the crops that are grown in the intercrop and the spatial relationship of one to the other.

Pangasinan cropping systems consisting of a legume alone, sorghum alone, one row legume and one row sorghum, and two rows legume and one row sorghum were compared for competition against weeds and for crop yield. Legumes used were cowpea and mung bean. Weed weights at 40 days after emergence and at harvest did not significantly differ between the different cropping patterns for the various weed control treatments.

For the sole crop cowpea or mung bean, the weed-free plot yielded significantly more than the unweeded check plot, but the yield difference among the other treatments was not significant. The yields of the sole crop sorghum did not differ among plots that had been weeded, but all weeded plots yielded significantly more than the unweeded check.

The yields of sorghum in the intercrop combinations did not differ significantly among treatments, but they were significantly lower than those of the sole crop. Cowpea and mung bean yields from the plot with two rows of legumes and one row of sorghum were equal to yields from the sole crop plots and significantly higher than the yields from the combination of one row legume and one row sorghum.

Yields of mung bean did not differ among weeding treatments in the two intercrop combinations used. With one row of cowpea and one row of sorghum, the yield of cowpea did not significantly differ among weeding treatments. With two rows of cowpea and one row of sorghum, the cowpea yield from the weed-free plot was significantly higher than that from the unweeded plot or the plot weeded twice, but not significantly different from the yield from the plot that was weeded once.

In an Iloilo study, different intercrop combinations reacted differently to weeding. The corn and soybean combination needed two weedings to yield significantly more than the unweeded check; the corn and peanut combination needed only one weeding.

In the intercrop combination of corn and Mexican yam bean, both crops yielded as well when unweeded as when weeded once or twice, indicating that the combination is competitive against weeds. Fewer weeds grew in the unweeded plots of the corn and yam bean combination than in the unweeded plots of the other combinations. Most weeds grew in the corn and soybean combination.

In the intercrop combination of corn and mung bean, the corn showed no response to weeding, but the mung bean yielded significantly higher when it was weeded twice than when weeded once or unweeded. In the corn and cowpea combination, one weeding was sufficient to produce optimum yield of corn, but two weedings were needed for optimum yield of cowpea.

Continuous cropping of transplanted rice (*Agronomy*). The effect of weed control treatment applied to a crop of transplanted rice on the weeds in and the yield of subsequent crops of transplanted rice was studied in two trials. In the first trial, rice was transplanted at 15- × 15-, 20- × 20-, and 25- × 25-cm spacings and subjected to 10 weed-control treatments. In the second and third crops, which were not weeded, only a 20- × 20-cm spacing was used.

Results of the first trial were reported in the 1976 Annual Report. Results from three crops are summarized in Tables 27 and 28. In the first crop, the grain yield reflected the degree of weed control that was achieved with a particular weeding treatment. The best yields were obtained from the plots that were hand weeded, while the poorest were harvested from the unweeded plot.

Table 27. Effect of various weed control practices applied to the first crop of transplanted rice on the weight of weeds at harvest in the first, second, and third crops. IRRI, 1976–77 dry and wet seasons.

Treatment[a]	Herbicide rate[b] (kg a.i./ha)	Weed wt[c] (g/0.5 m²)		
		First crop[d]	Second crop	Third crop
No weeding	—	134 e	116 c	187 a
2, 4-D	0.8	107 de	105 c	181 a
2, 4-D fb one rotary weeding	0.8	86 cd	74 ab	227 a
Thiobencarb – 2, 4-D	1.0 – 0.5	81 cd	74 abc	179 a
Two rotary weedings	—	80 cd	97 bc	231 a
Thiobencarb – 2, 4-D	0.5 – 0.25	62 c	111 c	192 a
Thiobencarb – 2, 4-D fb one rotary weeding	0.5 – 0.25	58 bc	77 abc	172 a
One hand weeding	—	41 ab	55 ab	189 a
Weed free for 30 DT	—	17 a	52 a	176 a
Two hand weedings	—	13 a	54 ab	190 a

[a]fb = followed by. A spaced dash (–) between 2 herbicide names indicates that the chemicals were formulated as a proprietary mixture. DT = days after transplanting. [b]a.i. = active ingredient. [c]In a column, any 2 means followed by the same letter are not significantly different at the 5% level. [d]Av. of 3 plant densities and 2 cultivars.

The weeds growing in association with the second crop were affected neither by plant spacing nor by variety grown in the first crop, but they were greatly affected by the weed-control practices used. Plots in which weeds were adequately controlled in the first crop had fewer weeds in the second crop than plots where weeds were poorly controlled in the first crop. In both cases, the lowest weed weight was associated with the plot that was hand weeded in the first crop. The weight of weeds from plots that had good weed control in the first crop tended to increase in the second crop while the weight of others remained relatively stable (Table 27).

In the third crop, no significant difference in weed weight resulted from the weed control treatments that had been applied to the first crop.

Plots that yielded best in the first crop also yielded best in the second crop (Table 28). The yields reflected the degree of weed competition — generally the greater the weight of weeds, the lower the yield. Yields from the second crop were 30 to 50% lower than those from the first crop.

Significant differences in yields were also observed in the third crop even though the treatments did not significantly differ in weed weights at harvest. Yields in all third-crop plots

Table 28. Effect of various weed control practices applied to the first crop of transplanted rice on the grain yield of the first, second, and third crops. IRRI, 1976–77 dry and wet seasons.

Treatment[a]	Herbicide rate[b] (kg a.i./ha)	Grain yield[c] (t/ha)		
		First crop[d]	Second crop	Third crop
Two hand weedings	—	3.5	2.3 ab	0.5 bcd
Weed-free for 30 DT	—	3.4	2.4 a	0.9 a
One hand weeding	—	3.4	2.3 ab	0.6 abcd
2, 4-D fb one rotary weeding	0.8	3.3	1.7 bcd	0.5 bcd
Thiobencarb – 2, 4-D fb one rotary weeding	0.5 – 0.25	3.3	2.1 abc	0.8 ab
Thiobencarb – 2, 4-D	1.0 – 0.5	3.1	1.6 cde	0.7 abc
Thiobencarb – 2, 4-D	0.5 – 0.25	3.0	1.4 de	0.3 cd
Two rotary weedings	—	2.9	1.8 bcd	0.5 bcd
2,4-D	0.8	2.9	1.2 de	0.3 cd
No weeding	—	1.8	1.1 e	0.2 d

[a]fb = followed by. A spaced dash (–) between 2 herbicide names indicates that the chemicals were formulated as a proprietary mixture. DT = days after transplanting. [b]a.i. = active ingredient. [c]In a column, any 2 means followed by the same letter are not significantly different at the 5% level. [d]Av. of 3 plant densities and 2 cultivars. Because interaction with plant density was significant, no test of significance was given.

Table 29. Weed count, weight, and crop yield as affected by weed control practices applied to a previous crop of transplanted rice.[a] IRRI, 1977 wet season.

Previous weeding treatment[b]	Weeds (no./0.5 m²)	Weed wt (g/0.5 m²)	Yield (t/ha)
Weed free	153 a	46 a	2.8 a
2, 4-D (0.8 kg a.i./ha)	144 a	50 a	2.5 ab
No weeding	153 a	56 a	2.4 b
Weeding at 21 DT	135 a	49 a	2.3 b

[a]In a column, any 2 means followed by the same letter are not significantly different at the 5% level. [b]a.i. = active ingredient; DT = days after transplanting.

were less than 1 t/ha. The plots that yielded highest in the first crop tended to yield highest in the third crop, but differences among treatments were not as great as those in the previous crop.

In the second trial, eight rice cultivars were transplanted and subjected to four weed-control practices. As the second crop, which was not weeded, only IR36 was grown. Weed numbers and weights, and yield of IR36 were not affected by the previous cultivar. No significant differences in weed number or weight at harvesting resulted from previous weeding treatments (Table 29). However, the yield obtained from the plots that were previously kept weed free was significantly higher than that obtained from the plots that were previously weeded once or left unweeded, but it was not significantly different from the yield obtained from the plots that had previously been treated with 2,4-D.

Management and control of *Scirpus maritimus* (*Agronomy*). A trial, initiated in 1974 to study the effect of soil and water management on weed growth and crop yield, was continued in 1977. The three cropping patterns were the same as those used in previous years except that corn was intercropped with soybean instead of peanut or mung bean.

In the continuous lowland rice cropping pattern, the population of *Scirpus maritimus* in the unweeded check plot increased during the 1977 wet season compared with the 1976 crop seasons. The annual weed population decreased substantially compared with that in previous years.

In the second cropping system (upland crops rotated with lowland rice), the total number of annual weeds was greatly reduced in both the 1977 wet and dry seasons, compared with the 1976 seasons. The population of *S. maritimus* was similar to that in the previous two seasons, but it was considerably lower than when rice was planted continuously. In the dry season, the population of *C. rotundus* was reduced to one-third in the alternating wet and dry soil conditions, compared with that in the third cropping system where upland rice was rotated with dry-seeded, rainfed, bunded rice.

In the third cropping system (upland crop rotated with dry-seeded rice), some *S. maritimus* survived because of the moist conditions that prevailed in the plots. The population of *C. rotundus* was lower than that in the two previous crop seasons. The annual weed population was considerably heavier in the wet season than in the previous year.

In the continuous lowland rice cropping pattern, the 1977 dry season yields from the rotary-weeded plots were 2.7 t/ha higher than those from the bentazon-treated plots. Bentazon did not adequately control the heavy infestation of *S. maritimus* and the yield from the plot treated with it (1.1 t/ha) was not significantly different from that obtained from the unweeded check (0 t/ha) (Table 30).

The yield of corn intercropped with soybean was similar to that obtained when corn was planted alone. The yield of sole-cropped corn from the unweeded plot was not significantly different from that in the weeded plots. In the untreated plots, the corn plants shaded out most of the weeds present.

In the continuous rice cropping pattern in the 1977 wet season, the highest yield was obtained from the plots that were rotary weeded. The unweeded plots failed to yield because they were heavily infested by *S. maritimus*.

Among the plots previously planted to a corn – soybean intercrop, the treated ones yielded significantly more than the unweeded ones. The rotary-weeded plots yielded significantly more than the bentazon-treated plots (Table 31). The unweeded plots yielded 1 t/ha, but in the other cropping systems, they yielded nothing.

In the rainfed rice crop in the third cropping system, the hand-weeded plots gave the highest

Table 30. Effects of weeding methods and crop rotation on crop yield and population of *Scirpus maritimus* and other weeds. Soil and water management trial initiated in 1974. IRRI, 1977 dry season.

Crop rotation, weeding treatment[a]	Yield[b]		Weeds (no./m²)				
			Annuals			Perennials	
			Grasses	Broadleaf weeds	Sedges	*Scirpus maritimus*	*Cyperus rotundus*
Continuous lowland rice	Rice (t/ha)						
Rotary weeding 15 and 30 DT	3.8 a		18	10	17	75	0
Bentazon (2 kg a.i./ha)	1.1 ab		125	41	84	33	0
No weeding	0 b		121	40	116	191	0
Upland crop + lowland rice	*Corn (ears/ha)*	*Soybeans (kg/ha)*					
Hand weeding 20 and 30 DS	43,000 a	657 a	93	0	1	4	8
Butachlor fb bentazon[c]	34,000 ab	273 b	350	1	0	17	9
No weeding	24,500 b	213 b	589	8	23	59	8
Upland crop + dry-seeded rice	*Corn (ears/ha)*						
Hand weeding 20 and 30 DS	41,500 a		47	1	4	0	4
Butachlor fb bentazon[c]	37,500 a		221	24	4	25	47
No weeding	27,500 a		431	73	17	26	38

[a]fb = followed by. DT = days after transplanting. a.i. = active ingredient. DS = days after seeding. [b]Av. of 2 replications. Within each crop rotation, any 2 means followed by the same letter are not significantly different at the 5% level. [c]1.7 fb 2 kg a.i./ha.

rice yield, 4.3 t/ha. Dinitramine gave good control of annual grasses and sedges but failed to control *S. maritimus* and *C. rotundus*.

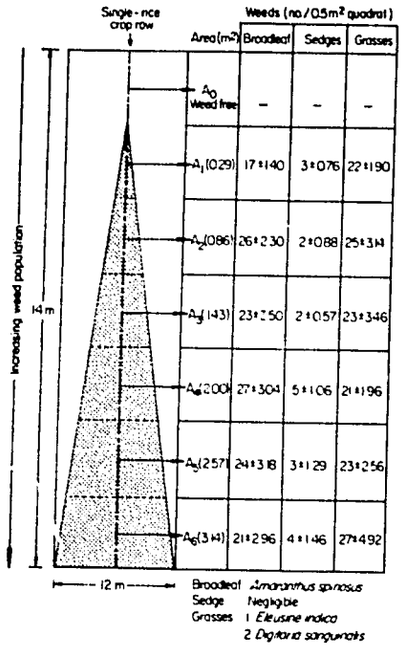
Weed-crop-water relationships *(Agronomy)*. Less reduction of weed growth than of crop growth during drought is commonly observed in rainfed rice. Severe weed infestation can often be traced to a preceding drought in which the weeds gained a competitive advantage. A continuous-function experimental design (Fig. 5) was used to create increasing competition for water between the rice crop and different weed species. During the rice crop's vegetative stage, beginning 20 days after emergence, water was withheld from half of the plots. Figures 6 and 7 illustrate the difference observed in leaf water potential of IR28 and the weed species *A. spinosus*, *E. incida*, and *D. sanguinalis* grown along the center line of the plot. Each point is an average of two observations in the designated subunit (Fig. 5).

The leaf water potential of rice was sig-

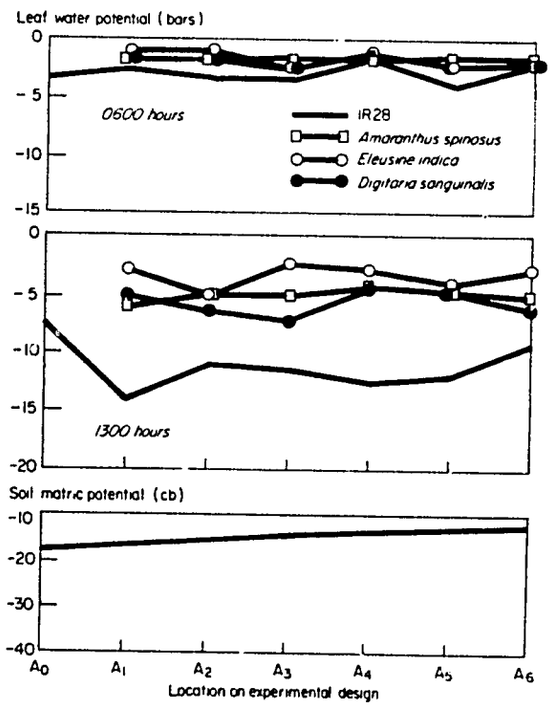
Table 31. Rice yield and number of weeds as affected by crop rotation and weeding treatment. IRRI, 1977 wet season.

Crop rotation, weeding treatment[a]	Rice yield[b] (t/ha)	Weeds (no./m²)				
		Annuals			Perennials	
		Grasses	Broadleaf weeds	Sedges	*Scirpus maritimus*	*Cyperus rotundus*
Continuous lowland rice						
Rotary weeding 15 and 30 DT	2.5 a	14	5	17	47	0
Bentazon (2 kg a.i./ha)	1.2 b	141	23	43	11	0
No weeding	0 c	71	9	9	421	0
Upland crop + lowland rice						
Rotary weeding 15 and 30 DT	5.1 a	9	12	32	33	0
Bentazon (2 kg a.i./ha)	4.0 b	44	29	70	1	0
No weeding	1.0 c	29	26	120	209	0
Upland crop + dry-seeded rice						
Hand weeding 20 and 30 DS	4.3 a	2	0	3	0	0
Dinitramine (2 kg a.i./ha)	2.6 b	5	4	0	84	45
No weeding	0 c	3722	17	2	35	9

[a]DT = days after transplanting. a.i. = active ingredient. DS = days after seeding. [b]Av. of 2 replications. Within each crop rotation, any 2 means followed by the same letter are not significantly different at the 5% level.



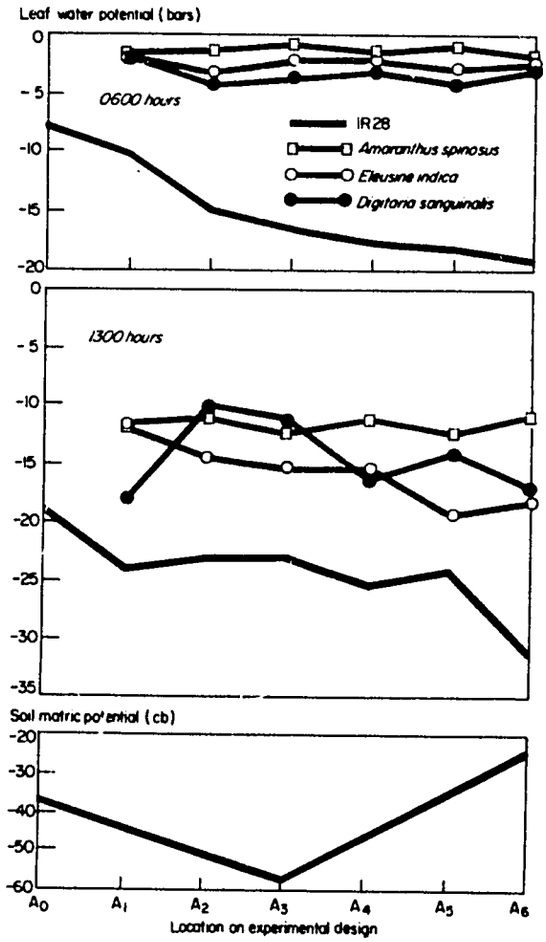
5. Continuous-function experimental design and resultant weed counts from 0.5-m² quadrats sampled along the center line.



6. Leaf water potentials in the well-watered plots at 0600 and 1300 for rice and the three dominant weed species, and soil matric potential along the center line.

nificantly lower than that of the weed species in all cases except in the dawn measurement of the well-watered (control) plots. At midday the leaf water potential of rice in the control plots was much lower than that of the weed species despite high soil matric potential. When a soil water deficit was imposed, the same trends were apparent and the magnitude of the differences among the species increased. Among the weed species, *A. spinosus* consistently showed a capability to maintain high leaf water potential.

Regardless of the soil (soil matric potential) or atmospheric (vapor pressure deficit) water status, the weed species demonstrates superior adaptation in maintaining leaf water potential relative to the cultivar IR28.



7. Leaf water potentials in the water-stressed plots at 0600 and 1300 for rice and the three dominant weed species, and soil matric potential along the center line.

PLANT PROTECTION

Cropping Systems Components of the Entomology and Plant Pathology Departments

Lowland rice-based cropping systems. (*Entomology Cropping Systems Component*). *Chemical insect control on a double rice crop pattern.* The first and second crops of a double rice crop pattern in Iloilo, Philippines, differed in insect control requirements. Each received broad-spectrum insecticides during the three major stages of plant growth: early vegetative (0-29 DT), late vegetative (30-49 DT), and reproductive (50-75 DT). Five treatments and an untreated control were compared. The maximum insecticide treatment protected the crop at all three growth stages, but each of three other treatments gave no protection during one growth stage.

In the maximum protection plots, 2 kg a.i. carbofuran granules/ha were incorporated into the soil during the last tillage before transplanting, and 0.75 kg a.i. monocrotophos/ha was sprayed 30, 40, 50, and 65 DT. An additional application, based on economic thresholds for insect damage, was made when one or more of the following pest situations arose: 1) more than 4 brown planthoppers/tiller, 2) more than 10% deadhearts before maximum tillering, 3) more than 10% leaf damage from leaf folders between flowering and grain filling, 4) more than 15% defoliation during tillering, and 5) more than 4 rice bugs/m^2 during the milky stage.

In the first crop, the maximum-protection plot and the control yielded 5.1 t/ha, indicating no insect pest problems. Early planting, timed with the onset of monsoon rains, is a form of cultural control because crop establishment occurs before a significant pest buildup.

Insect damage was significant in the second crop. Yield from the maximum-protection plot (4.9 t/ha) was 1 t/ha higher than that from the untreated control (Table 32). The rice pests were stem borers, predominantly the white stem borer *Tryporyza innotata* (Walker); rice caseworm *Nymphula depunctalis* Guenee; rice green-horned caterpillar *Melanitis leda ismene* Cramer; and rice bugs *Leptocorisa* spp. The early season defoliators caused the greatest yield loss (600 kg/ha), followed by stem borer whiteheads (300 kg/ha), and rice bugs (300 kg/ha). It was uneconomical to control all three pests. Most beneficial was protection at both the early and late vegetative growth stages (US$84/ha), followed by protection at the reproductive stage alone (US$46/ha). Least beneficial was protection at both the late vegetative and reproductive stages (net loss, US$40/ha).

Chemical insect control on dry-seeded rice. The 1977-78 rainfall pattern favored the establishment of dry-seeded rice at the Pangasinan sites and provided an opportunity to determine the chemical insect control requirements for that planting method.

Five insecticide treatments for insects attacking IR36 rice dry seeded at the onset of the rainy season were compared: 1) carbofuran granules at 1.5 kg a.i./ha placed in seed furrows, followed by endosulfan sprays at 0.75 kg a.i./ha at 40, 70,

Table 32. Effect of chemical insect control[a] on the second crop of double-cropped transplanted IR28, Iloilo, Philippines, 1976–77.

Protection with insecticide	Stem borers[b] (%)		*Melanitis*[c] (no./10 hills)	Defoliation[d] (%)	Rice bugs[e] (no./m^2)	Yield (t/ha)	Insecticide cost[f] (US$/ha)	Return to insecticide[g] (US$/ha)
	Deadhearts 35 DT	Whiteheads 64 DT	60 DT	20 DT	70 DT			
Maximum[h]	0.8 a	4.1 a	0.5	7 a	2.5 a	4.9 ab	144	- 5
None at early vegetative stage[i]	3.2 b	4.0 a	2.3	16 b	3.3 ab	4.3 d	95	-40
None at late vegetative stage[j]	1.0 a	4.8 a	0.7	10 a	3.7 bc	4.6 bc	96	1
None at reproductive stage[k]	1.2 a	3.6 a	1.7	9 a	3.8 bc	5.0 a	96	84
Economic threshold[l]	3.3 b	6.9 b	1.3	17 bc	3.7 bc	4.4 cd	23	46
None (control)	5.4 b	7.4 b	2.2	21 c	4.7 c	3.9 e		

[a]Av. of 6 fields, unreplicated within fields. Any 2 means followed by a common letter are not significantly different from each other at the 5% level. [b]One 5-m^2 sample area/plot. [c]10-hill sample/plot. [d]Visual estimate per plot. [e]Ten 1-m^2 samples/plot. [f]Carbofuran US$0.80/kg; monocrotophos US$5.04/946 cc. [g]US$0.14/kg rice. [h]Carbofuran granules (2 kg active ingredient a.i./ha) incorporated into soil during last harrowing; monocrotophos (0.75 kg a.i./ha) sprayed at 30, 40, 50, and 65 days after transplanting (DT). [i]Monocrotophos sprayed at 30, 40, 50, and 65 DT. [j]Carbofuran granules incorporated into soil at 50 and 65 DT. [k]Carbofuran granules incorporated into soil, monocrotophos sprayed at 30 and 40 DT. [l]Monocrotophos sprayed at 65 DT.

Table 33. Chemical insect control[a] on IR36 dry seeded in June in Mansoag, Pangasinan, Philippines, 1977–78.

Insecticide treatment	Leaf folder damaged leaves[b] (%)		Rice bug damaged grain (%)	Plant ht (cm) 35 DE	Plant stand (no. tillers/ m^2) 25 DE	Yield (t/ha)	Insecticide cost[c] (US$/ha)	Return to insecticide[d] (US$/ha)
	55 DE	90 DE						
1[e]	0 a	6 a	3.5 a	23 a	201 abc	6.4 a	111	40
2[f]	2 ab	16 b	8.8 c	24 a	228 ab	6.2 ab	42	86
3[g]	3 b	16 b	7.3 bc	24 a	240 a	5.9 abc	15	60
4[h]	1 ab	14 b	4.7 ab	22 b	183 bc	5.7 bc	28	15
5[i]	2 ab	14 b	6.7 bc	22 b	170 c	5.5 c	—	—

[a]Av. of 8 fields, unreplicated within fields. DE = days after emergence. Any 2 means in a column followed by a common letter are not significantly different from each other at the 5% level. [b]200-leaf sample. [c]Carbofuran, US$0.95/kg; endosulfan US$6.16/946 cc. [d]Rice, US$0.17/kg. [e]Carbofuran granules (1.5 kg a.i./ha) in seed furrow, endosulfan sprays (0.75 kg a.i./ha) at 40, 70, and 80 (DE). [f]Carbofuran granules in seed furrow. [g]Carbofuran (0.5 kg a.i./ha) seed treatment. [h]Endosulfan sprays at 55 and 90 DE, when economic thresholds were reached. [i]No insecticide.

and 80 days after rice emergence (DE); 2) carbofuran granules at 1.5 kg a.i./ha in seed furrows; 3) seed treatment with 0.5 kg a.i. carbofuran/ha; 4) sprays at 55 and 90 DE when economic thresholds were surpassed; and 5) no insecticide.

Insect sampling throughout crop growth identified the rice leaf folder and rice bug as the only abundant pests. The leaf folder attack was relatively late (ripening stage). Neither pest appeared important because there was no significant difference in yield response between treatment 1 (6.36 t/ha), where pests were controlled, and treatment 2 (6.22 t/ha), where they were not.

Yield differences between plots treated with carbofuran granules (treatments 1 and 2) and those without (treatment 5) were significant (Table 33). The carbofuran treatments resulted in more tillers per square meter and significantly taller plants. The differences in plant growth were particularly noticeable in three of the eight fields.

Pests associated with positive yield response to carbofuran were not detected but could have been overlooked. Mole crickets, ants, or other soil pests were not abundant. The early planting escaped pest buildup during the later vegetative and reproductive stages.

Effect of intercropping and nitrogen fertilizer on the Asian corn borer. Compared with sole cropping, intercropping reduced the Asian corn borer population (1972 Annual Report). Studies at IRRI in 1975-76 showed that plots that received nitrogen fertilizer had more borers than the no-nitrogen plots.

In separate fields, corn borer populations in a local corn variety (Singapore Orange) and in the yellow flint corn (Early Thai Composite) planted as sole crop and intercrop, with and without fertilizer, were compared. Iloilo farmers plant Singapore Orange either as a sole crop or with yam bean *Pachyrhizus erosus* (L.) Urban as an intercrop after rice. Early Thai Composite was introduced as a sole crop and with a peanut intercrop after rice in a 1976-77 study.

Both varieties were equally susceptible to the Asian corn borer. Singapore Orange received no fertilizer and was intercropped with yam bean. Early Thai Composite received 90 kg N/ha and was intercropped with peanuts.

There were more corn borers in the fields with nitrogen fertilizer than in the fields without (Table 34). Intercropping on unfertilized fields with low borer populations had no insect-depressing effect.

Chemical insect control of sorghum planted after rice. Sorghum is a promising crop for use after rice in Iloilo, but its insect control requirements are unknown. Broad-spectrum insecticides were used to determine the impact of insect pests attacking it at various growth stages when planted after rice in Iloilo. Treatments providing full, partial, and no protection were compared: 0.5 kg a.i. carbofuran/ha in the seed furrows, and monocrotophos sprays (0.75 kg a.i./ha) during vegetative (50 DE) and reproductive (70 and 85 DE) stages.

Only the corn earworm *Heliothis armigera* threatened sorghum. An average of three to four larvae were found feeding on the develop-

Table 34. Effect of intercropping and nitrogen fertilizer on Asian corn borer, Iloilo, Philippines, 1976–77.

Cropping pattern	Corn borers (no./15 plants)			
	0 kg N/ha[a]		90 kg N/ha[b]	
	Larvae	Larval holes	Larvae	Larval holes
Sole crop	3.3	4.1	27.8	32
Intercrop with yam bean	3.5	6.4	17	23
Difference due to intercropping	+0.2	+2.3	−10.8	−9

[a]Av. of 5 fields planted to Singapore Orange (2 sole crops and 3 with yam bean intercrops). [b]Av. of 2 fields planted to Early Thai Composite. Sole crop and peanut intercrop were replicated within each field.

ing grains. Corn earworms were fewest (2/plant) in the treatment at 50 DE, indicating that the earworm eggs were laid on the foliage before heading. The trial had uneven stands and will be repeated after agronomic problems in sorghum establishment are overcome. It, however, revealed the absence of the seedling maggot *Atherigona oryzae* Malloch, silk beetle *Monolepta bifasciata* (Hornstedt), and rice weevil *Sitophilus* spp., sorghum pests found elsewhere in the Philippines.

Chemical insect control on mung bean after rice. Insecticide regimes tested in 1975-76 in Pangasinan were retested in 1976-77. The emphasis was on the same preflowering pests — bean fly *Ophiomyia phaseoli* (Tryon); flea beetle *Medythia suturalis* (Motschulsky), formerly referred to as *Longitarsus manilensis* Weise; and leafhopper *Empoasca biguttula* (Shiraki). Monocrotophos sprays at 0.25 kg a.i./ha were compared with carbofuran granules placed in the seed furrows at 0.5 kg a.i./ha.

High populations of the corn earworm, which appeared at flowering, prevented pod development. The earworm incidence was attributed to the introduction of an alternate host, cotton, in the study area. A spray treatment (0.75 kg a.i. monocrotophos/ha) was added to control the earworm. The application was too late, however, and the best treatment yielded only 903 kg/ha, in contrast with the 1975-76 high of 1,500 kg/ha in the absence of the corn earworm (Table 35).

Table 35. Insect control,[a] costs and returns, and response to preflowering and postflowering insecticide treatments of CES'55 mung bean planted after lowland-rainfed rice in Pangasinan, Philippines, 1976–77.

Insecticide treatment	Defoliation[b] (%)		Flea beetle[c] (no./10 sweeps)	Bean fly 20 DE		*Empoasca* (no./ 10 plants)	*Heliothis* (no./ 10 plants)	Damaged pods (%)	Plant stand (thousand/ ha)	Pods (no./ plant)	Pods (millions/ ha)	Yield (kg/ha)	Insecticide cost (US$/ha)	Return to insecticide[d] (US$/ha)
	20 DE	35 DE	40 DE	No. larvae + pupae/ 10 plants	Infested plants (%/10 plants)	40 DE	40 DE							
1[e]	11 a	6 b	7 a	2 a	33	1	3 a	15	139 a	14 a	2.0	903 a	117	309
2[f]	12 a	5 a	3 a	1 a	28	0	4 a	29	133 a	11 a	1.5	639 a	78	190
3[g]	14 b	8 c	2 a	3 a	33	0	4 a	31	132 a	11 a	1.4	396 b	54	68
4[h]	24 c	45 d	21 a	7 a	75	1	2 b	24	112 a	6 b	0.7	193 c	—	—

[a]Av. of 6 fields. Two applications of benomyl to all plots. DE = days after emergence. In a column any 2 means followed by a common letter are not significantly different from each other at the 5% level. [b]0.75 kg a.i. monocrotophos/ha (45 DE). [c]Visual per plot estimate. [d]Mung bean price US$0.60/kg. [e]Monocrotophos sprays at 0.25 kg a.i./ha at 5, 21, 35 DE and at 0.75 kg a.i./ha at 45 DE. [f]Monocrotophos sprays (0.25 kg a.i./ha) at 5, 15, 25, and 35 DE. [g]Carbofuran basal (0.5 kg a.i./ha), monocrotophos spray (0.25 kg a.i./ha) at 21 and 35 DE. [h]No insecticide.

The best treatment gave a net return to insecticide usage of US$309/ha. Carbofuran granules (396 kg/ha yield) were not as effective as sprays (639 kg/ha yield). The untreated control yielded only 193 kg/ha. The low performance of carbofuran is attributed to the coarse soil texture after tillage of the previously puddled soil. Carbofuran performs well in upland soils.

The results show the need for testing control regimes for several years, because pest populations may fluctuate annually. A benefit from cotton introduced into the area was that it acted as a trap crop for the leafhopper.

Effect of tillage method on insect pests of cowpea. The farmers' method of broadcasting upland crop seeds into standing rice stubble results in uneven stands. High tillage requires several plowing and harrowing operations to incorporate the rice stubble and break up the encrusted soil. Planting is delayed because of labor and power requirements plus the wait for the soil to dry. A more rapid low-tillage method opens furrows between alternate rows of standing rice stubble with the plow, broadcasts seeds, and then covers the furrows with one pass of a harrow.

Studies in three high-tillage and two low-tillage fields were established after a double rice crop in Iloilo. Insecticide was not applied and insect pests were monitored throughout the crop. Several insect species were affected by the presence or absence of standing rice stubble (Table 36). The bean fly was almost totally absent in low-tillage fields during the early growth stages. The finding suggests an inexpensive cultural method to control this serious legume pest. With high tillage, bean fly control required repeated applications of insecticide. Most farmers did not recognize the bean fly as a pest, but unknowingly controlled it by broadcasting seeds into the standing rice stubble.

Aphids known to be attracted to crops set against a bare soil background had low populations. Leaf miners and leafhoppers increase significantly in low-tillage fields. Generally, however, they are not serious. On balance, low tillage is preferred for insect control.

Effect of interaction of foliar fungicide and insecticide on mung bean yield after rice. Powdery mildew *Erisiphe poloni* DC limited mung bean yield in 1975-76 trials in Pangasinan. A 1976-77 trial compared the effectiveness of three fungicides — thiophanate-methyl, benomyl, and benomyl × maneb (Delsene MX) — each sprayed once (35 DE) or twice (35 and 45 DE) at recommended rates. To isolate the effect of powdery mildew from insect damage, two treatments included fungicide plus insecticide, and insecticide alone.

The results showed a greater yield benefit from insecticide alone (32%) than from the best fungicide protection added to insecticide protection (44%-32% = 12%). One application (35 DE) of any of the three fungicides was as good as two applications (35 and 45 DE) but the use of thiophanate-methyl was the least costly. The conclusion was that insect control should receive first priority among farmers' objectives in using resources for pesticides.

Effect of interaction of fungicide seed treatment and insecticide sprays on yield of peanut after rice. In 1975–76, peanut stands in Iloilo were severely reduced (81%) by *Sclerotium* fungus that attacked the seed in the soil. In addition, an aphid-vectored virus mottle disease also occurred. In 1976–77 a trial compared the yield responses to 4 fungicide seed treatments (chloroneb, thiram, captan, and maneb) with either carbofuran granules (0.5 kg a.i./ha) applied to the seed or 3 foliar monocrotophos sprays (0.5 kg a.i./ha) at 21, 42, and 63 DE.

Yield was not benefited by the use of both insecticide and fungicide. The insecticide spray alone or granules alone or fungicide seed treat-

Table 36. Effect of tillage method on insect pests on EG2 cowpea planted after lowland rice in Iloilo, Philippines,[a] 1976–77.

Tillage method[b]	Insects (no./15 plants)					
	Aphid infestation[c]	Bean fly (larvae + pupae)		Leaf miner tunnels	Leaf folder tunnels	Leafhoppers (no./10 sweeps)
	40 DE	10 DE	20 DE	40 DE	40 DE	40 DE
High	2.3 a	45 a	30 a	11 b	3 a	1 b
Low	1.6 a	0 b	4 b	25 a	4 a	3 a

[a]Untreated with insecticide, DE = days after emergence. Any 2 means followed by a common letter are not significantly different from each other at the 5% level. [b]High tillage = plowed and harrowed twice (3 fields), low tillage = furrows opened between rows of standing rice stubble (2 fields). [c]On a 0-9 scale: 0 = no aphids, 1 = adult aphids, 3 = several colonies per plant.

Table 37. Effect of fungicide seed treatments and insecticide granules or sprays on infested seeds on yield of CES 101 peanut after rice in Iloilo, Philippines,[a] 1976–77.

Fungicide[b] seed treatment	Infested seed[c] (%) 5 DE		Yield (t/ha)			Return to insecticide[d] (US$/ha)		
	Carbofuran	No insecticide	Carbofuran	Foliar monocrotophos spray	No insecticide	Carbofuran	Foliar monocrotophos spray	No insecticide
Chloroneb	27 a	44 b	1.01 ab	1.05 a	0.93 ab	54	89	37
Thiram	21 a	28 a	1.15 a	1.02 a	0.97 ab	100	55	46
Captan	19 a	26 a	0.96 ab	1.15 a	1.04 a	61	96	76
Maneb	25 a	34 ab	0.96 ab	1.04 a	1.08 a	24	59	119
Untreated	30 ab	44 b	0.82 ab	0.96 ab	0.78 b	25	60	—

[a]Av. of 4 replicates, 1 field. DE = days after emergence. 0.5 kg active ingredient (a.i.) carbofuran/ha at planting, 0.5 kg a.i. monocrotophos sprays/ha at 21, 42, and 63 DE. In a column, any 2 means followed by a common letter are not significantly different from each other at the 5% level. [b]Recommended rates. [c]3 1-m row samples/plot. [d]Carbofuran, US$0.80/ha; monocrotophos, US$6.16/946 cc; chloroneb, US$0.95/50 g; thiram, US$0.72/50 g; captan, US$2.73/500 g; maneb, US$9.33/1,353 g; shelled peanuts US$0.40/kg.

ment alone resulted in significant yield gains (Table 37). The maneb seed treatment (net return, US$119/ha) resulted in the most economical control. Compared with the treatment with fungicide alone, however, the fungicide and carbofuran granules, where both were combined, apparently interacted and reduced the percentage of disease-infested seeds. This effect was particularly significant in the chloroneb treatment.

Effect of flooding, cropping pattern, and landform on plant parasitic nematodes. Previous studies in Pangasinan showed that flooding of the rice crop suppressed the parasitic nematodes (*Rotylenchulus* and *Meloidogyne*) of leguminous plants. To investigate the extent of that finding over the range of landforms and cropping patterns at the Iloilo site, fields with similar 3-year cropping pattern histories were chosen within each of the available landforms (knoll, river levee, plateau, plain, side slope, and bottomland). They were divided into groups according to flooding (unflooded, one crop flooded, and two crops flooded per year).

Flooding of lowland rice culture effectively controlled plant parasitic nematodes in all landforms except river levees.

The river levees with their light, well-drained soils harbored high nematode populations even if one crop of flooded rice had been grown. Unflooded knolls, as expected, also sustained nematode populations. All other landforms involving at least one flooded rice crop were suitable for *Rotylenchulus* and *Meloidogyne* populations, regardless of the cropping pattern. Bottomlands had the least number of nematodes.

Interaction of insecticide levels with yield of field corn and mung bean intercrop after rice. An insect control trial in a corn-mung bean intercrop in Pangasinan provided information on the crop dynamics involved in intercropping. The yields of plots with three levels of insecticide — mung bean (four applications) and corn (five applications), and mung bean (two applications) and corn (three applications) — and those without insecticide were compared.

The net returns from mung bean tended to decrease (US$254 to 63) and net returns from corn tended to increase (US$39 to 78) as the level of insecticide was reduced (Table 38). As the level of insecticide increased, mung bean responded positively in plant height and vigor and competed for plant nutrients with the corn companion crop. Corn yields from untreated plots were highest (530 kg/ha). The experiment also illustrated the benefit of intercropping — the prevention of crop failure in either crop grown separately.

Plant pathology cropping systems (*Plant Pathology Cropping Systems Component*). Plant pathology research in the cropping systems program was started late in 1977 to

- identify the major disease problems at the different experimental sites and determine the effect of various cropping patterns on the development of such diseases.
- develop scales of measuring intensity of diseases in crops other than rice to facilitate disease assessment under various crop environments, and
- develop and evaluate feasible control

Table 38. Interaction of 3 insecticide levels on yield and net returns of mung bean and corn intercropped after rice, Pangasinan, Philippines,[a] 1976–77.

Crop in intercrop	Insecticide applications (no.)	Yield (kg/ha)	Return to insecticide[b] (US$/ha)	Percentage of total return
Mung bean	4[c]	652	254	87
Corn	5[d]	360	39	13
Both	9	1012	293	—
Mung bean	3[e]	639	270	97
Corn	4[f]	179	8	3
Both	7	818	278	—
Mung bean	2[g]	445	173	73
Corn	3[h]	292	65	27
Both	5	737	238	—
Mung bean	0	135	63	45
Corn	0	530	78	55
Both	0	665	141	—

[a]Av. of 3 fields. Single corn rows were placed 1.5 m between rows of mung bean. [b]Corn US$0.15/ha, mung bean US$0.47/kg. [c]Seedling and early vegetative protection [0.25 kg active ingredient (a.i.) monocrotophos/ha], late vegetative protection (0.5 kg a.i. monocrotophos/ha), early reproductive protection (0.5 kg a.i. methomyl/ha). [d]Seedling protection (0.5 kg a.i. carbofuran granules/ha), early whorl and tasseling protection (x2) (0.5 kg a.i. monocrotophos/ha), late whor protection (0.5 kg a.i. carbofuran granules/ha in whorl). [e]Seedling and early reproductive protection. [f]Seedling, late whorl, and tasseling (x 2) protection. [g]Early vegetative and early reproductive protection. [h]Late whorl and tasseling (x 2) protection.

measures for the major crop diseases.

Survey of diseases at the experimental sites of cropping systems. In the Batangas upland area, no disease was observed during the rice-growing season. In the crop after rice, 4 out of 18 cropping pattern fields showed corn mosaic; the incidence on Macapuno, a local variety of green corn, was less than 5%. In sorghum (Cosor 3 variety), 25% of the plants were infected with *Rhizoctonia* sheath blight and 25% with zonate spot in localized areas. In some plants the sheath blight infection reached the flag leaves, causing empty panicles.

In Iloilo, except for one field of IR36, which had light infection of leaf blast, the cropping pattern fields planted to rice were disease free. In another cropping pattern field, which had been previously planted to lowland rice, 1% of cowpea plants (EG #2) at the cotyledon leaf stage suffered from postemergence damping-off caused by *Sclerotium rolfsii*. In previously flooded fields, less than 1% of the EG #2 cowpea plants also suffered from *Sclerotium* postemergence damping-off, and more than 50% of the soybean seeds (TK5) were infected with *Sclerotium* preemergence damping-off despite the use of thiram, a fungicide for seed treatment. The soybean field was previously planted to sorghum. In all those fields, the disease was observed in plots with zero or minimum tillage. In a peanut variety trial, 20% of the plants at the 3- to 4-leaf stage appeared to be infected with mottle disease.

In Pangasinan, bacterial leaf streak occurred in several rice fields. Its sudden appearance and spread could have been caused by a typhoon. In the crop after rice, 6 out of 9 cropping-pattern and research-managed fields planted to grain legumes exhibited less than 1% *Sclerotium* damping-off. All fields were previously planted to lowland rice. In a variety trial, *Cercospora* leaf spot of mung bean on early plantings and *Sclerotium* damping-off of cowpea on late plantings occurred in poorly drained areas.

Diseases also occurred on upland crops in experimental plots at IRRI. A 100% incidence of *Pythium* damping off of cowpea was observed on almost all the test varieties in a zero-tillage trial plot previously planted to lowland rice. In the continuous cropping experiment, the incidence of *Rhizoctonia* damping-off on the 10th crop of cowpea (EG #2) was about 20% compared with less than 5% infection in a plot alternated with upland rice. In a monthly planting of upland crops, the following diseases were considered severe: soybean rust, *Cercospora* leaf spot and mosaic of mung bean, leaf curl browning of cowpea, leaf spot and mottle of peanut, and *Rhizoctonia* sheath blight of sorghum.

In all disease surveys, specimens for laboratory diagnosis were collected. Whenever possible, the causal pathogens were isolated into pure cultures for future studies.

Preliminary disease scales for assessing some foliar diseases. Grain legumes used in the cropping patterns at the experimental sites were often infected with leaf spotting diseases. Because such foliar diseases are difficult to assess, sketches with scale units of 1 to 9 were made to standardize scoring. The sketches will be field tested in 1978.

VARIETAL TESTING

Multiple Cropping Department

The main crops studied in IRRI cropping systems research are rice, corn, sorghum, soybean, mung bean, cowpea, peanut, sweet potato, and cassava. Elite cultivars of upland crops from the screening program of the University of the Philippines at Los Baños (UPLB) and the Institute of Plant Breeding are evaluated after the rice crop. The crops are tested in replicated trials at IRRI and at IRRI cropping systems research sites in Cale, Batangas; Pao, Caaringayan, and Manaoag, Pangasinan; Oton and Tigbauan, Iloilo. Rice trials and a corn trial in Batangas were conducted during the wet season in May-June 1977. The variety trials of all upland crops were planted from October to December 1976 and harvested from January to March 1977. In a rice-based system, the upland 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.

Rice. Twenty-six IRRI rice varieties were evaluated in semilowland plots at IRRI for suitability for direct (dry) seeding. Water accumulated for a few days only after heavy rains during the late vegetative stages and after heading in two replications; there was no standing water in the third replication. On the average, all the entries yielded more in replication 1 (3.60 t/ha) and replication 2 (3.26 t/ha) than in replication 3 (2.60 t/ha). The yields ranged from 0.87 to 5.01 t/ha. IR36 gave the highest yield (5.01 t/ha), followed by IR28 (4.38 t/ha), which could be considered comparable with yields of transplanted rice. Table 39 lists the 12 best yields. IR36 and IR28 matured earlier than most of the other entries. The 12 outstanding varieties are relatively short (90 to 115 cm), tend not to lodge or to lodge slightly, tiller heavily (at least 400 tillers/m^2), and produce a large number of panicles (at least 400 panicles/m^2) and grains (at least 83 grains/panicle) with at least 73% filled.

In another trial at IRRI five high yielding varieties, as sole crops and with corn intercrop, were directly seeded in rows in upland plots. As sole crops, C171-136 and C166-135 significantly outyielded the other varieties. With corn intercrop (32,000 plants/ha with 1.25-m row spacing) C22 joined C171-136 and C166-135 in yielding significantly more. However, the collective intercrop rice yield did not differ significantly from the sole crop yield. Rice as an intercrop matured 5 days earlier and was 10 cm shorter than rice as the sole crop. Corn intercrop yields were significantly reduced by C171-136 and C22.

Fourteen upland rice selections were evaluated by row-seeding in Batangas (Table 40). Three replications had insect control and

Table 39. Yield and agronomic characters of 12 top-yielding, dry-seeded rice varieties grown under rainfed semilowland conditions, IRRI, 1977 wet season.

Entry	Grain yield (t/ha)	Maturity (days[a])	Plant ht (cm)	Lodging rating[b]	Tillers (no./m^2)
IR36	5.01	111	90	2	610
IR28	4.38	99	100	1	481
IR2823-399-5-6	4.22	132	106	3	490
IR4432-52-6-4	3.88	121	106	4	462
IR42	3.85	135	113	2	540
IR2058-78-1-3-2-3	3.84	121	113	4	514
IR4427-119-6-1	3.77	115	102	4	483
IR38	3.60	120	100	4	582
IR4722-36-1	3.60	117	108	4	547
IR1561-228-33	3.54	115	93	1	611
IR2071-586-5-6-3-4	3.52	132	118	4	521
IR42					
IR4232-38-6	3.41	120	107	6	440

[a]From seeding. [b]1 = no lodging, 9 = severe lodging.

Table 40. Yield and agronomic characters of 14 upland rice selections with insect control evaluated at Cale, Batangas, 1977–78 wet season.

Entry	Grain yield[a] (t/ha)	Maturity (days)	Plant ht (cm)	Lodging rating[b]	Tillers (no./m^2)
IR3839-1	5.64	115	99	1	304
IR1529-430-3	5.12	105	95	1	261
IR3304-23	4.75	115	140	1	223
IR36	4.65	100	79	1	289
IR9575	4.49	120	124	1	231
IR3880-13	4.31	119	120	1	270
C171-136	4.28	120	109	1	208
IR2035-242-1	4.29	119	93	1	250
C166-135	4.07	120	128	1	249
C22	4.01	120	124	1	207
IR3880-10	3.75	119	120	1	232
C171-120	3.74	120	110	1	216
MRC-348	3.39	120	86	1	288
Dagge	2.69	106	155	7	165

[a]LSD (0.05): 0.85; CV: 17.10%. [b]Lodging scale of 1-9 where 1 = no lodging and 9 = all plants flat.

one replication had none. IR3839-1 yielded highest (5.64 t/ha), followed by IR1529-430-3. Dagge, the local check, had the lowest yield. C171-136, a new variety now recommended for use in the cropping pattern trials, ranked seventh, but it was the highest yielder (5.48 t/ha) in the test without insect control.

Farmers' Evaluation of New Selections Applied Research Trials (FENSART) for transplanted rice were conducted in Pangasinan and Iloilo with eight entries each plus a local check. C166-135 and IR2058-78-1-3-2-3 had yields of 5.57 t/ha in Pangasinan and 6.29 t/ha in Iloilo. Among the top five yielders in each locality, IR2058-78-1-3-2-3, IR1529-430-3, and IR36 had consistently high yields. The yield advantage of the top yielders over the checks ranged from 0 to 83%. The entries in Pangasinan matured earlier and were shorter than those in Iloilo, but lodging incidence was about the same at both sites.

Corn. Nine corn varieties from the Philippine and Thailand breeding programs were used in trials. The IRRI trials had zero tillage (no land preparation) and seeds were dibbled at the base of the rice stubbles. Rainfall was about 532 mm and well distributed during the growing period. Philippine DMR Comp. #1 gave the highest yield (4.63 t/ha), which was 60% more than that of Tinumbaga, a local variety commonly used in Batangas as a check in cropping pattern trials. All varieties tested were significantly better than the check. Maturity ranged from 89–93 days.

Under upland conditions with a high level of tillage at IRRI, five entries were significantly better than Tinumbaga. TC#1 DMR (TC #1 Early × Phil. DMR 1)F_3 was the highest yielder (5.1 t/ha) and matured only 2 days later than Tinumbaga. In a Batangas trial under upland conditions with high tillage, TC #1 DMR (TC #1 Early × Phil. DMR 1)F_3 was also the highest yielder. In the 1977 wet season trial before rice and with high tillage at Batangas, yields ranged from about 3 t/ha to almost 5 t/ha, with Medium Early DMR Comp. #2 giving the highest.

The two 1977 trials in Manaoag, Pangasinan, had zero tillage. Rainfall was only 3 mm during the growing period. Yield levels at Pao (deep water table) were lower (range of 1.09–1.58 t/ha) than those at Caaringayan (shallow water table, range of 2.33–2.94 t/ha). The highest yielder in both locations was TC #1 DMR × Penjalinan F_3. The Philippine DMR Comp. #1, highest yielder in IRRI trials, also gave a good yield at Caaringayan but a poor yield at Pao. It flowered and matured later in Pao than in Caaringayan. Although there was no rainfall after the main rice crop, the corn yield in areas with high water table was reasonably good.

The Iloilo trial had high tillage. The 153-mm rainfall during the growing period was well distributed. The corn yields ranged from 2.86 to 3.45 t/ha. Early DMR Comp. #1 had the highest yield. Both TC #1 DMR × Penjalinan F_3 and Philippine DMR Comp. # 1 performed well and flowered earlier than in other corn trials.

Sorghum. Sixteen elite lines and promising varieties of sorghum from the breeding program of UPLB were evaluated in replicated trials. The trials at IRRI had zero tillage. After rice harvest sorghum seeds were dibbled in straight rows. Rainfall during crop growth — 534 mm — was well distributed. Yields ranged from 3.54 to 5.51 t/ha, with that of PBI Sor 1 highest, followed by those of D67-4, UPLB-SG5, CS 137, and CS 99. Days to maturity ranged from 86 to 92. The earliest maturing was 498003, but it had the lowest yield.

In IRRI upland trials, yields ranged from 2.29 to 3.74 t/ha, with UPLB-SG 5 giving the highest. D67-4, one of the high yielders under zero tillage, had the lowest yield under upland conditions with high tillage. In a Batangas trial, however, it had the highest yield (3.33 t/ha). D67-4 was 36% better than Cosor 3, the variety recommended for a pilot production program in Batangas.

Trials at Caaringayan and Pao in Pangasinan were conducted with zero tillage. In both places, a rice-straw mulch was added to conserve the soil moisture, lower soil temperature, and suppress weeds. Only 3 mm of rain fell during the growing period. The yields were higher in Caaringayan than in Pao. They ranged from 2.56 to 4.40 t/ha in Caaringayan and C137 was the highest yielder. In Pao yields ranged from 2.12 to 3.69 t/ha and D67-4 was the highest

yielder. Three of the top five entries in the Caaringayan trials performed poorly in the Pao trial. Plants were generally taller and flowered earlier in Caaringayan than in Pao.

The sorghum yields with zero tillage in Oton, Iloilo, ranged from 2.97 to 6.76 t/ha, with that of CS 174 the highest. D67-1, D67-4, and BPI Sor 1, the best yielders in Pangasinan, were the lowest yielders in Iloilo. The Iloilo trial had 205 mm of rainfall well distributed during the growing period. Rice straw was used as mulch. A high tillage trial in Tigbauan, Iloilo, was affected by too much water after planting (76 mm) and by uneven distribution of rainfall during the growing period, although the total rainfall was the same as that for Oton. Sorghum yields ranged from 1.71 to 2.87 t/ha. CS 174 and UPLB-SG 5 had consistently high yields in both trials.

Several sorghum varieties better than Cosor 3, the variety now used in the cropping pattern trials, were identified at the different sites. The most promising entries were D67-1, D67-4, and UPLB-SG5.

Mung bean. From 9 to 12 mung bean entries were evaluated at IRRI and the Philippine sites. Trials were with high tillage on an upland area at IRRI and Batangas. At the other sites, testing was after lowland rice at zero tillage and high-tillage. For zero tillage seeds were dibbled at the base of the rice stubble after harvest.

Under upland conditions, CES 1D-21 gave the highest yield (1.66 t/ha) at IRRI, and CES 14 (1.22 t/ha) the highest in Batangas followed by CES 1D-21 with 1.19 t/ha. A trial with zero tillage after lowland rice at IRRI gave yields comparable with those with high tillage, with CES 1D-21 being the highest yielder (1.43 t/ha).

The yield levels of zero-tillage trials in Iloilo and Pangasinan (at high water table), however, were low, ranging from 158 to 283 kg/ha in Iloilo and 131 to 134 kg/ha in Pangasinan. The yield levels of the high-tillage trial in Iloilo, which was planted almost at the same time as the zero-tillage trial, ranged from 1.24 to 1.41 t/ha. The highest yield was from CES 1D-21. Mung bean performs poorly with zero tillage if moisture is limiting.

CES 1D-21 was the most outstanding mung bean variety in all tests. Compared with CES 55 and CES 87, which were used in the cropping pattern trials; CES 1D-21 is generally a higher yielder, shorter, and smaller seeded. It tolerates powdery mildew and *Cercospora* leaf spot and matures at about the same time. Renamed Pagasa, CES 1D-21 has been released for national distribution and is now used in the cropping pattern trials in all the outreach sites.

Soybean. Fourteen soybean varieties were evaluated at IRRI on zero tillage with mulch after lowland rice. Plantings in November and December 1976 did not yield as well as the October plantings. Yields in the October planting ranged from 1.42 to 2.07 t/ha; the yield of UPLB-SY 2 was highest, and that of TK 5 (variety used in the cropping pattern trials), the lowest. UPLB-SY 2 has good seedling vigor, medium plant height, and large seeds. The yield levels for the December planting were lower. The yield of Kuro Daizu was highest (1.77 t/ha); that of UPLB-SY 2 was lowest (1.22 t/ha).

Under upland conditions with high tillage, UPLB-SY 2 was again the highest yielder (0.94 t/ha) at IRRI, and TK5 (0.67 t/ha) was a high yielder in Batangas, followed by UPLB-SY 2. In Pangasinan, yields from soybean planted in November after lowland rice ranged from 308 to 534 kg/ha in Caaringayan (high water table) and from 473 to 917 kg/ha in Pao (low water table). The best yielder in Caaringayan was TK5; in Pao it was Clark 63. In Iloilo TK5 at zero tillage and at high tillage also had the highest yield (922 kg/ha); Williams and TK5 also showed good performance.

Soybean performance with zero tillage is comparable with its performance with high tillage. Yield levels in Pangasinan and Iloilo were low because of drought stress and photoperiod sensitivity of the varieties.

Cowpea. Under upland conditions two cowpea introductions, PI 339587 and PI 221731 (determinate types), were the best yielders (1.59 and 1.57 t/ha) among 14 entries. Both varieties had more pods per plant but shorter pods than EG #2 in the IRRI trial. EG #3 and EG #2, recommended varieties in IRRI cropping pattern trials, were the best indeterminate types. In Batangas, All Season,

another indeterminate type, gave the highest yield (1.89 t/ha); V59-41, the highest yielder among the determinate types (1.42 t/ha), had tolerance for rust and insect pests.

The best cowpea at IRRI and in Iloilo and Pangasinan was EG #3, an indeterminate type developed by the Philippine Bureau of Plant Industry. In Pangasinan it yielded 2.11 t/ha in an area with a high water table and 1.45 t/ha in an area with a low water table. EG #3 matures at the same time as EG #2.

New introductions were evaluated in replicated upland trials with high tillage at IRRI. PI 339587 and EG #2 (check) were the best yielders out of 30 entries. In two uniform cultivar trials from the International Institute of Tropical Agriculture, no entry outyielded EG #3 and EG #2.

Peanut. Nine to 11 peanut entries were evaluated at IRRI and at the other Philippine outreach sites. Trials were with high tillage and upland conditions in Batangas and at IRRI, and in lowland rice paddies in Iloilo and Pangasinan. M10 and BPI P9 were promising at IRRI, in Iloilo, and in Batangas. Moket, a variety from Vietnam, also looked promising, particularly at the high and low water table sites in Pangasinan. The three varieties were significantly better than CES 101, the recommended variety for cropping pattern trials. The best peanut yields were in Iloilo, with M10 giving 3.38 t/ha. The plants matured in less than 95 days at all sites except Batangas.

Sweet potato. Nine to twelve sweet potato entries were evaluated at IRRI and at all outreach sites. BNAS 51, a variety now used in cropping pattern trials, gave the highest marketable tuber yield under upland high-tillage condition at IRRI (32.94 t/ha) and Batangas (17.61 t/ha). Highest tip yield was obtained from BNAS 51 (13.3 t/ha) in Batangas and from Karja (30.11 t/ha) at IRRI. A few entries were tested with zero tillage after lowland rice at IRRI. There was adequate (573 mm) rainfall during the growth period. BNAS 51 had the highest yield with 12.37 t/ha. That yield was low compared with the yield with high tillage at IRRI.

The trials in Pangasinan had lower yields than those in the other sites because rainfall was low during the growth period. In Caaringayan (high water table), BNAS 51 was the highest yielder (10.92 t/ha); in Pao (low water table), Karja had the highest yield (6.48 t/ha).

Despite only 219 mm rainfall during the growing period at Iloilo, the yield levels were good. Jewel yielded 36.51 t/ha, followed by Karja with 24.20 t/ha. BNAS 51 had only 19.88 t/ha. The percentage of marketable tubers was lower in Iloilo than in the other sites.

Cropping systems program

Preproduction evaluation

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APPLIED RESEARCH

Rice Production Training and Research Office

Preproduction research is aimed at the development of a methodology for the rapid transfer to farmers of the results from cropping systems site research.

The concept of evaluating results from site research under farmer conditions is illustrated in Figure 1. The work in 1977 involved the evaluation of growing two crops of rainfed rice plus an upland crop where possible.

Cropping systems trial plots. First-crop results from 1977 were received from 18 sites in 11 provinces of the Philippines (Table 1). Trials in 1976 had indicated that two crops of rice can be grown with higher yields and reduced risk in the Visayas and Mindanao than in Central Luzon. That conclusion holds despite the high 1977 yields obtained in Isabela. The uncertainty of rain in Central Luzon, in general, makes the growing of two crops of rice too risky. Low yields at Bukidnon, Mindanao, during the past 3 years are attributed to high soil pH and a reduced, sporadic, rainfall pattern.

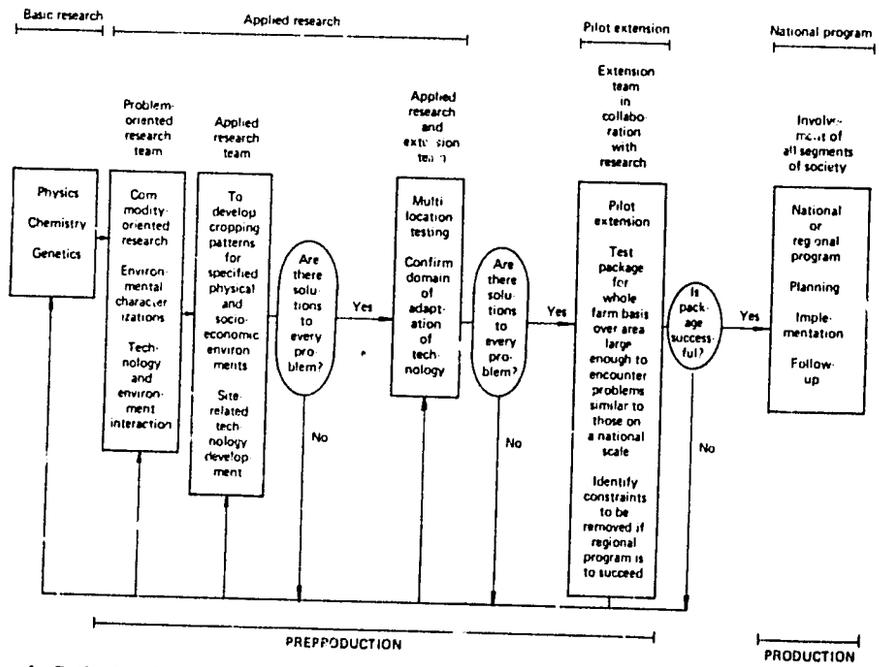
At all sites, except Paoay, Ilocos Norte, IR36 produced higher yields than IR2307. The significant differences between varieties observed in Cotabato Province were due to an attack of ragged stunt, which did not affect IR36. Rice yields were broken down by region for two crops in 1975 and the first crop of 1976. The analysis showed generally lower yields in Luzon than in Visayas or Mindanao (Table 2).

Direct-seeded rice, Luzon. Observations on direct-seeded rice in Luzon indicate that without supplementary irrigation, a two-crop rainfed rice pattern is not feasible. A pattern of a first-crop rice followed by an upland crop, especially on light soils, is less risky than a pattern with two crops of rice. Upland crops planted by September-October (especially soybean) have often been grown more successfully.

The same observation holds for Ilocos Norte and Ilocos Sur provinces, particularly where high-value dryland crops such as garlic and tobacco are grown.

Observations in La Union and Pangasinan indicate that the risk of two rice crops is great. Rice followed by an upland crop is less risky and can even be considered for purely rainfed areas with light soils (Fig. 2).

Direct-seeded rice, Mindanao and Visayas. Generally, a rice-rice-upland crop pattern was



1. Path of agricultural development.

Table 1. Yields of first-crop IR36 and IR2307, direct seeded in dry soil in 18 trials in 11 provinces. Philippines, 1977 wet season.

Site	Rainfall type	Yield (t/ha)[a]		
		IR36	IR2307	Difference
Echague, Isabela (San Fabian)	2.3	7.1 a	7.0 a	0.1
Matalam, North Cotabato	2.4	6.2 b	4.2 cde	2.0**
Norala, South Cotabato (Santo Niño)	2.4	5.5 c	4.6 bc	0.9**
Kabacan, North Cotabato	2.4	5.4 c	4.6 bc	0.8**
Norala, South Cotabato (San Isidro)	2.4	5.3 c	5.1 b	0.2
Echague, Isabela (Isabela State College of Agriculture Campus)	2.3	4.6 d	4.5 bcd	0.1
Narra, Palawan	2.5	4.3 de	3.8 defg	0.5
Bula, Camarines Sur	1.3	4.1 de	4.0 cdef	0.1
Victoria, Oriental Mindoro (Macatoc)	2.3	3.9 de	3.4 fgh	0.5
Barugo, Leyte (Kansagaya)	2.3	3.0 de	3.4 fgh	0.5
Victoria, Oriental Mindoro (Macatoc)	2.3	3.8 e	3.3 fgh	0.5
Valencia, Bukidnon	1.3	3.7 e	3.3 fgh	0.4
San Juan, La Union	3.4	3.6 e	3.5 efg	0.1
Valencia, Bukidnon	1.3	2.8 f	2.3 i	0.5
Barugo, Leyte (Bulod)	2.3	2.6 f	3.1 gh	0.5
Narra, Palawan (Malatgao)	2.5	2.4 f	2.7 hi	−0.3
Catarman, North Samar	1.2	2.2 fg	2.1 i	0.1
Paoay, Ilocos Norte	3.4	1.7 g	2.7 hi	−1.0**

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

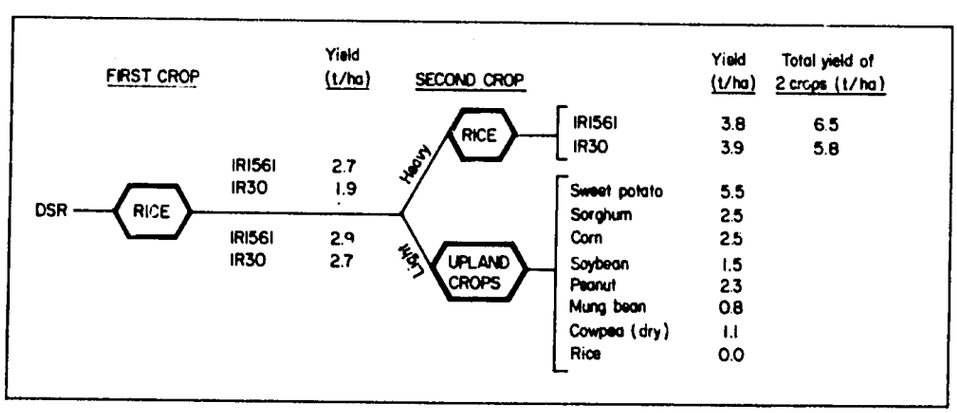
Table 2. Grain yield[a] of some IRRI varieties and selections used in the IRRI-PCARR[b] cropping systems trials for 1975, 1976, and 1977, Philippines.

Region	Grain yield (t/ha)											
	1975 (2 crops)				1976 (first crop)				1977 (first crop)			
	IR1561-228		IR30		IR36		BG34-8		IR36		IR2307	
Luzon	7.4 c	(10)	5.9 c	(10)	4.1 b	(3)	3.8 b	(3)	3.9	(6)	3.9	(8)
Visayas	7.9 b	(5)	7.4 b	(5)	5.0 a	(2)	4.7 a	(2)	2.9	(3)	2.9	(3)
Mindanao	9.1 a	(3)	8.8 a	(3)	4.8 a	(4)	2.9 c	(4)	4.8	(6)	4.0	(6)

[a]Means followed by a common letter are not significantly different at 5% level. Figures in parentheses indicate number of sites.
[b]Philippine Council for Agriculture and Resources Research.

successful for Mindanao and the Visayas region. Because rain onset was late in 1977, data for the second rice crop were not available. In 1975 and 1976, however, upland crops were planted after two rice crops. The pattern appears fairly stable.

1977 production plots. The package of technology developed at the Manaoag site in Pangasinan for direct-seeded rice is shown in Tables



2. A comparison of production potential of two crops of rice or one of seven upland crops on light and heavy soils under rainfed conditions in areas with five dry months (rainfall type 3.4). IRRI. DSR = direct-seeded rice.

Table 3. Agronomic practices for applied research. Manaoag, Pangasinan, Philippines. 1977–78.

Crop	Variety	Seeding rate or spacing	Fertilizer (kg/ha) Basal	Fertilizer (kg/ha) Topdressed
		First crop		
Dry-seeded rice	IR36	100 kg/ha	30-0-0[a]	30 N/40 N
Wet-seeded rice	IR36	120 kg.	30-0-0[a]	30 N/40 N
Transplanted rice	IR36	20 × 20 cm	30-0-0[a]	30 N/40 N
		Second crop		
Transplanted rice	IR36	20 × 20 cm	100-50-50	Santa Barbara and Calasiao area with silt loam soil
			80-50-50	20 N for Bani area with heavy clay soil

[a]Zinc oxide dust should be applied to the seed used for DSR (WSR?). Roots of TPR seedlings should be dipped in a ZnO slurry.

Table 4. Weed control practices for cropping pattern applied research trials in Manaoag, Pangasinan, Philippines, 1977–78.[a]

Crop	Seeding rate (kg/ha)	Spacing	Weed control method	Rate (kg a.i./ha)	Time of application
Dry-seeded rice	100	25 cm (furrows)	Butachlor fb one hand weeding	1.0	After germinating rain fb as needed
Wet-seeded rice (adequate water)	120	broadcast	Butachlor fb spot weeding	2.0	6–8 DS fb as needed (after 28 DS)
Transplanted rice (adequate water)	—	20 x 20	One rotary weeding	—	21-28 DT
Transplanted rice (water limiting)	—	20 x 20	Spot weeding	—	21-28 DT

[a]fb = followed by. DS = days after seeding. DT = days after transplanting.

3 and 4. Areas in Santa Barbara, Calasiao, Alaminos, and Bani were selected as 1977 evaluation sites. They differed somewhat in soil type from Manaoag; thus the package as tested showed some nutrient deficiencies.

Table 5. Grain yields, IRRI-PCARR-BAEX[a] cooperative projects on cropping systems in rainfed rice areas. Iloilo, Philippines, Series III, 1977–78. Production plots (1,000 m²) of IR36 first crop, 1977.

Location of farm[b]	Date seeded	Date of harvest	Yield (t/ha)
Oton	19 June	27 Sept.	7.6
Oton	18 June	2 Oct.	6.2 (phosphorus deficient)
Oton	21 June	2 Oct.	6.4
Oton	18 June	1 Oct.	3.5 (phosphorus deficient)
Oton	7 July	20 Oct.	6.4
Cabatuan	11 June	14 Oct.	5.1
Cabatuan	11 June	13 Oct.	6.6
Cabatuan	15 June	16 Oct.	4.0
Cabatuan	28 June	30 Sept.	3.5
Ajuy	12 June	1 Oct.	4.8
		Av. yield	5.4

[a]PCARR = Philippine Council for Agriculture and Resources Research, BAEX = Bureau of Agricultural Extension. [b]Rainfall type: 2.3 (2–4 consecutive dry months with 100 mm rain and 5–6 consecutive wet months with 200 mm rain).

In the Pangasinan sites, initial stand establishment was slow, plants were stunted, and tillering was extremely low. When the plots were topdressed with complete fertilizer, plant growth improved immediately. The initial stunting and slow growth may account for the reduced yields at Alaminos and Bani. The input package was effective in Iloilo where package yields were 5.4 t/ha; average yields in Pangasinan were 3.9 t/ha. Results are shown in Tables 5 and 6.

The first-crop yields in production plots established in the provinces of Aklan, Antique, and Capiz, Panay Island, averaged 5-6 t/ha in 24 locations (Table 7, 8, 9).

Supplemental irrigation trials. Supplemental irrigation, even in Mindanao and Iloilo, helped stabilize rice crops. It increased yields significantly in Bukidnon and Pangasinan (Table 10). But it did not influence yields in Isabela,

Table 6. Grain yields, IRRI-PCARR-BAEX[a] cooperative projects on cropping systems in rainfed rice areas. Pangasinan, Philippines, Series III, 1977–78. Production plots (1,000 m²) of IR36 first crop, 1977.

Location of farm[b]	Date seeded	Date of harvest	Yield (t/ha)
Santa Barbara	21 May	16 Sept.	5.6
Santa Barbara	9 May	14 Sept.	5.1
	14 May	14 Sept	4.2
Calasiao	7 May	22 Sept.	3.0[c]
Calasiao	8 May	23 Sept.	2.0[c]
	14 May	23 Sept.	2.4[c]
Alaminos	13 May	5 Sept.	3.2
Alaminos	13 May	—	2.8
Alaminos	—	—	2.8
Bani	4 June	21 Sept.	2.5
Bani	4 June	23 Sept.	2.9
Bani	4 June	27 Sept.	2.8
		Av. yield	3.93

[a]PCARR = Philippine Council for Agriculture and Resources Research, BAEX = Bureau of Agricultural Extension. [b]Rainfall type: 3.4 (5–6 consecutive dry months with 100 mm rain and 3–4 consecutive wet months with 200 mm rain). [c]70–75% damaged by birds and continuous rain at harvesting stage. Grains germinated at the panicle.

Table 7. Grain yields, IRRI-PCARR-BAEX[a] cooperative projects on cropping systems in rainfed rice areas at Aklan province, Series III, 1977–78. Production plots (1,000 m²) of first crop IR36, 1977.

Location of farm[b]	Date seeded	Date of harvest	Yield (t/ha)
Jumasap, Banga	19 June	10 Oct.	4.7
Calangcang, Makato	20 July	7 Nov.	4.0
Santa Cruz, Lezo	19 July	10 Nov.	5.7
Bagto, Lezo	13 July	4 Nov.	7.4
		Av. yield	5.5

[a]PCARR = Philippine Council for Agriculture and Resources Research, BAEX = Bureau of Agricultural Extension. [b]Rainfall type: 1.3 (< 2 consecutive dry months with 100 mm rain and 5–6 consecutive wet months with 200 mm rain).

Table 8. Grain yields, IRRI-PCARR-BAEX[a] cooperative projects on cropping systems in rainfed rice areas at Antique province, Series III, 1977–78. Production plots (1,000 m²) of first crop IR36, 1977.

Location of farm[b]	Date seeded	Date of harvest	Yield (t/ha)
Moson, San Jose	28 May	10 Sept.	9.1
Moson, San Jose	26 May	7 Sept.	8.8
Villavert-Jimenez, Hamtik	8 June	22 Sept.	8.0
Guintas, Hamtik	16 June	3 Oct.	8.8
Pantao, San Jose	2 June	19 Sept.	4.9
Maybato, San Jose	27 May	1 Sept.	7.4
Guintas, Hamtik	31 May	18 Sept.	8.1
Igbongio, San Jose	28 May	15 Sept.	5.3
La Granja, San Jose	3 July	18 Oct.	5.0
Nazareth, Sibalom	4 Aug.	15 Nov.	3.7
		Av. yield	6.9

[a]PCARR = Philippine Council for Agriculture and Resources Research, BAEX = Bureau of Agricultural Extension. [b]Rainfall type: 3.3 (5-6 consecutive dry months with 100 mm rain and 5-6 consecutive wet months with 200 mm rain).

Oriental Mindoro, and North Cotabato where rain was adequate.

In rainfed lowland areas, where rain is sufficient, rice yields are as high as they are in irrigated lowland areas. Thus, supplemental irrigation is necessary even in irrigated areas for growing rice during the wet season. If water in irrigation districts is stored during the wet season and used only as supplemental irrigation, it will be possible to store extra water for use during the dry season when solar radiation and yields are high. In some years no irrigation during the wet season will be necessary. More important, however, is the safety factor the stored water gives with regard to drought.

Herbicide trials. Eight promising liquid herbicides, applied 2 to 5 days after seeding, were

Table 9. Grain yields, IRRI-PCARR-BAEX[a] cooperative projects on cropping systems in rainfed rice areas at Capiz province, Series III, 1977–78. Production plots (1,000m²) of first crop IR36, 1977.

Location of farm[b]	Date seeded	Date of harvest	Yield (t/ha)
Bailan, Pontevedra	7 July	12 Oct.	6.7
Poblacion Sur, Ivisan	30 June	8 Oct.	6.0
San Jose, Dumalag	12 July	24 Oct.	5.0
Natividad, Pilar	28 June	26 Sept.	4.7
Lanot, Roxas City	6 July	19 Oct.	6.3
Guintas, Sigma	5 July	12 Oct.	4.3
Consiencia, Panitan	13 July	24 Oct.	4.3
Guintas, Sigma	6 July	15 Oct.	5.1
Cogon, Panay	14 July	26 Oct.	4.0
Manibad, Mambusao	23 June	1 Oct.	3.8
		Av. yield	5.0

[a]PCARR = Philippine Council for Agriculture and Resources Research, BAEX = Bureau of Agricultural Extension. [b]Rainfall type: 2.3 (2-4 DM [consecutive dry months with 100 mm rain] and 5-6 WM [consecutive wet months with 200 mm rain]) and 2.2 (2-4 DM and 7-9 WM).

Table 10. Effects of supplemental irrigation on rice yields.[a] Philippines, 1977.

		Yield (t/ha)		
Location	Rainfall type[b]	Supplemental irrigation	Rainfed	Difference
Pangasinan	3.4	5.3 b	4.6 b	0.7*
Pangasinan	3.4	5.8 b	4.4 b	1.4**
Isabela	2.2	7.4 a	7.0 a	0.4
North Cotabato	2.4	4.2 c	4.4 b	−0.2
Bukidnon	1.3	4.0 c	2.8 c	1.2**
Mindoro Oriental	2.3	3.4	3.8	−0.4

[a]Means followed by a common letter are not significantly different at 5% level. [b]3.4 = 5-6 DM (consecutive dry months with 100 mm rain and 3-4 WM (consecutive wet months with 200 mm rain); 2.2 = 2-4 DM and 7-9 WM; 2.4 = DM and 3-4 WM; 1.3 = <2 DM and 5-6 WM; 2.3 = 2-4 DM and 5-6 WM

Table 11. Grain yield of IR36, direct-seeded on dry soil at the start of the rainy season, as affected by promising liquid herbicides applied 2-5 days after seeding at three sites, Philippines, 1977 wet season.

Treatment	Grain yield[a] (t/ha)		
	Bukidnon	Isabela	Oriental Mindoro
Butachlor	3.1 a	4.9 bc	3.3 a
Dinitramine	3.3 a	5.3 ab	3.6 a
Butralin	2.4 a	4.9 bc	3.0 ab
Antor	2.9 a	4.4 d	3.7 a
AC 92553	2.9 a	5.2 ab	3.3 a
Benthiocarb	2.6 a	5.2 ab	3.1 ab
USB 3153	3.0 a	5.1 abc	2.1 b
Oxadiazon	2.4 a	4.7 cd	2.9 ab
Two hand weedings	3.1 a	5.5 a	3.5 a
Control	2.1 a	2.4 e	0.7 c

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

tested at 3 sites in the Philippines. IR36 was direct-seeded in dry soil at the start of the rainy season. Yield results are shown in Table 11.

Results varied because of differences in the onset and amount of rainfall before and after application of the herbicide. Soil type and soil moisture at the time of herbicide application also affected the results.

Variety trials. Five IRRI varieties and seven promising early maturing selections were direct-seeded in dry soil at the start of the rainy season at five sites. Yield results are shown in Table 12.

Results varied because of differences in the onset and amount of rainfall after seeding. Soil type, soil moisture, and bund location of the trials were also major factors affecting yield. In general, IR30, IR38, IR40, and IR2061-465 performed as well as the highest yielder at three sites. IR2307-217 performed as well as the highest yielder at four sites.

Pilot programs. *Sorghum pilot extension program.* The results of the 1975–76 IRRI-Bureau of Plant Industry research trials in five barrios of the municipality of Tanauan, Batangas, led to the establishment of a 1976–77 sorghum production extension program. Before the program was started, a market for sorghum was found and threshers were provided. The package of technology prepared is outlined in Table 13.

Three Bureau of Plant Industry technicians were assigned to work full time as technical assistants to direct the pilot program. Thirteen BPI and two Bureau of Agricultural Extension technicians were assigned on a part-time basis. The technicians underwent a 5-day training course at IRRI. Two additional training days were devoted to field work in Batangas.

An information drive including use of radio informed farmers of the program. Farmers were contacted individually, and enrolled in the program; 100 ha of land was committed.

The municipalities, areas planted to sorghum, and yields are shown in Table 14. Average yields of 1.34 t/ha, ranging from 0.04 to 6.6 t/ha, were obtained in open fields. Under coconut palms, average yields were 0.9 t/ha, ranging from 0.02 to 1.9 t/ha.

Before the pilot program started it was known that ratoon crops were necessary to make sorghum attractive economically. Only a few farmers grew ratoon crops and, therefore,

Table 12 Grain yield[a] of five IRRI varieties and seven promising early maturing selections direct-seeded in dry soil at the start of the rainy season at five Philippine sites, 1977 wet season.

Variety or selection	Grain yield (t/ha)				
	Bukidnon	Isabela	North Cotabato	Palawan	Oriental Mindoro
IR29	2.5 d	1.9 de	1.5 bc	0.4 c	—
IR30	4.1 a	2.1 bcde	2.4 ab	0.2 d	2.9 ab
IR36	4.1 a	2.8 ab	1.6 bc	0.4 c	3.0 ab
IR38	3.2 bcd	1.9 de	2.3 ab	1.1 a	3.1 ab
IR40	2.7 cd	1.6 e	1.9 ab	1.2 a	2.9 ab
IR2058-78	2.7 cd	2.0 cde	1.3 bc	1.2 a	3.0 ab
IR2061-465	3.5 ab	2.3 bcd	2.4 ab	0.3 cd	3.1 ab
IR2061-522	3.3 bc	3.0 a	1.6 bc	0.3 cd	2.6 abc
IR2307-217	3.7 ab	2.5 abc	2.9 a	0.6 b	3.3 a
IR3464-126	1.3 e	2.8 ab	0.6	—	2.2 b
IR3941-25	3.3. bc	2.0 cde	2.0 ab	0.4 c	3.4 a
IR5105-93	3.3. bc	1.7 e	2.1 ab	0.7 b	1.7 c

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

Table 13. Technology package for growing sorghum (Cosor 3) in an IRRI-Bureau of Plant Industry pilot extension program. Tanauan, Batangas, Philippines, 1976–77.

First crop		Ratoon	
Days before planting	Activity	Days before harvest	Activity
11–16	Land preparation; 2–3 plowings	1–3	Cutting stalks to ground level within 2-3 days after harvesting.
		4–5	Fertilizer application: 3–4 bags 21-0-0 or 1 bag 46-0-0
6–9	Harrowing: 2–3 times		Hilling up immediately
0–2	Furrowing: 50- to 75-cm rows, 3–5 cm deep		(Other operations same as in first crop)
0	a. Basal application of fertilizer 3 bags 16-20-20 1 bag 45- 0- 0		
	b. Seeding at a rate of 12–15 kg/ha (15–20 seeds/linear meter in 50-cm rows) (20–25 seeds/linear meter in 75-cm rows)		
	c. Cover seeds — pass "kalmot" or peg-tooth harrow		
Days after planting			
15	a. Observing for insect pests		
	b. Thinning (10–12 plants/linear meter in 50-cm rows) (15–17 plants in 60–70 cm rows)		
20	Off-barring		
25	a. Side-dressing: 3 bags 21-0-0 1.5 bags — 45-0-0		
	b. Hilling up immediately		
65–70	Insect control		
100–105	Harvesting: 30–35 days after flowering		
103–108	Drying		
104–109	Threshing		

yields and returns were not high. Prices for grain produced from ratoon crops were higher than those for the main crop (US$0.15–0.16 vs US$0.12). Two farmers reported that yields above 1.2 t/ha from their ratoon crop brought an additional income of US$180.00.

An evaluation of the pilot program based on the plan of development (Fig. 1) would receive a No answer as regards *solving all problems*. The farmers were interested in growing sorghum, evident from the short time required to enlist them to grow 100 ha of this crop. But the average yields of 1.3 t/ha and a net profit of US$70/ha were not economically acceptable for a single crop after rice. A ratoon crop was necessary for a profitable return.

Most of the farmers did not continue to plant sorghum, which indicated that the package of technology was not acceptable. Interviews with farmers in October 1977 indicate that threshing and markets remained as constraints in sorghum production.

Iloilo Pilot Project in Cropping Systems. Table 15 shows farmer adoption of a two-crop system of rainfed rice in Barrio Tigtig, Santa Barbara, Iloilo.

A pilot project to assist the early adoptors and to test the methodology for the various aspects of production was proposed to the Gov-

Table 14. Grain yield, cost of production, and income of farmers in five eastern Batangas municipalities in a sorghum production pilot extension program. Philippines, 1976.

Municipality	Farmers (no.)	Farm area (ha)	Yield[a] (t)	
			Total	Per hectare
Tanauan				
a. Open field	51	20	30.48	1.52
b. Under coconut trees	26	13	12.02	0.92
Santo Tomas-Malvar	7	3	5.06	1.68
Lipa	11	14	15.58	1.11
San Jose	8	6	6.32	1.05

[a]Excludes sorghum from 46 ha which was sold before grain yields could be determined by IRRI staff.

Table 15. Adoption of two-rice crop system in Barrio Tigtig, Santa Barbara, Iloilo, Philippines, 1973–77.

Year	Farmers (no.)	Area (ha)	Yield(t/ha) 1st crop	2nd crop	Total
1973–74	2	0.266	3.0	4.0	7.0
1974–75	30	25.0	4.0	5.0	9.0
1976–77	54	89.0	5.2	4.0	9.2

ernor of Iloilo province through the regional director of the Bureau of Agricultural Extension. The project was accepted, and in November 1976, IRRI and the government agencies involved signed a memorandum of agreement.

The pilot project was named *Kabsaka*, short for *Kabusugan sa Kaumahan*, meaning bountiful harvest on the farms.

Farmers from nine adjoining barrios in Santa Barbara joined the project. Of the total farm area (777 ha) covered by the barrios, 515 ha was rainfed lowland where the two-crop system was feasible. From that area, 179 farmers with a total of 262 ha joined the project (Table 16). Of the 179 farmers in the program, 100 farmers with about 167 ha were self-financed.

Land preparation started in March 1977 instead of January because the rainy season continued till mid-February. The 1977 rainy season started in June instead of May. The first crops were seeded in June and July and harvested in September and October.

Bureau of Agricultural Extension and IRRI staff assigned to the project collected data on the first crop through individual or group interview of 93 farmers. The yields from a total of

Table 16. Area covered and number of farmers involved in the pilot project in cropping systems in Santa Barbara, Iloilo, Philippines, 1977.

Barangay (village)	Farmers (no.)	Total farm area (ha)	Rainfed lowland rice area (ha)	Area covered by project (ha)
Tigtig	48	180	124	56
Miraga	19	65	36	29
Agusipan	17	125	86	31
Calaboa Este	17	76	49	27
Calaboa Este	18	42	21	29
Canipayan	18	79	42	37
Cunaynay	27	80	48	32
Tuburan	10	80	65	10
Mangacina	5	50	43	6
Total	179	777	515	262

147 ha averaged 4.45 t/ha. Ninety-eight percent of the loans made to 93 farmers were repaid. The cost of producing 1 ha of rice in the Kabsaka Pilot Extension Program in Santa Barbara was US$194, broken down as follows: US$48 for land preparation; US$23, seeds (100 kg at US$0.23/kg); US$68, fertilizers; US$41, insecticides and herbicides; and US$14, miscellaneous items.

One hundred eleven hectares or 41% of the original area was planted to rice on lower bunds; 10% of that was transplanted and the rest was direct-seeded on puddled soil. The area direct-seeded was significant inasmuch as it indicated a complete acceptance of direct seeding as a new method of planting rice in Santa Barbara.

The results were good and farmer response was high enough for the IRRI applied research team to withdraw from the project at the end of the 1977 season.

Cropping systems program

Asian cropping systems network

Multiple Cropping Department

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A Cropping Systems Network (CSN) of research sites in several countries in Asia helps national programs increase cropping intensities of rice areas through collaborative work on cropping systems research and development in the region. Priority is given to rice areas with potential for increased production per crop season and for more intensive cropping.

Research at the test sites is conducted in farmers' fields, and the farmers participate in developing the technology. A research team headed by a coordinator is assigned in each site.

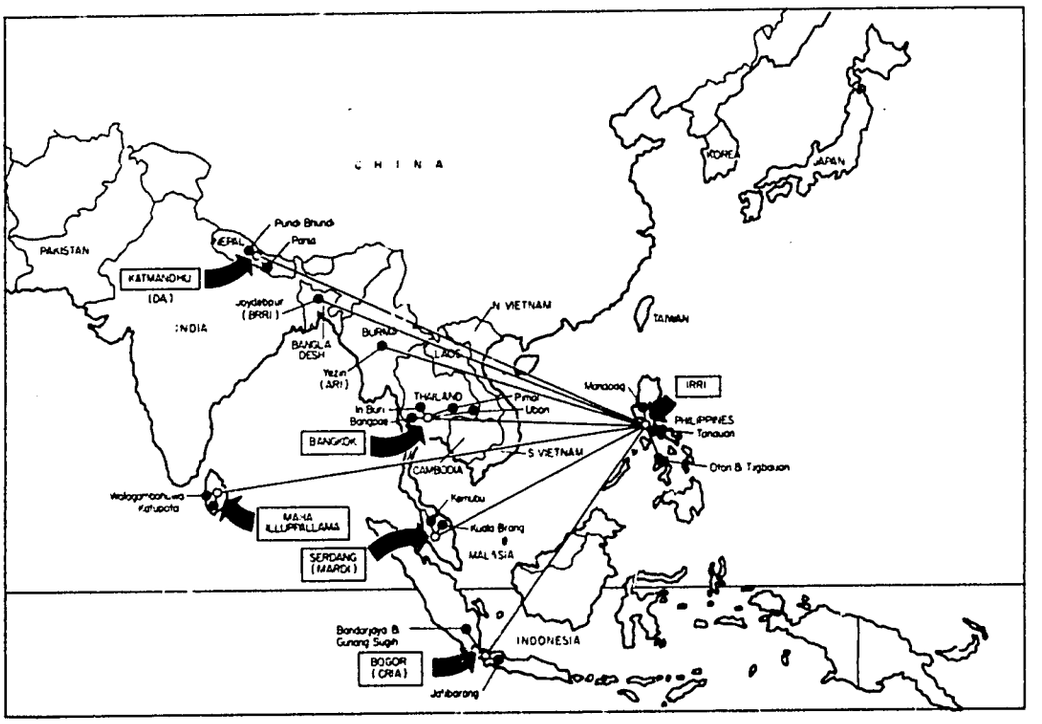
TESTING OF CROPPING PATTERNS

The network's major efforts in 1977 were on the design and testing of cropping patterns in the operational test sites: four in Thailand, three in the Philippines, two in Indonesia, two in Sri Lanka, two in Nepal, and one in Bangladesh. Except the three sites in the Philippines, which are managed by IRRI in cooperation with the Bureau of Plant Industry, Department of Agriculture, all the test sites are directly managed by the national programs. The test locations are shown in Figure 1; the target area, kind of rice land, rainfall, soil texture, soil suborder, and collaborators for the test sites are shown in Table 1.

Philippine network sites. The Philippine sites are in Tanauan, Batangas (upland rice); Tigbauan and Oton, Iloilo (rainfed-lowland and partially irrigated rice); and Manaoag, Pangasinan (rainfed-lowland and partially irrigated rice). The results and discussion of cropping pattern testing are in the Testing of cropping patterns section.

Indonesian network sites. The Indonesian network collaborates with the Central Research Institute for Agriculture. The test sites are in Lampung and Indramayu.

Bandarjaya and Gunung Sugih, Lampung, Indonesia (partially irrigated and upland rice). In Lampung, the farmers' dominant pattern in the 5-month irrigation category is lowland rice-fallow. The improved patterns studied were



1. Asian Cropping Systems Network, 1977.

Table 1. Description of Cropping Systems Network test sites, 1977.

Site	Kind of rice land	Immediate target area (ha)	Rainfall (no. consecutive months) Wet	Dry	Soil texture	Soil suborder	Collaborators
Philippines							
Cale, Batangas	Upland rice	40,000	5	5	Clay loam	Udolls	Bureau of Plant Industry
Tigbauan and Oton, Iloilo	Rainfed-lowland, partially irrigated	300,000	5–6	2–4	Clay loam to heavy clay	Uderts	Bureau of Plant Industry
Manaoag, Pangasinan	Rainfed-lowland, partially irrigated	500,000	3–4 (low and high water table)	5–6	Clay loam	Aquept Aquents	Bureau of Plant Industry
Indonesia							
Lampung	Partially irrigated upland rice	1,500,000	5	4	Sandy loam	Aquuits	Central Research Institute for Agriculture
Indramayu	Partially irrigated, irrigated	650,000	4	5	Clay loam	Aquents and Aquepts	Central Research Institute for
Thailand							
Pi Mai	Rainfed-lowland	850,000	2 (bimodal)	6	Sandy loam	Aquepts	Rice Division Department of Agriculture Division of Agricultural Economics
Ubon	Rainfed-lowland	500,000	3	6	Sandy loam	Aquults	Rice Division, Department of Agriculture Division of Agricultural Economics
In Buri	Irrigated and partially irrigated	500,000	2	6	Clay loam to heavy clay	Aquepts	Technical Division, Department of Agriculture, Division of Agricultural Economics
Bangpae	Rainfed-lowland	400,000	3	4	Silty clay loam	Aqualfs Aquepts	Kasetsart University
Sri Lanka							
Walagambahuwa	Partially irrigated (small tank)	101,000	3	4	Sandy loam	Aqualfs	Department of Agriculture
Katupota	Rainfed-lowland	25,000	1 (modal)		Sandy loam	Aquults	Department of Agriculture
Bangladesh							
Joydepur	Rainfed-lowland, and irrigated	6,300,000	5	5	Clay loam to heavy clay	Aquents and Udults	Bangladesh Rice Research Institute
Nepal							
Parsa	Rainfed, partially irrigated, and irrigated	39,000	5	6	Sandy and silty clay loam	Aquepts	Agronomy Division, Department of Agriculture International Agricultural Development Service
Pundi Bhundi	Rainfed-lowland	50,000	7	2	Sandy and silty clay loam	Udults	Agronomy Division, Department of Agriculture International Agricultural Development Service

rice-cassava, rice-corn, rice-corn + peanut intercrop, and rice-corn + soybean intercrop. The rice crop in the improved pattern yielded 2.4 more than that in the farmers' cropping pattern and 1.8 t/ha more than that in the farmers' cropping pattern with no constraint. The best pattern was rice-corn + soybean intercrop; it gave a net income of US$693/ha, 206% more than the farmers' pattern (rice-fallow) and 70% more than the farmers' pattern without constraints (rice-fallow). The second best pattern was rice-cassava (US$563).

In an old-settlement upland area, the yield of upland rice in the rice-corn intercrop was 19% lower in the introduced pattern because of blast, but the yield of corn was 160% higher than in the farmers' pattern. The most promising patterns were upland rice + corn intercrop + cassava relayed + corn + cowpea (net income of US$528/ha) followed by upland rice + corn intercrop + cassava relayed + peanut (net income of US$497/ha compared with US$245/ha of farmers' pattern).

Indramayu, West Java (irrigated and partially irrigated rice). The West Java network site is divided into 3 categories: areas with 10, 7, and 5 months of irrigation. Traditionally 2 rice crops are grown in areas with 10 months of irrigation, and only 1 rice crop in areas with 5 and 7 months of irrigation.

In the 10-month irrigation area, the 2 rice crops Pelita and C4 in the farmers' patterns yielded 10.1 t/ha, but the introduced pattern of IR28-IR30-IR28 yielded 11.1 t/ha. The second crop (IR30) was seriously damaged by gall midge. The total net income of the other introduced pattern, rice-rice-cowpea, was only slightly better (US$744/ha) than that of the farmers' cropping pattern (US$715/ha) of rice-rice.

In the 7-month irrigation area the yields of rice in the two improved patterns (IR28-IR30-soybean and IR28-IR34-cowpea) were better than those in the farmers' cropping pattern (Pelita-C4) and the farmers' cropping pattern without constraints (Pelita-IR26). IR28-IR30-soybean gave the highest net income (US$989/ha), which was 43% better than the net incomes of the farmers' cropping pattern and farmers' cropping patterns without constraints. The patterns of two crops of early maturing rice followed by either cowpea or soybean are promising in the 7-month irrigation area.

In the 5-month irrigation area, rice yields of the introduced patterns IR28-IR30-cowpea and IR26 (dry seeded) — IR30-cowpea gave much better yields (71% and 80% better, respectively) than the farmers' cropping pattern of rice-rice. IR28-IR30-cowpea gave the highest net income (US$1,146/ha) — 240% higher than the farmers' cropping pattern and 140% higher than the farmers' cropping patterns without constraints.

The other introduced pattern IR26 (dry seeded)-IR30-cowpea gave high yields, but the net income was low (US$542/ha) because of high labor cost for direct seeding.

Thailand network sites. Four test sites are in Thailand. Collaboration is with the Rice Division (for the Pi Mai and Ubon sites) and the Technical Division (for the In Buri site), Department of Agriculture; the Division of Agricultural Economics, Ministry of Agriculture and Cooperatives (for the Pi Mai, Ubon, and In Buri sites); and the Faculties of Agriculture and Economics, Kasetsart University (for the Bangpae site).

Farmers traditionally plant one rice crop; sometimes they cannot plant even that. The 10 patterns tested involved upland crops (mung bean, peanut, green corn, cucumber, and pumpkin) before and after rice. Among the upland crops before rice, green corn (US$279/ha), cucumber (US$271/ha), and corn-mung bean intercrop (US$282/ha) gave the highest net incomes. Peanut before rice was also promising.

Ubon, Ratchathani, Thailand (rainfed-lowland rice). In Ubon, which represents the wetter areas in northeast Thailand, farmers traditionally produce one rice crop a year. The improved patterns being tested there are rice-rice, rice-peanut, rice-corn, and rice-cowpea. Data were not available in 1977.

In Buri, Sing Buri, Thailand (irrigated and partially irrigated rice). In Buri is representative of the lighter soil areas of the Central Plain region. The work was concentrated in the lighter soil areas where rice-peanut was the dominant farmers' pattern. Six patterns of two to three crops were tested. The best pattern, rice

(RD5)-peanut-sweet corn, gave a total net income of US$901/ha.

Bangpae, Rajburi, Thailand (rainfed-lowland rice). The Bangpae site is representative of the rainfed rice areas in the Greater Mae Klong Development Project area covering six provinces west of the Central Plain.

The traditional pattern in the area is rice-mung bean. Six improved three-crop patterns with mung bean and green corn planted before rice, and sweet potato, bush sitao, black gram, soybean, green corn, and mung bean planted after rice were tested. A method-of-planting and fertilizer trials of mung bean were superimposed on the cropping pattern trials. Mung bean yields were low (average 276-420 kg/ha) because of drought. Fertilizer and herbicide trials were superimposed on the cropping pattern trial involving corn. The 80 kg N/ha treatment gave the highest green corn yield (7.3 t/ha). In the fertilizer and herbicide trial, fertilizer treatment alone gave the highest yield (7.7 t/ha), followed by fertilizer + herbicide (7.4 t/ha). Downy mildew and corn borer affected the corn crop.

Sri Lanka network sites. The network collaborators in Sri Lanka are the Maha Illuppallama Experiment Station (for the Walagambahuwa site) and the Batalagoda Rice Experiment Station (for the Katupota site) of the Department of Agriculture.

Walagambahuwa (rice partially irrigated from small tanks). The site is representative of 3,000 small-tank irrigation systems in the dry zone. Farmers traditionally wait for the tank to fill before preparing the land. In the last 7 years the lowland area was not planted to rice because water in the tank was not enough. In 1977 the average rice yield from 111 parcels was 2.31 t/ha.

The performance of the improved varieties varied with land classes. All varieties gave the highest yield on land class D, which has heavy-textured soils and poor drainage. The yield was 54% more than that on land class A, which has moderately to imperfectly well-drained soils. The yield of variety 62-355 (drought tolerant) on Class D land was 150% more than that of BG 34-8 on better drained land class A. In the yala, the average yield of green gram was 652 kg/ha; that of black gram, 930 kg; soybean, 681 kg; and soybean and cowpea, 924 kg. The farmers preferred soybean to other upland crops because it has a stable price and less problems with insects and diseases.

Alankara and Moragane, Katupota (rainfed-lowland rice). The Katupota site is representative of rice areas in moderately broad inland valleys and on the low slopes of uplands in Sri Lanka's intermediate zone. The traditional cropping patterns are rice-rice and rice-fallow.

The improved rice varieties in the trials were BG 11-11, H4, BG 34-8, BG 90-2, BG 94-1, and 62-355. Their performance depended on the landforms and microrelief. The best yielder in the Moragane tract, in both midslope and valley bottom, was BG 94-1, with an average yield of 6.66 t/ha. Rice yields were higher in the valley bottoms than in the midslopes; they averaged 5.88 t/ha for the bottoms and 3.82 t/ha for the slopes. Data on the second crop were not available.

Bangladesh network site. The network collaborator at Joydebpur in Bangladesh is the Division of Cropping Systems, Bangladesh Rice Research Institute (BRRI). The project concentrates on the BRRI pilot area, which covers 208 km² and the BRRI research station. Work is in the rainfed rice area of Bhogra village; an irrigated, lighter-soil area in Laskarchala village; the medium and low irrigated rice land in Salna village; and the Harunbari village deep-water area.

At Bhogra, the percentage of high yielding rice-rice patterns was significantly higher in 1977 than in 1976. More than 10 t/ha grain were produced with high yielding varieties in rainfed fields. Proper management increased the productivity of the farmers' cropping patterns by as much as 23%.

At the Salna irrigated medium land site, preliminary results indicated that double-cropping of two high yielding (boro-transplanted aman) rice crops was most profitable. Triple-cropping, including short-duration varieties, also looked promising. Crop management increased yields of farmers' aus and boro crops by as much as 46 and 20%, respectively.

In a partially irrigated lowland boro site (Jarunbari), IR8 was more profitable in the

farmers' single rice crop pattern than varieties such as Pajam or Muktahar (local variety). Proper crop management increased grain yield (over farmers' level) by as much as 32%. Relay cropping increased the cropping intensity in the higher elevation by 100%. Data indicate that double-cropping (boro-deepwater rice) has tremendous potential where a single boro crop is grown.

The traditional pattern in Laskarchala was direct-seeded rice followed by pulse or oilseed in the highland, and rice-rice on narrow valley land. The aus rice crop in the pattern planted to high yielding varieties yielded 45% more than the local varieties, but the yields were low and variability was high. With the start of tube well irrigation, wheat was introduced after rice; yields ranged from 0.426 to 2.4 t/ha and averaged 1.5 t/ha.

On a relatively lighter soil, patterns involving one rice and two nonrice crops seemed more practical in highland areas, and two rice crops with or without one nonrice crop showed potential in depressed valleys. Crops like wheat, corn, potato, and other vegetables have potential in the highlands.

Nepal network sites. The network collaborators in Nepal are the Division of Agronomy, Department of Agriculture, and the International Agricultural Development Service.

Parsa District (rainfed, partially irrigated, and irrigated rice). Parsa is representative of the Tarai (flat land) in Nepal.

The present patterns are rice in summer and wheat or legumes in winter. Eleven alternative cropping patterns were tested where rice is grown in summer; wheat, barley, and legumes in winter; and rice, mung bean, and green manure in spring. The yield of the first rice crop in the irrigated rice area was 4.55 t/ha (av. of 20 plots, ranging from 0.99 to 6.35 t/ha). Second crops of sole crop and intercrop wheat and legumes were planted in November 1977.

Pundi Bundi Panchayat (rainfed rice). The site in Pundi Bundi represents the hill growing areas. Its elevation ranges from 750 to 1,270 m. The dominant patterns in the rice areas are maize-rice or rice-wheat at from 750 to 1,060 m. In the lower elevations, rice-fallow is the common pattern. Thirteen rice-based and six upland crop-based cropping patterns were tested. The first crop was rice during summer, followed by monocrop and intercropped wheat, barley, and legumes during winter. The spring crop was corn intercropped with legumes.

Work in the site involved 23 farmers. Rice yields in 6 plots harvested in 1977 ranged from 374 to 2,934 kg/ha. CH45, an early maturing variety used in the trials, escaped the hail that destroyed the local variety. It was, however, affected by blast.

WORKING GROUP MEETINGS

The Cropping Systems Network working group — composed of program leaders from the collaborating countries, the IRRI program leader, and the network coordinator — met twice in 1977. One meeting (5th Working Group meeting), from 15-22 February 1977 in Bangladesh, was sponsored by BRRI and IRRI. Eleven members and 17 resource persons were present. The other meeting (6th Working Group meeting), held on 13-17 December 1977 in Sri Lanka, was cosponsored by the Department of Agriculture of Sri Lanka. Twelve members and 14 resource persons attended. At these meetings, the working group agreed on

- A system for cropping pattern monitoring that includes climatic, land, and socioeconomic factors in addition to cropping pattern performance;
- Standardized reporting for varietal screening;
- Methods for securing coordination between on-site research and extension programs;
- Pest control research methods for cropping systems research sites;
- Requirements for collaborative weed control research across the network; and
- Improved methods for costs and returns analyses of cropping patterns.

In addition, the participants monitored cropping systems research at the on-farm sites and experimental stations.

TRAINING

The training of scientists in cropping systems research and extension was intensified in 1977.

Priority for training was given to young scientists directly involved in the collaborative project and in national research and production programs. On-the-job, nondegree training was conducted for 3-12 months for 22 scientists in the Philippine outreach sites and at IRRI. Another 39 trainees attended a 6-month short course on cropping systems at IRRI. A total of 14 M.S. and 4 Ph.D. students are pursuing graduate studies through IRRI.

SHARING OF RESEARCH INFORMATION

One role of the CSN is to facilitate exchange of research information among scientists working on cropping systems research in Asia. In 1977, copies of 24 papers and 2 reports of the cropping systems working group were distributed to 257 scientists from Indonesia, Thailand, India, South Korea, Malaysia, Nepal, Philippines, Bangladesh, Burma, and Sri Lanka through the cropping systems program leaders or coordinators in each country. Another 43 scientists from 11 countries in Europe, North America, South America, and Africa also received the publications.

Machinery development and testing

Agricultural Engineering Department

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SUMMARY

Machinery development efforts concentrated on the 6- to 8- hp tiller, portable thresher, and portable grain cleaner, which were all released in 1977. These machines possess the performance and operating features sought by farmers, and preliminary reports from cooperators indicate that they will be well received in the field.

Four projects initiated this year were rotary tiller and harvester attachments to increase the versatility of the power tiller, a plow-sole chemical applicator, and an improved and cost-reduced batch dryer that will be released to manufacturers in early 1978. Work continued on the multicrop seeder, windmill and pump, and equipment for energy generation from agricultural residues.

The compacted soil studies are in their 10th season. Allowing the soil to dry for 1 month before land preparation for the 10th crop resulted in a marked reduction in the depths at which the cone indices were measured. This allowed use of the four-wheel tractor for the first time since the sixth crop.

An operational and economic study that compared power transplanting, manual machine transplanting, and hand transplanting showed that power transplanting required 40% of the labor needed for hand transplanting. However, its high cost requires that the machine plant 32 ha annually to compete economically with hand transplanting at the current Philippine wage rates.

Monitoring of the Philippine farm equipment industry continued. The sales of four-wheel tractors and power tillers fell in 1977; however, locally built tillers suffered least in the downturn. Farmers show a growing preference for diesel tillers with increased power and sophistication.

A survey of Filipino upland farmers indicated their interest in improved machines for land preparation and weed control. Generally, the farmer's interest in mechanization was positively related to farm size, income, and educational level.

The new Industrial Extension Subcontracts in Colombia and Nepal brought the total to nine. The United States Agency for International Development sponsored a workshop in which participants from 17 countries discussed the use and extension of IRRI designs, engineering problems, and mechanization policy.

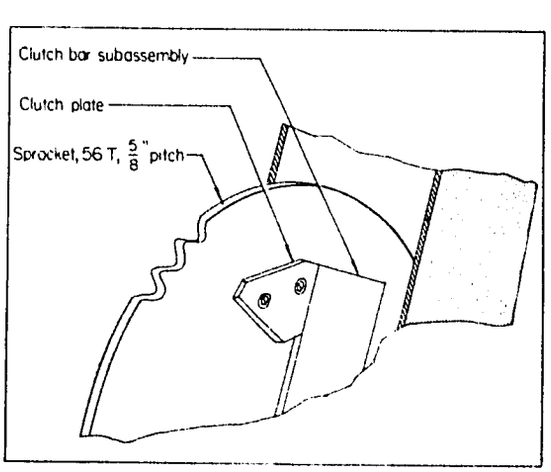
The Pakistan and Thailand Industrial Extension Project teams have modified the IRRI thresher to improve performance with local crop varieties. The 1977 production of the thresher increased two and one-half times over that of 1976.

MACHINERY DESIGN

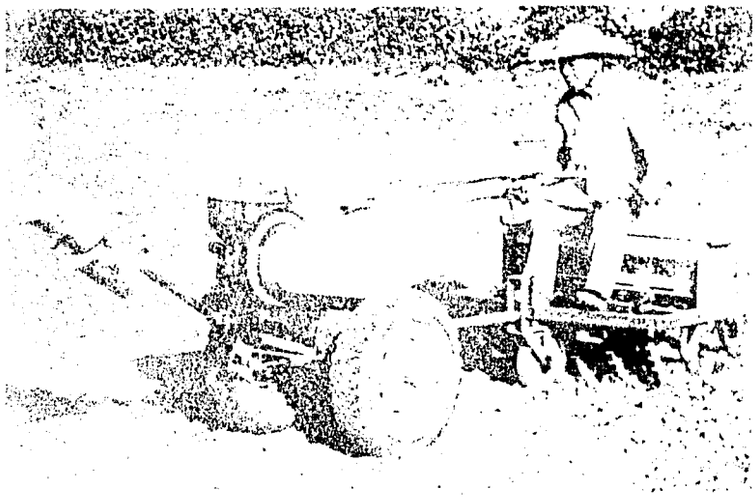
6- to 8- hp tiller with steering clutches. The steering-clutch tiller was released to manufacturers in the last half of 1977, after about 1 year of development. Information from 2,600 hours of dynamometer and field testing was used to refine the design and improve components.

Several chain failures early in the field test program were attributed to insufficient clearance between the chain and transmission housing. The housing was widened and sprocket center distances were adjusted to eliminate a half-link and permit the use of the same length of chain on all three drives.

An alternate steering clutch design (Fig. 1) was compared with the initial design, which used Allen capscrews to engage the clutch bar. The new design was selected for release because dynamometer and field tests showed it to be superior.



1. Revised power tiller steering clutch.



[illegible] Agricultural's prototype [illegible] was built to use high-shock loads. The initial chains also had many [illegible] failures. A series of excessive loading oscillograph measurements showed that clutch engagement produced peak loads of over five times the normal load. Although [illegible] due to the type of [illegible] not observed during [illegible] tests, development of a [illegible] was initiated to reduce high shock and [illegible] loadings that may occur during rotary tillage.

A simple [illegible] was developed for use with the tiller in [illegible] tillage. Because the operator can [illegible] and can operate the tiller [illegible] the more practical [illegible] along.

Rotary tiller attachment for the 6- to 8-hp tiller. A rotary tiller [illegible] designed to provide [illegible] increasing customer [illegible] small farms where farmers practice [illegible] for their use in [illegible] the upland crops that are grown in rotation with rice. A moldboard plow and a comb harrow, implements commonly used for wetland tillage in many parts of Asia, are available for use with the new tiller.

The rotary unit is attached to the power tiller by the hitch pin and adjustment of two stop bolts. A V-belt intermediate drive, with a belt tightener that is used for a clutch, drives the sealed chain final reduction transmission. This transmission can be easily inverted to produce rotor speeds of 225 and 350 rpm. Four rotors, each with three blades, give an effective tillage width of 90 cm.

The power tiller has a field speed of about 3.2 km/hour, which is too fast for rotary tiller operation. The engine-to-transmission belt drive was modified by the addition of an intermediate two-groove pulley. The arrangement provides four forward speeds, the minimum of which is 1.5 km/hour and maximum 16 km/hour.

The prototype rotary tiller performed satisfactorily in preliminary tests but intermediate drive belt life was poor. A chain drive and jaw clutch will replace the belt drive before testing is continued.

Multicrop upland seeder. Development of the upland seeder is in the third prototype stage. The features — multicrop capability, variable row spacing from 20 cm upward in 20 cm increments, adjustable seed spacing within the row, and simultaneous planting of two crops — have been retained.

The machine was revised to reduce cost, simplify construction, and improve performance (Fig. 2). Improved compactness and a caster wheel hitch improve turning at the end of the field and aligning the seeder with the last planted row. A divided hopper and a modified seed plate allow placement of fertilizer in the

furrow with the seeds. A simple mechanism enables the operator to lower the furrow openers and engage the seed plate drive simultaneously. Four rollers support the seed plate frame assembly to reduce friction during oscillation. Spring-loaded seed-tube assemblies maintain proper clearances between the hopper and seed plates. Band and split wheel-type press wheels are being evaluated for their effect on seed germination.

Rice transplanter. The pushrod of the experimental transplanter mechanism was redesigned to give a lower center of gravity and greater clearance for tall seedlings. The motion of the pushrod tip was similar to that in the previous design, but it gave smoother seedling release without bulldozing.

Tests showed that the prototype mechanism required more power than is practical with a manually operated transplanter. Therefore, the feasibility of a power tiller-mounted transplanter was studied. High cost could make the machine uneconomical for the small farmer, and its greater capacity could cause labor displacement.

Efforts were shifted to the improvement of a manual Chinese type, 5-row transplanter. The primary goal was to reduce its cost and make it easier to operate. The existing machine consists of a wooden skid that supports a seedling tray and a frame that holds five pincher type pickers. The operator uses two handles — one to actuate the transplanter mechanism and the other to pull and guide the transplanter.

The original machine requires four motions of the transplanting handle to pick the seedling from the tray and plant it. The redesigned machine requires only two motions of the handle during transplanting — the downward stroke picks and plants the seedlings and the upward stroke releases the planted seedling. To accomplish this, the three point pickers of the earlier IRRI experimental transplanter replaced the pincher type pickers.

Preliminary field trials revealed that the picker disturbed the seedlings on the upward stroke and missed during the downward stroke. This problem is being corrected before testing is resumed.

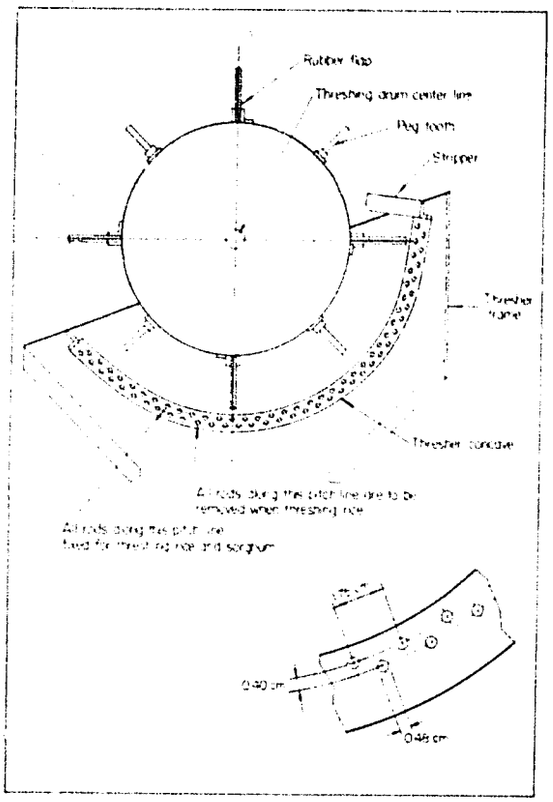
Plow-sole granular-chemical applicator. A project to develop a plow-sole granular-chemical applicator was initiated in cooperation with the Agronomy Department. The applicator will place fertilizer in the soil at a depth of 10–12 cm during plowing. Combining the plowing and fertilizing operations is expected to reduce the farmer's costs, eliminate the difficulty of pushing granular and liquid fertilizer applicators, and increase fertilizer efficiency over that of fertilizer applications by the traditional broadcast methods.

Work was begun on development of a metering device that would exhibit a linear relationship between metering adjustment and discharge rate. Several plain roller designs were evaluated and discarded. A fluted roller with a means to adjust the width of flute exposed to the fertilizer was chosen. Metering tests showed a linear relationship between flute width and discharge rate. The fluted roller uses the added advantage of positive displacement for more constant discharge rates.

The effectiveness of fertilizer application with the experimental applicator will be compared with deep placement with a plow-sole applicator, incorporation during final harrowing, and traditional split broadcast methods during dry-season yield trials.

Portable axial-flow thresher. After the release of the portable thresher to manufacturers in early 1977, development of its capabilities in threshing crops grown in [illegible]

3. Plow-sole chemical applicator.



4. Threshing cylinder or concave rod arrangement for rice and sorghum thresher.

was initiated. Sorghum threshing received primary attention and work in soybean and groundnut was planned.

Separation losses were high and capacity was low when sorghum was threshed with an unmodified portable thresher. In addition, about 10% of the grain was detached from the panicle in clusters and could not be easily separated by rethreshing.

Preliminary tests with rubber flaps made from used tire carcasses in place of peg teeth showed reduced loss of unthreshed grain, but the clusters problem persisted. Concaves with smaller screen openings were tried and one with two layers of 4.8-mm-diameter rods was selected because it produced low losses and is easily converted to the rice threshing mode by removal of the lower layer of rods (Fig. 4).

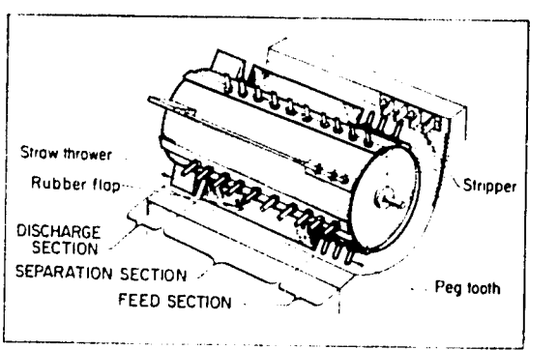
A series of tests with rice and sorghum was conducted to determine the best combination of peg teeth and rubber flaps that would produce high threshing capacity, low losses, and easy conversion from one crop to another. The results are shown in Table 1. Design A1 was selected for rice and design A2 for sorghum, on the basis of those performance criteria (Fig. 5). Endurance tests show that the rubber flaps will thresh 60–80 t of sorghum before replacement becomes necessary.

Stripper bars are necessary when threshing tall rice varieties, which tend to wrap around the threshing cylinder, and hard-threshing varieties that require a more aggressive threshing action.

Harvester attachment for power tiller. A harvester attachment for the power tiller is being developed. A conventional cutter bar header was selected over a stripper because it has multicrop capability and the reported losses in harvesting by stripper are high. The concept uses a cutter bar header for harvesting, the portable thresher for threshing and cleaning, and a power tiller to carry and power the thresher and header. Initial design work is complete and prototype drawings are being prepared.

The header assembly is mounted directly in front of the power tiller, the thresher behind the tiller and under the handle bar. An auger conveyor collects harvested paddy from the header and transfers it to the thresher by an enclosed underfeed belt conveyor. Threshed grain is collected under the thresher in a pan that can be pulled out from either side for unloading.

The power tiller will need only minor modifications to accept the harvester attach-



5. Threshing cylinder configuration A-2S.

Table 1. Results of threshing tests with the portable axial-flow thresher, IRRI, 1977.

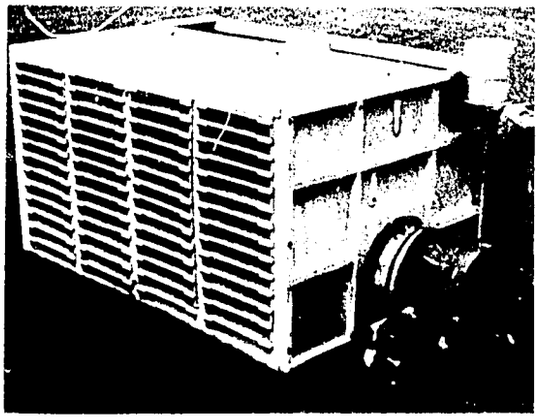
Configuration	Construction*		Capacity (kg/h)		Total loss (%)		Purity (%)	
	Feed section	Separation section	Rice	Sorghum	Rice	Sorghum	Rice	Sorghum
A-1	Pegs	Pegs	570	937	2.40	1.34	86	84
A-1S	Pegs w/ stoppers	Pegs	482	856	1.70	4.26	85	[illegible]
A-2	Pegs	1/2 pegs & 1/2 flaps	399	999	6.60	1.55	84	88
A-2S	Pegs w/ stoppers	1/2 pegs & 1/2 flaps	387	1008	6.32	1.94	85	89
A-3	Pegs	Flaps	344	1019	6.10	1.26	85	90
A-3S	Pegs w/ stoppers	Flaps	336	1101	6.06	1.70	85	90
B-4	1/2 pegs & 1/2 flaps	1/2 pegs & 1/2 flaps	375	1013	1.30	1.62	87	90
B-5	1/2 pegs w/ stoppers	Flaps	382	1040	0.36	1.21	83	92
C-6	Flaps	Flaps	290	1064	6.46	2.08	[illegible]	[illegible]

*See Figure 5. **Expressed as the percentage of clean grain to the total material passed through combine.

ment. The engine will drive a jackshaft mounted on the implement bracket of the power tiller. A roller chain drive from this jackshaft will drive the input shaft of the power tiller gearbox to obtain a forward speed of about 1.4 km/hour for harvesting. The jackshaft will also drive the thresher and header assemblies.

The estimated weight of the harvester-tiller combination is 295 kg. A tiller ballasted to 20% over that weight exhibited no mobility problems in a flooded, recently harvested paddy field.

Vertical-bin batch dryer. A cooperative value analysis project of the IRRI Agricultural Engineering Department and the Philippine National Grains Authority and Metals Industry Research and Development Center resulted in a lower-cost grain dryer with increased fuel efficiency and higher capacity (Fig. 6). Value analysis is an organized team effort to accomplish a desired function at the lowest cost without reducing quality.



6. Vertical-bin batch dryer.

A tube axial-type blower was designed to replace the vane axial-type used in the existing IRRI dryer. In the new design the blower and burner are in a single cylindrical housing, and the fan diameter was increased from 36 cm to 53 cm to provide sufficient air for the larger capacity bin. The airflow is 1.5 m³/min at 30-mm water gauge pressure at a fan speed of 2,000 rpm. Power input is about 2.3 kW when moving air at 32°C.

The burner of the present IRRI dryer was revised to improve fuel efficiency by relocating the baffle to a better position of the flame to aid combustion. A two-piece burner assembly with a combined baffle and cover was designed to allow for the new baffle position. Use of a coiled tube to preheat the incoming fuel reduces fuel consumption and allows the use of diesel fuel. But an undesirable cyclic change in size of the flame requires further work before the preheater can be used.

The value analysis team found that the perforated metal floor in the IRRI batch dryer contributes about 45% of total bin cost and causes serious maintenance problems because operators tend to damage the floor when

unloading the dried grain. The new bin is made of wood and has two vertical grain columns on each side of a central plenum. Heated air enters the plenum, diffuses through the louvered side panels of the grain compartments, and passes through the grain. The slats are removable, facilitating loading and unloading. Farmers usually do not like to have their grain mixed with that of other farmers, so a fixed vertical partition was added at the center of each bin to produce four separate bins.

This project resulted in a dryer of 2-t capacity, costing an estimated 45% less (per ton of capacity) than the previous IRRI design and reducing fuel consumption by 30–40% per ton-hour.

Steam and producer gas generation. Two types of LPG gas-fired boilers were evaluated for possible adaptation to a rice hull furnace. The first type is a single-drum, free-convection boiler where feed water is admitted at the bottom of the drum to a certain level and steam is produced by natural convection. Tests using a 4.36-mm-diameter steam nozzle gave a maximum generating capacity of 16 kg/hour at 0.7 kg/cm^2. This low capacity is attributed to a limited effective heating surface of 0.76 m^2 and insufficient heated-surface wettability because the boiler is a free-convection type.

The second boiler is an annular film evaporation, forced-convection type. The feed water enters tangentially along a 6-m long helical flat channel. The water flows around the channel at relatively high velocity and the turbulence aids in flushing the film of water into steam before it enters the steam chest. Steam nozzle tests gave a maximum generating capacity of 25 kg/hour at 1.4 kg/cm^2. The boiler could continuously operate the exhausting uniflow steam engine described in the 1976 Annual Report with 7.5 kg/hour steam at 3.5 kg/cm^2, which produced 0.2 hp at 900 rpm.

Thirty hours of operation produced a heavy scale approximately 0.4 mm thick along the entire helical channel. Under prolonged operation this deposit may cause boiler overheating and creep failure unless chemical water treatment or periodic mechanical cleaning is performed.

Evaluation of the results of the steam engine project and consideration of the comparative advantages of systems that could produce a fuel directly usable in existing internal combustion engines led to temporary suspension of the steam engine work. After a feasibility study in producer-gas generation, a small batch-type generator was designed and built.

To overcome the problem of high tar content in the gas, a dual-mode design was selected. After reaching an operating temperature of 500 to 1,000°C, the volatile matter in the rice straw (or other basic fuel), consisting of tar, CH_4, H_2, H_2O, and O_2, is evaporated and burned in the combustion chamber. Two-thirds of the resulting flue gas (now tar free) flows downward through the reduction chamber, reacting with the charred rice straw to form producer gas (CO, H_2, CO_2, and N_2). The remaining flue gas moves upward to distill the volatile matter of the rice straw to keep the cycle going.

Gas quality will be evaluated by ignition response and flame-length tests. If the results are favorable, a gas scrubber and gasoline engine will be added to test the performance of the complete system.

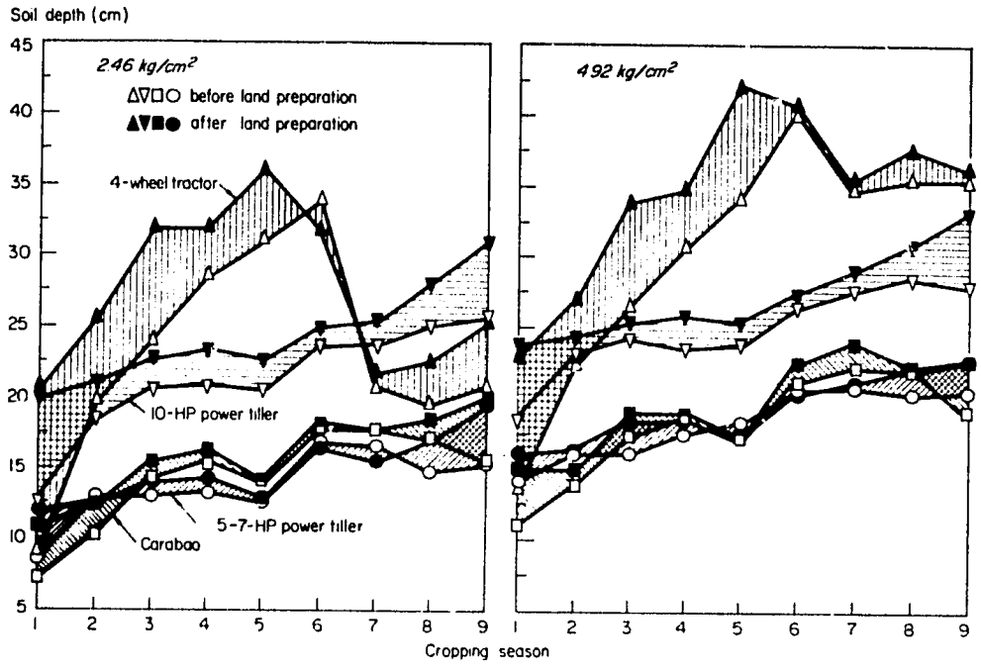
Engleberg rice mill project. The Engleberg rice mill is undergoing improvement to increase milling recoveries without major modifications in the machine.

Preliminary tests that used blades of polyvinyl chloride (PVC) and rubber from used tire carcasses in place of the steel blade showed improved milled-rice recovery without additional changes in the mill. Head-rice recovery was 90% with the PVC blade and 81% with the steel blade when the machine was used as a polishing unit only, but milling capacity was much lower with the PVC blade (75 kg/hour) than with the steel blade (200 kg/hour).

A study of grain condition inside the milling chamber reveals that mature grains break during hulling. Evaluation of the hulling section of the Engleberg mill will concentrate on the rotor, screen clearance, and feeding system.

MECHANIZATION RESEARCH

Compacted soil studies. The study of compacted soil is in the 10th cropping season. Depths at which a cone index of 2.46 kg/cm^2



7. Compacted layer depth under different tillage systems.

was measured increased up to 3 cm in some plots although depths at which 4.92 kg/cm² was encountered generally remained stable between the eighth and ninth crops (Fig. 7). It is possible that depth stability will not occur under the continuous cropping plan in soil that remains saturated throughout the year, even in plots tilled by the 5- to 7-hp tiller and by water buffalo. The four-wheel tractor plot was tilled by the 5- to 7-hp tiller for the ninth crop.

Plots were not irrigated during the 1-month fallow between the harvest of the ninth crop and the start of tillage for the 10th crop. This allowed the soil to dry somewhat. Previously the plots were kept saturated during fallow.

Cone indices of 2.46 and 4.92 kg/cm² were measured at sharply reduced depths compared with similar readings for the ninth crop. On the basis of these readings, a four-wheel tractor was used to till the four-wheel tractor plot for the first time since the sixth crop. Only minor mobility problems were encountered. An attempt will be made to determine the effects on soil depths of a 1-month dry period after each crop.

Power tiller upland tillage tests. An upland-crop survey showed that land preparation is traditionally done by water buffalo. Plowing requires an average of 11 days/ha, with considerable variability depending on the season and crop. Over half the farmers surveyed expressed interest in an improved power source.

Because of this interest, tillage and traction tests were conducted with the new 6- to 8-hp tiller to determine its suitability for upland soils. Rotary tillage with two blade shapes, and moldboard plowing with three different traction wheels were evaluated. Traction tests using four different wheels were also conducted. The tiller was equipped with a 5-hp diesel engine and it weighed 196 kg.

Rotary tiller test. Hoe- and slasher-type rotary blades were used in the tiller tests. The blades were attached to a blade flange of 31-cm diameter and mounted directly on the power tiller axle. Six flanges of six blades each were used, three on each side. The blades were uniformly spaced to till a total width of approximately 90 cm with a 20-cm strip of undisturbed soil in the center, which was partially tilled by a cultivator sweep attached to the restraining bar.

Upland clay soil plots, 29× 10 m, were tilled using the "go-around method," where the operator starts plowing at the edge of the field and goes around until he reaches the center.

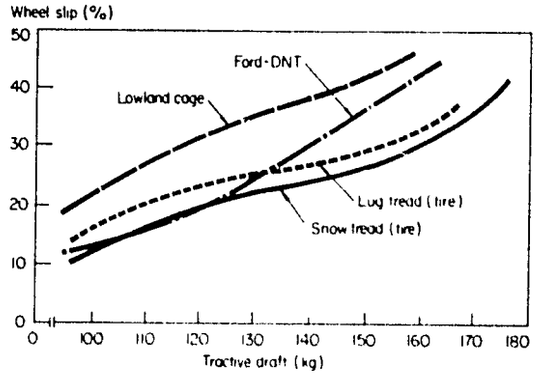
When used with axle-mounted blades the tiller was extremely difficult to control and physically exhausting to operate. The tests indicate that rotary tillage of upland soils with a tiller in the 5- to 8-hp class will, in most cases, require a power-take-off driven rotary tiller attachment.

Drawbar pull test. The small, two-wheel power tiller has relatively low traction, which frequently limits its use on hard, dry soils. To determine the capabilities of the IRRI tiller in upland soils, traction tests were conducted using four different wheels — 6.00–13 "snow" tread tire, 5.00–12 deep lug tire, lowland cagewheel, and Ford DNT wheel. The test tract was laid out on soil of the type used in the rotary tiller tests.

To provide stability and eliminate any vertical force on the drive wheels, resulting from towing the loading device, a two-wheeled cart was attached to the power tiller by an articulated hitch. A load sled was then connected to the cart through a dynamometer. The horizontal tractive force was varied by loading the sled with incremental weights. A total vertical force of 286.3 kg on the tiller wheels was obtained by adding wheel weights and a front counter weight. A cubic polynomial prediction equation expressing percentage of slip as a function of drawbar pull was selected because the residuals were significantly less than in either a straight line or quadratic equation. Results of the drawbar pull versus slip tests are shown in Figure 8.

Moldboard plowing test. The procedure of the moldboard plowing test was similar to that of the rotary tillage trials. Plots measuring 29 × 10 m and adjacent to the rotary-tillage plots were used. Each plot was plowed with an IRRI moldboard plow using the "head land method," where the operator plows one side, turns around at the end, and plows down the other side. The "snow" tread tire, lowland cagewheel, and Ford DNT wheel were compared. Results are shown in Table 2.

Field tests of three transplanting systems. Rice is still transplanted in standing water in most rice-growing regions of the world. Transplanting is one of the most labor-intensive operations in rice production and generally requires large amounts of labor for short periods. Approximately 30% of the total labor required for rice production goes into it.



8. Results of traction test of IRRI 6- to 8-hp power tiller.

Three transplanting systems are available to the farmer: transplanting with a power machine, with a manual machine, and conventional hand transplanting. A field experiment studied the comparative performance and economics of the three systems. Seedlings suitable for each system were prepared and all intermediate steps were performed and analyzed. The seedlings were transplanted under the same field conditions on the IRRI experimental farm, with two replications for each system. Standardized field management methods were used for all plots. Crop cuts were taken from each plot before harvest to estimate yield.

The highest yield was obtained from the conventional hand transplanting system (4.05 t/ha), the lowest from power-machine transplanting (3.27 t/ha). The manual-transplanter plot yielded 3.8 t/ha. Yield differences between hand and machine-transplanting methods were significant at the 5% level, as shown by a *t*-test. Differences between the manual machine and power machine systems were not significant. Yield differences among the three

Table 2. Results of moldboard plowing tests using the IRRI power tiller.

Wheel type	Av. time (min./plot)	Av. fuel (liter/plot)	Av. field efficiency (%)
Rubber tire	66.5	.95	44
IRRI lowland cage	69.1	.95	38
Ford/DNT	57.8	.86	49

transplanting systems were not significant at the 1% level.

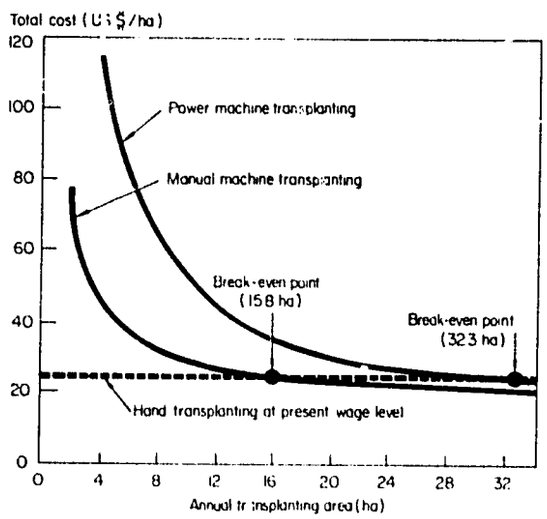
The total labor required to transplant 1 ha from seedling preparation to transplanting was 56 man-hours with the power-machine system, 95.7 man-hours with the manual-machine system, and 143.2 man-hours with the conventional hand system.

Machine costs were divided into fixed and variable components. Annual fixed costs included depreciation, interest, and repairs. Variable costs included fuel, lubrication, and labor plus seedling-preparation costs.

A present Philippine wage levels, the break-even point for the manual transplanter is 15.8 ha transplanted annually; for the power transplanter it is 32.2 ha. The relationships between total average costs and annual transplanting area for each transplanting system are shown in Figure 9.

Shortages in labor during transplanting are generally reflected in increased seasonal wage rates. Additional development is required to lower the cost of transplanting equipment to make the machines more attractive in countries suffering seasonal labor problems during critical planting periods.

Testing and evaluation. Testing for endurance and performance was concentrated on the machines that were released to manufacturers during 1977. Endurance test activities for 1977



9. Relationship between total cost and annual use.

included 2,730 hours for threshers, 2,530 for tillers, 1,370 for cleaners, and 370 for dryers. Performance tests involved 25 IRRI prototypes and 28 manufacturers' prototypes.

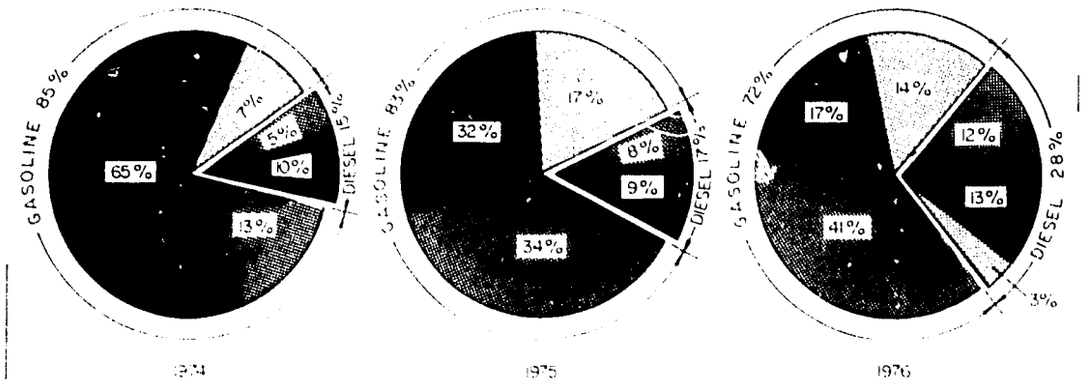
Tests were conducted in the laboratory under controlled conditions and in farmers' fields to evaluate the machines under actual operating conditions. The results were used to refine the designs and indicate their readiness for release to manufacturers. Operating and repair costs are collected during the endurance tests and used in determining total costs of ownership. Information on machine operations, adjustment, maintenance, and servicing acquired during testing is included in the operator's manual. Manuals on the portable thresher and the 6- to 8-hp tiller were published and made available to cooperating manufacturers in 1977.

MECHANIZATION SYSTEMS

Market for farm machinery. Work continued on monitoring the size, composition, and growth of the Philippine farm equipment industry. Although a $37.5 million World Bank credit line became available during the year, sales of both power tillers and four-wheel tractors fell. Rising prices, coupled with a poor repayment record during previous mechanization loan programs, made the bankers reluctant to participate in the new loan program. Sales of locally built power tillers suffered least from the changing economic climate and prices, although higher than those in the past, were more stable than those of imported machines.

Farmers have indicated a growing preference for diesel-powered tillers (Fig. 10) and an increase in power and sophistication of these units. There is less demand for the simple units that were introduced in the early 1970's. Average total costs for a range of tillers are shown in Figure 11. Locally built units show a decided cost advantage over both imported gasoline- and diesel-powered units and are economically viable for farms as small as 6 to 8 ha.

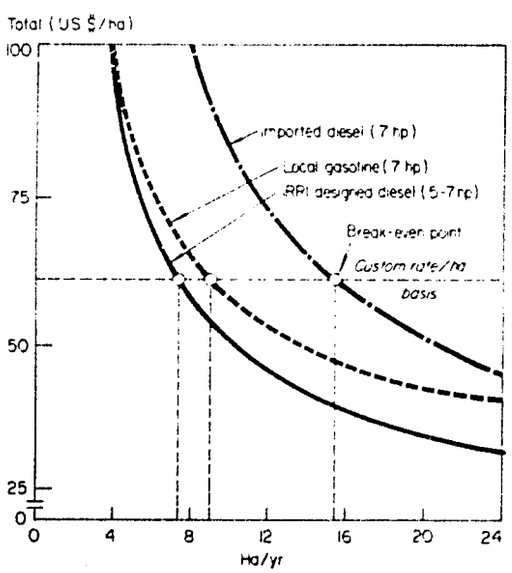
Over 60 firms, the largest number of which are located in the greater Manila area, manufacture and distribute power tillers and associated implements in the Philippines. Their production capacity greatly exceeds current local demand.



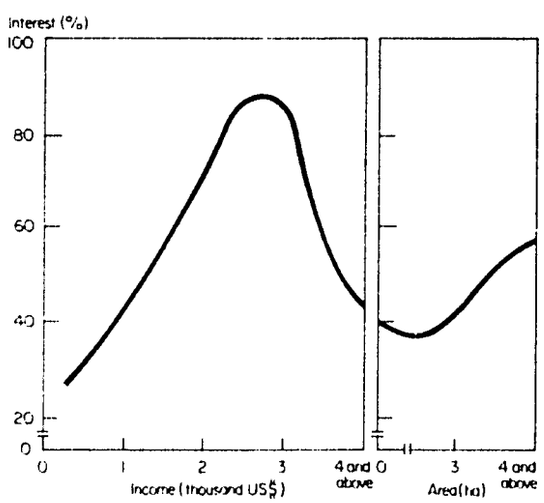
10. Sales of power tiller by horsepower and fuel, Philippines, 1974–77 (does not include Kubota sales of 5,000 units to DAR, 1974–75).

Mechanization in upland cropping systems. A survey of 100 upland farmers at two Philippine locations revealed a high degree of cropping intensity, but relatively low overall farm productivity. Farmers were asked to assess the need for improving techniques used in performing field activities associated with the crops grown on their farms. Land preparation and weed control were ranked high, while harvesting and threshing were ranked somewhat less important in both locations. Because upland cropping is highly dependent on available rainfall, the need for timely land preparation to ensure stand establishment is critical.

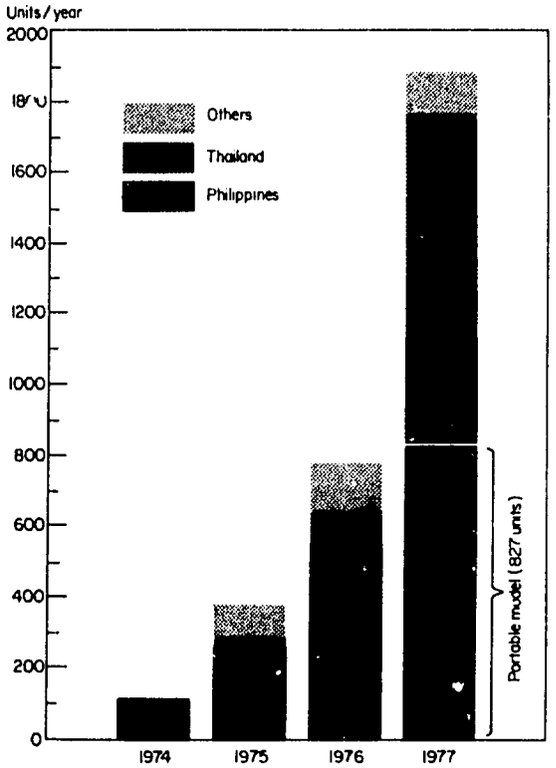
Evaluation of factors related to the farmer's level of interest in mechanization shows a positive relationship between farm income and farm size and the level of interest (Fig. 12). Age,



11. Power tiller costs.



12. Relationship between gross farm income farm size, and interest in mechanization in 100 upland farms, Philippines, 1976–77.

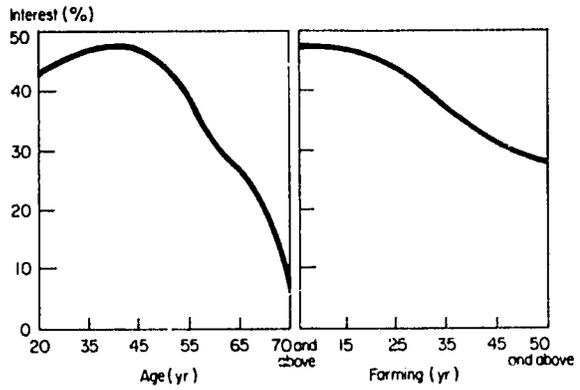


13. Relationship between age years in farming, and degree of interest in mechanization in 100 upland farms, Philippines, 1976–77.

years in farming, and interest in mechanization appeared to be negatively related (Fig. 13). Farmers less than 40 years old preferred improved equipment more than did those over 50. Years in farming and interest in mechanization were inversely related. Owner-share lessees and share lessees demonstrated significantly higher levels of interest than lessees or owners. Farmers with more education were more positively inclined toward mechanization than those with little or no education.

INDUSTRIAL EXTENSION PROGRAM

Industrial extension subcontracts in Colombia and Nepal were added in 1977 to the network of seven other core-funded subcontracts and three Regional Industrial Extension Projects funded by the US Agency for International Development (USAID). The USAID sponsored the International Machinery Workshop at IRRI in November to assemble the network cooperators and others associated with the IRRI



14. IRRI axial flow thresher production.

Machinery Development and Industrial Extension Program. Participants from 17 countries in Asia, Africa, and the Americas discussed the effective use of IRRI designs, shared experiences of formulating and implementing agricultural mechanization programs in their countries, and presented papers on the status of mechanization in the countries they represented. The proceedings of the workshop will be published in early 1978.

The project staffs in Pakistan and Thailand, working in cooperation with local manufacturers, have developed modifications for the IRRI axial-flow thresher that improve its performance with local rice varieties and crops grown in rotation with rice. Farmer and manufacturer interest in the thresher is evidenced by an increase of 2.5 times in the number of machines produced in 1977 over that in 1976 (Fig. 14).

The portable thresher described in the 1976 Annual Report was introduced in the Philippines. Acceptance was good and 812 machines were produced by 12 manufacturers. The modification for sorghum threshing, described in the Machinery Design section, was incorporated into about 100 of these machines.

Prototypes of the 6- to 8-hp tiller with steering clutches have been built by manufacturers in Pakistan, the Philippines, and Thailand, but Indian firms have shown the highest interest in the new design. The IRRI 5- to 7-hp tiller was not considered suitable for conditions in India, but interest generated by the new design resulted in four companies building prototypes for testing. One of the firms has completed the evaluation phase and has begun marketing.

Associated formal training

Educational programs continued to provide opportunities for rice researchers to improve their capabilities for research work through graduate studies and practical training in different departments and in various courses in support of international research networks. In 1977, 253 fellows, scholars, and trainees from 29 countries participated in these programs (Table 1). The largest number of scholars and fellows was in the departments of agronomy, agricultural economics, plant breeding, entomology and the cropping systems program. The highest number of man-years of training also occurred in these five Institute units.

RESEARCH PARTICIPANTS

Of the 129 participants in the research-oriented programs, 45 research scholars were working toward the M.S. degree and 22 for the Ph.D. degree. The majority were enrolled as graduate students at the University of the Philippines at Los Baños and some were students of other universities doing their thesis research at IRRI.

There were 26 nondegree research scholars and 8 nondegree research fellows. They stayed at the Institute from 1 to 12 months, depending on the specialized training required.

A total of 32 postdoctoral fellows were in residence for part of the year or during the entire year, undertaking special studies in IRRI research departments.

TRAINING PROGRAMS IN SUPPORT OF INTERNATIONAL RESEARCH NETWORKS

Genetic Evaluation and Utilization (GEU) course. The 4-month GEU training course (February–June) was attended by 33 participants from 11 countries. The course emphasizes the need for a multidisciplinary approach to the development of rice varieties. It is designed for individuals involved in the development of improved rice varieties.

Cropping systems training program (CSTP). The 6-month CSTP course began in September and was attended by 38 trainees from 8 countries. It 1) trains participants to conduct scientifically designed applied and adaptive research to solve problems in their respective areas, 2) identifies and endeavors to solve production constraints of crops when grown separately or in combination, 3) demonstrates the application of important concepts of crop science to better utilize farmer resources through improved cropping patterns, and 4) disseminates cultural practices for growing different field crops in rice-based cropping systems.

Agricultural engineering course (AEC). The two AEC 2-week courses, held in January and October, were attended by 24 trainees from 13 countries. Most of the participants are currently, or expect to be, associated with the manufacture and evaluation of IRRI-designed machinery.

RICE PRODUCTION COURSES

Six-month rice production training program (RPTP). A total of 37 trainees from 13 countries attended the RPTP, which began in March. The course is designed to prepare the trainees to conduct similar training programs in their home countries.

Two-week rice production courses. A total of 75 trainees from 13 countries participated in the 2-week rice production courses (August, December). The courses teach, within a short time frame, the latest technology in rice culture. The trainees perform various production operations in the field and observe rice plants at critical stages of plant growth and development.

OTHER TRAINING PROGRAMS

In addition to the formal and production-oriented courses, the Institute offered special training programs, such as those on the use of the IRRI library and documentation center, and familiarization with the operation of a research farm.

Seven individuals from six countries—Bangladesh, Germany, Indonesia, Malaysia, Thailand, and the United States of America—participated in these special programs during 1977.

A list of individuals who completed their programs in 1977, including their countries and research project areas, follows. An asterisk (*) indicates completion of the M.S. degree; two asterisks

Table 1. Participation in educational opportunities at IRRI, 1977.

Country	Training[a] (man-months)									Total
	Degree scholars		Nondegree		Postdoctoral fellows	Production courses[b] trainees				
	M.S.	Ph.D	Scholars	Fellows		GEU	RPTP	CSTP	AEC	
Bangladesh	74.0 (9)	18.0 (2)			6.5 (2)	8.0 (2)	12.0 (2)	24.0 (4)	1.0 (2)	143.5 (23)
Burma	48.0 (4)		1.0 (1)			12.0 (3)	24.0 (4)	18.0 (3)	1.0 (2)	104.0 (16)
Colombia	12.0 (1)									12.0 (1)
Egypt		6.0 (1)							0.5 (1)	6.5 (2)
England	2.0 (1)	10.0 (1)		2.5 (1)						14.5 (2)
Germany			5.0 (1)		1.0 (1)				2.0 (4)	1.0 (1)
India		36.0 (3)	40.0 (7)		111.5 (16)	12.0 (3)	12.0 (2)		0.5 (1)	178.5 (29)
Indonesia	50.5 (8)	50.0 (6)			9.0 (1)	32.0 (8)	42.0 (7)	78.0 (13)		302.0 (48)
Iran				1.5 (1)		8.0 (2)				9.5 (2)
Iraq			2.0 (1)							2.0 (1)
Japan			6.5 (1)	30.5 (4)	24.5 (6)					61.5 (11)
Korea	11.5 (2)	9.5 (2)	6.0 (1)		8.5 (1)				0.5 (1)	42.0 (7)
Liberia								6.0 (1)		4.0 (1)
Malaysia		6.0 (1)				4.0 (1)				7.0 (3)
Mali									1.0 (2)	21.5 (3)
Nepal	8.0 (1)		3.5 (1)				18.0 (3)			68.0 (14)
Netherlands					3.0 (1)	8.0 (2)	24.0 (4)	24.0 (4)	1.0 (2)	12.0 (1)
Nigeria					12.0 (1)					19.0 (2)
Pakistan			7.0 (2)				12.0 (2)			30.5 (9)
Philippines	31.5 (4)	7.0 (1)		3.0 (1)		8.0 (2)	18.0 (3)	18.0 (3)	1.5 (3)	79.5 (11)
Sierra Leone					17.0 (2)		6.0 (1)			18.0 (4)
Sri Lanka	23.5 (3)		6.0 (2)			12.0 (3)		18.0 (3)		76.0 (16)
Sudan			9.5 (3)			12.0 (3)	12.0 (2)		1.0 (2)	12.0 (2)
Taiwan	12.0 (1)						12.0 (2)			12.0 (1)
Tanzania									0.5 (1)	0.5 (1)
Thailand	77.0 (8)	29.0 (3)	19.5 (4)					42.0 (7)	1.0 (2)	208.5 (32)
USA	7.0 (1)	10.0 (2)	5.5 (2)			16.0 (4)	24.0 (4)		0.5 (1)	29.0 (7)
Venezuela	8.5 (1)						6.0 (1)			8.5 (1)
Vietnam	6.0 (1)			6.0 (1)	12.0 (1)					24.0 (2)
	371.5 (45)	181.5 (22)	111.5 (26)	43.5 (8)	205.0 (32)	132.0 (33)	222.0 (37)	228.0 (38)	12.0 (24)	1,507.0 (253)[c]

[a]Figures in parentheses denote number of participants. [b]Production courses are the 4-month Genetic Evaluation and Utilization training program, the 6-month Rice Production Training Program, the 6-month Cropping Systems Training Program, and the two 2-week Agricultural Engineering training courses. [c]A number of trainees and scholars were involved either in more than one department or in more than one kind of training. They were counted once in the total number of individuals trained during the year.

(**) denote completion of the Ph.D. degree during the year.

RESEARCH SCHOLARS

Agricultural economics

Germelino Bautista. Philippines. Factor shares and labor utilization in rice production. A study of two Pampanga barrios for the crop period 1976 wet, 1976–77 dry, and 1977 wet seasons.

Bruce Best. USA. The problem of nonrepayment of noncollateralized loans to small farmers in the Philippines.

Agricultural engineering

Kyeong Uk Kim. Korea. 1. Field tests on three transplanting systems. 2. Analytical method for kinematic analysis of the planting mechanism of a rice transplanter.

Agronomy

Francis Bolton. England. Minimum and zero tillage in lowland rice.

Harris Bernard. Sierra Leone. Chemical weed control in upland and lowland rice.

Achmad Fagi.* Indonesia. Environmental factors affecting fertilizer nitrogen efficiency in flooded tropical rice.

Honorato Jereza.* Philippines. Biological constraints to high yields in selected farmers' fields in Iloilo. Philippines.

Prasit Mongkolporn. Thailand. Studies on general soil fertility.

Evangelista Peruel.* Philippines. Testing methods for the estimation of evapotranspiration under Philippine condition.

Soemartono. Indonesia. Part I. Pulling force and its relationship with root characteristics of the rice plant in seedling stage. Part II. Study on the rice root characteristics in seedling stage.

Sadeli Suriapermana. Indonesia. Part I. Effect of different levels of nitrogen and *Azolla* sp. on growth of weeds in rice. Part II. Effect of different methods and rates of nitrogen application on weed competition in transplanted rice.

Cropping systems

Azis Azirin Asandhi.* Indonesia. The effect of topping time of corn and nitrogen on the yield of corn and rice in corn-rice intercropping.

Sitti Ningrum Machmud. Indonesia. 1. Nutrient uptake pattern of peanut and corn in monoculture and intercropping. 2. Effect of interaction within peanut, within corn and peanut on yield.

Hla Toe. Burma. Training on research procedures in the IRRI cropping systems outreach sites in the Philippines.

Irrigation and water management

Abdul Ghani. Bangladesh. Evaluation of rates of water seepage and percolation in field sites of different soil types in Bangladesh.

Kapila Goonasekere. Sri Lanka. Determination of field water use and crop use efficiency of selected crops grown in different drainage classes in the dry zone of Sri Lanka.

Le Ngoc Sen.* Vietnam. Field studies of effective rainfall for lowland rice.

Plant breeding

Panganignou Dolo. Mali. Training in general plant breeding techniques and procedures.

Rufino Dumlan. Philippines. On-site training in plant breeding.

Kehinde Elemo. Nigeria. Training in general plant breeding techniques and procedures.

Monty Patrick Jones. Sierra Leone. Comparative performance of some rice varieties to salinity.

Bambang Supribatno.* Indonesia. Effectiveness of protein per seed as a selection criterion for high-protein rice.

Rice production training and research

H. Senarath. Sri Lanka. Refresher on recent developments and techniques in rice production, research and training.

S. Subramaniam. Sri Lanka. Refresher on recent developments and techniques in rice production, research and training.

Soil microbiology

Masanori Saito. Japan. The nitrogen-fixing bacteria isolated from rice roots.

Statistics

Chantana Dumristolmark. Thailand. Analytical procedures for data from IRAEN.

S. Sitthivangkakul. Thailand. Analysis of multilocation trials.

Surapat Veerasak.* Thailand. Sampling for brown planthopper population in rice experimental fields.

RESEARCH FELLOWS

Agricultural economics

Mark Rosegrant. USA. The impact of institutionalized credit on the choice of technology,

production, income, and level of factor use for small rice farmers in the Philippines.

Cropping systems

Hans Anwarhan.** Indonesia. Effects of population density and fertilizer application on growth of corn and soybean planted as monoculture and intercrop.

Entomology

Mohammad Shamsul Alam.** Bangladesh. Varietal resistance to the brown planthopper *N. lugens* (Stal) biotype 3 insect in rice varieties.

Plant breeding

Nyat Quat Ng.** Malaysia. A biosystematic study of the Asian wild and cultivated taxa in the sativa species complex of genus *Oryza.*

Seyyed Javad Shahmoradi. Iran. Training in nursery management.

Plant pathology

Sang Won Ahn.** Korea. Evaluation of rice cultivars to blast.

Muhamed Ibrahim El-Rafaei. Egypt. Epidemiology of rice blast disease in the tropics.

Rice production training and research

Tjitropranoto Prabowo.** Indonesia. The educational effects on farmers of the pilot extension program on direct seeding of rainfed rice in Bulacan province, Philippines.

Soil microbiology

Thomas Lumpkin. USA. The effect of temperature and phosphorus on the growth of *Azolla.*

POSTDOCTORAL FELLOWS

Agricultural engineering

S. H. Mahmud. Pakistan. Work on design of a 12–14 hp power tiller.

Jose Samuel. India. Work on a series of handbooks for agricultural engineering.

Chemistry

Rangil Singh. India. Genetics of disease and insect resistance and studies on trisomics.

Yonemi Tanaka. Japan. Properties of rice protein bodies in relation to indigestible protein of cooked milled rice.

Cropping systems

Shiva Lohani. Nepal. 1. Intercropping of sorghum and mung bean at different crop densities under varying nitrogen level (in field). 2. Effect of corn of different maturity on rice in corn intercropping. 3. Effect of shading by corn on rice intercropping.

Martin Raymundo. Philippines. Field and laboratory studies of soils in relation to rice-based cropping systems. 1. Land units classification for cropping patterns. 2. Soil management studies for improved cropping patterns.

Entomology

R. C. Saxena. India. Factors affecting brown planthopper abundance.

Plant breeding

J. S. Nanda. India. General rice breeding.

G. S. Sidhu. India. Genetics of resistance to bacterial blight and brown planthopper in rice.

Plant physiology

D. B. Battacharjee. India. Pattern of development of rice roots under soil moisture stress.

Konosuke Fujita. Japan. Studies on physiological prospects for increasing yield of rice varieties.

Enrique Pacardo. Philippines. Studies on drought resistance in rice.

Soil chemistry

K. L. Sahrawat. India. Nitrogen transformations, availability and N use efficiency in rice soils.

OTHERS

Talukder Ijjat Ali. Bangladesh. One-month training in library management and operations.

Manos Gumpukul. Thailand. Training on experiment station development and management.

Joost Gwinner. Germany. Review of literature on rice growing particularly in marginal zones.

Nandang Kuswendar. Indonesia. One-month training in library operations.

Lim Kim Lu. Malaysia. General training in plant breeding, IRTP, entomology, plant pathology, and 2-week rice production course.

William Jeck Hian Wang. Malaysia. General training in agricultural engineering and 2-week rice production course.

FOUR-MONTH GEU TRAINING COURSE

Somapala Amuwala Dewage, Research Officer, Agricultural Research Station, Maha-Illuppallama, Sri Lanka

Mohammad Hossein Attar, Seed Controller, Agricultural Office, Ahwas, Iran

Rasidin Azwar, Assistant Breeder, Breeding Department, Central Research Institute for Agriculture, Cabang Padang, Indonesia

Gbey Sama Banya, Assistant Research Officer, Varietal Improvement, Rice Research Station,

Rokupr, Sierra Leone

Aan Daradjat, Researcher, Breeding Department, Central Research Institute for Agriculture, Sukamandi, West Java, Indonesia

Badrul Alam Dewan, Scientific Officer, Breeding Division, Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh

Durga Ghorai, Assistant Botanist, Central Rice Research Institute, Cuttack, Orissa, India

Noorul Haq, Research Assistant, Agricultural Research Institute, Peshawar, Pakistan

Harmel, Research Assistant, Breeding Department, Central Research Institute for Agriculture, Cabang Padang, Indonesia

Gamani Ranjit Jayaweera, Agricultural Experiment Officer, Weer-sevana, Tantinimulla, Panadur, Sri Lanka

Monty Patrick Jones, Research Assistant, Breeding Department, Rice Research Station, Rokupr, Sierra Leone

A. K. M. Mazibor Rahman Khan, Scientific Officer, Physiology Division, Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh

Shinh Kyaw, Deputy Assistant Manager, Agricultural Research Institute, Yezin, Pyinmana, Burma

Daw Kyu Kyu, Deputy Township Manager, Agricultural Corporation, Hlegu Township, Rangoon, Burma

Nyunt Maung, Deputy Township Manager, Agricultural Corporation, Tat Kon, Burma

Widhaya Pliandecha, Rice Breeder, Sanpatong Rice Experiment Station, Sanpatong, Chiang Mai, Thailand

Syahiaruddin Rahama, Research Assistant, Pathology Department, Central Research Institute for Agriculture, LPPM, Ujung Pandang, Sulawesi Selatan, Indonesia

Sampan Rattanasupa, Research Assistant, Kuan Gut Rice Experiment Station, Patthalung, Thailand

Ramawatar Sah, Assistant Entomologist, Agriculture Station, Tarhara, Sumsari, Nepal

Koesnang Saleh, Research Assistant, Pathology Department, Central Research Institute for Agriculture, LPPM, Ujung Pandang, Sulawesi Selatan, Indonesia

Chandradewa Sandanayake, Research Officer, Rice Breeding, Central Rice Breeding Station, Batalagoda, Ibbagamuwa, Sri Lanka

Rafiq Ullah Shah, Research Assistant, Agricultural Research Institute, Peshawar, Pakistan

Javad Shahmoradi, Rice Breeder, Rice Research Station, Amol, Iran

K. K. Sharma, Rice Breeder, J. N. Agricultural University, Jabalpur, India

Samlee Sophonsakulkaew, Research Assistant, Rice Division, Department of Agriculture, Bangkhen, Bangkok, Thailand

D. P. Srivastava, Senior Research Assistant, Central Rice Research Institute, Cuttack, Orissa, India

John Wood Stenhouse, Breeder, West Africa Rice Development Association, Rice Research Station, Rokupr, Sierra Leone

Suhaimi Sulaiman, Research Assistant, Breeding Department, Central Research Institute for Agriculture, Kalimantan Banjarmasin, Indonesia

Francis Jallah Sumo, Research Assistant, Central Agricultural Experimental Station, Suakoko, c/o Ministry of Agriculture, Monrovia, Liberia

Susanto Tirtowirono, Assistant Breeder, Central Research Institute for Agriculture, Bogor, Indonesia

Bharat Prasad Upadhyay, Assistant Plant Pathologist, Division of Plant Pathology, Department of Agriculture, Lalitpur, Nepal

Suparyono Wiryarija, Research Assistant, Pathology Department, Central Research Institute for Agriculture, Sukamandi, West Java, Indonesia

Jong Doo Yea, Junior Rice Breeder, Crop Experiment Station, Office of Rural Development, Suweon, Korea

Samark Yingyong, Technician, Bangkhen Rice Experiment Station, Bangkhen, Bangkok, Thailand

SIX-MONTH RICE PRODUCTION TRAINING COURSE

Nureldin A. Aamir, Seed Propagation Officer, Sudan Gezira Board, Department of Agriculture, Barakat, Sudan

Hudaja Achmad, Subject Matter Specialist, Dinas Pertanian Propinsi Jawa Barat, Department of Agriculture, Bandung, Indonesia

Adimulyono, Subject Matter Specialist, Dinas Pertanian Rakyat, Department of Agriculture, Sulawesi Selatan, Indonesia

Ghias Uddin A. Ahmed, Assistant Plant Pathologist, Rice Research Institute, Dokri, Pakistan

Muhammad Ali, Assistant Research Officer, Rice

Research Institute, Kala Shah Kaku, Pakistan

Arumugam Ariakuddy, Agricultural Instructor, Agricultural Productivity Centre, Kodikamam, Sri Lanka

H. M. Wijeratne Banda, Agricultural Instructor, Idamegama, Werallagama, Kandy, Sri Lanka

Karna Man S. Basnyat, Acting Agricultural Extension Officer, Department of Agriculture, Nepal

Birendra Nath Bose, Senior Agronomist, The Fertilizer Corporation of India, Indo-German Fertilizer Educational Project, Rabindranagar, Midnapore, West Bengal, India

Amando R. Centeno, Jr., Assistant Training Director, Bulacan Farmers' Training Center, Office of the Governor, Bulacan, Philippines

Lek Chantrakasem, Rice Breeder, Pithsanuloke Rice Experiment Station, Wang Tong, Pithsanuloke, Thailand

Montian Chinda, Rice Researcher, Rice Division, Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkok, Thailand

Mamadou A. Dembele, Institut d'Economie Rurale, Recherche Agronomique, Bamako, Mali

Panganignou Dolo, Rice Breeder, Institut d'Economie Rurale, Recherche Agronomique, Bamako, Mali

A. K. Elemo, Plant Breeder, Plant Breeding Division, National Cereals Research Institute, Ibadan, Nigeria

William N. Goldstein, 2851 Huntington Avenue, Minneapolis, Minnesota, USA

Ashim Ranjan Guha, Senior Agronomist, The Fertilizer Corporation of India, Indo-German Fertilizer Educational Project, Calcutta, West Bengal, India

U Saw Hla, Township Manager, Agricultural Corporation, Maubin, Burma

U Aung Khaing, Township Manager, Agricultural Corporation, Rangoon, Burma

Amadou Maiga, Rice Trainer, West Africa Rice Development Association, Monrovia, Liberia

Agus S. Mandala, Subject Matter Specialist, Dinas Pertanian Wilayah III, Department of Agriculture, Cirebon, West Java, Indonesia

Joseph A. Olofintoye, Research Officer, National Cereals Research Institute, Ibadan, Nigeria

Sompong Samapuksakit, Rice Researcher, Surin Rice Experiment Station, Surin, Thailand

Nelson Samosir, Subject Matter Specialist, Dinas Pertanian, Department of Agriculture, Sumatera Selatan, Palembang, Indonesia

Sheikh Md. Abdus Sattar, Scientific Officer, Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh

Ismat Ali Shah, Assistant Agronomist (Training/Farms), Rice Research Institute, Kala Shah Kaku, Pakistan

Ganga Prasad Gautam Shastree, Junior Technician, Department of Agriculture, Nepal

Sagar Prasad Shrestha, Acting Agriculture Development Officer, Department of Agriculture, Nepal

Pitamber L. Shrivastav, Assistant Agriculture Development Officer, Agriculture Development Office, Rupandehi, Bhairahawa, Nepal

U Htun Shwe, Assistant Divisional Manager, Agricultural Corporation, Magwe, Burma

Indrawati Soelaiman, Subject Matter Specialist, Dinas Pertanian/KBS Maros, Department of Agriculture, South Sulawesi, Indonesia

Herman Sumantri, Subject Matter Specialist, Dinas Pertanian Wilayah I, Department of Agriculture, Serang, West Java, Indonesia

Chand Tara, Farm Superintendent, Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh

U Hla Toe, Township Manager (Extension Service), Agricultural Corporation, Rangoon, Burma

Shobar Wiganda, Subject Matter Specialist, Department of Agriculture, c/o Diperta Prop. Dati 1, Kalsel, Banjarbaru, Indonesia

Jamroon Wongvivat, Rice Breeder, Khon Kaen Rice Experiment Station, Khon Kaen, Thailand

Mohd. Ahmed Younis, Seed Propagation Inspector, Sudan Gezira Board, Barakat, Sudan

SIX-MONTH CROPPING SYSTEMS TRAINING COURSE

Morakot Augsonsward, Agricultural Officer, Technical Division, Department of Agriculture, Bangkhen, Bangkok, Thailand

Bijuli Bahadur K. C., Junior Technician, Department of Agriculture, Harihar, Bhawan, Kathmandu, Nepal

Bahraini, Subject Matter Specialist, Department of Agriculture, Dinas Pertanian Rakyat, Sumbar, Padang, Indonesia

Rodrigo B. Bretaña, Agronomist/Assistant Provincial-in-Charge, Bureau of Plant Industry, Region VI, Iloilo City, Philippines

Kurniadhi Didi, Subject Matter Specialist, Department of Agriculture, Dinas Pertanian Rakyat, Subang, Indonesia

Mohamed Haniffa, Research Assistant, Regional Agricultural Research Station, Bandarawela, Sri Lanka

Suwan Hanviriyapant, Agriculturist, Rice Division, Department of Agriculture, Bangkok, Thailand

Md. Altaf Hossain, Scientific Officer, Bangladesh Agricultural Research Institute, Regional Agricultural Research Station, Jamalpur, Mymensingh, Bangladesh

Md. Afzal Hossain, Scientific Officer, Division of Rice Cropping Systems, Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh

Amarasena Jayalath, Research Assistant, Agricultural Research Station, Maha-Illuppallama, Sri Lanka

Supachai Kaewmeechai, Agricultural Officer, Oil Crop Project, Field Crop Division, Department of Agriculture, Bangkhen, Bangkok, Thailand

Yang-Soon Kang, Junior Researcher, Yeongnam Crop Experiment Station, Office of Rural Development, Milyang, Korea

Raj Kumar Lal Karna, Junior Technician, Department of Agriculture, Harihar, Bhawan, Kathmandu, Nepal

Shah Ahmed Ali Khan, Extension Officer, Dacca-Narayangaj-Demra Irrigation Project, Bangladesh Water Development Board, Dacca 3, Bangladesh

Jesus V. Kintana, Plant Pest Control Technologist, Bureau of Plant Industry, Digos, Davao del Sur, Philippines

U Win Kyi, Deputy Assistant General Manager, Agricultural Research Institute, Yezin, Pyinmana, Burma

Sabam Oloan Manurung, Research Assistant, Plant Physiology Division, Central Research Institute for Agriculture, Bogor, Indonesia

Ishak Noer, Seed Multiplying Division, Department of Agriculture, Dinas Pertanian Rakyat, Nusa Tenggara Barat, Mataram, Indonesia

U Aung Nyunt, Deputy Township Manager, Agricultural Corporation, Bassein (West), Burma

Posma Pangaribuan, Subject Matter Specialist, Department of Agriculture, Dinas Pertanian Rakyat, Sumatera Utara, Medan, Indonesia

Edmund Rajapaksa Pathirage, Research Assistant, Agricultural Research Station, Maha-Illuppallama, Sri Lanka

Kasidis Phanomsawarn, Plant Pathologist, Plant Pathology and Microbiology Division, Department of Agriculture, Bangkok, Thailand

Md. Abdul Quddus, Scientific Officer, Division of Rice Cropping Systems, Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh

Padma Kumar Rajbhandary, Junior Technician, Department of Agriculture, Harihar, Bhawan, Kathmandu, Nepal

Djoko Umar Said, Subject Matter Specialist, Department of Agriculture, Dinas Pertanian Propinsi, Lampung, Indonesia

Agus Setiyono, Trainer, Post-Harvest Technology Department, Central Research Institute for Agriculture, Bogor, Indonesia

Soekirno, Subject Matter Specialist, Department of Agriculture, Dinas Pertanian Rakyat, Jawa Tengah, Semarang, Indonesia

Soetardi, Subject Matter Specialist, Department of Agriculture, Dinas Pertanian Rakyat, Jawa Tengah, Indonesia

Silpachai Sojaiya, Agricultural Officer, Department of Agricultural Extension, Bangkok, Thailand

Briksha Lal Shah, Junior Technician, Department of Agriculture, Harihar, Bhawan, Kathmandu, Nepal

Hardi Suhardi, Subject Matter Specialist, Department of Agriculture, Dinas Pertanian Rakyat, Sulawesi Selatan, Indonesia

Sukamto, Research Staff, Central Research Institute for Agriculture, Bogor, Indonesia

Rachmadi Sarwo Samadijo, Subject Matter Specialist, Department of Agriculture, Dinas Pertanian Rakyat, Surabaya, Indonesia

Orlando B. Taleon, Farm Management Technologist, Bureau of Agricultural Extension, Region VI, Iloilo City, Philippines

Surasuk Tongpain, Agriculturist, Division of Agriculture and Economics, Ministry of Agriculture and Cooperatives, Bangkhen, Bangkok, Thailand

Daw Htay Htay Win, Deputy Farm Manager, Agricultural Corporation, Rangoon, Burma

Som-at Wirattigowit, Research Assistant, KU-IDRC Project, Department of Agricultural Economics, Kasetsart University, Bangkok, Thailand

Yafizham, Subject Matter Specialist, Department of Agriculture, Dinas Pertanian Rakyat, Sumatera Utara, Medan, Indonesia

TWO-WEEK AGRICULTURAL ENGINEERING COURSE

31 January–11 February 1977

Hamid Ayub, IRRI-Pakistan Agricultural Machinery Program, Rawalpindi, Pakistan

Poong-Ki Baek, Agricultural Engineer, Farm Machinery Division, Institute of Agricultural Engineering and Utilization, Office of Rural Development, Suweon, Korea

Aung Chit, # 1 Base Workshop, Agricultural Mechanization Department, Rangoon, Burma

Subrata Kisor Das, Assistant Engineer, Westinghouse Saxby Farmer Ltd., Entally, Calcutta, India

Jagdish Chander Dutt, Proprietor, Union Tractor Workshop, Mayapuri, New Delhi, India

Gaber Ismail Abou Elkasim, Works Assistant Director, Behera Company, Alexandria, Egypt

Ronald Llewellyn Hatch, Works Manager, Agro Tecnica Limited, Colombo, Sri Lanka

Thein Ngwe, Plant Manager No. 3, Heavy Industries Corporation, Sinderprome, Burma

Mozammel Reaz, Operative Director, Ittefaq Industrial Corporation, Tejgaon Industrial Area, Dacca, Bangladesh

Kiran Man Singh, Agricultural Engineer, Agricultural Development Bank, Kathmandu, Nepal

Ayob bin Sukra, Head, Agricultural Engineering, Water Management and Central Workshop Branch, Malaysian Agricultural Research and Development Institute, Serdang, Selangor, Malaysia

Chalermchai Suksri, Technical Staff, Agricultural Engineering Division, Department of Agriculture, Ministry of Agriculture and Cooperatives, Bangkhen, Bangkok, Thailand

3–14 October 1977

Om Prakash Agrawal, Chief Technical Advisor, Central Auto Engineering Works, Koteswar, Kathmandu, Nepal

Mohammed Ayub, Bengal Agricultural Implements, Bangshi Bazar, Dacca, Bangladesh

Ram Bansal, Agricultural Engineer, International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India

Fazal Haque. Roomi Industries, Mian Channu, Pakistan

Shahid Hayat, Sarhad Engineering Company, Mardan, Pakistan

Kermet Moh, Georgia Institute of Technology, Atlanta, Georgia, USA

Budi Pangarso, National Institute for Instrumentation, Indonesian Institute of Science, Bandung, Indonesia

George Pillainayagam, Farm Machinery Research Centre, Department of Agriculture, Maha-Illuppallama, Sri Lanka

P. V. Raghava Rao, Krishi Engines Ltd., Sanatnagar, Hyderabad, India

Abdul Majid Salleh, Standards and Industrial Research Institute of Malaysia, Shah Alam, Selangor, Malaysia

Juma Omar Suleiman, Ministry of Agriculture, Zanzibar, Tanzania

Chaiwat Takulchai, Chaiwat Panich, Chachengsoa, Thailand

International activities

GENERAL SERVICES

Conferences, workshops, and a symposium were held at IRRI to facilitate the exchange of information and to develop plans for cooperative work.

Rice blast workshop, 21–23 February. Twenty-six scientists from seven countries met to discuss the current status of the rice blast disease and to formulate new strategies for breeding resistant cultivars.

Workshop on interfaces between agriculture, nutrition, and food science, 28 February–3 March. In joint sponsorship with the United Nations University (Tokyo), IRRI organized the workshop that sought to identify major nutritional problems in East and Southeast Asia. A total of 39 nutritionists, food scientists, and agriculturists from 9 countries met and discussed mechanisms for interaction of inputs to solve nutritional problems in Asia.

Workshop-seminar on agricultural extension and rice development, 14–23 March. The World Bank and IRRI jointly sponsored the workshop-seminar designed to focus on improved ways of increasing agricultural production through exchange of information on field performance, exposure to the latest rice culture practices and multiple cropping technology, and development of ways of removing production constraints through research extension. The workshop-seminar was attended by 55 scientists and extension workers from 14 countries.

Workshop on village-level studies, 17–18 March. The 29 socioeconomic scientists from 4 nations who attended the workshop discussed focal points for village-level studies, recent research procedures and findings at IRRI and other institutions, and the concept of a research network for village or community studies in Asia.

International rice research conference, 18–22 April. Rainfed lowland rice was the major topic of the Institute's largest annual conference, which was attended by 139 scientists working in 33 nations.

Workshop on international cooperative project on national rice programs, 15–18 August. The need for an international cooperative research project on national rice programs was assessed and evaluated by the 25 economists from 6 nations who attended the workshop. Projections of the rice supply and demand for the Philippines, Indonesia, and Thailand, and the methodology for research were also discussed.

Soils and rice symposium, 20–23 September. Soil scientists working on rice soils in the tropics exchanged information on and discussed wetland rice soils and their effect on rice production. The 91 scientists from 21 nations attended the symposium.

International workshop on the manufacture and use of IRRI agricultural machinery, 2–5 November. The workshop was organized to bring together the country cooperators and manufacturers of IRRI-developed farm machinery to discuss constraints to the acceptance of this adaptive technology, to review new machinery designs being developed at IRRI, and to compare and evaluate respective country experiences in the implementation of agricultural mechanization policies. It was attended by 37 participants from 17 countries.

Rice genetic conservation workshop, 12–15 December. The workshop on rice genetic conservation followed the dedication ceremonies for the Rice Genetic Resources Laboratory at IRRI. A total of 59 scientists from 19 countries developed a plan for a global network for germplasm collection.

The scientists discussed the status of germplasm collection in Asia and West Africa, identified geographic areas where the need to collect rice germplasm of threatened varieties was critical, and discussed a collaborative plan for field collection with the participation of international research centers.

OUTREACH SERVICES

The efforts of IRRI scientists based in rice-growing nations and working with local scientists in national programs are an essential and highly important part of the Institute's cooperative activities. A summary report of the research programs in which IRRI scientists participated follows.

Bangladesh. The cropping systems agronomist participated in and supported activities of the Cropping Systems Division of the Bangladesh Rice

Research Institute (BRRI). BRRI hosted a meeting of the working group for the Asian cropping systems network. The group noted the intensity of cropping in Bangladesh in the dry season despite the lack of rain for 4 months. Work was begun to organize a national workshop on cropping systems in February 1978 to plan the establishment of a cropping systems network within Bangladesh with all of the agricultural institutes, universities, and private groups.

Four sites were selected for cropping systems work in the BRRI project area: Bhogra, Salna, Jarumbari, and Laskarchala. Supportive component technology studies were done at the main station at Joydebpur, at other BRRI substations, and at a Bangladesh Agricultural Development Corporation (BADC) development estate within the BRRI project area. A suitable methodology was developed to describe the physical, biological, and socioeconomic factors that influenced the existing cropping systems at the four sites selected for study. Economic returns from most of the mixed cropping combinations, especially the wheat and pulse combinations, appeared to be higher than those from monocropping. Twelve cropping patterns tested at the Joydebpur station revealed that all crops performed well, but the actual selection of crop combinations will depend upon the physical environment selected.

In varietal selections done on upland rice, peanut, soybean, and chick-pea, the variety C-22 was the only upland rice that gave better yields than the local Hashikalmi. Hashikalmi, however, matured 26 days earlier. Two peanut varieties found to be superior to the local variety are being extensively multiplied on BADC farms.

From the several soybean yield trials conducted in the dry and postmonsoon seasons, 15 varieties were identified as suitable for further testing. Several hectares of these soybean varieties are being grown in farmers' fields to produce seeds to plant about 21 ha in the Laskarchala area during the dry season. Additionally, 15 varieties of chickpea were selected for further testing.

The rice production specialist worked in the BRRI extension and training division, which implements training programs, prepares publications, and plans and tests adaptive research methodology. Two sessions of a new 4-month rice production course were completed by 35 participants. The first class included only extension workers from the Bangladesh Department of Agriculture; the second included participants from other agencies. All those who took the training will serve as rice production specialists responsible for giving on-the-job technical training and assistance to village extension workers.

Duplicated pest management trials in farmers' fields confirmed the newly recommended "as and when needed" use of insecticides in comparison with preventive applications. Simple varietal observational plots in each nearby union were found to be an effective means of acquainting farmers with newly released varieties and with optimum management practices. Results from 50 seed production plots (0.15 ha) testing BRRI's newest photoperiod-sensitive variety BR-4 confirmed the practicality of farmer-to-farmer distribution of seeds of new rice varieties.

In a cooperative study with the BRRI Cropping Systems Division, the use of relay establishment of a deepwater rice crop in a winter rice stand in low areas made possible two rice crops where winter irrigation was available.

The rice breeder continued work on the development of modern deepwater rices with elongation capability, high yield potential, and resistance to pests. Immediately after the construction of the deepwater rice tank facility was completed about mid-July, materials for screening for elongation ability were planted. The facility permits the evaluation of a moderately large volume of breeding materials for submergence tolerance and for elongation ability at defined and controlled rates of flooding.

Of the 7,500 entries screened for the ability to survive a 5-cm/day rise in the water level, starting at 33 days after planting, to a depth of 110 cm, 1,670 entries survived. Most of the native deepwater rice varieties exhibited good elongation ability. From among the hybrid progenies, a large percentage of the lines from BR-222 (a cross between Habiganj Aman 1 and TKM 6) elongated as well as or generally better than T 442-57, a commonly used check with moderate elongation ability in shallow-flood conditions.

Several F_3 lines were grown in tidal submergence conditions. Likewise small populations of early generation progenies were tested in direct-seeded, rainfed conditions in order to advance larger vol-

umes of early segregating generations, thereby minimizing time and resources. This procedure allows the handling of large numbers of early generation progenies and the simultaneous selection for plant type, disease and insect resistance, drought tolerance, and photoperiod sensitivity. Thus, plant selections could then be screened for elongation ability the following season.

Among the 126 entries planted in shallow-flood and medium-flood situations at the Habiganj deepwater paddy substations, 10 survived the 2-m water level in the medium-flood conditions. In the shallow-flood situation (93 cm was the maximum water depth), several BR lines with good disease resistance, satisfactory maturity time, and reasonable yield levels appeared promising.

Land development at Joydebpur was completed and a permanent irrigation system was being constructed. The prototype diaphragm pump developed by BRRI engineers was further improved. Initial tests of the IRRI-designed power tiller indicate it may be too light for the dry, heavy clay soils when the first crop is planted at the Joydebpur Station. One portable axial flow thresher was found satisfactory. Arrangements were completed for the local fabrication of a second portable thresher from plans and specifications supplied by IRRI to a local manufacturer.

An agronomist-soil scientist who joined the program in late October will encourage collaborative work among scientists of the Physiology, Soil Chemistry, and Agronomy Divisions at BRRI to identify the causes of low rice yields and to develop practices to improve yields.

BRRI and IRRI cosponsored a 5-day international seminar on photoperiod-sensitive transplanted rice during 24–28 October. The seminar focused on the urgent need to plan, organize, and carry out research to develop improved photoperiod-sensitive rice varieties.

India. The considerable cooperation achieved in 1977 was reflected in the interaction of research scientists, exchange of seeds and provision of materials, and field and nursery trials for screening rices.

The Indian Council on Agricultural Research (ICAR) invited IRRI's cooperation in a Government of India-IRRI survey of rice production problems in the states of Bihar, Orissa, and West Bengal in Eastern India. Over a long period, the average rice production in this area of India has not responded to the new technologies available. A team of 5 IRRI scientists made site visits over a 3-week period. The survey report and recommendations were well received by ICAR and the states involved. Three pilot projects, based on the recommendations in the report, are being planned.

IRRI received from the Central Rice Research Institute the final installment of the valuable Assam rice collection of 2,896 varieties from northeastern India. It also received 2,815 samples from the collection at Chinsurah. Similarly, IRRI sent seed materials from its germplasm bank to many research centers in India.

In India there is a wide range of agroclimatic testing sites and problem areas for rice with serious problems of adaptation. In 1977, 120 International Rice Testing Program (IRTP) trials were conducted at 41 sites. Two IRTP monitoring tours of Indian stations took place in 1977: the deepwater rice tour in August and the tour of eastern India in October.

Collaborative arrangements between the Agricultural Engineering Department of the G. B. Pant Agricultural University, Pantnagar, and IRRI involve work at the Indian university to modify the axial flow thresher, multihopper paddy seeder, and paddy husk furnace for local conditions. Arrangements between the Suri Research Foundation, New Delhi, and IRRI provide for the Foundation to supervise the introduction of IRRI machines into India to encourage local manufacturers to make machines, and to test the final products. Several small firms have produced prototypes from IRRI blueprints that have passed Suri's critical tests; one version of the power tiller passed a test by the Government Agricultural Tractor Testing Unit at Budhni, Madhya Pradesh. The locally produced power tiller and threshers on display at the Agri Expo 1977 in Delhi attracted much attention.

Indonesia. Indonesia made significant progress toward strengthening the scientific capability in rice and rice-based cropping systems research during the year.

Excellent progress was made in the improvement of staff qualifications. The overall training program is on schedule. As of 1977, 12 individuals had completed their Ph.D. programs and another 9 were working toward the degree; 16 had obtained the M.S. and another 12 were working toward it. In addition, 29 individuals completed

the 6-month rice production training course at IRRI, 58 participated in various cropping systems training programs, and 29 completed the IRRI 4-month Genetic Evaluation and Utilization (GEU) training program. Moreover, 21 others received specialized training in various fields at IRRI, e.g., operations and maintenance of a research farm, operation of a library and documentation center in support of researchers, and others.

The development of rice varieties resistant to the brown planthopper (BPH) and the virus diseases it transmits continued to be the major focus in the plant breeding efforts. In addition, programs for the development of varieties suited for rainfed areas and tidal swamps were established. Intermediate height, photoperiod-sensitive breeding lines that can elongate when grown in deep water were evaluated. Observational nurseries were grown in organic and acid sulfate soils to identify rices tolerant of such substrate conditions. Breeding efforts to develop rices with resistance to rice blast were intensified in view of the problems encountered in establishing acceptable rice-based cropping patterns for upland transmigration areas.

Three cold-tolerant varieties developed in Indonesia were released for growing at high elevation. Two early maturing varieties for direct-seeding (gogo rancah) production were released. The gogo rancah method allows farmers to plant rice much earlier than if they wait for adequate water for puddling fields and transplanting in the traditional manner. Early seeding also allows the rice crop to escape flood damage.

Field evaluations of promising lines with resistance to BPH and gall midge revealed some lines with resistance to BPH biotype 2 and to the grassy stunt virus. Several of these lines will be increased during the 1977–78 wet season.

Regular monthly meetings helped to improve coordination and collaboration among the GEU scientists at Bogor and Sukamandi. Distance, however, precluded the regular participation of scientists at Maros and other locations in the GEU meetings; these scientists are furnished assistance as needed.

The cropping systems research methodology developed in the initial sites at Lampung, Sumatra, and at Indramayu, West Java, expanded into additional sites in South Sumatra, East Java, Central Java, and South Kalimantan. The study in Lampung is directed toward evaluating management techniques for upland rice-based cropping systems suitable for transmigration areas with red-yellow podzolic (Orthoxic Tropudults) soils. Cropping patterns were designed and evaluated to avoid flooding during the wet season and drought during the dry season in the Indramayu area. The methods by which secondary crops use residual moisture during the dry season, direct seeding of rice early in the rainy season, and reduction of tillage and shortening of the turnaround time for a second rice crop were studied.

The ragged stunt virus occurred in April in the Sukamandi research station, and subsequently in West, Central, and East Java, Bali, and in North and West Aceh in Sumatra. Transmission experiments confirmed the BPH *Nilaparvata lugens* as the vector of this newly identified rice disease.

A tungro virus distribution map for South Sulawesi, showing the endemic and epidemic areas, was prepared. The green leafhopper (GLH) population increased abruptly about 2 to 3 months after planting in both the wet and dry seasons and tungro increased concomitantly with the GLH population.

In South Sulawesi an experiment on yield loss caused by bacterial leaf blight (BLB) showed that 100 kg N/ha did not affect the incidence of BLB in the resistant rice varieties IR34 and Pelita I-1, but aggravated it in the susceptible variety C4-63.

A 2-year study on insect phenology in South Sulawesi was concluded. Rice insects, excluding the rice seedbug, can reduce by 30% the yield of such varieties as Pelita I/1, C4-63, IR5, IR20, IR26, SPR 726-76-2-3, and B 462c-Pn-3-1-3. Infestation by early feeders (up to 4 weeks after transplanting) such as *Hydrellia philippina, Cnaphalocrosis medinalis, Nymphula stagnalis, Spodoptera* species, and grasshoppers can reduce yields by 5 to 10%.

Field surveys showed that such BPH-resistant rices as IR26, IR28, IR30, and IR34 were completely destroyed in Aceh, North Sumatra, East Java, and Bali probably because of the appearance of a new BPH biotype.

All soil types at 18 of 28 sites in South Sulawesi responded to the addition of sulfur (S). Apparently, the agrochemicals applied in the region did not supply adequate S to the soil. Ammonium sulfate, gypsum, and elemental S were found to be equally

effective as sources of S for lowland rice. Yield increased with 80 kg S/ha; however, 10 to 20 kg S/ha appeared sufficient to support a normal crop of IR30 rice. Varietal reaction to different levels of S differed in a trial with 51 entries.

The 230-ha area at the Sukamandi research center was increased to 430 ha and a topographical map for the entire research farm was completed. Four alternative designs for the development of the area into an experimental farm were prepared. Other progress made on land development during the year included the construction of 2 km of farm roads, leveling of 30 ha, provision of irrigation to 40 ha, and building or improvement of drains or both

A consultant (agricultural engineer) did a 2-month feasibility study for an expanded industrial extension program to introduce on a wider scale the use and local manufacture of IRRI-designed agricultural machinery for small-scale rice farmers.

A new Office of Information and Training was established by the Central Research Institute for Agriculture (CRIA) in Bogor, Java. The office will be responsible for printing, distributing CRIA publications, developing visual aids for training, conducting training programs for CRIA and extension personnel, maintaining liaison with extension services, and developing a library. It is headed by a recently returned Indonesian scientist who completed an IRRI-UPLB (University of the Philippines at Los Baños) Ph.D. degree program.

Pakistan. The IRRI-Pakistan cooperative program has two components: 1) an agricultural machinery project and 2) an applied rice research project. The applied research project began in May 1977 with the arrival in Pakistan of an IRRI rice production specialist.

Applied research trials (58) were conducted in the major rice-producing districts of Punjab province to test the important variables that influence rice yields. Nine different types of trials were conducted: variety, herbicide, insecticide, fertilizer response, levels of management, direct seeding, spacing, insecticide placement, and nitrogen placement. The efficiency of both the insecticide Furadan and the nitrogen source urea, when incorporated into dry soil immediately before flooding, was markedly enhanced.

IRRI-designed agricultural machinery is being introduced in Pakistan through the agricultural machinery project. Some design modifications were needed to adapt IRRI-designed machines developed for wetland rice production to the farming conditions in Pakistan.

The testing and adaptation of the two multicrop (for rice and wheat) threshers were the major program activities during the year. Manufacturers showed interest in producing these threshers. Some machines are expected to be marketed commercially during the first rice-harvesting season in 1978.

The design of a low-cost portable axial flow paddy thresher developed at IRRI was modified to improve threshing of Pakistan's tall traditional paddy varieties. The modified machine can successfully thresh wheat and other small grain crops. The wheat-threshing model can cut the straw into small pieces to make *bhoosa* for animal feed. The machine is relatively lightweight and is mounted on two wheels for easy transport.

The project on testing and development of low-cost manual and animal-drawn transplanters focuses on the introduction of a five-row manually operated and a seven-row bullock-drawn transplanter.

Farm surveys and personal discussions were held with many farmers and manufacturers to gain a better understanding of the economics of use and production of threshers and transplanters and to develop design specifications for demand-oriented machines on which the program should concentrate. Field demonstrations were held at many locations in the country and publications were distributed. The publications provided a general description of program activities and achievements in machinery design and development, industrial extension, manufacturing development, and mechanization.

Philippines. For the fifth year, an IRRI crop production specialist worked cooperatively with the Government of the Philippines in its national rice program.

During 1977 the Philippines continued to maintain its self-reliance in rice, first attained in late 1975 under the Masagana 99 national rice production program. By the year's end, some 100,000 metric tons of milled rice equivalent were available for export, still leaving a 90-day buffer stock over expected consumption. About 39,000 tons of rice were exported in 1977.

In late 1976 (end of the wet season) more than 50,000 ha of IR26 rice in Mindanao were affected by brown planthopper, mainly biotype 2; the new rice virus disease ragged stunt also appeared in that region. However, a rapid shift to IR36 and IR32 varieties during 1977 and an emergency insecticide schedule, combined with favorable weather for rice growth, increased hectarage under irrigation, and increased use of recommended Masagana 99 technology, resulted in an abundant rice crop in 1977.

During mid-1977, it was recommended that in zinc-deficient areas, of which the Philippines has about 500,000 ha, rice seedlings be dipped in a 2% aqueous solution of zinc oxide. In 436 farms surveyed in 20 provinces, the dip treatment resulted in an average yield increase of 0.8 t/ha.

Soil incorporation of granular carbofuran before transplanting effectively controlled all insects for up to 50 days after transplanting. Thus, the Philippine Bureau of Agricultural Extension prepared and distributed 500 microkits (for 0.01 ha) to Masagana 99 rice extension technologists to verify the suitability of the new crop protection method on irrigated rice farms.

The Philippines named two IRRI-developed rice lines as official varieties during 1977. IR2070-414-3-9 was named IR40. IR2071-586-5-6-3 was named IR42; this variety is a sister line of IR36, the most widely grown rice in the Philippines during 1977.

Sri Lanka. The Department of Agriculture of Sri Lanka and IRRI have cooperated in rice production research since 1970. A new cooperative project was initiated in 1977. The primary focus is on strengthening the research capability for rice research, with particular reference to the development of high yielding rices and rice-based cropping systems suited to the range of environmental and socioeconomic conditions prevailing in Sri Lanka. The three components of the cooperative project are 1) a multidisciplinary program for rice varietal improvement, 2) a rice-based cropping systems component, and 3) a program for adaptive research for the evaluation of technology at the farm level.

The cropping systems component is aimed at the organization and development of applied research trials to intensify land use through rice-based cropping patterns. The emphasis is on the dry zone of Sri Lanka where village tank systems are most prevalent and critical to ensure successful crop production. The rice breeding program is designed to develop and implement a multidisciplinary approach to the development of rice varieties. A rice working group was established; it holds regular meetings to evaluate and plan varietal improvement activities. The adaptive research component focuses on problem-solving field experimentation oriented toward farmer adoption of useful technology. A testing program to solve certain specific or local rice production problems and to meet national needs is being planned.

Three IRRI scientists joined the project — a cropping systems agronomist, a rice breeder, and a crop production specialist-team leader.

Thailand. Collaborative programs in Thailand in 1977 involved deepwater rice research, small-farm machinery, water management, rice production constraints, soil fertilizer network, and microbiology research. A Rockefeller Foundation staff member continued to serve as the Institute's representative and leader of the deepwater rice research program; an IRRI core staff member devoted full time to deepwater rice breeding, and an agricultural engineer worked with the Thai Government on small-farm machinery.

A water management research project was begun in cooperation with the Royal Irrigation Department to assess the effectiveness of different irrigation schemes and to train Thai government irrigation personnel in new research techniques.

The Agro-Economic Network site was moved from Suphanburi to Singburi to assess yield constraints in a different area of the Central Plain. Inadequate fertilizer, high water levels in the field in the wet season, and use of traditional tall, photoperiod-sensitive varieties appear to be the major factors limiting rice yields.

The collaborative deepwater rice program identified new experimental lines showing greater fertilizer response than traditional tall varieties when grown in 1-m water depths. One or more of these lines may be released as recommended varieties early in 1978. Better screening techniques are being developed for studying rice plant tolerance for submergence in deepwater tanks. Varieties transplanted when 21 days old and submerged for 1 week in 114 cm of water 20 days after transplanting differed markedly in tolerance for submergence.

The agricultural machinery program provided

numerous machinery fabrication shops, especially those in the major rice-producing regions, with consultative services, blueprints of newly designed machinery, and demonstrations. Most of the requests were for assistance on the axial flow thresher. Thai government agricultural engineers, IRRI personnel stationed in Thailand, and an agricultural engineer from IRRI conducted a 1-week training course in the Thai language.

A collaborative rainfed rice experiment was conducted at the Chumpae Rice Experiment Station in northeast Thailand. In severe drought conditions, the three top yielders were Thai varieties and experimental lines. In irrigated conditions in an adjacent field, two IRRI lines were among the top yielding rices. The 10 top yielders in both experiments included 5 Thai entries but no IRRI entry.

Collaborative work on microbial fixation of nitrogen in paddy fields continued for the second year. A Thai researcher serves as a member of the advisory board.

Information resources and experimental farm

LIBRARY AND DOCUMENTATION CENTER

Bibliographies. The 1976 Supplement to the *International Bibliography of Rice Research,* prepared in 1977, contains 4,712 references to scientific rice literature. The coverage is worldwide and includes references to scientific literature in 24 languages, classified according to subject matter. Author and keyword indexes are included. This 470-page publication includes 15 rice literature translations, mostly from Japanese to English.

The 1971–1975 cumulative index was also published in 1977. This 232-page comprehensive guide to world rice literature is divided into three sections – author, subject, and geographic indexes.

The 1975 Supplement to the *International Bibliography on Cropping Systems* includes references to worldwide published and unpublished technical works produced in 1975. It deals with all aspects of cropping systems involving food crops. The entries in this 300-page supplement are classified according to subject; author and keyword indexes are also provided.

The 1977 Supplement to *Theses and Dissertations on Rice Available in the Library of the International Rice Research Institute* lists 72 additional titles. The total number in the collection is now 686.

The bibliographies were distributed to agricultural libraries and documentation centers of rice-producing regions, for the use of rice research workers.

The monthly *Library List of Acquisitions* continued to be widely circulated.

Reference and circulation. Among the numerous requests for information and photocopying services received, requests for Japanese literature on genetics and breeding exceeded those for all other aspects of rice culture. The requests for short subject-specific bibliographies increased. The Library's assistance in library organization and management and in the selection and acquisition of agricultural literature was also sought. Requests for such assistance came mostly from Bangladesh, Thailand, Indonesia, and Malaysia.

The number of books and journals and other library materials borrowed within the Institute increased markedly during 1977.

Library holdings. The addition of 3,101 monographs (books, pamphlets, and reprints) increased the total number in the monographic collection to 46,039. The 131 serial titles added during 1977 were received through subscription, exchanges, and gifts and donations. Maps, translations, and microfilms were also added to the collection.

Other library activities. The Library continued to circulate tables of contents of newly received journals to scientists within the Institute, and to the Bangladesh Rice Research Institute; the Lembaga Penelitian Pertanian Maros in Indonesia; the Central Research Institute for Agriculture, Sukamandi Branch, Indonesia; IRRI, Sri Lanka; and the West Africa Rice Development Association in Liberia.

The Library continued to purchase and distribute books to the Institute's research scholars and trainees.

The librarian of the Central Research Institute for Agriculture, Sukamandi Branch, Indonesia, and the librarian of the Bangladesh Rice Research Institute received 1-month training in agricultural librarianship at IRRI.

OFFICE OF INFORMATION SERVICES

Information services to support IRRI research and training, and communications activities to put research results into the hands of potential users increased in 1977.

IRRI publications include two regular news series, a research series, technical bulletins and books, and brochures and leaflets about the Institute's program and progress.

Series publications. The *IRRI Reporter,* a quarterly newsletter, was distributed to more than 11,000 rice scientists, extension workers and others interested in the activities and achievements of the Institute. *The International Rice Research Newsletter (IRRN),* a bimonthly report on rice-

related research throughout the world, went to more than 8,000 readers.

Analysis of a random sample from 8,000 cards from *IRRN* subscribers revealed that 80% are in developing nations and more than 70% are in Asia. The research areas of highest interest to *IRRN* readers are pest management and control genetic evaluation and utilization (GEU), and soil and crop management. This was reflected in the articles published in *IRRN* during 1977 – 42% on pest management and control, 41% on GEU, and 15% on soil and crop management.

Nine issues of the *IRRI Research Paper Series (IRPS)* were published and distributed globally: 1) Biological nitrogen fixation in paddy field studies by in situ acetylene-reduction assays, 2) Transmission of rice tungro virus at various temperatures: a transitory virus-vector interaction, 3) Physicochemical properties of submerged soils in relation to fertility, 4) Screening rice for tolerance to mineral stresses, 5) Multi-site tests environments and breeding strategies for new rice technology, 6) Behavior of minor elements in paddy soils, 7) Zinc deficiency in rice: a review of research at the International Rice Research Institute, 8) Genetic and sociologic aspects of rice breeding in India, and 9) Utilization of the *Azolla-Anabaena* complex as a nitrogen fertilizer for rice.

Major publications. Major publications during the year were:

- *Annual Report for 1977*
- *Research Highlights for 1977*
- *Proceedings of the Symposium on Climate and Rice*
- *Proceedings of the Workshop on Deep-water Rice*
- *Statistical Procedures for Agricultural Research, with Emphasis on Rice*
- *Constraints to High Yields on Asian Rice Farms: an Interim Report*
- *Training Manual for Rice Production*, a revision of the 1970 manual.

Publications in preparation were:

- *Cropping Systems Research and Development for the Asian Rice Farmer*
- *Economic Consequences of New Rice Technology*
- *Irrigation Policy and Management in Southeast Asia*
- *Rice Blast*
- *Interfaces Between Agriculture, Nutrition, and Food Science*
- *Brown Planthopper*
- *Soils and Rice*
- *International Farm Machinery*
- *Rice Genetic Conservation*
- *Interpretive Analysis of Selected Papers from Changes in Rice Farming in Selected Areas of Asia*
- *Rice Improvement*
- *Rice: Soils, Water, Land*
- *Anatomy of a Peasant Economy: A Rice Village in the Philippines*
- *A Farmer's Primer on Growing Rice*

General information material. A brochure on the facilities and functions of the Rice Genetic Resources Laboratory was published to coincide with the December 1977 dedication of the building. Three thousand copies were printed to serve researchers whose work relates to the world rice germplasm collection.

Field Problems of Tropical Rice continued to be the most frequently requested IRRI publication. A set of 35-mm slides of the 92 color plates in the booklet remained popular and 65 sets were distributed worldwide.

Research and training support. A project to prepare a series of slides-cassette tape self-instructional units for the Office of Rice Production, Training and Research continued. A *Rice Morphology* unit was completed; it included 71 color slides, a cassette tape, and an accompanying booklet of script and visuals. Twenty other units, including *Stem borers of Rice, Economic Analyses of Experimental Data, Principles of Experimental Design*, and *Bacterial Blight of Rice*, were in different stages of scripting and visualization.

A research project on rice breeding in Asia continued with analysis of a survey of plant breeders and their records on hybridization of rice. The results are reported in the GEU section on Rice Breeding in Asia of this report.

Visitors. More than 11,500 people visited IRRI in 1977. The visitors included government cabinet members, members of the diplomatic corps, representatives of donor agencies, scientists, development workers and educators, news media representatives, farmers, students, and tourists from more than 40 nations around the world. Students and tourists constituted about 63% of the visitors,

and farmers about 12%. Rice scientists from throughout the world constituted about 10% of all the visitors; many spent several days for an in-depth look at IRRI research and training.

EXPERIMENTAL FARM

Land development in the lowland farm is almost complete. About 97% of the farm has been developed. Approximately 44 ha have been planted, and a first crop of rice was harvested on some plots. The underground irrigation system and two deep wells are in operation. Three water reservoirs were completed.

In the upland farm, all roads have been built. Two deep wells and two water reservoirs were completed and are in full operation. About 110 ha were prepared for planting.

The Experimental Farm continued supporting the research departments by supplying labor needs and attending to land preparation, planting, weeding, pest management (including application of herbicides and insecticides), and harvesting. About 138 ha of the lowland rice area were prepared in 1977. The fertilizers used were ammonium sulfate, urea, solophos, and muriate of potash.

The largest expenditure was for land preparation, using both hand tractors and carabaos, followed by that for bird boys. Over 144 tons of dried rice was handled by the Experimental Farm, and this included foundation, registered, and certified seed.

Publication and seminars

PUBLICATIONS

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SEMINARS

The following seminars were held at IRRI during 1977. Unless otherwise stated, the speakers were staff members.

Productivity growth in Asian agriculture – 1948 to 1975. Dr. R. E. Evenson, ADC (Agricultural Development Center) associate, Institute of Agricultural Development and Administration, University of the Philippines at Los Baños.

The effect of climatic fluctuations on rice production in Thailand. Dr. Hiroshi Tsujii, Center for Southeast Asia, Kyoto, Japan.

Secrets of the monarch butterfly. Dr. J. Seiber, visiting scientist, Pesticide Residue Analysis Laboratory, Chemistry Department, IRRI.

Mechanized rice in two Americas. Dr. D. S. Mikkelsen, visiting scientist, Agronomy Department, IRRI.

Development communication and the IRRI scientist. Dr. Nora C. Quebral, professor, Department of Development Communication, University of the Philippines at Los Baños.

The importance of soil microorganisms in crop production. Dr. Albert D. Rovira, chief research scientist, Division of Soils, Commonwealth Scientific and Industrial Research Organization, Adelaide, Australia.

Soil organic matter and soil formation in paddy field. Dr. Hidenori Wada, associate professor of Soil Science, Tokyo University, Japan.

Care and feeding of editors. Prof. R. L. Disney, visiting associate editor, Office of Information Services, IRRI.

Thoughts of a visiting agricultural engineer. Dr. Clarence W. Backhop, head, Agricultural Engineering Department, Iowa State University, USA.

The philosophy and strategy of agricultural engineering research. Mr. Charles James Moss, director of Research Station, National Institute of Agricultural Engineering, Wrest Park, Silsoe, Bedford, England.

Legume breeding in Indonesia. Dr. R. D. Freed, visiting scientist, Plant Breeding Department, IRRI.

Visualizing agricultural research. Mr. Don L. Esslinger, visiting associate editor, Office of Information Services, IRRI.

Development of a pest management in rice – present status and future prospects. Dr. R. S. Rejesus, visiting scientist, Entomology Department, IRRI.

A review of factors in irrigated rice production system design. Dr. Jaw-Kai Wang, professor of agricultural engineering, University of Hawaii, Honolulu, USA.

Wheat protein genetics and breeding for improved nutritional quality. Dr. Cal Qualset, University of California, Davis, USA.

Energy and agriculture. Dr. Wesley W. Gunkel, visiting agricultural engineer, Agricultural Engineering Department, IRRI.

Wildlife conservation in the Philippines today. Dr. D. S. Rabor, College of Forestry, University of the Philippines at Los Baños.

Communication constraints we face. Mr. W. G. Rockwood.

Rice improvement in Burma. Dr. Pedro Escuro, plant breeder, ARI/UNDP, Yezin, Burma.

Cassava research program at the International Center of Tropical Agriculture (CIAT), Colombia. Dr. James H. Cock, physiologist and leader of the CIAT Cassava Production Systems Program, Colombia.

Peanut harvesting mechanization in the US. Mr. John A. McMennamy.

Plant pathology research at Sukamandi. Dr. Louis T. Palmer, IRRI team leader, Sukamandi, Indonesia.

Viking project and landing on Mars. Dr. Gerald A. Soffen, Viking Project scientist, National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia, USA.

Women and cancer. Dr. Takahito Sonoda, participant and speaker, Third Asian Cancer Conference, Philippine International Convention Center, Manila.

Computers and ARC (Agricultural Resource Center). Dr. N. T. Ison, director, Agricultural Resource Center, Inc., University of the Philippines at Los Baños.

Residual nutrient effects and their evaluation. Dr. J. S. Russell, Commonwealth Scientific and Industrial Research Organization, the Cunningham Laboratory, Brisbane, Australia.

Recent advances in chemical application techniques. Dr. Graham A. Matthews, Imperial College Field Station, Silwood Park, United Kingdom.

China in May, too early for lychees and too late for apples. Mrs. I. Zandstra and Mrs. P. Broadbent, Staff Housing, IRRI.

Extraction of ancestral components of natural polyploids and its implication in modern plant breeding. Dr. Khushnood Siddique, principal scientific officer and head, Division of Plant Genetics, Atomic Energy Research Center, Tandojam, Sind, Pakistan.

CIMMYT's experience in China. Mr. Haldore Hanson, director general, International Maize and Wheat Improvement Center, Mexico.

Salt tolerance of rice. Dr. C. A. Bower, visiting scientist, Soil Chemistry Department, IRRI.

The US national agricultural pesticide impact assessment program, Dr. Arthur A. Muka, professor of entomology, Cornell University, Ithaca, New York, USA.

The production, processing, and marketing of natural rubber. Dr. C. Barlow, visiting scientist, Agricultural Economics Department, IRRI.

The Philippine forest resources: their importance tc the socioeconomic development of the country. Mr. M. J. Williamson, project manager, United Nations Development Programme Forest Project, University of the Philippines at Los Baños.

Tomato production, diseases, and variety development. Dr. J. Pat Crill, plant pathologist, Peto-Seed Company, Woodland, California, USA.

Finances

The Institute received cash grants amounting to $14,225,668 in 1977.

The Ford Foundation gave $496,810, of which $300,000 was for core operations and capital expenditures. The balance supported rice research and development programs of

- Sri Lanka – $15,000 for the project on modernization of rice processing and distribution;
- Pakistan – $111,562 as part of a 2-year grant to assist the Agricultural Research Council, Pakistan, in research and training related to rice and agricultural mechanization; and
- Thailand – $70,248 as part of a 2-year grant to the Government of Thailand's Royal Irrigation Department for support of water management research and training in northeast Thailand.

The Rockefeller Foundation contributed $310,000, which covered $300,000 for core operations and capital needs and $10,000 toward the publication of the proceedings of the workshop on *Interfaces between Agriculture, Nutrition, and Food Science.*

The United States Agency for International Development (USAID) released a total of $3,500,809 to IRRI. This included

- $3,000,000 for core operations;
- $339,214 for industrial extension of small-scale agricultural equipment developed at IRRI;
- $25,369 for expanding, strengthening, and further institutionalizing the National Applied Research and Extension Program for Transplanted Rice; and
- $12,500 for a 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 $959,701 plus Rp479,111,405 managed by USAID in Djakarta. In 1977 USAID released $107,904 of those funds to IRRI.

USAID contributed $15,822 to IRRI's training program by supporting scholars and trainees from countries where USAID has active programs.

The Ministry of Overseas Development, United Kingdom, gave $780,000 toward the support of IRRI's core program.

The International Development Research Centre (IDRC), Canada, granted IRRI $1,012,003. Of that, $680,276 was part of a 2-year funding of cropping systems research in the Philippines. The IDRC contribution also included

- $120,373 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;
- $2,739 for the operational support of two consultants to advise IRRI on the rice soils of Asia;
- $73,181 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;
- $53,433 as part of a 4-year grant to enable the University of the Philippines at Los Baños to conduct varietal screening for corn, sorghum, mung bean, eggplant, tomato, and sweet potato;
- $74,001 as part of a 4-year grant to support a multiple cropping research project at the Bangladesh Rice Research Institute; and
- $8,000 for a supplemental grant to publish the second volume of *Changes in Rice Farming in Selected Areas of Asia.*

The Japanese Government gave $1,800,000 in 1977 for the construction of a Rice Genetic Resources Laboratory and for the direct and indirect expenses of the Institute's Plant Physiology Department.

The procurement of equipment for the Rice Genetic Resources Laboratory was facilitated by a $500,000 grant from the Asian Development Bank.

The International Development Association gave $1,175,000 toward core operations and capital expenditures of the Institute.

The Federal Republic of Germany gave $593,646, of which $427,121 was for core opera-

tions, $60,000 to support the 1977 Soils and Rice Symposium, and $106,525 for the Institute's training program.

The Australian Government gave $682,261 in 1977. Of that, $572,371 was for core operations including travel of Australian scientists, and $109,890 for expansion of technical assistance and collaborative relationships with the Bangladesh Rice Research Institute.

The Canadian International Development Agency gave $1,037,850 toward core operations and $192,825 toward a cooperative program for research and development between the Bangladesh Rice Research Institute and IRRI.

The Government of Iran gave $250,000 for the core program.

The Ministry of Agriculture and Water, Saudi Arabia, gave $125,000 for the core program.

The United Nations Environment Programme gave $70,000 for research for developing rice varieties with low pesticide and fertilizer requirements.

The Government of Belgium gave $148,677 for the core program.

The Government of Sweden gave $56,830 for the core program.

The Government of Denmark gave $50,748 for the core program.

The Government of New Zealand gave $25,000 for the core program.

The Government of Indonesia, using a World Bank loan, released $441,985 to IRRI as part of a 7-year contract for development of research facilities and for scientific and technical assistance to rice research at the Sukamandi Branch of the Central Research Institute for Agriculture.

The Netherlands Government gave $67,395 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 $536,210 as part of a 5-year grant for the International Rice Testing Program; $242,603 as part of a 5-year contract to investigate nitrogen fixation in association with lowland rice; $50,000 for a regional rice training program; and $4,000 for travel of officials from Laos, Fiji, and Vietnam.

The US National Institutes of Health reimbursed $762 on a 5-year contract to study ways of increasing protein and essential amino acids in the rice grain through plant breeding.

The International Board for Plant Genetic Resources gave $8,100 to support a Rice Advisory Committee meeting 12–16 December 1977.

Other donors, the areas they supported, and the amounts contributed are:

- National Food and Agriculture Council, training government extension technicians $13,514
- Philippine Council for Agriculture and Resources Research, cooperative applied research on rainfed rice 29,951
- Boots Company, weed control . . 1,000
- Chesterfolk Park Research Station, rice research 2,000
- Chevron Chemicals, support of entomology program 993
- Stauffer Chemical Company, weed control 3,000
- Potash Institute of North America and International Potash Institute, soil fertility 4,957
- FMC International S. A., pesticide research 2,000
- Montedison, rice research 2,982
- Shell Chemicals Company, research grant to IRRI 6,757

Staff changes

January

Dr. Frank W. Sheppard, Jr., joined the Institute as research systems analyst/IRRI representative at the BRRI/IRRI Project in Bangladesh.

Dr. Sadiquil I. Bhuiyan from the Engineering University in Dacca, Bangladesh, joined IRRI as associate agricultural engineer at the Department of Irrigation and Water Management.

February

Dr. Richard A. Morris, statistician/IRRI representative in Indonesia, transferred to IRRI headquarters at Los Baños, Philippines, as agronomist in the Multiple Cropping Department.

Atty. Zosimo Q. Pizarro, senior administrative associate, returned from study leave at Case Western Reserve University in Cleveland, Ohio, USA.

March

Dr. Soon Jai Park resigned as plant breeder in Sukamandi, West Java, Indonesia.

Mr. Augusto P. Corpuz joined the Institute's staff as manager of the Buildings and Properties Department.

May

Mr. Vernon E. Ross rejoined the Institute as rice production specialist with the outreach project in Pakistan.

June

Dr. Manuel J. Rosero, formerly of the International Center for Tropical Agriculture (CIAT) located in Cali, Colombia, South America, joined IRRI as liaison scientist for Latin America and is headquartered at CIAT.

Mr. Fred E. Nichols resigned as associate agricultural engineer in the Bangladesh project.

Mr. Richard L. Disney completed his 1-year sabbatic leave as visiting associate editor in the Office of Information Services (OIS) and returned to his professorship in the Department of Journalism and Mass Communication at Iowa State University, Ames, USA.

Mr. Angelito O. del Mundo resigned as assistant to the director general.

Dr. Thomas R. Hargrove, associate editor in the OIS, returned from studies for the Ph.D. degree in Agricultural Education at Iowa State University.

Dr. Alan C. Early joined IRRI as associate agricultural engineer at the Department of Irrigation and Water Management.

Dr. Duane S. Mikkelsen completed his 1-year sabbatic leave in the Department of Agronomy as visiting scientist and returned to his post as professor of agronomy in the Department of Agronomy and Range Science at the College of Agriculture and Environmental Sciences, University of California, Davis (CAES/UC, Davis).

July

Mr. Donald L. Esslinger completed his 1-year sabbatic leave with the OIS as visiting associate editor and returned to his post of information specialist at the University of Missouri, Columbia, USA.

Dr. V. Arnold Dyck, associate entomologist in the Department of Entomology, returned from a study leave at the UC, Berkeley.

Dr. J. Ritchie Cowan, plant scientist seconded by Oregon State University to IRRI, transferred to the Institute's Indonesian project as liaison scientist based in Bogor, Java, Indonesia.

Dr. Harold E. Kauffman, plant pathologist in the International Rice Testing Program, returned from study leave at Pennsylvania State University.

Dr. D. S. Athwal resigned as deputy director general.

Dr. Russell D. Freed, associate plant breeder, transferred to the IRRI project in Sri Lanka.

Dr. Richard L. Tinsley, visiting scientist in the Multiple Cropping Department, joined the IRRI project in Sri Lanka as associate agronomist.

Dr. Yujiro Hayami of the Tokyo Metropolitan University began a 2-month assignment as visiting economist at the Department of Agricultural Economics.

August

Dr. Ramesh C. Saxena joined IRRI as visiting associate entomologist at the Department of Entomology on the IRRI/International Center on Insect Physiology and Ecology (ICIPE) Collabora-

tive Project.

Dr. H. David Catling resigned as project leader cum entomologist from the IRRI/BRRI Collaborative Project in Bangladesh.

Dr. A. A. App, project director of Cell Physiology and Virology of the Boyce Thompson Institute for Plant Research (Ithaca, New York, USA), began a 1-year sabbatic leave as visiting scientist at the Department of Soil Microbiology.

Dr. Floyd H. Nordland, assistant dean of the School of Science at Purdue University (Lafayette, Indiana, USA), began a 1-year sabbatic leave as visiting communications specialist at the OIS.

Mr. Everett L. Metcalf, publications editor at the Editorial Department in Washington State University (Pullman, USA), began a 1-year sabbatic leave as visiting editor at the OIS.

Dr. Wesley W. Gunkel, completed a 1-year sabbatic leave as visiting scientist at the Department of Agricultural Engineering and returned to his professorship at the Department of Agricultural Engineering at Cornell University (Ithaca, New York, USA).

September

Mr. Ildefonso L. Guinoo joined IRRI as assistant to the director general.

Dr. H. W. Scharpenseel of the University of Hamburg (Germany) began a 6-month sabbatic leave as visiting scientist at the Department of Soil Chemistry.

Mr. Marvin D. Davis joined IRRI as crop production specialist/team leader of the IRRI project in Sri Lanka.

Dr. C. J. Moss, former director of the National Institute of Agricultural Engineering in the United Kingdom, joined IRRI as agricultural engineer and head of the Department of Agricultural Engineering.

Dr. James N. Seiber, associate professor in the Department of Environmental Toxicology at CAES/US, Davis, completed a 1-year sabbatic leave at the Department of Entomology.

December

Dr. J. S. Nanda of the G. B. Pant University of Agriculture and Technology (India) began his assignment as visiting plant breeder at the Department of Plant Breeding.

Mr. James E. Wimberly resigned as rice processing engineer from the IRRI project in Sri Lanka.

Crop weather

The climatic environment at IRRI in 1977 was less than ideal for the requirements of crops under rainfed conditions.

The solar radiation values for June, August, October, November, and December 1977 were much higher than the 1966–76 values for those months (Table 1, Fig. 1). The solar radiation values for 3 other months were similar to the 11-year averages. On the average, solar radiation was higher than in 1976, but it was lower in February, June, July, and September.

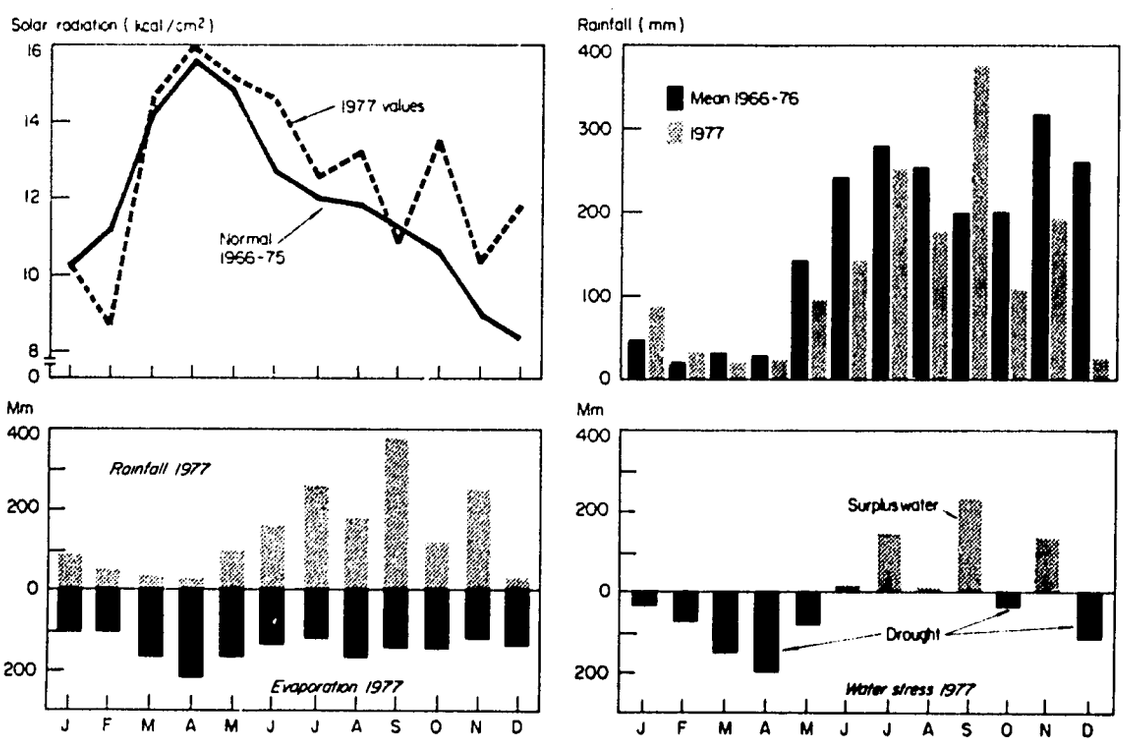
The total rainfall in 1977 was 485 mm lower than the 11-year average of 2,040 mm. The rainfall of May, June, August, October, and December was lower than the average. The extreme dryness in December caused considerable drought damage to second rice crops in rainfed rice-growing areas. A typhoon in November accounted for the high rainfall average for that month.

Bright sunshine duration was lower in January, February, May, September, and November than the 11-year average; it was higher during the other 7 months.

Evaporation values were similar to the 11-year averages. Evaporation was lower than the average in January, February, June, July, and November, but higher during the rest of the year. Overall, evaporation was lower in 1977 than in 1976.

When rainfall was compared with evaporation, water stress was readily discernible during January through May and maximum in April. Drought stress occurred again in October, after the rainy season, and in December.

In June, the water surplus was meager. The rainfall was inadequate to offset the depleted soil moisture conditions and recharge the aquifers. The water surplus for July and August was barely adequate to compensate for the water lost during the previous period. A major water deficit occurred in December.



Characteristics of crop climate at IRRI, 1977.

Table 1. The climatic environment at IRRI: 1977 and 1976 totals and 11-year (1966–76) averages.

Month	Total for 1 year	Solar radiation (g·cal/cm²)	Rainfall (mm)	Sunshine duration (h)	Evaporation (mm)	Air temperature[a] (°C)		Relative[c] humidity (%)
						Max.	Min.	
January	1977	10,112	81.8	161.2	105.8	31.1	25.0	87
	1966–76[b]	10,161	49.9	180.9	120.8	28.4	22.8	81
	1976	8,174	43.7	135.1	99.6	26.1	22.8	84
February	1977	8,689	33.4	109.9	106.1	28.7	24.6	84
	1966–76[b]	11,589	13.9	203.8	121.4	28.9	22.8	80
	1976	9,992	9.2	211.1	199.9	26.7	22.2	80
March	1977	14,580	16.2	264.5	175.6	31.2	25.2	80
	1966–76[b]	14,426	32.7	229.9	166.6	29.4	22.8	78
	1976	12,663	30.7	255.1	200.6	29.4	22.8	79
April	1977	16,561	16.7	291.6	219.7	32.6	24.5	73
	1966–76[b]	15,943	27.5	282.4	190.1	31.7	24.4	85
	1976	15,477	54.9	262.5	233.9	31.7	23.3	76
May	1977	15,267	93.0	255.1	178.1	29.8	22.8	71
	1966–76[b]	14,832	141.8	272.2	173.8	32.8	25.0	80
	1976	13,297	849.6	172.3	169.1	30.6	23.9	82
June	1977	14,268	145.5	224.6	140.2	31.6	23.3	77
	1966–76[b]	12,607	224.8	177.3	143.5	32.2	25.0	80
	1976	14,349	371.0	191.7	146.1	32.2	25.6	78
July	1977	12,513	249.6	182.5	113.5	29.8	23.8	74
	1966–76[b]	11,974	278.2	155.5	129.9	30.6	25.6	80
	1976	15,055	86.1	190.3	149.8	32.8	26.1	82
August	1977	13,170	175.7	209.8	168.0	29.4	22.7	81
	1966–76[b]	11,881	247.2	146.0	129.4	31.1	25.0	83
	1976	11,683	303.3	127.5	132.5	33.9	27.8	88
September	1977	10,778	371.7	117.1	145.5	28.1	23.3	78
	1966–76[b]	10,884	204.8	136.4	128.9	31.1	25.0	84
	1976	11,676	224.3	134.4	118.6	32.8	26.7	83
October	1977	13,600	109.8	220.4	147.6	27.2	21.1	82
	1966–76[b]	10,484	248.3	160.5	112.5	30.0	24.4	83
	1976	12,302	128.8	149.2	121.5	33.3	26.7	84
November	1977	10,195	239.9	150.6	117.1	26.8	21.8	78
	1966–76[b]	8,904	314.9	156.3	120.0	30.0	25.0	81
	1976	8,774	143.5	118.8	147.8	31.1	25.6	86
December	1977	11,606	21.1	207.2	124.6	24.6	17.8	79
	1966–76[b]	8,358	258.0	136.5	97.9	28.9	23.9	81
	1976	8,537	203.4	117.9	116.8	29.4	25.6	90

[a]The values in this column are means, not totals. [b]Total for 1 year, averaged over 11 years.

The average maximum temperature between January and April was higher than the 11-year average for that period, but was lower for the remainder of the year. The maximum temperatures from May to the end of the year, in general, were lower than in 1976, but those from January to April were higher.

Generally, January is the coolest month of the year, and the minimum temperature increases from February through December. In 1977, however, the minimum temperature in January was higher than normal (25° versus 22.8°C). A downward trend followed and the minimum temperature during the second half of the year fell below the 11-year average.

The 1977 relative humidity from January to March was higher than the 11-year average, but that in the 9 other months was lower.

Of the seven tropical cyclones that reached the Philippines in 1977, four crossed major areas. Typhoon Elang (16–19 July) crossed the Bicol region of southern Luzon, and Central Luzon; typhoon Luming (31 August–3 September), the southern provinces of northern Luzon; typhoon Openg (14–23 September), northern Luzon also; and typhoon Unding (10–17 November), Central Luzon.

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Genetic evaluation and utilization (GEU) program

Control and management of the pests

Irrigation and water management

Soil and crop management

Climate, environment and its influence

Postharvest technology and management

Consumers on the yields

Consequences of the technology

Cropping systems program

Machinery development and testing