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Research Highlights

THE INTERNATIONAL RICE RESEARCH INSTITUTE

Research Highlights for 1977

THE INTERNATIONAL RICE RESEARCH INSTITUTE
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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.

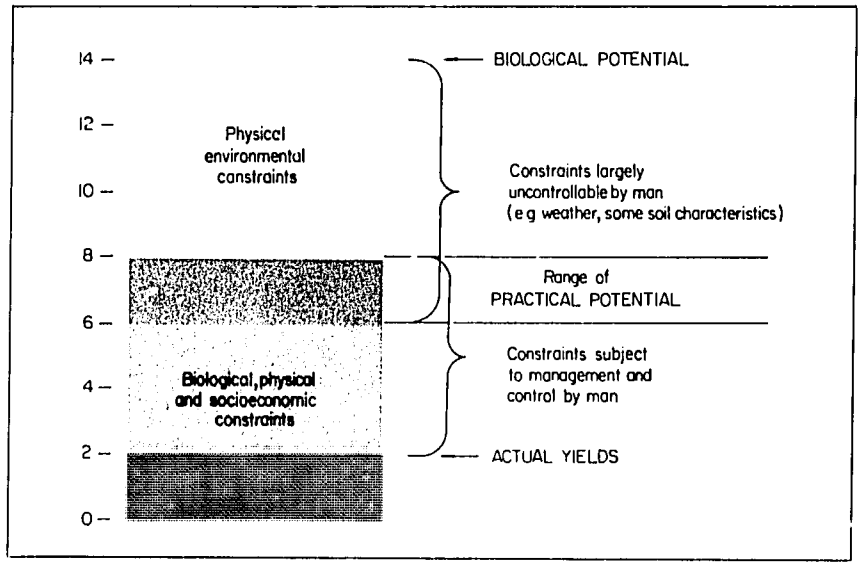
Rice scientists have the responsibility of identifying reasons for the wide yield gap and of ascertaining means of reducing it. Research shows three primary factors to be responsible for this wide yield gap.

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 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.

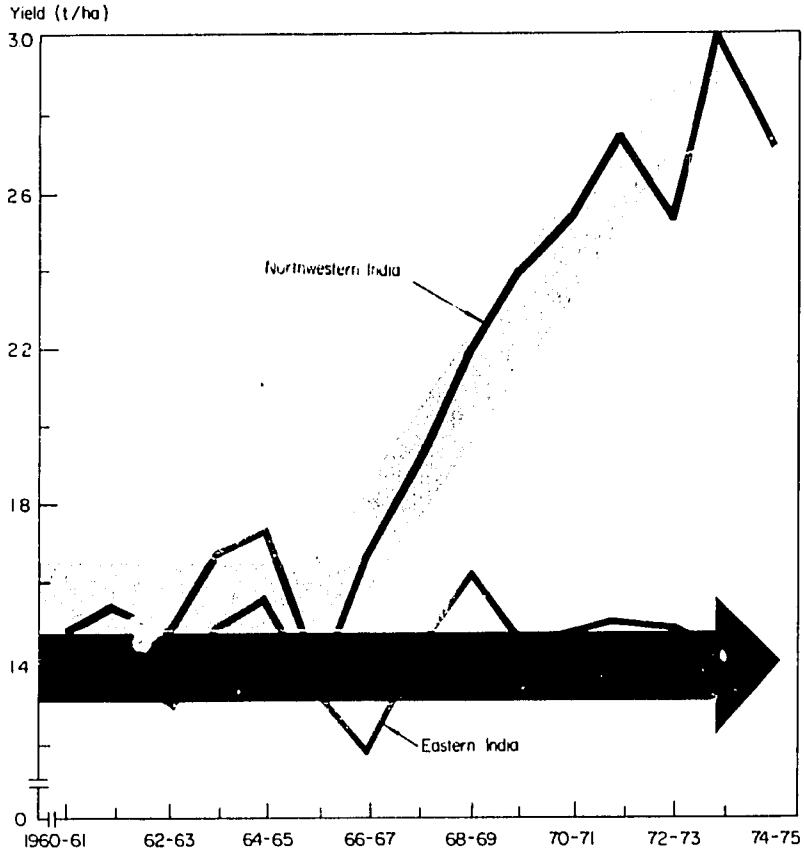
The ***third*** gap-producing factors are the socioeconomic constraints



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.

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



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.

northwestern India where appropriate technology is available and is used by farmers.

IRRI researchers are playing a vital role in identifying the socio-economic 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 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

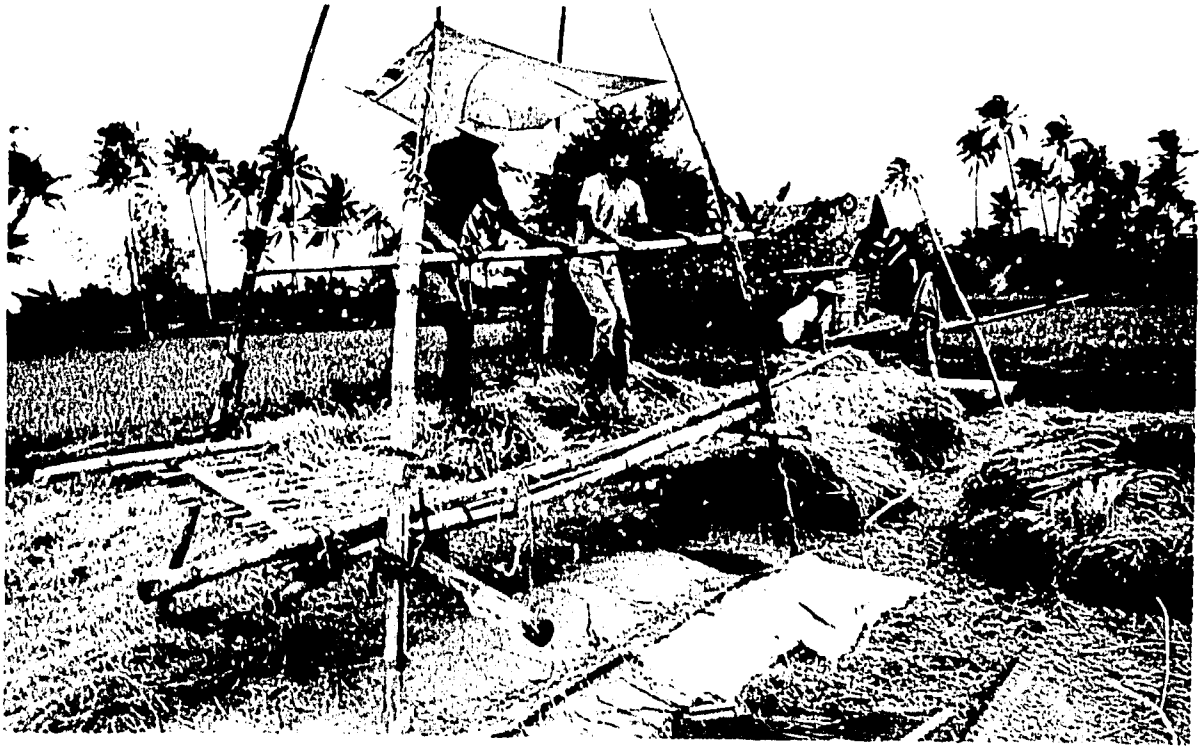
National rice production levels for 1977 in Asia were variable but generally good. Drought struck some countries of Southeast Asia and parts of China, and lowered production levels. Brown planthopper and other pests also took their toll. But production in India, Korea, and the Philippines was at record 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 *international* 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.



The Asian rice farmer seeks less risk and more income from any new rice technology.

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.

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 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:

- 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:

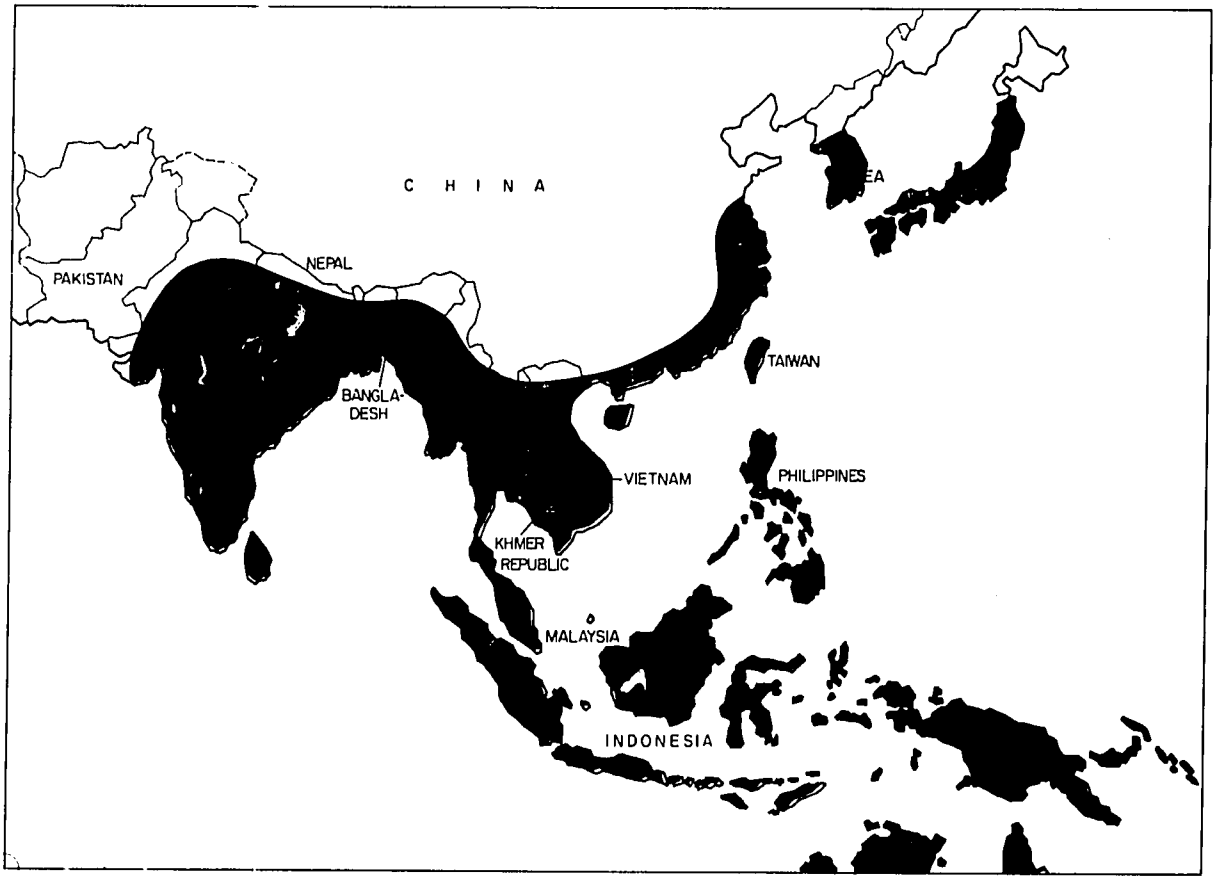
- Drought resistance studies in Indonesia and Thailand;
- High temperature tolerance work in India, Iran, and Pakistan;
- Cold tolerance work in Korea and the Philippines;
- Deep-water tolerance research in Bangladesh, India, and Thailand;
- Acid sulfate soils study in Indonesia, Malaysia, and Thailand;
- 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

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.



Small water bugs (Microvelia *sp.) seen here eating a brown planthopper were subject of an IRRI research on predators during 1977. The bugs prey on brown planthoppers that fall into the paddy water, or on small brown planthopper nymphs that feed on the lower part of the rice plant.*

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 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.

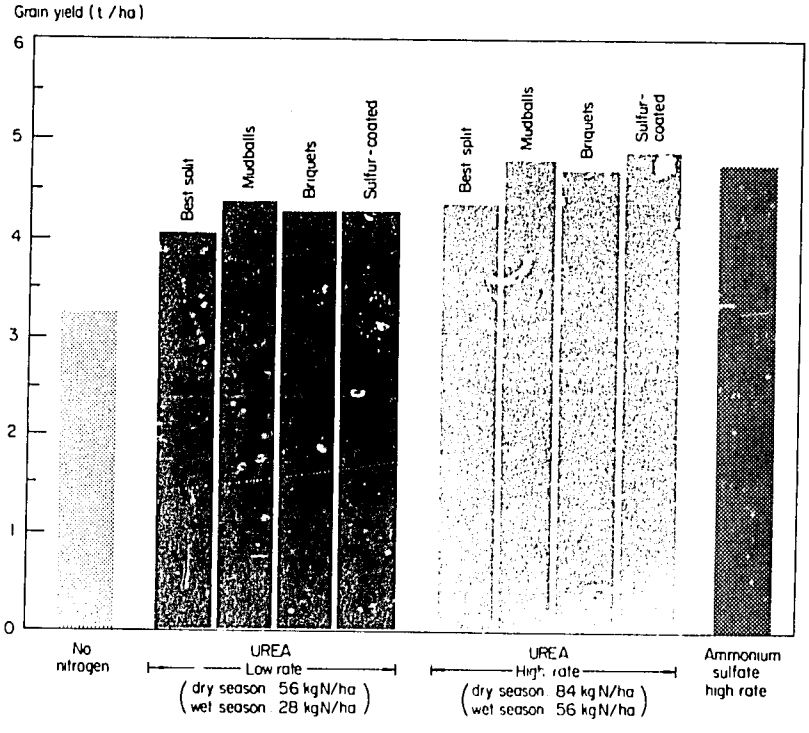
Innovative GEU approaches

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.

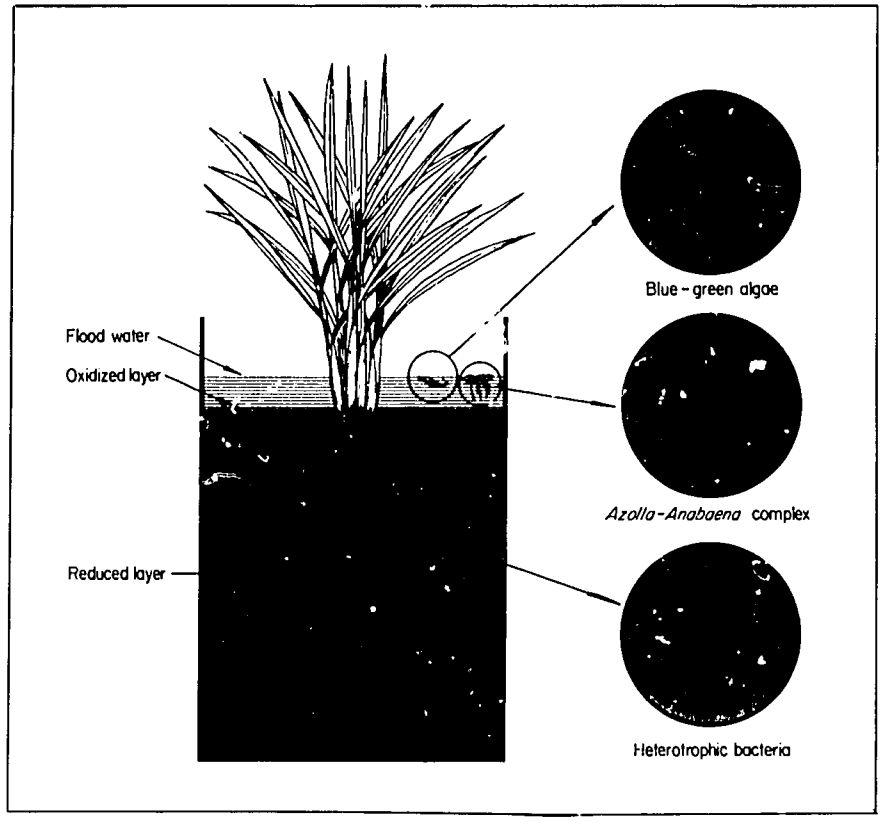
We invited plant breeders from nine major rice-growing countries to come to IRRI to evaluate breeding materials in our nurseries and gave them seeds of materials they selected. We also intensified our efforts to ascertain the gene source of resistance to diseases and other pests and of tolerance for 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).



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 yields 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.

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 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

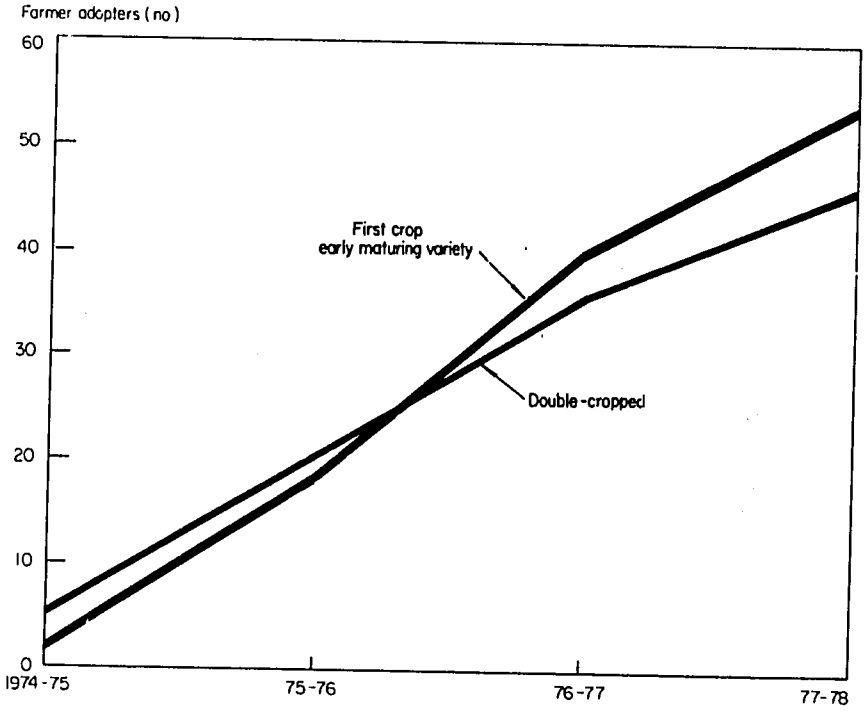
needs. Figure 6 illustrates the rapid adoption of early maturing rices and the practice of double-cropping in Iloilo province, Philippines.

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.

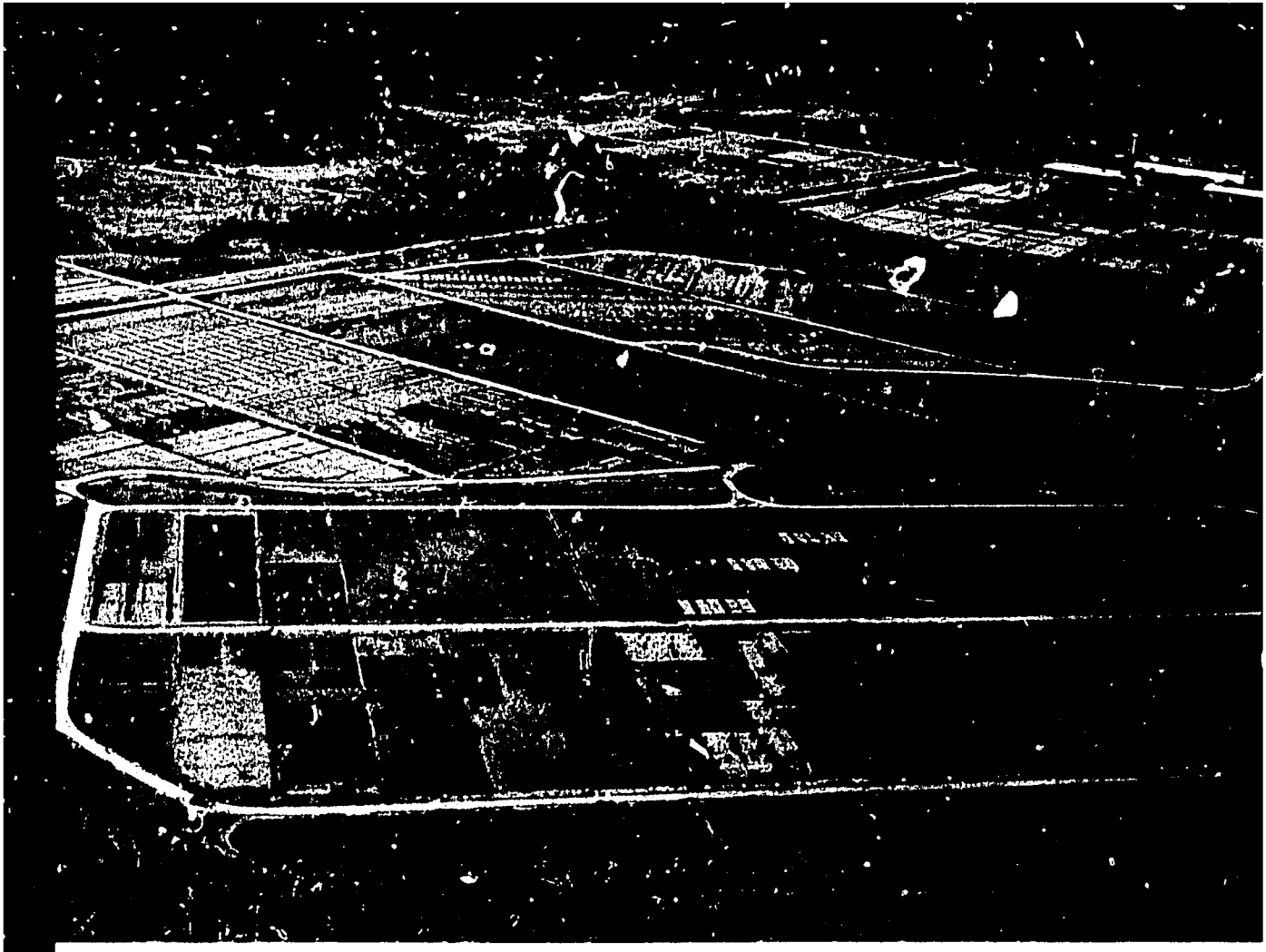
The availability and, in turn, the cost of labor often dictate the farmers' willingness to adopt new cropping systems. We found labor rates at harvest time to be 3 to 4 times those common during the early growing season. Such high labor costs could discourage farmers from adopting cropping patterns that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

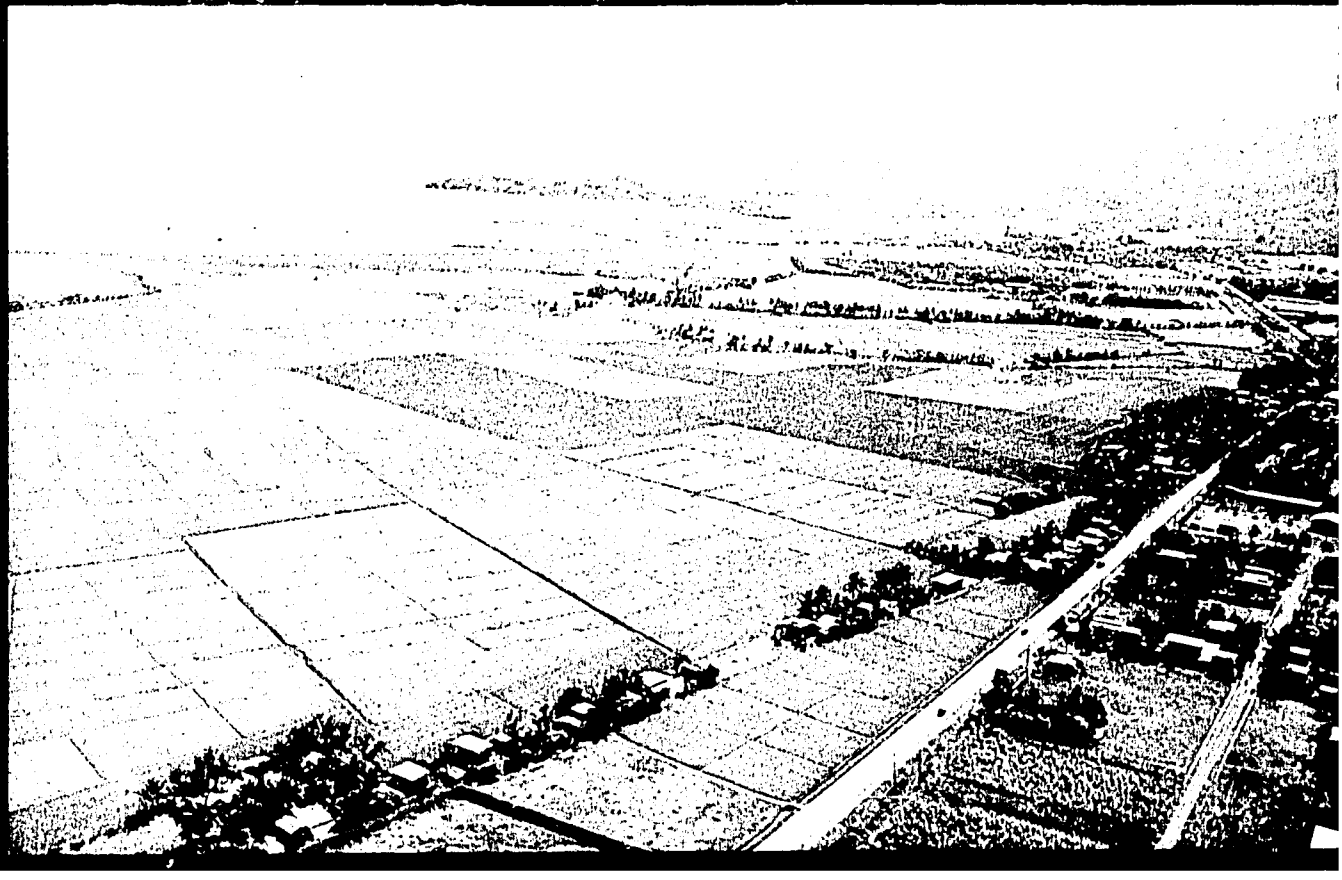
Focus on low-income people

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.



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.





Major research results

Genetic evaluation and utilization

The development of improved rice varieties has the potential to increase yields for Asia's rice farmer faster than any other scientific endeavor. To tap that potential, teams of IRRI scientists in our Genetic Evaluation and Utilization (GEU) program worked throughout 1977 to

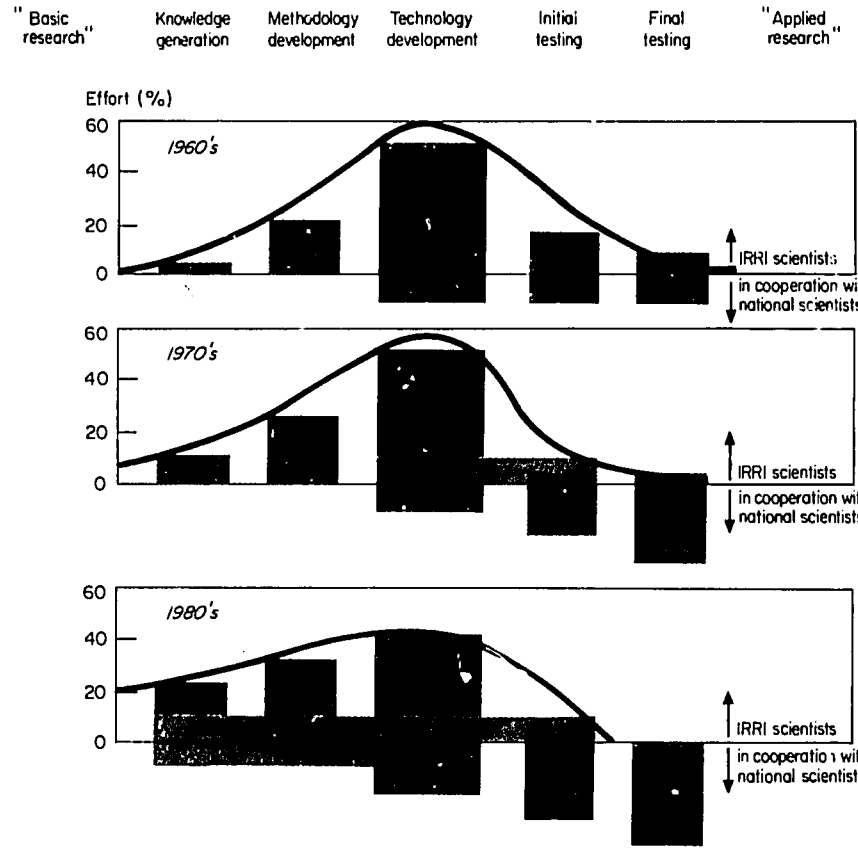
- collect and conserve valuable rice germplasm from throughout Asia. Nearly 37,000 accessions were in our germplasm bank at the end of 1977;
- generate knowledge and design methods to effectively use the genetic variability in rice. Refinement and testing of a *rapid generation advance* technique for breeding day-length-sensitive rices may cut 3 years off the delivery time to farmers;
- expand distribution of early generation (F_2 and F_3) progeny to permit selection of new rice varieties under a wide range of environments;
- develop superior genotypes of rice. IR42, named in the Philippines in 1977, has superior yields on a wide range of soil fertility and currently resists attack by all major diseases and insects;
- systematically distribute improved germplasm for use around the world. Nearly 50,000 seed packets were sent out in 1977; and
- train a cadre of dedicated scientists to work in national and provincial centers to use the improved germplasm and modify it for practical use by rice farmers.

Since IRRI research started in the 1960's the concentration has shifted solidly from work at the IRRI level to collaborative research with national rice improvement and extension programs (Fig. 1).

INTEGRATED APPROACH

The IRRI research effort has contributed greatly to increased rice production in the irrigated areas of the tropics. But tall, traditional rice varieties still predominate in the lowland areas where farmers depend on rainfall – a total area that accounts for 30% of the world's rice land, or about 50% of the rice area of South and Southeast Asia.

Our GEU plant breeders reorganized their work in 1977 to permit sharper focus on improvement of rainfed lowland rice. We already



1. The concentration of IRRI's core research efforts has shifted away from final testing and field-applied research since the 1960's. Note the establishment of cooperative research programs and heavy shift of technology development and testing to national programs projected for the 1980's.

have several improved lines, with relatively long growth duration and intermediate to tall stature, for rainfed lowland areas where only one crop is feasible. Hopefully, farmers in the major rainfed-rice areas will find the plant type, growth duration, eating quality, and disease and insect resistance of IR3464-75-1-1, IR3351-38-3-1, and IR4570-83-3-3 acceptable. Table 1 lists the important characteristics of 10 lines selected as promising during 1977.

IRRI lines named

Two IRRI lines were named as varieties in national programs. That makes a total of 62 IRRI lines named as varieties, 51 of which were released by national programs. IRRI had named 11 varieties directly when we stopped the practice in 1975.

The Philippine Seed Board released two IRRI lines as varieties in 1977.

- IR40 (IR2070-414-3-9), an early maturing (115 days), short-

Table 1. The 10 lines listed here, from among thousands tested in 1977, reflect a broad range of desirable characteristics needed in farmers fields. Seven of the 10 will adapt to rainfed fields, all have a high degree of disease and insect resistance, and several will grow in areas of problem soil and climate.

Designation	Ht (cm)	Growth duration (days)	Amylose content (%)	Reaction[a] to								Special traits and potential[b]
				Bl	BB	T	GS	GLH	BPH		SB	
									Bio-type 1	Bio-type 2		
IR2070-414-3-9	100	115	25	R	R	MR	R	R	R	R	MR	Resistant to whorl maggot; I
IR2071-586-5-6	100	130	29	R	R	R	R	R	R	R	MR	High yield potential at low levels of nitrogen; I; RL
IR3351-38-3-1	110	130	15	MR	R	R	R	R	R	R	MR	RL
IR3464-75-1-1	120	140	Waxy	MR	R	R	R	R	R	R	MR	I; RL
IR4432-28-5	100	120	25	R	R	R	R	R	R	R	MR	Drought resistant; I; RL
IR4570-83-3-3	115	130	23	R	R	R	–	R	R	R	MR	I; RL
IR4630-22-3-3-1-1	125	125	25	MR	R	R	–	R	R	S	–	Salinity tolerant; RL
IR5657-33-2-2-3	110	120	20	MS	R	R	–	R	R	S	–	Salinity tolerant; I; RL
IR5853-118-5	100	110	27	R	R	R	–	R	R	R	MR	Drought resistant; I; RL
IR5853-162-1-2	110	120	27	R	R	R	–	R	R	R	MR	I

[a]Bl = blast; BB = bacterial blight; T = tungro; GS = grassy stunt; GLH = green leafhopper; BPH = brown planthopper; SB = stem borer. R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible.
[b]Potentially suited to growing condition as indicated: I = irrigated; RL = rainfed lowland.

statured variety with translucent, high-quality grain of medium length. IR40 is the first known modern variety resistant to whorl maggot, and has resistance to most of the major rice diseases and insects in the Philippines. It is moderately tolerant of iron toxicity, zinc deficiency, and phosphorus deficiency. It has a relatively weak straw and is not suitable for highly fertile rice-growing soils.

- IR42 (IR2071-586-5-6-3), a high yielding, short-statured variety with particularly high yield potential at moderate levels of applied nitrogen in the wet season. It matures in about 130 days, and has medium-length, translucent, high-quality grain. It resists

the major rice disease and insect pests in the Philippines, is moderately tolerant of zinc deficiency and phosphorus deficiency, and has considerable drought resistance.

Collaborative GEU projects are reinforced by plant breeders from the national programs who spend 4 months in an IRRI GEU training course. Shown, from left, at work in the crossing screenhouse are D. L. Wichremasingha, research officer, Rice Research Station, Bombuwela, Sri Lanka; P.K.S. Ray, scientific officer, Sonagazi Substation, Bangladesh Rice Research Institute; E. M. Mendoza, assistant scientist, IRRI; A. Kartohardjono, assistant entomologist, Central Research Institute for Agriculture, Indonesia; and M. Potisurintara, agriculturist, Sakolnakon Rice Experiment Station, Thailand.

Crosses numbers to stabilize

The volume of crosses in our GEU program decreased slightly in 1977, while the number of F_2 combinations and pedigree lines grown continued to increase, reflecting an expanded crossing effort in previous years. The number of crosses is expected to stabilize at about the present level or to increase slightly as collaborative projects expand. The number of seed packets dispatched continued to decrease because of a further reduction in the volume of IRRI material included in the International Rice Testing Program (IRTP) as national programs increased their participation.

In response to special requests, we distributed 9,200 seed packets of improved GEU lines and varieties. The IRTP provided another 36,583 packets of the best GEU lines and varieties to participating national programs. Our newly established early generation testing program distributed 720 packets of F_2 seed from 159 crosses to 28 sites in 15 countries.

Innovative GEU approaches

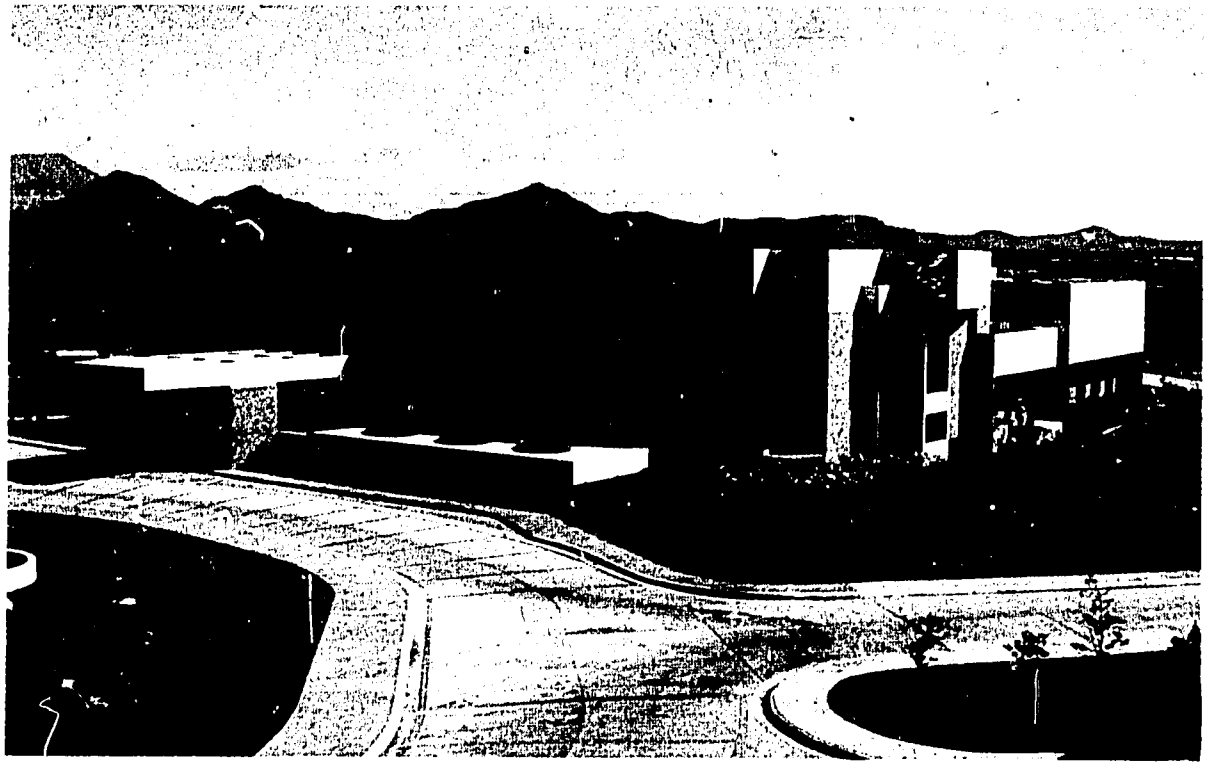
We tried three innovative approaches to accelerate the movement of new genetic materials into national rice programs.

- First an *early generation testing* program was initiated in cooperation with selected scientists in several countries. F_2 and F_3 seed from specific crosses made at IRRI were sent to the cooperators who will evaluate the progeny and make selections of promising lines. In this way superior location-specific lines are promptly identified.
- The second approach, *rapid generation advance,* was tested during 1976–77 to speed the development of photoperiod-sensitive rices. These photoperiod-sensitive rices are needed in medium-deep- and deep-water areas where it is desirable for the rice plant to mature late in the year after floodwaters recede.

  We grew F_2 and F_3 plants of these photoperiod-sensitive rices in short day-lengths artificially created in the IRRI phytotron. Superior plants were selected from F_4 populations grown in the field from December 1976 to March 1977 and photoperiod sensitive lines with resistance to major insect and disease pests were identified. Good F_5 photoperiod-sensitive lines were selected from the initial F_2 in less than 2 years. Encouraged by progress in 1977 we modified a greenhouse dark chamber to accommodate several thousand progeny of rapid generation advance studies in 1978.
- *Monogenic male sterility* was our third innovative approach to rice breeding in 1977. This technique is useful for repeated hybridization of segregating lines to enhance recombination. To develop male sterility we treated seeds of IR36 with a chemical mutagen and planted about 2,000 M_1 plants. Among 93 plants with distinct partial sterility, about 10 had low pollen viability with normal ovule function. Testing will continue in 1978 and some plants with monogenic male sterility are expected.

Computerized data management

We made steady progress in converting IRRI breeding records to the computerized data management system designed in 1976. There are 36,956 registered rices in the germplasm bank, and a computer-based data-management system gives complete information on varietal origin, seed source, and name. The system also gives complete information on 38 morphoagronomic characteristics for 26,000 rices and existing information on 37 GEU traits for 33,946 rices. It greatly facilitates the exchange of information among GEU scientists at IRRI



The Rice Genetic Resources Laboratory was opened for use in December 1977. The new building provides badly needed space for processing the hundreds of thousands of seed packets that annually go to collaborators around the world. Adjoining the processing room are seed fumigation rooms, storage rooms, milling and quality laboratories, and office space.

and with their counterparts in cooperating national programs.

A computer-based information management system to monitor age and movement of seed in the Rice Genetic Resources Laboratory was developed and tested. It gives instant information on the location and current status of any seed in the seed bank.

Germplasm collection and maintenance

The new Rice Genetic Resources Laboratory, dedicated in December, is headquarters for the processing, storing, and dispatching of seed. A workshop cosponsored with the International Board for Plant Genetic Resources was held after the dedication. The forum developed long-range plans for each of the world's major rice-growing regions. The plans guide the development of annual work plans to collect and maintain rice genetic resources.

We continued to collaborate on germplasm collection with several Asian countries – Bangladesh, Bhutan, Indonesia, Malaysia, Pakistan, Philippines, Sri Lanka, and Thailand. IRRI provides support for the collaborative collection of rices in West Africa – a project involving five other international bodies interested in preserving African rice

Table 2. Field collection, preservation, and seed distribution of *Oryza sativa* cultivars have increased steadily since 1970. In addition to more than 2,700 accessions added to the germplasm bank in 1977, more than 8,000 samples received late in 1977 awaited registration and entry. The 25% increase in samples used within IRRI reflects our increased emphasis on identifying the genetic potential within the germplasm.

Year	Distinct accessions in germplasm bank	Samples distributed	
		Inside IRRI	National programs
1970	12,800	16,000	5,600
1971	14,712	10,600	2,300
1972	16,893	2,740	2,500
1973	24,162	8,275	9,777
1974	26,818	19,236	2,603
1975	30,332	22,155	4,043
1976	34,229	40,200	4,819
1977	36,956	50,354	4,126

germplasm. The Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT), the International Institute of Tropical Agriculture (IITA), and WARDA have major responsibilities for implementing the West Africa program.

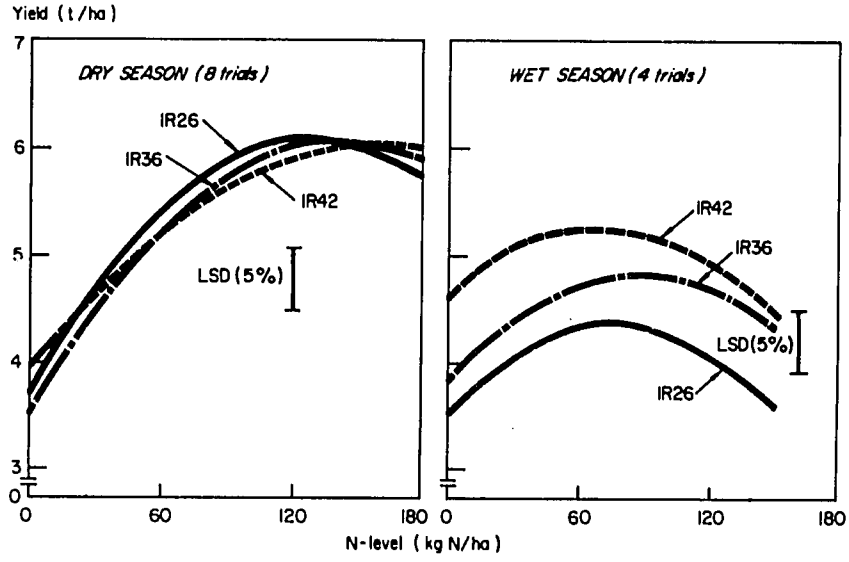
Several major rice research centers in India turned over a duplicate set of their seed samples – a total of 5,865 in 1977 – to us for preservation. Replacement samples for nonviable seeds received earlier totaled 629. The 9,144 seed sets received in 1977 from all countries exceeded the 1976 volume. Most of those have been processed and will be catalogued and included in the germplasm bank in 1978. Table 2 summarizes our 1970–77 germplasm activities.

AGRONOMIC CHARACTERISTICS

We expanded our research to develop and test rices with short growth duration. Several breeding lines mature in 105–110 days and one of them, released as IR36 in the Philippines, is widely grown by farmers. We started developing rices that mature in 90 to 95 days.

Specifications for the early maturing rices include high yield ability and resistance to major diseases and insects. Our earliest maturing line, IR747B2-6 (100 days), has good vigor and high yield but is susceptible to tungro. Several early maturing varieties obtained from China and some traditional varieties from India mature in 90 days but they yield low and are susceptible to diseases and insects.

We crossed the early maturing Chinese and Indian rices with IR747B2-6 and backcrossed to it. Some lines from those crosses



2. Recently released IR42 was superior in performance to IR26 and IR36, especially during the wet season. Data are averages for all nitrogen experiments at IRRI where the 3 varieties were compared.

mature in 90 days, have the vigor and yield of IR747B3-6, and are resistant to blast, bacterial blight, and brown planthopper.

Yield performance of irrigated and rainfed rice

We ran yield and nitrogen-response trials at IRRI and at three Philippine Bureau of Plant Industry (BPI) research stations during 1977. IR42 – highlighted for performance in 1976 as IR2071-586-5-6-3 and released by the Philippines in 1977 – was generally outstanding in all trials, in both seasons, and at all levels of nitrogen. In experiments during the past 3 years IR42 has been uniquely productive during the wet season (Fig. 2). In wet season tests it consistently outyielded other varieties and was also a high yielder in dry season tests.

Several breeding lines had high dry-season yields in trials without nitrogen – IR2071-588-6-2-6-4, IR2797-125-3-2-2-2, IR4432-52-6-4, and IR4432-103-6-4. Wet-season lines with good yields at low levels of applied nitrogen include IR4570-83-3-3-2, IR4570-117-2-1-2, and IR5853-162-2-1.

Grain size and yield potential

The yield potential of a rice plant is the product of spikelet (grain) number per square meter and average weight per grain. To verify our 1976 findings that yield potential correlates positively with grain size, we grew 12 varieties in the field at a 10- × 10-cm spacing. We

found that spikelet number per square meter (N) decreased linearly with increasing grain size (W):

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

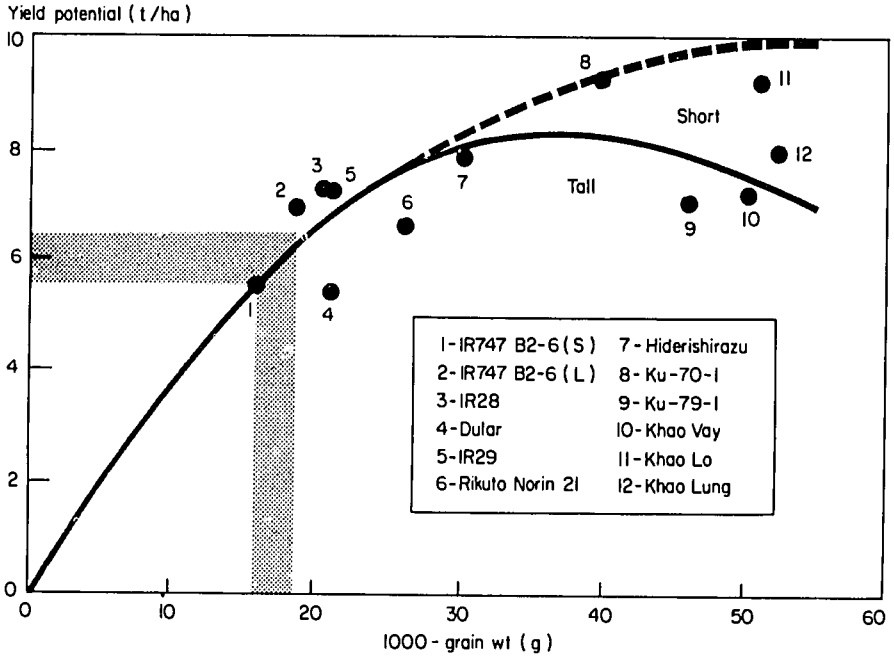
where N_o and a are constant.

By our definition the yield potential becomes:

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

Figure 3 shows this relationship where the solid line is computed from equation 2 and the dotted line is the expected relationship if large grain size is combined with short stature. In the solid line, the estimated optimum grain size to give the maximum yield potential is about 39 g/1000 grains. Among the 12 varieties, IR747B2-6 (L) and IR747B2-6 (S) are isogenic lines, and differ only in grain size. For them a 2.6 g difference in grain size per 1,000 grains means about 1 t/ha difference in yield potential.

Considering partition of photosynthates between growing panicles and vegetative parts before heading, we expect that the optimum grain size will increase if the present tall, large-grain varieties are shortened. Our study suggests that selection for larger grain is an easy way to increase yield potential of the existing varieties. Combining



3. Based on 12 varieties grown at a 10- X 10-cm spacing the dotted line indicates the expected increase in yield potential if large grain size is combined with short plant stature. The shaded portion indicates about 1 t/ha increase in yield potential possible from a small increase in the 1,000-grain weight between isogenic breeding lines.

large grain with a short plant stature may increase yield potential over that of IR8 and similar dwarf indicas.

DISEASE RESISTANCE

The modern rice varieties' high degree of natural resistance to major rice diseases contributes much to high yields and the varieties' wide farmer acceptance. We have steadily increased the disease resistance of IRRI breeding lines, and are constantly screening the world germplasm collection for new gene sources of resistance. We routinely screened more than 150,000 entries for disease resistance during 1977; of that number more than 73,000 were screened for bacterial blight alone (see Table 4).

Resistance to rice blast

Breeding of rice varieties with stable resistance to blast has been a long, difficult task. But we have identified several lines in the International Rice Blast Nursery (IRBN) with a broad spectrum of resis-

Separate plots with eight varieties each were used in 1977 to check the level of blast resistance through measurement of the rate of disease development. A plastic cover at night ensured disease development after inoculation. S. H. Ou, principal plant pathologist (right), and F. Nuque, assistant scientist, IRRI, check the spread of blast among the varieties in one plot.

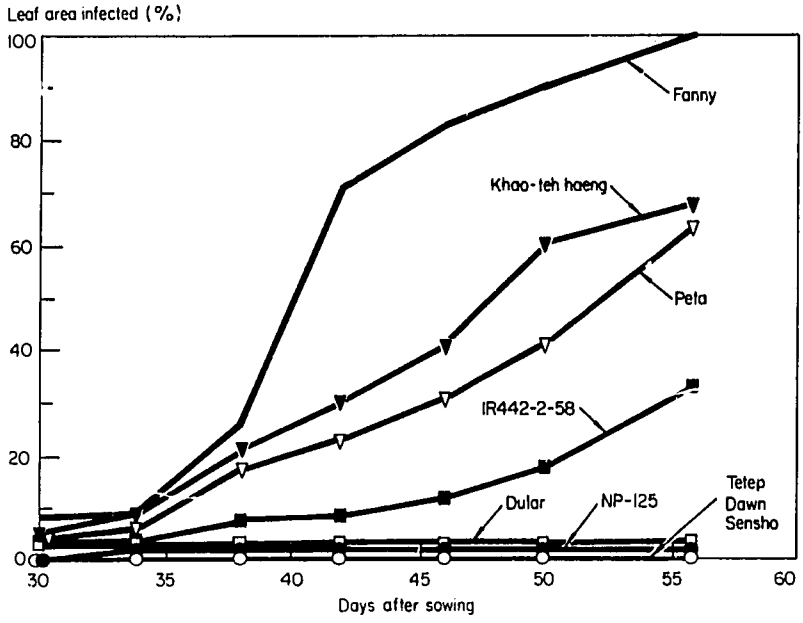
Table 3. IR1905-81-3-1 was outstanding among 10 IRRI breeding lines in the International Rice Blast Nursery, with blast resistance that compared favorably with that of the blast-resistant varieties Carreon and Tetep.

Designation and cross	Testing countries	Testing stations	Tests	Frequency of reaction								
				Resistant							Susceptible	
				1	2	3	4	5	6	7	8	9
IR1905-81-3-1 IR8/Tetep	17	32	48	29	9	7	2				1	
IR1905-PP21-73-4 IR8/Tetep	14	19	23	16	4	3						
IR3259-PP11-186-4 $IR8^3$/Tetep	14	19	24	19	2	2	1					
IR3259-PP11-182-4 $IR8^3$/Tetep	14	20	25	20	2	1	1	1				
IR3259-PP8-172-6 $IR8^3$/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 $IR8^3$///IR8/Tetep// IR8/Carreon	14	19	24	16	5	2	1					
IR9669-PP836-1 $IR8^3$/Carreon	14	19	24	18	6							
Tetep (resistant)	17	30	46	27	12	4	3					
Carreon (resistant)	17	32	48	26	14	5	2		1			
IR26 (susceptible)	16	31	46	13	5	3	5	3	3	1	7	6

tance equal to that of the resistant varieties Tetep and Carreon (Table 3). To supplement the IRBN approach we tried other methods to measure so-called horizontal blast resistance. Our experiments were based upon the general concepts that

- when vertical resistance is removed by inoculating plants with virulent isolates of the blast organism, the level of resistance remaining should be horizontal resistance; and
- the rate of blast development should be low for varieties with horizontal resistance.

In a study of eight varieties with various degrees of blast resistance, Tetep, Dawn, and Sensho had low numbers of lesions when each was



4. Excellent horizontal resistance to blast was confirmed for Sensho, Dawn, Tetep, and NP-125 when they developed almost no infection after being inoculated with isolates of blast disease from both their own leaf lesions and those from the other seven varieties.

inoculated with isolates from its own lesions and with isolates from the lesions of the seven other varieties. Figure 4 shows the rate of disease development when all eight varieties were inoculated with three virulent isolates.

In that study Tetep, Dawn, and Sensho had a high degree of horizontal resistance to blast. We found, however, that varieties from Japan that are "field resistant" become susceptible to blast at IRRI. That indicates that different races of the blast fungus could affect our study results, and that different races from the various rice-growing regions of Asia must be tested to confirm horizontal resistance. The IRBN provides an opportunity for this type of testing.

Resistance to bacterial blight

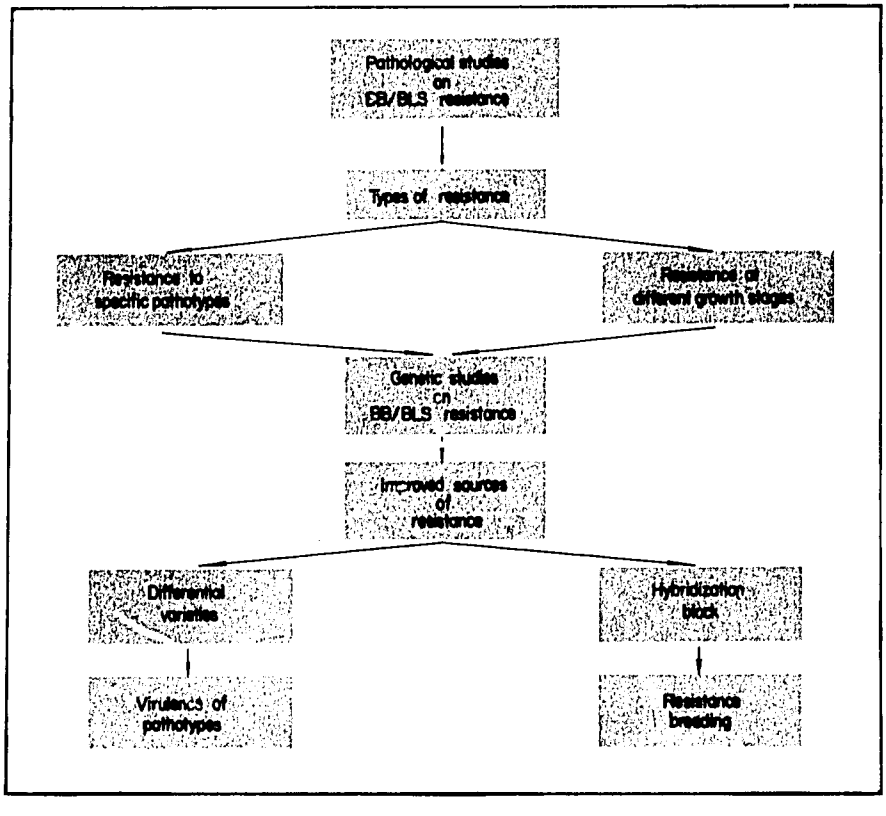
More than 73,000 breeding lines were evaluated for bacterial blight resistance in 1977. A high percentage of those lines were resistant to pathotype 1 of *Xanthomonas oryzae* in the Philippines (Table 4) but most were susceptible to pathotype 2. An operational procedure for genetic evaluation and utilization of bacterial blight resistance was developed in 1977 (Fig. 5). Genetic studies of 55 resistant varieties from different geographic areas failed to identify a gene source for resistance to bacterial leaf blight other than *Xa 4*, *xa 5*, and *xa 7*, which were already known.

During the past few years, we have used IR1545-284 in the

Table 4. Screening of nine groups of lines and varieties for bacterial blight in 1977 indicated that IRRI has high percentages of materials that are resistant or moderately resistant to pathotype 1.

Materials screened	Rices tested	Percent resistant or moderately resistant
Replicated yield trials (RVT)	650	89
Observational yield trials (OYT)	2,326	47
Germplasm bank	5,534	13
Hybridization block	590	51
Pedigree nurseries	60,843	80
Seed increase blocks	246	92
Upland RYT	749	29
Upland OYT	2,165	37
Cold tolerance nursery	435	47
Total	73,538	71

crossing program. That line carries the *xa 5* gene, which conveys resistance to pathotypes 1 and 2. Several promising lines from the IR1545-284 crosses were evaluated, and IR4563-52-1-3-6 is a most promising line, with resistance to pathotypes 1 and 2 conditioned



5. An operational procedure to systematically utilize genetic resistance to rice bacterial diseases was set up in 1977.

by *xa 5*. The proportion of our breeding materials with the *xa 5* gene is increasing.

A computer file of selected germplasm entries for the bacterial blight reaction was started. Each entry will be tested for 2 years (four seasons) both at maximum tillering and flowering stages against a single pathotype in the field and against different pathotypes in the greenhouse. The long-term objective is to group the germplasm entries according to the genes for resistance to the Philippine isolates, origin of the germplasm, and types of resistance.

Kresek phase of bacterial blight

There are three types of symptoms of the bacterial blight syndrome in the tropics – leaf blight, kresek, and pale yellow plant. Kresek-infected plants may serve as a source of inoculum for leaf blight, and leaf blight infection may turn to kresek if infection occurs in the early growth stage, or if the variety is highly susceptible to bacterial blight. But we reconfirmed that kresek and leaf blight are distinct and relatively independent symptoms. Kresek and leaf blight result from the primary infection; pale yellow is a secondary effect of both. Several varieties were found highly resistant to kresek in greenhouse and field tests (Table 5).

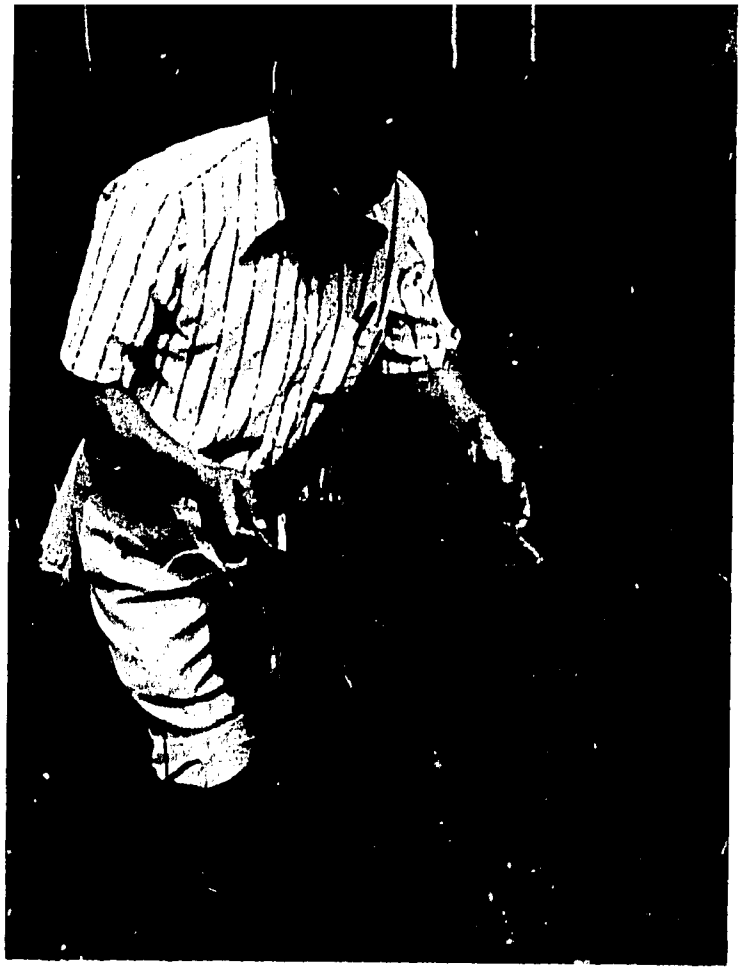
Ragged stunt, a new virus disease of rice

Ragged stunt, a new virus disease of rice transmitted by the brown planthopper, became widespread in the Philippines and was reported in India, Indonesia, Sri Lanka, and Thailand. The disease causes stunting of the plant, twisting of leaves, swelling of veins, and partial

Table 5. Several varieties with resistance or moderate resistance to bacterial leaf blight were found to have good resistance to kresek. Ranking for kresek resistance is based on 1 = most resistant, and 14 = most susceptible.

Variety	Gene for leaf blight resistance	Reaction to pathotypes[a]			Ranking for kresek resistance	
		1	2	3	Greenhouse	Field
Indian Dular	Not identified	R	R	R	1	1
Ketan Lumbu	"	MS	MS	MR	2	5
DV85	*Xa 5, Xa 7*	R	R	R	3	4
IR20	*Xa 4*	R	S	MR	9	–
IR1545-339	*xa 5*	R	R	S	11	9
IR8	None	S	S	S	13	10
Pelita I-1	*Xa 4*	R	S	MR	14	8

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



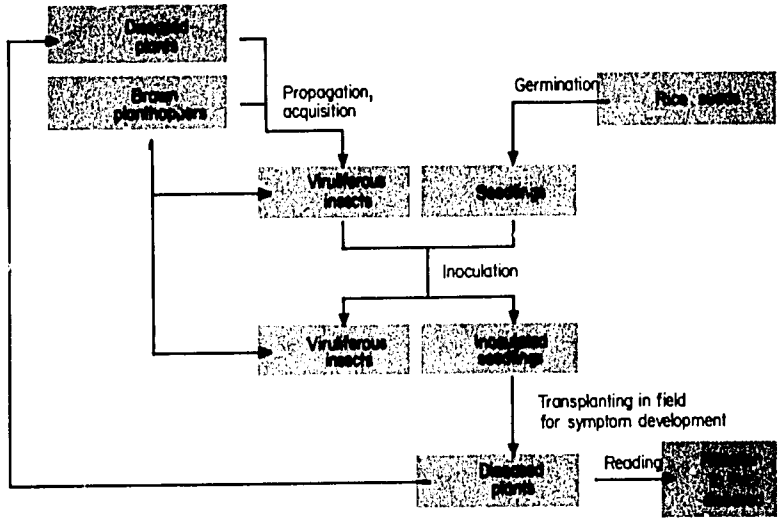
K. C. Ling, IRRI plant pathologist, moves a flat of seedlings into the screenhouse in tests to develop methods of determining resistance to ragged stunt.

panicle emergence (see section on control and management of rice pests, page 59). We had to develop methods to evaluate resistance to ragged stunt.

Because ragged stunt is a systemic disease, we adopted the standard system for evaluating rice virus diseases by degree of natural infection (a scale of 0 to 9, based on percentage of infected rice hills in a field). About 40% of 4,643 entries in various trials at IRRI had field resistance ratings of 3 or less. From more than 12 replicates in the field, 14 entries showed excellent resistance to ragged stunt:

IR32	IR4219-35-3-3
IR36	IR4227-28-3-2
IR38	IR4417-179-1-5-2
IR2071-588-6-2-6-4	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

It is likely, however, that a low susceptibility in the field did not always imply high plant resistance to ragged stunt, but rather



6. An operational procedure for testing for varietal resistance to rice ragged stunt in the screenhouse was developed at IRRI in 1977.

resistance to the brown planthopper, which transmits the virus. Also, the disease pressure on the plants in the field maj have been low.

A large screenhouse (700 m^2) was built to test varietal resistance to ragged stunt. The testing procedure we developed (Fig. 6) involves controlled inoculation of rice seedlings with ragged stunt, and growing and scoring them in the field.

Table 6 lists 14 crosses from the 1977 Pedigree Nursery that showed good level of ragged stunt resistance.

Table 6. The 1977 Pedigree Nursery had 14 crosses that appeared to have good resistance to ragged stunt.

Cross	Parents
IR9252	IR2768-11-133/IR2034-289-1-1-1//IR2071-625-1
IR9710	ADT26/IR2071-636-5-5//IR36
IR13523	Ptb 33/IR2153-159-1//IR2061-628-1-6-4-3
IR13524	Ptb 33/IR2153-159-1//IR42
IR13525	Ptb 33/IR2153-159-1//IR36
IR13526	Ptb 33/IR2153-159-1//IR2863-38-1
IR13539	Rathu Heenati/IR2153-159-1//IR36
IR13548	Rathu Heenati/IR4432-53-73//IR36
IR13592	WC 1253/IR36//IR36
IR13618	IR2588-49-3-3-3/IR2071-486-9-2-6//IR2683-38-1
IR13640	IR1704-3-2-3/IR2307-64-2-2//IR1628-632-1/IR36
IR15318	Ptb 33/IR3403-267//IR36
IR15323	Ptb 33/IR4432-53//IR5201-127-1
IR15324	Rathu Heenati/IR3403-267//IR4417-177-1-4

INSECT RESISTANCE

Insect damage in farmers' fields remains a major threat to rice production. We continue to increase the number of lines resistant to the major insect pests, a characteristic that encourages farmers to accept a variety. But at the same time breakdown of that resistance – as in the case of resistance to the brown planthopper – is a constant threat that challenges entomologists and plant breeders to search for new and better genetic sources of resistance.

Our GEU work focuses on resistance to seven insects – brown planthopper, green leafhopper, whitebacked planthopper, striped and yellow stem borers, whorl maggot, and leaf folder. The brown planthopper receives major emphasis. Table 7 shows the volume of our insect resistance screening in 1977. Almost 177,000 entries were tested.

Brown planthopper resistance

Varietal resistance continues to play a major role in controlling brown planthopper damage to the rice crop, but the development of new biotypes emphasizes the need for more stable types of resistance. We identified several moderately resistant varieties and breeding lines that usually do not suffer heavy brown planthopper damage in the

Table 7. The volume of rices tested for resistance to major insect pests increased sharply in 1977. Those listed under *others* include materials from India, Korea, Bangladesh, Indonesia, Solomon Islands, and Ivory Coast. The 22 entries tested for whorl maggot were wild rices.

Insect	Germplasm		Breeding lines		Others	
	Tested	Selected	Tested	Selected	Tested	Selected
Brown planthopper						
Biotype 1	3,301	431	64,343	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
Green leafhopper	586	177	40,177	25,935	0	0
Whitebacked planthopper			1,981	1,405	0	0
Stem borer						
Striped borer			652	5		
Yellow borer	33	3	713	144		
Whorl maggot	956	5	221	16	22	19
Leaf folder	27	5	1,159	114		
Total	6,633	627	167,166	117,358	3,103	649

field. Survival of the brown planthopper on those varieties is intermediate, compared to that on resistant and susceptible varieties.

We screened hundreds of cultivars from the germplasm bank for resistance to the three biotypes of brown planthopper found in the Philippines. Most of the resistant cultivars are from Sri Lanka (Table 8). They are being crossed with IRRI lines that have good plant type, high yield ability, and high levels of resistance to other diseases and insects.

Most of our breeding materials have either the *Bph 1* or *bph 2* gene for resistance. After the *Bph 3* and *bph* 4 genes were identified in 1975, however, we began to incorporate them into our breeding materials. Donors of *Bph* 3 (Rathu Heenati) and *bph* 4 (Babawee) have poor plant type and grain quality. Similarly, the plant type of Ptb 33, another variety that has either *Bph* 3 or *bph* 4 is poor. These three varieties were crossed with improved plant type selections IR3403-267-1, IR4432-53-3-3, and IR2153-159-1, which are susceptible to brown planthopper but resistant to most other major diseases and insects. The F_1's were either backcrossed to the parent of improved plant type or topcrossed with another improved cultivar. F_3 progeny from those crosses were grown in 1977. Some promising breeding lines – carrying the new genes for resistance – were selected and will be evaluated in 1978 at IRRI and in cooperation with national programs.

We analyzed 20 brown planthopper-resistant varieties for new genes

Table 8. In a study of reactions of selected rice cultivars to three biotypes of brown planthopper in seedling bulk tests, a high proportion of entries showing resistance to all three biotypes were from Sri Lanka.

Cultivar	Origin	Cultivar	Origin
Ac-1613	India	Ptb 21 (Tekkan)	India
Babawee	Sri Lanka	Ptb 33	India
Balamawee	Sri Lanka	Rathu Heenati	Sri Lanka
Gangala	Sri Lanka	Sinna Sivappu	Sri Lanka
Hondarawala 378	Sri Lanka	Sudu Hondarawala	Sri Lanka
Hondarawala 502	Sri Lanka	Sulai	Sri Lanka
Hondarawala	Sri Lanka	Thirissa	Sri Lanka
Horana Mawee	Sri Lanka	*O. australiensis*	India
Kahata Samba	Sri Lanka	*O. australiensis*	Australia
Kalu Samba	Sri Lanka	*O. australiensis*	USDA
Kuruhondarawala	Sri Lanka	*O. brachyantha*	Africa
Lekan Samba	Sri Lanka	*O. brachyantha*	India
Mudu Kiriyal	Sri Lanka	*O. latifolia*	Guatemala
Ptb 19	India	*O. latifolia*	Costa Rica
Ptb 20	India		

Table 9. The reaction of varieties and selected lines to the brown planthopper and virus disease at IRRI in the 1977 wet season. The brown planthopper damage rating is based on the Standard Evaluation System for rice: 1 is no damage, and 9 is all plants dead; DT is days after transplanting.

Variety or line	BPH count/hill			BPH damage rating	Virus disease (%)	
					Ragged stunt	Grassy stunt
	30 DT	50 DT	70 DT	80 DT	80 DT	80 DT
IR36	10	4	39	1	45	0
IR42	7	2	58	1	16	0
IR2863-38-1-2	11	3	27	1	0	2
IR4432-52-6-4	8	3	47	1	2	2
IR4432-103-6-4	9	3	35	1	0	2
TN1 (susceptible check)	9	7	121	9		

for resistance. Ptb 19, Gangala (acc. 7733), Gangala (acc. 15207), Horana Mawee, Kuruhondarawala, Mudu Kiriyal, and Muthumanikam have the *Bph 3* gene for resistance; Gambada Samba, Heenhoranamawee, Hotel Samba, Kahata Samba, Kulukuruwee, Lekam Samba, Senawee, Sulai, Thirissa, and Vellai Illankali have the *bph 4* gene for resistance; and the varieties Ptb 33, Sudu Hondarawala, and Sinna Sivappu have two resistance genes, one dominant and the other recessive.

Table 9 shows the reactions of five entries to brown planthopper and virus disease at IRRI in the 1977 wet season.

Whitebacked planthopper

We have used N22 from India as a source of resistance to the whitebacked planthopper, but the variety matures early and combines poorly. Therefore, we crossed it with several varieties of improved plant type, backcrossed it with the improved parent once or twice, and evaluated promising selections. We selected promising lines with the N22 gene for resistance to whitebacked planthopper and resistance to other major diseases and insects. The selections have excellent grain quality and vary in growth duration from 100 to 130 days. Some of the lines are being cooperatively evaluated in India and Indonesia. Examples of the crosses from which whitebacked planthopper-resistant lines have been selected appear in Table 10.

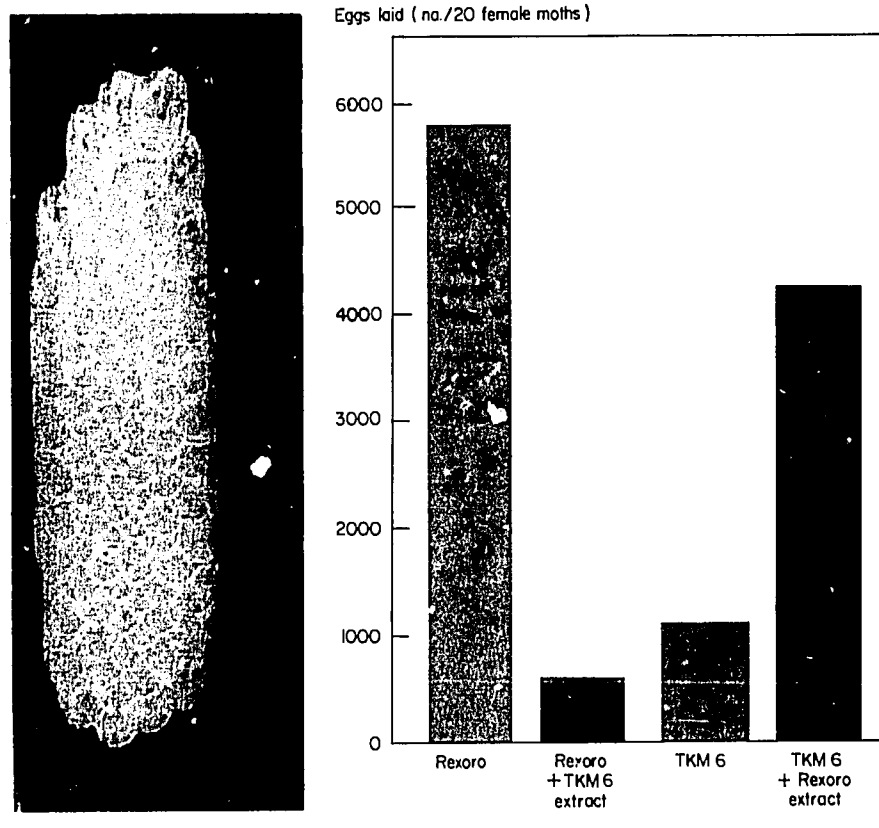
Striped borer

We studied egg laying of the striped borer on plants treated with extracts from the leaves of resistant and susceptible plants. When an

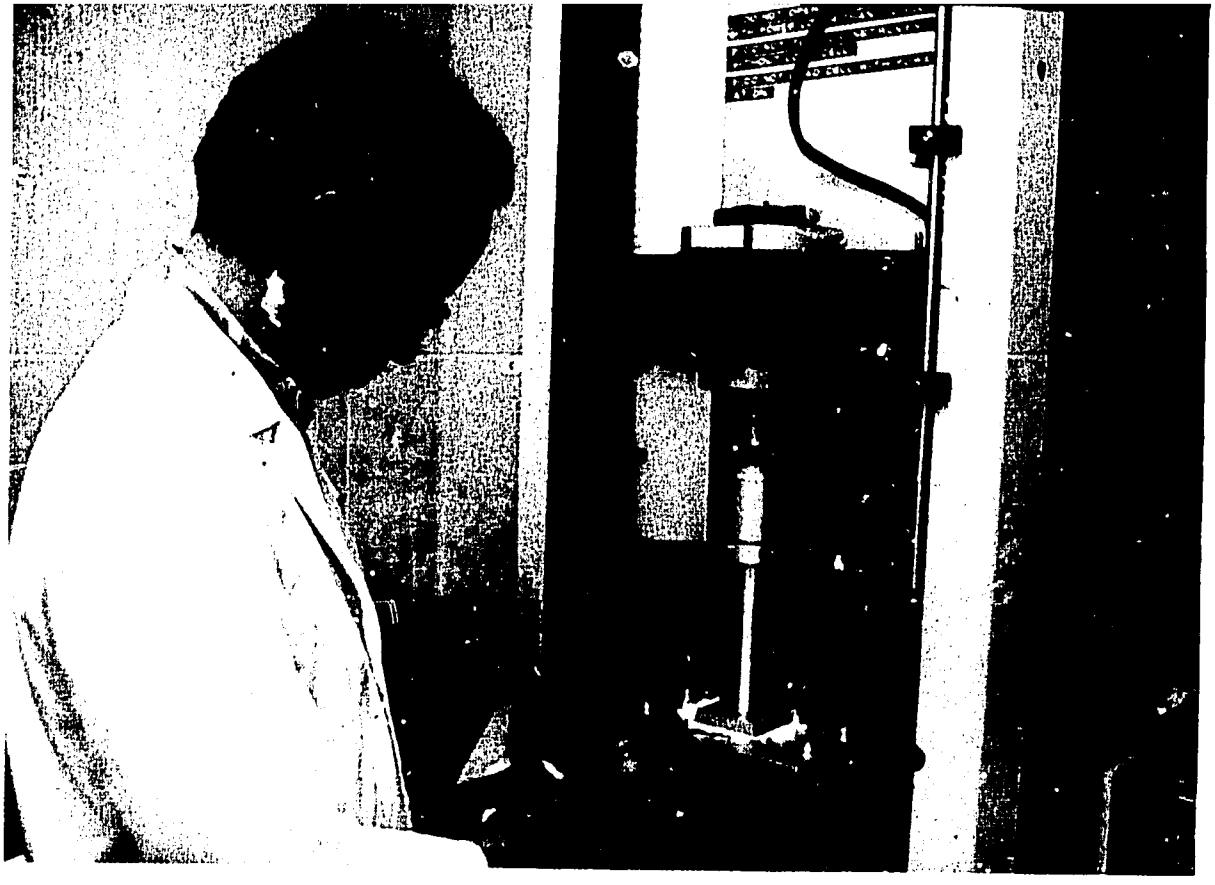
Table 10. N22 from India has been a dependable source of plant resistance to whitebacked planthopper. It has been crossed with varieties of improved plant type and those lines with resistance to whitebacked planthopper were selected in 1977.

Cross	Parents
IR11933	IR28³/N22
IR11934	IR30³/N22
IR13294	IR1632-93-2/N22//IR36
IR13384	IR36²/N22
IR13453	N22/BG90-2//IR36
IR13467	N22/IR2061-465-1//IR36
IR13471	N22/IR2061-628-1//IR36

extract from TKM 6, a striped borer-resistant variety, was sprayed on the susceptible variety Rexoro, the insects laid fewer eggs on Rexoro than on TKM 6. On the other hand, the borer laid eight times more eggs on resistant TKM 6 sprayed with susceptible Rexoro plant extract (Fig. 7).



7. Application of a plant extract from plants resistant or susceptible to the striped borer markedly changes the borer's egg laying preference. Resistant varieties become susceptible and susceptible varieties gain resistance to egg laying. The photo shows a typical egg mass laid on a rice leaf.



B. O. Juliano, IRRI chemist, puts a rice sample through a stickiness test in an Instron tester. After flattening the cooked rice the Instron gives a measurement of stickiness by recording the force and distance required (grams times centimeters) to separate the plunger from the base plate.

GRAIN QUALITY

Rice is the only cereal consumed mainly as whole milled and boiled grain. Its market price is determined by grain appearance and yield of total and head (whole grain) milled rice. Eating quality is not generally related to market quality. Nevertheless local preferences for grain shape and size and for eating quality are major factors in the acceptance of new improved varieties by farmers. We know that the proportion of amylose to amylopectin in rice starch, as indexed by amylose content, is a major determinant of eating quality, and we continue to emphasize intermediate amylose content in our breeding program.

We analyzed about 12,000 entries in the world germplasm collection for amylose content. Our current amylose test at pH 4.5 for undefatted milled rice was found superior to the test at pH 10.2, because the pH 4.5 test is less sensitive to differences in residual fat of the rice.

We used stickiness and hardness of cooked rice to indicate eating quality of promising IRRI lines. Hardness of cooked rice measured by the new Instron tester correlated with gel consistency as well as amylose content.

In the food texture tester, the stickiness of cooked rice between two metal surfaces correlated better with amylose content than hard-

ness (resistance to extrusion) for all rices. Stickiness of waxy rices also correlated with gelatinization temperature. Differences in hardness among varieties of similar amylose content were related to known differences in eating quality of those rices.

- During 1977 we reconfirmed that the most widely preferred rice varieties have intermediate amylose content.
- We were unable to obtain an intermediate-amylose type from crosses between high- and low-amylose types. All IRRI varieties, except IR24 (low amylose) and IR29 (waxy), are high amylose, but we now have advanced lines with intermediate amylose content (Table 11).
- We developed rapid simple tests requiring a minimum sample size to screen for amylose content and gel consistency and use them to evaluate every breeding line – more than 50,000 in 1977 – from the F_3 generation onward.

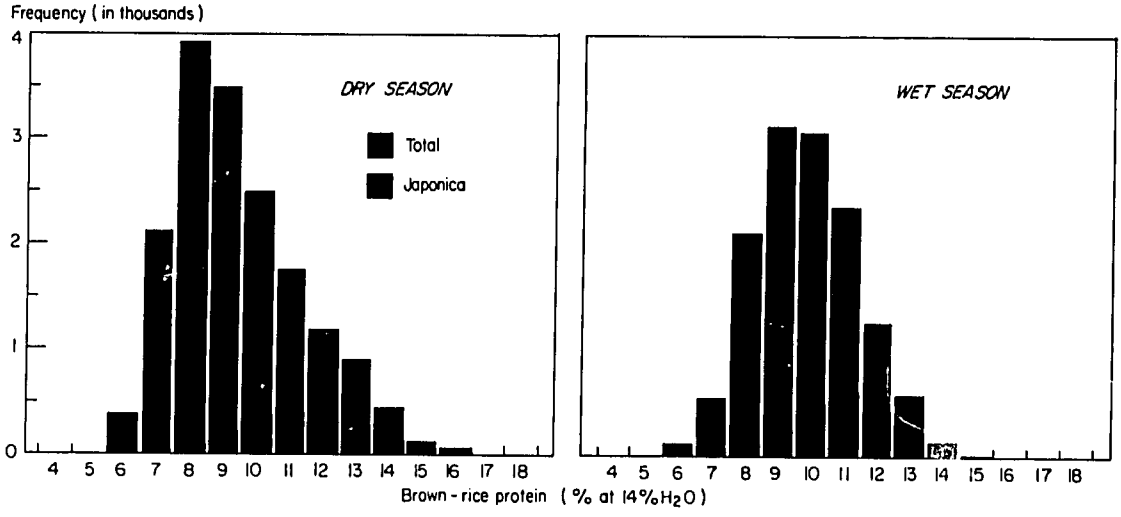
PROTEIN CONTENT

Because of its favorable amino acid balance rice protein is one of the most nutritious among cereals. But the low protein content of rice is a major nutritional limitation. Nevertheless, man will probably consume the same amount of rice regardless of protein content. Thus, it is essential that the protein content of new varieties be equal to or higher than that of varieties they replace, especially in Southeast Asia where diets are deficient in both calories (energy) and protein.

We screened about 18,000 more entries in the world rice collection for brown-rice protein (Fig. 8). High-protein and non-japonica entries from among the more than 29,000 screened to date were selected

Table 11. IRRI advanced breeding lines with intermediate amylose content were identified during 1977.

Intermediate amylose entry	Protein (%)	Alkali spreading value	Instron reading for cooked rice	
			Hardness (kg)	Stickiness (g·cm)
IR4215-301-2	6.4	2.5	6.4	122
IR4215-409-2	6.6	2.5	5.5	93
IR4570-74-2	6.8	7.0	7.6	75
IR4570-124-3	7.4	7.0	7.2	89
IR7963-30-2	8.3	6.9	7.9	90
IR9575	8.5	2.5	6.0	84
BPI-121-407 (check)	8.9	6.9	7.6	117
C4-63G (check)	6.8	2.0	5.9	78



8. Many high-protein entries were identified among about 18,000 indica and japonica rice screened during 1977. Those entries with high brown-rice protein will be further evaluated for use in our GEU program.

for further evaluation as sources of high protein. In replicated yield trials, grain yield and brown-rice protein were not significantly negatively correlated, in contrast with trials of previous years. This suggests good overall progress in our efforts to improve rice protein without sacrificing yield potential.

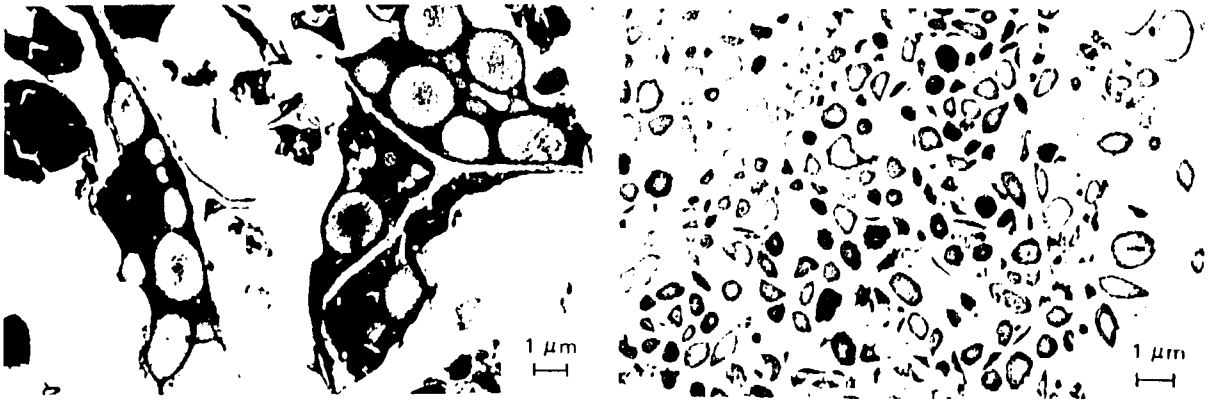
In high-protein rice, we found that the subaleurone, or outermost cells of the endosperm, rather than the bran had the highest protein content, which explains why high-protein rice retains more protein during milling than low-protein rice does.

Rice protein digestibility and retention

Cooperative nitrogen balance studies were run on four Filipino children and five Taiwanese men who ate high-protein and low-protein milled rice at the same level of protein intake in diets that had 90% or more of the protein from rice. These studies verified previous human studies in which protein intakes were different. It is clear that the protein digestibility and nitrogen retention of high-protein rice are as good as those of low-protein rice.

We prepared destarched milled rice with 70 to 80% protein content by gelatinizing the starch granules, and by removing the starch using fungal amylase. The preparations had net protein utilization values equal to those of raw rice protein, and protein recovery was more than 75%. The high-protein preparation was added to a low-protein rice diet to reduce bulk and allow us to run nitrogen balance studies on children.

Protein bodies prepared by destarching cooked milled rice were



9. These transmission electron micrographs show protein bodies from destarched cooked IR480-6-9 milled rice before (left) and after (right) pepsin digestive treatment. The small undigested protein particles shown in the right photo are from the core of the larger protein bodies in the photo on the left. The micrographs were made by the U.S. Grain Marketing Research Center, Manhattan, Kansas.

confirmed to be less susceptible to pepsin digestion than protein bodies from raw rice, which agreed with digestibility data previously obtained for rats. Transmission electron microscopy showed that the undigested protein from pepsin digestion and the fecal protein particles from man or rat on cooked rice diets represent the core of the rice protein bodies (Fig. 9).

Cooperative protein study

A cooperative study was started with Australian chemists to separate pericarp, aleurone layer, and embryo of rice grain and to characterize the protein of low- and high-protein rices. Methods were developed to separate the pericarp from rice grain. The embryo was separated by hand dissection. The identity and purity of the separated components were checked by light and electron microscopy.

DROUGHT RESISTANCE

Drought devastated the rice crop in vast areas of several Asian nations during 1977. Losses from it made news headlines. Shorter dry spells – even in lowland rice-growing areas – were not so devastating but they did reduce yields substantially.

Our research on drought resistance continued with the primary objective of better understanding the adaptive mechanisms available in rice germplasm, and developing techniques to rapidly select and recombine them in lines for diverse rainfall systems.

We included many rainfed lowland rices in our 1977 drought resistance program. Promising lines were field-screened and evaluated in three Luzon provinces. Our dry-season drought screening at IRRI expanded to include some 16,000 entries many of which were lowland rainfed types. We selected promising parents and made

10. Nam Sagui, shown here in drought screening field plots, has both drought resistance and elongation ability. In deep-water areas the rice crop often suffers from drought early in the season but is later submerged in floodwater. The breeding lines IR5825 and IR5853 have Nam Sagui as a parent.

372 crosses to incorporate drought resistance into breeding materials for upland culture and 110 crosses for rainfed lowland conditions.

Several rices such as Leb Mue Nahng, C-22, Sigadis, and Nam Sagui 19 contributed to drought resistance in the improved breeding lines IR3304, IR5825, IR5853, IR8098, and IR8105 crosses. Nam Sagui 19 has both drought resistance (Fig. 10) and elongation capacity, an important combination of characters for deep-water rice areas. Figure 11 shows the drought resistance of Khao Dawk Mali, a rice from Thailand with excellent drought tolerance in soils that limit rooting depth.

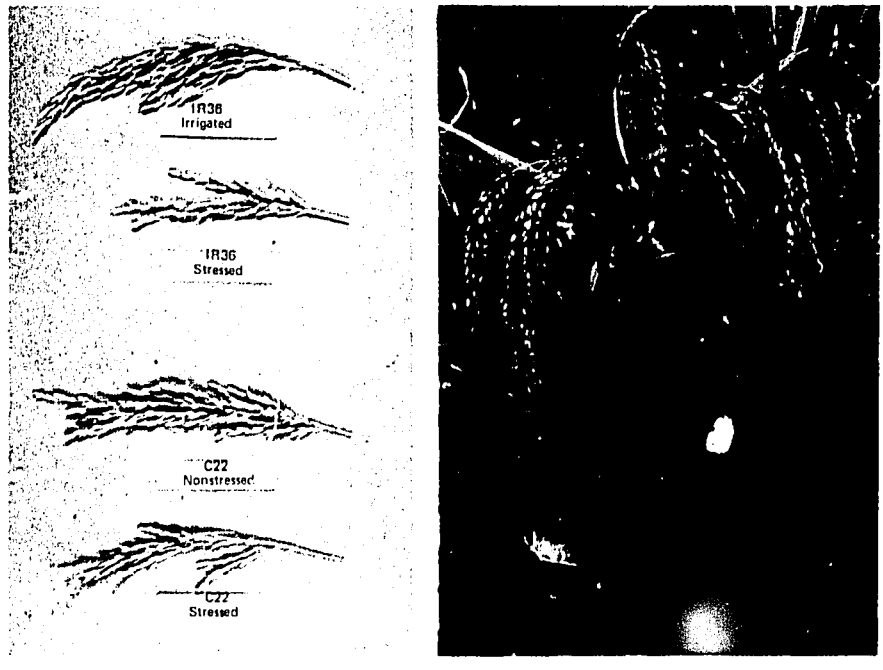
Field evaluation identifies promising materials

Our 1977 tests again confirmed that the good performance of the rices tested is associated with drought resistance and recovery ability.

Drought periods during early July and early August gave us opportunities to evaluate drought-resistant, stable, high yielding breeding lines by comparing performance in an upland site at IRRI with that in more favorable upland sites elsewhere. Among the early maturing lines of 95- to 105-day maturity, IR6115-1-1 and IR3839-1 performed well at all three upland sites. IR5716-18-1 and IR3880-10 were promising lines of medium maturity. Among the late-maturing lines, IR2035-242-1 and IR3260-91-100 performed well at all sites

11. Drought resistance studies in an IRRI drought screening greenhouse identified rices with drought resistance in a naturally dried soil that limited rooting depth. Khao Dawk Mali, a Thai variety, was the only survivor in this set of drums.

because they received rains in September. IR36 and C22 yielded high at the wet fertile sites but low at the dry sites. Much of the yield reduction was ascribed to small panicles and low spikelet fertility (Fig. 12).



12. The effect of drought on yield is clearly reflected in these panicles from IR36 – an irrigated lowland variety – and C22 – an improved Philippine upland variety. Kinandang Patong, a traditional upland variety used as a check in the same drought study plots, shows fully fertile panicles.

Table 12. Separation and ranking of 10 lowland rices based on their mean leaf water potential 24 days after draining the paddy during dry-season lowland drought screening at IRRI, 1977.

Variety or line	Leaf water potential[a]
IR1754-F_5B-23	- 13.0 a
IR1746-226-1-1-2	- 14.8 ab
IRAT 13	- 15.28 ab
IR34	- 17.4 bc
Kaibid	- 17.6 bcd
G11B-Si-213-1	- 18.7 bcde
IR2070-320-6-5-3	- 20.1 cde
IR4215-4-3-1	- 21.6 de
Intan	- 22.4 e
IR2061-628-1-6-4-3	- 23.8 e

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

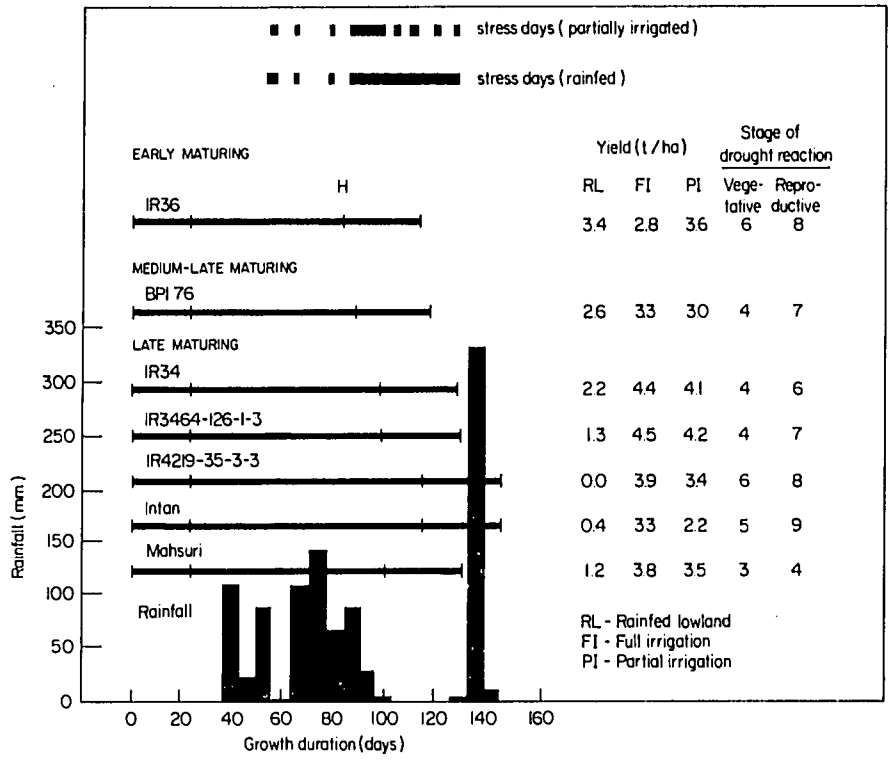
Visual scoring and plant water status

In tests in lowland fields (wet land preparation – puddled soils) 10 rices were visually scored for drought effect and their leaf water potentials were monitored 24 days after the field was drained. The mean leaf water potential was calculated for each variety (Table 12) after leaf water potential was recorded every 2 hours for 2 consecutive days. The relationship of those values to visual scoring is similar to that reported for upland field screening. As in upland dry-season drought screening, we visually score varieties on their capability to maintain high leaf water potential or to avoid internal water deficit.

A prolonged drought in Central Luzon from late September to early November provided an excellent opportunity to evaluate drought resistance in farmers' rainfed-lowland fields. Early maturing varieties (115–120 days) escaped the drought and produced good yields regardless of differences in drought resistance. Yield differences between the irrigated and rainfed treatment were small in the medium-maturing group. Such differences between treatments were dramatic in varieties of 135–145 days maturity, partly because they differed markedly in drought resistance, especially at the reproductive stage. IR34, IR3464-126-1-3, and Mahsuri performed markedly better than Intan and IR4219-35-3-3 (Fig. 13).

Aluminum toxicity and drought

Aluminum toxicity retards rice root growth and impairs water and nutrient uptake. Thus, on acid upland soils, aluminum toxicity is



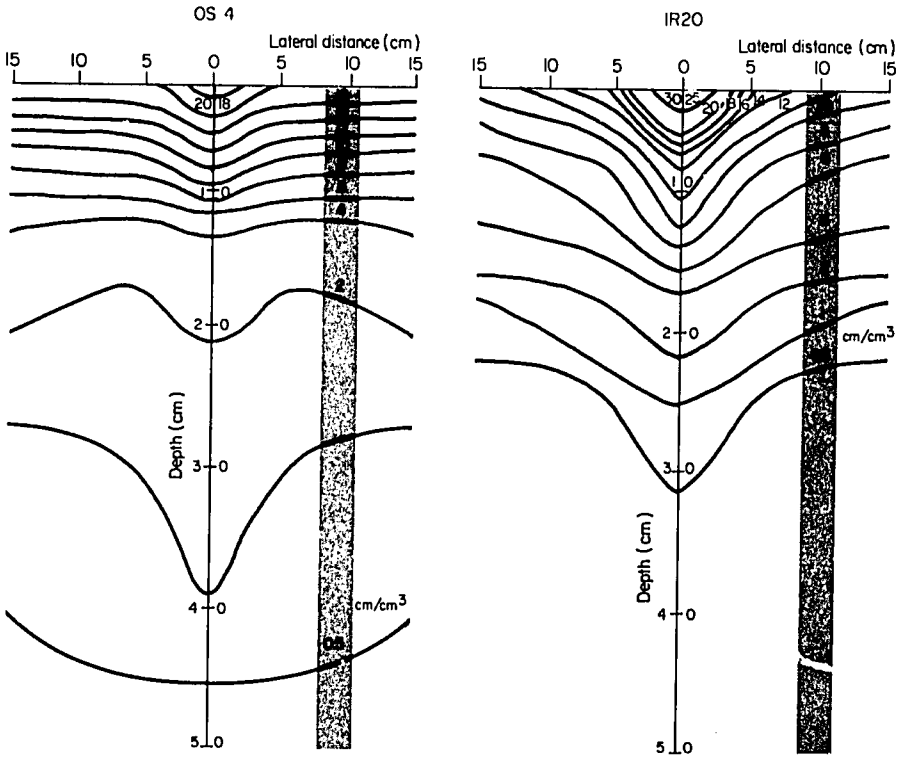
13. Rainfall distribution, stress days, growth duration, drought reactions and yields of 7 rices tested at Talavera, Nueva Ecija, during the 1977 wet season, show the advantage of drought resistance (0 = slight effect, 9 = all plants dead), especially for varieties that took 130 days or more to mature in rainfed fields. H is date of heading. IR36 yields were reduced by rat damage under full irrigation.

closely associated with the rice plant's endurance of drought. We ran a series of experiments to examine aluminum toxicity and varietal differences in tolerance for it.

We added aluminum to the rooting media at 0- to 60-ppm concentrations. At 60 ppm aluminum, toxicity was so severe that varietal differences were slight. But at 30 ppm aluminum, varietal differences were large. At 3 ppm aluminum, only varieties susceptible to aluminum toxicity were affected. Upland varieties are generally tolerant of aluminum toxicity while lowland varieties are susceptible. Among lowland varieties, Bluebonnet 50 is relatively tolerant of aluminum.

Vertical and lateral distribution of roots in the field

We studied the vertical and lateral root distribution of varieties OS4 and IR20, planted at 30- × 5-cm spacing in the field. Iso-root density curves were constructed to show points of the same root density both vertically and laterally (Fig. 14). Roots of IR20 were concentrated around the center of the plant, but those of OS4 were



14. This iso-root density diagram of two rice varieties grown in the field illustrates the difference between the root systems of upland (OS4) and lowland (IR20) varieties. Density of roots (cm/cm^3) along the isometric lines is given in the shaded area on the right of each diagram.

well spread laterally. Vertical distribution differed significantly between the two varieties below 30 cm from the soil surface.

TOLERANCE FOR ADVERSE SOILS

The need for rice varieties that can grow in adverse soils – those with either excess of toxic substance or shortage of needed elements, or both – stems from the combination of increasing demand for food and decreasing availability of good rice-growing land. In a 1976 survey, we identified more than 100 million hectares of adverse soils that are potentially suitable for rice growing.

During 1977 we concentrated on the search for varieties tolerant of adverse soils and on breeding to improve those rices for farm use in the adverse-soil areas. Our main activities included:

- developing and improving screening techniques for tolerance for adverse soils. Because some adverse soil conditions cannot be duplicated at IRRI, some screening was required in countries where such conditions exist;

- mass field screening of the world germplasm collection for tolerance for phosphorus and zinc deficiency, and for iron toxicity;
- screening elite breeding lines for tolerance for alkalinity, salinity, iron toxicity, reduced soil problems, and phosphorus and zinc deficiencies;
- breeding for adverse-soils tolerance, screening the progeny of lines that are tolerant of salinity and alkalinity and phosphorus deficiency;
- research on the chemical basis of the rice plant's tolerance for adverse soil conditions.

We screened more than 14,500 rices at IRRI for adverse-soils tolerance and found 259 with near normal growth in one or more adverse soil conditions (Table 13).

In Philippine field tests, the hybrid line IR4360-22-3 yielded 2.6 t/ha on a coastal saline soil in Camarines Sur where three other IR rices yielded less than 1.3 t/ha. On a zinc-deficient soil in Bohol, the local variety Lumbang gave 2.8 t/ha, outyielding nine IR rices. IR2307-247-2 yielded 3.9 t/ha without phosphorus fertilizer on a phosphorus-deficient soil on which IR36 yielded only 2 t/ha.

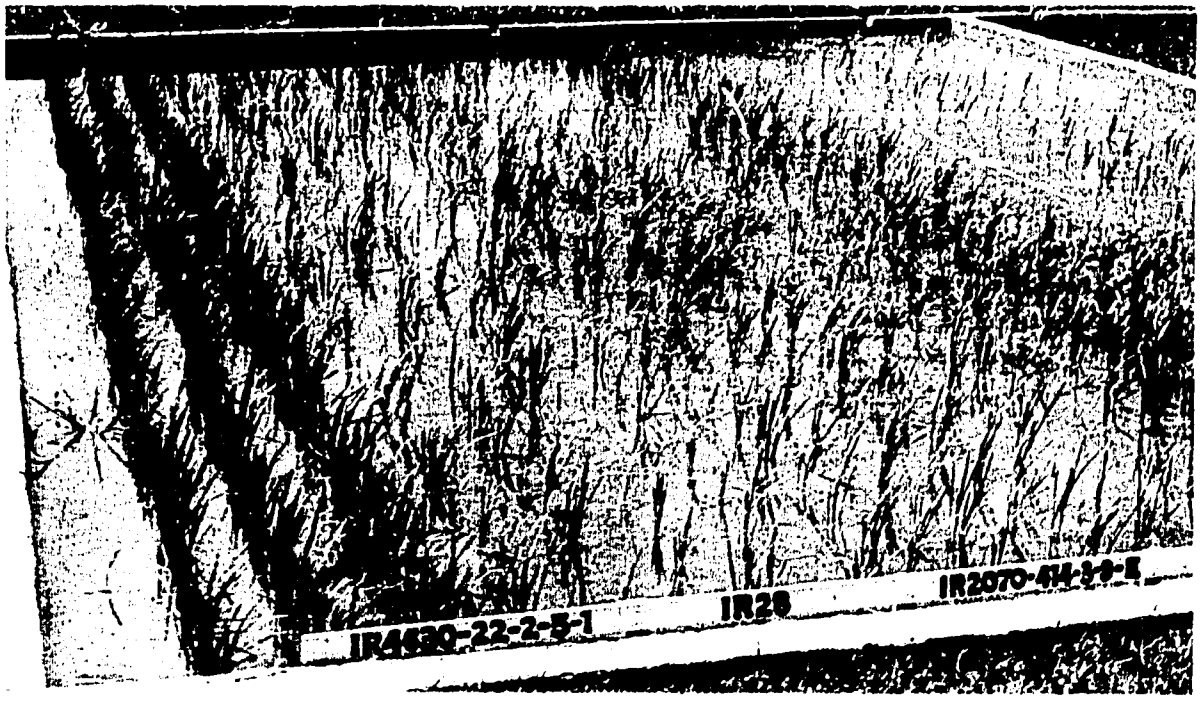
Salinity and alkalinity

We tripled our greenhouse capacity for salinity and alkalinity screening and developed a piezometric system to monitor salinity and improve the reliability of field screening.

We tested more than 2,000 pedigree lines from 20 crosses in the

Table 13. More than 14,500 rice were tested by IRRI in 1977 to identify those with promising tolerance for adverse soil conditions. The number in parentheses is the total screened.

Rices with a promising level of tolerance for					
Salinity (5,562)	Alkalinity (1,876)	Iron toxicity (288)	Histosol problems (1,923)	Phosphorus deficiency (731)	Zinc deficiency (4,200)
IR2863-35-3-3	C59	Bakut	Kuatik Putih	IR26	IR20
IR4432-28-5	Lubang	Cadung Go Gung 1601	CI 8636-5	IR34	IR34
IR5657-33-2	Aronlea	Radin Goi 36	Bengawan	IR2061-522-6	Orkayama
IR7199-28	Kwei Yiwe	IR20		IR2367-247-2	Pokkali
IR8073 (19 lines)	CP 231	IR36		IR2823-299-5	IR2070-414-3
IR10168-1	Gottelu	IR2070189-4		IR3445-172-2	IR2307-247-2
IR10206 (3 lines)	CSR 2	IR2070-414-3		IR3941-9-2	IR2681-163-5
IR1358 (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	



IR4630-22-2-5-1, a salt-tolerant breeding line from a Pokkali cross, grows in a saline soil beside IR28 and other nontolerant lines.

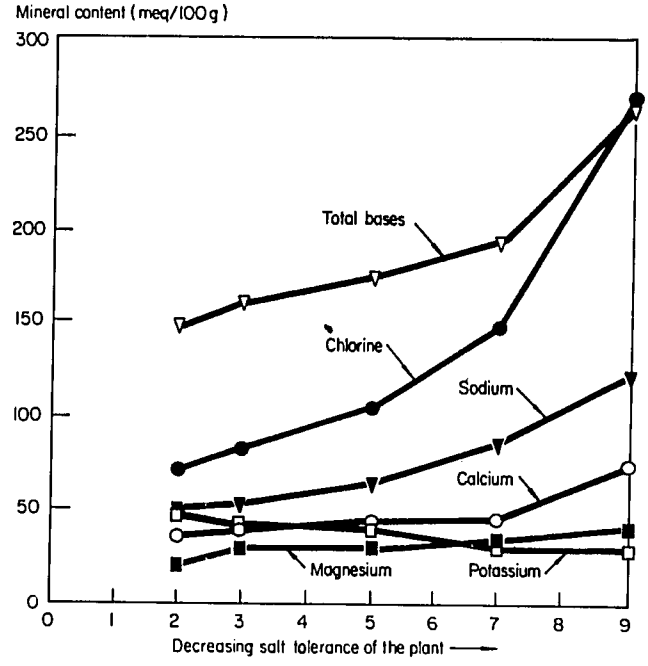
greenhouse and grew 3,000 pedigree lines on a coastal saline soil in Camarines Sur. The advanced breeding lines IR4630-22-2-5-1 and IR4630-22-3-3-2 consistently showed good salt tolerance, and IR2863-53-3, IR4432-28-5, and IR5657-33-2 showed remarkable tolerance.

Alkali-tolerant lines were easily identifiable in routine testing in an artificial alkali field at IRRI. We sent 43 alkali-tolerant lines to national projects in India, Pakistan, Australia, and Mexico for further testing.

Collaborative screening

We initiated collaborative projects for mass screening rice for phosphorus deficiency and iron toxicity in Sri Lanka. We also provided hybrid populations with potential tolerance for problem soils to rice research centers in Nigeria, Indonesia, and India.

In Sri Lanka mass screening for phosphorus deficiency revealed that IR22, IR24, TN1, IR480, and IR1514A-E666, which have been intensively used in IRRI hybridization program, have high tolerance. In a similar test for iron toxicity, IR32, three IR4422 lines, and two IR4819 lines showed high tolerance. Many advanced lines were highly tolerant of phosphorus and zinc deficiency.



15. In 1977 studies of the mineral content of the rice shoot it was found that as the mineral content of the shoots increased the salt tolerance of the plant decreased. Salt tolerance is measured on a scale of 0 to 9, with 0 indicating high tolerance.

Chemical basis of tolerance

In a study of the mineral content of rice roots we found that salt tolerance increased as the salt content of the roots increased. Conversely, we found that salt tolerance decreased as the mineral content of the shoot increased. Figure 15 illustrates the change in tolerance with change in mineral content of the rice shoots.

Breeding for adverse-soils tolerance

Although repeatability is not as high as desired, the heredity of salt tolerance is quantitative. Among advanced breeding lines derived from Pokkali, IR4630-22-2-5-1 consistently revealed salt tolerance comparable with that of Pokkali in greenhouse and concrete-bed tests. Because of their intermediate stature and resistance to tungro virus, bacterial leaf blight, and brown planthopper, the new lines are suited to coastal saline areas. The salt tolerance of other Pokkali crosses (IR4763-73-1, IR4763-141-2, and IR4595-4-1) indicates that Pokkali's tolerance can be combined with other desirable traits.

DEEP-WATER AND FLOOD TOLERANCE

Excess water or flooding affects from 30 to 40% of Asia's rice land. Farmers in about a fourth of that area contend with water

depths from 1 to 6 m and depend on traditional low yielding, deep-water or floating varieties. Intensive research to produce a modern rice technology for those areas began in 1975. Work during 1977 at IRRI and in Thailand through the Thai-IRRI Cooperative Deep-water Project indicates that modern, high yielding rices adapted to deep water can be tailored to replace farmers' low yielding varieties.

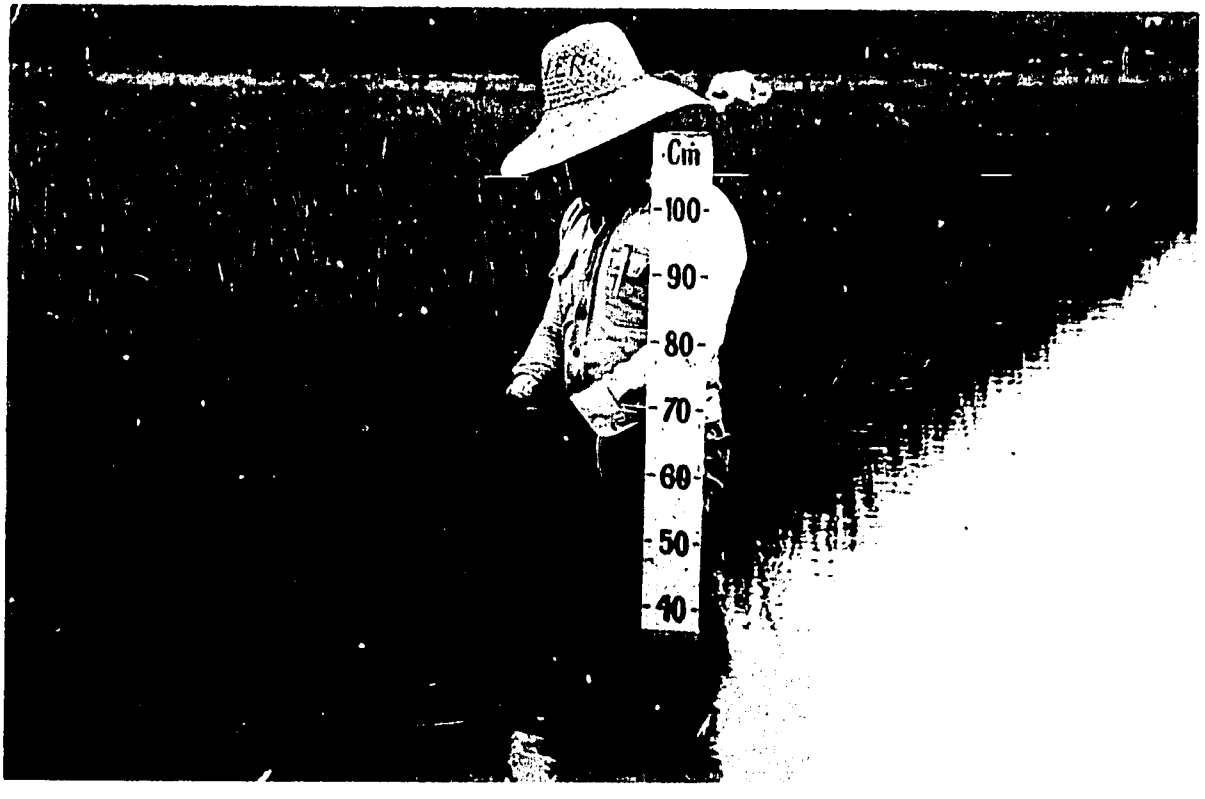
Major emphasis in 1977 was on screening varieties in the germplasm collection and new breeding lines for flood tolerance and elongation ability. Several new varieties were identified as possible donors of plant characters needed in deep-water rice.

We tested more than 3,000 varieties and lines at IRRI for flood tolerance. Flood-tolerant advanced lines that yielded well were IR5857-3-2E-1-1, IR5857-3-2E-1-38, and IR5857-64-IE-1-6.

In field screening for flood tolerance in Thailand, all plants under test were destroyed at 134- and 154-cm water levels. A few entries were badly damaged at 90-cm depth. BKN 6987-82 and BKN 6987-161-3 survived and recovered best.

Of the 4,350 varieties screened for flood tolerance since 1975, 62 performed as well as or better than the resistant checks Nam

At IRRI research emphasis for deep-water rice is in the medium depth range. IR42, shown here, was bred as a variety for shallow water, but it does well when planted in medium-deep water.



Sagui 19 and SML Temerin when submerged completely for 8 days. Seedlings of tolerant varieties were retested with 10 days of submergence. Several varieties survived better than the two tolerant checks (Table 14). 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 removal of water.

Elongation testing

About 14,000 lines and 300 varieties were screened by Thai and IRRI scientists at Huntra Experiment Station in Thailand for ability to elongate at different water depths.

Several varieties with early ability and good capacity to elongate at water depths of up to 155 cm were identified.

Response to fertilizer at different water depths

Good fertilizer response is a key factor in the breeding of improved varieties that are tolerant to deep water. Soils in the areas now planted to traditional tall varieties are relatively infertile and the rice crop receives little or no added fertilizer.

The response of four photoperiod-sensitive rices to fertilizer at

Table 14. Fifteen flood-tolerant varieties performed better than Nam Sagui 19 and SML Temerin after 10 days of submergence at the seedling stage in flood-tolerance tests of 4,350 entries since 1975.

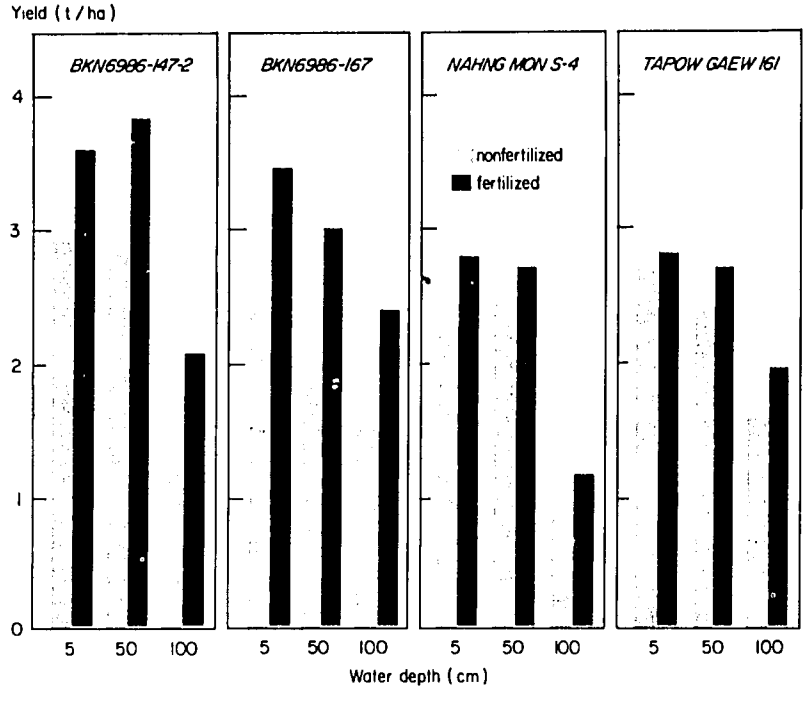
Variety	Survival (%)	Increase in plant ht (%)
F.R. 13 A	100	19
Goda Heenati	85	30
Kurkaruppan	85	24
Thavalu	85	10
Anlong Phnom	80	33
ARC 10661	70	15
Thavalu	65	7
ARC 614-25 (b)	60	41
ARC 10238	60	33
Beti Chikon	60	58
Kalu Gires	60	29
ARC 12059	55	23
ARC 12606	55	60
Cai Don	50	40
Tangul	50	47
SML Temerin (check)	30	82
Nam Sagui 19 (check)	40	25

water depths of 5, 50, and 100 cm was studied in the Thai-IRRI cooperative project.

Yields of the two lines BKN 6986-147-2 and BKN 6986-167 increased markedly with fertilizer application compared with yields of the tall traditional variety Nahng Mon S-4 and the recommended semifloating variety Tapow Gaew 161 (Fig. 16). That suggests that genetic factors as well as water depth may limit fertilizer response. Yields were lower in deeper water, especially at 100 cm, but the plants responded to fertilizer in deep water as well as, or better than, in shallow water. Despite its inherent tallness, Nahng Mon S-4 could not tolerate the deepest water.

Multilocational yield trial

We continued multilocational yield trials to determine if the incorporation of elongation genes into semidwarf rices reduces yields. The elongation trait is important in areas where semidwarfs are commonly grown but which are subject to occasional flooding. The elongating semidwarfs yielded as much as the Thai modern semidwarf RD7, and were clearly superior in water 90 cm deep. BKN 6986-108-3 was outstanding and BKN 6986-66-2 performed well under a wide range of conditions.



16. The results of breeding for deep-water rices that respond to fertilizer are shown by two elongating semidwarf lines (left) compared with a traditional tall variety, and a semifloating variety (right) at different water depths at the Huntra Experiment Station in Thailand in the 1977 wet season.

Drought resistance at seedling stage

In the 1977 dry season we tested the drought resistance of deep-water hybrid lines and floating varieties on raised beds that accelerated drought stress. After seeding, the beds were watered sufficiently to ensure good stand establishment; then water was withheld for 29 days. Nineteen deep-water-tolerant hybrids resisted drought and recovered acceptably well, as shown by the ratings at 66 and 112 days after sowing. Both BKN 6986-108-3 and BKN 6986-66-2 were rated relatively high. They gave stable yields under a wide range of water depths.

Submergence and drought resistance in a single variety

Traditional rice varieties are generally rugged but vary widely in tolerance for submergence and drought. During the 1977 dry season, we screened 4,115 rices for drought resistance in the field; several traditional varieties had good drought resistance.

We also screened many modern rices with submergence resistance. Some, such as IR5825-44-3-P1 and IR5825-44-3-P2, had both submergence and drought resistance. IR5825-44-3-P2 recovered after about 60 days of drought.

TEMPERATURE TOLERANCE

In many rice-growing areas modern rices that are adapted to grow better at both ends of the current temperature range for the rice crop would increase rice production. Those rice areas include many mountainous sites in Asia where low temperature limits rice growth, and vast arid areas where irrigation is available but high temperature adversely affects the rice plant. During 1977 we developed a simple procedure to identify rices with tolerance for high temperature. We also began a collaborative program with the Republic of Korea for cold-tolerance research.

Low temperature tolerance

We used as parents in our cold-tolerance breeding all varieties identified to date as cold tolerant. We screened seedlings of more than 2,000 new lines and planted those with cold tolerance on mountain sites at Banaue, Philippines, for further evaluation. We also made 424 new crosses for cold tolerance in 1977.

From mass screening of our germplasm collection we identified five more varieties with cold tolerance at the seedling, panicle initiation, and flowering stages. Those varieties, plus six identified

Table 15. Eleven indica varieties have been selected for tolerance for low temperature on the basis of growth duration, plant height, spikelet sterility, leaf color, and flowering. They were among 17,689 entries from the germplasm bank.

Variety	Origin	Spikelet sterility (%)	Flowering at 21°C (%)
Padi Sasahal	Malaysia	29	100
C21	Philippines	25	100
Pratao	Brazil	8	100
Silewah	Indonesia	13	100
Mitak	Indonesia	29	90
Lambayeque 1 (PI 207010-2)	Peru	14	90
Dourado Agullia	Brazil	11	80
Thangone	Laos	9	80
Leng Kwang	China	27	70
Jumali	Nepal	21	70
Padi Labou Alumbis	Malaysia	11	70

earlier – from 17,689 entries screened – have suitable plant height and duration when grown in cold areas (Table 15). Our collaborative use of the Korean cold-tolerance testing site will speed screening and provide us with field plots for cold-tolerance studies.

High temperature tolerance

We developed a simple new procedure for screening varieties for high temperature tolerance. Plants at the flowering stage are subjected to high temperature in the IRRI phytotron and tolerance is rated on the basis of empty spikelets. In 1977 we identified 14 donors of high temperature tolerance from about 390 selections (Table 16). N22 consistently shows a high degree of tolerance for high temperature. Interestingly, the early maturing and waxy IR3941-97-1, which has some cold tolerance, has a high degree of high-temperature tolerance.

Table 16. Five IRRI breeding lines were among these 14 identified as tolerant of high temperature during 1977. They were selected from about 400 entries screened by a simple new procedure in the IRRI phytotron.

Variety, selection	Origin	Variety, selection	Origin
IR2006-P12-12-2-2	IRRI	IET5085	India
IR2798-115-2-3	"	IET5236	"
IR3941-97-1	"	CR138-994-A29	"
IR4427-51-6-3	"	Krishna	"
IR4482-5-3-9-5	"	N22	"
IET4658		Ching Yu I	China
(UPR96-1-1-1)	India	*O. glaberrima*	
IET4897 (AD-1140)	"	(Acc. No. 100149)	Guinea

Its sister line IR3941-25-1, however, did not tolerate high temperature.

We found clear differences in flowering time among selections of *O. sativa* and *O. glaberrima.* The *O. glaberrima* selections start flowering earlier in the morning than *O. sativa* selections. In the hot rice-growing areas, temperature normally rises above 35°C after 1000 hours and remains high until 1600 or 1700 hours. In such areas, early morning flowering is desirable. We consider early anthesis as an escape mechanism from sterility induced by high temperature. Selections identified as tolerant of high temperature do not flower early in the morning, indicating they have true tolerance for high temperature.

INTERNATIONAL RICE TESTING PROGRAM

The workload of the International Rice Testing Program (IRTP) in coordinating the sharing and testing of varieties and breeding lines by the world's rice scientists continued to increase. More than 100,000 seed packets were dispatched in 1977. The major impact of IRTP is measured, however, in the use of genetic materials by national scientists.

More than half of the total entries in the IRTP nurseries for 1977

International Rice Testing Program nurseries at Cuyuta, Guatemala, were visited during a 1977 IRTP monitoring tour in Latin America. From left are Manuel Rosero, IRRI liaison scientist for Latin America; Leonardo Hernandez Aragon, Mexico; S. K. De Datta, IRRI agronomist; Ezequiel Espinosa, Panama; and Walter Ramiro Pazos, Guatemala.

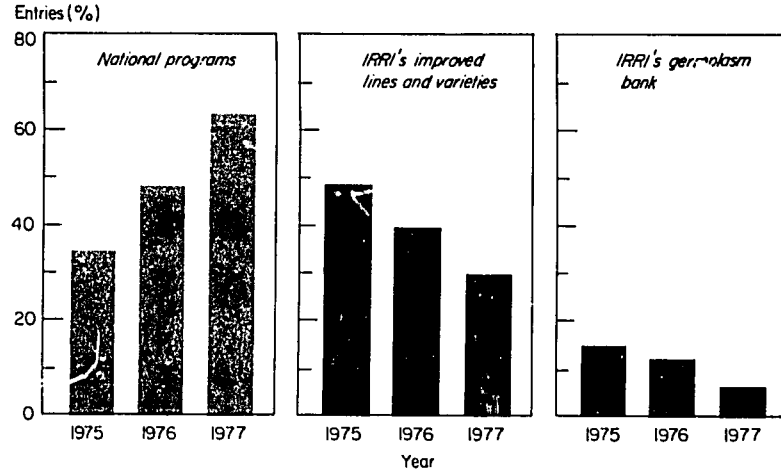
were entries from national programs (Table 17). We distributed 549 nursery sets for tests in 41 countries. In one nursery, the International Rice Yield Nursery-Late, comparisons are made of the new long-duration rices suited for the delta regions of monsoon Asia where rice cannot be harvested until the monsoons end. Six nurseries for Latin America were prepared jointly with the Centro Internacional de Agricultura Tropical (CIAT).

Although precise data are hard to obtain, our observations, based on scientists' travel and questionnaires, indicated that most national programs are using the best performing entries either as donors in specific breeding programs or for yield evaluation in advanced national-level trials, and in adaptive trials in farmers' fields. Some

Table 17. The International Rice Testing Program distributed more than 100,000 seed packets of varieties and lines in 1977. The nomination to nurseries from national programs continued to increase in 1977.

Nursery	Sets dispatched	Entries[a]	Entries from: National programs		IRRI: Improved lines or varieties		IRRI: Germplasm bank		Packets (total)
			No.	%	No.	%	No.	%	
• Yield									
Lowland									
Early	56	28[b]	20	71	8	20			4,704
Medium	50	28[b]	20	71	8	29			4,200
Late	18	28[b]	23	82	5	18			1,512
Upland	46	25[b]	13	52	12	48			3,450
• General observational	97	391	260	66	131	34			37,927
• Environmental stress									
Upland	65	153[c]	94	61	52	34	7	5	19.890
Salinity-alkalinity	35	77	38	49	32	42	7	9	2,695
Deep water	26	70	56	80	11	16	3	4	1,820
Cold	11	380	260	68	78	21	42	11	4,180
• Biological stress									
Blast	48	476	232	49	244	51			22,848
Sheath blight	32	154	58	38	62	40	34	22	4,928
Tungro	15	187	132	71	38	20	17	9	2,805
Brown planthopper	28	128	85	67	3	2	40	31	3,584
Gall midge	24	119	99	83	20	17			2,856
Stem borer	26	82	42	51	37	45	3	4	2,132
Total	577								119,531

[a]Including check varieties. [b]Three replications. [c]Two sets for two planting dates.



17. The number of trial nominations from national rice research programs has nearly doubled in the 3 years of IRTP operation. In addition to growth this increase in flow of national program materials reflects a spirit of cooperation among the world's rice workers.

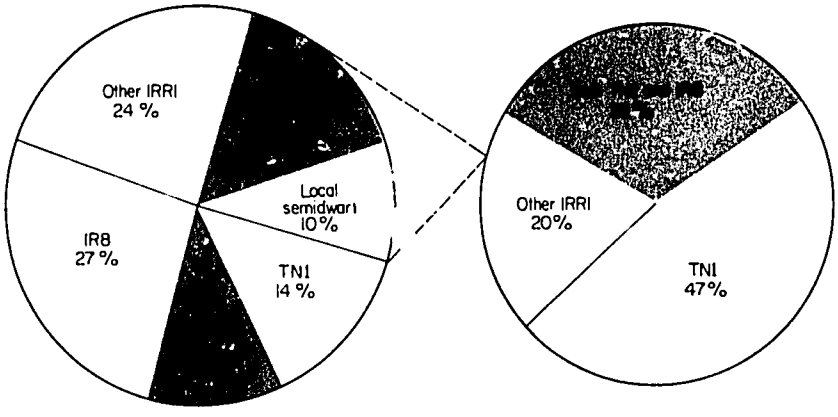
countries are multiplying the seed of the more promising IRTP entries.

The following major trends are apparent in IRTP operations.

- IRTP serves as a link among various national programs and between them and IRRI's GEU program.
- The IRTP network is an effective transfer system for rice technology. Increasing numbers of test entries in the nurseries are being nominated by national rice improvement programs (Fig. 17). The trend reflects the participants' growing interest in cooperating and sharing of materials.
- Development and evaluation of germplasm for specific agro-ecosystems received increased emphasis.
- Close cooperation among national programs (e.g., those of Korea, Indonesia, and Nepal on cold tolerance) is an outgrowth of the IRTP nurseries and, more directly, of the IRTP monitoring tours. In 1977, for the first time, tours outside Asia – to the Middle East and Latin America – were made.

RICE BREEDING IN ASIA

The spread of the early developed modern rice varieties onto farmers' fields is well documented. But little is known about their movement through national rice improvement programs, where they are used as parents to develop modern varieties better suited to local conditions. During 1977 we continued the analysis of data gathered in 1975 on the diffusion of rice germplasm used as parents in 10 Asian nations. The 1977 analysis included 355 crosses and involved 819



18. *Left* The source of the dwarf gene in 59 locally developed semidwarfs which Asian scientists used as parents in 1974–75 crosses. *Right* TN1 and IR8 were the main sources of the dwarf gene for the locally developed semidwarfs used in the crosses.

parents, randomly selected at 14 agricultural research centers in 7 Asian nations.

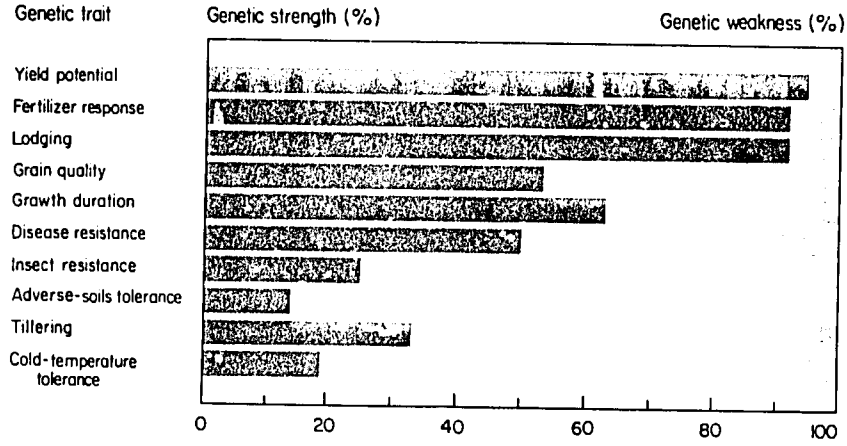
In 1965–67, 61% of the crosses involved at least one semidwarf parent; by 1974–75 semidwarfs were involved in 84%. Taichung Native 1 (TN1) and IR8 were the most popular gene sources in 1965–67; each was used in about 20% of the crosses. But by 1974–75 TN1 use dropped to only 1%, and IR8 to only 3%. During the same period, the use of other semidwarfs from IRRI increased to 44% of the total and that of locally developed semidwarfs to about 50%.

The genetic makeup of the local semidwarf parents was traced back two generations. About 76% had IR8 or other IRRI rices as parents, and 25% was progeny of locally developed semidwarfs. Eighty percent of the second-generation ancestors of local semidwarfs was progeny of TN1 and 33% had IR8 in their ancestry (Fig. 18).

Yield potential, fertilizer response, and lodging resistance were breeding objectives in 80% or more of 1974–75 crosses. Grain quality was an objective in 73%; growth duration, 61%; disease resistance, 53%; insect resistance, 41%; cold tolerance, 11%; and drought resistance, 6%.

Semidwarf rices were almost invariably used as parents for the yield, fertilizer-response, nonlodging complex and were usually used as donors of disease and insect resistance. But tall varieties were most often used as donors of preferred grain quality. Semidwarfs that breeders used for grain quality or growth duration were generally locally developed, but 60–70% of the semidwarfs used for pest resistance were from IRRI.

Among the 36 newest varieties released in 10 countries about 70%



19. The 10 major genetic strengths and weaknesses of 36 newest rice varieties released at 27 agricultural experiment stations and universities in Asia, based on data analyzed from a 1975 survey.

were semidwarf. Seventeen were progeny of IR8. Desired growth duration was a favored genetic trait of 64% of the new rices; earliness, of 50%. Grain quality was a favored trait of 53% and resistance to at least one disease, of 50%. Figure 19 shows 10 major genetic strengths and weaknesses of the newest varieties cited in the survey.

Control and management of pests

Diseases, insects, and weeds that attack or compete with the rice plant continue to impose risks on rice farming throughout Asia. The appearance early in 1977 of the new virus disease ragged stunt – spread by the brown planthopper as is grassy stunt – suggested the nature of the risk. Weeds took an increased toll of rice yields in 1977 in water-short areas. And with the emergence of its different biotypes, the brown planthopper again showed its ability to directly devastate thousands of hectares at a time.

Controlling rice pests with efficient chemicals, or with a combination of chemicals and crop management, adds to the advantage of growing disease- and insect-resistant varieties and cuts farm risks of yield loss.

DISEASES

Ragged stunt, a new virus disease of rice, was reported by Philippine government scientists in southern Philippines in January 1977. The disease was found at IRRI in February and was reported at several Philippine sites and later in Indonesia, India, Sri Lanka, and Thailand.

Many farmers suffered severe yield losses because of it.

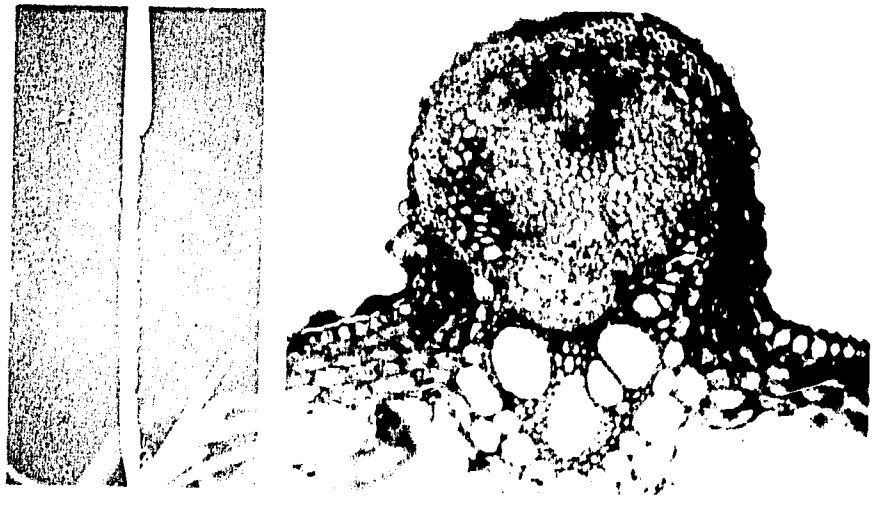
Our plant pathologists immediately started a near-emergency effort to identify the disease and assess its potential for damage to the rice crop.

Ragged stunt

The symptoms of ragged stunt vary according to stage of plant growth. They include various degrees of stunting at all growth stages and ragged and twisted leaves, vein-swellings, nodal branches, and incomplete emergence of panicles (Fig. 20). We were unable to transmit the disease by mechanical means, through the soil, or by seed. The brown planthopper is the only known vector of the disease.

Three biotypes of the brown planthopper that differed in ability to attack rice varieties did not differ strikingly in their ability to transmit ragged stunt. Electron micrographs indicated the presence of 50- to 70-nm virus particles in phloem cells and in the cells of the vein-swelling area of an infected rice plant. A rice plant can be dually infected with both ragged stunt and grassy stunt or both 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.

IRRI research on control and management of rice pest gives major emphasis to the brown planthopper. Each field cage keeps brown planthoppers on four hills of rice for measurement of hopper damage to the plants during different lengths of time at different stages of growth.



20. The center photograph shows a rice plant attacked by ragged stunt in the paddy. Some characteristic symptoms of the disease are stunting (plant at upper left), nodal branches (upper right), and ragged leaf (lower left). Both the healthy and the diseased, stunted plant (upper left) were found in the field and potted for the photograph. At lower right is a microscopic cross section of vein-swelling that results from the virus attack.

Table 18. A 5-year study of tungro vectors in 37 Filipino farmers' fields confirmed that the incidence of rice tungro disease in paddy fields can be used to predict later outbreaks of tungro in the main wet-season rice crop. The 1974 incidence was affected by an intensive green-leafhopper control program in the study area during July and August.

Year	Insect vectors found in April–June		Tungro disease incidence in June–October (%)
	No./10 sweeps	Infective (%)	
1973	5.8	0	0.60
1974	11.0	1.77	2.38
1975	9.8	0.69	3.32
1976	3.9	0.18	0.33
1977	3.0	0	0.03

Tungro forecast confirmed

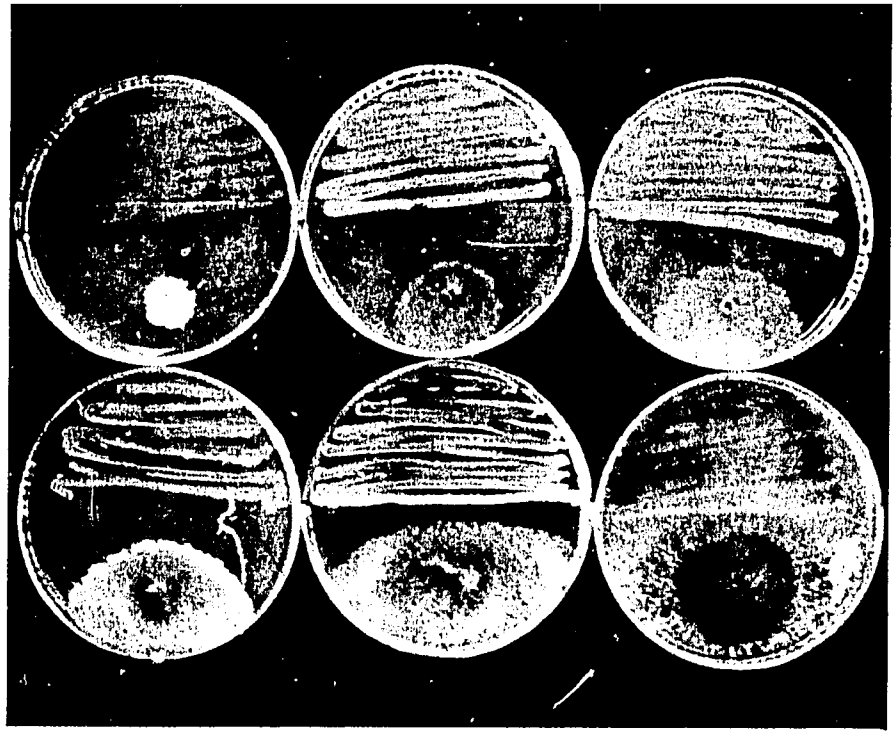
Our 1977 work on a continuing 5-year study of tungro disease in 37 rice farmers' fields confirmed our 1976 hypothesis that tungro outbreaks can be predicted. Farmers can therefore prepare to control the insects that carry the tungro virus and stop its spread in a field.

The tungro incidence from June to October can be predicted from the number of insects and the percentage of those that are infective for tungro in April, May, and June.

The 1977 results (Table 18) substantiated our 1976 hypothesis. The number of insect vectors and the percentage of infective insects in April, May, and June were lower than those of the previous years. Similarly, the 1977 tungro incidence from June to October, the period of the rainy-season rice crop, was lower than that in previous years.

New approach to sheath blight

Because we have not found a high level of genetic resistance to sheath blight among the many thousands of varieties tested, we started research on other ways to reduce sheath blight damage. Sclerotia that remain in the field from previous crops are the major inoculum source for sheath blight. We studied their survival, with particular attention to natural enemies among the microorganisms associated with them. Several bacteria isolated from field water and from the sclerotia have activities antagonistic to sheath blight (Fig. 21). The population of bacteria in the field water was increased about a hundredfold by the addition of rice straw. Our initial tests are



21. Some bacteria in paddy water antagonize sclerotia of sheath blight, which drop off a diseased plant and remain in a rice field and infect a following rice crop. The bacteria in the plate (upper left) almost completely stopped the sclerotia from growing, while the sclerotia without bacteria thrived (lower right). Increasing the number of antagonistic bacteria in field water could offer biologic control of sheath blight.

encouraging but we face difficulties in finding a practical method to use the bacteria in the field.

INSECTS

Insects that damage rice can be effectively controlled with existing insecticides, and our research with insecticides includes laboratory and field evaluation of their effectiveness at given rates and methods of application. Research on management as a means of controlling rice insects is, however, in the early stages in the tropics. Its progress is reflected in Figure 22.

Evaluation of insecticides

We continued greenhouse evaluation of insecticides and found several formulations effective against the three major hopper species when applied as foliar spray (Table 19).

Recent research has shown that certain insecticides remain effective longer when applied in the rice root zone than when broadcast on paddy water. Greenhouse studies in 1977 identified granular insecticides as effective against planthoppers and leafhoppers at rates of only 0.5 kg active ingredient/ha when applied in the root zone (Table 20). The broadcast rate is usually more than 2 kg/ha.

In work to develop a root-zone application method we investigated use of perlite, a volcanic material. When seedling roots were dipped in a suspension of perlite and carbofuran the perlite stuck to the

Insect	Whorl maggot	Green leaf-hopper	Zigzag leaf-hopper	White-backed plant-hopper	Brown plant-hopper	Yellow stem borer	Striped stem borer	Leaf folder	Rice bug
DECISION MAKING									
• Economic thresholds									
• Surveillance system									
• Forecasting									
VARIETAL RESISTANCE									
CHEMICAL CONTROL									
• Effective insecticides									
• Selective insecticides									
• Timing (based on life cycle)									
• Minimum effective rates									
• Sex pheromones									
BIOLOGICAL CONTROL									
• Augmentation of natural enemies									
• Prediction of natural enemy effectiveness									
• Importation of natural enemies									
CULTURAL CONTROL									
• Fertility management									
• Weed management									
• Water management									
• Crop residue management									
• Trap crop									
• Spacing									
• Cropping pattern									

Key to symbols:

- Component available for use in integrated rice pest management.
- Component available but more research needed to increase effectiveness.
- Component available but incompatible with other management practices.
- Component not available, but research currently being conducted.
- Component not available, nor is any research being conducted.

22. The status of development of rice insect pest management systems at IRRI.

Table 19. Several insecticides in 1977 greenhouse tests were effective as foliar sprays against the brown planthopper (BPH), green leafhopper (GLH), and whitebacked planthopper (WBPH). The insecticides were applied as 0.04% solutions. A plus (+) sign indicates 80% or higher mortality and a minus (–) indicates the insecticide was not effective.

Insecticide	Formulation	Mortality		
		BPH	GLH	WBPH
A 47171	24 EC	+	+	+
ABG 6070	48 EC	–	+	+
ABG 6071	24 EC	–	+	+
Acephate	75 SP	+	+	+
Azinphos ethyl	40 EC	+	+	+
Bendiocarb	80 WP	+	+	+
BMPC	50 EC	–	+	–
Carbofuran	20 F	+	+	+
Carbophenothion	30 EC	+	+	+
Carbaryl	85 WP	+	+	+
Cypermethrin	40 EC	+	+	+
FMC 35001	48 EC	+	+	+
Fenvalerate	20 EC	+	+	+
Fensulfothion	63 EC	+	+	+
Fenthion	50 EC	–	+	+
Monocrotophos	16.8 EC	+	+	+
Methyl parathion	50 EC	–	+	+
Perthane	45 EC	+	+	+
Permethrin	10 EC	+	+	+
Phenthoate	50 EC	–	+	+

seedling roots and became a reservoir for carbofuran, which was then released to the roots after transplanting. In greenhouse studies an application of 0.15 kg active ingredient carbofuran/ha applied via perlite provided 100% mortality of brown planthopper immediately after transplanting and gave effective control for an additional 30 days.

Resurgence and resistance to insecticides

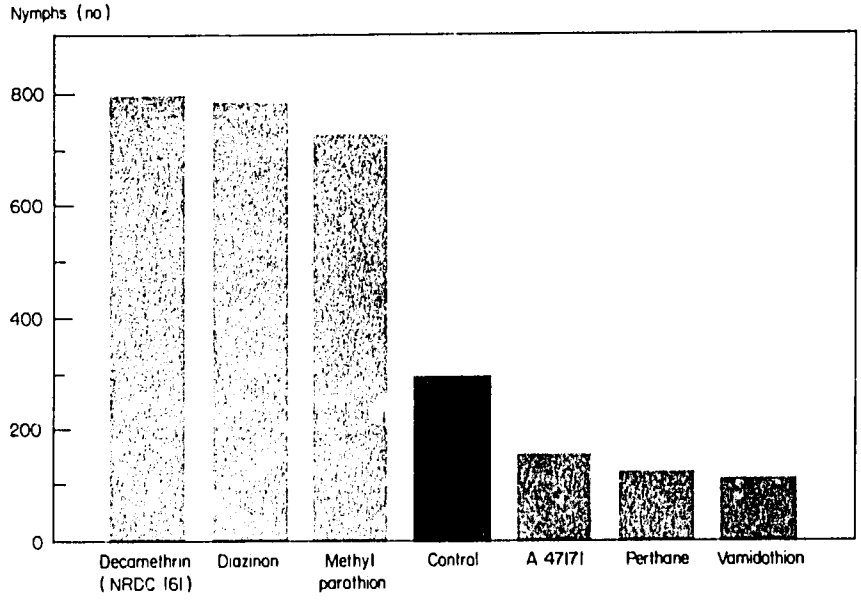
Increases in brown planthopper damage where certain insecticides are applied have been observed throughout Southeast Asia. It is known that insecticides destroy the natural enemies of the brown planthopper, but our entomologists are also studying the possible effect of insecticides on plant chemistry and on the insect.

Greenhouse studies confirmed that some insecticides, especially when used at sublethal doses, stimulate brown planthopper reproduction. Reproduction increased when adult females were placed on plants 15 days after spraying (Fig. 23).

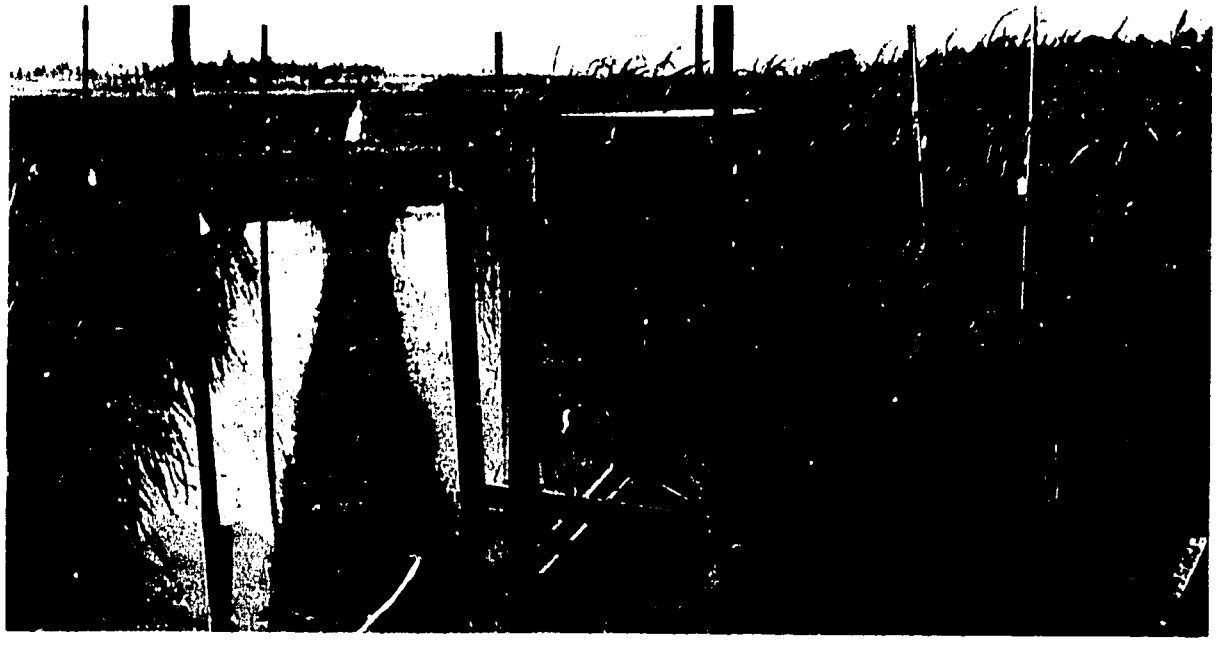
Table 20. Greenhouse studies in 1977 identified four granular insecticides effective against the three major hoppers – brown planthopper (BPH), green leafhopper (GLH), and whitebacked planthopper (WBPH) – attacking rice when the compounds were applied to the root zone at 0.5 kg active ingredient/ha. A plus (+) indicates 80% or higher mortality of hoppers; the minus (–) signifies not effective.

Insecticide	Mortality		
	BPH	GLH	WBPH
Carbofuran	+	+	+
FMC 35001	+	+	+
FMC 27289	+	+	+
Bendiocarb	+	+	+
Aldicarb	–	+	+
BPMC	–	+	+
Cytrolane	–	–	+
Diazinon	–	–	–

Field control of the brown planthopper by carbofuran at the IRRI experiment station was poor in 1976. In 1977 we started studies to determine if insect resistance to carbofuran had developed. The greenhouse strain of the brown planthopper – never exposed to carbofuran – was compared with the field strain. The lethal dosage of carbofuran for the field-grown hoppers was more than seven times that required for the greenhouse hopper. It was evident that the



23. The brown planthopper's reproductive rate increased after sprays with the three insecticides on the left. Five adult female hoppers were placed on the plants 15 days after the last spray and were allowed to oviposit for 7 days. (Rate of insecticide was 0.75 kg active ingredient/ha at 20, 30, and 40 days after transplanting, except for NRDC 161, which was applied at 0.10 kg active ingredient/ha.)



Research on the control of the stem borer includes use of the female sex pheromone to confuse the male moth. The circular pan trap contains a small vial of male attractant. On the stakes around the trap are vials of the pheromone in high dosage. Effectiveness of the pheromone is related to the number of male moths trapped in the pan. This research is in collaboration with the Tropical Products Institute, London, England.

brown planthopper in the field had developed resistance to carbofuran after several years of the insecticide's use at IRRI.

Biological control

We confirmed that a female sex pheromone completely confuses the male stem borer moths and disrupts mating. Studies with pheromone mimics – (Z)-9-tetradecenyl formate and (Z)-11-hexadecenyl formate – as attraction inhibitors indicate their good potential for controlling stem borers by disrupting mating. The pheromone-mimic inhibitors are more stable in sunlight than the confusion pheromone.

WEEDS

Our primary goal is to develop weed control technology that meshes with the practices and resources of the Asian rice farmer – in short, an effective means of weed control the farmer can afford. We continued research to identify effective herbicides for rice and associated upland crops, but gave increased attention to the effects of cultivar, tillage, water depth, and season.

Herbicide performance

Advanced trials at IRRI and at three stations of the Philippine Bureau of Plant Industry showed eight herbicides or combinations highly

Table 21. Trials at four sites in the Philippines tested both the existing and the new herbicides to determine their best use on a rice crop. Those herbicides with slant bar (/) were applied as a mixture, the plus sign (+) indicates herbicides applied separately at about the same time.

Herbicide	Previously tested	New formulation	Highly effective 1977 on	
			Transplanted	Direct seeded lowland
MT-101/thiobencarb	√		√	√
NTN 5810/2,4-D	√		√	√
X-52/2,4-D	√		√	√
Benzglycereth	√		√	√
Butachlor + 2,4-D	√		√	√
Pendimethalin	√		√	√
Piperophos/2,4-D	√		√	√
Oxadiazon	√		√	
M3432 + 2,4-D	√			√
CGA 26423		√	√	
R-40244		√	√	
RH 6201		√	√	
Fluridone		√	√	
Oxyfluorfen		√	√	

effective for transplanted rice, eight herbicides or combinations effective for direct-seeded rice, and five new herbicides promising for transplanted rice (Table 21).

Cultural practices plus herbicide

We studied the complementary effects of herbicides, tillage, and water depth on weed infestation and yield of a semidwarf and a medium-tall rice variety.

Table 22. The comparative yield of medium tall (IR34) and semidwarf (IR36) varieties as affected by number of harrowings, water depth, and herbicide treatment.

Treatment	Dry season yield (kg/ha)			
	2.5 cm H_2O		7.5 cm H_2O	
	IR34	IR36	IR34	IR36
		No herbicide		
1 harrowing	1.4	0.0	1.8	1.8
2 harrowings	1.2	0.7	3.6	1.8
3 harrowings	3.1	0.9	4.7	3.5
		Herbicide		
1 harrowing	3.5	5.1	4.3	4.3
2 harrowings	4.2	5.2	5.0	5.9
3 harrowings	5.3	5.8	4.6	6.1

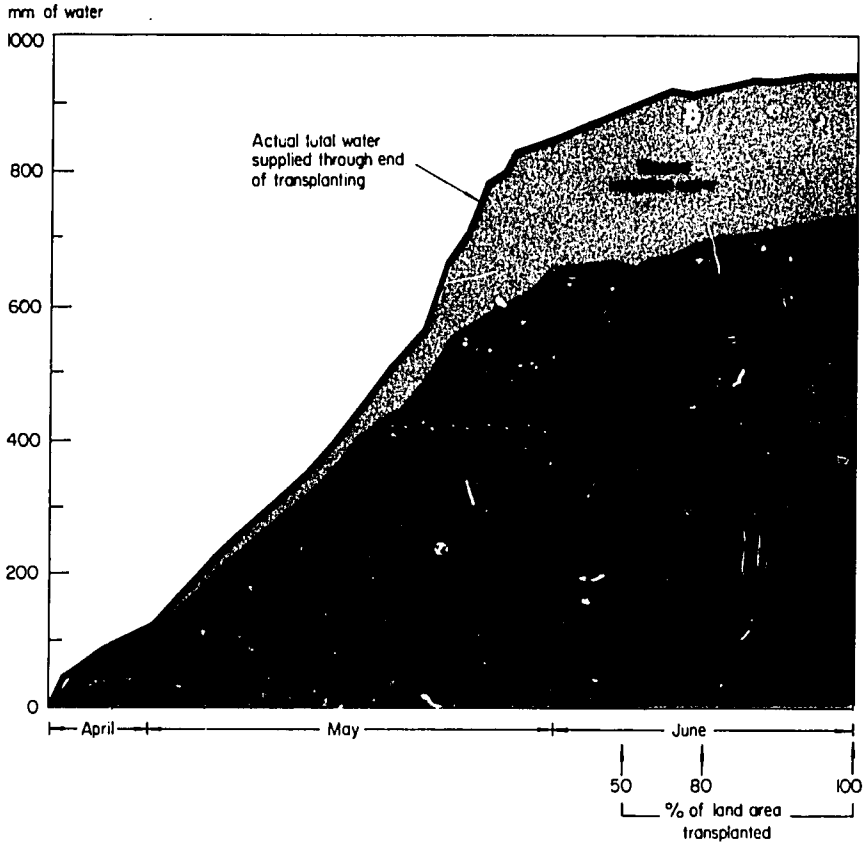
The medium-tall IR34 and the semidwarf IR36 were direct seeded in paddies that had been harrowed one, two, or three times. Two water depths and one herbicide treatment were superimposed on the tillage treatments. The medium-tall IR34 generally outyielded the semidwarf IR36 where no herbicide was used, especially if the water depth was kept low (2.5 cm). The opposite was true when herbicide was used. Apparently the taller variety was better able to compete with weeds. Tillage helped control weeds and increase yields of both varieties without herbicide (Table 22).

After the fifth rice crop in a separate long-term study of the effects of reduced tillage on weeds, conventional tillage continued to produce less weeds. The use of the heavy-tillering line IR1632-93-2-2 resulted in lower weed weight at harvest for all tillage systems.

This dry-season aerial view of part of an irrigation system in Central Luzon, Philippines, sharply reflects the potential for increased rice production with irrigation. IRRI research seeks technology that will increase the efficiency of all inputs to irrigation systems.

Irrigation and water management

Inefficient management of water remains a major constraint in realizing full benefit from many irrigation systems. We try to improve irrigation system management and on-farm delivery of water.



24. In a study of a 145-ha, 85-farmer irrigated unit in the Philippines the total water supplied was 250 mm more than needed for land preparation and transplanting. Better management by irrigation workers and farmers could have reduced water use by 25% and cut 18 days off land preparation time.

Water and time requirement for land preparation

More than 40% of the total water supplied to lowland rice is often supplied before the crop is transplanted. We studied the water delivery requirement and time for land preparation for 85 farmers on 145 ha in a Philippine irrigation unit. A total of 950 mm of water was supplied from irrigation and rainfall to complete land preparation, but 250 mm was wasted through surface drainage. More than half of the 700 mm balance was lost as seepage and percolation (Fig. 24). The main reason for the high water delivery requirement was that the farmers took more than 2 months from time of first water delivery to complete transplanting.

About 70% of the farmers cited undependable delivery of water as their chief constraint to rapid land preparation. Skeptical of the continuity of water delivery after the start of irrigation, they wait for an assured supply of water before starting land preparation. They also delay seedbed planting until water is assured.

We were able to show that better water management could pro-

duce considerable savings of water. If water had been supplied at a rate of 22 mm/day – the maximum design rate – instead of the actual average rate of 9 mm/day during the initial irrigation period, 12 days would have been saved in the soaking period and the 85 farmers in the area would have completed land preparation 18 days earlier. That would have saved 25% of the total water delivered for land preparation.

In many remote areas, farmers could not begin land preparation until almost a month after first water release. They were unable to make up for that delay because they had to wait about 27 days for seedlings to reach transplanting age. Improved water management would offer farmers in remote areas the option to transplant 14-day-old *dapog* seedlings and further reduce the total water requirement.

Field water management saves nitrogen

We studied the effects of three major practices of field water management and two methods of nitrogen application at four sites. Our water management treatments were

- continuous flow of irrigation water across the field after nitrogen application,
- infiltration flow, where the field was not drained for 5 days after nitrogen application, and
- temporary drainage, where the field was drained 1 day before and irrigation water was applied 2 days after nitrogen application.

In all water management treatments nitrogen was either topdressed or incorporated into the soil before rice was transplanted. Net losses of nitrogen were calculated from the differences between amounts of nitrogen in water entering and leaving the treated paddies.

As expected, the greatest net loss of nitrogen in irrigation water occurred in the treatment that combined topdressing and continuous water flow (Table 23). No net loss of nitrogen occurred with the infiltration flow in either season. Instead we noted that even the nitrogen from irrigation water was retained in the paddy by the soil and plants. A nitrogen loss in paddy water from the temporary-drainage treatment occurred only when nitrogen was topdressed in the wet season.

Rice yield was significantly higher with incorporated nitrogen than with topdressed nitrogen for all water management treatments in the wet season. Mean yields were higher for the nitrogen-incorporation treatment in both seasons. Farmers generally topdress their nitrogen into standing water. Our results suggest that a combined water-

Table 23. In a two-season study of the effect of field water management and method of nitrogen application, the loss of nitrogen in irrigation water was greatest in a treatment combining topdressing of nitrogen and continuous water flow.

Fertilizer[a]	Water management					
	Continuous flow		Infiltration flow		Temporary drainage	
	Wet	Dry	Wet	Dry	Wet	Dry
			Net nitrogen[b] (kg N/ha)			
Topdressed	-3.4	-4.2	1.0	5.1	-0.3	0.8
Incorporated	-1.2	-0.8	0.9	4.3	0.5	3.4
			Grain yield[c] (t/ha)			
Topdressed	3.7 a	4.3 a	4.0 a	4.3 a	3.8 a	4.2 a
Incorporated	4.0 b	4.5 a	4.7 b	4.6 b	4.0 b	4.3 a

[a]For all treatments nitrogen fertilizer was applied at 20 kg N/ha before transplanting and 40 kg N/ha 45 days after transplanting.

[b]Negative value reflects net loss and positive value reflects net gain.

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

fertilizer management practice where fertilizer nitrogen is incorporated into the soil and water is retained for at least 5 days has the best potential for high rice yield.

Instrumentation for water flow measurement

Measurement of irrigation water flow is as much required in effective everyday operation of an irrigation system as it is in water management research. But an effective, reasonably priced, flow-measurement device is needed. We designed, fabricated, and tested a low-cost vane-type instrument measuring water flow in the field.

25. An IRRI-developed, low-cost vane-type instrument installed on a trapezoidal concrete channel in a Philippine irrigation system.

The vane instrument allows us to determine the amount of water flowing in an open channel. Its advantages over other available devices are that it operates with little or no headloss, accounts for backflow, and is sensitive to almost all water levels and velocities. It is also inexpensive, easy to build and operate, and gives accurate flow measurement. Its disadvantages are a tendency to catch weeds and debris from the water and to be affected by strong winds.

We designed and fabricated prototype vane instruments for channels with rectangular and trapezoidal cross sections at about US$10 each (Fig. 25). Their calibration has shown a high correlation (r^2 = 0.98) with actual flow quantities measured by other reliable methods. Eight instruments have been installed for operation and research purposes.

Soil and crop management

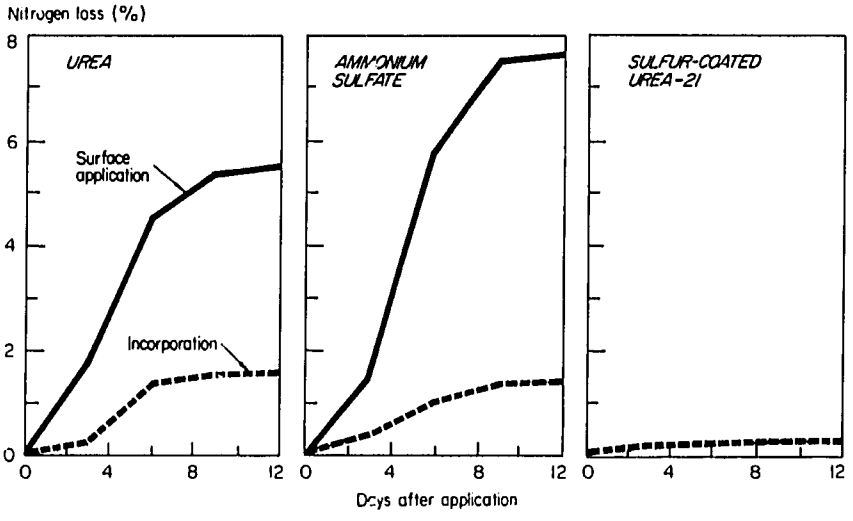
Efficiency is a key word in soil and crop management research. Fertilizer remains a major contributor to high on-farm yields from modern rice varieties but many factors influence the efficiency of fertilizer use. But high fertilizer prices cause the farmer to say he can't afford to use fertilizers at levels called for by the new rice technology. And often farmer practices cause high losses of applied nitrogen.

Our research seeks a basis for soil and crop management recommendations that will make farmer use of fertilizer more efficient and more profitable.

Nitrogen losses

Much of the nitrogen fertilizer applied by rice farmers in South and Southeast Asia is either broadcast onto a wet soil and incorporated before transplanting or broadcast into shallow water after transplanting. We consistently find that placement of nitrogen fertilizer in the soil at depths of 10 to 12 cm gives high fertilizer use efficiency. We continued research started in 1976, which had suggested that part of the increased fertilizer efficiency is due to a reduction in ammonia losses when nitrogen is placed in the rice plant's root zone (Fig. 26). Sources of nitrogen also affect nitrogen efficiency in the soil.

In experiments during the 1977 dry season we found that grain yields and efficiency of fertilizer use were generally best when nitrogen was placed 10 to 15 cm deep in the soil in mudballs. When 84 kg N/ha was applied in mudballs or broadcast and incorporated as sulfur-



26. A loss of nearly 8% of nitrogen from ammonium sulfate applied on the soil surface drops to less than 0.5% nitrogen loss when sulfur-coated urea-21, a slow-release fertilizer, is incorporated in the soil. The photograph at right shows the IRRI greenhouse setup for measurement of ammonia volatilization from soils.

coated urea, yields were similar to those obtained when 120 kg N/ha was applied as ammonium sulfate in split doses (Table 24).

In another study, deep placement of urea using an IRRI-designed plow-sole applicator gave a yield similar to that from deep placement of urea briquets but significantly higher than that from split application of nitrogen at an equal rate. Grain yield with 56 kg N/ha as urea deep-placed by the plow-sole applicator was 5.2 t/ha. Split application of urea at 56 kg N/ha gave 4.2 t/ha, and at 84 kg N/ha it gave 4.8 t/ha.

Table 24. At IRRI and in three farmers' fields in the Philippines, the 1977 dry-season yields obtained by applying 84 kg N/ha in mudballs or broadcast and incorporated as sulfur-coated urea were similar to those obtained by applying 120 kg N/ha in split doses.

Treatment	Yield[a] (t/ha) of IR36 on			
	Neutral Alfisol (IRRI)	Acid Ultisol (Luisiana, Laguna)	Neutral Vertisols	
			Teresa, Rizal	Tanay, Rizal
No fertilizer N	3.2 g	3.5 e	3.0 h	4.0 e
		84 kg N/ha		
Split application	6.3 cdef	5.6 c	5.5 bcde	5.7 cd
Band placement	7.0 abc	5.0 abc	4.9 efg	6.2 efg
Mudball placement	6.9 abcd	6.1 ab	5.6 bc	6.1 b
Supergranule placement	6.4 cdef	6.1 ab	5.5 bcd	6.0 bc
Sulfur-coated urea	7.6 a	6.4 a	6.3 a	6.6 a
		120 kg N/ha		
Split application	7.3 ab	6.3 a	6.0 ab	6.3 ab

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

Table 25. In 1977 experiments at IRRI, organic matter and nitrogen content increased with time as straw was incorporated into a flooded rice soil.

Straw	Content after 5th crop, averaged for 3 soils[a]		Content after 10th crop, averaged for 3 water treatments[b]	
	Organic matter (%)	Nitrogen (%)	Organic matter (%)	Nitrogen (%)
Removed	2.57	0.138	3.68	0.174
Incorporated	2.70	0.157	4.52	0.198

[a]Greenhouse study. [b]Field study.

Nitrogen gains in flooded rice soils

The nitrogen content of a soil can be increased by continuous submergence and by straw incorporation. In a controlled study of three soils we confirmed marked gain of nitrogen in soils kept continually flooded (flood fallow). The mean nitrogen contents for three soils just before the 24th crop were 0.186% for flood fallow, 0.182% for flood fallow with midseason soil drying, 0.126% for dry fallow, and 0.118% for dry fallow with midseason soil drying.

Straw incorporation increased the organic matter and nitrogen content of the soil in both drum and field experiments (Table 25).

Biological nitrogen fixation

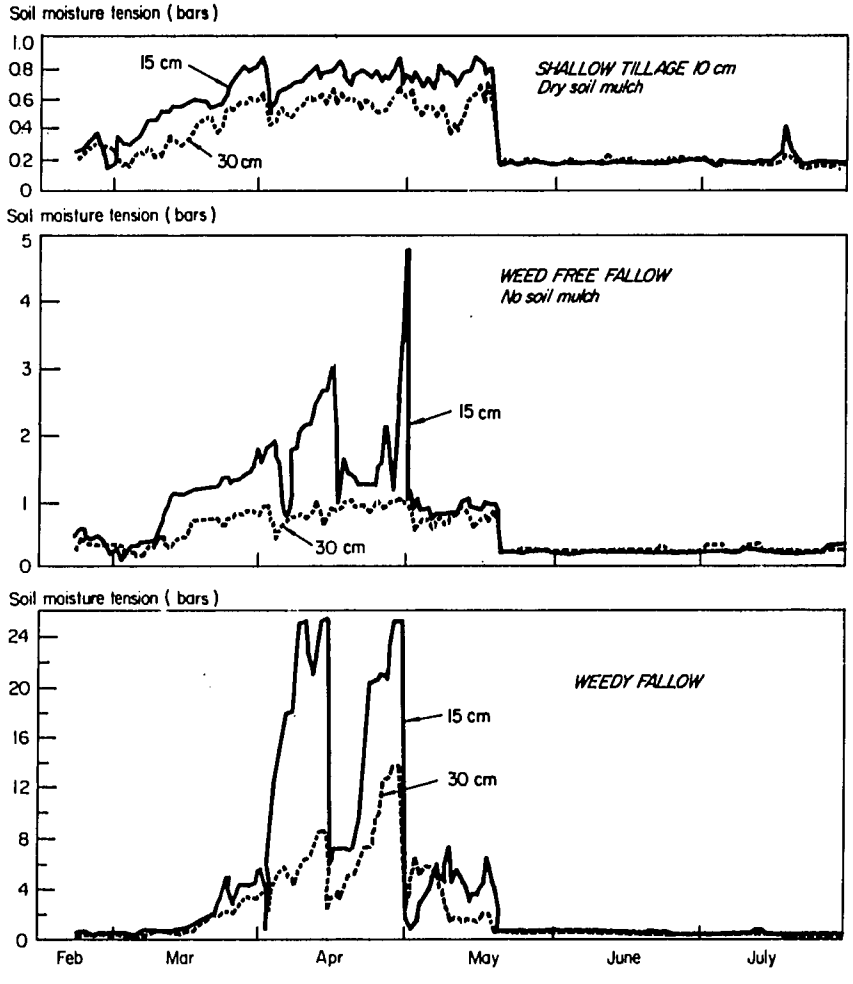
Biological fixation of atmospheric nitrogen and its potential use for the rice crop received increased attention in 1977.

We used two methods to quantify biological nitrogen fixation in flooded soil nitrogen balance studies and acetylene reduction assays. Both techniques suggest higher nitrogen fixation by blue-green algae in the paddy flood waters than by organisms associated with rice roots.

We measured nitrogen fixation in the root zone of several rice varieties and of some plants of related *Oryzae* species. Although some differences were noted, no variety had a consistently higher nitrogen-fixing activity.

Dry soil mulch and moisture conservation

Soil moisture tension under a dry soil mulch for dryland rice culture did not exceed 1 bar at any time during the 1977 dry season. Although some moisture was conserved by keeping the fields weed free, moisture tension went higher than it did in soil-mulched plots. Plots that were fallow with weeds had about 25 bars soil moisture tension at a 15-cm depth by the end of the dry season (Fig. 27).



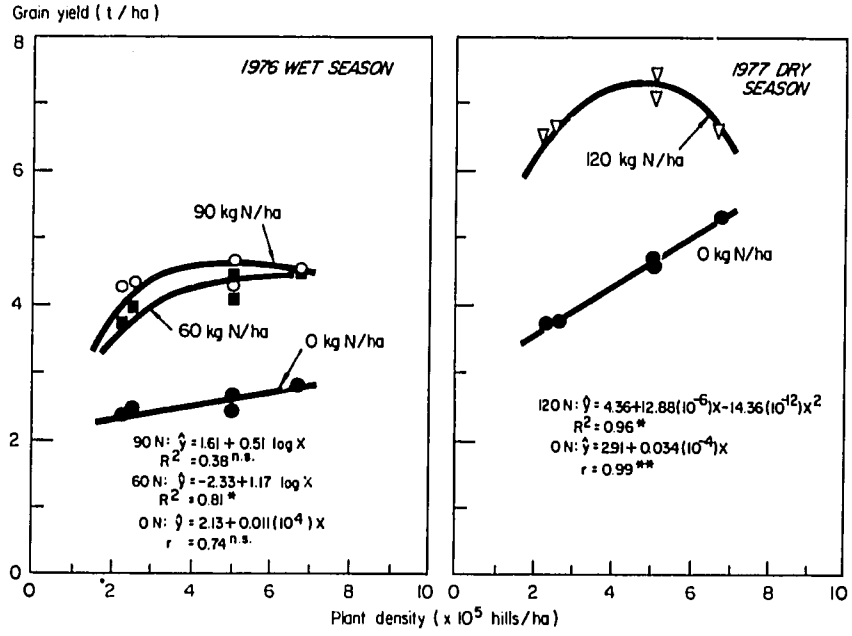
27. Weeds allowed to grow in an unbunded dryland soil during the dry-season fallow created a soil moisture tension (SMT) of 25 bars at a 15-cm depth. Under a weed-free fallow the SMT at 15-cm depth approached 5 bars. When shallow tillage created a soil mulch the SMT at 15 cm stayed below 0.9 bar throughout the season.

These results on dryland unbunded rice fields follow a trend similar to that reported in 1976 for dryland bunded fields.

Plant density and spacing, and nitrogen efficiency

Plant densities were tested at different spacings with different nitrogen fertilizer treatments. The factors studied were planting dates (to study solar radiation and temperature effects), cultivars (with different growth durations), and nitrogen fertilizer treatment (two rates and four times of application). Up to a certain level, an increase in grain yield is possible with an increase in either rate of nitrogen application or plant density, or both (Fig. 28).

In the wet season IR26 and IR36 yielded higher at 20- X 10-cm



28. Grain yield increased with increase in either rate of fertilizer application or plant density, or both in the 1976 wet and 1977 dry seasons.

spacing than at 40- X 5-cm. In the dry season, that increase was not observed; the first crop of IR36 actually yielded more at the 40- X 5-cm spacing than at 20- X 10-cm (Fig. 29).

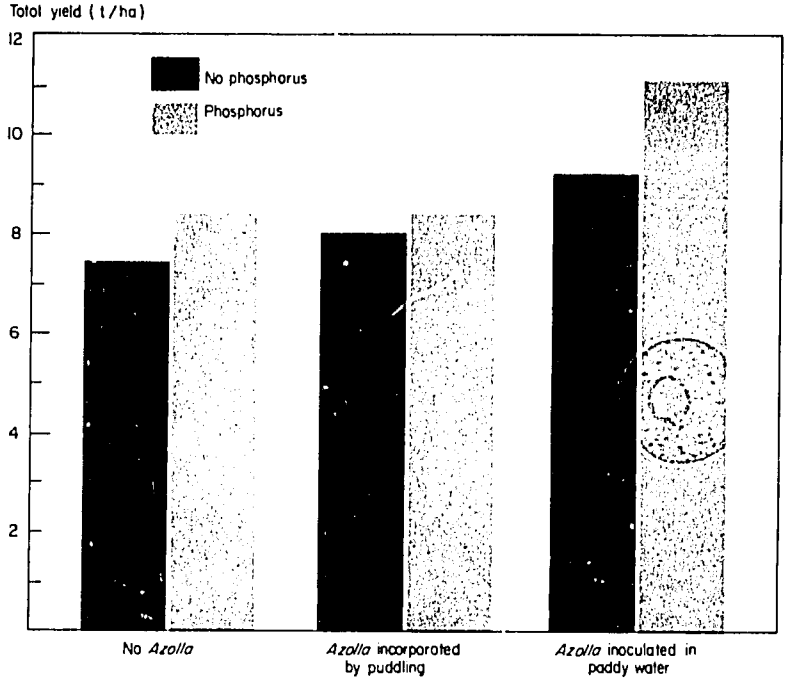
Potential of *Azolla*

We continued to study the potential of the *Azolla-Anabaena* complex to fix nitrogen for use by the rice crop. Studies of the nitrogen

Plant geometry[a]	Grain yield (t/ha)		
	Aug '76[c]	Oct '76[c]	Jan '77[c]
		IR36	
20 cm X 10 cm	4.4	4.2	6.7
40 cm X 5 cm	4.1	3.8	7.1
Difference[b]	0.3**	0.4**	- 0.4**
		IR26	
20 cm X 10 cm	4.2	4.2	6.7
40 cm X 5 cm	3.8	3.9	6.6
Difference[b]	0.4**	0.3**	0.1[ns]

[a] With north-south row orientation.
[b] ** = significant at the 1% level; ns = not significant.
[c] Planting date.

29. Grain yields of IR36 and IR26 were measured for a plant density of 500,000 hills/ha at two rectangular spacings for two 1976 wet season crops and one 1977 dry season crop. Except for the dry season crop, the 20- X 10-cm spacing gave significantly higher yields than the 40- X 5-cm spacing. High yields for the dry season crop were associated with high solar radiation during this period.



30. A total of 11 inoculations of *Azolla* before (6) and after (5) transplanting a rice crop showed that the two-crop 1977 yields were most affected by a treatment that combined *Azolla* inoculation with phosphorus fertilizer.

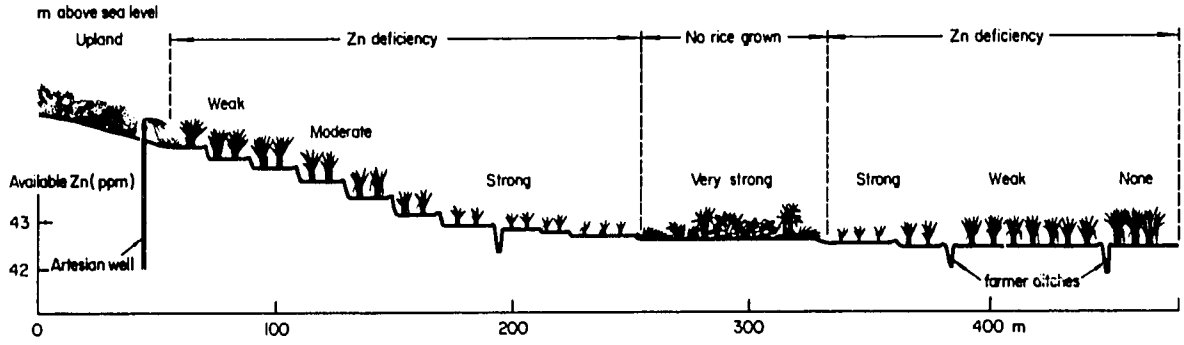
yield of 10 *Azolla* strains put emphasis on temperature and pH effects.

In 1977, 14 crops of *Azolla pinnata*, grown for 220 days in the field, produced 330 kg N/ha. Inoculation and the subsequent incorporation of *Azolla* (before and after transplanting) increased rice yields in 1977 dry- and wet-season crops (Fig. 30). *Azolla* inoculation in the presence of added phosphorus was especially effective in increasing yields.

Amelioration of problem soils

Our studies of zinc deficiency of rice since 1970 have shown that zinc deficiency occurs, regardless of pH, in many continuously wet soils. Zinc deficiency is also common on other soils with high pH regardless of drainage status. We find that most zinc-deficient soils in the Philippines are high in organic matter.

In a 1977 field study at Tiaong, Quezon province, Philippines, we examined the role of landscape in zinc deficiency (Fig. 31). Zinc deficiency appears most severe where underground water surfaces (upwells) and the soil stays wet year-round. Farmers can make ditches to intercept groundwater and reduce the severity of zinc



31. This NE-SW cross section of the Tiaong, Quezon, Philippines, toposequence shows the relationship of zinc deficiency to landscape. Rice growth suffers in the area kept continuously wet by upwelling of groundwater. Note the farmer ditches that cut off groundwater in lower area, which reduced zinc deficiency and improved rice growth.

deficiency, or zinc can be applied to the soil. Table 26 shows the yield response of rice to zinc application at Tiaong.

Table 26. Zinc applied to the soil as zinc sulfate gave a yield of 3.9 t/ha compared to no yield with no zinc on a Lipa clay loam at Tiaong, Quezon province, Philippines.

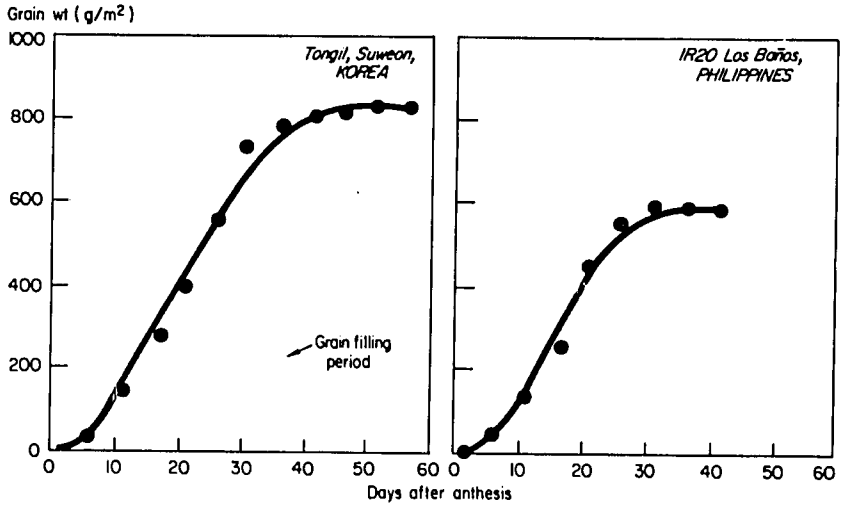
Rice crop	Zn application	Grain yield (t/ha)
Transplanted	None	0
Transplanted	Zinc oxide to roots (2% suspension)	2.7
Transplanted	Zinc sulfate to soil (50 kg/ha)	2.1
Direct seeded	None	0
Direct seeded	Zinc oxide as seed coating (2% of seed weight)	2.4
Direct seeded	Zinc sulfate to soil (50 kg/ha)	3.9

Environment and its influence

The effect of climatic variables – temperature, solar radiation, and water – on rice growth and, hence, on rice yields is often overshadowed by more tangible variables such as diseases, insects, and fertility. Our research continues to seek better understanding of the climatic environment and its influence.

Temperature

Temperature affects spikelet number, the most critical yield component of the rice crop in the tropics. Moderately low temperatures during the rice plant's reproductive stages favor high spikelet number. Temperature also affects the period for grain filling. Cooperative research with Korean scientists indicates that the effective grain-filling period is 22 days at IRRI and 32 days at Suweon, Korea. The



32. The effective grain filling period – the physiological maturity period – of IR20 is 22 days at IRRI; that of Tongil at Suweon, Korea, is 32 days. The 10-day difference is largely due to temperature.

difference is attributed to difference in temperature (Fig. 32).

We ran experiments in 1977 to determine the relative importance of relative humidity and high temperature on sterility of the rice plant, a phenomenon commonly observed in areas with high seasonal temperatures. We found that temperature affected fertilization more than did relative humidity, at least within the vapor pressure deficit range of 12 to 36 millibars (Table 27). This finding emphasizes the need for temperature-tolerant rices for countries such as Iran and Pakistan, where summer temperatures are extremely high.

Table 27. Increase in the temperature and vapor pressure deficit increased the percentage of unfertilized grain of N22 grown in an artificially controlled environment at IRRI.

Day temperature (°C)[a]	Grains at vapor pressure deficit of					
	12 millibars		24 millibars		36 millibars	
	Empty	Unfertilized (%)	Empty	Unfertilized (%)	Empty	Unfertilized (%)
29	11	7	17	12	–	–
32	17	14	30	25	–	–
35	86	78	62	47	82	41

[a]Night temperature was 21°C.

Temperature-nitrogen interaction

With a *mini-crop* of rice in the phytotron we found that within a daily mean temperature range of 22 to 31°C, spikelet number per square meter decreased with increasing temperature. This trend was more pronounced at a high soil nitrogen level than at a low nitrogen

level. The experiment demonstrated that both rice yield and the efficiency of nitrogen are highest with moderately low temperatures during the reproductive stage of the crop.

Water balance

Measurement of water balance is a rational approach to improvement of rainfed and upland rice cultivation. We found a simple energy balance useful in predicting water balance in a paddy field.

Maximum potential evapotranspiration (E) from a paddy field is given by:

$$E = \frac{Rn}{L} = \frac{0.62 \cdot S}{L} = 0.0105 \cdot S(\text{mm} \cdot \text{T}^{-1})$$

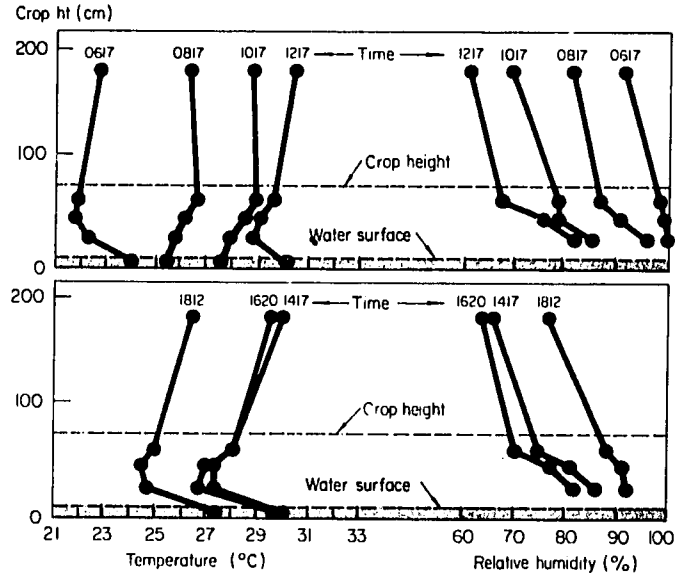
where

- Rn is net radiation,
- S is incident solar radiation, and
- L is latent heat of vaporization.

After the crop has been established, a realistic estimate of evapotranspiration (E_R) is given by

$$E_R = \frac{0.82 \cdot 0.62 \cdot S}{L} = 0.0086 \cdot S(\text{mm} \cdot \text{T}^{-1})$$

Data derived using these two equations agree with pan evaporation data and results of agronomic irrigation experiments at IRRI. With appropriate data on effective soil (or root) depth and available soil



33. The microenvironment under the canopy of different plant types was studied in 1977. This figure shows an hourly record of microclimate for IR747B at 30- x 30-cm spacing on 1 April 1977.

moisture content, we can use the equations to predict the length of dry spell that would induce a water deficiency stress in a rice crop in a certain environment.

Microenvironments

Relative humidity and temperature in the dry season within rice canopies of contrasting plant types were compared. Relative humidity was always higher inside the canopy than outside. Close spacing produced a more humid environment than wide spacing. The relative humidity under a tall, droopy-leaved canopy was not higher than that under a short, erect-leaved canopy. Temperature inside the canopy was generally lower than that outside. Temperature differences as large as 1.4°C were observed between a point down in the canopy (20 cm above water level) and a point above the canopy. Figure 33 illustrates the vertical distribution of temperature and humidity for IR747B2-6 planted at a 30- X 30-cm spacing.

Constraints on increased yields

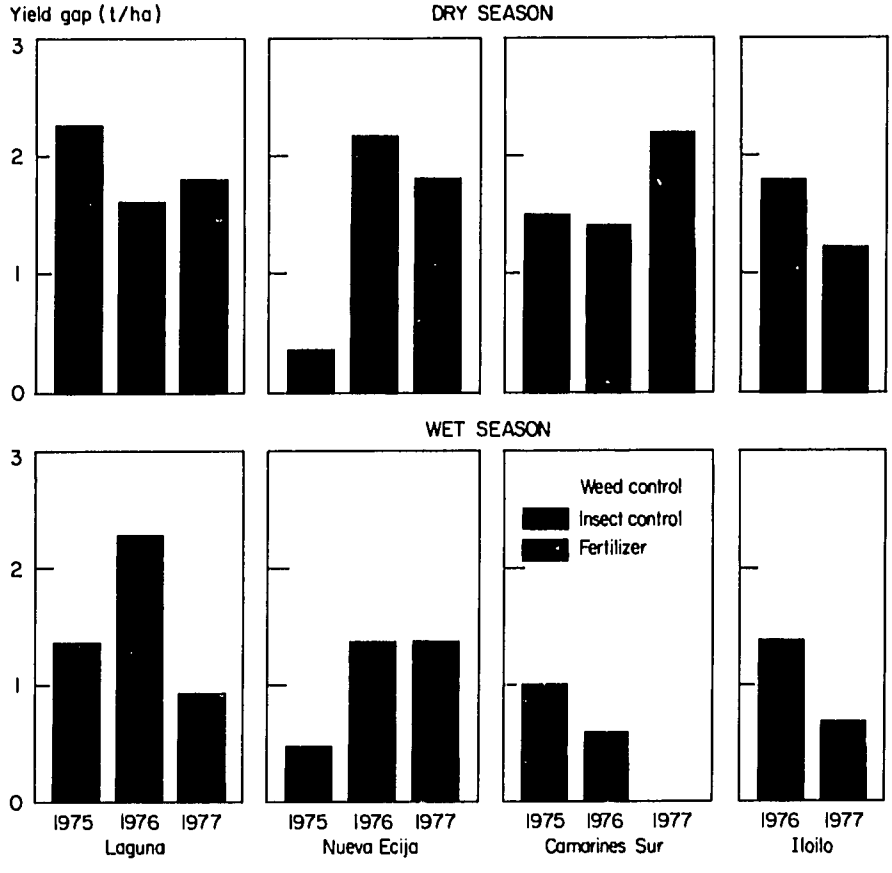
Over the past 3 years, we developed and tested a joint experimental-survey methodology to identify the critical factors that explain the gap between the farmers' actual yield and the potential on-farm yield. We made surveys, in conjunction with our studies in farmers'

The network for research on the constraints to rice yields included cooperative trials in six Asian countries in 1977. The on-site, on-farm nature of the network trials is reflected by this Thai farmer (left) who records rainfall on his farm during the trials, and the Sri Lanka researcher (right) who measures yields from crop-cuts in a farmer's field.

fields, to pinpoint socioeconomic constraints. The methodology was tested during the 3-year period at four sites in the Philippines and in cooperative trials by national level researchers in Bangladesh, Sri Lanka, Indonesia, Thailand, and Taiwan. In 1977 a modification in our research design permitted us to conduct experiments on a much larger number of farms.

The contributions of the individual factors to the yield gap in the four Philippine sites for 1975–77 are shown in Figure 34. The yield gap varied from 0 to 2.5 t/ha, and tended to be larger in the dry than in the wet season. In most cases, fertilizer and insect control contributed to the major portion of the yield gap; weed control never accounted for more than 0.5 t of the difference.

Economic analyses of our data from the Nueva Ecija sites indicate that in the 3-year period, the likelihood of profit is highest for fertilizer in the dry season (Table 28). In the wet season profits for the use of fertilizer, insecticides, and weed control chemicals decreased with application of high level of inputs in 43% of the cases.

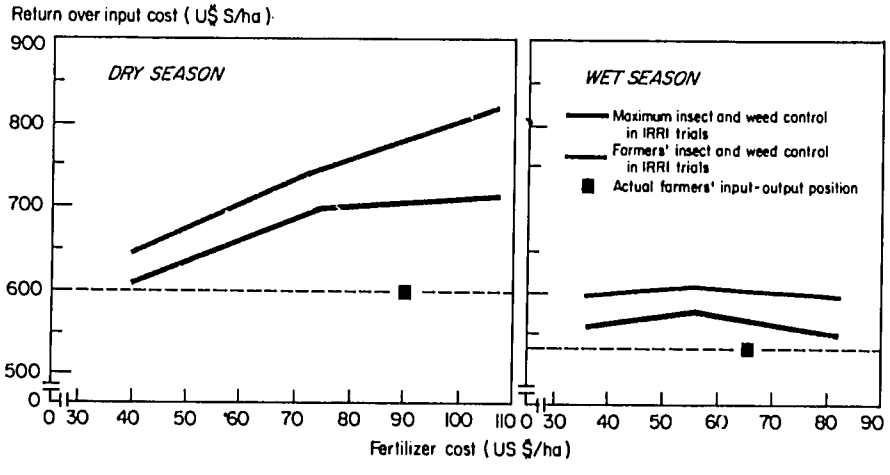


34. Contribution of selected test factors to the gap between farmers' actual yields and the potential on-farm yields as determined by experiments in farmers' fields at four sites. Philippines, 1975–77.

Table 28. The percentage of Nueva Ecija experimental sites where profits increased by more than US$10/ha and where profits declined as a result of the application of the maximum-yield level of inputs indicates the profitability of high and medium levels of inputs by seasons. Figures in parentheses are for medium-level inputs. Weed control has only a high level of input

Year	Percentage of experimental sites with profit changes from					
	Fertilizer		Insect control		Weed control	
	Increase > $10	Decrease	Increase > $10	Decrease	Increase > $10	Decrease
			Dry season			
1975	67	33	0	100	67	33
1976	89 (89)	0 (0)	67 (56)	34 (44)	67	33
1977	86 (86)	14 (14)	71 (14)	14 (86)	43	57
All	84 (88)	10 (6)	58 (38)	37 (62)	58	42
			Wet season			
1974	0	90	20	80	60	40
1975	55	27	18	82	44	27
1976	56 (44)	33 (34)	89 (89)	11 (11)	22	67
1977	56 (67)	33 (33)	56 (22)	33 (44)	22	56
All	41 (55)	43 (33)	44 (56)	54 (28)	44	46

In our surveys we asked farmers why they did not use more fertilizer in the dry season. The two most common answers were, *I thought I applied enough* and *I lacked money*. But our investigation of fertilizer use during four seasons in Nueva Ecija province suggests that almost half of the farmers apply fertilizer inefficiently. When we applied the same amount of fertilizer as the farmers did we got significantly higher returns (Fig. 35). The reason for the apparent



35. Rice yields obtained by farmers (actual farmers' input-output position in both seasons) were consistently lower than the yields IRRI researchers obtained on those farmers' fields using either the farmers' level of insect and weed control, or maximum levels.

inefficiency was not established but may be related to the farmers' method and time of application of fertilizer. Our research in Laguna province, where farmer practices are different, did not substantiate the Nueva Ecija finding.

Consequences of new technology

Our main objective in studying consequences of the new rice technology is to understand the impact or potential impact of technological changes. The current research deals with impact both at the farm level and at the level of government policy for increasing rice production.

The farm-level research focused on village studies. A detailed investigation of a single village laid the foundation for further investigations into the dynamics of rural change. Several village surveys in process will document the changes in institutions that have accompanied technological change and population growth.

A Philippine village family gives Yujiro Hayami, IRRI visiting agricultural economist, information for his survey form. An IRRI publication, Anatomy of Peasant Economy, will be available in 1978.

Implications of a village study

We observed the following from a village study in the Philippines:

- Income of village dwellers was almost exclusively from production within the village and almost 80% comes from rice. Employment opportunities outside the village were limited.
- The expansion of irrigation systems and introduction of modern rice technology have resulted in significant gains in income and production, but the population has expanded rapidly and the proportion of landless laborers is growing.
- Since land reform and the adoption of new rice technology the total income in the village has increased, but large tenants seem to have captured the major benefits. A patron-client relationship has developed, through both the subleasing arrangements and the contracts between tenants and landless laborers. That may have assisted the landless in receiving some share of the gains in productivity from rice production.
- If present trends continue, farm size will decline further and landless laborers will continue to increase in number relative to farmers (Table 29). Real wages will decline and the value of tenancy rights will rise, widening the income gap between farmers and landless workers. With the rising number of landless workers the long-term viability of the village is open to question.

There seems to be ample opportunity for increasing production of both rice and nonrice crops. But capital investment is required to improve irrigation and drainage, land facilities, and livestock. Such capital may be built by mobilizing village labor that is surplus during the slack months of rice farming.

Prospects for Asian rice production

Analyses of sources of output growth for the past decade show that seed-fertilizer technology, and development and expansion of irriga-

Table 29. The trend, based on selected factors examined in a rice-growing village in Laguna, Philippines, 1956–76, is for farm size to decrease and number of landless workers to increase faster than number of farmers.

Year	Population	Household type		Farm size (ha)	Rice yield per ha (t/yr)	Village rice output per ha (t/yr)	Rice output per capita (kg/yr)
		Farmer (no.)	Landless worker (no.)				
1956	317	–	–	2.3	2.5	178	562
1966	383	46	20	2.3	5.5	572	1,493
1976	644	55	54	2.0	6.7	724	1,124

Table 30. 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. Production, total area, and yield data are from the U.S. Department of Agriculture except those for Indonesia and Thailand, which use national sources. Irrigation data are from national sources. Fertilizer data are estimated from FAO *Annual fertilizer review*, national sources, and special studies.

Country	Period	Annual rate of production growth (%)	Proportion of growth (%) attributed to			
			Area		Yield	
			Irrigated	Un-irrigated	Fer-tilizer[a]	Residual[b]
Pakistan	1965–73	7.9	1.4	0.0	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]Calculated on the basis of 10 kg yield/kg of fertilizer.

[b]Includes the contribution to yield of improved quality of land due to higher proportion of irrigated area.

tion account for a substantial portion of rice production growth in all countries studied except Thailand (Table 30).

Most countries seem to have experienced more rapid growth in yield in the periods 1963–67 to 1968–72 than in the following 5-year period (Table 31). There is no substantial evidence that the trend in the rate of output growth is declining for the region as a whole.

Table 31. Growth rates in rice yields in South and Southeast Asia, 1963–67 to 1973–77. The basic data are from the U.S. Department of Agriculture except those for the Philippines, which are from a country source.

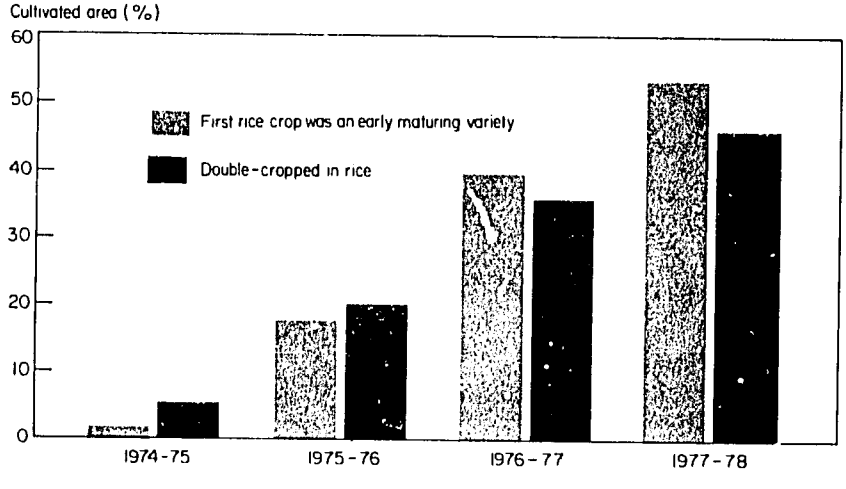
Country	Rice yield (t/ha)			Annual compound growth rate (%)	
	1963–67	1968–72	1973–77	1965–70	1970–75
Bangladesh	1.69	1.67	1.77	-0.24	1.17
Burma	1.54	1.60	1.77	0.77	2.04
India	1.46	1.65	1.73	2.48	0.95
Indonesia	1.77	2.33	2.65	5.65	2.61
Malaysia (West)	2.54	2.76	2.94	1.68	1.27
Pakistan	1.47	2.20	2.27	8.40	0.63
Philippines	1.30	1.54	1.69[a]	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]1973–76 average only.

In 1977 we developed a model to project increasing Asian rice production until 1985 at a rate fast enough to keep pace with demand through investments in fertilizer production, irrigation, research, and extension. The most important finding was that investment in irrigation and fertilizer at the levels considered – much larger than historical levels – will not be sufficient to increase productivity more than 2.4% annually. The study convinced us of the need to undertake detailed projections of consumption and supply on a country-by-country basis. In August 1977, we held a workshop to develop the methodology for a cooperative research project on national rice programs. It was agreed that the research would be conducted initially in three countries – Indonesia, the world's largest importer; Thailand, a major exporter; and the Philippines.

Cropping systems

The advent of the modern, early maturing rices created a need for farmers – especially those growing rainfed rice – to look at changes in their system of cropping. The modern varieties give such farmers – who traditionally grow one crop a year – an added 30–60 days with enough water in the soil for another crop. This implies an opportunity for change in cropping pattern from rice-fallow to rice-rice, or rice-upland crop. An example of such a change is at the IRRI-Bureau of Plant Industry rainfed lowland rice research sites at Iloilo, Philippines, where farmers rapidly shifted to early maturing rice varieties (Fig. 36). The rapid shift was motivated by the potential for increased income from double-cropped rice.



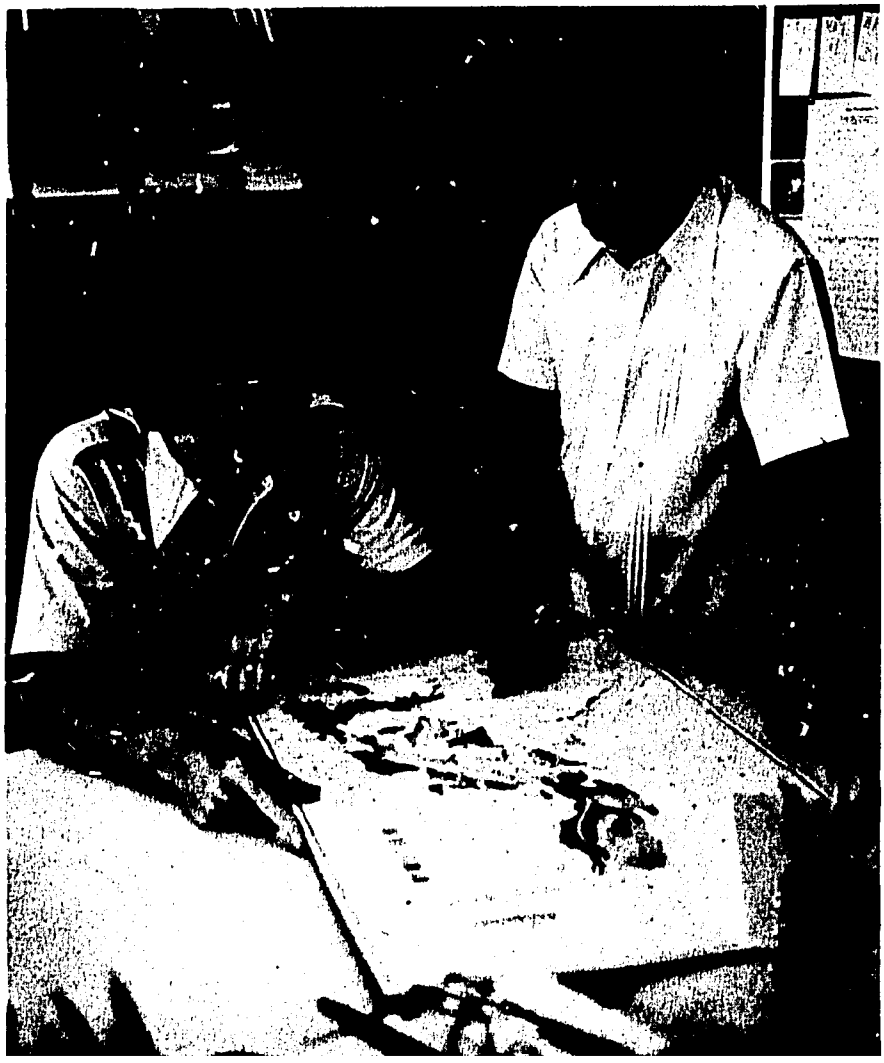
36. Since the start of cropping systems research at Iloilo in 1974 the adoption of early maturing varieties and double-cropping of rainfed lowland rice have increased rapidly. Growth of the practice for the municipalities of Oton and Tigbauan is shown here.

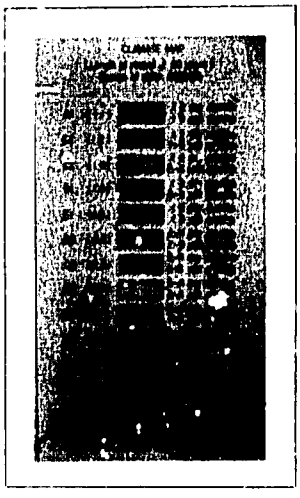
Our cropping systems research has the running objective of developing and testing farmer-acceptable technology that permits and encourages increased rice-based cropping intensity. The techniques are also used by cooperators in an Asia-wide cropping systems network.

ENVIRONMENTAL CLASSIFICATION

Rainfall

We continued to classify and map rainfall patterns of significance to cropping systems. In cooperation with national research agencies in the Philippines (PAGASA) and Bangladesh (BRRI) we completed analysis of rainfall patterns in those countries. The Philippine map is shown in Figure 37. Cooperators in Indonesia (Central Research





37. The agroclimatic map of the Philippines, prepared by IRRI with data from the Philippine Atmospheric, Geophysical, and Astronomical Services Administration, is examined by Hubert Zandstra, IRRI agronomist and cropping systems program leader, and Eugenio Manalo, assistant scientist, IRRI agroclimatic unit. The map will serve designers of improved cropping systems for the Philippines.

Institute for Agriculture) have completed similar studies for Java and Sulawesi, and initial contacts were made in Thailand for preparation of a rainfall pattern map.

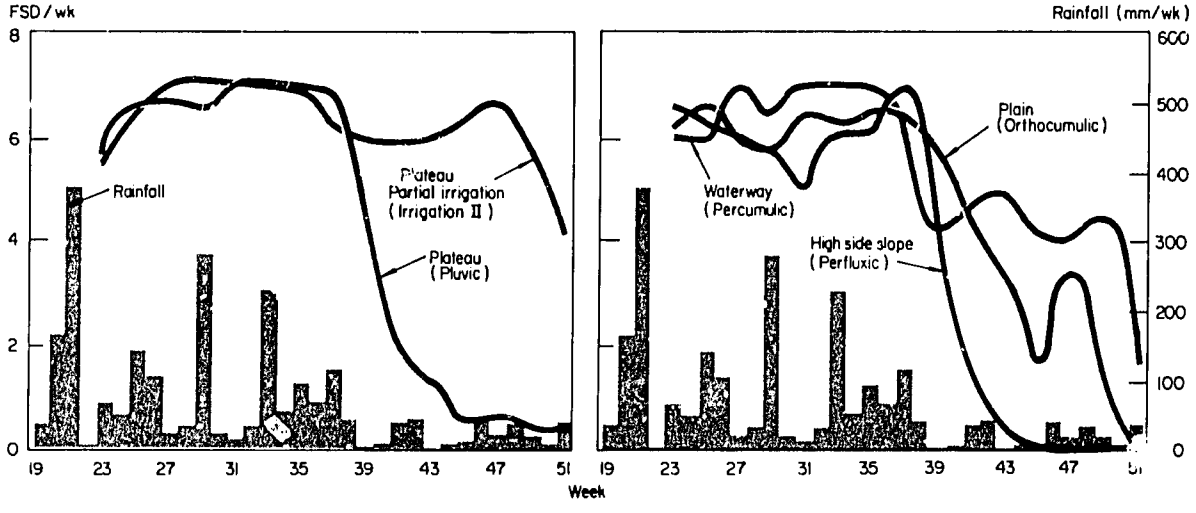
Land class and moisture levels

The length of time a field retains standing water determines to a great extent the potential for cropping patterns with two crops of rice. Past research has used the stress days (days beyond 3 successive days with no standing water on the field) to indicate availability of water for a rainfed rice crop. We looked at the factors affecting duration of standing water on a field and developed a positive flooded status day (FSD) concept. The FSD is any day with standing water on the field. We counted FSD during a 7-month period to indicate how long water can be kept standing on a field for given land units.

Estimated FSD for Iloilo rainfed sites with a heavy-textured soil – one with partial irrigation – are shown in Figure 38. When going from drainageway positions to high side slopes the trend is toward decreased FSD. Understanding the FSD regime within a land system provides an improved basis for defining where rice-based cropping patterns fit best.

Landscape classification

A landscape classification scheme was designed and is being tested. In its most complete form it takes into account landscape position, hydrology, type of drainage control, and soil texture and mineralogy (Table 32). Observations were made of cropping pattern performance



38. Weekly total rainfall and estimated flooded status day (FSD) regimes for heavy-textured rainfed and irrigated Iloilo land units clearly illustrate the frequency of FSD at different sites in a landscape.

Table 32. This landscape-hydrology classification is being tested in cropping systems research at IRRI.

Hydrology	Typical landscape position	Water table (wet months)	Ponding or flooding potential	Drainage potential	
				Surface	Internal
Pluvic	Knolls, hill summits	Deep	Very low Nonpaddy	High	High
Fluxic					
Perfluxic	Upper side slopes undulating summits	Deep	Low	High	Moderate
Orthofluxic	Lower side slopes and waterways in rolling hilly areas	Moderately deep	Moderate	High	Imperfect
Cumulic					
Orthocumulic	Lowest paddies on side slopes or high or low plains	Fluctuates near soil surface	High	Moderate	Low
Percumulic	Low plains and other areas of phreatic and surface enrichment	At or above soil surface	Very high	Low	Very low
Delugic					
Orthodelugic	Low plain areas subject to inundation	Rises 30 to 50 cm above soil surface	Shallow flooded	Very low	Very low
Perdelugic	Same as orthodelugic	Rises 50 to 100 cm above soil surface	Deeply flooded	Very low	Very low

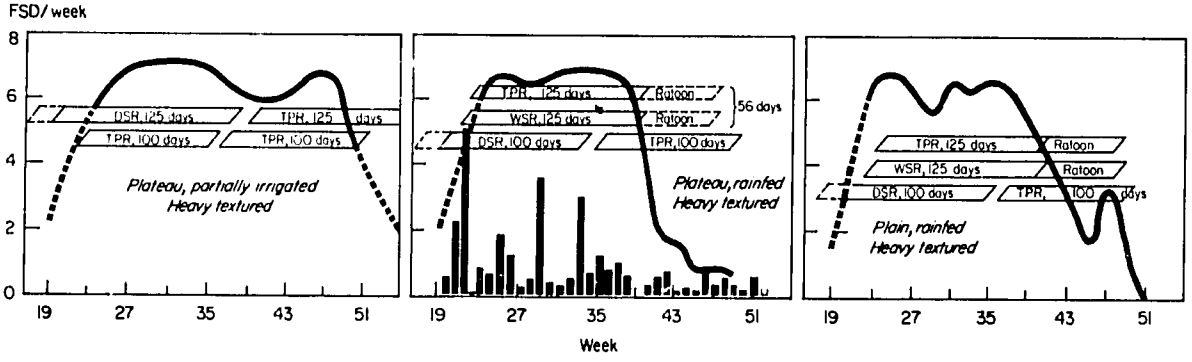
on different landscape positions. Field results from our Pangasinan and Iloilo research sites in 1977 showed differences in crop yields and in days of flooded status in relation to landscape position as well as irrigation class.

IMPROVED SYSTEMS DESIGN

Designing rice-based cropping patterns

We used FSD data from three land units measured in the 1976–77 crop year to design appropriate rice-based cropping patterns. The FSD and the fit of components for two land units are shown in Figure 39.

With partial irrigation two transplanted 100-day rice crops are feasible, even on the plateau unit. But two crops of rices with longer maturities would be risky. Under rainfed conditions on the plateau



39. Possible rice components of patterns designed for three land units are superimposed on flooded status days (FSD) based on results for crop year 1976–77 at Iloilo. The dotted lines of the curve represent projections of the FSD model. For dry-seeded rice the dotted area covers a no-rainfall period after seeding.

two rice crops are less attractive than one crop and a ratoon crop. On the plain unit two rice crops are somewhat more attractive, but the risk of water shortage would still be high.

Effects of toposequence position

Corn, soybean, cowpea, mung bean, sorghum, and peanut were planted with tillage and weed control (rotovator plus butachlor), and zero tillage supplemented with a rice-straw mulch, to determine the effects of field position in a toposequence and establishment method on performance of upland crops following rainfed rice. The high field had dry-seeded rice and the medium and low fields had transplanted rice as a first crop.

Field position in the toposequence generally had little consistent effect on the grain yields (Table 33). The significantly lower yields of peanut in the lower fields were due to excessive moisture and a high

Table 33. Yields of six upland crops reflect the small differences caused by field position when two tillage levels and three topographic positions in a toposequence are compared. The study was made at IRRI during the 1976–77 dry season.

Crop	Yield (t/ha)[a]				
	Tillage level		Topographic position		
	High	Zero	High	Medium	Low
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	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	0.5[illegible] a

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

Table 34. Effect of tillage levels and previous rice crop on weed number and weight at first weeding in stands of six upland crops. Interaction was significant between weed number and weed weight.

Previous rice type	Weeds (no./m²)		Weed (g/m²)	
	High tillage	Low tillage	High tillage	Low tillage
Dry seeded	36.7	75.8	12.7	72.7
Transplanted	77.0	79.5	13.5	41.7
Mean	56.8	77.7	13.1	57.2

incidence of scab on the pods. Tillage had no appreciable effect on yields at a given field position. Only peanut had significant yield reduction with zero tillage at all field positions.

We noted a difference in the weed density and the dry weight of weeds across tillage levels and previous rice planting methods. Compared with previously dry-seeded plots, previously transplanted plots had increased weed numbers but decreased weed weight (Table 34). In general, the grasses (including volunteer rice) were more dominant than the broadleaf weeds and sedges.

The effect of toposequence on a cropping pattern can be visualized in this view of Iloilo farmland. The land area relates to the hydrology classification in Table 32: the knolls at upper right are pluvic; the paddy fields running diagonally from lower left are cumulic; the fringe areas of the cumulic area are fluxic.

Differences in the dates of upland crop establishment indicated that turnaround time was influenced more by field position than by tillage. The crops in the high field were established a week earlier than those in the medium position paddy, and 30 to 35 days earlier than those in the low field. The difference in turnaround time was due mainly to inability to plant the lower fields because excessive soil moisture hampered planting.

As we moved to the lower fields, the advantage of zero tillage in reducing turnaround time increased. Crop establishment was about 5 days earlier with zero tillage than with tillage in the high field, and zero tillage allowed planting 2 weeks earlier than tillage in the low paddy. But the shorter turnaround time with zero tillage in the lower fields increases risk of flooding after seeding.

Turnaround time between crops

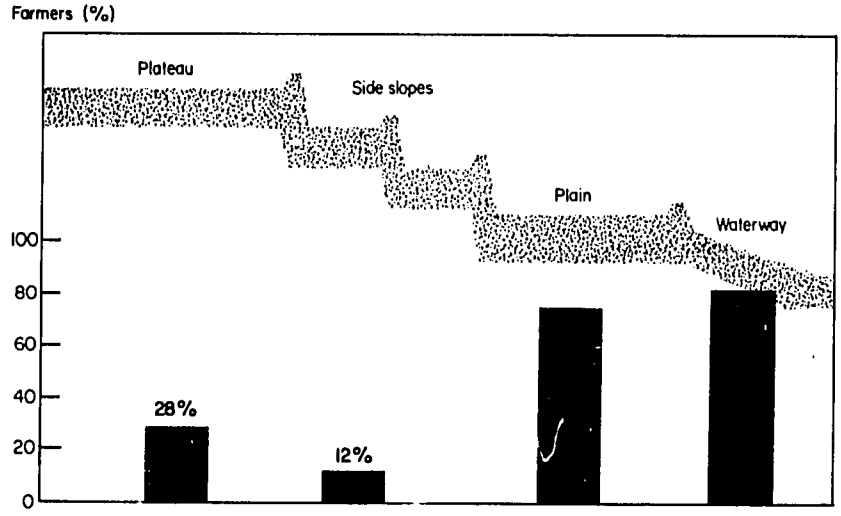
We continued studies to determine reasons for the lengthy turnaround times between harvest of the first crop in a sequence and the planting of a second crop. Among farmers in the Iloilo area, labor did not appear to limit farmers' ability to plant second crops. The labor use data in Table 35 suggest that farmers who replant rapidly are in fact busier than those who replant slowly. They cut turnaround time by working longer hours.

Power limitations likely constrain earlier planting of second crops. During the first 4 weeks following first crop harvests, the time for land preparation remains constant at a level that approximates the tillage capacity of one carabao. Note also the higher labor requirement for harvesting and threshing during the 4 weeks after harvest. Equipment and techniques to reduce the time required to thresh the previous crop and to prepare the land for the next crop could reduce turnaround times significantly.

The capacity of plots to retain water is also a factor affecting turn-

Table 35. Total labor use on the farm, and distribution by activity during the turnaround period between first and second crops at Iloilo, Philippines, during the 1976-77 crop year.

Weeks of lag until plot is 100% replanted	Plots observed (no.)	Average hours per week of labor during turnaround period					
		Land preparation	Planting nursery	Crop tending	Harvesting	Threshing	Total
1-2	10	34	25	5	18	28	110
3-4	11	31	15	5	26	18	95
5+	11	13	18	5	12	22	70



40. In a survey of 35 farmers in the Iloilo area during 1975, the percentage of farmers willing to plant a second crop of rice on rainfed lowland, by landscape position, was found to increase as risk of lack of water decreased, as in the lower parts of a toposequence.

around time, as is the farmers' willingness to even try a second crop. This is illustrated in Figure 40. Farmers on the side slopes and the plateau were much more reluctant to plant a second crop than those in the lower toposequence positions – the plain and the drainageway areas.

CROPPING PATTERN TESTING

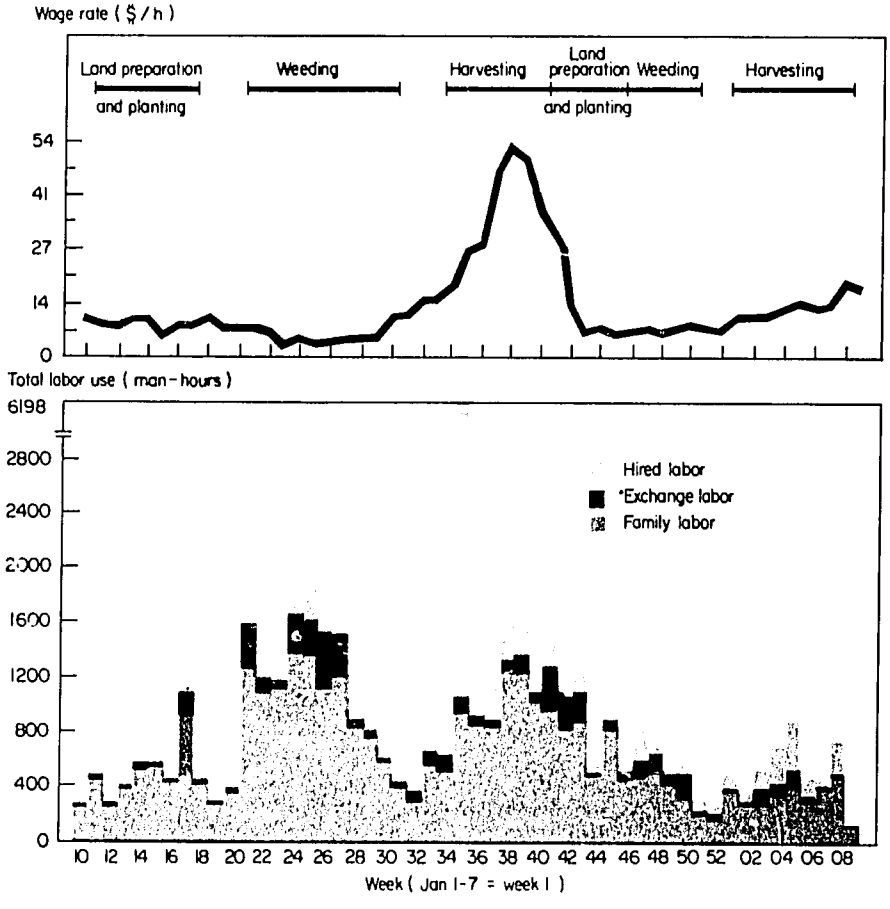
Seasonal wages and cropping pattern

A 1977 labor study in Indonesia and results of earlier labor analyses suggest that we need new cropping patterns that will use farm labor resources more evenly through the year. Previous approaches were based on the principle of pricing labor resources at the level they would earn in their next best opportunity for employment. In 1977 we developed a simpler technique for testing new cropping patterns for profitability based on *opportunity cost* pricing of resources.

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 in kind, by the observed work hours. Wages were interpolated for weeks when no hiring was observed, and the series was smoothed by taking a 5-week moving average. Figure 41 shows weekly imputed wages in Cale, Batangas, charted with weekly labor use in the village for all crop activities. A highly significant correlation indicated that the total labor requirement in a village influenced the labor wage rates for all activities. We obtained similar results using wage data from Indramayu, Indonesia.

The imputed wage schedule in Figure 41 was used to evaluate the profitability of the new upland rice variety C171-136 in Cale, Batangas.

C171-136 was compared with the variety Dagge in split fields under farmers' management. Its yield averaged 1.5 t/ha more than that of Dagge when each variety was planted as sole crop and 1.3 t/ha more when each was intercropped with glutinous corn, harvested green. C171-136 and Dagge did not differ significantly in their effect on corn yields, but both yielded slightly more when intercropped, probably because of the high nitrogen rate applied to the corn. When both varieties were intercropped, the evenly maturing C171-136 required substantially less labor to harvest and farmers could harvest the entire crop at once. Combined with the increased gross returns, the lower labor requirement resulted in an average increase in net returns of 153% for C171-136 over Dagge as a sole crop and 80%, as intercrop. This assumed a cost of $0.34/hour for any activity



41. Weekly labor use and imputed weekly wage rates on 36 farms in Cale, Batangas, Philippines, 1975–76.

requiring animals and a constant $0.17/hour for all other labor inputs.

Opportunity cost pricing of labor showed that it is more appropriate to value labor for hand weeding at $0.17/hour and that for harvesting at $0.34/hour based on the imputed labor wage in Cale, Batangas (see Fig. 41). At those wage rates, C171-136 as sole crop increased average net return by 290% over Dagge; as intercrop, it had an increase of 158%. It also gave higher average returns to labor and cash. But the introduction of corn into the rice crop reduced returns to cash and to labor for C171-136. The 90 kg N/ha applied to the corn intercrop, in addition to the 75 kg N/ha applied to rice, may have been too high.

The reduced labor for harvest of C171-136 may reduce turnaround time between rice and corn and allow earlier planting.

Testing a rice-mung bean pattern

The rice-mung bean cropping pattern – practical on 50% of the cropland in Pangasinan – is the only pattern of 30% of the area's farmers. Since 1973 mung bean prices have continually increased to a present level of 2.7 times the rice price. But farmers' mung bean yields are extraordinarily low – 0.25 t/ha compared with a possible minimum of 0.75 t/ha with moderate management (Table 36). Because of the crop's value, popularity, and ability to grow immediately after rice on heavy soils, emphasis was put on research to develop techniques for growing mung bean after rice.

We identified farmers' management practices as the starting point for developing and evaluating new techniques. Seeding rates and insecticide application were low and no fertilizer was used on 67 farms checked. Tillage varied from none to two plowings and two harrowings.

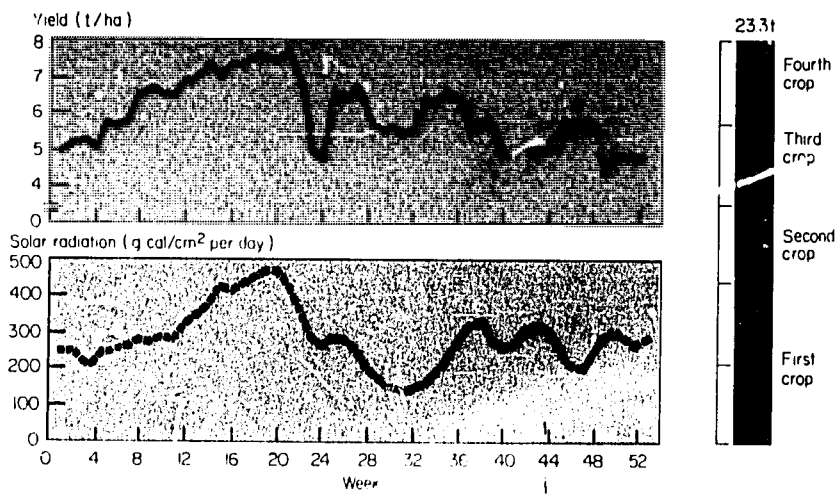
The gains in mung bean production in trials resulted mainly from better control of bean fly and flea beetles, due partly to increased rates of insecticide application – reflected in higher material costs – and partly to improved timing. (Farmers had generally applied insecticides too late.) Control is best done 10 days after plant emergence, when the pests and their damage are hardly visible.

A continuous rice-rice production model

In a continuous rice production model we planted and harvested three times a week in a system using 40 plots of 250 m^2 each. As can be seen from Figure 42, a total of 23.3 t/ha was produced – a daily production of 66 kg. This system, using IR36, which requires only

Table 36. With a moderate amount of management farmers can treble mung bean yields in a rice-mung bean cropping system. This is seen in records of costs and returns for a rice-mung bean pattern on 9 experimental and 37 farmers' plots in Manaoag, Pangasinan, for the crop year 1976–77.

Item	Rice (1st crop)	Mung bean (2nd crop)	Total or average
Yield (t/ha)			
Experimental plot	3.76	0.73	–
Farmers' plot	1.65	0.22	–
Gross returns (US$/ha)			
Experimental plot	701	444	1145
Farmers' plot	308	133	431
Labor input (man-hours/ha)			
Experimental plot	1723	400	2123
Farmers' plot	504	344	928
Material costs (US$/ha)			
Experimental plot	133	163	296
Farmers' plot	44	26	70
Returns to labor (US$/man-hour)			
Experimental plot	2.3	4.9	2.8
Farmers' plot	3.2	2.2	2.8
Returns to material cash (US$/US$)			
Experimental plot	5.3	2.7	3.9
Farmers' plot	7.0	5.1	6.3



42. The average weekly yield of IR36 and solar radiation (23 days after heading) shown here gave 23.3 t/ha annual yield in a continuous rice production model at IRRI, 1977. The sharp yield drop at week 24 was caused by rice ragged stunt disease. The lodging at week 49 was due to a typhoon.

about 90 days from transplanting to harvest, permits an average of nearly four crops a year.

During the year, solar radiation had a dramatic effect on yields (Fig. 42). During weeks 22–24, a severe outbreak of rice ragged stunt virus coupled with a marked reduction in solar radiation caused a yield reduction. Damage by a typhoon caused a sharp yield drop in week 49. The average yield per crop was 5.9 t/ha in our 1976–77 continuous 1-ha rice trial, and about 7.0 t/ha in a February planting.

The continuous system has these benefits for the farmer:

- With 1-day turnaround, more crops can be grown in a year.
- All tasks are performed three times a week by three workers each working 40 hours/week, eliminating the usual high levels of hired labor required at transplanting and harvest times.
- The farmer has a continuing weekly income and regular but low requirements for purchased inputs. He also has a year-round rice supply for his family.

The system, however, has disadvantages:

- Land preparation costs more on small plots than on large plots.
- With 40 crops at different stages of growth, labor overhead costs of about 250 hours/crop were used for each day's diverse activities, compared with the usual overhead time of 35 hours/crop.

Nevertheless, we found the continuous system profitable compared to the alternatives. Table 37 compares labor requirements of alternative systems and Table 38 shows the comparative returns. Late in 1977 we shifted experimentation to a 10-plot/ha system of 1,000-m^2 plots, giving 3.77 crops/year. In the new system reduced labor over-

Table 37. The benefits of the continuous rice production model (CRPM) show in this comparison of labor requirements (man-hours) between continuous-rice cropping and other multiple-rice crop patterns.

Cropping pattern	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 crops/yr	145	190	95	325	250	1005
CRPM 10 plots 3.77 crops/yr	115	290	95	325	35	760

Table 38. Comparison of costs (land and capital costs excluded) and returns of the continuous rice production model (CRPM) and other multiple-rice cropping patterns shows the marked increase in net return for the model.

Cropping pattern	Variable costs (US$)/crop			Total returns (US$/ha)		Net returns (US$/ha)	
	Labor	Materials	Total	1 crop	All crops	1 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 crops/yr	136	274	409	800	3162	391	1544
CRPM 10 plots 3.77 crops/yr	103	274	376	798	3000	422	1587

head and land preparation costs were offset by lower total production. Thus, the systems are about equally profitable.

COMPONENT TECHNOLOGY

Disease and insect awareness

Most farmers practice both traditional and modern pest control. Many traditional practices are of questionable value, but some are based on sound principles of mechanical, physical, and cultural control. Farmers are aware of plant resistance to diseases and insects – they were using resistant varieties. They know the general concept of biological insect control, but they do not intentionally manipulate natural enemies. All farmers surveyed used insecticides on their farms, but not on every crop. Fungicide usage was minimal to nonexistent.

As a result of the studies we modified pest control recommendations for cropping patterns to make them more readily acceptable to farmers.

We found that substantial yield increases resulted from better use of pesticide – more than that from any other insect control method. But farmers are not getting adequate results from pesticides used for three main reasons:

- They generally are not aware of the pests and the required control procedures.
- Most of their pesticide applications are ill-timed.
- The dosages they use are sublethal. In mixing pesticides in sprayers, farmers follow the directions on the package, using tablespoons per sprayer load. Underdosage results because pest-

icide amounts in the directions of the package are based on spray volumes of 1,000 liters/ha, but farmers using knapsack sprayers average less than 200 liters/ha.

Competitiveness of upland crops against weeds

Seven upland crops varied considerably in their ability to compete with weeds. On the basis of weed weight at harvest, cowpea was the most competitive against weeds and rice was the least competitive. The percentage of yield reduction due to weeds was not necessarily related to weed weight. The lowest yield reduction caused by weeds occurred in cowpea, the most competitive crop, but the highest yield reduction was in a rice cultivar, IR661-170-1-3. Yield losses of mung bean caused by weeds were less than those occurring with sweet potato and soybean, even though more weeds were competing against mung bean (Table 39).

With rice the greatest yield losses occurred with the shortest cultivar; however the medium-statured cultivar BPI 76/9 X Dawn was more competitive and had less yield reduction due to weeds than the taller cultivar IR1746-88-1-2-1. Also cowpea was more competitive against weeds than corn or sorghum. The reason for the differing competitive ability of crops and cultivars is not known, but it is not plant height.

Weed-crop-water relationships

We ds are commonly observed to suffer less than rice during drought periods. In fact, increased weed problems can often be traced to

Table 39. In a study of the competitive ability of seven crops grown in an area at IRRI, the cowpea was most competitive against weeds – soybean and rice were least competitive.

Crop (cultivar)	Weed weight (t/ha)	Yield (t/ha)	
		Weed free	Unweeded
Cowpea (EC #1)	0.6	1.3	1.1
Corn (DMR 2)	1.6	7.3[a]	4.2[a]
Sorghum (Cosor 3)	1.9	3.2	1.7
Mung bean (CES 55)	2.9	0.47[b]	0.23
Sweet potato (BNAS 51)	1.9	19.6	6.7
Soybean (Multivar 80)	2.4	0.36[b]	0.1
Rice (BPI 76/9 X Dawn)	3.2	3.1	1.2
Rice (IR1746-88-1-2-1)	5.6	2.6	0.7
Rice (IR661-170-1-3)	5.3	3.8	0.0

[a] Weight of green corn on the cob.

[b] Yields of weed-free mung bean and soybean were low because of high wet-season level of diseases and insects.

previous year's drought during which weeds gained a competitive advantage. We studied the effect of increased competition for water between the crop and weed species in a continuous function design (Fig. 43).

During the vegetative stage, beginning 20 days after emergence, water was withheld from half of the plots. Figure 44 shows the difference observed in leaf water potential of rice cultivar IR28, and the three weed species *Amaranthus spinosus, Eleusine indica,* and *Digitaria sanguinalis* along the center lines of the water-stressed plot.

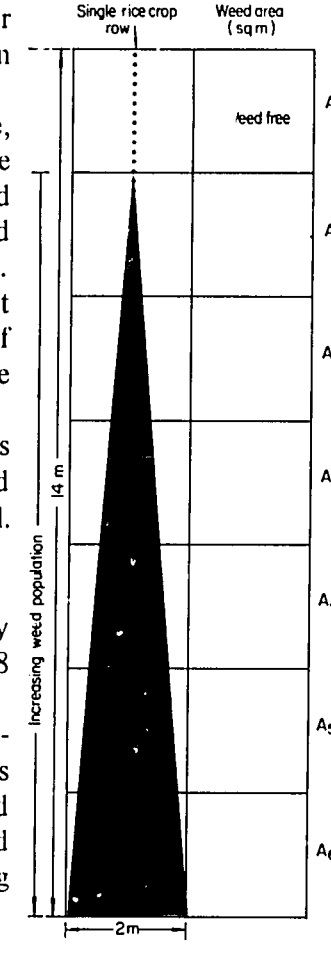
The leaf water potential of rice was significantly lower than that of the weed species in all cases, except in the dawn measurement of watered plots. When a soil water deficit was imposed the magnitude of the differences among species increased.

Regardless of the soil or atmospheric water status, the weed species demonstrated superior adaptation relative to IR28. Among the weed species, *A. spinosus* consistently maintained high leaf water potential.

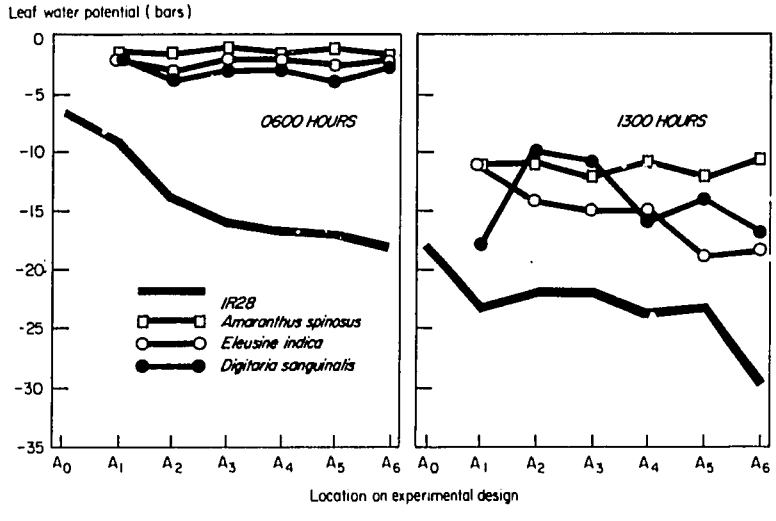
Varietal testing

We evaluated 26 IRRI lowland rice varieties for suitability for dry seeding. IR36 had the highest yield (5.5 t/ha) followed by IR28 (4.4 t/ha) at a semilowland site.

The upland crops in our cropping systems research are elite cultivars generated by screening at the University of the Philippines at Los Baños (UPLB) and by its Institute of Plant Breeding. They are tested in IRRI lowland fields after the wet-season rice crop, in IRRI upland fields, and at outreach sites in the Philippines. The 1977 testing included:



43. A continuous function experimental design was used to study the effect of increased competition between rice and weeds for water when a single row of rice was planted in an increasing weed population (above).



44. When leaf water potentials in rice and weed plots were measured at 0600 and 1300 hours the weed species present had a clear advantage over IR28 (left).

R. A. Morris, IRRI cropping systems agronomist, checks a cowpea varietal trial at Iloilo. Cowpea showed distinct varietal response to the local environment. The best cowpea at Iloilo in the 1977 trials was EG #3, a variety developed by the Philippine Bureau of Plant Industry.

- *Rice.* In upland testing of 14 rice selections IR3939-1 had the highest yield (5.6 t/ha), followed by IR1529-430-3. C171-136 had the highest yield (5.5 t/ha) in tests without insect control.
- *Corn.* Nine corn varieties from Thailand and the Philippines were tested after rice. At IRRI with zero tillage (corn dibbled into rice stubble) Philippine DMR Comp. 1 yielded 4.6 t/ha, which was 60% more than the yield of a commonly grown local corn.
- *Sorghum.* We tested 16 elite and promising sorghum lines from the UPLB breeding program. The most promising entries with stable yields at all sites were D67-1, D67-4, and UPLB-SG 5.
- *Mung bean.* CES 1D-21 was the outstanding mung bean in tests at IRRI and at outreach sites. The Philippine Government renamed it Pagasa and released it for national distribution.
- *Soybean.* Fourteen soybean varieties were evaluated with zero tillage and mulch, after lowland rice at IRRI. Soybean performance with zero tillage was equal to that with tillage.
- *Cowpea.* At IRRI, PI 339587 and PI 221713, both determinate types, had high yields (1.6 t/ha) among 14 cowpea entries. EG#3 and EG#2, the recommended cowpea varieties in our cropping systems trials, were the best indeterminate types.

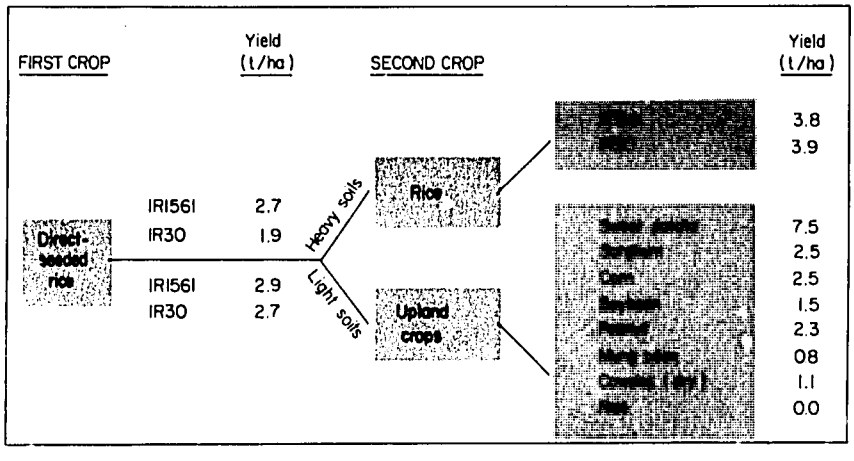
- *Peanut.* Peanut trials were in upland fields at IRRI and in Batangas, and in lowland paddies in Iloilo and Pangasinan. All varieties were significantly better than CES 101. Peanut yield was highest at Iloilo where M10 yielded 3.4 t/ha.
- *Sweet potato.* Among sweet potato varieties tested at IRRI and at outreach sites, BNAS 51 had the highest marketable yield.

PREPRODUCTION EVALUATION OF DIRECT-SEEDED RICE

After 3 years of research in the Philippines on use of direct-seeded rice in a cropping system, we conclude that, without supplementary irrigation, the two-crop rainfed rice pattern is probably not feasible in Central Luzon during most years. The pattern of a first crop rice followed by an upland crop is less risky than two crops of rice, especially on light textured soils (Fig. 45). Rice grown with increasing rainfall (seeded in May) has less risk from drought than rice planted on a decreasing rainfall pattern. Moreover, typhoons are more damaging in October–November than in May–July. Upland crops planted by September–October (especially soybean) are grown more successfully after one rainfed rice crop than after two rice crops.

In areas where the water table is shallow small pumps for supplementary irrigation can greatly reduce drought risks for the second crop. Such irrigation could facilitate a third crop in areas with an extensive shallow water table where only one crop of rice is now grown.

For Mindanao and Visayas, a rice-rice-upland crop pattern has been successful, however. Since 1975 upland crops have been planted after two rice crops and the pattern appears to be fairly stable.



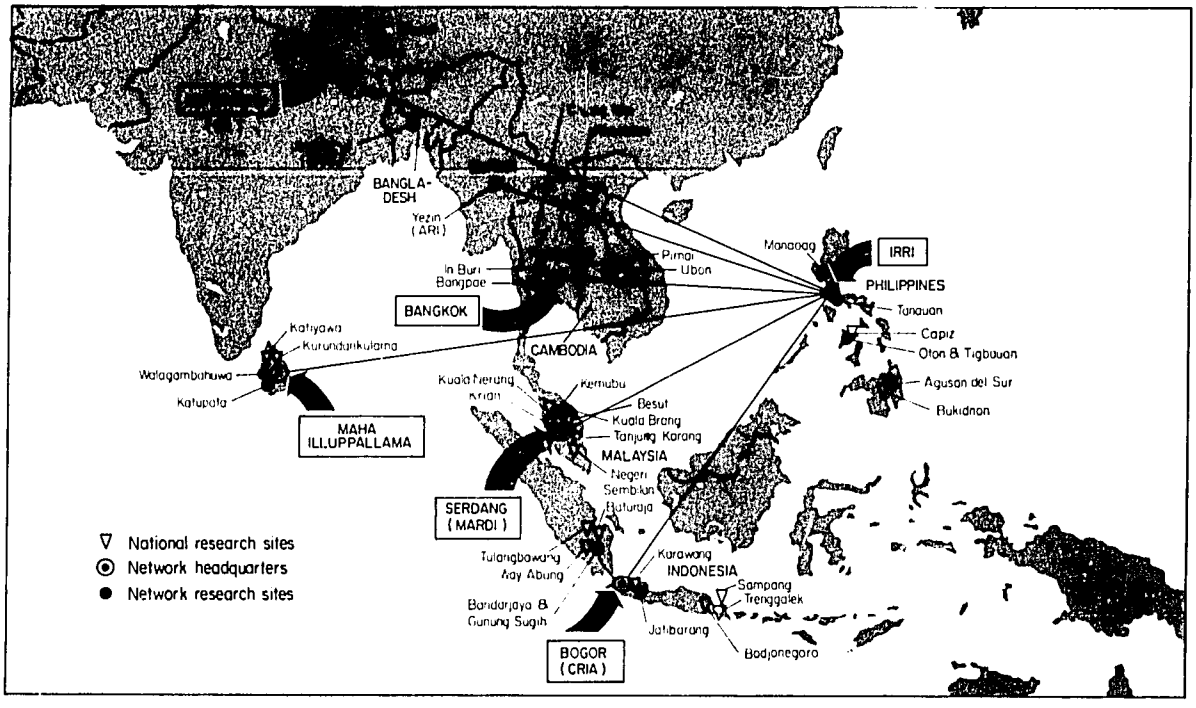
45. A comparison of production potential of two crops of rice and of one crop of rice followed by upland crops on light and heavy rainfed soils in areas with 5 dry months (rainfall type 3.4).

THE CROPPING SYSTEMS NETWORK AND THE WORKING GROUP

The Cropping Systems Network now includes Bangladesh, Burma, Indonesia, Malaysia, Nepal, Philippines, Sri Lanka, and Thailand, and has research in progress at 17 sites. National cropping systems research adds to network activity through work at 19 other sites (Fig. 46).

Table 40. The cropping systems network test sites provide IRRI a broad range of climatic zones throughout Asia for the development and testing of improved cropping systems. Sites in Burma and Malaysia are in the planning stages.

Site	Kind of rice land	Immediate target (ha)	Rainfall (consecutive months)		Soil texture
			Wet	Dry	
Philippines					
• Cale	Upland rice	40,000	5	5	Clay loam
• Tigbauan and Oton	Rainfed lowland Partially irrigated	300,000	5–6	2–4	Clay loam to heavy clay
• Manaoag	Rainfed lowland Partially irrigated	500,000	3–4	5–6	Clay loam
			(low and high water table)		
Indonesia					
• Lampung	Partially irrigated Upland rice	1,500,000	5	4	Sandy loam
• Indramayu	Partially irrigated Irrigated	650,000	4	5	Clay loam
Thailand					
• PiMai	Rainfed lowland	850,000	2	6	Sandy loam
			(bimodal)		
• Ubon	Rainfed lowland	500,000	3	6	Sandy loam
• In Buri	Irrigated Partially irrigated	500,000	2	6	Clay loam to heavy clay
• Bangpae	Rainfed lowland	400,000	3	4	Silty clay loam
Sri Lanka					
• Walagambahuwa	Partially irrigated (small tank)	101,000	3	4	Sandy loam
• Katupota	Rainfed lowland	25,000	2 + 2	1	Sandy loam
			(bimodal)		
Bangladesh					
• Joydebpur	Rainfed lowland Irrigated	6,300,000	5	5	Clay loam to heavy clay
Nepal					
• Parsa	Rainfed Partially irrigated Irrigated	39,000	5	6	Sandy and silty clay loam
• Pundi Bhundi	Rainfed lowland	50,000	7	2	Sandy and silty clay loam



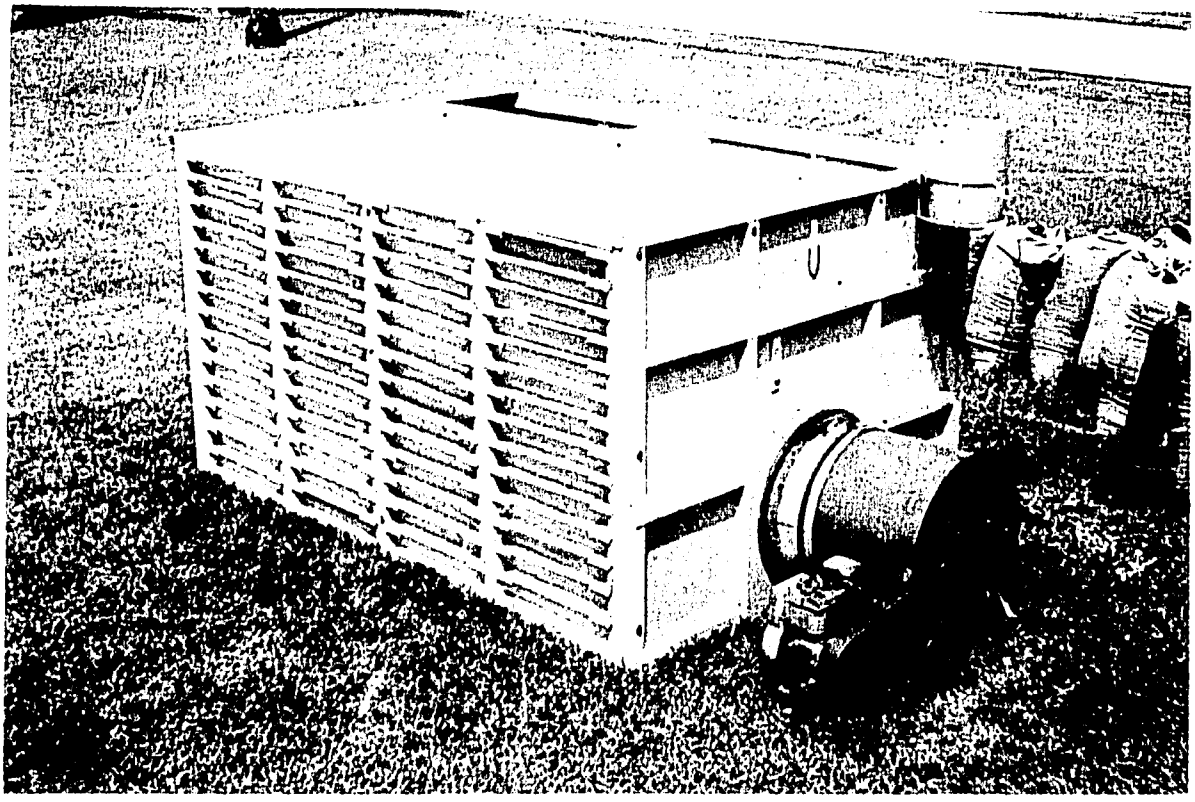
46. The Cropping Systems Network expanded to include Burma, Malaysia, and Nepal during 1977. Network and national cropping systems research is done at 34 sites across a wide sampling of Asian crop environments.

The details on 15 sites in Table 40 shows the broad sampling of Southeast Asia's climatic zones that is made possible by the network.

Supporting and guiding network activities is a small group of researchers who make up a Cropping Systems Working Group. The Group met in Bangladesh early in 1977 and again later in the year in Sri Lanka. Working Group meetings are informal working sessions concerned mainly with research orientation, methodology results, and network problems. They also serve as a forum for comments on our cropping systems research at IRRI as it relates to national programs.

Machinery development

Much of the potential of the high yielding, early maturing, modern rice varieties is not achieved because of repeated handling in the field and spoilage losses. The latter are due to the absence of village-level facilities to dry the first rice crop, which is harvested during the rainy season. We designed, developed, and promoted the use of a small thresher and a low-cost dryer. These machines cut threshing



47. Grain spoilage losses for rice farmers run high, especially in the wet season. The design of this batch grain dryer was released in 1977 for use by dryer manufacturers in Asia. The dryer is an all-wood construction, features easy loading and unloading of 2-ton batches, and is less expensive to build and operate than a previous design.

losses and spoilage and reduce the turnaround time between the first and the second crop.

We modified the design of the IRRI axial-flow thresher to permit threshing of wheat, sorghum, and tall rice varieties. This thresher continues to gain acceptance by farmers and cooperating manufacturers in several Asian countries. Manufacturers in Thailand produced 420 units in 1977 – a fourfold increase over the number in 1976. Acceptance of our new portable thresher design was excellent. More than 800 units were built and sold in the Philippines in 1977.

We released the design of a wooden, 2-ton-capacity batch dryer. The dryer uses heated air blown into a central plenum chamber. The hot air moves through the grain in louvered compartments on both sides of a central duct (Fig. 47). The louvers are removable for loading and unloading. Although the dryer has double the capacity of our previously developed flatbed design, it costs 20% less. Fuel consumption was also reduced by 20–40% in the redesigned kerosene burner. The dryer uses either an electric motor or internal combustion engine to operate the blower.

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 the 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 steering clutch tiller which was developed last year was released to manufacturers in the last half of 1977. We refined the design and improved components using information from 2,600 hours of dynamometer and field testing. The steering clutch, together with a simple training sled on which the operator can ride, greatly increases the maneuverability of the tiller and reduces operator fatigue.

A rotary attachment for the 6- to 8-hp tiller is being developed to increase the versatility of the equipment, especially for use under both lowland and upland conditions. This equipment is desired where rice and upland crops are both being grown on the same farm.

We are also developing a harvester attachment for the power tiller. The concept uses a cutter bar header and the portable thresher mounted on a power tiller. Initial design work is complete and prototype drawings are being prepared.

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 workload, eliminate the difficulty of pushing granular and liquid fertilizer applicators, and improve fertilizer efficiency over that of fertilizer applied by the traditional broadcast methods.

The effectiveness of fertilizer application with the experimental applicator (Fig. 48) will be compared with deep placement with a Japanese applicator, incorporation during final harrowing, and traditional split broadcast methods during dry-season yield trials.

We determined the utility of the power tiller for upland soils by making a series of tillage and traction tests. Our results showed that:

- The rotary tillage of upland soils using a 5- to 8-hp tiller will, in most cases, require a power-take-off driven rotary tiller attachment.

48. A plow-sole chemical applicator is attached to the 5- to 8-hp power tiller. The fertilizer is placed in the root zone which gives best fertilizer use efficiency.

- Wheel slippage was much higher with lowland cage wheels as compared to snow tread or lug tread tires.

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 sale 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.

International activities

Our international activities strengthened links with national programs and facilitated collaboration with national scientists. We continued, on a request basis, to provide services to national rice programs that sought to improve their research capacities.

National program on-site collaboration

During 1977 IRRI was associated with expanding rice research programs in Bangladesh, Indonesia, Pakistan, Sri Lanka, and Thailand.

- Seven IRRI scientists worked with scientists at the Bangladesh Rice Research Institute in the areas of agronomy, breeding, engineering, entomology, and rice production.
- Eleven IRRI scientists were assigned to work with Indonesian rice researchers in agronomy, breeding, pathology, and engineering.
- An IRRI scientist had been working in farm machinery research and development in Pakistan. A rice production specialist was added in 1977.
- The staff of IRRI scientists in Sri Lanka increased to three

Participants at the 1977 International Rice Research Conference toured IRRI research plots. D. S. Mikkelsen, visiting scientist from the University of California (right), and S. K. De Datta, IRRI agronomist, explain nitrogen balance studies with labeled nitrogen (N^{15}) fertilizer to participants that include Sermsak Awakul and Arron Jugsujinda, Thailand; Manuel Rosero, IRRI liaison scientist for Latin America; and P. B. Escuro and Ohn Kyaw, Burma.

during the year. They worked in agronomy, breeding, and production.

- Two IRRI researchers continued to work in plant breeding and engineering in Thailand.

In all research with national programs, IRRI scientists worked with IRRI-trained local staff who made significant contributions to the progress of their respective programs.

Within the ongoing cooperative projects in Pakistan and Sri Lanka we developed new activities.

- A Pakistan project to demonstrate the feasibility of greatly increasing rice production in farmers' fields was added. A rice production specialist joined the project in May to assist with planning and conducting field trials.
- A new Sri Lanka project is aimed at expanding the technical base for accelerated development and use of improved rices and cultural practices. The project will develop and implement a multidisciplinary program for rice varietal improvement, rice-based cropping systems, and adaptive field research aimed at farmer use of the technology developed.

International liaison scientists were appointed during 1977 for Indonesia and Malaysia (Region I) and Latin America (Region VI).

Collaborative research and network coordination

Our collaborative research on rice extends far beyond formalized projects with national programs in Asia. During 1977 we collaborated with 18 national research centers, including several working on rice, in developed countries. Such collaboration often makes available equipment and expertise that we cannot provide at IRRI. Collaborative research of that nature included:

- Rice virus diseases studies with Hokkaido University, Japan; Wageningen University, the Netherlands; Rothamsted Agricultural Research Station, United Kingdom; and the Ohio Agricultural Research and Development Center, USA;
- Drought resistance studies with Cornell University, USA; and Cambridge University, United Kingdom;
- Rice protein evaluation with the Australian National University; the Agricultural Research Laboratory, Denmark; and the US Grain Marketing Research Center, USA;
- Study of the sex pheromone of rice stem borers with the Tropical Products Institute, United Kingdom;
- Brown planthopper studies with the Centre for Overseas Pest Research and Cardiff University College, United Kingdom; and

the Tropical Agricultural Research Center and Hokkaido University, Japan;

- Bacterial leaf blight studies with Kyushu University, Japan; and
- Cropping systems budgeting study with the Australian National University.

Collaboration on rice research with national projects in Asia was with 12 countries. The research areas included early breeding generation selection; drought resistance; brown planthopper and gall midge; bacterial leaf blight, tungro virus, and blast; nitrogen fertilizer efficiency; high and low temperature tolerance; and soil problems including salinity, acid sulfate and organic soils, iron toxicity, and phosphorus deficiency.

An example of our collaboration on the national level is the brown planthopper research with scientists at the Indian Council of Agricultural Research. The collaboration in India seeks to identify different biotypes of the brown planthopper, and sources of varietal resistance to those biotypes. This work at Cuttack, Hyderabad, Pantnagar, and Pattambi involves testing a differential set of rice varieties with the

Vice Premier Nguyen Duy Trinh of Vietnam views rice plants used in research on brown planthopper biotypes at IRRI with M. D. Pathak, IRRI director for research coordination. The Vice Premier's visit established a basis for an IRRI team's visit to Vietnam early in 1978.

local brown planthopper population and studying insect survival on selected varieties. Several F_3 breeding populations of selected rice varieties were tested to identify lines resistant to various brown planthopper biotypes.

IRRI continued to serve as coordinator and as a research resource base for several networks serving Asian rice research. These are the

- Cropping Systems Network that covers 8 Asian countries and involves work at 36 sites;
- International Rice Agroeconomic Network with research on constraints to rice production in 6 countries;
- International Network on Fertilizer Efficiency in Rice with trials in 10 countries; and
- Farm Machinery Development Network with work in 9 Asian countries plus Colombia.

International meetings

Nearly 500 scientists from national rice programs participated in meetings at IRRI during the year (Table 41).

- The annual International Rice Research Conference (IRRC) again brought together rice scientists from all major rice growing areas. Emphasis in 1977 was on the brown planthopper, which was the topic of a symposium held in conjunction with the IRRC. The symposium proceedings will be published in 1978.

Table 41. Conferences, symposia, and workshops at IRRI during 1977.

Title	Date	Attendance	Countries represented	
			Asia	Others
Rice Blast Workshop	21–23 Feb.	26	4	4
IRRI-UN Workshop on Interfaces Between Agriculture, Nutrition, and Food Science	28 Feb. – 3 Mar.	38	9	–
IRRI-IBRD Workshop on Agricultural Extension for Rice Development	14–23 Mar.	50	13	3
International Rice Research Conference	18–22 Apr.	139	15	12
International Cooperative Project on National Rice Programs Workshop	15–18 Aug.	10	4	1
Soils and Rice Symposium	20–23 Sept.	93	12	9
Research Planning Workshop on the Consequences of Small Farm Mechanization on Production, Employment, and Incomes in Asia	31 Oct. – 1 Nov.	13	4	1
International Agricultural Machinery Workshop	2–5 Nov.	42	11	4
Advisory Committee on Microbial Fixation of Nitrogen in Rice Fields	8–29 Nov.	23	5	5
Rice Genetic Conservation Workshop	12–15 Dec.	60	9	10

- The International Soils and Rice Symposium brought together for the first time the world's scientists specializing in soils on which rice is grown. Until this meeting contact among soils scientists was limited. The symposium proceedings will come out in 1978.
- At the Rice Genetic Conservation Workshop, scientists concerned with the collection and conservation of rice genetic resources developed a 5-year plan for the collection and storage of these precious seeds.

Visitors to IRRI

In 1977 visitors to IRRI numbered about 12,000 from 43 countries. They ranged from farmers to national leaders. The latter were either agricultural policy makers or political leaders whose visit served to initiate collaboration or to strengthen ongoing collaboration.

Associated formal training

Our training program provides opportunities for rice researchers and rice production technicians to acquire skills for carrying out responsibilities in national rice improvement programs. Training opportunities at IRRI are an integral part of both our core research program and our international cooperative effort.

The opportunities are either research oriented, production or extension oriented, or support our different international research

IRRI training ranges from 2-week rice production courses (trainees seen here making a seedbed) to programs for Ph.D. scholars and postdoctoral fellows. Training activity in all categories increased in 1977.

networks. We provided 1,507 man-months of training for trainees from 29 countries in 1977 (Table 42), an increase of about 360 man-months over that in 1976.

RESEARCH PARTICIPANTS

We had 32 postdoctoral fellows, 67 degree candidates (45 for the M.S. and 22 for the Ph.D. degrees), and 34 nondegree research scholars or fellows at IRRI. The number of postdoctoral fellows

Table 42. Training provided by IRRI, 1977.

Country	Training (man-months)					
	Degree scholars		Non-degree	Post-doctoral fellows	Production courses[a]	Total
	M.S.	Ph.D.				
Bangladesh	74.0	18.0		6.5	45.0	143.5
Burma	48.0		1.0		55.0	104.0
Colombia	12.0					12.0
Egypt		6.0			0.5	6.5
England	2.0	10.0	2.5			14.5
Germany				1.0		1.0
India		36.0	5.0	111.5	26.0	178.5
Indonesia	50.5	50.0	40.0	9.0	57.5	302.0
Iran			1.5		8.0	9.5
Iraq			2.0			2.0
Japan			36.5	24.5	24.5	61.5
Korea	11.5	9.5	6.0	8.5	6.5	42.0
Liberia					4.0	4.0
Malaysia		6.0			1.0	7.0
Mali			3.5		18.0	21.5
Nepal	8.0			3.0	57.0	68.0
Netherlands				12.0		12.0
Nigeria			7.0		12.0	19.0
Pakistan			3.0		27.5	30.5
Philippines	31.5	7.0		17.0	24.0	79.5
Sierra Leone			6.0		12.0	18.0
Sri Lanka	23.5		9.5		43.0	76.0
Sudan					12.0	12.0
Taiwan	12.0					12.0
Tanzania					0.5	0.5
Thailand	77.0	29.0	19.5		83.0	208.0
United States	7.0	10.0	5.5		6.5	29.0
Venezuela	8.5					8.5
Vietnam	6.0		6.0	12.0		24.0
	371.5	181.5	155.0	205.0	594.0	1507.0

[a]Production courses include a 4-month Genetic Evaluation & Utilization training program, a 6-month Rice Production Training Program, a 6-month Cropping Systems Training Program, and a 2-week Agricultural Engineering training course.

substantially increased from the 1976 level of 16. Most of the M.S. candidates were enrolled at the University of the Philippines at Los Baños (UPLB). A few of the Ph.D. candidates were enrolled at UPLB, but most had completed their course work at other universities and were at IRRI for the research phase of their degree program.

RICE PRODUCTION COURSES

Our rice production courses and 6-month cropping systems courses are organized and run by the Rice Production Training and Research Department. The 6-month rice production course had 37 participants 13 countries. Three 2-week rice production courses were offered in 1977.

TRAINING FOR THE NETWORKS

Thirty-three individuals from 11 countries participated in a 4-month GEU training program in 1977. On the basis of an evaluation of that course and the number of requests for training received, the decision to offer two GEU courses in 1978 was made.

We had 38 participants from 8 countries in a 6-month cropping systems course. In the group were several site coordinators from the cropping systems network sites in Indonesia, Thailand, and Sri Lanka. The course included on-the-job training in outreach sites in the Philippines.

The 2-week agricultural engineering course was attended by 24 engineers from government and private organizations who are associated with the manufacture and evaluation of IRRI-designed machinery.

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. That 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 operations, $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 U.S. National Institutes of Health reimbursed $762 on a 5-year contract to study ways to increase 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

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MANUEL ROSERO, Ph.D., IRRI liaison scientist

Pakistan

AMIR U. KHAN, Ph.D., IRRI representative and agricultural engineer
VERNON E. ROSS, M.S., rice production specialist

Philippines

REESHON FEUER, Ph.D., crop production specialist

Sri Lanka

JAMES E. WIMBERLY, M.S., IRRI representative*
MARVIN D. DAVIS, M.S., crop production specialist and team leader
RUSSELL D. FREED, Ph.D., associate plant breeder

RICHARD L. TINSLEY, Ph.D., associate agronomist

Thailand

BEN R. JACKSON, Ph.D., IRRI representative

DERK HILLERISLAMBERS, Ph.D., associate plant breeder

P. STEWART BARTON, M.S., associate agricultural engineer

CORE STAFF

ALVA A. APP, Ph.D., visiting scientist

RANDOLPH BARKER, Ph.D., agricultural economist

COLIN BARLOW, Ph.D., visiting agricultural economist*

SADIQUL I. BHUIYAN, Ph.D., associate agricultural engineer

CHARLES A. BOWER, Ph.D., visiting scientist*

GORDON J. BURCH, Ph.D., visiting scientist*

VIRGILIO R. CARANGAL, Ph.D., agronomist and cropping systems network coordinator

TE-TZU CHANG, Ph.D., geneticist

W. RONNIE COFFMAN, Ph.D., plant breeder

J. RITCHIE COWAN, plant scientist**

SURAJIT K. DE DATTA, Ph.D., agronomist

RICHARD L. DISNEY, M.S., visiting associate editor*

J. BART DUFF, M.S., associate agricultural economist

V. ARNOLD DYCK, Ph.D.. associate entomologist

ALAN C. EARLY, Ph.D., associate agricultural engineer

DONALD L. ESSLINGER, M.S., visiting associate editor*

RUSSELL D. FREED, visiting associate plant breeder*

KWANCHAI A. GOMEZ, Ph.D., statistician

WESLEY W. GUNKEL, Ph.D., visiting scientist*

THOMAS R. HARGROVE, Ph.D., associate editor

L. DALE HAWS, Ph.D., crop production specialist

YUJIRO HAYAMI, Ph.D., visiting scientist*

ELVIS A. HEINRICHS, Ph.D., entomologist

ROBERT W. HERDT, Ph.D., agricultural economist

DERK HILLERISLAMBERS, Ph.D., associate plant breeder

HIROSHI IKEHASHI, Ph.D., plant breeder

BEN R. JACKSON, Ph.D., plant breeder

BIENVENIDO O. JULIANO, Ph.D., chemist

HAROLD E. KAUFFMAN, Ph.D., plant pathologist

GURDEV S. KHUSH, Ph.D., plant breeder

YASUMITSU KISHIDA, Ph.D., visiting scientist*

DONALD O. KUETHER, M.S., associate agricultural engineer

KEH-CHI LING, Ph.D., plant pathologist

JAMES A. LITSINGER, Ph.D., associate entomologist (cropping systems)

JOHN A. MCMENNAMY, M.S., associate agricultural engineer

EVERETT METCALF, M.S., visiting editor

TWNG-WAH MEW, Ph.D., associate plant pathologist

DUANE MIKKELSEN, Ph.D., visiting scientist*

KEITH MOODY, Ph.D., agronomist

FRANS R. MOORMANN, Ph.D., visiting scientist*

RICHARD R. MORRIS, Ph.D., agronomist

CHARLES J. MOSS, Ph.D., agricultural engineer

J. S. NANDA, Ph.D., visiting plant breeder

FLOYD NORDLAND, Ph.D., visiting communications specialist

JOHN C. O'TOOLE, Ph.D., associate agronomist

SHU-HUANG OU, Ph.D., principal plant pathologist

MANO D. PATHAK, Ph.D., entomologist†

FELIX N. PONNAMPERUMA, Ph.D., principal soil chemist

EDWIN C. PRICE, Ph.D., agricultural economist

FEDERICO V. RAMOS, M.S., farm superintendent

ROMEO R. REJESUS, Ph.D., visiting scientist*

WALTER G. ROCKWOOD, M.S., editor

MANUEL ROSERO, Ph.D., IRRI liaison scientist

ORLANDO G. SANTOS, M.P.S., associate farm superintendent
RAMESH C. SAXENA, Ph.D., associate visiting entomologist
H. W. SCHARPENSEEL, Ph.D., visiting scientist‡
JAMES N. SEIBER, Ph.D., visiting scientist*
DURVASULA V. SESHU, Ph.D., plant breeder
KAZUSHIGE SOGAWA, Ph.D., visiting scientist*
RICHARD L. TINSLEY, Ph.D., visiting scientist**
JOYCE C. TORIO, Ph.D., communications scientist
BENITO S. VERGARA, Ph.D., plant physiologist
LINA M. VERGARA, M.S., librarian
IWAO WATANABE, D. Agr., soil microbiologist
THOMAS H. WICKHAM, Ph.D., agricultural engineer
SHOUICHI YOSHIDA, D. Agr., plant physiologist
HUBERT G. ZANDSTRA, Ph.D., agronomist and cropping systems program leader

*Left during year.
**Transferred during year.
†On part-time basis.
‡Soil Chemistry and Agronomy Departments.