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IRRI Highlights 1985

Accomplishments & Challenges

1986
International Rice Research Institute
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INTRODUCTION

The year 1985 was one of self-examination for IRRI. We reviewed progress and set guidelines for future research, training, and national program collaboration in a series of scientific meetings during our 25th anniversary. The impact of the international agricultural research centers was assessed by the Consultative Group on International Agricultural Research (CGIAR). And the Technical Advisory Committee (TAC) set new and expanded priorities.

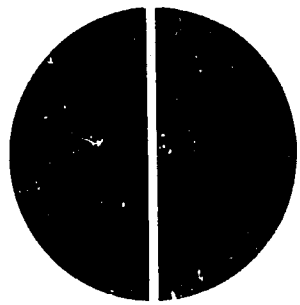
The CGIAR study showed striking increases in rice production as a result of collaboration between IRRI and national agricultural systems. Farmers grow high yielding rice varieties on 70 million hectares — about 55% of the riceland in developing countries. The yield increase contribution of modern varieties alone, not considering their catalytic role in encouraging other inputs that increase yield, is about one-half ton per hectare. That 35 million tons of additional rice per year feeds one-third of a billion people.

India and Indonesia, countries that once faced widespread food shortages themselves, contributed 100,000 tons of wheat and rice, respectively, to drought-stricken countries of Africa in 1985.

The 25th anniversary symposium *Rice Research: Accomplishments and Challenges* gathered ministers of agriculture and policy makers who decide the key issues of resource allocation for R&D, agricultural scientists, and farmers. They largely supported the conclusions of the impact study:

"*. . . IRRI actively supported and assisted in establishing the China National Rice Research Institute. . . .*" He Kang, Minister of Agriculture, Animal Husbandry, and Fishery, China.

"*IRRI, in particular, has been very important to us, especially in its association with the Thai Rice Research Institute . . . .*" Barom Tanthien, Deputy Minister of Agriculture and Cooperatives, Thailand.



Twenty-five percent of the world's rice farmers occupy 50% of the riceland and produce 75% of the world's rice. They have fertile soils, irrigation, and access to inputs. IRRI is developing varieties and management practices for the other 75% who are economically disadvantaged and bound to harsh environments.

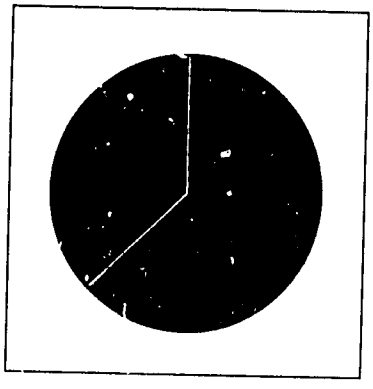
◄ *Rice-based cropping patterns, livestock raising, mushroom growing, vegetable gardening, and compost making are important components of the Prosperity Through Rice Project. For a detailed discussion of this activity, see the* Systems Approach *section.*

"*. . . for the first time in [Madagascar]. . . a national program for rice research has been established . . . implemented by a multidisciplinary team including two IRRI researchers . . . .*" Rabesa Zafera Antoine, Minister of Scientific and Technological Research for Development, Madagascar.

But another message was also clear: that much more work remains.

"*Let us also ask IRRI to continue its services for the benefit of our countries.*" A. Affandi, Minister of Agriculture, Indonesia.

"*Toward the realization of national mandate[s]. . . and the international mandate of IRRI, there should be greater and more effective collaboration.*" Buta Singh, Minister of Agriculture and Rural Development, India.



Of the more than 3,800 IRRI trainees, 37% have participated in research-oriented programs.

IRRI's first trainees, all degree scholars, arrived in 1962; the first group of short-term trainees came in 1964. By 1985, more than 3,700 rice workers had participated in IRRI training. Fully one-third of them were degree scholars, many of whom are continuing careers in rice research while some are now research administrators and agricultural policy makers in national programs. A TAC report on training in the CGIAR system commended IRRI's programs and recommended that individual countries take responsibility for some training while IRRI develops new courses and phase out older ones.

We are implementing those recommendations. Last year we offered eight new courses, and cooperated with Bhutan and Burma to develop trainers and course materials for local rice production courses.

Appropriate technology for harsher physical and economic conditions is more difficult to develop and disseminate than the earlier technology developed for areas favored by well-controlled water, fertile soils, and other factors suitable for high production. The TAC priorities paper called for greater research emphasis on solutions to the economic and environmental problems faced by farmers in less favored areas.

The most urgent needs are the development of rice varieties and management practices for farmers in economically and environmentally disadvantaged areas, those bound to rainfed upland and lowland rice areas, deep water rice areas, or problem soil areas. At the same time we must

IRRI is working to develop varieties and management practices for farmers who toil in harsh economic and physical environments.

continue to develop, for farmers in more favored irrigated areas, low cost smallholder-friendly technologies to permit them to reduce production cost without sacrificing yield gains already made.

In this report, we emphasize our efforts to develop rices for harsh environments and adverse soils. These rices, too, must have strong and stable insect and disease resistance. Germplasm collection and management and basic research to increase yield potential are integral components of these efforts.

In agronomic management we emphasize special technologies for problem soils, increasing fertilizer efficiency, using biological nitrogen fixation and biofertilizers to reduce mineral nitrogen requirements, and tillage practices and implements to conserve energy and maximize crop production.

We seek to develop methods for maximizing water use efficiency by reducing irrigation and improving flood control.

Synthetic insecticides are expensive and may be dangerous if mishandled. Our pest management program emphasizes integration of disease- and insect-resistant rice varieties, need-based chemical controls, methods to encourage natural enemies of pests, botanical insecticides, and simple pest monitoring procedures.

In the farming systems program, we try to integrate all facets of IRRI rice research with research on other crops conducted by national institutions and international centers. For economically disadvantaged farmers in adverse environments, sustainable, stable high yields are particularly important.

We have benefited from our year of self-examination with the help of national scientists, policy makers, and donors, as well as that of farmers, who are the ultimate judges of our work. Their commendations gave us hope. Their in-depth reviews gave us the insight to focus more sharply on the urgent work ahead. We are more than ever convinced that the proven model of purposeful cooperation between international centers and national programs is the pathway to enduring agricultural progress.

GENETIC IMPROVEMENT

he initial impact of IRRI's rice improvement work was greater yield from irrigated rice and was typified by the IR8 plant type. The second phase embodied high yield potential, wide-spectrum insect and disease resistance, and early maturity, as shown by IR36. We are continuing to widen the genetic base for pest resistance in varieties such as IR64, which, in addition to other desirable characteristics has excellent grain quality. But our current major breeding goal is to develop varieties for adverse conditions, thereby benefiting economically disadvantaged rice farmers.

Full irrigation is available on only about half the world's ricelands. Other areas er from drought, flooding, and adverse soils, as well as pests. Our strategy for rice

improvement in these areas has been to categorize the different rainfed rice environments by their major constraints; to determine the characteristics of rice desirable for better performance under different constraints; to develop appropriate methods to screen rices for tolerance for those constraints; and to use the germplasm bank, in collaboration with many national breeding programs, to identify tolerant lines, and then to combine them with lines that have high yield potential.

Finally, hot spot screening of early generation and stable breeding lines is conducted in close collaboration with national program scientists. We are making good progress in identifying improved rices adapted to different adverse environments, in characterizing and extending the resources of the germplasm bank, and in developing new approaches to discovering tolerance for adverse conditions through tissue culture and wide hybridization.

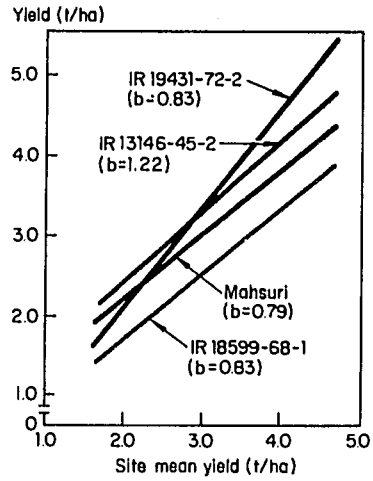
RAINFED LOWLAND RICE

More than 35 million ha in South and Southeast Asia are planted to rainfed lowland rice. IRRI breeders screen pedigree lines for important agronomic traits, including drought and submergence tolerance. Agronomists and breeders then evaluate lines in observation and yield nurseries for adaptation to specific stresses in different countries.

In 1985, we evaluated more than 300 breeding lines in yield and observation nurseries at IRRI and in farmers' fields. Philippine sites representing three unfavorable rainfed lowland environments important throughout Asia have been identified. They include

- drought-prone environments at Liloan, Cebu; Guimba, Nueva Ecija; and Solana, Cagayan;
- a drought- and submergence-prone environment at Solana, Cagayan; and
- medium deep, stagnant environments at Bay, Laguna; and Laganes, Iloilo.

Farmers were assisted to evaluate entries in the trials, and promising lines were identified for IRTP nurseries. In drought-prone areas, IR13146-45-2 and, where stress was not too severe, IR19431-72-2 outyielded check varieties. They also performed well in IRTP nurseries (Fig.1).



1. Advances in breeding of rice varieties adapted to rainfed shallow water conditions.

2. Two selections from the Assam Rice Collection (ARC) showed outstanding drought tolerance for 6 years: ARC10372 (left) and IRRI-bred line IR9782-111-2-1-2.

We also worked with national programs to develop strategies for rainfed lowland rice improvement. Thailand-IRRI pedigree nurseries were grown for the third year in northeast Thailand, and agronomic studies were initiated. Similar trials are planned in other Asian nations.

Drought is a major constraint in many rainfed lowland areas. We continued screening breeding lines and new genetic sources for drought tolerance in the field in the dry season. In 1985 we found 64 of 8,561 entries had better drought tolerance at vegetative stage than did the drought-tolerant check Salumpikit. Thirty-one promising lines were from IRRI crosses and 33 were from national programs. Of these, ARC10372 from India and IRRI line IR9782-111-2-1-2 (Fig. 2) had consistent, outstanding drought tolerance. Outstanding rices had 25% or less leaf area desiccation when soil moisture tension reached 20 bar at 20-cm soil depth. Salumpikit had 50% desiccation. The 64 rices and Salumpikit recovered fully when soil moisture stress was relieved.

UPLAND RICE

Rice yields in upland environments may be limited by drought, adverse soils, and pests. In 1985, we surveyed scientists in 37 countries, representing more than 90% of total upland rice area, to identify and rank major environmental constraints to upland rice production and to develop breeding objectives for increasing upland rice yields and yield stability.

Respondents ranked biological constraints as weeds, blast, brown spot, and bird damage and environmental

constraints as drought, P deficiency, and acid soils. Among currently grown varieties, lack of drought tolerance and disease resistance and low yield potential were most important.

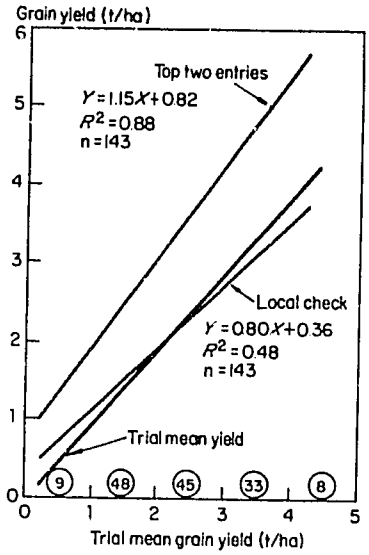
Developing upland varieties with resistance to stem borer, rice bug, blast, and brown spot and tolerance for P and Zn deficiencies were given as major breeding objectives. Breeding objectives, however, are largely determined by local conditions, which vary substantially.

The survey also provided names and main features of 505 widely grown traditional varieties, 287 widely grown improved varieties, and 280 promising lines. Such locally adapted strains are the starting point for further improvement.

Upland rice research has been significantly strengthened in recent years, and we have a better understanding of the characteristics of the major upland rice environments. Mechanisms are needed to make the exchange and evaluation of elite germplasm as efficient as possible with respect to the major target ecosystems.

Several varieties such as IR43, IR45, UPL Ri-5, and UPL Ri-7 have performed well in favorable upland environments. At Caliraya, Philippines (an upland site with a long wet season and acid, infertile soil), 1985 trials with several hundred varieties gave these results:

- With few inputs, traditional japonica-derived upland varieties produced better than other *O. sativa* rices. Varieties IRAT140, ITA235, and Padi Seneok were outstanding, and progenies IRAT104/Palawan, IRAT140/Palawan, and ITA235/Palawan were very promising.
- With moderate inputs, including moderate N application, many varieties and breeding lines had severe blast infection. Where blast was not severe, UPL Ri-5, BPI 9-33, BR319-1, Aus 122, and Aus 454 have potential. IRAT140 also performed well. Among the progenies, IRAT112/Sein Talay and advanced lines B2997C (Indonesia) and P1358 (Colombia) were promising.
- Insect resistance, mainly to seedling flies, generally was moderate or low.
- Japonicas were the main source of blast resistance.



3. Regression of yields of best two entries and the local check on mean yields from the International Upland Rice Yield Nursery, 1975-83. Circled numbers show number of trials.

Indica and aus varieties had sheath blight resistance.

- Rices from Brazil and West Africa were generally well adapted to acid, low fertility soils and had good blast resistance. They were moderately to very susceptible to sheath blight and seedling flies.

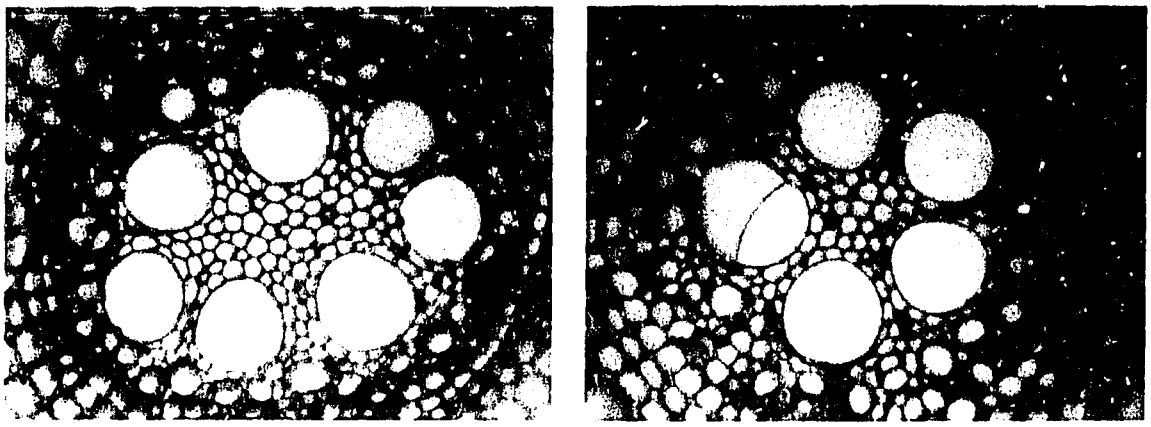
Results of trials between 1975 and 1983 at many sites (Fig. 3) show that considerable progress has been made in producing better upland varieties for specific locations. Predicted yields for the top two entries exceeded the predicted local check yields over the entire range of yield levels. The gap between the best entries and the local check increased from low-productivity trial environments to relatively favorable-trial environments. When trial mean yields were less than 1.0 t/ha, the best entries yielded 0.5-0.8 t/ha more than the local check. The differences in yield between the two entries and the local check were statistically significant in 75% of the trials. The best entries yielded twice as much as the local check in low-yield situations and about 50% more in the most favorable conditions.

These results must be interpreted with caution. They indicate nothing about the yield stability of the high yielding cultivars, but they do suggest the existence of germplasm that may raise the yield potential of the varieties used in many local programs. Whether or not this yield gap would remain substantial under actual farm conditions is unknown.

Much research has sought to identify rices with deep and thick roots to avoid drought. In Bangladesh varieties, a comparison of the root structure of drought-tolerant and susceptible varieties showed that plants with deep and thick roots have more xylem vessels than varieties with shorter, thinner roots (Fig. 4).

The number and diameter of the xylem vessels were positively correlated with root weight and plant height, but negatively associated with root and tiller number. Abundant, large xylem vessels enhance water movement from roots to upper plant parts, thus reducing stress during short drought.

Several drought-tolerant lines with deep and thick roots have performed well in low-fertility, low-P soil with pH 4.0. IR30714-B-1-1 and IR30716-B-1-7, both with



4. The rice variety Mijingem (left) has abundant xylem vessels in its roots and is better able to withstand short drought periods than Kataktara, which has fewer xylem vessels.

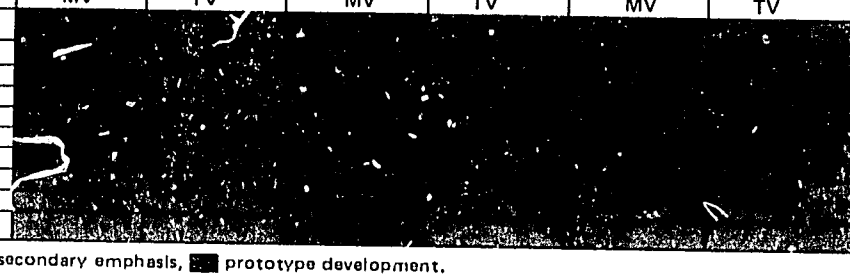
West African parentage, yielded twice as much as traditional Kinandang Patong and Dinorado and four times as much as IR43. In favorable upland areas IR63 outperforms the others.

DEEP WATER RICE

The cultural type designated as deep water rice contains several distinct ideotypes that are adapted to different deep water environments. Criteria for assigning potentially promising deep water rice lines to appropriate environments include:

- *deep water survival strategy*. Deep water rices should have elongation ability (the ability to keep the crop canopy above rising water at all times), submergence tolerance (the ability to survive after not more than 10 days submergence), and fast emergence from flood (the ability of the crop canopy to emerge quickly from total submergence).
- *time of maturity*. Deep water rice should mature 1 month after fields have drained. In the northern hemisphere, this trait ranges from 150-day duration for October maturity, to photoperiod sensitivity with a range of critical daylengths for maturity as late as January. Assuming a tolerance of 10-day intervals, there are 10 maturity groups from late October to late January.
- *internode length (plant height)*. The choice of

Maturity timing	DEEP WATER ADAPTATION						
	None	Elongation		Emergence		Submergence	
	TV	MV	TV	MV	TV	MV	TV
150 d							
25 Oct							
5 Nov							
15 Nov							
25 Nov							
5 Dec							
15 Dec							
25 Dec							
5 Jan							
15 Jan							



major emphasis, secondary emphasis, prototype development.

5. Deep water rice ideotypes for the northern hemisphere. TV = traditional variety, e.g., Khao Tah Haeng; MV = modern variety, e.g., RD19.

medium or tall stature depends on expected water depth and flooding speed.

If we multiply the options for each of the categories, there would be 60 distinct, mutually exclusive ideotypes to choose from when selecting promising deep water rices for field trials. While some options can be ruled out for any location, it is difficult to narrow the choices without some trial and error.

IRRI is therefore conducting deep water rice research on three levels based on the framework in Figure 5:

- breeding and field testing new lines and varieties;
- making crosses on request and sharing IRRI lines with other deep water rice breeders; and
- developing prototypes with combinations of appropriate traits. (Research concentrates on obtaining prototypes before evaluating their usefulness.)

Field testing promising deep water rices

Results of field tests in naturally flooded farmer fields were available in 1985 from Asian sites of the International Rice Testing Program and from trials in Panay, in the Cagayan River Valley, and in Bicol, Philippines. Table 1 lists lines that were outstanding in at least two sites.

Choosing F_2 populations for exchange

To ensure selection of deep water rices under proper environmental conditions, we invited breeders who grew IRTP deep water rice nurseries to request F_2 hybrid populations descending from their favored IRTP entries. We then sent out hundreds of requested F_2 populations.

Table 1. Lines outstanding in at least two naturally flooded sites.

Designation type	Site	Flood type
	Stem elongation	
BKNFR76010-108-2	Huntra, Thailand	Stagnant
	Iloilo, Panay	Stagnant
BKNFR76026-29-2-1-3	Solana, Cagayan	Flash
	Huntra, Thailand	Stagnant
BKNFR76026-3-2-2-2	Iloilo, Panay	Stagnant
	Huntra, Thailand	Stagnant
	Prachinburi, Thailand	Stagnant
IR11288-B-B69-1	Huntra, Thailand	Stagnant
	Prachinburi, Thailand	Stagnant
	Cagayan, Valley	Stagnant
IR21038-77-P2-5-2-3-1-1	Iloilo, Panay	Stagnant
	Huntra, Thailand	Stagnant
	Prachinburi, Thailand	Stagnant
IR21064-48-2-1E-P1	Solana, Cagayan	Flash
	Pusa, Bihar	Flash
IR38793-248-6	Iloilo, Panay	Stagnant
	Huntra, Thailand	Stagnant
IR6370-K23-1	Iloilo, Panay	Stagnant
	Huntra, Thailand	Stagnant
	Prachinburi, Thailand	Stagnant
	Cagayan Valley	Stagnant
SPR7274-0-0-1	Huntra, Thailand	Stagnant
	Prachinburi, Thailand	Stagnant
	Cagayan Valley	Stagnant
SPR7282-2-0-24-1	Iloilo, Panay	Stagnant
	Huntra, Thailand	Stagnant
	Prachinburi Thailand	Stagnant
	Submergence tolerance	
IR26716-12-2-1-3	Iloilo, Panay	Stagnant
	Solana, Cagayan	Flash
IR31142-14-1-1-3	Iloilo, Panay	Flash[a]
	Solana, Cagayan	Flash
	Bicol, River Valley	Flash
IR33279-1-501-1-1-2	Iloilo, Panay	Stagnant
	Solana, Cagayan	Flash
IR33284-4-503-1-1-3-2	Iloilo, Panay,	Stagnant
	Solana, Cagayan	Flash

[a]Also saline.

Selecting F_2 populations in farmers' fields

Where logistically possible, F_2 selection in representative farmer fields is a most efficient way to combine selection for proper maturity with that for appropriate deep water adaptation. We evaluated 21 F_2 populations of deep water rice in a naturally flooded field near Ayutthaya, Thailand. Water level reached 1 m in a slowly rising flood. Survival was 1-90%. The best populations were those with elongation ability and late maturity. Populations with only one of these attributes died.

Elongation

In studies of deep water rice elongation, we found that lower light intensity created by submergence increased elongation. Dry matter accumulation decreased as light intensity decreased, indicating the photomorphogenetic role of light in elongation. Green, yellow, and red light stimulated elongation, and blue and far-red light inhibited it.

Internodes elongated in complete darkness when presubmergence carbohydrate content of plants was sufficient and oxygen was bubbled through the water. Under natural light, underwater photosynthesis supplemented the oxygen requirement, and oxygen content of water increased when plants were submerged. Because plant elongation depends on aerobic respiration, differences in oxygen requirement partly explain why submerged internodes elongate more than leaf sheaths.

Floodwaters usually are turbid, which affects photosynthesis. However, as long as plants had enough carbohydrate, turbidity did not inhibit internode elongation.

Optimum water temperature for plant elongation and growth under submergence was around 30 °C. In many deep water rice areas, floodwater temperature is far below optimum. We found that internode elongation rate at different water temperatures was not related with internodal ethylene concentration. Plants elongated fastest when water depth increased 20 cm per day or when 80% of the plant was submerged. Increasing water depth stimulated carbohydrate and N mobilization to elongating plant parts.

Flood and drought tolerance

In large areas of India and Thailand, rice may be affected by both drought and flooding. We are conducting extensive research at a field laboratory in Solana, Philippines, that represents these conditions.

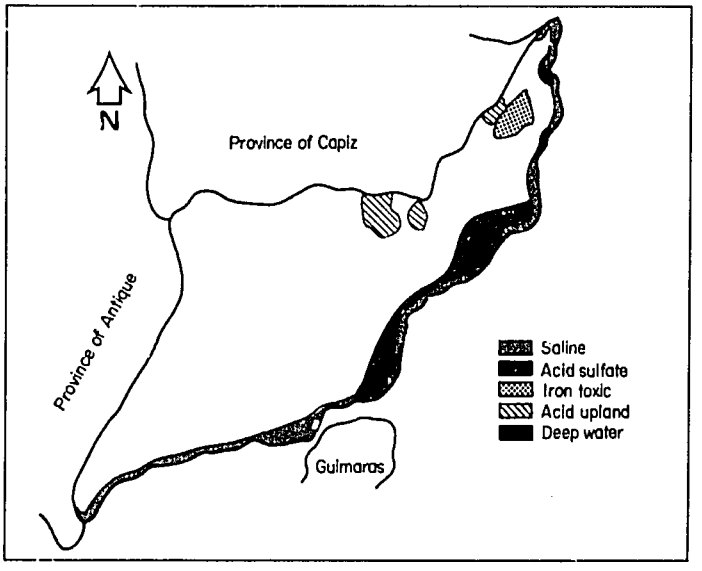
We have found that photoperiod-sensitive rices perform better than photoperiod-insensitive varieties. Photoperiod-sensitive varieties recover better from late transplanting, which is necessitated by the lack of water control, and flower as floods begin to recede. Each year at Solana we screen and yield test hundreds of breeding lines

for drought tolerance, flood tolerance, and recovery from late transplanting.

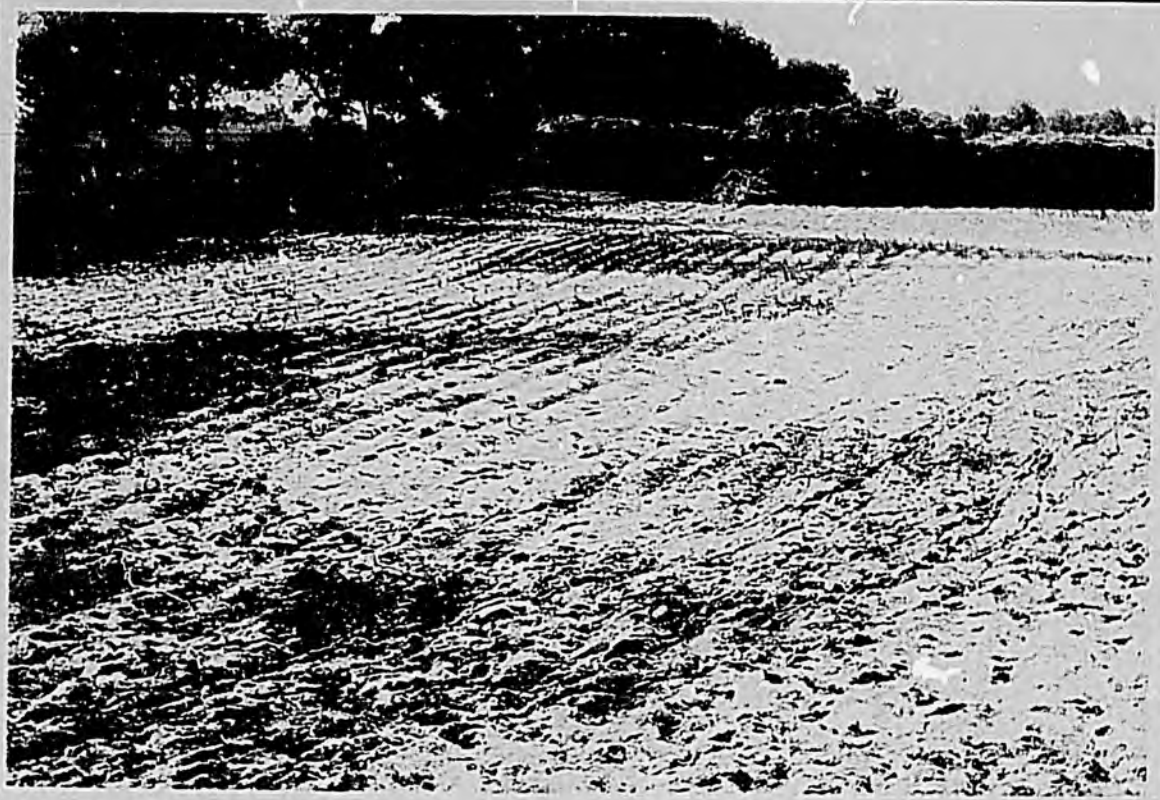
Genetic improvement for difficult rice environments relies on a close working relationship between breeders and agronomists. Breeders generate materials that are field tested by agronomists at carefully selected sites that represent a range of adverse hydrological environments. The agronomists then feed back performance data and the plant characters critical to adaptation.

ADVERSE SOIL CONDITIONS

Screening varieties for adverse soils tolerance requires a range of sites. The problems rarely occur in isolation, and in addition it is necessary that the lines to be tested be resistant to major pests and diseases. We rely on initial screenhouse and field testing under simulated adverse conditions at IRRI, followed by testing in several field sites in the Philippines, and then further testing through IRTP collaborative research projects in different countries. We recently strengthened our screening program by identifying a range of sites in Iloilo, Philippines (Fig. 6).



6. Different adverse soils in Iloilo.



Saline rice soil near Dokri, Pakistan. After harvest, salt rises to the surface and must be flushed before a subsequent rice crop. In the background is rice ready for threshing.

Salt tolerance

Drainage, reclamation, and good water management can improve saline land, but they are expensive measures and may not be economic in many Asian rice growing countries. We are therefore emphasizing research to develop salt-tolerant rice varieties for saline areas.

We developed a simple, efficient screening technique to select salt-tolerant rices. One-week-old seedlings were grown in a culture solution with 0.5% NaCl. Tolerance was determined by percent seedling survival. Rices with >60% survival were resistant, 31-60% moderately resistant, and 1-30% susceptible. Of 87 rices screened for salinity, Nona Bokra, IR4595-4-1-13, Pokkali, KR1-24, and BR4-10 had tolerance.

Osmotic effects, ionic toxicity, and nutritional imbalances are the major causes of salt injury, the symptoms of which are stunting and withered leaves.

To develop salt-tolerant varieties, it is necessary to understand the genetics of tolerance and the interactions

Table 2. Promising entries from the International Rice Salinity and Alkalinity Tolerance Observational Nursery, 1977-84.[a]

Variety or line	Years tested (no.)	Vegetative stage tests		Maturity stage tests	
		Locations (no.)	Salinity score	Locations (no.)	Salinity score
CSR1	3	7	5.4	5	3.2
CSR4	6	9	5.8	5	5.4
Getu	6	8	5.2	6	4.3
IR46	7	17	5.0	14	5.2
IR2307-247-2-2-3	7	15	5.3	12	5.5
IR4595-4-1-13	3	5	4.8	3	5.3
IR4630-22-2-5-1-3	3	7	4.4	5	3.4
IR9764-45-2-3	6	2	4.0	2	5.0
IR10198-66-2	6	15	5.3	10	5.4
Nona Bokra	4	12	4.8	10	4.8
Pokkali	9	23	5.2	16	5.6

[a]Scored on a scale of 1 (almost normal plants) to 9 (almost all plants dead).

between salinity and environmental factors. Genetic variability in salt tolerance exists, and is being used in breeding programs. Genes that control Na level in shoots are partially dominant and at least three groups of genes are involved in seedling stage tolerance. Selection by shoot length, Na level in shoots, shoot and root dry weight, plant height, and yield per plant, characters whose effects are cumulative and highly heritable, could lead to the development of salt-tolerant rices.

Improved germplasm for adverse soils developed at IRRI and in different countries is distributed to national programs through the IRTP nurseries. The first International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON) was initiated in 1976. By 1984 more than 400 entries had been tested. Some of the promising breeding lines or varieties from those tests are listed in Table 2.

In 1985 we initiated our breeding program to develop rice varieties for tidal lowlands. Breeding priorities were established and representative sites were selected for evaluating segregating populations and breeding lines. In cooperation with the Philippine Ministry of Agriculture and Food, we selected several sites in Iloilo representing tidal lowlands with saline, acid-saline, and acid sulfate-saline soils. We also are collaborating with the Thai Rice Research Institute to test breeding materials for tolerance for acid sulfate soils.

All sites were planted to a hundred varieties, elite lines, and breeding populations. We found that improved varieties for tidal lowlands must possess tolerance not only for soil stresses but also for hydrological stresses such as flooding and submergence.

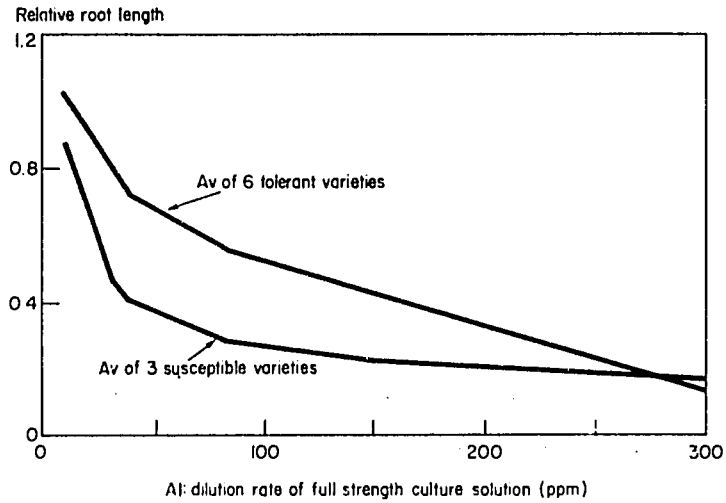
When tolerance for Fe and Al toxicity is incorporated into varieties with other desirable characteristics, rice varieties yielding well in acid soil conditions are obtained. IR42 has been widely grown under adverse conditions, and more recently IR9764-45-2-2 was identified as having outstanding tolerance for lowland soil toxicities and deficiencies. IR54 and IR62 also perform well in these conditions, and have high yield potential and good insect and disease resistance.

Tissue culture to produce tolerance for adverse soils

Tissue culture offers opportunities for generating variability, which is important in breeding rices tolerant of soil stresses. We used tissue culture to regenerate plants from Taichung 65, Fujisaka 5, Reiho, and Nona Bokra. From 526 R_1 (R_1 = plant regenerated from culture; $R_{2...n}$ = subsequent generations) lines of variants tested, 725 R_2 seedlings were selected and treated as individual lines. Screening continued through R_3, R_4, and R_5. At R_5, six lines had moderate salinity tolerance. Although the percentage of variants with moderate salinity tolerance increased with each generation, variants were still segregating at R_5.

In 1984 wet season, we planted an observational nursery of 1,720 plants regenerated from Nona Bokra. Of them, 282 variants had semidwarf to intermediate plant height, erect leaves, and compact tillering. The variants were planted again in 1985 dry season and three R_3 lines were homozygous in having compact tillers and erect leaves. However, when the three lines were tested for salt tolerance, they were susceptible. It appears that although Nona Bokra plant type could be improved through tissue culture, it could become susceptible to salinity in R_5. We are continuing these studies to understand better how to utilize tissue culture methods for breeding for salinity tolerance.

We regenerated plants from Reiho calli that had been exposed in NaCl-enriched medium for 32 months. The regenerated plants, however, were susceptible to salt,



7. Relation between relative root length and Al to dilution of full-strength culture solution.

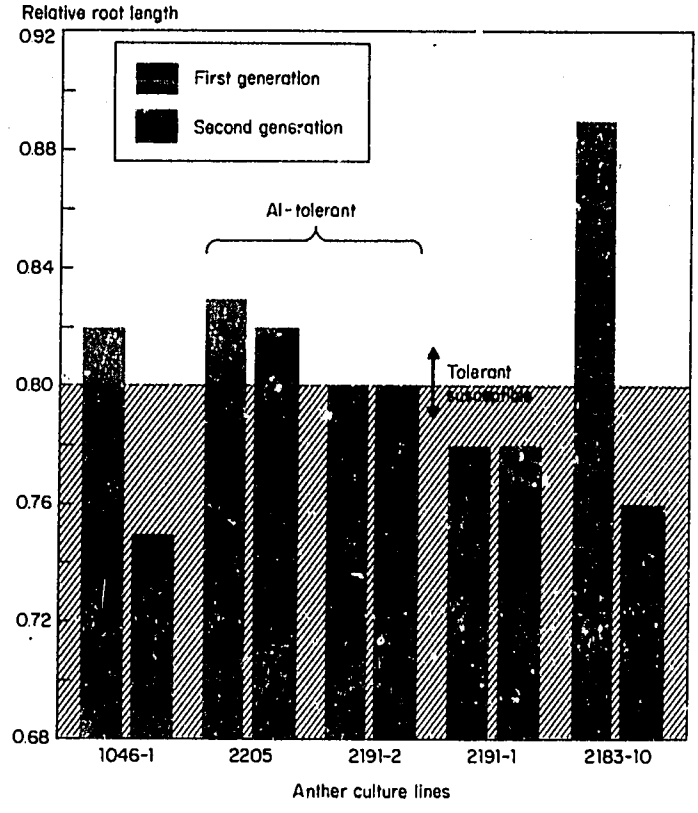
suggesting that they were regenerated from susceptible cell lines. We are working to improve ways of discriminating between susceptible and resistant cell lines, and thus improve the selection procedure for regeneration of tolerant lines.

Varietal response to aluminum toxicity

Al toxicity is a serious problem in highly acid soils. Usually, rices are screened for Al tolerance in a solution of 30 ppm Al, which is much higher than the critical level of 2 ppm Al in soil solution. In earlier work we found that 5 ppm Al may be used for screening if the nutrient solution is diluted to 1/5 strength, indicating that varietal tolerance for Al may change with nutrient concentration.

In 1985 we grew tolerant and susceptible rices for 2 weeks in solutions with graded Al and nutrient concentrations. Al tolerance declined as Al to nutrient ratio increased (Fig. 7). Varieties responded up to an effective Al concentration of 150 ppm. Results imply that a wide range of Al and nutrient combinations may be used to screen for Al toxicity tolerance. As little as 3 ppm Al may be used for screening if the nutrient solution is diluted to 1/10 strength.

These results also show that Al toxicity in acid upland soils may be alleviated by appropriate fertilizer application.



8. Two anther culture-derived lines from Giza 170, an Al-susceptible variety, exhibited a genetic basis for Al tolerance when grown through two generations.

We recovered tolerant gametoclonal variants from Al-susceptible Giza 170 and Fujizaka 5 (Fig. 8). Four of 71 anther culture lines from Giza 170 and 4 of 29 lines from Fujizaka 5 had Al tolerance at seedling stage. When plants from the eight selected lines were grown to maturity, two from Giza 170 and one from Fujizaka 5 remained Al tolerant, indicating that the lines have a genetic basis for tolerance.

COLD TOLERANCE

Rice is grown in many areas of high altitude and in some at high latitude where low temperature is a serious limitation. In high altitude areas such as those in Nepal, Bhutan, and Kashmir, and in countries such as Korea and Japan, rice yields often are limited by cold weather and cold irrigation water. We established cold tolerance screening with the

Korean Rural Development Administration, and use a high altitude site at Banaue in the Philippines.

In Korea, cold water is brought from a high altitude lake and provides a temperature gradient as it runs across the nursery beds. Each varietal entry of 90 hills grows in 17 °C water at the inlet. At the outlet, water has warmed to air temperature (24 to 30 °C). Ten plant traits are measured. An analysis of 4 years' data showed that measuring plant traits at the inlet is highly reliable in differentiating cold tolerant and susceptible entries.

High spikelet fertility was the most important trait for cold-tolerant entries, followed by large number of panicles and spikelets per panicle, days to heading and culm length, and phenotypic acceptability. Leaf discoloration and panicle exsertion did not significantly affect the number of filled spikelets.

Spikelet fertility in NC99, Fuzi 102, Jodo, and Diog Jeog Jodo proved adaptable to a wide range of environments and seasons.

Of 1,102 entries screened in 17 °C water in 1985, several performed well: IR20913-B-60, IR9202-25-3, Sangpungbyeo, SR11027-B-B-127, Kuchum, Janack, Che Eu Hung, Chun Lum 4, Chun Nen Tsan, HR4467-8-4-2-1, and Lien Chan Ze Thou. Janack also was identified as a good source of lodging resistance. We have compiled a computerized list of different plant traits for all rices screened for cold tolerance since 1978.

We also screened 187 rices for tolerance for 18-20 °C air temperature at flowering. Entries with > 65% spikelet fertility were Diamante Inia, Barkat, Quella Inia, Tatsumi-Mochi, Chun Lum U Le Thou, C11561-1, Suweon 303, and Rodira.

In observational trials in Korea, yields greater than 6.5 t/ha were obtained from B2983b-Sr-13-4-1-10-1-2-2, YR1964-16-1-2-4-B-2, YR2404-15-4-9-3-2, IR8866-30-3-1-4, SR111010-B-403, and YR2617-7-2. Similar yields were obtained with low fertilizer application (100 kg N/ha) from Pungsanbyeo, YR1654-16-2-4-*B-2, and SR10649-B-504. These entries are ready for testing in national programs.

We also continued to use anther culture to develop cold-tolerant lines from F_1 sexual crosses. Of 23 F_1 crosses,

Measuring chlorophyll content in the field is one way of determining cold-tolerant rice plants.

18 responded to anther culture. We regenerated 6,640 lines, of which 2,700 were homozygous diploids and 1,182 lines have been sent to Korea for cold tolerance and blast resistance screening.

Chlorophyll content is strongly correlated with high plant productivity and dry matter production, and is a good indicator of cold tolerance because low temperature causes chlorophyll degradation in susceptible plants.

We compared three methods of measuring chlorophyll content — actual content, chlorophyll fluorescence, and the SPAD-501 chlorophyll meter. Measurements from the SPAD-501 meter correlated more closely with actual chlorophyll content than those determined by chlorophyll fluorescence. The meter provided rapid, reliable measurements that agreed with visual cold tolerance scoring, and was easy to use.

GERMPLASM COLLECTION AND MANAGEMENT

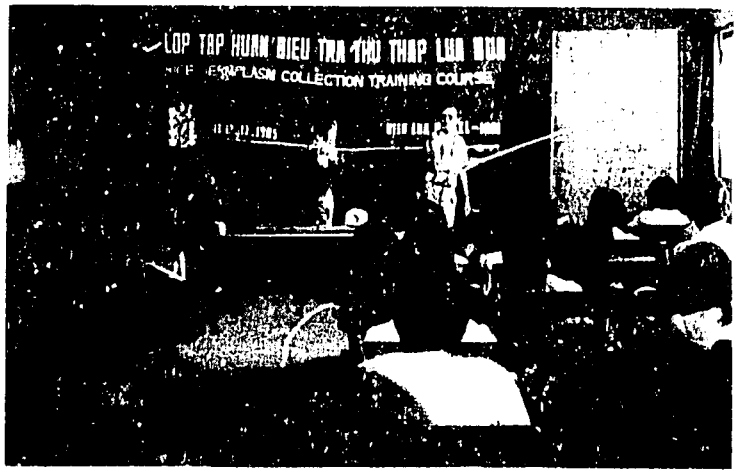
Since 1971, when we initiated coordinated, collaborative field collection of rice germplasm, more than 40,000 seed

samples have been collected in 14 Asian countries and deposited in the germplasm bank at IRRI. The International Board for Plant Genetic Resources financed collection of 14,600 seed samples and we have gathered an additional 13,000. Many of the rices were collected from remote areas where small rice farms face various edaphic or biotic stresses. The collection exceeded 80,000 accessions by the end of 1985.

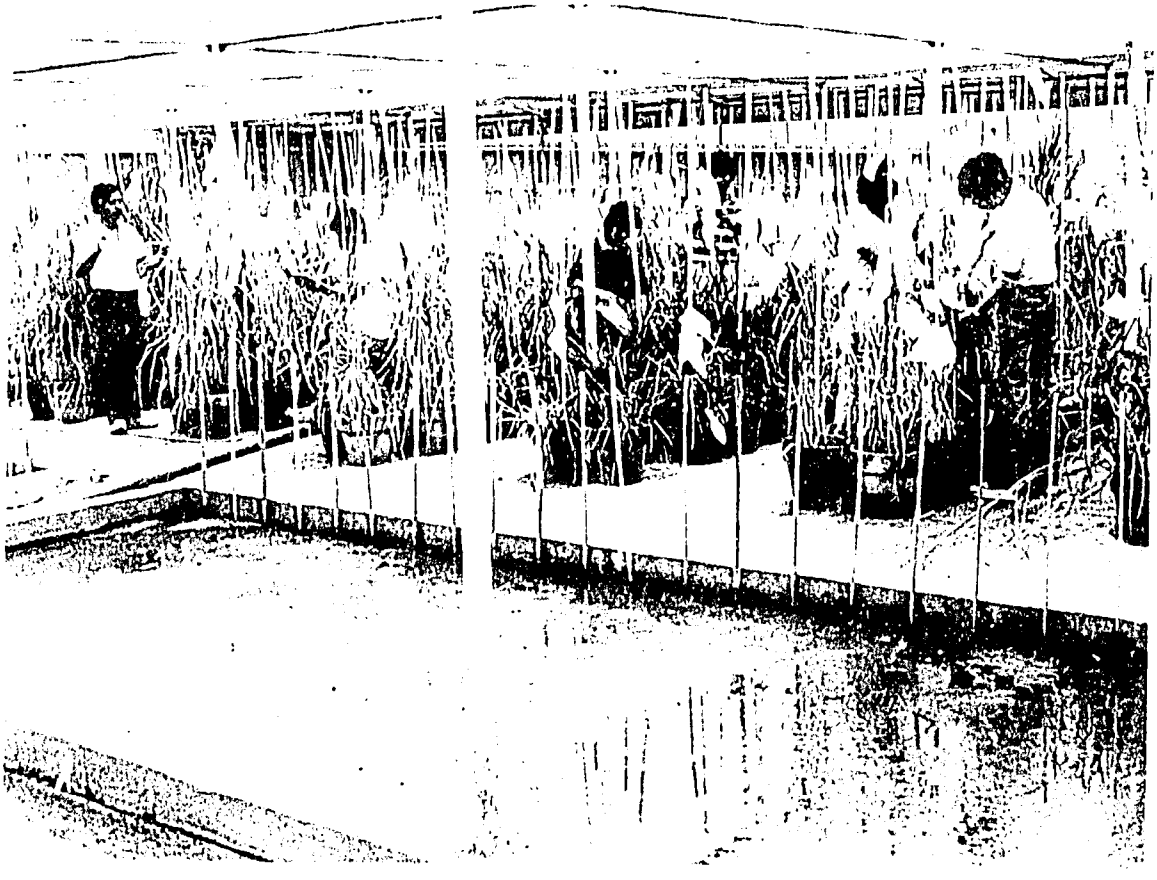
In 1985, we helped collect rices in Sabah, Malaysia, and Madagascar. To help germplasm-rich countries continue their own field exploration and sampling, we organized short training courses for field collectors in national and provincial centers in Indonesia, Burma, and Vietnam. Thirty field collectors were trained in Indonesia, 51 in Burma, and 42 in Vietnam. Lectures were complemented by collection trips to farmers' fields (Fig. 9). The need to collect wild rices was emphasized.

Once collected, rice seeds are shared and preserved in national gene banks and the International Rice Germplasm Center at IRRI. We endeavor to ensure security of all collected samples through good management of the collected material. Where seed storage centers have inadequate facilities and staffing, seeds often quickly lose viability and may be misidentified, thus causing another kind of genetic erosion and cancelling the inputs of field collection.

Demands for exotic rice germplasm continue to rise because genetic engineers use temperate-zone germplasm



9. Roy Denton, rice collection specialist, lectures to Vietnamese field collectors.



10. IRRI's expanded nursery for seed production from exotic germplasm

for tissue culture, and plant pathologists and entomologists find pest-resistance genes in wild rices. Seeds of the exotic types are difficult to grow and harvesting requires bagging of individual panicles. Therefore, we recently quadrupled our nursery for seed production from exotic germplasm (Fig. 10). Many wild species have desirable resistance characteristics. Advances in molecular genetics provide opportunities for moving genes across sexual barriers; therefore, we are expanding our collection and breeding with wild species.

To characterize the germplasm, we are developing biochemical markers by surveying enzyme activity in germplasm and determining its genetic control. Such markers permit monitoring gene expression, stress alleviation, juxtaposition, and recombination in the various materials developed from wide hybridization and cell and

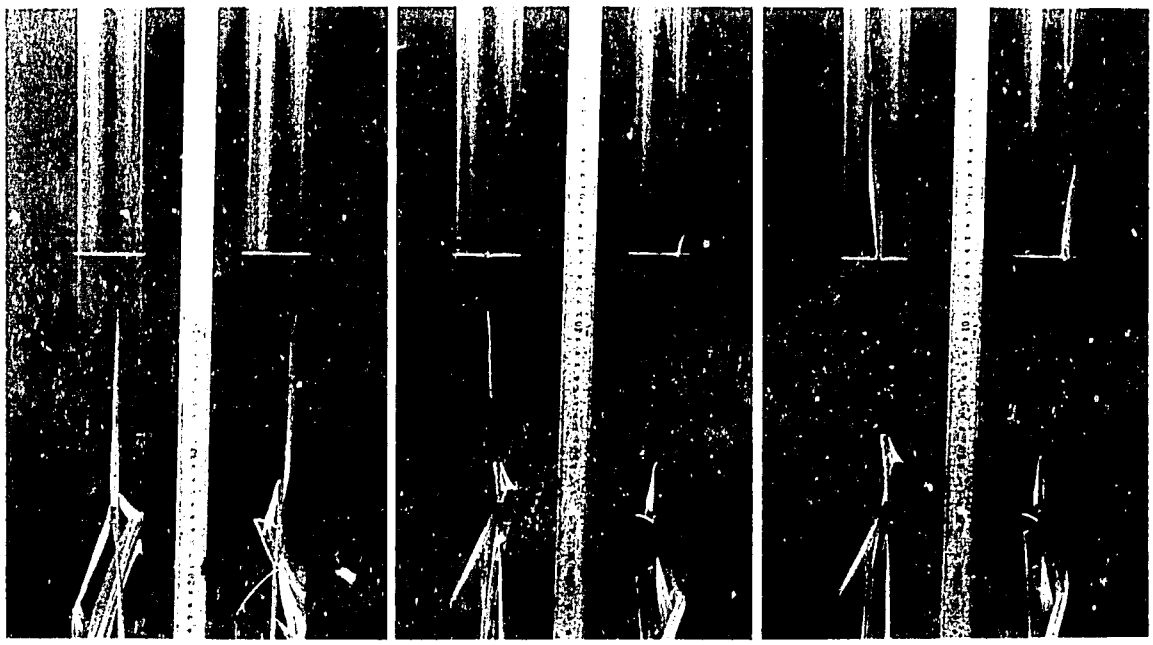
tissue culture, and thus are powerful tools for our biotechnology-based breeding programs.

Our studies of isozyme variation among *O. sativa* germplasm have modified the perception of subspecific organization. Clear varietal groups that do not always correspond to the identified morphological trait appeared. Using both types of characters will improve the utilization of available germplasm.

Understanding the basic genetics of rice is imperative for utilizing emerging techniques of genetic engineering in rice improvement. However, such knowledge lags behind that of the genetics of crops such as wheat, maize, barley, and tomato. To stimulate cooperative research on rice genetics, we organized in May 1985 an international symposium on rice genetics that was attended by 200 scientists from 31 countries. Seventy-seven papers on different aspects of rice genetics were presented. Participants founded the Rice Genetics Cooperative, an informal, incorporated scientific society to

- foster cooperative research on all aspects of rice genetics to promote rice improvement;
- develop standard rules for gene symbolization and nomenclature and prepare and continuously

Ethylene production can be used as a biochemical marker to determine elongation ability during submergence stress. The floating rice TCA 177, at left in all photos, elongated 22 cm and produced about twice as much ethylene as the deep water rice on the right, which elongated only 13 cm. The pictures were taken at 0, 12, and 24 hours after submergence.



update linkage maps and develop a standard system of numbering chromosomes;

- ensure proper maintenance of genetic and chromosome marker stocks;
- monitor and promote the application of genetic engineering and tissue culture techniques;
- publish the *Rice genetics newsletter*; and
- organize periodic international rice genetic symposia.

INCREASING YIELD POTENTIAL

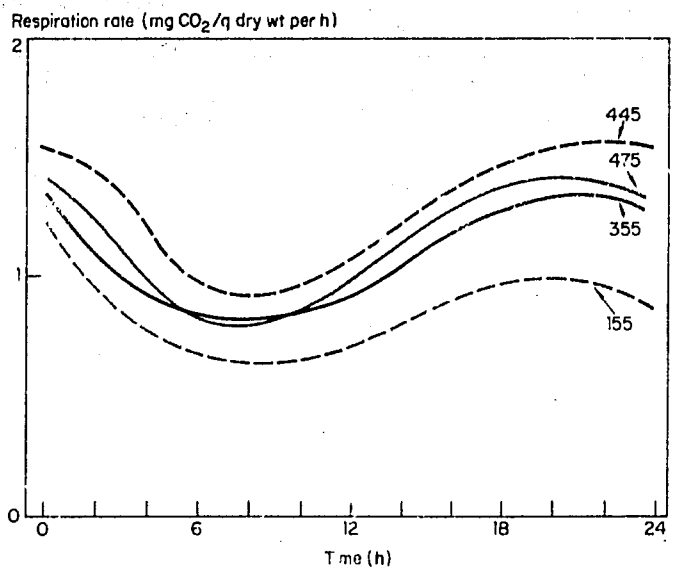
We have used various methods to increase rice yield potential, such as changing plant architecture, increasing spikelet size and number, and increasing photosynthetic rate. Yield potential can also be increased by increasing grain density or modifying dark respiration.

Most IR8 grains, for example, weigh 28 mg: a high density grain weighs 31 mg. Milling and head rice recovery of heavy grains are higher than those of lighter grains. IR8 yield can be increased 35% by increasing the number of heavy grains.

Removing any of the top three leaves at flowering decreased the number of heavy grains. Removing only the fourth leaf, however, increased their number, indicating that it is a liability and that assimilates are diverted for its maintenance. Most heavy grains are on the primary branches of the panicle, followed by the secondary branches. None develop on tertiary branches.

Varieties differ in the number of heavy grains they produce. Preliminary studies show that the character is heritable. We have developed a screening method that uses a seed blower to separate high and low density grains.

Low dark respiration rate may improve crop growth rate. Dark respiration is affected by environment and plant physiology. We detached flag leaves of 16 rice varieties at heading and found that diurnal dark respiration varied markedly (Fig. 11). Respiration decreased for 6 hours (Phase A), remained almost constant for 6 hours (Phase B), increased again, and then leveled off (Phase C). Phase B dark respiration was little affected by solar radiation preceding sampling, and did not vary with variety.



11. Diurnal change of dark respiration with detached IR58 flag leaves. Numbers on the curves show solar radiation (mWh/cm²) on the day before sampling.

Lodging resistance

Lodging reduces rice grain yields. Node and internode physiology, root distribution, and soil moisture determine lodging susceptibility.

We studied lodging of several very high yielding rices. Even with N fertilizer, IR64 and IR32429-47-3-2-2 did not lodge, whereas in IR21820-154-3-2-2-3 lodging increased linearly with N level and reduced grain yield. When plants lodged at ripening, stems bent, but did not break.

IR21820-154-3-2-2-3 had longer culms than IR64 or IR32429-47-3-2-2, but culm length response to N level was unclear. IR64 and IR32429-47-3-2-2 had highest straw elasticity indices. IR21820-154-3-2-2-3 straw elasticity decreased linearly as N level increased.

Effective nitrogen utilization

In collaboration with the University of California at Davis, we used ^{15}N-depleted N fertilizers to examine the relative ability of 24 different rices or breeding lines to use fertilizer N, and to collect N from soil and air. Over three seasons, IR13429-150-3-2-1-2 and IR15323-78-1-3-1 showed consistently better soil and fertilizer N utilization and produced superior yields. They performed significantly better than

IR42 or IR50, which other studies have shown to perform well under relatively low N.

The experiment was conducted at IRRI in soil with relatively high N. Fertilizer contributed only 10 to 20% of the N in the plants at maturity. If the same varietal differences are observed when the plants are grown in less fertile soil, then the way should be open to developing rices able to perform well in low N conditions and that are superior to IR42, previously the most efficient variety for such conditions. IR13429-150-3-2-1-2 matures in 110-days, much earlier than IR42.

IR2863-38-1, a progeny of IR480, an outstanding high-protein rice, also collected N well, but did not reflect it in yield.

In 1985 we also compared morphological traits of rice as influenced by standard split fertilization and deep placement at later growth. N deep placement at later growth suppressed unproductive tiller growth; it increased effective tillers and decreased leaf area at some stages. Basal internodes were significantly shorter with deep placement, crop growth was faster during reproductive phase and after heading, and dry matter efficiency for spikelet production was higher.

Deep placement increased panicle number and spikelets per panicle but seemed to decrease the number of filled spikelets and 1,000-grain weight. Yield component analysis suggested there are varietal differences in yield response to deep placement at later growth stages.

PEST RESISTANCE

Breakthroughs in rice production achieved through improved varieties are threatened by periodic emergence of new disease and insect problems. Yield stability depends upon genetic diversity among improved varieties, which ensures resistance to many races and biotypes of different pests. Therefore, our major emphasis in rice breeding continues to be identification of diverse genes for resistance and their incorporation into improved, high yielding rice varieties.

We are genetically analyzing germplasm for resistance to major rice insects and diseases. When resistance

sources are identified, their genes for resistance are incorporated into improved germplasm. If a variety with one gene becomes susceptible, then a variety with another gene or genes can be released.

Breeding for brown planthopper control is a successful example of this strategy. Serious brown planthopper outbreaks began in the early 1970s. IR26, with *Bph 1* gene for resistance, was released in 1973. It became susceptible when biotype 2 developed in 1976.

IR36 and IR42, with *bph 2* for resistance, were released in 1976 and 1977. They have been widely grown for 10 years and their resistance has held in most areas. However, both were damaged in North Sumatra and Mindanao in 1982. By then, IR56 and IR60, with *Bph 3*, were available. Lines with *bph 4* gene for resistance have been developed and we recently identified the *bph 5* and *Bph 6* genes, which convey resistance to brown planthopper biotype 4. Biotype 4 is becoming a problem in South Asia. We also successfully transferred resistance to *Oryza sativa* from wild *O. officinalis* that conveys resistance to all known brown planthopper biotypes.

Similarly, we have identified seven genes for bacterial blight resistance. Most IR varieties have the dominant *Xa 4* gene for resistance. We also have developed varieties with *xa 5* for resistance to bacterial blight races 2 and 3, which are becoming important in the Philippines, and to races prevalent in Indonesia. We recently identified a dominant gene that gives resistance to races 2 and 3 and moderate resistance to race 1.

We have similar gene identification and utilization programs for resistance to tungro, grassy stunt, blast, and green leafhopper. The genes identified for resistance are incorporated and combined to develop varieties with multiple resistance.

Pyricularia oryzae, which causes blast disease, is the most variable of rice pathogens. In the blast nursery in 1985, we screened more than 125,000 entries for blast resistance. We also have adopted several strategies for blast control. We are identifying and incorporating major genes for blast resistance. We are also incorporating into elite breeding lines the partial resistance governed by minor genes. We do this by studying the rate of disease spread using compatible

races of the fungus. Varieties with both major and minor genes should have greater stability of resistance. IR36, for example, has major and minor genes for resistance and has rarely been affected by blast.

IR64, released by the Philippine Seed Board in 1985, resists bacterial blight, tungro and grassy stunt virus diseases, and brown planthopper and green leafhopper insects.

In 1985, we screened breeding lines for resistance to brown planthopper, whitebacked planthopper, yellow stem borer, leaffolder, whorl maggot, and caseworm. About 63,000 lines were screened for brown planthopper resistance and 92,000 for green leafhopper resistance. Nearly half were resistant or moderately resistant to brown planthopper and green leafhopper, but none were resistant to whorl maggot or caseworm.

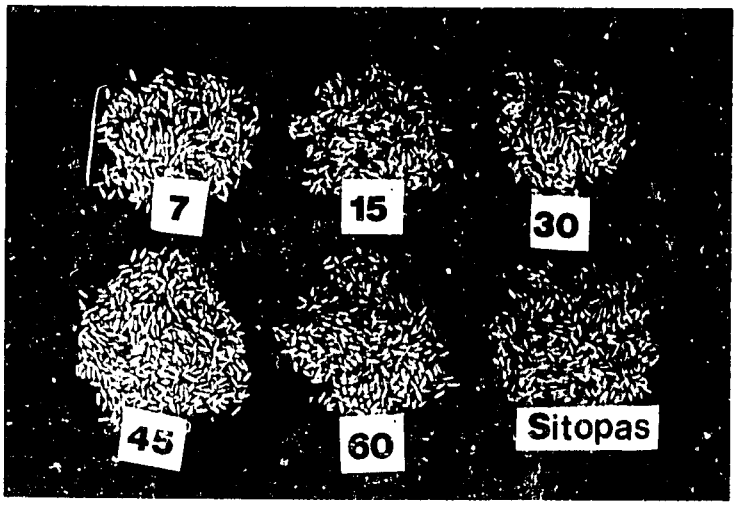
IRTP nurseries for disease and insect resistance are being screened extensively at hot spot locations around the world. The nurseries continue to provide valuable information on:

- genetic donors of resistance to insects and pathogens at different locations, and
- genetic variation in the major rice insects and pathogens.

Bacterial blight strains and brown planthopper biotypes in South Asia are more virulent than those in East and Southeast Asia. Despite the genetic variation in the causal organisms, varieties and breeding lines with broad-spectrum resistance have been identified. Some examples are PTB33 and IR17494-32-1-1-3-2 for brown planthopper; IR13475-7-3-2 and WC1240 for whitebacked planthopper; B4143d-Pn-51-4, IR54, and RP633-76-1 for bacterial blight; and ARC11554 for tungro virus.

Tolerance for ragged stunt virus

We identified rice varieties Sitopas, Tetep, PTB 8, and Lemo as tolerant of ragged stunt virus. Although Sitopas is susceptible to infection and has prominent symptoms at seedling stage, it recovers quickly. At heading, infected plants had mild or no stunting with vein swellings, but still bore grain. Sitopas plants accumulate little of the virus.



12. Comparison of filled grains produced in Sitopas rice plants that were infected with ragged stunt at 7, 15, 30, 45, or 60 days after seed soaking with grains produced by an uninfected plant.

When seedlings were artificially infected, the virus reduced yields only 40% compared to 85% reduction in susceptible TN1 (Fig. 12).

GRAIN QUALITY

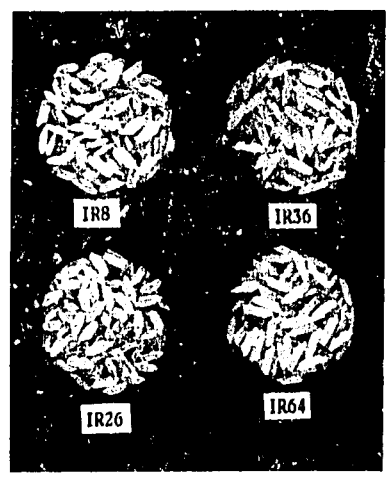
Traditional rices grown in adverse environments — drought-prone uplands and deep water areas — often have superior quality, and command a price advantage in local markets. Rice breeding strategies for adverse conditions must therefore include careful attention to quality factors.

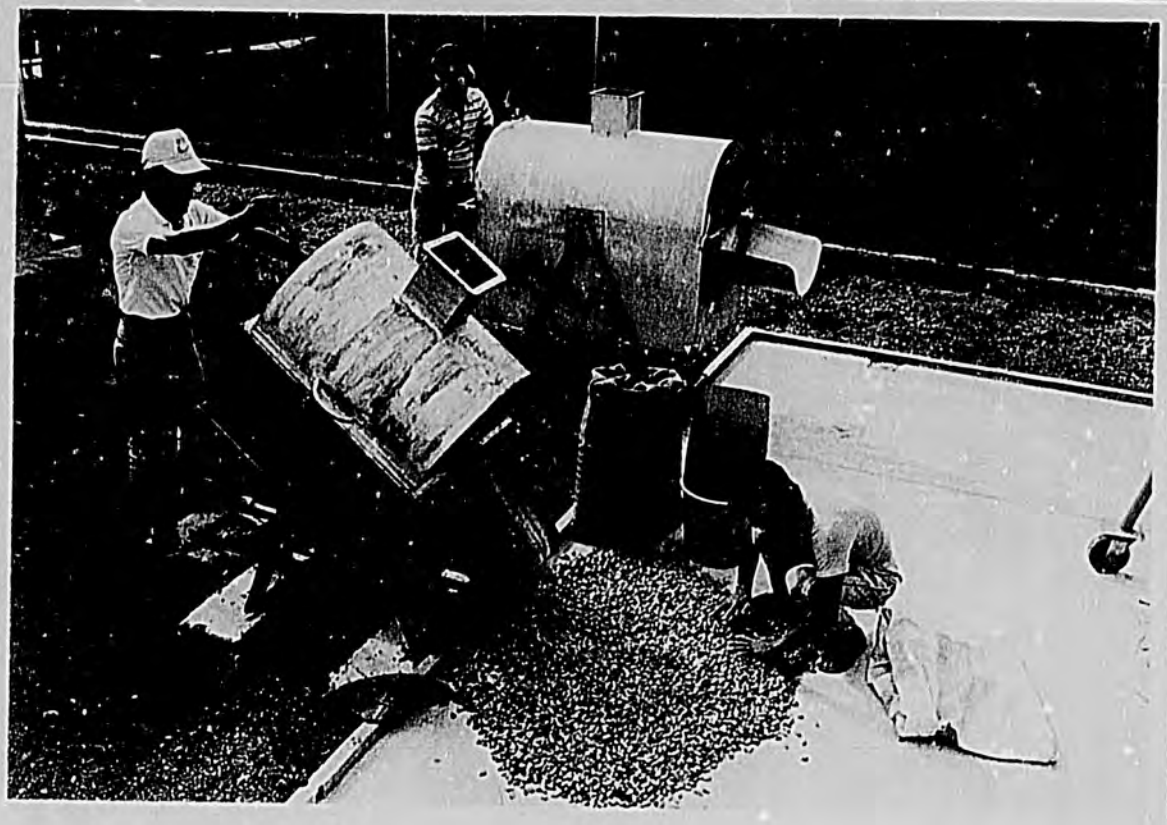
We have worked for 10 years to develop improved breeding lines with intermediate amylose content and gelatinization temperature. One such line is IR18348-36-3-3, released as IR64 in 1985. It has long, slender, translucent grains (Fig. 13) with high milling recovery, is popular in the Philippines, and is being evaluated in many countries.

IR64 outyielded IR36 by 21% in trials at 10 experiment stations in 1983-84, has multiple disease and insect resistance, matures in 112 days, and resists lodging.

Milling quality is highly dependent upon correct drying. Although many IR varieties have good milling yields when harvested at maturity, delayed harvesting or overdrying may cause grain fissuring. Fissuring occurs when grains adsorb moisture after overdrying.

13. Milled grain of IR8, IR26, IR36, and IR64.





14. Direct-fired rotary drum dryer (foreground) and indirect-fired unit (background)

We developed a simple screening method to identify resistance to fissuring. An infrared moisture balance is used to overdry correctly dried samples. This requires removal of 1% moisture from brown rice or 2% from rough rice. The dried grains are exposed overnight to ambient humidity and temperature, milled in a small friction mill, and milling yield is recorded. This test has shown important varietal differences in tolerance for overdrying.

Newly harvested rice and other grains often are too wet to store, and grain storage at too high a moisture content may lead to the production of aflatoxin. Partial drying immediately after harvest prevents deterioration and yields better quality grain.

Grain drying is a major problem for small farmers who often must sun dry their grain on paved roads. We developed two portable, hand-operated, rotary drum dryers (Fig. 14) for predrying cereals. The drum is directly or indirectly heated and grains dry on contact with it.

The direct-fired dryer is built of perforated, corrugated steel and equipped with baffles for mixing the grain. Charcoal is burned beneath the drum. The indirect-fired dryer is similar, but is made from a nonperforated metal drum, and heat is supplied by burning waste products such as coconut husks and rice hulls. In initial evaluation, the direct-fired dryer had 20% thermal efficiency and the indirect-fired dryer 10%. We are improving the prototypes and designing a larger unit.

In 1983, we introduced the commercial size (7-8 t) warehouse dryer to a rice miller in North Cotabato and compared it with a commercial dryer in General Santos City, Philippines. We are monitoring the drying systems and adjusting them for different capacities and applications. Increasing demand for small to medium multicommodity drying and storage facilities encouraged the design of a 1-t warehouse dryer (Fig. 15), a greenhouse dryer, and a 3- to 4-t winged dryer. Designs stress simple construction techniques that use local materials, and also emphasize the use of renewable energy forms such as solar and wind energy and agricultural residues.

15. Warehouse dryer for individuals or groups of farmers.

AGRONOMIC MANAGEMENT

Management to achieve more output for less input is essential for all small farmers. The importance of low cost input technology is even more important for farmers who cultivate crops in environments with poor soils, flooding, or periodic drought. Management that combines purchased inputs with farm-grown organic manures, biofertilizers, and botanical pesticides can minimize input costs without lowering yield and can be used for many crops.

We have made significant progress in quantifying the extent of adverse environments and in identifying major problems associated with them. With this information, we are improving rice production methods for adverse soils and drought- and flood-prone areas. Targeting these environments helps to refine our breeding objectives, which is an essential requirement for adverse environments that lack the unifying effects of constant shallow floodwater.

PROBLEM SOILS

The major adverse soils for rice production are saline, sodic, acid sulfate, and peat. New surveys indicate there are 58 million ha, or slightly more than half of the rice area, of such soils in Asia. Although large, this figure is significantly less than previous estimates. Additionally, many of the peat lands cannot be economically developed for rice or other crops.

Certain deficiencies and toxicities also are common to many rice soils: P, S, and Zn deficiency, and Fe and Al toxicity. While P, S, and Zn deficiencies can be cured by adding fertilizers, it costs farmers much less if they can grow tolerant varieties. Fe and Al toxicity can be cured by liming, but tolerant varieties are more economic.

Some rices combine adverse soil tolerances with high yielding ability. IR42 has been widely grown under

adverse conditions, and IR9764-45-2-2 recently was identified as having outstanding tolerance for lowland soil toxicities and deficiencies. IR54 and IR62 also perform well in these conditions, and have high yield potential and good insect and disease resistance.

In a plant nutrition study on saline soils, salt-resistant IR9884-54-3 had higher K:Na, K:Ca, K:Mg, and Ca:Na than a rice with less resistance. IR9884-54-3 accumulates K and Ca and maintains a balance of nutrients. These ratios were higher in nonsaline soil; therefore, salinity resistance may be associated with tolerance for cation imbalances.

Not all environments can be simulated in the greenhouse, so we have used sites at Iloilo for mass screening and yield performance tests to evaluate the limits of genotypes in terms of phenotypic responses to P, K, and Ca deficiencies, saline acid sulfate soils, and Fe toxicity. IR9764-45-2 and IR9884-54-3 consistently yielded more than 2.5 t/ha, 1.4 t/ha more than local varieties.

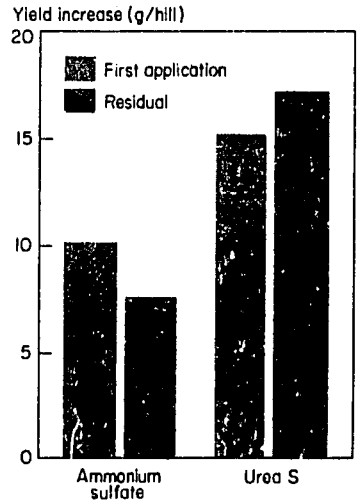
Sulfur deficiency

S deficiency is becoming a serious problem to rice, especially in Bangladesh, where about 80% of the irrigated rice area is claimed to be S responsive. Indonesia, India, China, Thailand, Burma, and Sri Lanka also have reported S deficiency. We are surveying Philippine soils for S deficiency, have initiated varietal screening for S deficiency tolerance, and are testing different management techniques to reduce S deficiency.

IR20, IR30, and IR21820-154-3-2-2-3 were more tolerant of S deficiency than IR56, IR60, Syntha, and other late-maturing varieties. Adding S to deficient soils increased tiller number and grain and straw yield.

Among the fertilizers tested, urea S was most promising. In greenhouse experiments, urea S performed somewhat better than ammonium sulfate (Fig. 16). Urea is the most common fertilizer N for rice, and adding S during processing adds very little cost.

16. Increase in IR36 yield with applied S. Average of 11 Philippine soils.



INCREASING NITROGEN FERTILIZER EFFICIENCY

The most common nutrient deficient in rice is N. All soils supply some N to rice, but it is usually not enough to meet

17. Plunger-auger fertilizer applicator.

18. Press-wedge fertilizer applicator.

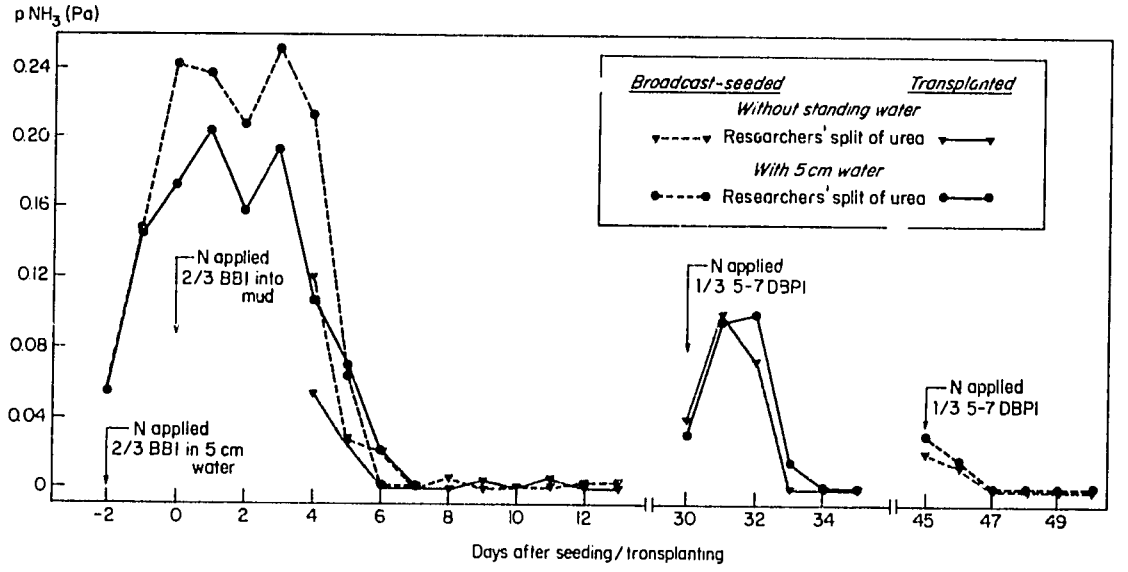
yield potential. The simplest remedy is to add fertilizer N, the cost of which represents the largest cash outlay for many small rice farmers. We have sought many ways to reduce the cash requirement for N fertilizers while still obtaining the needed rice production. Our research stresses technology to improve the efficiency of applied N, harness biologically fixed N, and supplement existing soil N by applying organic manures.

In earlier work we showed that fertilizer N recovery usually is 30% or less if the fertilizer is broadcast into field water, the most most common practice. Incorporating fertilizer in the soil before planting can double its N efficiency. Because hand placement requires high labor inputs and costs, we have developed small, inexpensive machines that efficiently incorporate fertilizer. The fertilizer applicators are designed for local manufacture and marketing.

Designs for the plunger-auger injector for commercially available fertilizers (Fig. 17) and the press-wedge applicator for urea supergranules (Fig. 18) were finalized in 1985. These machines can increase fertilizer use efficiencies 20-80% over Philippine farmers' broadcast methods. The plunger-auger injector is being tested on farms in many parts of the Philippines, and two businesses have started manufacturing and test marketing. The machines have also been distributed for wider testing in the INSFFER network.

Most earlier N efficiency studies used transplanted rice. In Malaysia, the Philippines, and Thailand, many farmers broadcast seed to minimize production costs and increase labor use efficiency. We therefore compared losses in broadcast-seeded and in transplanted fields, as most losses occur when ammonia volatilizes from the floodwater, and so may be expected to be influenced by the plant canopy.

With both planting methods, broadcasting and incorporating two-thirds urea into mud 3 days before flooding with 5 cm water reduced ammonia levels below those when urea was broadcast in 5-cm standing water and incorporated (Fig. 19). Topdressing one-third urea 5-7 days before panicle initiation caused higher floodwater ammonia



19. Ammonia levels in floodwater following urea application under two rice establishment methods. BBI basal broadcast and incorporated, DBPI days before panicle initiation.

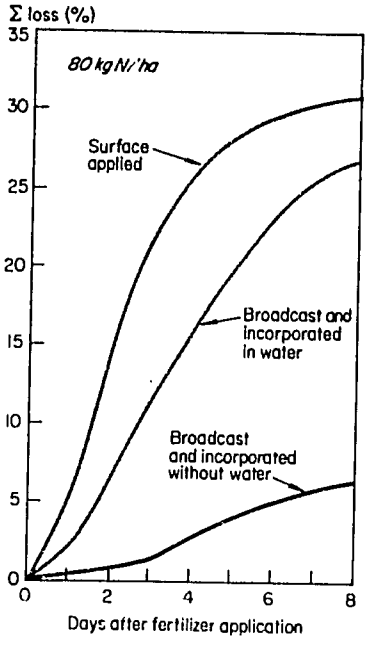
concentrations in transplanted than in broadcast-seeded rice.

Floodwater ammonia concentration did not differ between planting methods when N fertilizer was topdressed by the farmers' method 15 days after seeding or transplanting, and one-half at 10 days after panicle initiation.

Losses were higher with ammonium sulfate than with urea. Thus, soil incorporation of N fertilizers is likely to be more important for broadcast seeded rice than for transplanted rice.

Rapid techniques for measuring ammonia volatilization

Scientists from IRRI and the Commonwealth Scientific and Industrial Research Organization of Australia worked together in 1985 dry season to compare total N loss and ammonia volatilization using simple techniques. Nitrogen loss was determined by ^{15}N balance and NH_3 loss was determined by measuring the NH_3 concentration and windspeed at one height above the floodwater. Total N and NH_3 losses were measured at Mabitac and Calauan, Philippines. N losses also were compared for different management practices and application rates.



20. Effect of fertilizer management on cumulative N loss.

High NH_3 volatilization was observed between 1400 and 1600 h for 3 days after broadcasting urea into floodwater. At Mabitac, fields lost 55% of applied N after 30 days. Of that, 31% was lost by ammonia volatilization during the first 8 days after fertilizer application.

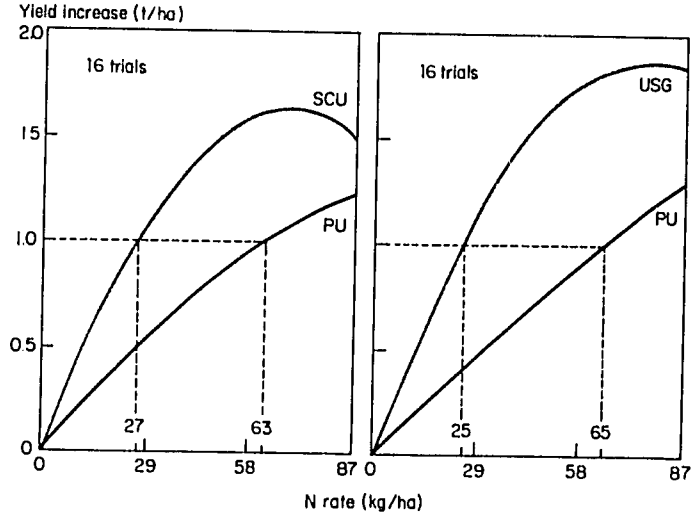
Maximum volatilization occurred when urea was broadcast into floodwater, and least when urea was incorporated into soil without standing water (Fig. 20).

This research is an example of how collaborative research with developed country institutions using sophisticated equipment can generate information that is of vital importance to farm management for resource-scarce farmers.

INSFFER collaborators work to increase N fertilizer use efficiency. Multifertilizer response trials and fertilizer tests were conducted in irrigated lowland rice at 18 sites in 5 countries. Broadcast and incorporated S-coated urea (SCU) gave significantly higher yields than prilled urea, local best split in 50% of the trials. Deep placing urea supergranules (USG) gave significantly higher yields in 56% of the trials. To increase yields 1 t/ha, 45% less N was required if applied as SCU and 50% less as USG.

In rainfed rice (Fig. 21), yield responses to S-coated urea and urea supergranules were significantly higher than

21. Estimated average yield responses of rainfed lowland rice to broadcast and incorporated S-coated urea (SCU) and deep placed urea supergranules (USG) in trials where responses to SCU and USG were significantly greater than the response to prilled urea (PU), best split.



those to prilled urea in 35% of the trials. For a yield increase of 1 t/ha, 57% and 62% less N were required if applied as S-coated urea or urea supergranules.

HARNESSING BIOLOGICAL NITROGEN FIXATION

Microorganisms that fix N from the air contribute it to rice fields. N fixers include blue-green algae that live on and in field water, the soil, around rice, and with azolla; bacteria living on and in rice roots; and bacteria that grow on the root and stem nodules of legumes such as *Sesbania rostrata*. Growing and incorporating them before rice increases soil N content and N supply to rice.

Blue-green algae

Most research on blue-green algae has stressed soil inoculation. However, a study of blue-green algae populations in 120 rice soils from 5 countries and 20 samples of soil-based inocula collected from India, Egypt, and Burma or produced at IRRI showed that the population of N_2-fixing blue-green algae in the quantity of inoculum recommended for rice (10 kg/ha) is almost always less than that of N_2-fixing blue-green algae already in the soil.

The ratio of indigenous to inoculated blue-green algae was larger than 100 in 80% of the soil samples and more than 1,000 in 50% of the samples. Inoculation, therefore, is not the only way to use blue-green algae. Emphasis should be placed on agricultural practices that enhance indigenous growth.

In microplot experiments controlling invertebrates that eat blue-green algae, split application of P and, sometimes, algal inoculation enhanced photodependent N_2 fixation and the accumulation of algal N at the soil surface.

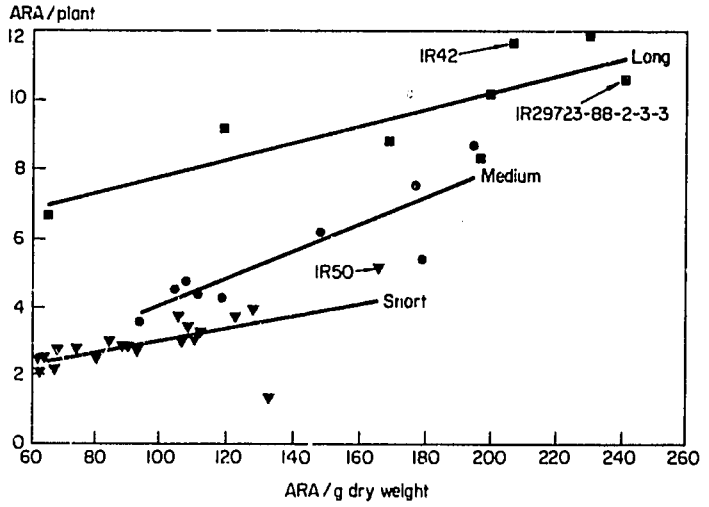
Azolla

Except in P-rich soils like those in Koronadal, South Cotabato, Philippines, azolla growth is limited by P deficiency. Efficient use of P fertilizer or soil P is essential for good azolla growth and N fixation. In a Leyte, Philippines, survey, for example, about two-thirds of azolla had less than 0.2% P, and only 10% had optimum P content.

Instead of applying P in the main field, we applied it to the inoculum to enrich azolla with up to 1.1% P. Azolla multiplied 7 times in the main field, giving 1.0 kg fresh weight/m^2. Proper application of water-soluble P allowed *A. microphylla* #418 to fix 80 kg N/ha in 35 days, the highest rate we have so far measured. *A. microphylla* is more tolerant of high temperatures than other species and has erect growth that increases biomass production. Incorporating this quantity of azolla N supplies as much N to rice as adding an equivalent amount of urea N.

In March, we sponsored jointly with the Fujian Academy of Agricultural Sciences an international symposium on azolla, during which the Chinese National Azolla Research Center in Fuzhou was opened (Fig. 22). Fuzhou is in the heart of a region where azolla has been used for centuries as a green manure for rice. Workshop participants heard papers; discussed azolla classification, management, and use; and visited local farms to observe azolla use in practice.

22. Chinese National Azolla Research Center.



23. Acetylene-reducing activity (ARA) per plant and per gram of plant dry weight of 37 rice varieties.

Bacterial biological nitrogen fixation

Significant differences in the ability to support N_2 fixation were detected among 37 lowland rice varieties by measuring acetylene-reducing activity at heading stage for 3 consecutive days. Varieties differed both in acetylene-reducing activity/plant and acetylene-reducing activity/g dry weight (Fig. 23). Long-duration IR42 and short-duration IR50 had high acetylene-reducing activity. ^{15}N dilution showed that grain N from the atmosphere was higher in IR42 than in other varieties. This confirms pot experiment results, and suggests it should be possible to breed rices for high N-fixing ability.

Because biofertilizers are a major component of our strategy to substitute farm-grown nutrient sources for purchased mineral fertilizers, we are intensifying collection of blue-green algae, azolla, and bacteria germplasm. At the end of 1985, the collection contained 150 strains of blue-green algae, 390 strains of bacteria, and 8 species, including 159 strains, of azolla. Our International Biofertilizer Germplasm Conservation Center for Rice will help develop technology to reduce the cost of rice production while maintaining high yields.

Sesbania rostrata green manure

In 1985, we confirmed our findings on N accumulation by *S. rostrata*, a fast-growing, stem-nodulating, green manure

24. N_2-fixing nodules on the stem of *S. rostrata*.

species (Figs. 24 and 25) from West Africa that will grow in standing water. In 58 days, *S. rostrata* accumulated more than 200 kg N/ha when it was not flooded the last 25 days before incorporation. N accumulation in 44 days was 165 kg N/ha. When the crop was flooded during the last 25 days, which occurs when monsoon rains come early, N accumulation decreased about 30%, but the 44-day crop still exceeded 100 kg/ha.

Rice grain yields increased when N-rich *S. rostrata* and other green manures were incorporated. Rice yields were strongly influenced by N accumulated in the green manure, but green manure species had little effect. Therefore, it is important to accumulate N as rapidly as possible between the beginning of early rains and when enough water accumulates to start soil puddling. In many environments, this interval is 35 to 55 days.

We also continued long-term studies on green manures, but in 1985, *S. rostrata* was substituted for *Vigna* sp. A 45-day green manure crop increased rice yield 2.0 t/ha and a 35-day crop increased it 1.4 t/ha (Fig. 26). Topdressing 30 kg N/ha at panicle initiation increased grain yield 0.6 t/ha regardless of green manure N.

In another experiment we examined the response of rice grain yields to inorganic N levels with and without *S. rostrata*. Where *S. rostrata* containing 116 kg N/ha was incorporated, response to supplemental topdressed N was maximum between 25 and 50 kg N/ha (Fig. 25). Green manure provided the equivalent of about 55 kg inorganic N/ha.

This year we conducted our first green manure (*S. rostrata*) experiment in farmers' fields. Two types of experiments were implemented in Nueva Ecija, Philippines. The first experiment compared rice yields with and without green manure and farmer and researcher incorporation methods. *S. rostrata* was sown when early rains fell. Farmers incorporated green manure using traditional practices or by plowing with a small power tiller fitted with knives on the cage wheels. Yields in green manure plots were 1.3 t/ha higher than the unfertilized control and 0.7 t/ha higher than those that received 60 kg fertilizer N/ha. Green manure incorporation method had little effect on grain yield.

25. A 35-day-old *S. rostrata* crop growing in an experimental plot at IRRI.

The second experiment compared yields with inorganic N and *S. rostrata*. Incorporating 45-day-old *S. rostrata* increased yield more than did 70 kg inorganic N/ha, and 60-day-old *S. rostrata* increased yield more than did 105 kg inorganic N/ha.

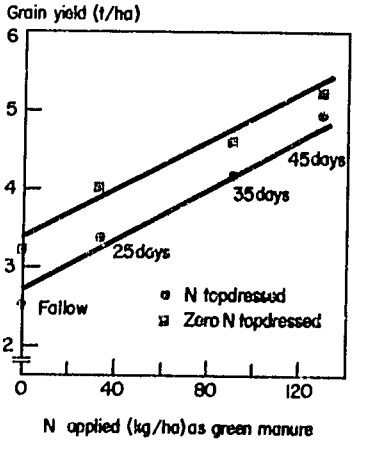
S. rostrata had good root and stem nodulation. Nodulation was 2 or 3 weeks later in some fields than in others, but when stem nodulation started it developed rapidly. As part of the research, we quantified populations of the rhizobium that nodulates *S. rostrata*. The infective rhizobia were detected in all samples, indicating that the organisms occur naturally in the area. That the organism occurs naturally is important because it removes the need to develop inoculation technology.

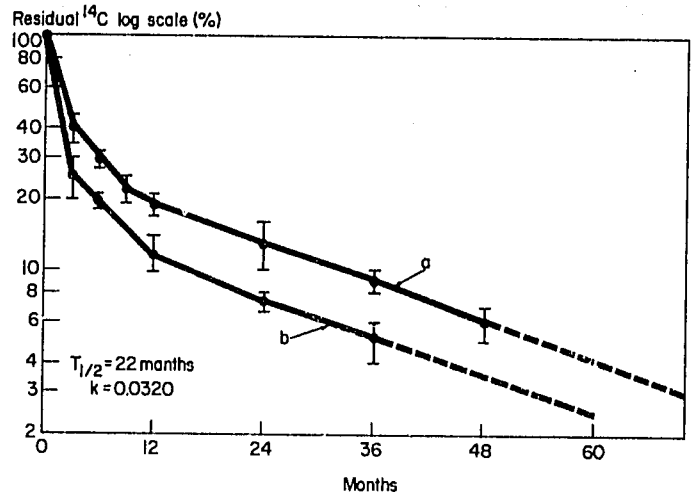
Using organic manures

Recycling crop residues and growing and incorporating organic manures can significantly increase N supply to rice and reduce chemical fertilizer requirements.

Four years' data from ^{14}C-labeled straw experiments show that in the tropics submerging neutral and alkaline soils only slightly retards the initial decomposition

26. Incorporating 135 kg N/ha as *S. rostrata* increased rice yield by 2.0 t/ha. Yields were lower but significantly different when *S. rostrata* was grown for fewer days. Supplemental inorganic N topdressed at panicle initiation (PI) increased grain yield 0.6 t/ha.





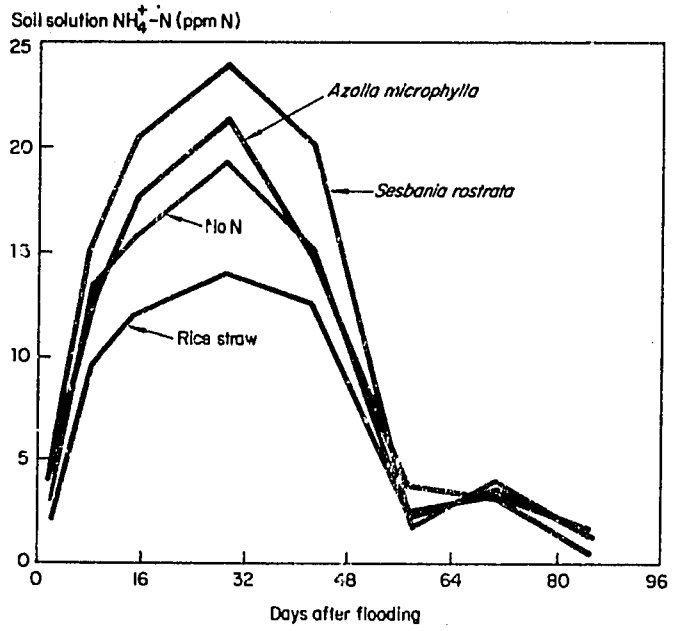
27. Decomposition of ^{14}C-labeled rice straw in the field (1981-85). a) Lowland soil: Andaqueptic Haplaquoll, 4.4% organic matter (OM), 38% clay, pH 6.0; Typic Tropaquept, 1.6% OM, 37% clay, pH 7.6; Aeric Paleaquult, 4.1% OM, 46% clay, pH 4.8; and upland Orthoxic Palehumult, 4.1% OM, 46% clay, pH 4.8. b) Upland soil: Andic Eutropept, 1.6% OM, 43% clay, pH 6.0; Fluventic Entropept, 1.6% OM, 37% clay, pH 7.6.

of rice straw and does not affect straw decomposition in acid soils (Fig. 27).

About 80% of straw incorporated in submerged soils and 90% in drained neutral and alkaline soils mineralizes in 1 year. The remaining compounds and metabolites decompose at similar rates irrespective of soil and water regimes. The half-life of resistant residues is about 2 years, 3 to 4 times less than in aerobic soils in temperate climates, and many times less than in flooded soils in temperate climates.

High constant soil temperature (27-30 °C), neutral pH (7.0), low bulk density (0.6 g/cm^3) of puddled soil, and high aquatic invertebrate activity speed straw mineralization. Floodwater ecology may be as important to organic matter decomposition as soil properties. High rates of decomposition imply that N in added organic manures will be rapidly available to rice.

Incorporating organic matter, such as rice straw, with high C:N ratio reduced rather than increased N availability. In 1985, no yield advantage was observed unless straw was composted. Incorporating straw decreased NH_4^+-N and Zn^{2+} soil solution concentrations even in soils with initial high organic matter content, and increased P, K, Fe, and Mn concentration. Incorporating azolla or *S. rostrata*, however, caused slight or no Zn^{2+} concentration decrease and increased N supply (Fig. 28) and rice yield.



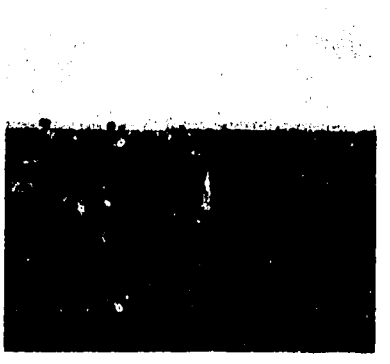
28. Changes in NH_4^+-N in soil solution of a flooded Maahas clay (planted to rice) as affected by rice straw, azolla, or *S. rostrata* incorporation.

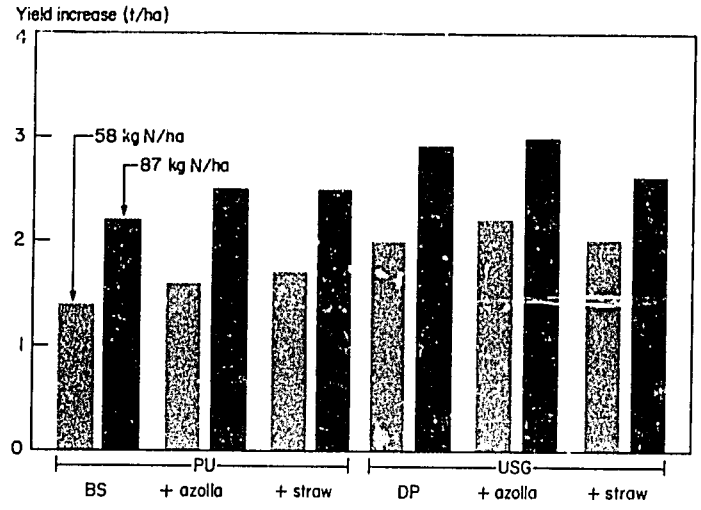
Long-term experiments on different soils in different countries have shown that straw incorporation slowly increases organic C and N and available P, K, and Si. About 3 t of C must be applied each season in a dry fallow - rice - rice system to reach or maintain an optimum 4% soil organic matter content for lowland rice. Constant submergence slightly enhances organic matter accumulation, but most yield gains may be offset by decreased Zn and S availability.

Much, however, depends on straw N content and site characteristics. We have therefore established collaborative trials on integrated use of inorganic and organic fertilizers for lowland rice in a range of sites and countries in INSFFER trials (Fig. 29).

In the first experiments, 30-50% of required N was applied as azolla and fresh straw, and the remainder as split-applied prilled urea or deep point placed urea supergranules. Combining inorganic and organic N produced yields comparable to those with inorganic fertilizer alone (Fig. 30). Yields with azolla and with straw plus prilled urea were comparable and both were higher than yields with prilled urea alone at 58 or 87 kg N/ha. Azolla plots, however, yielded more than straw plots when treated with urea supergranules at both N rates.

29. INSFFER trials of integrated use of organic and inorganic fertilizers on lowland rice, fourth crop, Bulacan, Philippines.





30. Average yield increases of irrigated lowland rice due to best split (BS) applied prilled urea (PU) and deep placed (DP) urea supergranules (USG) alone or with azolla and straw at 2 N rates. Data are averages of 9 trials at 3 sites in India and 4 sites in the Philippines.

Incorporating tall green manure and rice straw with power tillers is difficult because the residues accumulate on the plow beam. We developed ring knife attachments for power tiller cage wheels (Fig. 31) to cut green manure and rice straw into small pieces before incorporation. The knives fit many power tillers and use cage wheel slippage and machine weight to cut green manure and straw as the tiller passes over the crop. We are testing the knives and demonstrating them to farmers.

31. Cage wheel knives cut and incorporate green manure at the same time.

TILLAGE

Land preparation for lowland rice

Economic use of water is vital in rice production. Farmers conserve water by puddling soil to reduce water percolation. Saving energy in puddling also is important, particularly to poor rice farmers who are likely to use a water buffalo for draft rather than a powered rototiller or tractor.

Intensive studies (Fig. 32) showed that effective puddling, measured as the decrease in total vertical water percolation, can be achieved with lower water and tillage inputs than are traditionally used. Water percolation could be reduced from 3,000 to 120 mm without reducing yield.

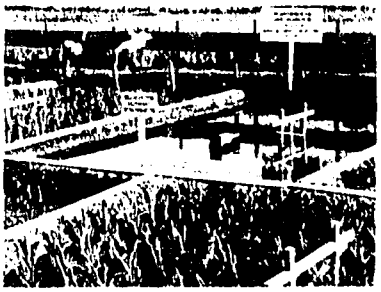
We evaluated the effects of different tillage treatments on soil physical properties and IR36 yield. Soil properties of puddled and zero-tillage plots differed more

widely in a clay loam soil dominated by kaolinitic clays of 1:1 minerals and with a water table below 0.60 m than in clay soil dominated by 2:1 minerals and with a water table above 0.30 m.

Puddling increased root length density and reduced soil bulk density and strength. Root length density was positively correlated and bulk density and soil penetration resistance were negatively correlated with grain yield (Fig. 33).

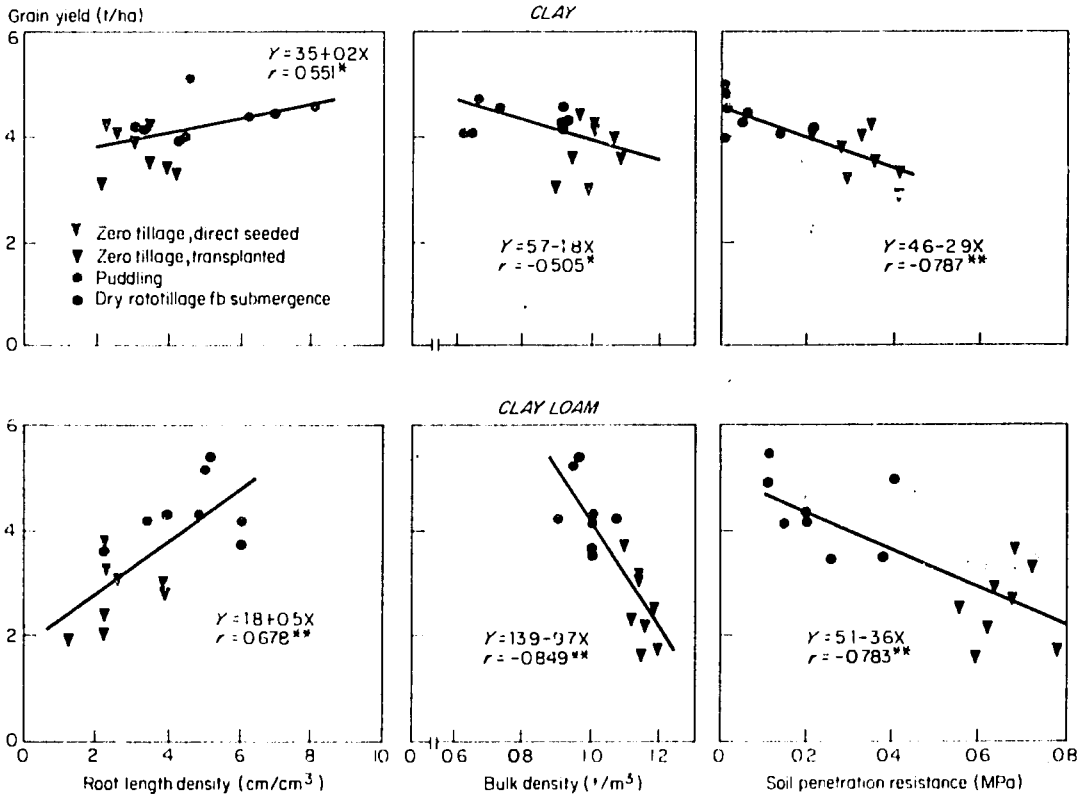
In soil with 2:1 clay minerals, yield was similar in puddled and dry rototilled (minimum tillage) plots, indicating that in easily dispersible, low-permeability, fine- to medium-textured soils with proper weed control, minimum tillage can produce grain yields similar to those with puddling.

Percolation rate was strongly influenced by subsurface hydrology and regional drainage, and possibly by the more porous zone of unpuddled soil beneath bunds.

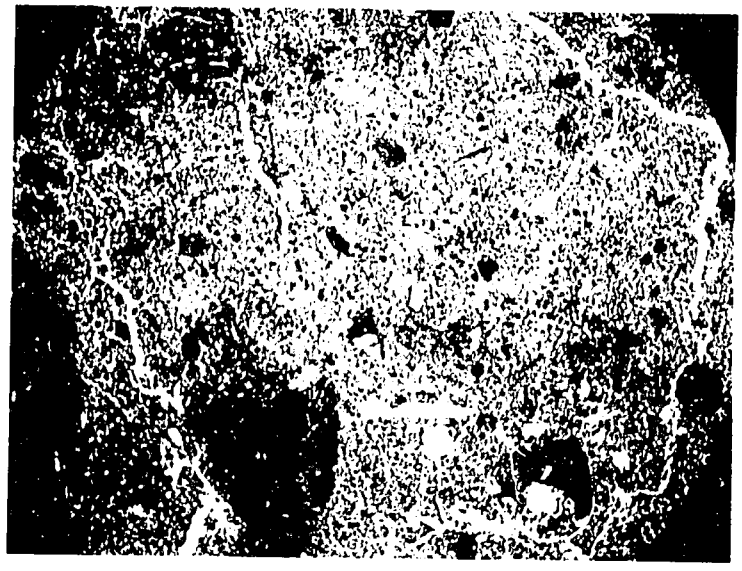


32. Measurement of the effects of puddling treatments on water percolation and yield.

33. Relation between rice grain yield, root length density, bulk density, and soil penetration resistance.



Microstructure from 0-5 cm layer of puddled soil, showing some water-transmitting elongated pores that remain after puddling.



34. Field trials of a floating rototiller invented by a commercial farm equipment manufacturer in Iloilo, Philippines

Preliminary trials of a new hydrotiller (floating rototiller) (Fig. 34) developed in Iloilo, Philippines, showed that it puddled soil as effectively as a skid-supported rototiller, but required less operator effort.

We worked with the Italian National Council for Research to measure the effects of puddling on soil microstructure. Elongated pores, which facilitate water transmission, were less abundant in puddled soil. Measurements also indicated that trampling by transplanters' feet reduced surface soil porosity about as much as did mechanical puddling.

35. Animal-drawn rotary tiller with a cone-shaped rotor

Minimum tillage lowland puddlers

Lowland tillage equipment often tills soil deeper than is necessary for good yields, and so wastes energy. Sometimes, two or three times more energy than is necessary is used for lowland preparation.

We developed an animal-drawn rotary tiller to reduce energy needed to cultivate soft rice fields. When the cone-shaped rotor is rolled along a straight path, soil is displaced by blades on the cone. Horizontal back and forth action limits tillage depth to 10-12 cm. Tests with the prototype (Fig. 35) indicated that, with the same energy, the machine can till more than twice the area as conventional tillage machines.

a b

36. a) Grass weeds in a bundle of rice seedlings. b) Transplanted weed in rice hill.

WEED MANAGEMENT

In transplanted rice in Guimba, Nueva Ecija, and in upland rice in Claveria, Misamis Oriental, Philippines, we found that additional weed control during the critical competition period could increase yields 10 to 95%, indicating that farmers' weed practices usually were inadequate.

We found in Guimba that farmers transplanted 4 to 14% weed seedlings with rice seedlings (Fig. 36). The proportion of weed seedlings was negatively correlated with the time spent in preparing seedling nurseries.

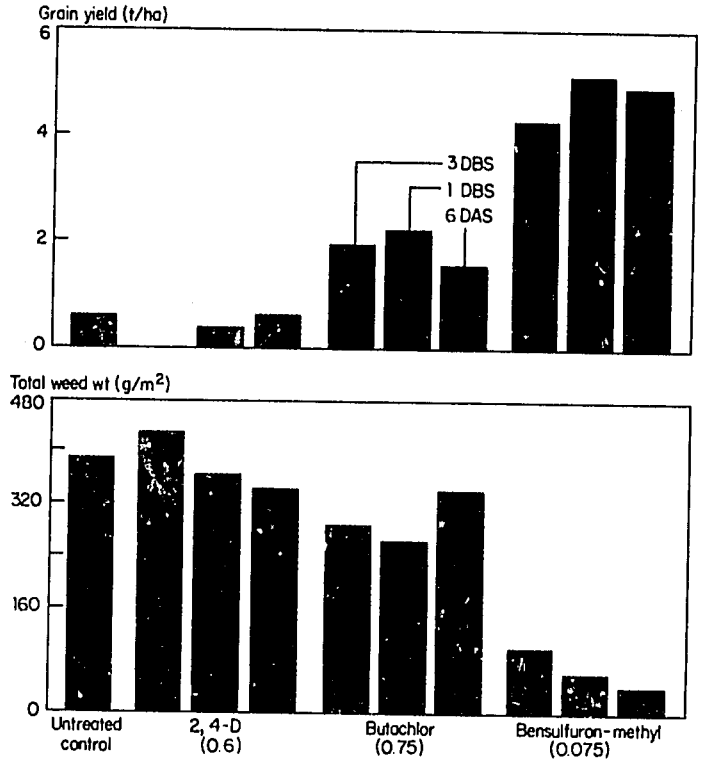
Weeders

Thorough weeding is expensive and labor intensive. We developed single-row and multirow push weeders with conical rotors (Fig. 37) that need only one-third as much energy as conventional weeders. One operator can weed four times faster with a two-row cone weeder than with a push rotary weeder. Two Philippine manufacturers have started test production.

37. Multirow push weeder with conical rotors.

Herbicides for broadcast-seeded, flooded rice

Weed control in broadcast-seeded flooded rice is more difficult and critical than in transplanted rice. Many herbicides kill or severely damage young rice seedlings. One way of avoiding crop injury is to apply postemergence



38. Effect of granular herbicides applied before (DBS) and after (DAS) seeding on weeds and yield of direct-seeded, flooded IR62.

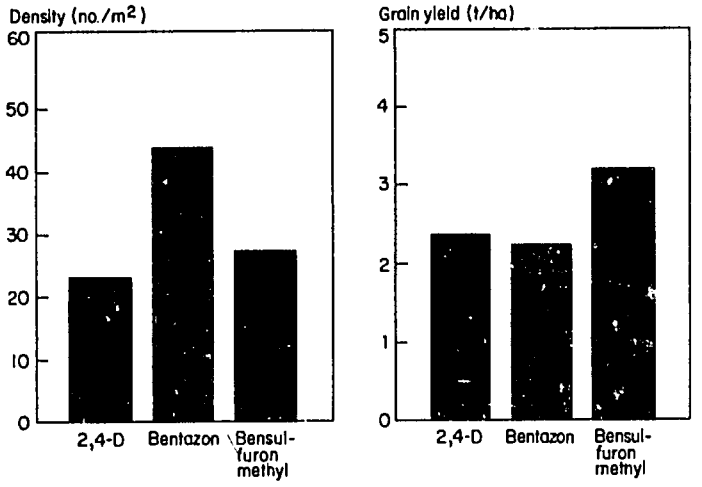
herbicides 6-8 days after seeding, but this timing often reduces herbicide efficiency.

We compared a preseeding treatment of bensulfuron-methyl, which usually is applied postemergence, with 2,4-D and butachlor. Bensulfuron-methyl did not reduce crop stand. It controlled *Monochoria vaginalis*, *Echinochloa* sp., and *Scirpus maritimus* better than other herbicides and produced higher yields (Fig. 38).

Controlling *S. maritimus* with low-volume sprayers

S. maritimus is becoming an increasingly important problem in lowland rice. Low-volume herbicide applicators are popular control devices, particularly in rainfed areas where water is scarce.

We evaluated postemergence herbicides applied by 4 sprayers for controlling *S. maritimus* — 2,4-D isobutyl ester (IBE), bentazon, and bensulfuron-methyl at 0.25, 0.5, and 1.0 times their recommended rates of 1.0, 1.0, and 0.05 kg/ha. They were applied with Birky (a low-volume



39. Effect of herbicides on control of *S. maritimus* density 60 days after transplanting and grain yield of rainfed transplanted IR58. Average of 3 herbicide levels and 4 sprayer types.

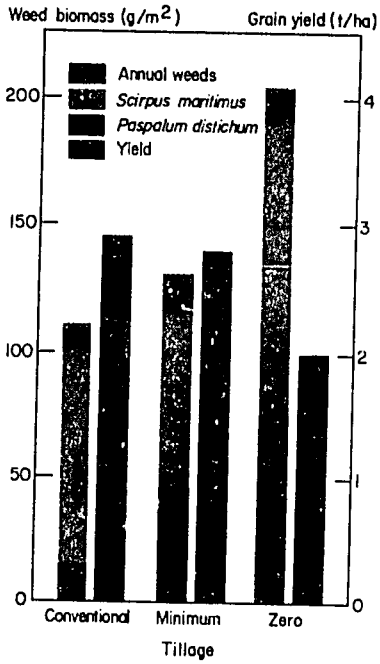
pneumatic sprayer), Micronherbi (a battery-operated ultralow-volume disk sprayer), VLV-50 (very low volume nozzle), and hydraulic knapsack sprayers.

Bensulfuron-methyl and 2,4-D controlled *S. maritimus* better than bentazon (Fig. 39), but bensulfuron-methyl gave highest grain yields. Plots sprayed with half the recommended dosage yielded highest, but yields were similar in those sprayed with recommended rates. Micronherbi and Birky sprayers controlled *S. maritimus* best because they directed more spray onto weeds.

We also evaluated 2 formulations of 2,4-D (dimethylamine salt and IBE) at 0.5 and 1.0 kg ai/ha. Herbicides controlled *S. maritimus* best when applied with the Birky. Grain yields from VLV-50 and Birky plots were similar. Low-volume sprayers not only reduce the amount of water that must be carried to the field, but are more effective, therefore reducing chemical needs.

Effect of minimum and zero tillage on weed population

Minimum and zero tillage shorten turnaround time between crops and help increase cropping intensity, but also



40. Reduced tillage increased *P. distichum* and annual weed biomass and decreased grain yield.

cause weed problems. In a long-term study, reducing tillage increased *Paspalum distichum* and annual weeds and decreased grain yield (Fig. 40). Monitoring long-term weed shifts helps us develop appropriate weed management technology.

Direct seeding and weed population

Most farmers in irrigated areas in Central Luzon and Bicol, Philippines, have shifted from transplanting to broadcast seeding onto puddled fields, particularly in dry season. To reduce weed competition, they use extremely high seed rates: 140-275 kg/ha in Central Luzon, and 100-150 kg/ha in Bicol. In 1985 dry season, we evaluated three seeding rates with farmers' and researchers' weed control and different N levels in Nueva Ecija, Bulacan, and Camarines Sur.

Yield was highest with both weed control methods at 80 kg N/ha. On most farms, yield differences among seed rates were not significant, suggesting that farmers can use 100 kg seeds/ha to achieve high yield. Researchers' weed control (granular butachlor at 1.0 kg ai/ha applied 3 days before seeding) generally was best. In Bulacan, farmers' and researchers' weed control methods were equal.

Seeding

Because more farmers are direct seeding, we developed in 1984 a 10-row seeder for pregerminated rice. The seeder uses 60 kg seed/ha, about half what farmers use and less

41. Improved 8-row rice seeder.

than is needed for broadcast seeding. Limited production has started and farmers bought several machines at $127.

In 1985 we developed a simpler, lighter, 8-row seeder (Fig. 41) that will sell for less than $52. The seeder has a centrally mounted single wheel for mobility. Two long, cylinder-shaped hoppers with holes for seeds are mounted on the axle. Seeds drop from the hoppers onto the soil. The machine plants pregerminated seed at the rate of 40-60 kg/ha.

UPLAND RICE

Constraints to upland rice yields

We began constraints research for upland rice in 1985 wet season with studies including modern varieties and improved weed control and fertilizer technology.

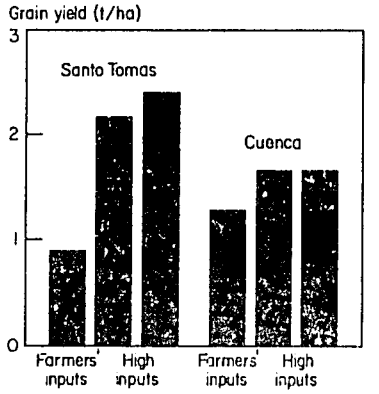
In Batangas, Philippines, yields with farmers' inputs averaged 0.9 t/ha on 5 Santo Tomas farms and 1.3 t/ha on 5 Cuenca farms (Fig. 42). Modern varieties and improved weed control significantly increased yields in Santo Tomas, despite 92 centibars soil moisture tension at vegetative stage, but not in Cuenca, where soil moisture tension reached 89 centibars at reproductive stage. Modern varieties outyielded farmers' varieties under farmers' and improved weed control. Improved weed control increased yields of farmers' varieties by 0.3 t/ha and those of modern varieties by 1.0 t/ha. High fertilizer did not increase yields because of moisture stress in Cuenca, and moisture stress and high soil N in Santo Tomas.

Unlike in lowland rice, where often only the effects of individual inputs are significant, interaction effects were significant in upland rice. Results suggest that adopting modern varieties and weed control practices will increase upland rice yield.

Fertilizer management in upland soils

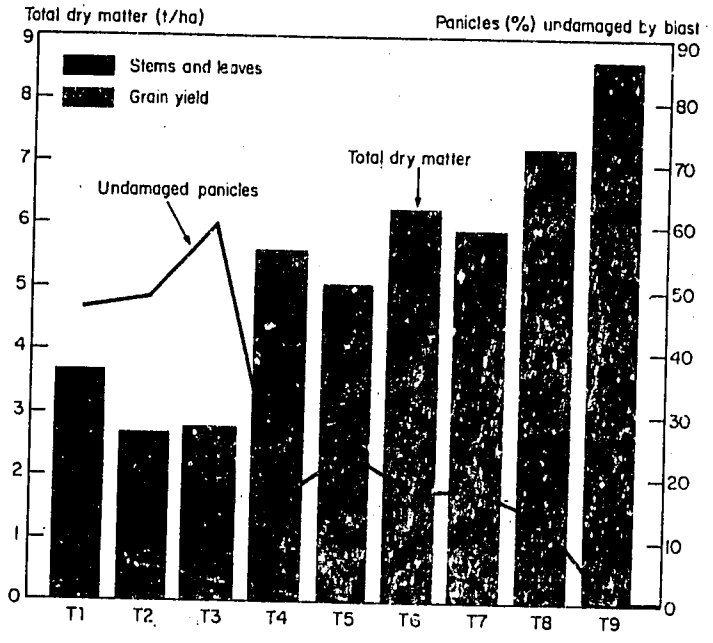
Upland rice often is grown on acid soils with severe N and P deficiencies. Adding N and P, however, often causes blast at heading.

We evaluated graduated increases of N, P, K, lime, and manure with improved UPL Ri-5 in a very acid (pH = 4.0), P-deficient (5.8 ppm available P) upland farmer's field.



42. High inputs (variety, fertilizer, and weed control) significantly increased average yields on 5 Santo Tomas farms despite 92 cb soil moisture tension at vegetative stage, but not on 5 Cuenca farms where soil moisture tension reached 89 cb at reproductive stage. Farmers' varieties were Kinandang Patong, Kalibo, and B733C-167-3-2 in Santo Tomas and Kinandang Patong in Cuenca.

43. Improved N and P nutrition dramatically increased upland rice growth on an acid infertile soil, but also stimulated severe blast infection.



Fertilizer added (kg/ha)

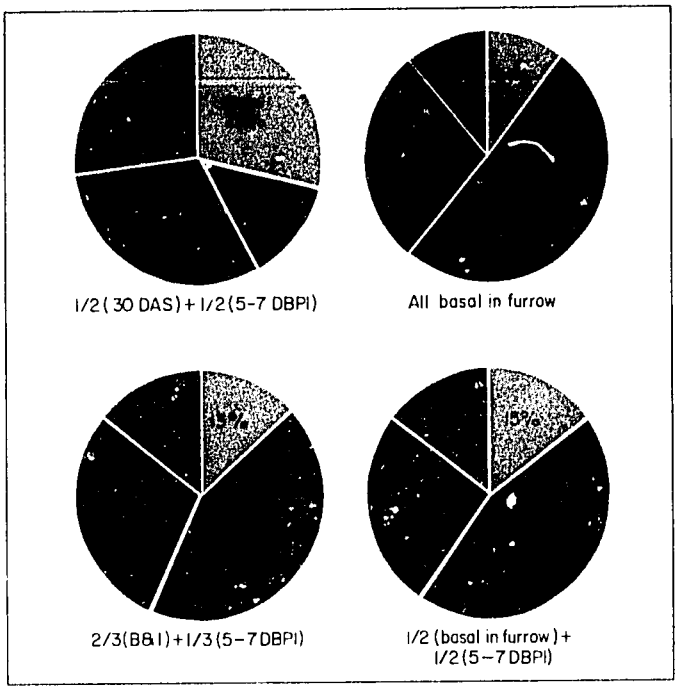
N	–	35	70	70	35	70	70	70	70
P	–	–	–	20	10	20	20	20	20
K	–	–	–	–	10	20	20	20	20
Lime	–	–	–	–	–	–	500	2000	2000
Manure	–	–	–	–	–	–	–	–	3000

Applying N reduced dry matter and grain yield below the levels without fertilizer (Fig. 43). Adding N increased P deficiency. Applying P and N increased yields, but dramatically increased panicle blast. At high nutrient applications, all plants had neck blast, which was related to total N uptake.

N and P application is essential to increase upland rice yields in acid, infertile soils, but fertilization is futile unless blast is controlled. Blast-resistant varieties can help, but few have stable resistance. Quantifying blast × nutrient interactions is essential to developing appropriate nutrient management for blast control and high upland yields.

Nitrogen transformation in upland rice

Although we know a great deal about N availability to flooded rice, our knowledge of N transformations in soils under upland rice is less complete. Such knowledge is essential to improving upland rice management.



44. ^{15}N isotopic tracer enabled us to show that N recovery by upland rice (IR43) was 87% when urea was applied as a split dressing 30 days and 60 days after seeding (DAS), but only about 50% when application was earlier. Results contrast with those obtained with flooded rice.

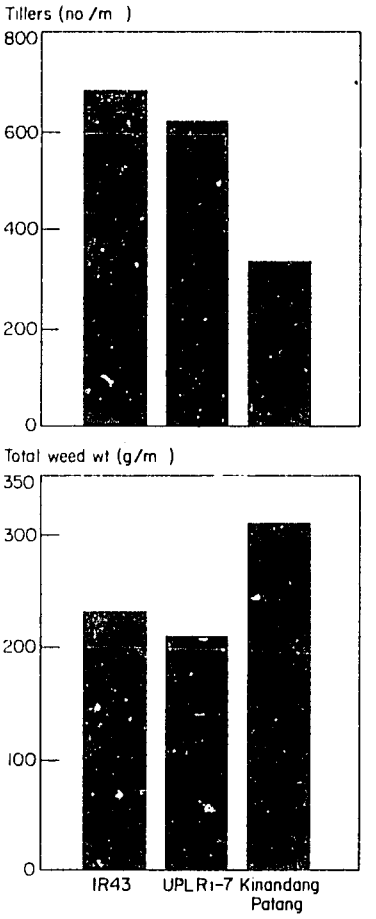
We used ^{15}N to measure the effect of fertilizer application methods on N losses. In contrast to the low recoveries observed in flooded soils, we found that IR43 recovered 87% of applied N (56% in straw + grain and 31% in soil + roots) when N was topdressed in equal splits in weeded fields 30 days after seeding and 5-7 days before panicle initiation (Fig. 44).

N recovery was 55-56% when two-thirds fertilizer was broadcast and incorporated and one-third was applied 5-7 days before panicle initiation or when fertilizer was applied in equal splits in the furrow and 5-7 days before panicle initiation. N recovery was lowest (49%) when fertilizer was applied in furrows and covered with dry soil.

Integrated weed management in upland rice

Chemicals are an important component of integrated weed management in harsh upland environments. We studied the interactions of varieties and chemical and manual weed control on upland rice. IR43 and UPL Ri-7 plots had more tillers and fewer weeds than Kinandang Patong plots (Fig. 45). Tiller number rose as weed competition declined.

45. Tiller count and total weed weight for 3 rice varieties. Average of 10 weeding regimes



Two hand weedings controlled weeds best. Pre-emergence butachlor application followed by interrow cultivation was the next best treatment, and similar to butachlor, butachlor followed by one hand weeding, and one hand weeding alone.

DEEP WATER RICE

Traditional deep water rices in Thailand are relatively unresponsive to cultural practices and fertilizer application, and yields seldom average above 2 t/ha. However, 3 years of trials in Thailand have shown that interplanting can increase total production per unit area.

If rainfall is favorably distributed from early May to late July, when flooding begins, a rainfed crop of early-maturing (95-100 days) rice is possible and yield potential is almost double that of the average deep water yield. Rainfed rice yield has varied from 3.5 t/ha in good years with even rainfall to less than 1 t/ha in bad years.

Interplanting rows of deep water rice with early rice or another early-maturing crop is less risky. In the 10 weeks between harvesting the early crop and flowering of deep water rice, deep water plants can spread, thus compensating for lower plant number. Yields can approach those of a normally spaced monoculture crop.

In field trials, deep water and early rice have been planted in alternate rows with up to 1 m space between the deep water rice rows. With 60-80 cm spacing, deep water yields usually exceeded 85% of the monocrop with which it was compared. In some trials, yield from widely spaced rows was greater than that from broadcast monoculture. Consequently, the additional yield from the early variety greatly increased total production.

In best conditions, total production with interplanting has been 4 t/ha. When yields of both crops were low because of environmental stresses, particularly drought in early stages, monoculture deep water rice yields were less than 1.5 t/ha. The interplanted deep water rice yield, however, was equivalent to or even higher than that of the monocrop, so total production per unit area was still more than with monoculture.

Crops that mature more quickly than early rice, such as mungbean, soybean, and cowpea, can perform well where fields are not waterlogged during the 80 days after planting.

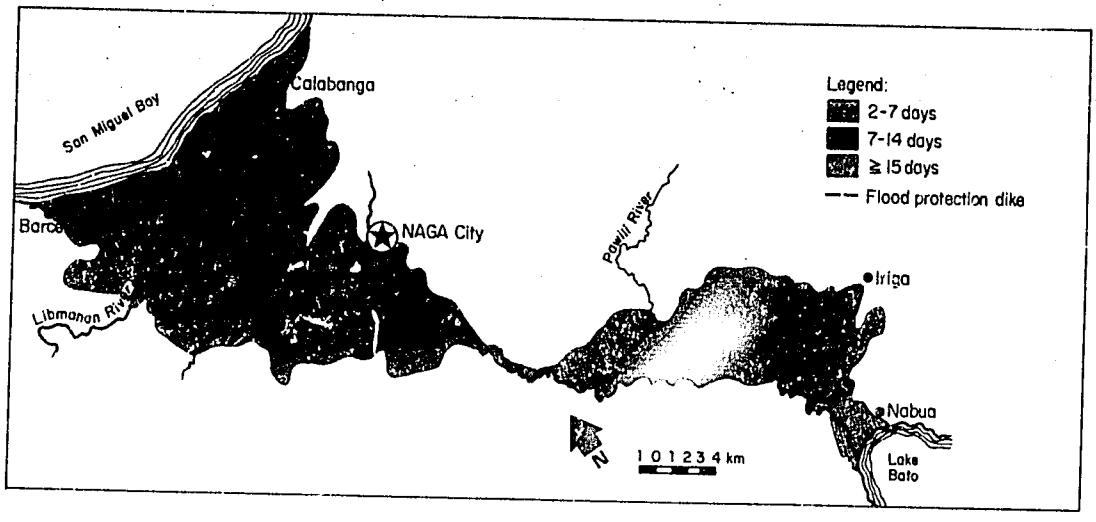
Techniques are being developed to help farmers use interplanting. Hand sowing uses too much labor for the return obtained, but broadcasting the early variety and dropping deep water rice seeds along a line is quick and effective. We modified a six-row seeder by removing the floats and increasing the size of the wheels. It drops seed on the soil surface and works well for row sowing. We are evaluating row sowing machines and deep water interplanting in farmers' fields in different environments.

WATER MANAGEMENT

We use research on several rice production systems to devise general approaches to better water management. Inadequate water control is common among resource poor rice farmers, but better water distribution and management can help them improve their situation without major investment. Some of the most difficult problems occur in flood-prone areas and areas where water must be pumped from groundwater reserves. We have made a project study of a flood-prone area in the Bicol River Valley of the Philippines and of pump systems in Bangladesh and in Guimba, Philippines.

Improving productivity in flood-prone areas

Farmers in flood-prone areas generally obtain lower yields than farmers in flood-free areas. The risk of crop damage or loss discourages farmers from using recommended levels of inputs. In 1985, we evaluated the impact of flooding in the central and lower Bicol River Basin of the Philippines and identified ways to improve production conditions in flood-prone areas.

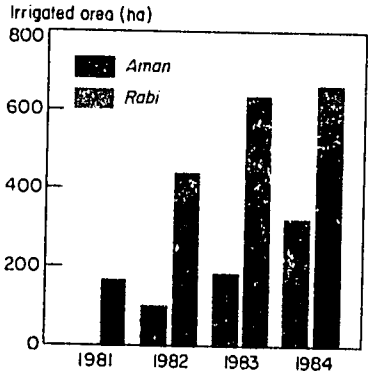


46. Flooding in the central and lower Bicol River Basin after typhoon *Saling*.

In October 1985, a major flood followed typhoon *Saling*, which brought 250 mm rainfall in 30 hours. That gave us an opportunity to assess the impact of a major flood. *Saling* inundated 33,000 ha of riceland. About 25,000 ha had partially damaged crops; 5,500 ha were severely affected, with flooding lasting 7-14 days; and 2,500 ha were flooded for more than 1 month (Fig. 46). Similar floods occur every 2 or 3 years.

In trials with 12 flood-tolerant varieties, we found that rapidly rising and turbid water killed most plants. In less severely flooded areas, short-duration varieties 125 cm tall or taller performed best.

47. Area irrigated by 12 deep tubewells in 1981-84 rabi (dry) and aman rice seasons.



Increasing effectiveness of tubewell irrigation

Unreliable water delivery limits crop production and income on small farms in the North Bangladesh Tubewell Irrigation System. Although the system has 378 deep tubewells, most farms in the irrigated area harvest no dry season crop or only a low-yielding crop that grows with residual moisture. About 85% of farmers planted low-yielding local rices in the main aman season.

We have participated in multidisciplinary research with the Bangladesh Rice Research Institute and the Bangladesh Water Development Board since 1982. Project goals are to increase irrigation effectiveness, crop production, and farmer income. Figure 47 shows improvements

made for aman rice and rabi wheat in the 12-tubewell research area.

We introduced suitable modern rices to maximize crop production through a more reliable irrigation supply and tested several cropping patterns to increase farmer income. Within the area served by the 12 wells, main aman season rice area and the proportion of modern varieties grown have substantially increased (Fig. 48) as water management has been improved.

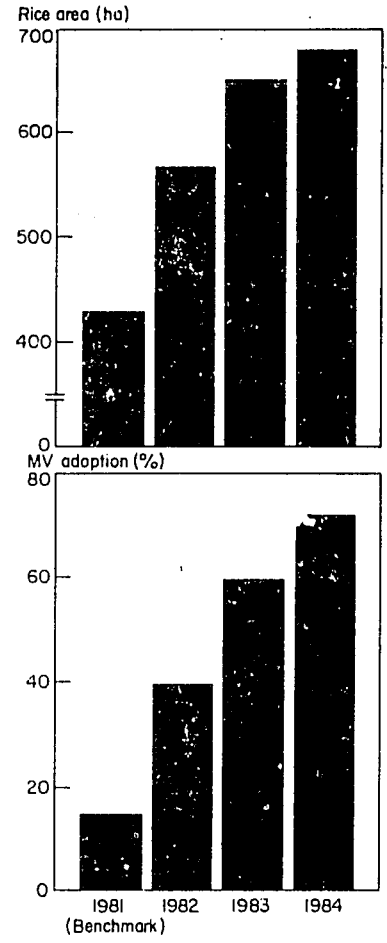
Improving pump irrigation efficiency

At the Guimba cropping system site in Central Luzon, Philippines, we identified the constraints to efficient water use in a rice-based, deep tubewell irrigation scheme struggling to survive increasing energy costs. In 1984 wet season, water use efficiency was fairly high because farmers tried to make maximum use of rainfall and only pumped when fields were dry. In those periods water use efficiency generally exceeded 65%. All farmers harvested a wet season crop, but many did without pump irrigation to avoid paying the irrigation fee.

The 1985 dry season pattern was very different. There was little effective rainfall and pumped water was essential for crop growth. The irrigation fee of 800 kg rice/ha represented a significant input cost to farmers. Such conditions should favor high water use efficiencies; however, efficiency was low largely because of losses along the main channel.

Organizational problems are compounded by split responsibilities for maintenance and operation. The farmers' organization allocates and distributes water and the National Irrigation Administration maintains and operates the pump. Slow response to pump failures and electricity interruptions increase the uncertainty of water availability, and have discouraged farmers from working together to solve scheduling problems.

In 1985 dry season at Guimba, most farmers planted in February, but our research indicates October planting would enable more area to be planted with the same water use efficiency because of greater early season pump discharge. It was impossible to irrigate more than 35 ha of dry season rice from one pump if planting was later than mid-



48. Rice area and farmers planting modern varieties (MV) in aman season in the deep tubewell research area.

November. If planting is delayed until late January, only 17 ha can be irrigated unless water use efficiency exceeds 80%. Current dry season water use efficiency is 48%.

In 1985 dry season, farmers planted 35 ha of rice, but many had severe, late season water shortages. Several farmers irrigated fields from private, shallow tubewells and did not always use deep tubewell water.

Our experiments indicated that dry season upland crops that require less water than rice can be successful throughout the command area. Planting them would reduce energy costs to about one-third of those required for rice.

Farmers, however, have shown little interest in upland crops, which would need more cooperation over water allocation and distribution than rice. Their reluctance partly results from inadequate opportunities for remunerative marketing of the alternative crops. An October or November planting of half rice and maize would increase the irrigated area from 17 to 60 ha, and pumping costs would decline from $222 to $84/ha.

PEST MANAGEMENT

The most user-friendly pest control method is incorporation of natural resistance into rice varieties. For some pests, however, sources of varietal resistance have not been identified, and changes in insect biotypes and disease races and consequent breakdown of resistance mean other controls also must be available. Chemicals are costly, may be hazardous to animal and human health with improper use, and may pollute the environment. Nevertheless they remain a valuable adjunct to varietal resistance and are an important component of integrated pest management.

We are seeking to minimize the need for chemical controls by identifying biological control agents and ways to encourage the natural enemies of rice pests by determining economic thresholds, and by studying natural pesticides

derived from plants that may be grown on the farm where they are to be used. To support these studies we also are characterizing viruses and their vectors.

BIOLOGICAL CONTROL AGENTS

Chemical insecticides can cause resurgence, insecticide resistance, and other adverse effects, and may be incompatible with an effective integrated pest management program.

Bacillus thuringiensis for leaffolder control

We tested *B. thuringiensis* Berliner (var. kurstaki), a commercially available bacterium, for leaffolder control. *B. thuringiensis* is specific for caterpillars, does not cause resurgence or resistance, and is safe to applicators.

B. thuringiensis significantly reduced field populations of leaffolder *Cnaphalocrocis medinalis*, and persisted 5 days without harming beneficial parasites and predators. Insect predator populations reached 24/m^2 and complemented *B. thuringiensis* in preventing leaffolder damage. Laboratory screening with 5 times less than the recommended rate killed all leaffolder caterpillars.

Mass producing fungi for brown planthopper control

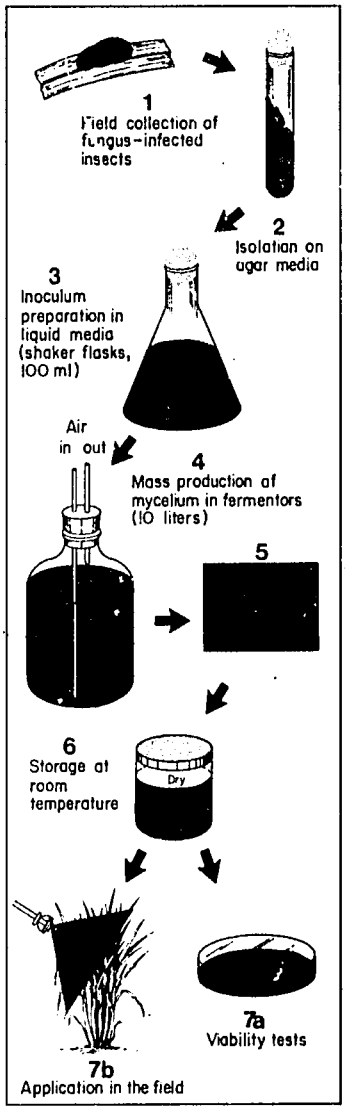
We developed a liquid fermentation unit for mass producing fungal pathogens of brown planthopper (Fig. 49) that can inexpensively produce large supplies of the fungi.

Applying *Metarhizium* sp., *Hirsutella* sp., and *Beauveria* sp. satisfactorily controls brown planthopper populations (Fig. 50) without killing biological control agents or causing side effects that may occur with chemical controls. Figure 51 shows a brown planthopper infected with *Hirsutella*.

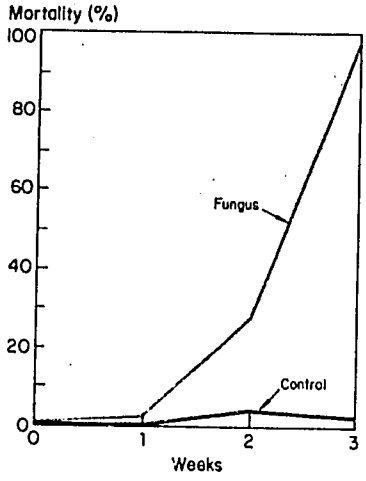
Collaboration with the University of the Philippines at Los Baños and with Korean scientists has identified other insect pathogens.

Mycorrhizae and reduction of sheath blight damage

Knowledge of changes in the population of effective mycorrhizal fungi in an agricultural ecosystem helps improve management of beneficial mycorrhizal symbiosis.



49. Schematic of the process to mass produce dry, viable mycelium of entomopathogenic fungi.



50. Field mortality of brown planthopper after applying mass-produced fungi.

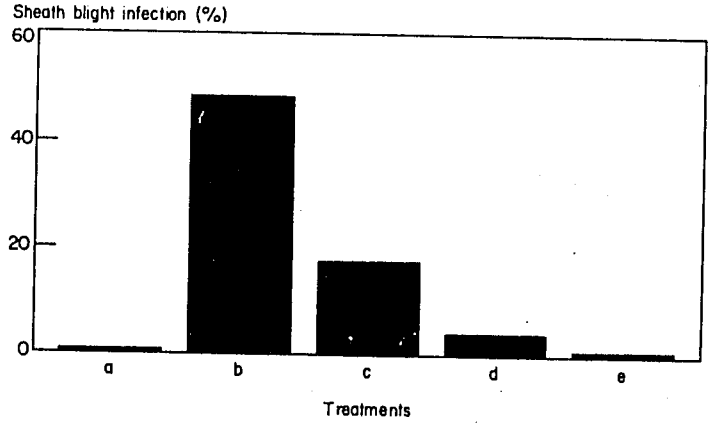
51. A brown planthopper killed by *Hirsutella*.

We quantified by the *most probable number* method the populations of vesicular-arbuscular mycorrhizal fungi at different stages in the rice-based cropping system in Guimba, Nueva Ecija, Philippines. The measurement also indicates the inoculum potential, which is important because adding mycorrhizal fungi to soil containing *Rhizoctonia solani* sclerotia reduced sheath blight incidence 45% (Fig. 52).

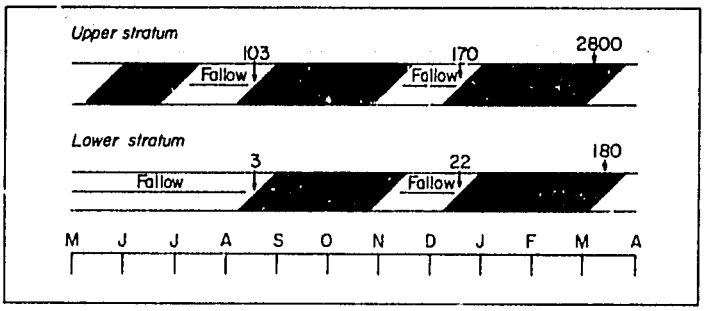
Mycorrhizae population was low after 2 months fallow, but increased during dry season cropping. Population increased more in fields planted with maize than in those with lowland rice. Inoculum potential declined between the dry season and wet season crops, and then rose again. There were consistently more vesicular-arbuscular mycorrhizal fungi propagules in fields planted with one rice and two upland crops each year than in fields with two lowland rice crops and a long fallow (Fig. 53).

Biological control of fungal pathogens

In 1984 we discovered in rice fields bacteria that exhibit broad-spectrum control of fungal diseases of rice. When applied as a seed treatment, the bacteria reduced disease incidence in the seedbed and protected the plants from bakanae infection. In an integrated pest management trial in the 1985 wet season, we applied the bacteria as a seed treatment and as a spray at maximum tillering. The bacteria controlled sheath blight as well as a commercial fungicide application.



52. Sheath blight infection in rice plants with and without mycorrhiza.



53. Endomycorrhizal fungal population at various stages of the cropping patterns in two lowland rice fields. The numbers show fungal propagules per gram of air-dried soil.

Botanicals for pest control

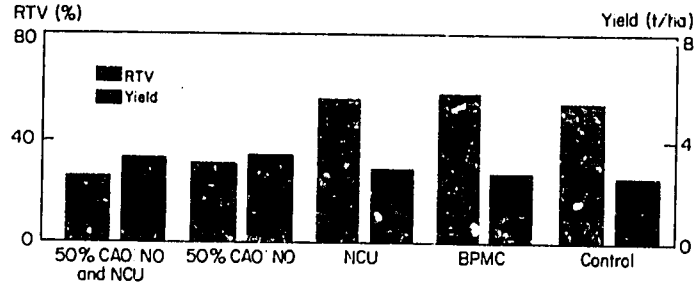
The complexity of rice insect pests and the virus diseases they transmit requires an integrated pest control that uses resistant varieties, appropriate cultural practices, selective and inexpensive pesticides, and conservation and encouragement of natural enemies. Resistant varieties alone provide inadequate control because new insect biotypes and virus races continually develop. Applying synthetic insecticides may be uneconomical and is often ecologically undesirable.

Recent IRRI studies have shown that derivatives of some plants, such as the Asian neem tree *Azadirachta indica* (A. Juss), can be safe, inexpensive alternatives to commercial pesticides. Although they may not perform at par with synthetic pesticides, they often can meet the crop protection needs of Asian and African rice farmers.

Neem leaves have been used as a natural insecticide for more than 1,000 years. The tree has natural chemicals that deter insects from feeding, causing them to die of starvation. When extracts of its leaves are sprayed on rice and other plants, they help control insects and virus diseases that they transmit during feeding. Neem derivatives are safe, low cost, locally available, and effective against a variety of pests.

For three consecutive 1984-85 crops, IR42 plants treated with neem oil alone or combined with neem cake-urea had generally low green leafhopper population, consistently low tungro infection, and good yields (Fig. 54). When 50% of plants in the area were infected with tungro, plants treated with neem oil or the combination had markedly lower tungro infection and yielded significantly more than insecticide-treated and untreated plots.

Bakanae control with antagonistic bacteria.



54. Yield and tungro infection in plots planted to susceptible IR42 and treated with custard-apple and neem oil (CAO:NO), neem cake-urea (NCU), their combination (CAO:NO and NCU), butylphenyl-N-methylcarbamate (BPMC), or a detergent-water solution (control).

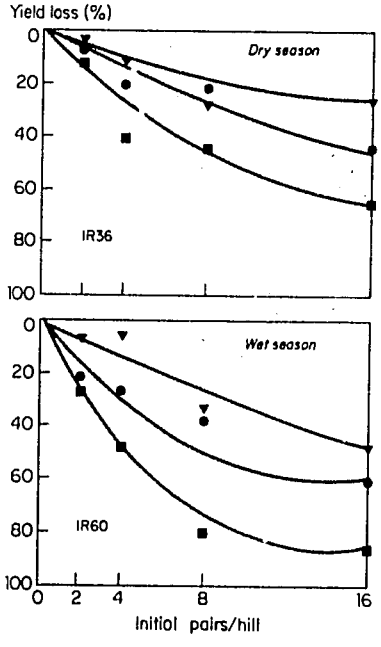
Economic injury levels

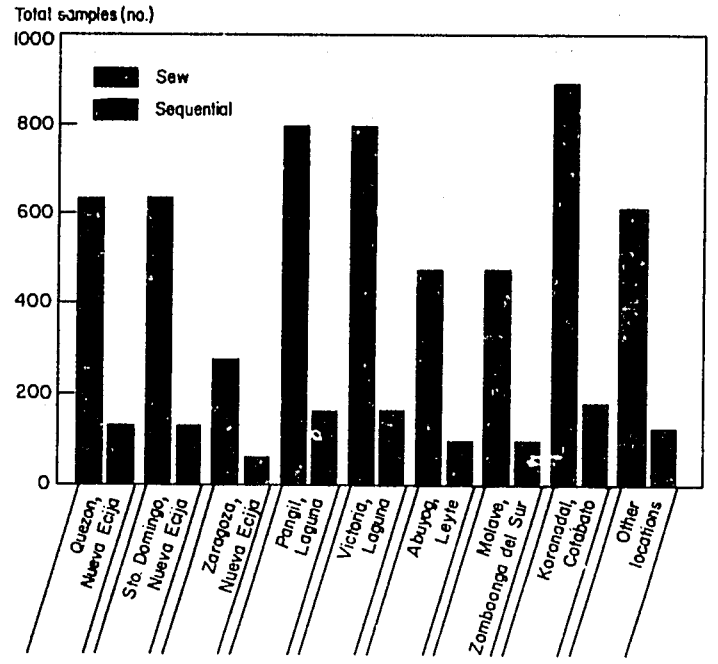
Prophylactic insecticide applications are seldom economic. We are working to develop action thresholds based on insect population and damage to determine when to apply insecticides. We start by estimating the relation between insect population and yield loss under controlled conditions of increasing pest abundance. Those values are tested in farmers' fields and insecticide application costs and yield return are included. Results of those tests become action thresholds. We are also working with farmers to find ways in which they can be trained to determine for themselves when and what should be sprayed.

The concept of surveying fields for insect pests and damage before spraying is not new to rice farmers. In a survey of Central Luzon farmers, only 35% applied insecticide as a prophylaxis; 47% observed insects or their damage before spraying; and 18% quantitatively recorded insect abundance. Farmers surveyed the wettest fields first because they have learned that pest populations develop there earliest. Farmers generally do not enter their rice fields but walk along the bunds scanning the crop and noting the distribution of damage. They also may tap hills of rice to record insect numbers.

In 1985 we established action thresholds for black bug on IR36 and IR60 (Fig. 55). Thresholds change with variety, density of adult black bugs, and infestation time. Using data from the figure, we can estimate potential yield loss and decide if insecticides should be applied. For example, when 9, 20, and 38 adults per hill were present on IR36 at 28, 42, and 56 days after transplanting, 20% yield loss could be expected.

55. Relations among *S. coarctata* pairs per hill, caging time, and yield loss, Palawan, Philippines. DT = days after transplanting.



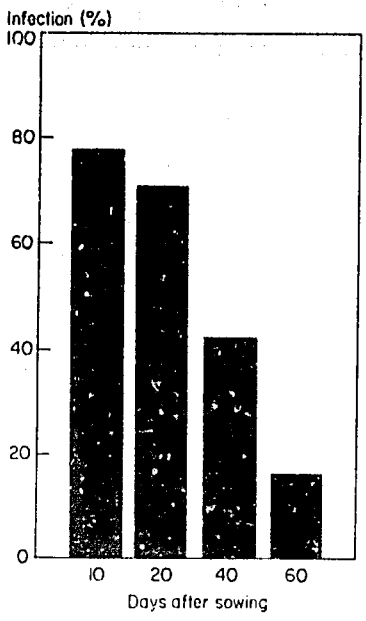


56. Samples per location using intensive (SEWS) and sequential sampling.

We also worked to establish action thresholds for whorl maggot, which attacks rice the first week after transplanting. Effective controls include insecticide treatment at transplanting and soaking seedling roots in a systemic insecticide before transplanting. Whorl maggot population varied by location and we found the best way of estimating potential level was to survey damage in adjacent fields with older crops. In Zaragoza, Nueva Ecija, Philippines, a high yield loss area, the action level was 0.5 egg/hill in older crops. In Guimba, Nueva Ecija; Calauan, Laguna; and Koronadal, South Cotabato, which are low yield loss areas, the treatment threshold was 2.0 eggs/hill.

We developed a simple insect sampling program, tested it at 12 Philippine sites, and compared it with the conventional method, which requires a fixed number of samples. The plan is based on insect distribution, economic threshold, and the level of risk the farmer will take.

Figure 56 shows results from more than 160 samples. The results agree with those of the conventional sampling method. Sequential sampling took 80% less time to decide whether or not to treat, and so should be more practical for farmer use.



57. Tungro infection in IR36 plants at different growth stages.

VIRUS STUDIES

Green leafhopper resistance and tungro infection

Green leafhopper, the tungro virus vector, grew poorly on IR36, and applying IR36 extracts to susceptible varieties repelled the insect. Resistance to green leafhopper generally increased with plant age, and tungro damaged older plants less than younger plants (Fig. 57). Studies also show that green leafhopper population increased twice as fast on susceptible as on resistant varieties.

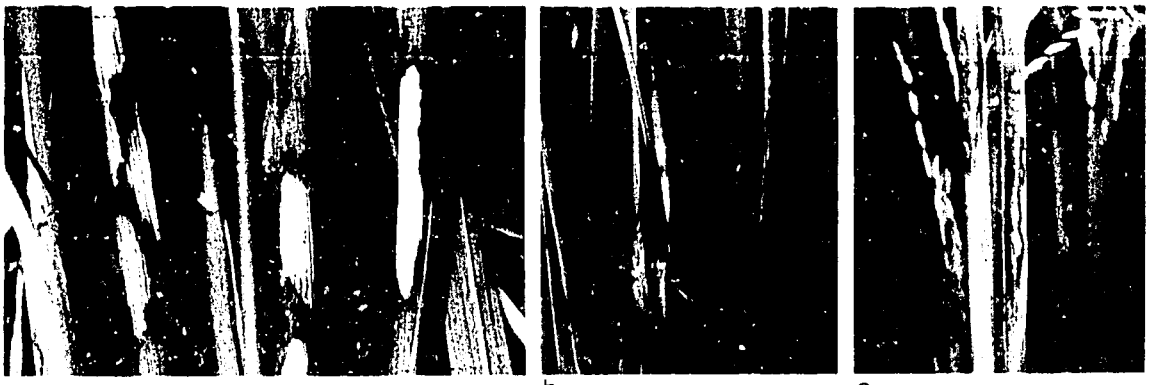
Monoclonal antibodies to grassy stunt virus

Working with the American Type Culture Collection, we have identified a hybridoma cell line in mice that produces ascitic fluid with excellent antibodies against grassy stunt virus (GSV). The monoclonal antibody reacts to both GSV 1 and GSV 2 in ELISA and dot immunobinding assay (DIBA) tests. ELISA tests showed the monoclonal antibody could detect GSV in plant sap diluted 10,000 times. The antibody also detected GSV in as little as 2.5 μl of infected sap in modified DIBA tests and gave much lower background in both tests than a polyclonal (conventional) antibody. Monoclonal antibody diagnosis is sensitive, specific, and a reliable tool for studying grassy stunt epidemiology.

Sheath blight and sheath blight-like rice diseases

Sheath blight caused by *R. solani* occurs wherever rice is grown, and incidence is increasing with intensification of rice cultivation. Two other *Rhizoctonia* species also frequently occur in irrigated rice (Fig. 58). *R. oryzae* causes sheath spot and *R. oryzae-sativae* causes aggregate sheath spot. The symptoms caused by all three species are similar; however, their growth on agar medium is very different (Fig. 59).

In rice fields, sclerotia distribution frequencies were 57% for *R. solani*, 42% for *R. oryzae-sativae*, and 0.4% for *R. oryzae*. We estimated there were 2.4-2.6 million sclerotia/ha for *R. solani* and 1.3-2.0 million/ha for *R. oryzae-sativae* before land preparation and 2.1-2.3 and 1.1-1.2 million/ha after land preparation.



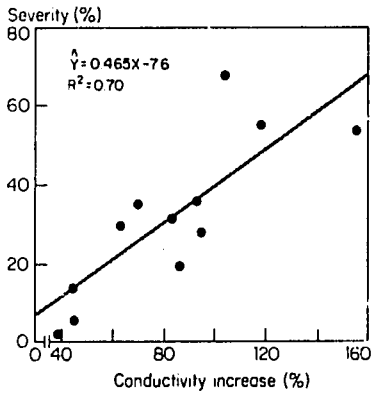
a b c

58. Symptoms of a) sheath blight, b) sheath spot, and c) aggregate sheath spot.

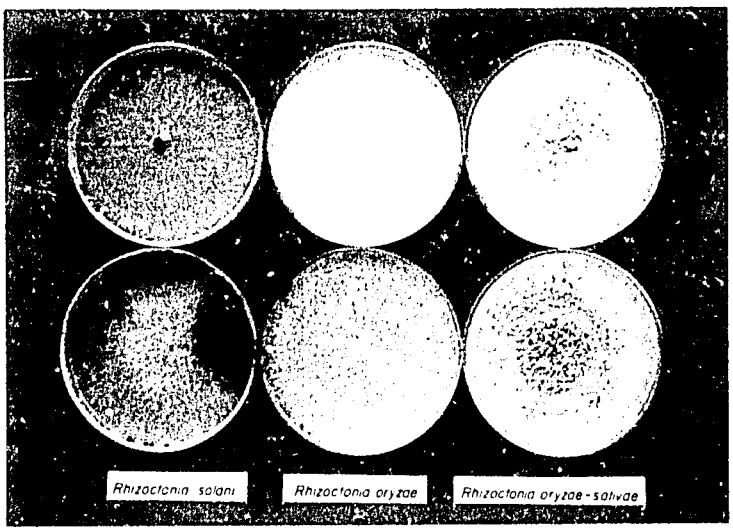
Sclerotia viability was 27-39% and was spatially distributed. Disease probability was higher where sclerotia were densely distributed, which was along the edges and in corners of the fields, rather than in the center of fields, where there were fewer sclerotia. This information will facilitate sheath blight control.

Assessing sheath blight resistance at tissue level

The nature of varietal resistance to sheath blight is not fully understood. We measured electrolyte leakages from tissues to relate resistance and susceptibility to the degree of damage caused by sheath blight and found that electrolyte conductivity increased with tissue damage (Fig. 60). No



60. Relations between electrolyte leakage from sheath blight-infected rice sheath tissue and field infection.



59. Colonies of fungal pathogens causing sheath blight, aggregate sheath spot, and sheath spot.

correlation, however, existed between electrolyte conductivity of sheath tissue and that of leaf tissue, thus indicating different levels of resistance in leaves and sheaths of the same variety. Our findings imply that increasing resistance level of sheaths would decrease damage caused by sheath blight.

FARMING SYSTEMS

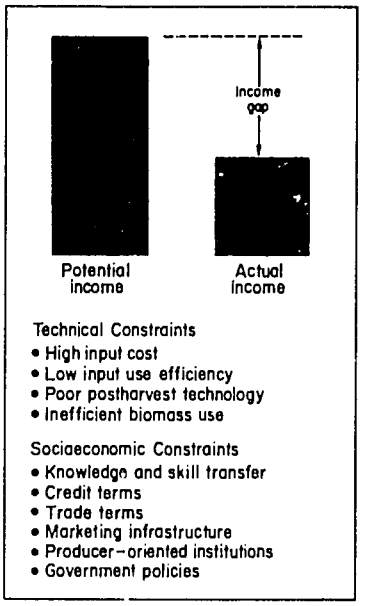
IRRI farming systems research seeks to maximize the use of year-around sunshine for crop production. The full use of annual solar radiation is restricted by water shortages, scarce labor and energy, and lack of appropriate crops. The program emphasizes intensification of the crop production system on farms where there are different physical and economic constraints. Opportunities for double or triple cropping created by short-duration, high yielding rice varieties have been studied and identified for rainfed and irrigated areas.

In 1985, we continued to develop our farming systems methodology and gave greater attention to social factors, including specific attention to the role of women. Our research has shown the importance of maximizing income, rather than yields, from small rice farms. We therefore are working with the University of the Philippines at Los Baños to identify income-generating component technologies, including animal production from crop residues and azolla, fish rearing during wet season, and subsidiary enterprises such as mushroom culture and making paper from straw and rice husks. We also are studying ways of optimizing income from rainfed and irrigated farms.

In 1985, our two major sites for cropping systems research were a partially irrigated area in Central Luzon and an upland rice area in northern Mindanao, Philippines. At both sites, we made important progress in identifying better varieties and management methods, and in developing

simple, inexpensive machines to resolve labor constraints. These research developments are shared with and widely evaluated by national scientists through the Asian Rice Farming Systems Network (ARFSN).

Just as in the 1970s IRRI pioneered research on the yield gap — the difference between the potential yield of the rice plant and yields achieved by farmers — we now must play a similar catalytic role in assessing the reasons for the *income* gap that plagues small farmers. Our farming systems work will help us identify the factors that prevent such farmers from realizing the full income potential of their farms.



Model for studying constraints responsible for income gap, assuming no yield gap.

UPLAND CROPS TO FOLLOW RICE

Among our collaborators in the Rice Farming Systems Program and ARFSN are the International Institute of Tropical Agriculture (IITA), Philippine Institute of Plant Breeding (IPB), Indonesia's Central Research Institute for Food Crops (CRIFC), Thailand's Field Crops Research Institute, the International Center for Research in the Semi-Arid Tropics (ICRISAT), and the Asian Vegetable Research and Development Center (AVRDC).

In 1985, collaborators concentrated on screening mungbean, soybean, and peanut. From yield trials in Los Baños and Pangasinan, Philippines, IPB recommended mungbean IPB M 79-12-168, IPB M 79-20-113, IPB M 79-17-91, IPB M 79-25-106, and IPB M 79-25-115 and soybean IPB Sy 138-28, GC 60068-9, GC 50193-7-6, Acc. 770, and GC 50123-8-6 for evaluation as upland crops after rice.

The IRRI-IITA project identified early-maturing (55- to 60-day) cowpea IT8D-891, -889, and -892 as promising prerice varieties. They yielded 0.9-1.0 t grain/ha and 16-20 t green fodder/ha, which can be fed to cattle or incorporated as green manure. Cowpea can also be grown after rice. TVx 2724-01F, 3381-02F, IT81D-1069, and IT81D-1205-174 yielded 1.2-1.3 t grain/ha and 12-17 t fodder/ha, and matured in 75-80 days.

Soybean 30290-11-11, TGx 888-48C, SJ-2, and TGx 562-4D yielded 2.5-3.0 t grain/ha in 85-90 days, have good seed longevity, nodulate profusely, and resist diseases

and insects. We also identified pigeonpea ICPL 84060, ICP 909-E3-5EB, and ICP 3009-E3-4EB from ICRISAT for cropping after rice. Grain yields were 0.78 to 3.25 t/ha, and in addition had excellent fodder yields and pod borer resistance.

We distributed 169 trials of upland crops to be grown before rice (mungbean, cowpea, bush sitao, soybean, peanut, sorghum, and 50 maize) and 268 trials to be grown after rice (mungbean, cowpea, bush sitao, soybean, peanut, sorghum, maize, and pigeonpea). These were evaluated at 236 sites in 12 countries. Most experiments were in farmers' fields.

ARFSN also monitored climate and crop and economic performance at 44 sites in 12 countries. Most introduced cropping patterns gave higher total production and income than farmers' patterns. Several national programs have implemented or expanded multilocation and pilot production testing.

In 1985, ARFSN cooperators also evaluated maize and cowpea intercropping, crop - livestock systems, forage grasses, and grain and forage legume intercropping.

In Philippine sites, yield of improved soybean varieties was 1.3-2.9 t/ha. Willis, TGx 562-4D, and Improved Pelican yielded best, matured in 90-95 days, and were disease resistant. Early-maturing peanut varieties yielded 1.1-1.8 t/ha. ECGS(E)-56, 91176, and ICGS(E)-114 performed best and matured in 90 days.

In the dry season immediately following rice, we evaluated maize and cowpea intercropping for grain and fodder production. Intercropping decreased cowpea green pod and dry bean yield, but fresh fodder and dry matter yields increased significantly with up to three pickings of green pods. Cowpea crude protein content and digestibility of fodder and in-vitro dry matter of varieties were significantly reduced when pickings were delayed until after 50% flowering.

Maize yield decreased when cowpea harvest was delayed from flowering until three dry pod pickings, but yields did not differ significantly between maize monoculture and intercropping, and maize crude protein significantly increased with up to three pickings of cowpea dry pods. Digestibility of in-vitro dry matter of maize grown as

an intercrop and used as fodder was better than that of maize grown in monoculture.

CROP AND LIVESTOCK RESEARCH

We collaborate in crop-livestock research with the Philippines, and ARFSN has crop-livestock sites in Thailand, Indonesia, Nepal, and China. The Philippine project is in two villages: one with a rainfed environment and one annual rice crop, and the other an irrigated lowland site with two rice crops.

To grow more animal feed, we evaluated field legumes before and after rice in rainfed lowland fields, and mungbean between rice crops in irrigated fields. Cowpea and mungbean were the most promising crops before and after rice. In the research area in 1985 dry season, 67% of farmers planted mungbean after rice compared to very few in 1984. On irrigated land, rice straw spoiled in rainy season, and mungbean was flooded at early blooming. Both events reduced supplies of animal feed.

We evaluated 16 forage grasses planted on 0.4 m × 0.3 m high bunds. Forage was harvested at 30- to 60-day

Cowpea + sorghum intercropping is a way to increase food grains and provide fodder for livestock

intervals for 10 months. Napier yielded highest with 41.3 t dry matter/ha. Alabang X, para grass, Setaria cv Nandi, Setaria cv Kazungula, and ruzi grass also yielded well.

In evaluations of grain and legume intercropping as no-tillage component technology for smallholder crop-livestock farming systems, maize DMR Composite No. 1 or sorghum UPL SG5 was intercropped with *Macroptilium atropurpureum*, *Stylosanthes guianensis*, *Centrosema pubescens*, and *Vigna unguiculata*. Maize yielded 0.5 and sorghum 2.2 t/ha, and yields were unaffected by legume intercrops. *M. atropurpureum* yielded 3.4 t fodder/ha, dry weight, with 0.5 t maize stover, and 2.8 t/ha with 3.3 t sorghum stover. *S. guianensis* yielded 0.4 t straw/ha with maize or sorghum, and *V. unguiculata* yielded 0.04 and 0.1 t grain/ha.

COMPONENT TECHNOLOGY FOR UPLAND CROPPING SYSTEMS

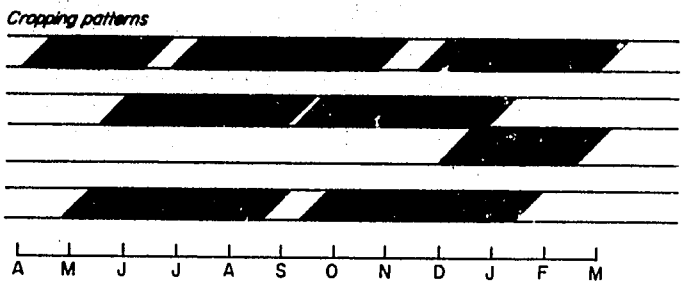
Insect control and crop yields in an acid upland environment

In collaboration with the Philippine Ministry of Agriculture and Food, we expanded research on insect pest control in upland rice. In Claveria, Mindanao, insects and panicle diseases caused 40% yield loss in farmers' fields. Yield was 5.1 t/ha from fully protected plots and 3.1 t/ha from unprotected plots. Rice roots were attacked by white grub, root aphid, termite, and mealybug (Fig. 61). Seedling maggot attacked emerging tillers, caused stunting, and reduced tillering. Leaffolder, stem borer, rice bug, and panicle diseases caused yield losses on older plants.

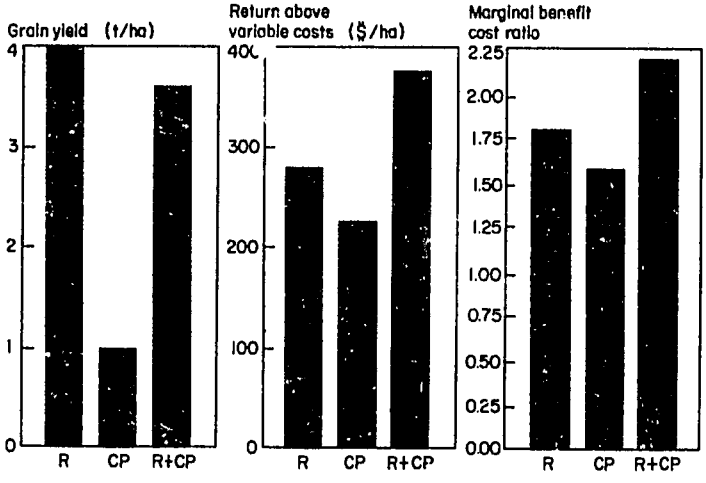
61. Soil inhabiting insect pests severely damaged upland rice roots (left) which caused stunting and reduced yields.

Pest control, particularly of soil-inhabiting insects, appears to be important to obtaining high yields from modern upland rice cultivation practices. Although responses to N, P, and lime were observed, they were not as dramatic as those to pest control.

Yields from the best treatments in many experiments exceeded 5.0 t/ha; average local upland rice yields are 1.5 t/ha. Mean yields from the first rice crop in the pattern (Fig. 62) were 4.0 t/ha, with high returns above variable costs (Fig. 63). Returns above variable costs and marginal benefit:cost ratios were highest for a rice and cowpea intercrop. Yields were high and costs were low because N



62. Upland rice-based cropping patterns being tested in Mindanao.



63. Grain yields, returns above variable costs, and marginal benefit cost ratios of crops planted as first crops in sequences being tested in an acid upland area in Mindanao. R = rice, CP = cowpea.

fertilizer was not applied. The early-maturing cowpea line was developed by IITA and tolerates the acid soils in the research area.

Factors restricting rice and legume germination

Sometimes, upland rice uses groundwater to augment the water it abstracts from the unsaturated soil matrix. We identified conditions under which groundwater uptake may affect rice growth and yield.

Early-season rain must be sufficient to raise water tables to within 0.8 m of the soil surface, the water table must recede no faster than 10 cm/day, and there must be 3 or 4 rainless weeks to dry surface soil (0-20 cm) to -0.1 MPa (-1 bar) soil-water potential.

The drought stress effects on rice growth and yield are probably amplified by water-related chemical effects,

Controlled environment studies of effect of soil moisture content and temperature on mungbean germination.

such as those on N and Ca nutrition and on Fe-Mn dynamics; by mechanical effects when drier soil inhibits more rapid rooting to depth; and by biological effects, as with weed competition. Contour-terracing of upland rice fields, which is important in Indonesia, the Philippines, and some parts of Africa, encouraged rainwater infiltration and soil moisture conservation and increased IR36 height 5% and UPL Ri-5 height 15%. Afternoon soil temperature at 2-cm depth during and just after seeding was as high as 38 °C — close to the 40 °C which, if continuously maintained, suppresses rice germination.

Controlled-environment-chamber studies done on rice germination showed strong interaction of soil temperature, soil moisture, and seed size. However, soil acidity had little effect on germination. Soybean germination was drastically reduced when soil temperature and moisture together respectively exceeded 35 °C and 0.40 kg/kg. At 20 to 35 °C, mungbean germination fell from 90 to 10% when soil moisture declined from 0.35 to 0.25 kg/kg. These two findings highlight the difficulty of upland rice systems. We must seek to identify crop varieties and methods that enable farmers to plant legumes at the end of wet season when they may be waterlogged by late rains, so that crop is established before the soil becomes too dry.

Upland seeder

We evaluated a seeder designed at Massey University, New Zealand, for sowing upland crops in tilled and untilled rice soils. It uses an inverted-T opener to make seed grooves with favorable soil microenvironments for seed germination, root penetration, and seedling emergence. A press wheel ensures precise seed depth, soil cover, and seed-soil contact. A disk in front of the opener cuts through crop residue left from the previous crop. A foam-pad seed metering mechanism provides good intrarow seed spacing and allows damage-free planting with different seed sizes.

The seeder can be attached to tractors or power-tillers, and a carabao-drawn seeder is being made.

The seeder is being evaluated for several upland crops, and initial crop establishment is better than that with hand sowing.

Rice hull carbonizer and charcoal briquetting

We are developing technology to use rice hulls as solid fuel. A rice hull carbonizer (Fig. 64) has been designed to be

64. Rice hull carbonizer coupled with center-tube furnace.

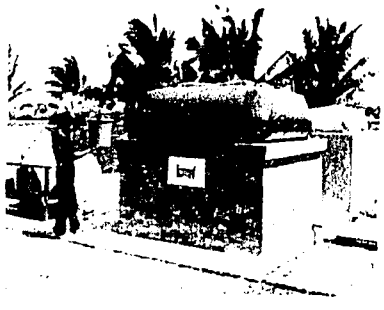
integrated into rice mills for producing char and hot flue gases for crop drying. The char is combined with a soil binder and formed into charcoal briquets by hand or with a hand-operated compactor.

The briquets are used in direct-heated drying systems and for cooking and other domestic purposes. They burn with a clean flame. We also developed simple stoves for burning the briquets.

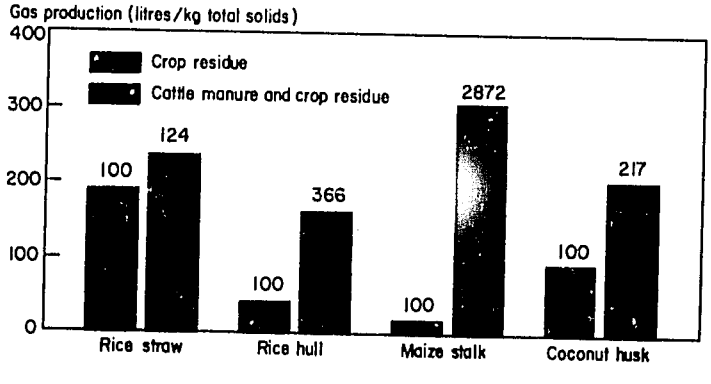
Biogas

We modified the Korean biogas generation system to allow for easy adaptation to local conditions (Fig. 65). Modifications improved gas production and recovery, simplified construction, and reduced investment cost. We also quantified the biogas production potential of rice straw, rice hull, coconut husk, and maize stalk. We found that

- combining animal manure 1:1 with crop residues produces more gas than that from crop residues alone (Fig. 66);
- treating coconut husk by aerobic fermentation for 1 week increases biogas production;
- fresh rice straw alone produces more gas than straw mixed with animal manure;
- substituting azolla or water lily for animal manure is promising -- azolla and rice straw yielded more gas than manure and rice straw; and
- methane bacteria are highly sensitive to substrate pH. They become almost inactive at pH < 5, as observed with ipil-ipil substrate. They also are sensitive to temperature fluctuations.



65. IRRI biogas generation system modified from an earlier Korean design.



66. Comparison of gas production from crop residue and a mixture of crop residue and cattle manure. Figures over the bars represent production index based on pure crop residue.

TH-8 maize sheller attachment

We developed an attachment for the TH-8 axial-flow rice thresher for shelling maize. The thresher can easily be converted to a maize sheller, without using special tools or additional parts, by switching the return valve chute, closing the thrower outlet, and reducing drum speed to 545 r/min.

Machine capacity is 2.5 t/h, with unshelled maize losses averaging 1.6% and breakage averaging 3.4%. Cooperating farmers and grain traders found both figures acceptable.

TECHNOLOGY SHARING

ong before the term technology transfer came into vogue, IRRI was committed to the sharing of research results with and between national programs. In fact, the technology sharing, or transfer, concept is at the heart of IRRI.

Five of our six statements of purpose are directed to that goal. The first purpose, of course, is to conduct research on rice production and management for the benefit of the people of Asia and other areas. The remaining five all relate directly to technology sharing: publish and disseminate research findings, distribute improved plant materials, educate promising young scientists, operate an information center and library, and hold periodic local, regional, or international conferences.

We conducted our first training course in 1964. Since our founding we have sponsored more than 60 international conferences and workshops. We have coordinated international networks such as the International Rice Testing Program and the Asian Rice Farming Systems Network. And we have actively cooperated with national research programs through bilateral collaborative agreements.

In-country rice production training course in Wangdiphodrang, Bhutan.

Last year saw significant changes in our training programs and the expansion of our collaborative work to Africa.

TRAINING

The hallmark of IRRI training programs has always been training of researchers. Theory and practice ensure that our trainees can conduct problem-solving research. Although that has been a successful formula in technology transfer, it has not always permitted the ready tailoring of information and training to the specific needs of various national programs.

Recently we began to teach teaching methods in addition to course content. This will enable trainers to tailor courses to meet in-country needs, whether to train researchers or extension workers who can in turn teach the farmers.

Two trainees from IRRI's first rice production training program visit with a farmer in Bontoc, Philippines

In Bhutan, for example, we are developing an in-country rice production course. The adaptation of the course began in 1984 with the assignment of a Bhutanese scientist at IRRI to work with the Training and Technology Transfer Department to learn the course basics. Then he and his colleagues in Bhutan prepared field materials for the first program while IRRI trainers prepared course materials.

The first course in 1984 was conducted by IRRI staff with support from their Bhutanese counterparts. In 1985 it was conducted jointly, with IRRI serving more of a support role in course evaluation. We have begun a similar program to adapt and transfer a longer rice production course for Burma.

All IRRI courses reflect technology or expertise developed at the Institute, and respond to needs expressed by national program cooperators or recognized by IRRI staff. Of the eight new courses introduced last year, three bear special mention because they illustrate the way training courses are developed.

Genetic resources conservation and management

At a time when many national agricultural research centers are investing large sums in rice germplasm conservation, there is a lack of trained germplasm managers. Because no institution offered training for germplasm managers, IRRI began the Genetic Resources Conservation Management Course in October 1985 with support from the Italian Ministry of External Affairs and the International Board for Plant Genetic Resources.

The course not only provides academic training in botany and plant genetics but gives firsthand experience in field collection, gene bank management and documentation, and evaluation and utilization of crop germplasm.

Statistical procedures and computer applications

In the Third World, as in developed countries, microcomputers have proliferated in agricultural research. The familiar pattern of hardware availability outstripping the availability of trained personnel has manifested itself quickly in developing countries.

The Statistical Procedures and Computer Applications to Agricultural Research Course focuses on practical applications, integrating crop knowledge with statistics and computing knowledge. Trainees undergo a basic rice production course to introduce them to the relevant application of statistics to crop research before proceeding to material on statistics and computing.

System analysis and simulation for rice production

We began a special training program in System Analysis and Simulation for Rice Production in September 1985 with interdisciplinary teams of scientists from seven countries, including a team from IRRI. The course will enable the teams to develop and implement models of crop growth and use these for evaluating production potentials under various 1) environmental conditions, 2) pest infestations and disease incidence, and 3) management tactics.

The course has four phases: 1) in-country identification of problems that can be addressed through simulation modeling, 2) formal course work at Wageningen, the Netherlands, 3) joint studies by the teams in their countries, and 4) a workshop to share research results. The course is being conducted in collaboration with the Centre for Agrobiological Research and the Department of Theoretical Production Ecology, Wageningen, with a grant from the Netherlands.

Editing and publishing

National research programs are developing the knowledge and technology to produce better crops, better health, better quality of life. But Third World research is not always efficiently disseminated because there are not enough trained communicators to interpret and popularize research findings.

The Editing and Publishing Course, sponsored by IRRI and Canada's International Development Research Centre, is for staff engaged in editing and publication at national or related research and extension institutions, or who are responsible for starting such programs. All trainees complete a publication (Fig. 67) that they have revised, edited, designed, and produced during the course.

67. Publications written, edited, and designed by first editing and publishing trainees.

IRRI-NATIONAL PROGRAM COOPERATION

Bangladesh

We plan to increase cooperation in farming systems research with Bangladesh Agricultural University and the Bangladesh Agricultural Research Institute as well as the Bangladesh Rice Research Institute. Bangladesh harvested a record rice crop of 15.2 million tons in 1985.

Burma

Three IRRI scientists worked with Burmese colleagues on the development of early maturing rice varieties and new cropping systems for the different Burmese rice environments, and on the design and adaptation of bullock-drawn farm implements. That work has opened opportunities for two or even three rice crops annually. Burmese scientists attended short courses at IRRI and some undertook graduate training in Canada.

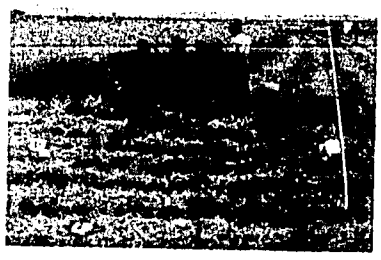
China

A severe epidemic of blast disease, particularly in a single hybrid variety grown on 1.3 million ha, led to increased cooperation with the Chinese Academy of Agricultural Sciences (CAAS) to strengthen resistance breeding and diversify the genetic makeup of hybrids. IRRI continued to cooperate in the development of the China National Rice Research Institute at Hangzhou and the National Germplasm Conservation Center. With Academia Sinica, we cooperated in tissue culture and haploidy research. IRRI initiated new research initiatives with the Chinese Academy of Agricultural Mechanization Sciences (CAAMS) and CAAS on the economics of agricultural mechanization, and with CAAMS on postharvest technology and farm machinery development (Fig. 68). Twenty-five Chinese MS and Ph D scholars studied at UPLB and conducted thesis research at IRRI in 1985; 30 participated in short-term training.

68. Root-washed seedling transplanter developed by IRRI and the Chinese Academy of Agricultural Mechanization Sciences.

Democratic People's Republic of Korea

The Democratic People's Republic of Korea (DPRK) annual food grains production is about 9 million tons. DPRK hopes to increase that to 10 million tons in 1986 and



Machine-harvesting rice on reclaimed tidal lands in the Democratic People's Republic of Korea

15 million tons by 1995. During an IRRI team's first visit to DPRK last year, cooperation was proposed in breeding for early maturity and resistance to blast and bacterial blight, hybrid rice and tissue culture, and tidal wetlands. DPRK will send students to participate in IRRI degree and nondegree training programs, and promote the exchange of scientists, germplasm, and information.

Egypt

Two IRRI scientists in Egypt helped identify IR lines with resistance to Egyptian races of blast. IRRI is participating through an extension liaison scientist in *Mabrouk-4*, a production intensification program with a goal of 10 t/ha (Fig. 69). Plans were made to establish a training center, in cooperation with the Sakha Rice Centre, for other African countries.

69. Research at the Sakha National Rice Institute in Egypt is leading to improved lines and management practices capable of achieving yields of more than 10 t/ha

Indonesia
IRRI and the Agency for Agricultural Research and Development (AARD) planned an upland rice research and training program at the Sukarami Research Center. On-farm management of water use is the focus of a new cooperative irrigation management project covering nearly 250,000 hectares in the Jatiluhur area. The development and local manufacture of implements to streamline the production and postharvest phases of rice farming systems are priorities of the farm machinery program.

Republic of Korea
IRRI cooperation focused on screening for disease and insect resistance and pest monitoring. We evaluated IRRI lines for resistance to bacterial blight and virus diseases, and IRRI and commercial Korean varieties for resistance to blast. Insect studies concentrated on susceptibility of insect pests to insecticides, resistance of Korean and IRRI varieties to white tip rematodes, and biological differences between Korean and Philippine planthoppers. We intensified studies on hybrid rice, anther culture, cold tolerance, rapid generation advance, and seed multiplication.

Malagasy Republic
The IRRI-Malagasy Rice Project was begun in 1984 to strengthen rice research in Madagascar. In 1985 seven scientists were trained in five IRRI training courses and a special basic rice production course was conducted at IRRI. Two hundred twenty-eight introduced and indigenous cultivars were tested in 21 trials at 10 sites.

Pakistan
IRRI and the Pakistan Agricultural Research Council (PARC) jointly undertook a program for biological control of rice pests. IRRI cooperates with the University of Agriculture, Faisalabad, in a joint MS and Ph D educational program. A monitoring tour enabled scientists from other countries to observe recent progress in the control of soil salinity in Pakistan.

Newly transplanted irrigated rice crop in the Antananarivo highland of Madagascar.

Madagascar's per capita rice consumption of 150 kg/year is among the world's highest.

Philippines

IRRI began cooperation in developing a plan for a Philippine Rice Research Institute and in identifying areas of collaborative research. The Philippine Seed Board released IRRI lines as IR64 and IR65. Since 1982 we have held semiannual technology transfer workshops with officials of the Philippine Ministry of Agriculture and Food at IRRI headquarters. In March 1985 we held the first off-site workshop at a Philippine research station and helped to review the Ministry's management recommendations for transplanted irrigated and rainfed lowland rice culture.

Sri Lanka

IRRI and Sri Lanka strengthened collaboration in germplasm collection, rice breeding, weed control, and cropping systems improvement. A joint postgraduate program was developed with the University of Peradeniya. IRRI works with the Mahaveli Development Authority to develop improved rice technologies for 1 million hectares recently brought under irrigation through a well-planned, well-executed large irrigation project.

Thailand

Cooperative research is being intensified in improving yields of rainfed lowland rice, particularly in northeast Thailand, and in saline areas. Improvement of grain quality will help Thailand maintain its lead in the world's export market. A shuttle breeding program was developed to speed the development of deep water rice varieties.

Missions to Africa

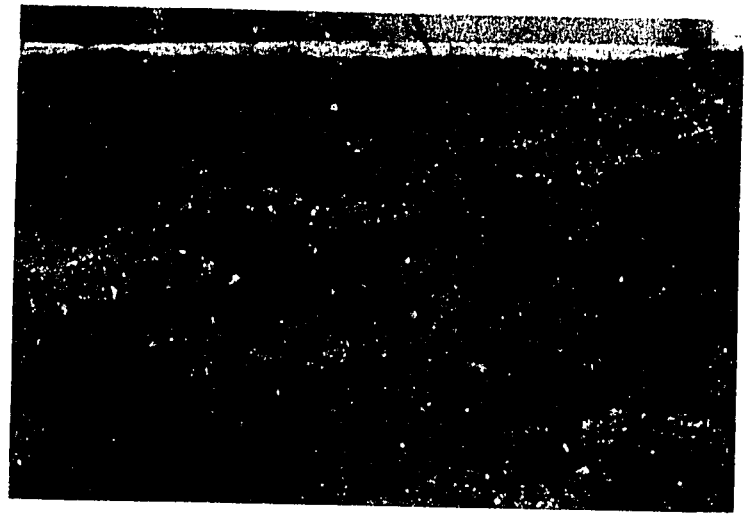
In late 1985 IRRI sent missions to East and Central Africa (Tanzania and Malawi) and West Africa (Guinea, Ghana, and Nigeria) to identify on-farm agronomic constraints (Fig. 70) and ways in which IRRI could help alleviate them; document rice policies that influence research and production; identify opportunities for and the preconditions necessary to establish rice research and production programs, and establish a framework in which IRRI could cooperate with national programs. The International Institute of Tropical Agriculture in Nigeria, the West

70. IRRI and Malawi rice scientists on a field visit to study rice production methods.

Africa Rice Development Association in Liberia, and IRRI entered into a 5-year agreement to implement the recommendations made in the areas of training, networking, and technical assistance.

COLLABORATION WITH ADVANCED INSTITUTIONS

Progress in science and technology is moving so rapidly that no single institution can initiate research in every frontier of science. Collaborative programs allow IRRI to tap *upstream* technology — the scientific expertise and equipment available in advanced institutions in developed countries — to solve the *downstream* problems of small-scale rice farming.



71. The African rices *Oryza glaberrima* sp in this screening test all survived 14 days exposure to green leafhopper infestation. The *O. sativa* variety TN1 did not.

For example, sophisticated measurement techniques and equipment (upstream research) are being used in a Laguna farmer's field to better understand the problem of minimizing the loss of nitrogen fertilizer. Australian scientists from the Commonwealth Scientific and Industrial Research Organization work with IRRI agronomists on the downstream problem.

Similarly, IRRI scientists developed a serology technique that enables rapid and accurate diagnosis of tungro and other virus diseases from dry leaf samples collected in remote areas. The work was made possible by electron microscopes and facilities contributed by the Government of the Netherlands. With the electron microscopes we visually confirmed the presence of the virus — its size, shape, and concentration — throughout the purification process to produce antiserum.

Wild rices and cultivated African (*Oryza glaberrima*) rices are remarkable reservoirs of genetic resistance. Of 49,000 rices screened, only 2.6% of the cultivated vs 53% of the wild rices had green leafhopper resistance. We will put that resistance to use in farmers' fields through *wide hybridization*, or the crossing of wild and domestic rices — the focus of a new cooperative genetic engineering program with the Rockefeller Foundation.

Fifteen IRRI departments had 90 such special projects with institutions and international agencies in developed and developing countries in 1985.

COMMUNICATION AND PUBLICATIONS

The basis for technology sharing is active information sharing. Although we publish almost exclusively in English, we move information into the multitude of languages of our clientele through copublication — a joint effort with national programs and private publishers to publish IRRI materials in local languages. Last year saw the publication of 13 more non-English editions of 10 more IRRI books. We have published more than 800,000 copies of 31 IRRI books in 87 non-English editions.

In 1985 IRRI editors traded in their blue pencils for computers and now edit electronically. Interfacing the computer disks with our phototypesetting unit eliminates redundant keyboarding and allows faster turnaround time in a publications effort that released 22 major books last year in addition to 30 issues of 5 periodicals.

Rice Abstracts

Vitally needed literature bypasses many agricultural improvement agencies in developing countries because they lack the funds to subscribe to international scientific journals. IRRI and the Asian Development Bank are cooperating with CAB International to provide bimonthly subscriptions of *Rice Abstracts* to 1,000 key rice improvement programs in developing countries. *Rice Abstracts* now carries a dual CAB and IRRI imprint. Our Library and Documentation Center provides Chinese and Japanese literature not previously included in *Rice Abstracts*.

Macrophotography-microphotography laboratory

The Eastman Kodak Co. through a USAID grant established a state-of-the-art macrophotography and microphotography laboratory at IRRI and trained five of our staff in the use of the new equipment. Equipment includes a camera for light-scanning macrophotography — one of about a dozen in the world and the only such unit in a developing country.

The macrophotography camera allows us to capture both detail and depth of field in a macrophotograph (Fig. 72), enabling us to take high-quality photos to help rice workers and farmers identify problems of rice such as

72. The scanning macrophotograph of an azolla plant (top) has greater detail than the conventional photograph of the same specimen.

insects, diseases, or weed seeds. We will also provide national agricultural improvement programs with transparencies to use in publications or training. Moreover, the updated photography laboratory will be a training facility for national information specialists.

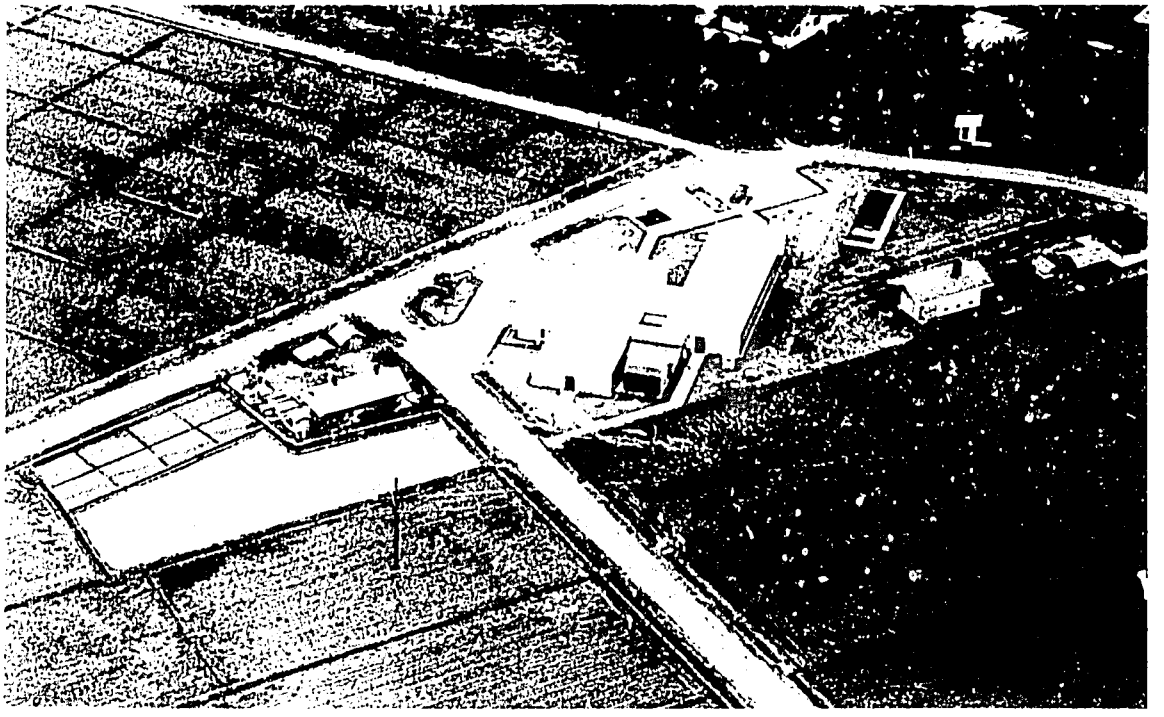
SYSTEMS APPROACH

In the ultimate analysis, net and stable income mean more than yield to South and Southeast Asian rice farming families who typically consist of five or six members on a holding of less than a hectare. Population pressure on land tends to be high in irrigated areas, where there are large numbers of landless agricultural laborers.

Therefore the greatest challenge to rice research and development agencies is to increase the purchasing power of rice farmers by providing them with greater opportunities for skilled on-farm and off-farm employment. In 1983 IRRI joined with other Los Baños institutions and formed, with financial support from the Asian Development Bank, the Prosperity Through Rice Project to:

- demonstrate how to reduce production costs without lowering yield;
- demonstrate ways to optimize employment and income potential of rice farming systems through the most efficient use of land, water, labor, and capital available;
- demonstrate how to make value-added products from the rice biomass--straw, bran, and hull; and
- share with national program officers the best available information on whole-plant utilization and income-maximizing methods.

IRRI's cooperators in this venture are the University of the Philippines at Los Baños, the Philippine Council for Agriculture and Resources Research and Development, and the Forest Research Institute.



73. Aerial view of Prosperity Through Rice demonstration farm

DEMONSTRATION FARM

We do our research and training on a demonstration farm that includes rice-based cropping patterns, livestock, azolla propagation, mushroom culture, compost making, home vegetable gardening, and biogas generation (Fig. 73). In 1985 we studied farming systems components and ways to increase yield at minimum cost, and demonstrated several whole-plant utilization technologies. We experimented, too, with a low cost solar dryer and an improved village rice mill.

Low cost yield-increasing technology

The major components of the rice yield demonstration were varietal choice, timing of crop establishment, nutrient management, pest management, and cropping patterns (Fig. 74).

Varieties used in the demonstration utilized soil N efficiently, were responsive to fertilizer N, and had built-in resistance to pests and diseases, especially to rice tungro

74. In this cropping pattern study a potato crop was intercropped with rice

virus. The crop was established so that it received maximum solar radiation at reproduction and ripening, and escaped major pest and disease pressures.

We increased profits by reducing the fertilizer N requirement 40%. We accomplished this by split applications of N: two-thirds applied basally at planting without standing water, and one-third topdressed 5-7 days before panicle initiation.

We monitored pest populations regularly and held pesticide application to a minimum. Under Los Baños conditions, however, weed management was most economical with commercial herbicides such as butachlor at 0.75 kg ai/ha or 2,4-D at 0.5 kg ai/ha preemergence.

The choice and management of the nonrice crop is critical to ensure high profitability. For the second consecutive year, the rice - rice - off-season tomato pattern gave the highest gross margins of 10 patterns tested. This cropping sequence provided continuous utilization of farmland and generated year-round employment.

75. Mushrooms are grown on a rice straw substrate.

Farming systems and biomass utilization

Two major activities during 1985 were crop intensification and crop-livestock integration. We tried several cropping patterns in an attempt to match harvests with the most favorable local markets for each crop. In addition to three rice crops, we tried fish raising between two rice crops, and two successive rice crops followed by a crop of hybrid corn, sweet corn, or mungbean.

Rice biomass and other crop residues are fed to livestock in an integrated crop-livestock operation that includes cattle, swine, goats, and both broiler and laying chickens.

Some of the livestock manure and crop residues are used to generate biogas or are composted for organic fertilizer. Azolla is also grown as an organic fertilizer, and rice straw used as a substrate in mushroom growing (Fig. 75) ultimately is composted.

We use the rice biomass as a raw material for value-added products as well as for animal feed, compost, or biogas generation. We use rice straw to make paper, and rice hulls to make solid and hollow building blocks, and charcoal, or to fuel crop dryers.

Training

The first Prosperity Through Rice Course was held in January 1985 for 16 senior officers from 9 countries and was repeated in October. The course teaches the concept of a

rice refinery for efficient utilization of the rice biomass, maximization of income and employment through crop integration with livestock and aquaculture, and methods for maximizing production using low cost, farm-grown inputs.

FUTURE WORK

Our experience with the project so far indicates that we should place more emphasis on cropping systems and incorporate new principles into our approach.

- Opportunities for remunerative marketing should guide our choice of multiple cropping and mixed farming systems.
- The impact of new technologies on women requires specific consideration as does the development and testing of technologies for women-specific occupations.
- Human nutrition requirements should be linked to the development of cropping sequences to remedy important nutritional maladies of a region.
- Increased promotion of group endeavor is required to achieve optimum results from integrated pest management, water management, and improved postharvest technology.

Above all, we must continue to develop methods for identifying and alleviating the constraints responsible for the gap between income potential and actual farm incomes in rice growing countries. Higher and more stable income for farming families with small holdings will be the measure of success of both scientists and development administrators.

FINANCES

Summary of financial support to IRRI core and to special and collaborative projects received in 1985.[a]

	US$ (thousand)			
	Core		Spec & Collab. Proj	Total
	Unrest.	Rest.		
Details of sources of support from grants				
United States Agency for International Development	**7,419**	—	1,599	9,018
Japanese Government	—	3,384	427	3,811
International Bank for Reconstruction and Development	2,500	—	—	2,500
Canadian International Development Agency	1,199	—	1,233	2,432
United Nations Development Programme	—	1,570	352	1,922
European Economic Community	—	**1,172**	—	1,172
Overseas Development Administration, United Kingdom	933	—	—	933
Federal Republic of Germany	459	150	75	684
International Development Research Centre	—	215	359	574
Australian Government	571	—	—	571
Government of Italy	145	—	319	464
Asian Development Bank	—	—	421	421
Government of Sweden	349	—	—	349
Government of the Netherlands	—	92	232	324
Government of Saudi Arabia	**300**	—	—	300
International Fund for Agricultural Development	—	**300**	—	300
Government of India	**250**	—	25	275
Government of the Philippines	**90**	—	113	203
Ford Foundation	150	—	48	198
Government of Denmark	172	—	—	172
Government of Belgium	**80**	—	80	160
Office of Rural Development, Korea	—	—	132	132
Government of Mexico	**132**	—	—	132
Government of Norway	102	—	—	102
Government of China	100	—	—	100
Government of Islamic Republic of Iran	—	—	58	58
Swiss Development Corporation	—	206	55	261
Rockefeller Foundation	—	**000**	50	50
Government of Spain	**25**	—	—	25
Government of New Zealand	13	—	—	13
Miscellaneous research grants	—	—	86	86
Funds reimbursed under collaborative research program				
Resource Management International, Indonesia	—	—	89	89
International Food Policy Research Institute	—	—	84	84
International Institute of Tropical Agriculture	—	—	76	76
International Centre of Insect Physiology and Ecology	—	**69**	—	69
International Fertilizer Development Center	—	—	43	43
International Board for Plant Genetic Resources	—	—	42	42
Food and Agriculture Organization of the United Nations	—	—	8	8
United Nations Environmental Programme	—	—	4	4
Total	14,989	7,158	6,010	28,157

[a]Receipts are accounted for on a cash basis. Amounts shown in boldface differ from 1985 pledges from grantors in that they may reflect 1984 pledges received in 1985, or may not reflect the full amount of 1985 pledges, which are anticipated to be received in 1986. The Governments of France (through the research organizations ORSTOM and IRAT) and The Netherlands provided IRRI the services of three resident scientists; the value of their services cannot be quantified.

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