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IRRI HIGHLIGHTS 1984

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INTERNATIONAL RICE RESEARCH INSTITUTE
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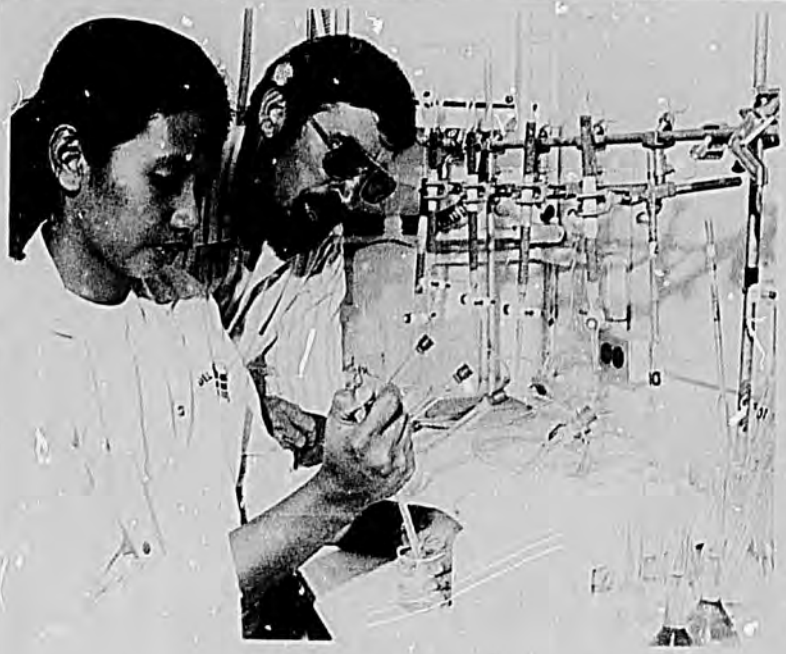
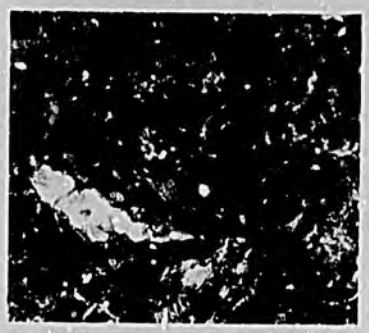




The success of IRRI research and collaborative programs, whether basic or adaptive, depends upon the pride and skill of our researchers, and cooperators in national agricultural systems.

NEW DIRECTIONS

In 1984, as we approach our 25th anniversary, it is important that we evaluate past achievements and look forward to the new directions the current global agricultural situation demands.

When we began, our efforts concentrated upon improving yields and production in the irrigated lowlands of South and Southeast Asia. Through collaborative work with national research systems, short-statured, fertilizer-responsive, pest-resistant varieties were developed, introduced, and widely adopted. The real price of rice to consumers fell and some rice-importing nations became exporters. Confidence in rice research increased, and through training and collaborative research we helped establish a secure foundation for continued improvement of rice production and management.

Ripple bugs (Microvelia) attack brown planthopper larvae when they fall from rice plants into field water.

Our first and most important challenge in coming years is to defend the gains already made. Although many modern rices have resistance to insects and diseases such as brown planthopper, stem borer, tungro, and bacterial blight, pests continue to evolve and change. Our entomologists, pathologists, and breeders must monitor insect biotype development and disease virulence patterns to keep in the development pipeline new breeding lines with a wide spectrum of resistance genes for the time when a new pest causes economic losses.

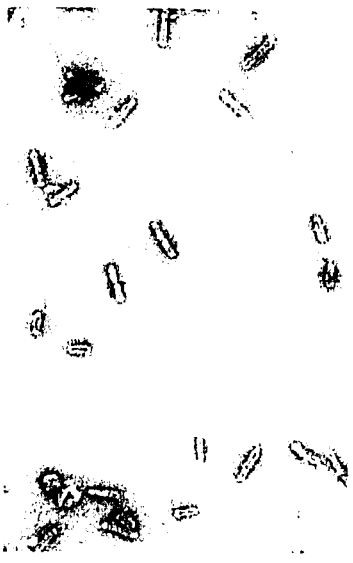
In 1984, we carefully watched planthopper evolution in Indonesian and Philippine fields and observed changes in green leafhopper populations. Virulence patterns of bacterial blight in some countries are substantially different from 5 years ago. Research on tungro, with the help of an electron microscope, has identified different shaped virus particles and particle combinations and related them to disease intensity.

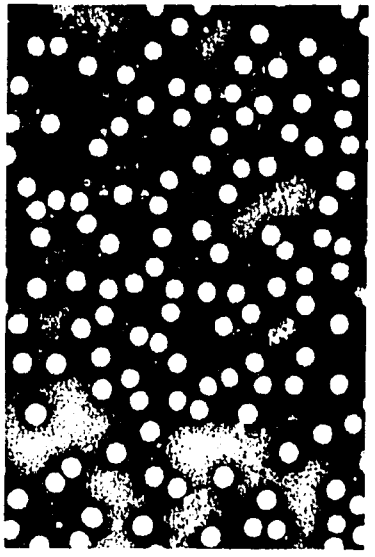
Rices with wider genetic sources of pest resistance and more tolerance to soil and environmental stresses will remain essential to stable and increased yields. Expanding the rice germplasm collection, including the wild rice collection, will broaden the pool from which genes for resistance may be extracted.

Soil stresses such as salinity, aluminum and iron toxicity, and phosphorus deficiency limit yields or prevent useful cropping on large land areas around the world. Rice, often used as a reclamation crop in poor soils, has shown substantial potential for tolerating adverse soils. Soil chemical and soil physical

research are essential to understand tolerance mechanisms and growth patterns that will help researchers develop varieties for areas where rices cannot now survive.

The development and use of low-cost technologies such as organic manuring and cultural methods to encourage growth and multiplication of nitrogen-fixing organisms are receiving increasing attention. These will complement the use of inorganic fertilizers to increase soil nutrients and reduce investments in purchased inputs. To improve the efficiency with which fertilizers maintain and increase yields, we must optimize





Field infected with tungro virus (top). Through electron microscopy, we have identified two tungro virus particles: bacilliform particles (left) and spherical particles (right)

water management to decrease nitrogen volatilization and encourage the use of fertilizer deep-placement and injection machines, and correct timing of applications.

For those countries that have reached self-sufficiency in rice, research into the nutritional value of the rice grain and consumer grain quality preferences is increasingly important. In 1984, we conducted preliminary marketing surveys to identify rice types that consumers prefer and worked with researchers in the United Kingdom and Denmark to quantify the nutritional value of rice varieties and effects of milling on different types of rice grains.

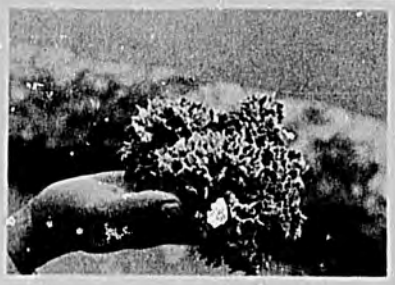
As we work to defend those gains already achieved for favorable rice growing areas, we also must intensify our efforts to find better adapted varieties and management methods for adverse environments and give greater attention to social and equity issues.

We are continuing our efforts to more precisely classify world rice environments. *Terminology for rice growing environments*, published in 1984, is the first step in developing a universal language for rice cultural types and environments around the world. More than 50 rice workers contributed time and ideas to the booklet. We will continue to incorporate additional data and work to fine-tune the terminology.

Breeding and management for adverse environments, in which more than half of the world's rice farmers must survive, are challenging problems to address. In most harsh environments, farms are small, management practices may degrade what are already poor soils, and the economy and market infrastructure are underdeveloped. We are working to develop drought- and submergence-tolerant varieties; simple, low-cost input management practices; and simple machines that will increase yields and cropping intensity while reducing human drudgery.

In these environments, homegrown inputs such as nitrogen-fixing green manure crops and ecologically advantageous cropping patterns may be especially important. Cropping systems projects in disadvantaged areas are answering questions about modern technology adoption and its consequences for farmers, families, and laborers; and establishing a basis for extrapolating new technology to other impoverished areas.

Similarly, we need studies to identify the effect of modernization on the availability of work traditionally performed by women and other landless laborers. Technologies for increasing the income of women farmers and laborers will receive attention under the Asian Rice Farming Systems Network. Research to understand market infrastructure also will contribute to the introduction of better farming methods.



Azolla green manure is used on large areas of rice in Vietnam.

Always, our research must respond to the specific needs of our clients — the national research systems, farmers, and consumers of the rice world.

Three groups of rice-growing nations can be identified. Group I countries have almost no gap between current and potential production and yield. Harvests average more than 4 t/ha. Research for these areas will attempt to raise the yield ceiling, achieve greater yield stability through improved soil and plant health care, intensify cropping, and develop input-output pricing policies that stimulate production and consumption.

In Group II countries, there are technological and socioeconomic constraints to improving yields, which average 2-4 t/ha. These countries require increased support from the major IRRI networks: the International Rice Testing Program, the International Network on Soil Fertility and Fertilizer Evaluation for Rice, and the Asian Rice Farming Systems Network. For Group II countries, such as Burma and Thailand, that export rice, technology will grow in importance.

Many Group III countries, with yields below 2 t/ha, have a large, untapped production reservoir. Some have harsh environments, poor soils, and severe socioeconomic constraints. The first research step for these nations will be multidisciplinary analysis to identify ecological, technological, economic, institutional, and sociopolitical constraints that cause the yield gap. A carefully designed malady-remedy analysis will help formulate short- and long-term research and development strategies. We have recently begun a cooperative program with the Malagasy Republic, using this strategy.

IRRI research programs can be divided into three categories: *maintenance research*, to defend gains already made; *downstream research*, to solve immediate field problems through applied and adaptive research; and *upstream research*, to harness the latest advances in science and technology for solving downstream problems and raising the yield ceiling to a new plateau of stability.

With sophisticated tools such as the electron microscope, the phytotron, interactive computer programs, and satellite imagery, we will seek to understand the intricacies of virus disease development and transmission, climatic influence on rice growth, the social impacts of new technologies, and the interactions of land use patterns and pest populations.

New techniques in biotechnology are helping us to move valuable genes across sexual barriers. For example, by culturing embryos of seeds from a cross of *O. sativa* and the wild rice *O. officinalis*, we successfully grew F_1 hybrid plants that had genes and exhibited traits of both parents. Tissue, anther, and somatic cell culture may speed the development of new rices that perform well in complex adverse environments, such as those where almost every rice crop needs drought and submergence tolerance and may need traits such as photoperiod sensitivity. The new techniques also may reduce for farmers the cost of proven technology such as hybrid rice production.

Anther culture can reduce breeding time for new cultivars, increase selection efficiency, and save space and labor in experimental fields.

S. H. Escudero III, Philippine minister of agriculture and food, addressing the biannual IRRI-Philippines Technology Transfer Workshop.

Essential to our work will be strong cooperation and collaboration with universities and research institutes that have expertise in fundamental studies, state-of-the art instrumentation, and interest in applying their strengths to solving practical problems in rice production. These associations will allow the newest advances in genetic engineering to be applied to rice research

The finest of agricultural science is useless if the results remain inaccessible to extension workers and farmers. Communication of knowledge and skills will remain essential to all our programs. We communicate through degree and non-degree training programs, subject-matter conferences, publications, and person-to-person contact with researchers and extension workers around the world.

Transferring developed and proven training programs and methodologies from IRRI to national programs will place training closer to trainees and permit IRRI to develop new courses. Copublication with book publishers and national programs helps spread information to diverse, non-English speaking audiences. Interactive, computer-aided instruction also will help bridge the language gap. We are continuing to broaden our communications activities and adjust them to the needs of our national cooperators.

These techniques, in combination with constant fine-tuning of cooperative and research programs and the growing inventory of opportunities for increased rice yields and production, will guide our new directions as they have guided our past successes. In agriculture, there is no time to relax. We must continually meet new challenges of plant and soil health care and consumer and market needs. Eternal vigilance and a dynamic response to changing needs therefore are IRRI's guiding principles.

GENETIC EVALUATION AND UTILIZATION

CONSERVING, DISTRIBUTING, AND USING RICE GERMPLASM

Collection activities

Expansion of irrigated farmland and accelerating demand for higher rice production continue to threaten the existence of wild species and traditional varieties that may harbor invaluable genes for diverse insect and disease resistance and tolerance to adverse environments.

In response to recommendations made at the 1983 Rice Germplasm Conservation Workshop, we expanded and accelerated our collection activities. Working with the Inter-

Collecting a rice variety in Bhutan with the help of a village headman.

Collecting rices and interviewing farmers in Bhutan. In the background, harvested rice dries at the edge of terraces.

In Sri Lanka, a Central Agricultural Research Institute team member collects seed of a wild species, O rufipogon.

national Board for Plant Genetic Resources (IBPGR) and national workers, we gathered more than 500 traditional varieties from remote areas and special environments in Bangladesh (103), Bhutan (66), Indonesia (174), Sri Lanka (108), and Malagasy (98).

We now have a rich collection of aus varieties from Bangladesh, and our collection is virtually complete for Sri Lanka and for most accessible, high- and medium-altitude areas of Bhutan.

In response to the urgent need to identify and preserve rapidly disappearing wild *Oryza* species for use in breeding programs, we collected in Sri Lanka 14 populations of *O. rufipogon*, *O. nivara*, *O. officinalis*, *O. granulata*, and hybrid swarms between *O. sativa* and its wild relatives. We also worked with Indonesian scientists and assembled four *O. officinalis* populations from Aceh and Nias Island in northern Sumatra.

In Thailand, we participated in a short training course for field collectors. The course to promote more intensive collection of hill rices was held at the Northern Regional Agricultural Development Center in Chiangmai. The Department of Agriculture and Public Welfare Department staffs have collected 2,996 rice seed samples.

Seed preservation

We found that several stored accessions had lost viability sooner than expected. We used tissue culture to revive seed stock with less than 2% germinability.

Dehulled seeds of 75 accessions were cultured in artificial medium and incubated for 10-25 days in a dark room. Seedlings from 11 of the cultured accessions grew successfully to maturity in the phytotron. Tissue culture may help reconstitute seed stock that might otherwise be lost.

In 1984 we expanded our field area for rejuvenating seed stock for medium- and long-term storage and doubled seed processing for storage. More than 6,000 accessions were sealed in aluminum cans under partial vacuum for safe keeping.

AGRONOMIC AND PHYSIOLOGICAL CHARACTERISTICS

Ratooning

Ratooning, or growing a second crop from established roots and stems after harvest, may increase production per unit area and time and reduce labor costs.

To be productive and economic, the ratooning ability of varieties must be identified and improved and suitable management practices developed. We conducted further exper-

Early ratoon tiller growth

1. Development stages of IR44 ratoon tillers

iments with IR44, which ratoons well, to document biological and cultural factors that affect ratooning.

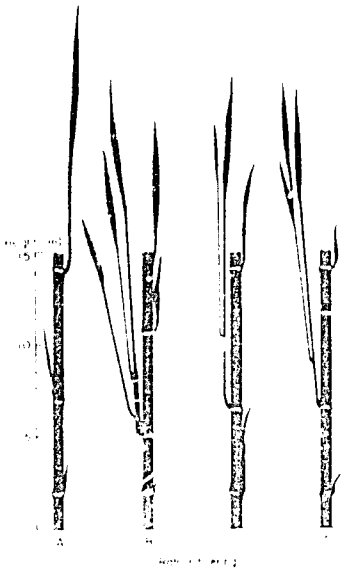
Budding. When IR44 was cut at 15 cm, 4 to 7 nodes were available for regrowth. About 73% of the buds at the lowest node were dead, indicating the importance of leaving ample stubble for regrowth.

At main crop cutting, buds of the first three nodes below the cut did not vary in average length. However, substantial variation began 2 days after cutting. After 6 days the bud at the first node grew fastest and secondary ratoon tillers began to develop (Fig. 1, 2).

The two upper nodes produced the most ratoon tillers, but they tended to break and have poorly developed root systems. They depended on the main crop tiller for support and nutrition. Tillers from lower nodes had more roots and derived nutrients from soil and through old roots.

Regeneration. Tiller regeneration took 1 to 10 days from cutting, but 60% of the plants tillered in 3 to 5 days. Selection for ratooning ability can be based on early tiller development because varieties that take more than 7 days to regenerate tend not to mature uniformly.

Temperature. Tiller regeneration was highest at moderate temperatures (21-29° C), followed by high (27-37° C) and low (20-23° C). High temperatures encouraged ratoon tillering, but



2. Variations in ratoon tillering 10 days after cutting IR44.

because of high sterility yields were low. Low temperatures reduced panicle number and grain yield. Ratoon crops yielded best at moderate temperatures.

Light intensity. Shading before crop cutting was more detrimental than afterward. At 60 and 40% shading from main crop flowering to maturity, 19 and 44% of the plants regenerated, versus 81% without shading.

There was no trend in tiller production in shaded and unshaded treatments, and reduced light intensity before or after main crop cutting did not influence grain yield per plant.

Growth regulators. Rapid, main crop leaf senescence is associated with low ratoon grain yield. Because most carbohydrates are produced during ripening, late leaf senescence promotes carbohydrate accumulation. Using growth regulators to delay main crop senescence could enhance ratoon crop potential.

Applying 100 ppm of the growth regulator Ga_3 15 days after the main crop flowered significantly increased panicle number and ratoon grain yield. Applying ethrel and kinetin did not affect regeneration, tillering, or yield.

Root systems. Root vigor and distribution substantially influenced ratooning. Root dry weight declined from 0 to 14 days after harvest, probably because mother culms and roots supply most of the carbohydrates for initial growth of ratoon tillers. From 14 to 28 days, when new roots develop, root dry weight increased, after which it gradually declined. After 42 days most plants have well-developed white roots from ratoon tillers.

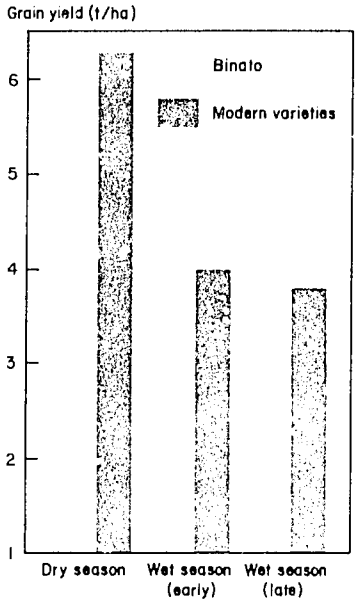
Ratoon tiller development appears to depend on main crop roots for nutrients for at least 21 days after harvest. Thereafter, nutrient requirements were supplemented by new roots.

Seedlings per hill. Planting more seedlings per hill improved plant stand of the ratoon crop and encouraged early ratoon tiller regeneration. Four seedlings per hill gave the highest main crop and ratoon grain yield.

Deep water rices with ratooning ability

In many deep water rice areas, rising floodwater seriously reduces seedling stand and therefore yield. Availability of photoperiod-insensitive, elongating rices with ratooning ability would allow farmers to ratoon a transplanted crop just before flooding, achieve a good stand of deep water rice because the ratoon crop would be well-rooted, and therefore achieve a good harvest.

We obtained 6 outstanding selections (Gowai 50-9, Cholamon 658, Karkati 87, CN691-3, CN658-R-R-R, and CN665-R)



3. Average yield of traditional Binato and three modern rices, 1970-84.

from 118 deep water rices evaluated for ratooning ability. They had consistent high regeneration, good main crop yield, and some lodging resistance.

Individual plants and lines were selected for high ratoon tiller number (≥16), at least 3 leaves/tiller before flowering, and resistance to virus diseases. Further selection was made for immediate and delayed flowering after ratooning.

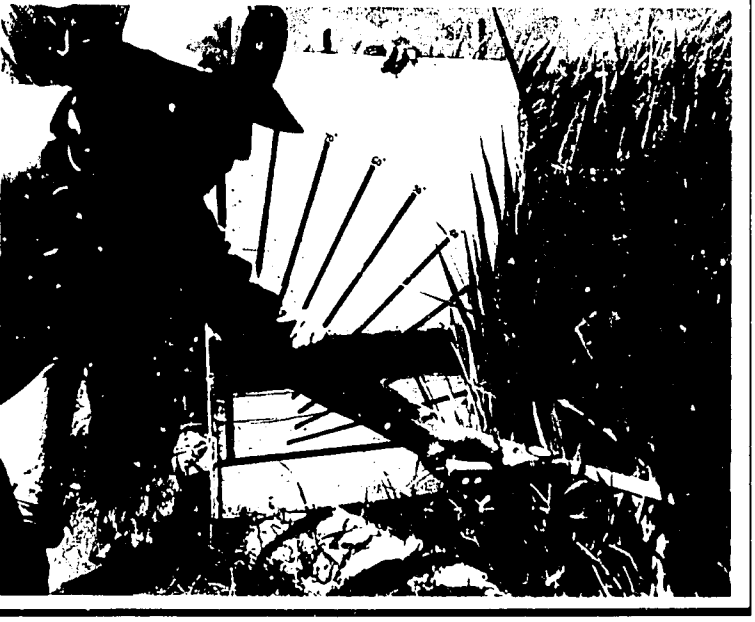
Yield potential of traditional and modern rices

For 14 years we have grown 3 annual crops of traditional variety Binato and 3 modern rices at IRRI to compare yield potential. Nitrogen was applied in split doses and at higher rates in wet season than in dry season. Binato always received 30 kg less N/ha because it is tall and lodges under heavy fertilization, which reduces yields. Binato yielded consistently less than the modern varieties (Fig. 3).

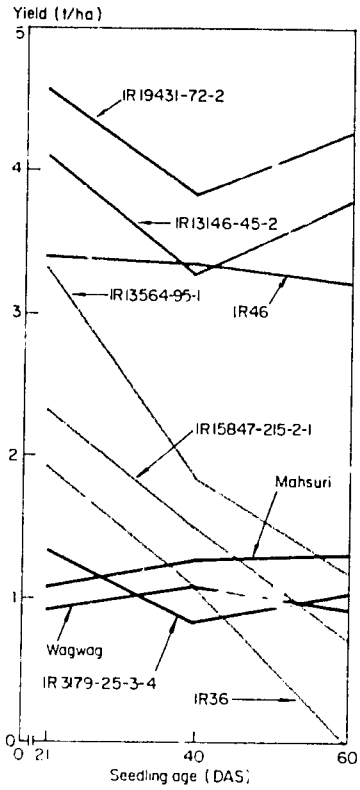
For 9 years in plots without added nitrogen, Peta, another traditional variety, was compared with IR36 and IR42. At Philippine Bureau of Plant Industry experiment stations in Maligaya, Bicol, and Visayas, the modern rices consistently outyielded Peta. IR42 performed best in wet season, yielding 1.0 t/ha more than Peta and 0.4 t/ha more than IR36.

Lodging resistance

Lodging significantly reduces grain yield. We used a push gauge attached to a rigid bar to test culm bending resistance of different rices (Fig. 4). Lodging at ripening stage was observed



4. To measure culm strength, 3 randomly selected center-plot plants were pushed to 30° above the water level with a gauge attached to a 60-cm rigid bar. The resistance, in kilograms, shows culm strength.



5. Some high-yielding genotypes are unaffected by late transplanting.

only in medium maturing rices IR29725-3-1-3-2 and IR31851-6-3-3-3-2. Lodging increased and grain yield declined when more nitrogen fertilizer was applied.

Insensitivity to late transplanting

Because of late water availability, most farmers in rainfed lowlands transplant 30- to 60-day-old seedlings. Late transplanting injures many modern varieties but does not harm traditional, photoperiod-sensitive rices. We have begun research to identify modern photoperiod-insensitive varieties that are not affected by late transplanting. Several high yielding, modern varieties suffered no yield reduction when transplanted at 60 days (Fig. 5).

Weed suppression

Weeds are the most serious constraint to upland rice production. Elite upland rice varieties differ greatly in weed suppression ability. Selection for weed suppression ability may be important in upland variety development. Short varieties tended to compete poorly with weeds, even with hand weeding. Intermediate (100-115 cm) varieties effectively suppressed weeds and yielded well.

GRAIN QUALITY AND NUTRITIONAL VALUE

Grain cracking

Cracked grains cause poor recovery of whole-grain milled rice during processing. Some brown rices, such as IR42, are prone to cracking while others, IR28150-84-3, are not. We found that tolerance to moisture adsorption stress is not simply related to bending hardness of brown rice. We are working to develop a screening method applicable to rough rice to test varieties for susceptibility to cracking.

Weaning food

Extrusion cooking is a convenient way of preparing precooked, rice-based weaning food. Working at the University of the Philippines at Los Baños, we evaluated nutritional quality of milled rice extrudates at different moisture contents and temperatures.

Volume expansion was better with 15% moisture content and 150°C than with 20 and 25% moisture at 120 and 135°C. However, extrudate at 150°C with 15% moisture was less nutritional because it had 11-13% less lysine and 7-8% less net protein utilization in rats than untreated flours.

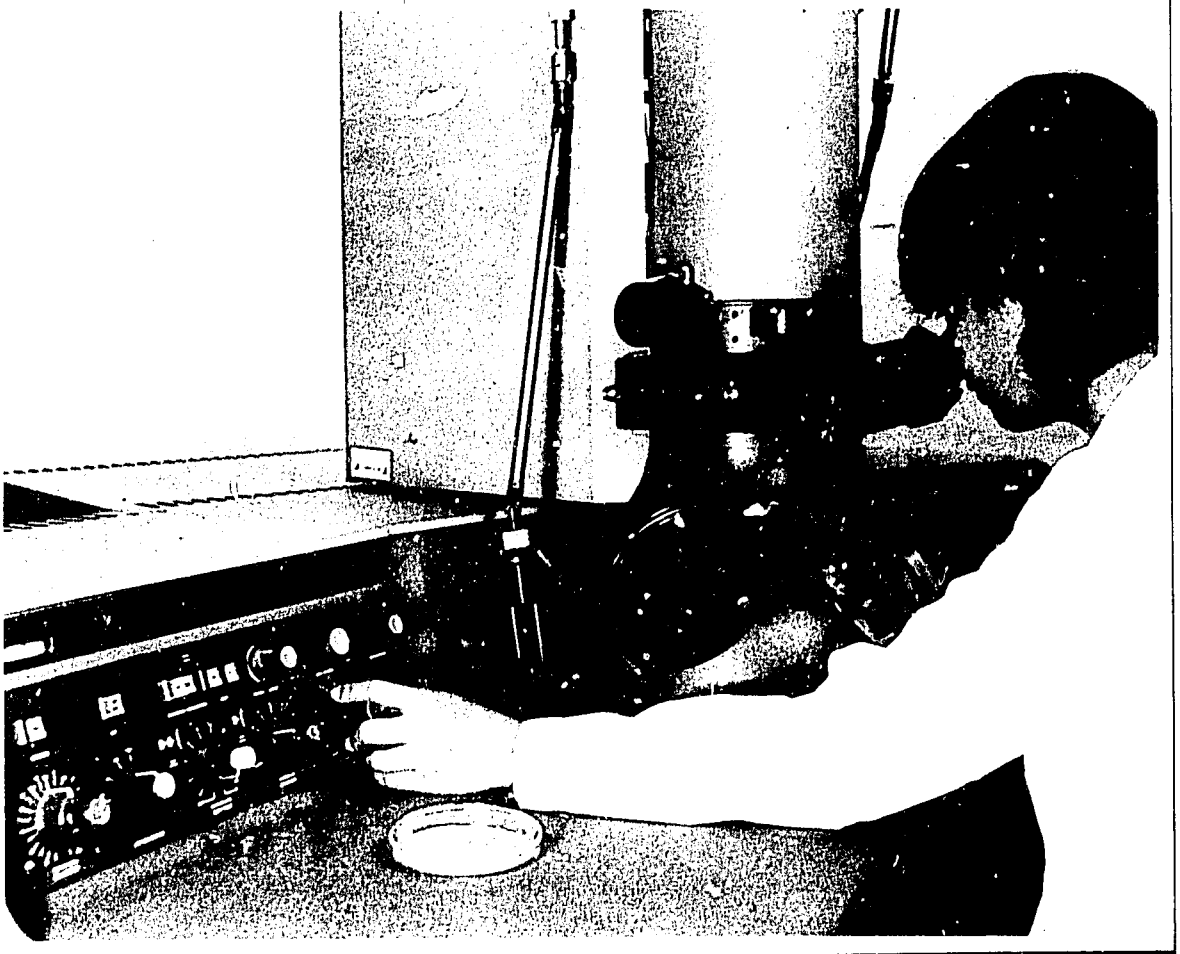
Protein distribution

Rice scientists do not agree on the importance of protein distribution in the endosperm as an index of protein content of milled rice. Cooperative studies with the University of Durham verified that 10% polishing removes 18% of brown rice protein. In rices with relatively low ridges and shallow grooves, brown rice protein content determines protein content after milling because a constant fraction of brown rice protein is lost during milling.

DISEASE RESISTANCE

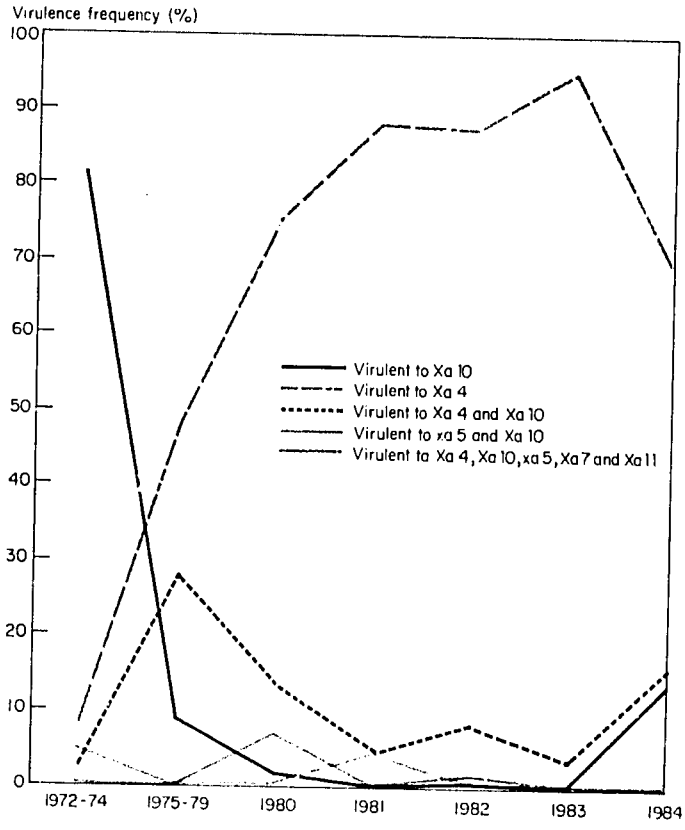
Electron microscope

The Government of the Netherlands provided IRRI with an electron microscope (Fig. 6). The microscope was installed in a new laboratory and began operating in May. The laboratory is equipped with transmission and scanning microscopes, an



6. The electron microscope will help in research to identify viruses, fungi, and soil microorganisms important to rice.

7. Shifting virulence of the bacterial blight pathogen in the Philippines, 1972-84.



ultramicrotome, vacuum evaporator, spatter coater, critical point dryer, and photographic enlarger. It is used in research on rice viral, fungal, and bacterial pathogens; pathogens of rice insects; soil microorganisms; and rice tissues and organs.

Virulence of the bacterial blight pathogen

We evaluated the changing virulence of the bacterial blight pathogen *Xanthomonas campestris* pv. *oryzae* in the Philippines from 1972 to 1984. Virulence patterns are shifting. Since 1983, virulence to the *Xa 4* gene for resistance has decreased from 95 to 70% (Fig. 7).

There was no correlation between changes in virulence and bacteriological properties. Analysis of protein patterns by sodium dodecyl sulfate gel electrophoresis indicated differences in zones A, B, and C within the pathogen. This information provides an additional key for recording the characteristics of races.

Collaboration with Japan on bacterial blight resistance

In our collaboration with Japan on bacterial blight resistance we are developing a set of international differentials for race identification and working to identify additional resistance genes for use in breeding programs.

Susceptible rices IR24, Milyang 23, and Toyonishiki were selected as parents for the backcrossing program and progenies have been developed with specific genes for resistance.

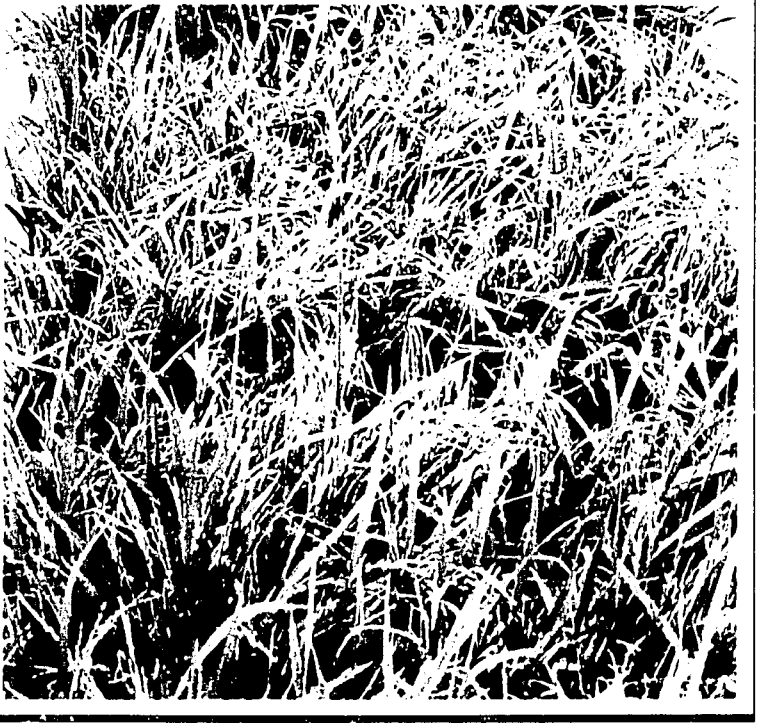
A genetic analysis of Sateng, inoculated at booting, indicated that it has a dominant gene for resistance at adult stage, which contradicts earlier information. In the earlier study, inoculation and scoring were at maximum tillering when heterozygous plants may have a susceptible reaction.

Tests showed the dominant gene is allelic to the *Xa 3* gene for resistance. The *Xa 6* gene, first identified in Zenith, also is allelic to *Xa 3*. Thus, the resistance genes of Chugoku 45, Java 14, Zenith, Sateng, and Cempo Selak appear identical. The gene is closely linked with *Xa 4*.

Varietal resistance to sheath blight

Intensive rice cropping and heavy nitrogen fertilization encourage sheath blight. Absence of stable sources of resistance and effective methods for evaluating varietal resistance has hampered breeding for resistance.

Sheath blight on leaves and in test plots.



Under heavy disease pressure, upper leaves and flag leaves are more seriously affected than sheaths. We developed an evaluation scale that uses leaf damage as an additional character for judging varietal resistance. Screening plots similar to those used for determining resistance to blast were effective for identifying sheath blight resistance, and a nursery of this type is under construction on the upland farm.

Field and greenhouse studies confirmed a relatively high level of resistance in rices Ta-poo-cho-z, RP4-14, Ratna, Kataktara Da-2, Nampungbyeo, and several breeding lines. Through these resistant varieties we are monitoring the population dynamics of the inoculum at different resistance levels in a continuous planting of the same cultivar. This information will help determine the level of varietal resistance that will give adequate disease control.

Chemical and tissue culture studies to determine resistance to brown spot disease

We isolated and characterized a chemical that simulated symptoms typical of brown spot disease caused by *Helminthosporium oryzae*.

Virulent and avirulent isolates produced the toxin, but virulent isolates were several times stronger than avirulent isolates. When the virulent isolate was repeatedly subcultured on a solid medium, it lost virulence and its ability to produce toxin.

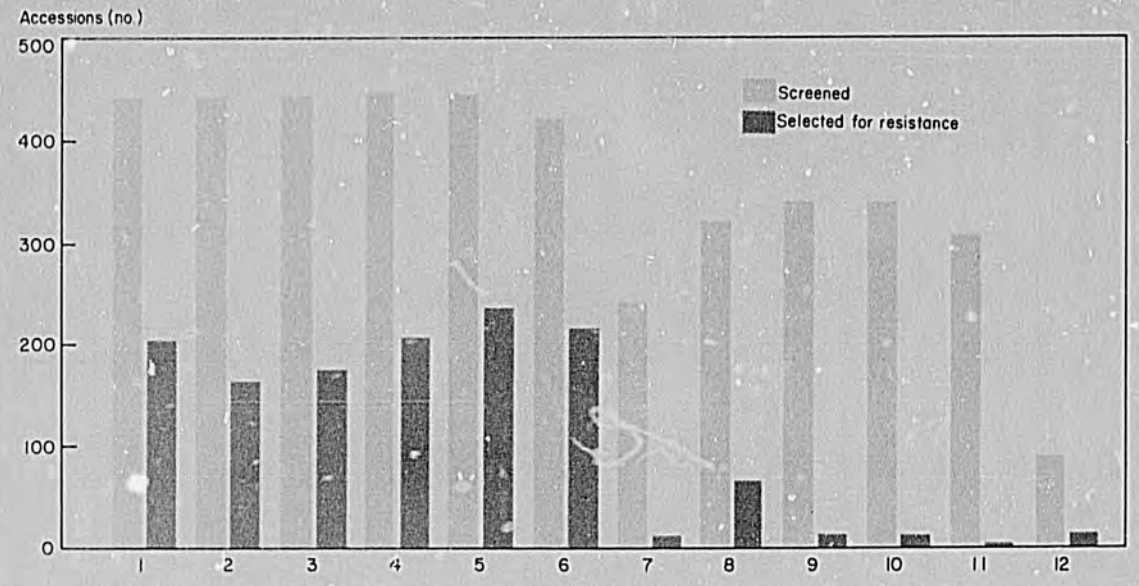
Calli derived from IR8, IR36, and IR54 and whole plants reacted similarly to the toxin and fungus. Calli suspended in liquid medium containing 50% of the toxin for 24-48 hours died, but at 25% concentration some survived. Plantlets regenerated from surviving calli were resistant to the toxin.

Incomplete blast resistance

When resistance is incomplete, the blast pathogen can reproduce on the host. For several plant diseases, incomplete resistance is associated with resistance that is durable in farmer fields. In a greenhouse study, we sought to measure the relative incomplete blast resistance of six rices — IR36, Milyang 30, and Milyang 42 with durable resistance relative to IR50, Milyang 57, and Suweon 264.

When plants were inoculated separately with several *Pyricularia oryzae* isolates, IR36, Milyang 30, and Milyang 42 had fewer and smaller lesions that sporulated less than lesions on the other varieties.

Although not all incomplete resistance will be durable, the varieties we studied had higher incomplete blast resistance in those with longer lasting resistance.



8. Number of wild rice accessions in the IRRI germplasm collection with insect resistance. 1-3 = *N. lugens* biotypes 1, 2, and 3; 4 = *Sogatella furcifera*; 5 = *Nephotettix virescens*; 6 = *Recilia dorsalis*; 7 = *Chilo suppressalis*; 8 = *Scirpophaga incertulas*; 9 = *Cnaphalocrocis medinalis*; 10 = *Hydrellia philippina*; 11 = *Nymphula depunctalis*; 12 = *Stenchaetothrips biformis*.

INSECT RESISTANCE

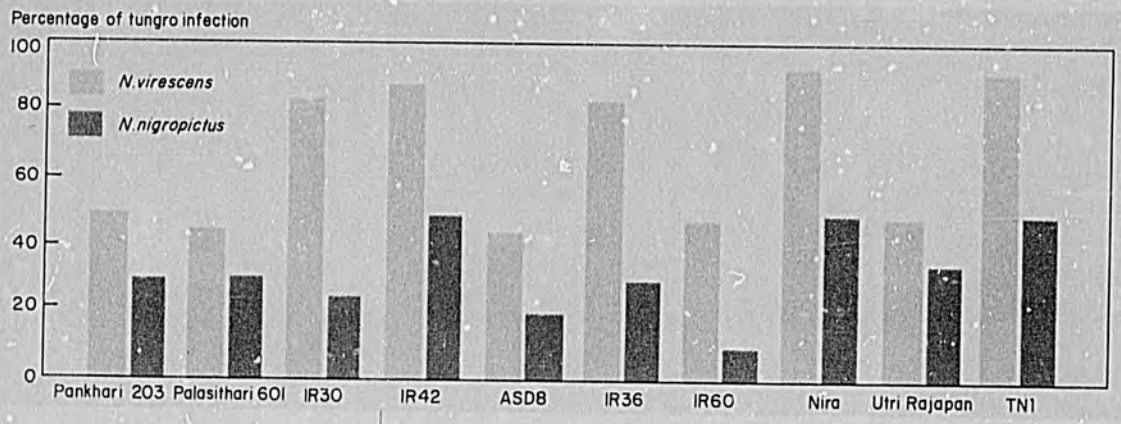
Sources of insect resistance

In the IRRI germplasm collection, we have found *Oryza sativa* varieties resistant to 12 insects. More than 1,200 accessions are resistant to *N. virescens* and 400 have resistance to biotype 1 of brown planthopper *Nilaparvata lugens*. We did not find sources of resistance to caseworm *Nymphula depunctalis* and rice bug *Leptocorisa oratorius*, and we identified only one variety with moderate resistance to whorl maggot *Hydrellia philippina*.

We also evaluated the wild rice collection for sources of new genes for resistance and for sources of resistance that were not found in the *O. sativa* collection. About half the 450 wild rices evaluated are resistant to planthoppers and leafhoppers. Seven accessions are highly resistant to whorl maggot (Fig. 8). The resistance genes of these wild rices is being incorporated in agronomically superior *O. sativa* lines.

Nephotettix nigropictus and *Nephotettix virescens* as tungro vectors

We compared the efficiency of green leafhoppers *N. nigropictus* and *N. virescens* as tungro vectors. Both leafhoppers were caged on rices with high and moderate resistance to *N. virescens*. Although both transmitted tungro, infection was highest with *N. virescens* (Fig. 9). Of the IR varieties tested, IR60 was most resistant.



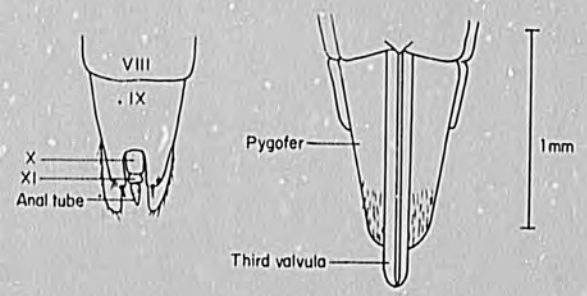
9. Percentage of tungro infection in rice cultivars, each infested with one pair of viruliferous *N. virescens* and *N. nigropictus*.

Cross virulence of green leafhopper biotypes

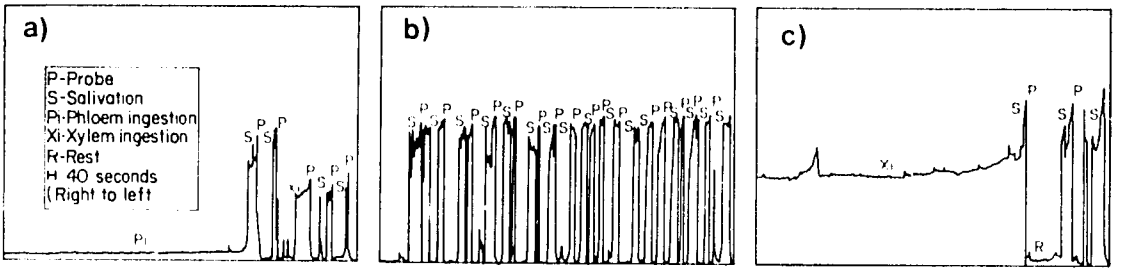
After 10 generations of rearing on resistant IR8 (with *Glh 3* gene for resistance), a green leafhopper colony that was virulent to IR8 evolved, as indicated by plant damage, insect survival, and population growth. When the colony was tested on other rices with the *Glh 3* gene, virulence to IR24 had significantly increased, but not that to other varieties.

Morphometric variations between green leafhopper biotypes

Different reactions of resistant rices to green leafhopper *N. virescens* in Bangladesh and the Philippines may indicate that they are different biotypes. We compared the morphometric variations of green leafhopper populations from the two countries. Significant differences were observed in male and female genital, abdominal, and tarsal characters (Fig. 10) of both color morphs, one with black-spotted tegmen and the other with uniformly green tegmen. For example, the 11th abdominal segment is significantly wider in spotted and nonspotted leafhopper males from Bangladesh than in those from the Philippines. Rostral and antennal characters also were significantly different between *N. virescens* populations.



10. Abdominal terminalia of green leafhopper male (left) and female (right).



11. Waveforms recorded during green leafhopper feeding on susceptible TN1 (a) and resistant Pankhari 203 (b, c) rice varieties

Rearing green leafhopper

We developed a rearing method to provide large numbers of the green leafhopper *Nephotettix nigropictus* for use in identifying sources of resistance. Of the rices and weeds tested, rice variety Nira was the most suitable green leafhopper host. Placed on 4-day-old Nira seedlings, 50 pair of green leafhopper will produce 3,000 to 5,000 individuals in a 20-day generation.

Feeding behavior of green leafhopper

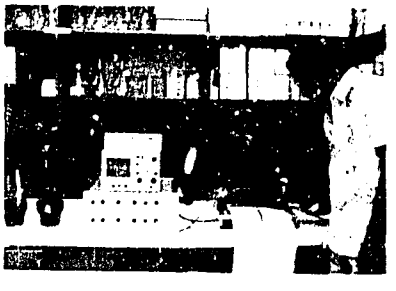
We used an electronic recorder to monitor green leafhopper feeding behavior on seven rices with genes for resistance (Pankhari 203, ASD7, IR8, Ptb 8, ASD8, IR36, Moddai Karuppan), highly resistant IR29, and susceptible TN1. Waveform patterns indicated the leafhopper was primarily a phloem feeder on susceptible TN1, but fed on xylem on resistant plants (Fig. 11). The insect made more brief, repeated probes on resistant varieties than on TN1, but differences in mean duration of salivation did not correlate with resistance.

Feeding behavior of brown planthopper biotype 3

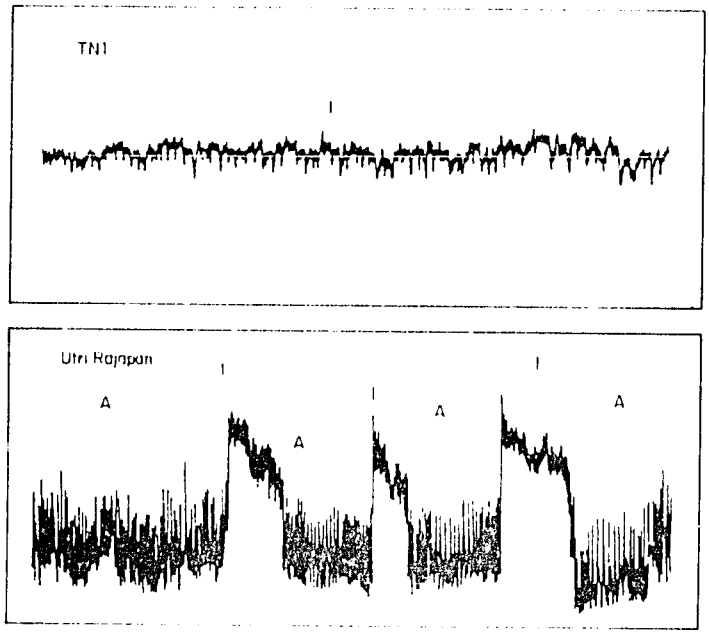
To determine the mechanisms of resistance, we are studying the feeding behavior of brown planthoppers on rices with moderate resistance to all planthopper biotypes. Utri Rajapan has low seedling resistance, but resistance increases with age.

We electronically recorded (Fig. 12) the feeding of brown planthopper biotype 3 on 10- and 40-day-old plants over 3 hours. Ingestion time was determined by the length of the ingestion waveform on the recording paper.

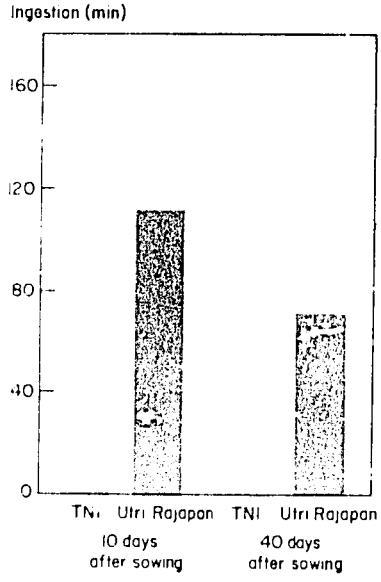
On susceptible TN1, planthoppers fed most of the time. Feeding time on Utri Rajapan was much shorter (Fig. 13). On 40-day-old plants, ingestion period was 73 minutes on Utri Rajapan versus 137 minutes on TN1 (Fig. 14). On Utri Rajapan, planthoppers spent most of the time probing and salivating rather than ingesting the phloem sap.



12. Postdoctoral fellow R. Velusamy electronically measuring brown planthopper feeding behavior



13. Feeding behavior of brown planthopper biotype 3 on susceptible TN1 and moderately resistant Utri Rajapan. Ingestion by waveform I is continuous. Waveform A shows interrupted feeding.

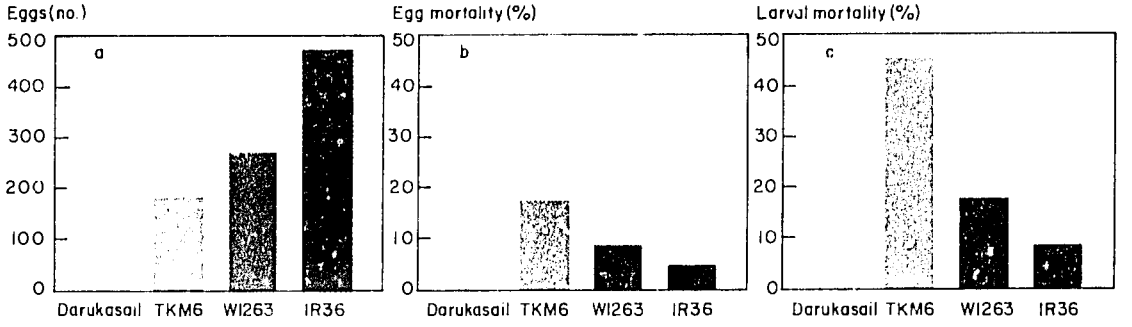


14. Brown planthopper biotype 3 spent less phloem-ingestion time on moderately resistant Utri Rajapan than on susceptible TN1.

Locating leafhopper and planthopper eggs

We developed a simple technique for finding insect eggs on rice plants. Plants exposed to gravid females are bleached in boiling water for 5-7 minutes, kept in 95% ethanol for 3 days, and transferred to a 1% aqueous acid fuchsin solution for 2 days, after which they are thoroughly rinsed in water. The stained hopper eggs are located by examining leaves and stems under a 20X binocular microscope (Fig. 15).

15. Acid fuchsin-stained green leafhopper eggs in cleaned rice leaf tissue.



16. Mechanisms of leaffolder resistance a oviposition preference b mortality of eggs dipped in a 3,000 ppm extract from the indicated variety c mortality of larvae feeding on leaves dipped in the extract

Chemical bases of leaffolder resistance

More than 100 rices in the germplasm collection have resistance to leaffolder *Cnaphalocrocis medinalis*. Some varieties have been used as donors of leaffolder resistance in IRRI's breeding program. We found that resistant rices contain chemicals that repel ovipositing moths and cause egg and larva mortality.

Leaffolder moths laid fewer eggs on resistant Darukasail, TKM6, and W1263 than on susceptible IR36 (Fig. 16a). When eggs were dipped in extracts of those varieties, the Darukasail extract caused the highest mortality (Fig. 16b). When leaves of a susceptible rice were dipped in a 1,000 ppm oil extract of resistant and susceptible varieties and fed to leaffolder larvae, extracts of resistant varieties caused greater mortality (Fig. 16c).

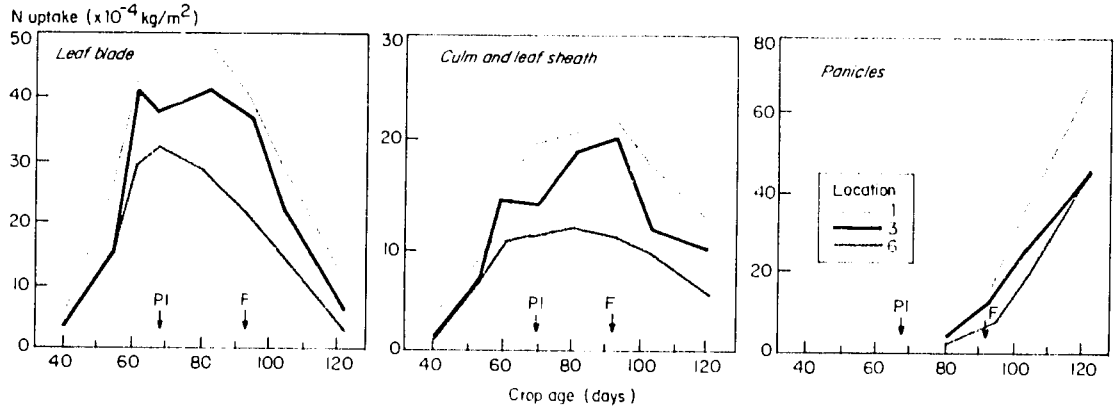
DROUGHT RESISTANCE

Water stress and nutrient uptake

Water stress limits nutrient uptake. We quantified nitrogen, phosphorus, and potassium uptake by IR58 in dry season. IR58 was grown in a lowland field at different irrigation levels provided by a line-source sprinkler. Locations 1 (flooded control), 3, and 6 received 89, 54, and 0 mm applied water.

IR58 continuously accumulated nitrogen, phosphorus, and potassium in leaf blades until about 13 days after flowering, after which leaf accumulation declined. Maximum nutrient uptake was during flowering, and continued to maturity.

Comparing plants from locations 1 and 6 showed that water stress depressed nutrient uptake by about 40% in leaf blades and 14-40% in culms and leaf sheaths (Fig. 17, 18, 19). Nitrogen and potassium uptake were least affected by water stress. At maturity, panicles of stressed plants had 25-43% less of the nutrients than plants in the control.



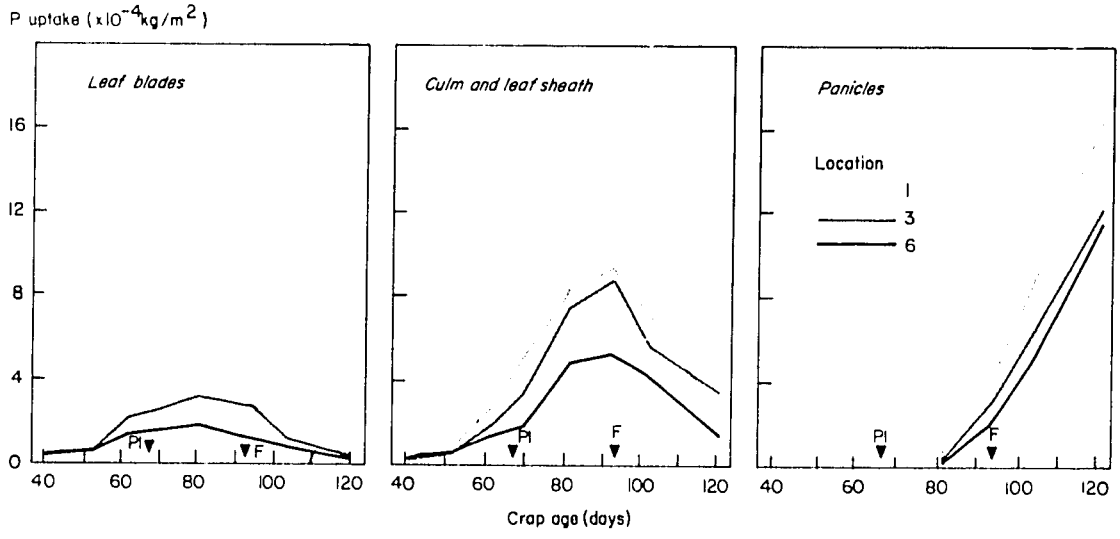
17. Nitrogen uptake of IR36 plant parts at different irrigation levels, as determined by location. PI = panicle initiation, F = flowering.

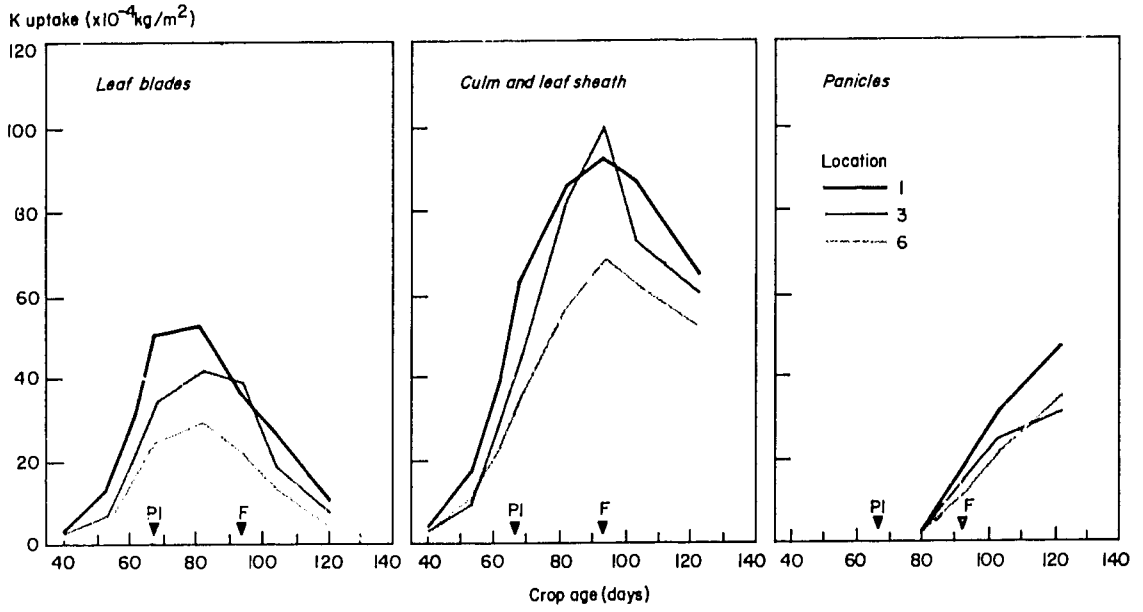
Root response to water stress

In 1984 dry season we studied the response of IR54 roots to water stress under simulated lowland conditions. The adverse effects of water stress on root growth were greatest at 0-10 cm soil depth.

In the flooded control at that depth, root length density and root mass density increased linearly with time. At line-source sprinkler locations 3, 5, and 6, root length density increased, then decreased at maximum stress. Root dry weight responded similarly. Although reflooding reduced soil strength and increased root length density, the negative influence of earlier stress continued to affect crop growth.

18. Phosphorus uptake in IR36 plant parts at different irrigation levels, as determined by location. PI = panicle initiation, F = flowering.





19. Potassium uptake in IR36 plant parts at different irrigation levels, as determined by location. PI = panicle initiation, F = flowering.

Increased soil mechanical impedance decreased root length density. Soil mechanical impedance as low as 0.05 MPa inhibited root growth and values greater than 0.3 to 0.5 MPa consistently decreased root growth and extension by 25%, thereby limiting efficient water and nutrient uptake.

Drought-tolerant rices

Of 6,165 rices screened for drought tolerance, IRRI variety IR18349-22-1-2-1-1, Habiganj Aman II from Bangladesh, and ITA119 from the International Institute of Tropical Agriculture in Nigeria (Fig. 20) performed admirably during vegetative growth. They had only slight leaf tip drying when soil moisture tension at 20 cm was 5 bars, and half the leaves had 25% leaf length desiccation at 10 bars. All three recovered at rewatering. Tolerant checks Salumpikit and IR442-2-58 had 25 and 50% dry leaves at 5 and 10 bars and 80% stand recovery.

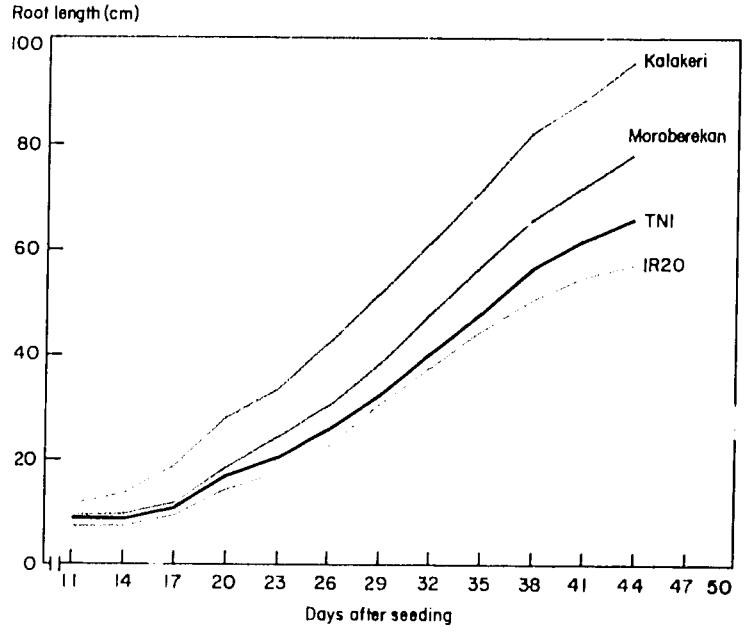
20. Three outstanding rices of 6,165 entries screened for drought tolerance.

IR18349-22-1-2-1-1 and IR20

Habiganj Aman II

ITA119

21. Rate of root growth development of rices grown under aeroponic culture.



Root growth

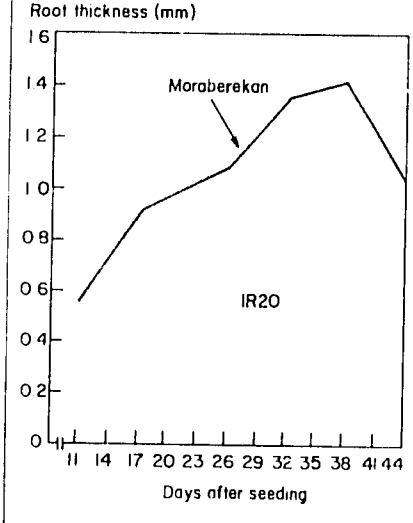
Rapid root growth is vital to rice's ability to compete with weeds and to avoid water stress at early growth. We studied root growth patterns of one dual-purpose, five upland, and seven lowland varieties under aeroponic culture.

Lowland BPI-76 root growth began 14 days after seeding and length continued to increase rapidly until 38 days after seeding. Roots of most lowland varieties did not grow significantly until 20 days after seeding. Upland varieties Kalakeri, RN21, and Kinandang Patong, and dual-purpose Dular had significant root growth at 17 days. Upland varieties Moroberekan and Palawan began lengthening at 20 days.

Significant differences in root length developed 20 days after seeding (Fig. 21). Up to 40 days, roots of upland varieties usually grew faster than those of other rices.

Moroberekan and IR20 had significantly different root diameter 11 days after seeding (Fig. 22). Diameter increased most from 17 to 26 days after seeding. Moroberekan roots reached maximum diameter (1.44 mm) at 34 days and IR20 (0.86 mm) at 29 days. Upon reaching the maximum, diameter declined but length, branching, and root hair growth rapidly increased, thereby expanding the nutrient and water absorbing surface.

Our findings further confirm that deep- and thick-rooted plants can be readily selected from segregating progenies at 21 days after seeding.



22. Development of root diameter of Moroberekan and IR20 in aeroponic culture.

ADVERSE SOILS TOLERANCE

In 1984, our selections and tests for adaptability to adverse soil conditions emphasized soil problems common to unfavorable rainfed environments. Although we tested 13,438 rices for soil toxicities and nutrient deficiencies, the bulk of our effort was to identify lowland rices suited to coastal saline soils and upland rices adapted to acid soils.

Salinity

Of 7,658 rices tested from the salt tolerance and general breeding programs, 1,477 tolerated salinity. Outstanding among them were IR5657-33-2, IR9884-54-3, IR9764-45-2, and IR10206-29-2, which yielded nearly 3 t/ha in unreclaimed coastal saline soils in the Philippines.

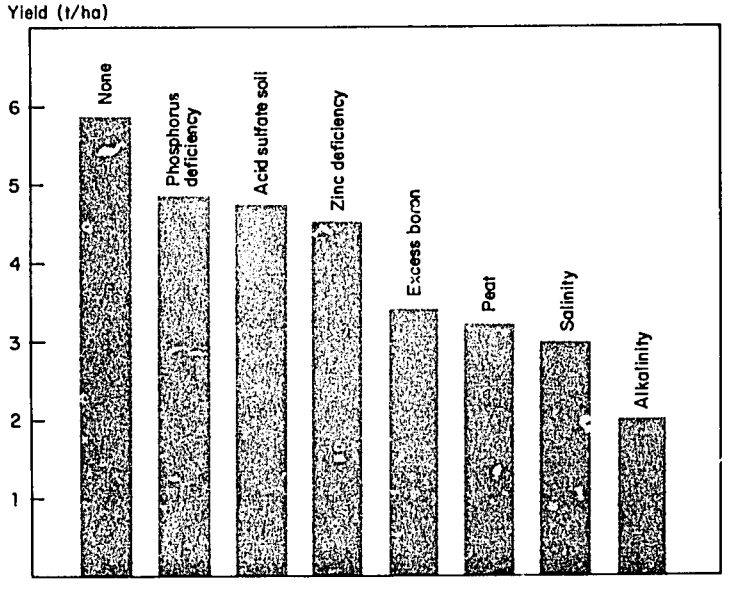
Acid uplands

Of 224 rices screened, 10 were tolerant of acid upland conditions. IR43, IR6115-1, and IR12721-24 yielded more than 3 t/ha in farmer fields.

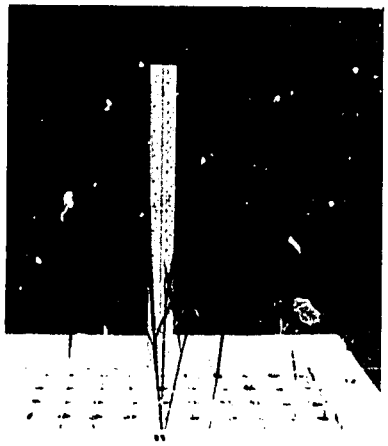
Multiple soil stresses

The remarkable tolerance of IR8192-200 and IR9764-45-2 for salinity, alkalinity, acid sulfate soil conditions, iron and boron toxicity, excess organic matter, and phosphorus and zinc deficiencies was confirmed in field trials (Fig. 23).

Both lines have good agronomic characteristics and resistance to common rice pests. Their multiple soil stress tolerance



23. Dry season yields of IR9764-45-2 on some unamended problem soils.



Screening for salt tolerance.

will enable small farms in unfavorable rainfed environments to obtain moderate, stable yields without cash inputs.

Efficient use of phosphorus and zinc

Efficient users of soil and fertilizer phosphorus and zinc are varieties with growth duration exceeding 120 days. Varieties that mature in less than 113 days are poor users of these nutrients. Most early varieties respond well to phosphate fertilizers but not to zinc.

Physiological studies of salt tolerance

Calcium has an ameliorating effect on plant growth under saline conditions. We studied the effect of calcium on seedlings of salt-susceptible IR28 and salt-tolerant Nona Bokra grown in a salinized nutrient solution containing 0.5% NaCl and CA^{++} ion concentrations of 4, 100, and 200 ppm.

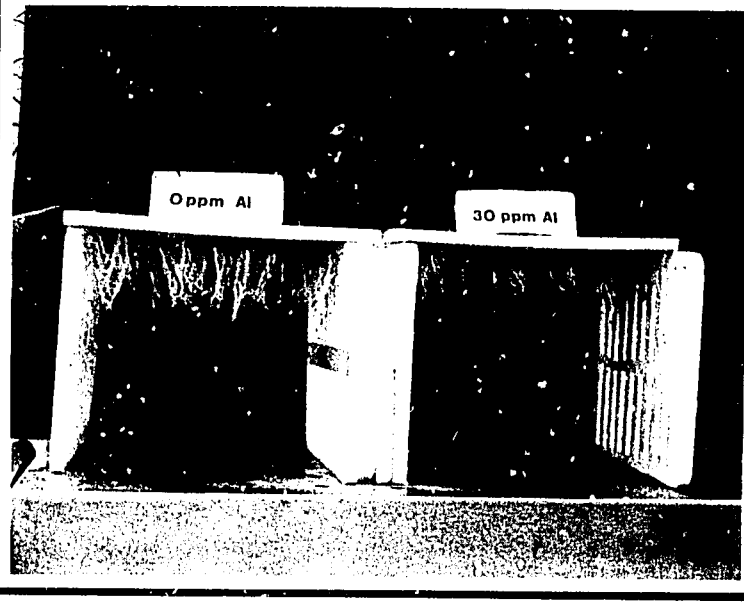
Different calcium concentrations had little effect on survival of IR28, but more Nona Bokra plants survived at 40 ppm Ca^{++}.

IR28 absorbed more salt than Nona Bokra and adding calcium did not decrease the translocation of salt ions from root to shoot. Nona Bokra appeared to tolerate high salinity by regulating salt uptake and by low salt and calcium accumulation. Adding calcium increased tolerance of Nona Bokra.

Screening for tolerance of aluminum toxicity

We screened 352 rices from the 1983 International Upland Rice Observational Nursery and the 1983 Acid Upland Soils Screening Set for tolerance of aluminum toxicity. Seedlings were

Comparison of roots of anther culture-derived plants grown in 0 and 30 ppm aluminum solutions.



grown in nutrient solutions with or without 30 ppm aluminum. After 2 weeks, we measured root length.

Seven percent of the entries were tolerant. IRAT104, Azucena, IR5853-196-1-P_1, and IR7812-16-1-4 were outstanding.

Screening R_3 variants for tolerance of aluminum toxicity

We selected 46 aluminum-tolerant and 5 aluminum-susceptible R_2 seedlings derived from a Taichung 65 callus and grew them until maturity. The 51 R_3 variants harvested were screened for tolerance of aluminum toxicity in 0 and 30 ppm aluminum solutions.

The variant lines TNV C-9-2-1-A-1, TN II 5-8-2-A-1, and TN II 5-7-1-1-C-4 were highly tolerant. All variants except two were more tolerant of aluminum than Taichung 65.

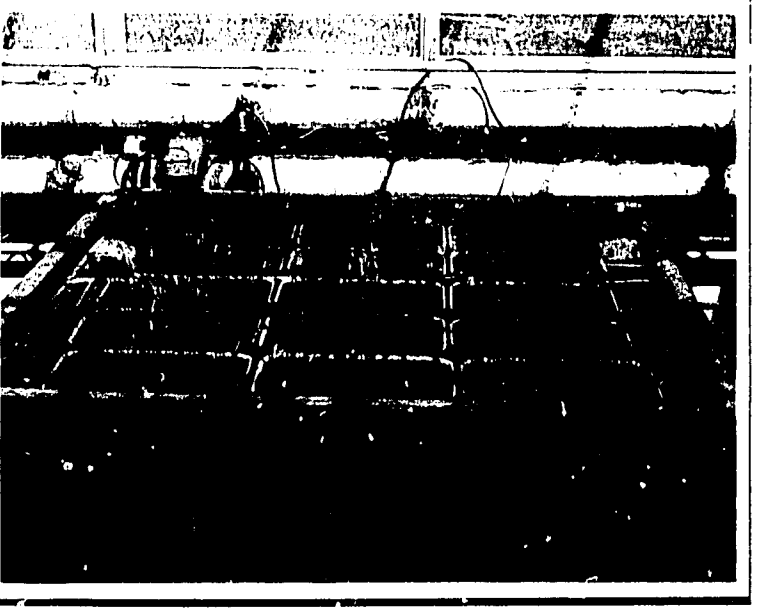
ADVERSE TEMPERATURE TOLERANCE

Korea-IRRI collaborative project

This is the seventh year of the Korea-IRRI Collaborative Project on Rice Cold Tolerance. In 1984, eight experiments were conducted at Chuncheon, Korea.

Cold tolerance screening nursery

More than 1,100 entries from different sources were screened at the cold water gradient facility for earliness, spikelet fertility, leaf discoloration, phenotypic acceptability, and short growth duration. Among the outstanding entries nominated to observational yield trials were IR9202-25-1-3, IR13155-60-3-1-1-3-



Cold tolerance screening of anther culture-derived lines at seedling stage.

2, IR13155-60-3-1-1-3-2-3-2, IR15889-113-3, IR18476-86-3-1, IR18476-86-3-3, IR18476-108-1, Ta-San-Bir-Co, YR1654-16-1-2-4-B-2, and YR2404-15-4-9-3.

Observational yield trial

In the observational yield trial, highest yields were obtained from the indica/japonica varieties Pungsanbyeo (Iri 346) and Samgangbyeo (Milyang 55). In the Korean rice production contest, Samgangbyeo yielded 10 t/ha.

IR8866-30-3-1-4 gave top yields in 1983 and 1984 in Korea and Banaue, Philippines. IR5716-18-1, IR23325-R-R-B-7-3-1, and IR8866-30-3-1-4 should be useful in low temperature areas where intermediate plant height is preferred and nitrogen application is low.

Plant type for high yield at different nitrogen levels

We found that tall, lodging-susceptible varieties such as China 988 and IR7167 performed well at low nitrogen levels. They have high 1,000-grain weight and relatively high harvest index at 75 kg N/ha. Rices Manseokbyeo and Taebaekbyeo responded well at higher nitrogen applications. They have short stature and lodging resistance.

Nutrient uptake and use at low temperatures

We found that 20 days of low temperature during vegetative stage greatly inhibited nitrogen, potassium, phosphorus, and silicon uptake. Even at heading, the effect of 18°C temperature treatment showed in lower dry weight and nutrient uptake.

Screening for high temperature tolerance

In some parts of Pakistan and northern India temperatures of 35°C and above seriously reduce spikelet sterility and yield. Screening for high temperature tolerance has identified the following tolerant rices: Chianung sen yu 13 from China, IRAT127 and IRAT128 from Malagasy, SKL 17-67-11 and UPR251-101-2 from India, IR10198-66-2 and IR19746-28-2-2 from IRRI, and Ghraiba from Iraq.

INNOVATIVE BREEDING METHODS

Wide hybridization

Several *Oryza* species are highly pest resistant and tolerant of abiotic stresses. Although it is easy to transfer useful genes from some closely related wild species to cultivated rice, those species with nonhomologous genomes are extremely difficult to cross with cultivated rice. Even if F_1 hybrids are obtained, there is little pairing and recombination of chromosomes

Plants of a wild rice species, a cultivated variety, and a cross of the two.

belonging to different genomes. In 1984, we began work to transfer useful genes from *O. officinalis* and *O. australiensis* to *O. sativa*.

Eighteen *O. officinalis* and four *O. australiensis* males were crossed with three brown planthopper susceptible *O. sativa* females. Seed set ranged from 0.5 to 30%, but seeds were imperfectly developed and began aborting 14 days after pollination. Embryo development was normal but the endosperm degenerated.

The 14-day-old embryos were excised and cultured on growth medium. Embryo germination varied from 33 to 88% in different F_1 hybrids. Young seedlings were planted and 450 hybrid plants grew. The F_1 plants were intermediate between parents in some respects but had many traits of the wild parent. They were generally robust and extremely vigorous, but male sterile.

Most F_1 plants were diploid. However, five F_1 hybrids from a

cross of IR1529-680-3-2 and *O. officinalis* were triploid. The diploid and triploid hybrids were backcrossed to cultivated parents. Seed set was 0-8% in diploids and 0.5-2% in triploids. Nevertheless, some well-formed seeds germinated to produce healthy seedlings. Some of the backcross progenies, especially from triploids, are expected to have the full chromosome complement of cultivated rice and one or two alien chromosomes.

The alien addition lines will be screened for brown planthopper resistance, which will permit identification of *O. officinalis* chromosomes that carry genes for planthopper resistance. We will then try to transfer small chromosome segments with those genes to *O. sativa* by radiation treatments.

Physiological bases of heterosis in hybrid rice

Yield and components at different spacings. In studies of yield and growth characteristics of F_1 hybrid rices, heterosis for grain yield was high at wide spacing because of many spikelets and high grain weight. Little heterosis was apparent in filled spikelet percentage and panicle number.

Panicles were largest at close spacing and most abundant at wider spacing, always producing more spikelets than the parents. Based on average grain yield, optimum spacing may be between 20 × 20 and 30 × 30 cm.

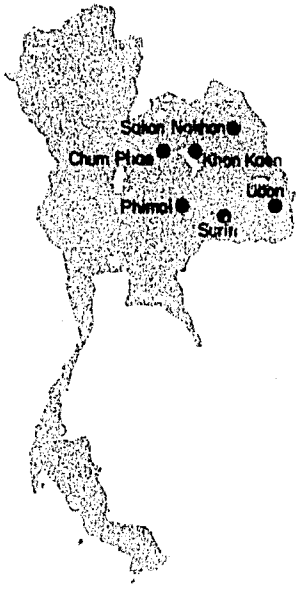
Roots. F_1 hybrid roots produced more dry matter and were heavier than those of their parents. However, dry matter partitioning into roots was less than for their parents. Per plant α-naphthylamine oxidation was higher for F_1 hybrids than for their parents.

Population improvement

Progress in breeding for traits that are under complex genetic control or are linked to undesirable traits has been slow because standard breeding methods are limited by small population size and the low number of parents included in crosses. Population improvement can partially overcome such obstacles.

In 1978, a genetic male sterile mutant of IR36 was developed by induced mutation. Since then we have used the IR36 mutant to develop random mating populations for specific breeding objectives such as high yield; improved grain quality; rainfed lowland adaptation; tolerance to drought, adverse soils, and submergence; and blast and stem borer resistance.

After three generations of random intermating, the bulk populations are ready for selection. They can be handled as a composite cross by the modified bulk breeding method, or can serve as a random mating population and source of desirable



24. Pedigree nurseries for the Thailand-IRRI Collaborative Breeding Project are grown under rainfed lowland conditions at six rice research stations in northeast Thailand

traits. We have initiated recurrent selection programs in some populations to develop germplasm sources for national programs.

Shuttle breeding

For breeding objectives that involve conditions not present in the Philippines, IRRI has used shuttle breeding in collaboration with national programs. Crosses are made and F_1 hybrids are grown at IRRI, but F_2 populations are grown at a national breeding station. Local scientists and IRRI breeders make plant selections, and the resulting F_3 seeds are grown at IRRI for off-season generation advance and screening. The resulting F_4 selections are returned to the national program where the process is repeated.

Using shuttle breeding, we are working with the new China National Rice Research Institute at Hangzhou to develop short-duration varieties with disease and insect resistance, superior grain quality, and photoperiod insensitivity.

It is difficult to breed higher yielding varieties for the rainfed lowland conditions in northeast Thailand because of the many traits required for the drought and submergence prone area. Additionally, the necessity of photoperiod sensitivity limits to one per year the generations grown at one location. Our shuttle breeding program with the Thailand Rice Research Institute began in 1982. The F_2, F_4, and F_6 generations are grown in northeast Thailand under lowland conditions (Fig. 24). By growing a December-seeded, off-season pedigree nursery at IRRI we have doubled the generations obtained per year.

Anther culture

In 1984 collaboration with the Office of Rural Development, Korea, we emphasized development of cold-tolerant lines through anther culture. Although not all the F_1 hybrids could be cultured, 4 of 13 crosses produced enough plants for cold tolerance studies.

We screened 607 anther culture-derived lines from 5 crosses for cold tolerance at seedling stage. Twenty-two lines, including AC608-1 (Taipei 309/Tatsumi Mochi) and AC 1166 and AC 116-4 (Tatsumi Mochi/BG90-2), exhibited strong cold tolerance characteristics. The 22 lines have been included in field screening for cold tolerance in Korea.

We screened 48 entries from Tatsumi mochi/BG90-2 for aluminum toxicity tolerance. Fifty percent were more tolerant than Tatsumi mochi, the most tolerant parent, and one line was more tolerant than the resistant check. In the reciprocal cross, five of six lines screened were more tolerant than Tatsumi mochi.

Isozyme studies of anther culture-derived lines confirmed that regenerated plants originate from pollen and not from maternal tissues.

Replicated yield trials of promising anther culture-derived lines were conducted in Egypt and Korea. Of 6 lines from 4 F_1 crosses, 3 yielded higher than the mid-value of the parents, with 1 line yielding almost 13% more than the parents.

Somatic cell culture

Reiho and Nona Bokra rices regenerated from long-term calli that were subcultured 12 times at 4 week-intervals. Seed-derived calli of Reiho and Norin 10 kept on salt-enriched medium for 30 months also produced plantlets.

Three of 98 lines regenerated from 4 IR varieties were resistant to the *Helminthosporium oryzae* toxin.

One hundred forty-four somatic culture-derived progenies of IR36 were evaluated for salt tolerance at seedling stage. Although three showed somaclonal variation for increased salinity tolerance, further tests for stability are needed.

COMPUTERIZED DATA MANAGEMENT

In 1984 there was a sharp increase in the volume of requests for information retrieval from IRRI scientists and collaborating national programs. The germplasm master file was converted

Computer use at IRRI continues to sharply increase.

from sequential to random access to enhance the speed and flexibility of information retrieval and data processing, and the Interactive Germplasm Bank Information Retrieval System was made more user-friendly.

We continued to update GEU data files, adding 4,147 registered accessions of *O. sativa* to the germplasm bank master file and 3,477 IR crosses to the history-of-crosses file. Data were updated on 18 GEU traits used for selecting 24,318 early generation lines from 145,339 tested in 1984.

We completed preparations for printing the *Parentage of IRRI crosses IR1-IR50,000.*

INTERNATIONAL RICE TESTING PROGRAM

The International Rice Testing Program (IRTP) promotes the efficient exchange and evaluation of elite rice germplasm. In 1984, 24 international nurseries were composed, 13 of which were for target environments. A new nursery was composed to assess yield performance of upland rices with early and very early (115 day) duration for upland rainfed environments with short growing seasons. Eleven nurseries emphasized selection for disease and insect resistance, adverse soils tolerance, and low temperatures. The new International Rice Whitebacked Planthopper Nursery already has provided important information on varying genotype response at different locations.

Nursery results

The 1983 nurseries included about 2,500 entries. Several new lines performed exceptionally well (Table 1), and many are being used in the breeding programs of cooperating nations. In 1984, national programs released several IRTP entries, bringing the total released to 77. The entries originated from 15 countries and were released in 37 countries.

Monitoring tours and workshops

An international workshop on Rice Improvement in Eastern and Southern Africa assembled for the first time rice scientists from these countries as well as from IRRI and the International Institute of Tropical Agriculture. Methods for cooperation to solve common problems were developed. A monitoring tour of rice research and production in Zambia and Tanzania followed the workshop.

A second monitoring tour covered rainfed lowland rice research at stations in eastern India and Bangladesh, and 10 scientists evaluated IRTP germplasm and the national rice research programs in a team visit to Central America and northern South America.

Table 1. This list includes more than 200 rice cultivars that performed well in many sites in 1983 IRTP tests. Data from the tests were submitted by scientists at test sites and analyzed and summarized at IRRI.

Nursery	Promising lines
	Yield - Irrigated
IRYN-VE (Very-Early)	• IR25924-51-2-3, UPR103-80-1-2, BG367-4, IR25588-7-3-1, IR50, IR25925-84-3-2, IR9729-67-3
IRYN-E (Early)	• KAU1727, IR18348-36-3-3, IR13540-56-3-2-1, C1322-28, IR21015-80-3-3-1-2
IRYN-M (Medium)	• BG400-1, IR19672-140-2-3-2-2, IR21820-154-3-2-2-3, IR28118-138-2-3, ITA212
	Yield - Rainfed
IURYN (Upland)	• UPL Ri-7, BR319-1, IR5931-110-1, UPL Ri-5, IR12721-24-3-1, IR43, IR6023-10-1-1, IR9782-111-2-1-2, UPL Ri-3
IRRSWYN (Shallow Water)	• IR19431-72-2, BR4, IR13146-45-2-3, RP975-109-2, Cisadane, IR10781-75-3-2-2, IR14632-2-3, IR4819-77-3-2
	Observational - Irrigated
IRON	• Chianung sen yu 26, IR18349-135-2-3-2-1, IR28128-45-2, C662083, IR28128-45-3-3-2, IR29692-65-2-3, IR9698-16-3-3-2, Chianung sen yu 13, IR18349-22-1-2-1-1, IR24632-145-2-2-2-3, IR28154-101-3-2, IR18348-36-3-3, IR21015-80-3-3-1-2
IRARON (Arid Region) (only one test, Sakha, Egypt)	• GZ1028-4-2-2, GZ1077-24-1-2, GZ1077-7-1-3, GZ948-2-2-1, GZ944-5-2-2, GZ951-7-1-2, Reiho
	Observational - Rainfed
IURON (Upland)	• Medium duration, intermediate/tall stature B2997C-TB-60-3-3, B3623G-TB-41, IR3646-13-3-2, Salumpikit • Medium duration, short stature UPL Ri-7, C1019-1, IRAT140, IRAT13, C894-7, IR3179-25-3 • Short duration, intermediate/tall B3619C-TB-8-1-4
IRRSWON (Shallow Water)	• IR21567-18-3-1, IR21037-2-1-2E-P1, IR54, IR21567-18-3, RP975-109-2, IR4829-89-2, IR15853-89-7E-P3, IR21567-16-3, BR51-282-8, IR10781-75-3-2-2, IR21836-90-3, IR21056-9-P2
IRDWON (Deepwater)	• BKNFR76014-1-9-2, SPR7292-151-2-1-B-B, BKNFR76014-1-9-3, TCA180-4, DWCB-B-715-1, RD19, IR11141-6-1-4
IFRON (Floating Rice)	• Habiganj Aman II, HTAFR77043-2, Leb Mue Nahng III, HTAFR77068-2, HTA7426-5-0-1-5, IR4935-K103-0-2-0, SPRC72-357, SPR7233-44, SPR7228-7-1-2-1-0, SPR7282-2-0-4-2, SPR7282-2-0-7, SPR7290-9-1-1-0
ITPRON (Tidal-Prone Rice)	• BKN6986-1, BKN6986-108-2, B3333C-PN-104-2-1-1, B3333d-163-3, Chato, Chato Aristado, CNM539, CN540, Mahsuri

Table 1 continued

Nursery	Promising lines
	Stress Screening
Temperature	
IRCTN (Cold)	• HPU5010-P1-21-2-13, China 1039, IR13155-60P-3-1-2-1, K31-163-3 (Khudwani), IR22623-R-R-4-2, RP1442-4-6-1-1, IR24312-R-R-19-3-B, Barkat (K78-13), IR9202-6-1-1, Wase-toramochi
Heat Tolerance	• Chianung sen yu 13, IRAT127, IRAT128, IR10198-66-2, IR19746-28-2-2, IR50, SKL17-67-11, UPR251-101-2
Problem Soils	
IRSATON (Salinity and Alkalinity)	• Salinity CSR4, C100, C2, C7 PNL5-30, PNL36-184-3-2, IR14632-22-3, IR4630-22-2-17, IR4630-22-2-5-1
Acid Upland	• Azucena, ITA142, IRAT104, ITA235, ITA116
Acid Lowland	• IR2153-26-3-5-2, IR2797-125-3-2-2-2, IR42, IR4227-109-1-3-3, IR44, IR5741-73-2-3, IR9129-136-2, Khao Dawk Mali 105, MRC172-9
Diseases	
IRBN (Blast)	• Carreon, Tetep, Suweon 300, #5287, Ta-poo-cho-z
IRBBN (Bacterial blight)	• BR161-2B-59, IR13423-17-1-2-1, BR319-1-HR38, IR18348-36-3-3, BR40-300-2-1, IR21820-154-3-2-2-3, BR51-282-8, IR21848-65-3-2-2, Chianung sen yu 29, IR22082-41-2, Chianung sen yu 31, IR25840-64-1-3
IRTN (Tungro) (only one test - Indonesia)	• BR51-331-4-HR28, CNM539, Gam Pai 30-12-15, IR13429-299-2-1-3, IR13524-21-2-3-3-2-2, ARCC11554, IR19743-46-2-3-3-2, IR19774-23-2-2-1-3, IR21015-3-3-1-2, IR24637-38-2-2-1, IR25586-36-1-2, IR25586-82-1-2, IR29, IR30, IR9209-48-3-2, IR9729-67-3, Kachamota, Naria Bachi, RP1476-24-3-1-4-1, TNAU658, TNAU9426-7, TKM9, UPR103-80-1-2, Utri Rajapan (Acc. 16684)
Insects	
IRBPHN (Brown Planthopper)	• BG367-2, BG379-2, IR13427-40-2-3-3, IR19661-23-2-2, RP1756-121, IR27325-111-2-1, Rathu Heenati, PTB-33, ARC6650
IRWBPHN (Whitebacked Planthopper)	• ASD8, IR17307-11-2-3-2, HAU2-165-3-3, IR17492-18-6-1-1-3-3, IR2035-117-3, ADR52, IR13458-117-2-3-2-3, PTB19, IR15529-253-3-2-2-2, Rathu Heenati (Acc. 11730), IR15795-151-2-3-2-2, Sinna Sivappu (Acc. 15444), IR15797-74-1-3-2
IRSBN (Stem Borer)	• BPT1235, IR46, IR15314-43-2-3-3, IR46, IR29, IR17494-32-1-1-3-2, IR9288-B-B-52-1, IR9752-71-3-2, IR38, Tainung sen 12
Rice Thrips	• Dudmona (white), Heenati 662, Duhunala 2220, Kalubalawee (Acc. 36264), Kaluwee 715, Mudukinal 783

INTEGRATED GEU PROGRAM

IRRI rices named in six countries

In 1984, 6 national programs named 10 IRRI breeding lines as varieties.

- IR930-67-2-2 is a high yielding line with long, slender grains. It was released in Bihar, India, as Sita.
- IR1347-45-2 is a short-duration variety with multiple pest resistance, including resistance to all known brown planthopper biotypes. It was released in Pondicherry and Tamil Nadu, India, as PY3. Its popular name is Bharathidasan.
- IR2053-261-2-3 was named DR83 in Pakistan and released for general cultivation in Sind Province. It has excellent grain quality and can be planted late.
- IR2058-78-1-3-2-3 was released as IR46 in Indonesia. It has been released in Brazil, Cameroons, and the Philippines.
- IR8423-132-6-2-2 was released as CR203 in Vietnam for cultivation on the Red River Delta.
- IR13543-66 was released in Indonesia as Kelara. It has high yield potential and is resistant to all known brown planthopper biotypes.
- IR13525-43-2-3-1-3-2 was released as IR62 by the Philippine Seed Board. It matures in 115 to 120 days and has multiple pest resistance, including all known brown planthopper biotypes. It has excellent grain quality and high yield potential.
- IR19746-11-3-3 was released as CN2 in Vietnam. It is very early maturing and grows well in intensive cropping systems.
- IR21836-90-3 was named Hmawbi 2 in Burma. It has long, slender grains and high yield potential.
- IR21841-91-2-3-3 was named Hmawbi 3 in Burma. It is a long-duration variety with excellent grain quality.

Upland rice

Diallel crossing. We have made 5 sets of 8 × 8 diallel crosses to determine the dominance of plant characters important to upland environmental conditions. F_1 seeds were sown in lowland and upland conditions to compare their performance. Promising medium-height, early maturing, high-tillering plants with high per panicle grain potential were identified from the progeny of crosses from E425, Dular, N22 (A), IRAT10, IRAT109, IAC1132, ARC10372, MTU17, and Bateswar 2.

Acid-upland screening. A new upland site at Caliraya, Philippines, was found suitable for identifying varieties adapted

Evaluation of upland rice varieties and lines.

to soils with low pH; low nitrogen, potassium, and phosphorus; and high aluminum saturation. Heavy leaffolder infestation revealed a wide variability in resistance.

The first screening of 340 varieties and lines revealed the adaptability of aus varieties from Bangladesh and some varieties from Thailand. Kinandang Patong was highly adaptable and tolerant of leaffolder infestation. Moroberekan was highly adapted but susceptible to leaffolder.

Adverse environments

We continued our efforts to test rices developed for deep water and adverse soil conditions in farmer fields. Sites were selected for their location among farmers eager for improved rices for difficult environments and for the presence of an agency with a mandate for assisting those farmers.

Solana, Philippines. We tested 150 lines in submergence and drought-prone farmer fields of Solana. Twenty lines were evaluated in farmer-managed yield trials.

Iloilo, Philippines. We are working with the Philippine Ministry of Agriculture and the University of the Philippines at Iloilo on Panay Island to test breeding lines for salinity tolerance, zinc deficiency, iron toxicity, and flooding.

We planted 1,026 lines in 5 salinity trials at 3 sites. About one-third of the rices performed well. Of several hundred deep water rices planted in fishponds near Iloilo City, only two survived an unusually sudden flood in November 1984.

Thailand. We exchanged several hundred breeding lines with the Rice Research Institute and the Department of Land Development of Thailand for testing in saline, phosphorus-deficient environments.

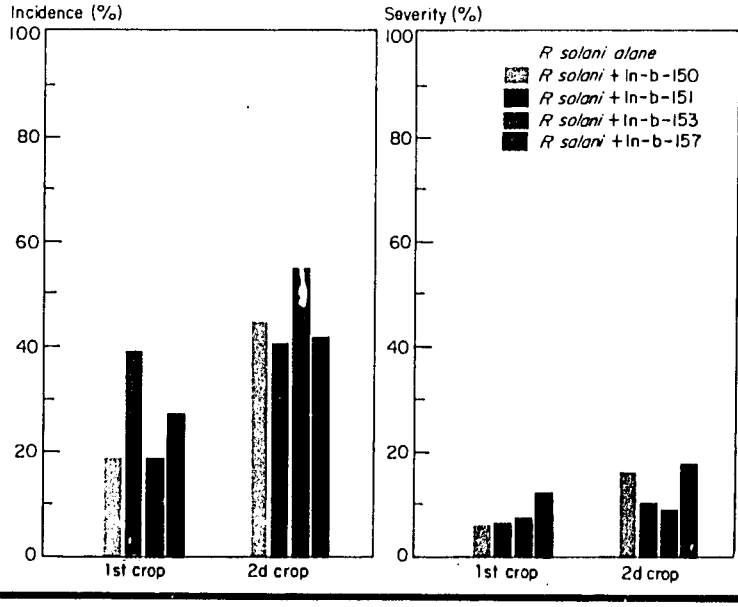
CONTROL AND MANAGEMENT OF RICE PESTS

DISEASES

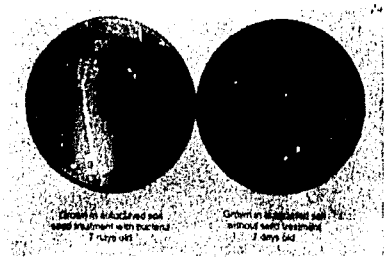
Sheath blight control

Sheath blight, caused by *Rhizoctonia solani*, is an important rice disease. Sclerotia are a primary source of inoculum. In 1983 we found that fluorescent *Pseudomonas* and nonfluorescent bacteria isolated from *R. solani* reduced sclerotia viability and sheath blight infection.

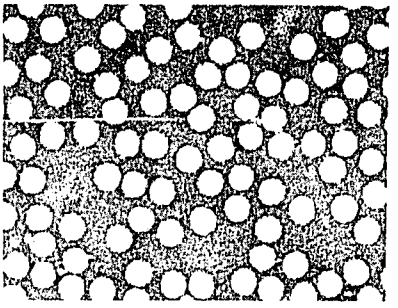
Further evaluations show that treating IR36 seed with the bacteria promotes plant growth and reduces disease incidence and severity (Fig. 1), even in a second crop, with untreated seeds, planted in the same soil. Bacterial growth from plant prints on agar medium indicated that bacteria could establish themselves on the plant surface and inside the leaf sheath after seed treatment (Fig. 2). The number of bacteria in soil planted with bacteria-treated seeds was higher than in that without.



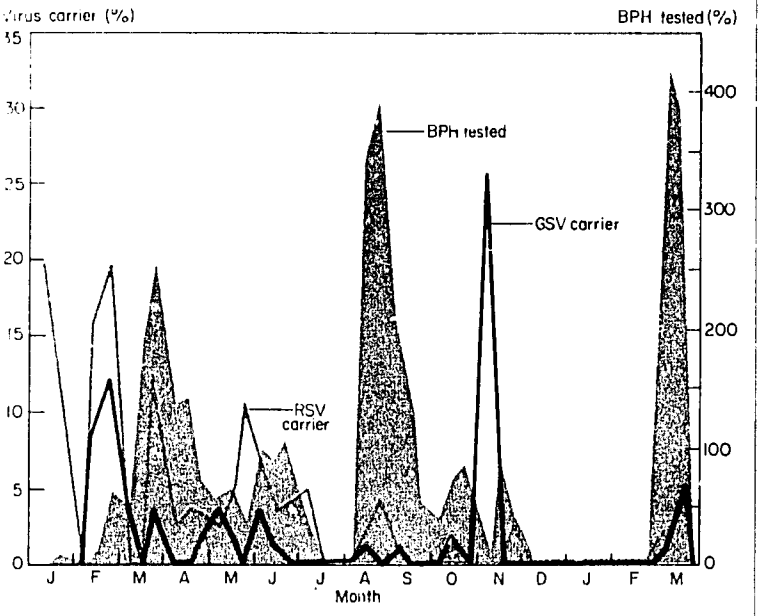
1. Sheath blight incidence and severity on IR36 when seeds were treated before sowing in *R. solani*-infested soil. Only the seeds of the first crop were treated.



2. Plant prints of IR36 on agar medium indicate that fluorescent bacteria (left) readily establish themselves on the plant surface after seed treatment.



3. Electron micrograph of purified rice tungro spherical virus 200 000X



4. Proportion of grassy stunt and rice ragged stunt virus carriers in migrating brown planthoppers collected in a high beam trap.

Diagnosing virus diseases

Symptom-based virus disease diagnosis is inconclusive and transmission testing takes 2-3 weeks. With our electron microscope, we successfully diagnosed two tungro-associated viruses and ragged stunt virus. The new serodiagnosis technique allows virus identification from leaf extracts in only 5 minutes.

We purified and developed antisera specific to rice tungro spherical virus (Fig. 3) and a new strain of grassy stunt virus. Enzyme-linked immunosorbent assay and immunosorbent electron microscopy detected rice viruses from pieces of fresh or dried diseased leaves.

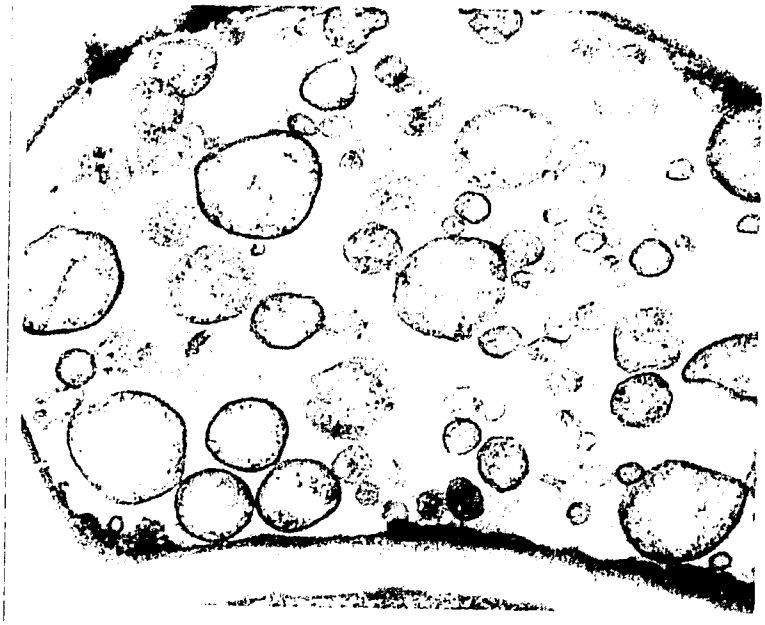
We started a virus disease diagnosis service to test leaf samples for rice tungro spherical and bacilliform viruses, ragged stunt virus, and grassy stunt virus. Serodiagnosis is being used in virus disease epidemiology (Fig. 4) and resistance studies.

Plans for international collaboration on tungro virus were made during a workshop at Bhubaneswar, India, in October.

Mycoplasma etiology of orange leaf

We collected rice plants with orange leaf-like symptoms from six locations in the Philippines to identify vector transmission and disease agents.

Recilia dorsalis transmitted the disease agent persistently from 13 to 33 days after exposure until the insect died. In addition to previously reported orange leaf symptoms, ragged



5. Electron micrograph of mycoplasma-like organisms found in a sieve tube of rice leaves infected with orange leaf 27,000X

and twisted leaves also were observed. Infected seedlings died 3-4 weeks after visible symptoms developed.

We observed thin sections from infected leaves and found mycoplasma-like organisms in the sieve tubes. The organisms are bonded with a unit membrane and a pleomorphic 50-1100 nm in diameter (Fig. 5). This indicated that mycoplasma-like organisms cause orange leaf.

6. Cone sampler developed for insect monitoring in research plots.

INSECTS

Measuring insect populations

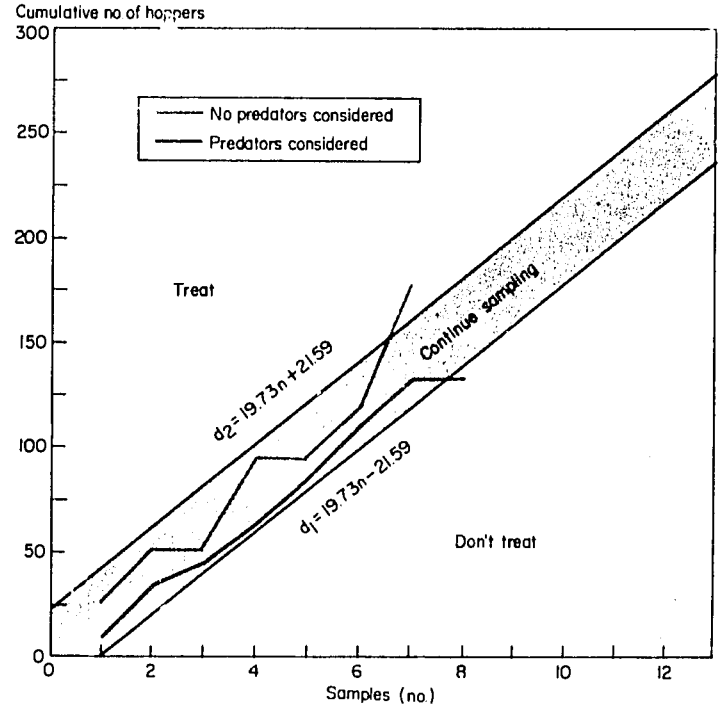
We developed a sampling device for rice insect field populations (Fig. 6). A plastic or aluminum cone is placed over a hill of rice and charged with carbon dioxide from a small, portable tank. The carbon dioxide anesthetizes insects and spiders, which fall onto the water and are collected with a small strainer. As many insects can be collected with the cone sampler as with more complicated and expensive devices. Unlike suction-type samplers, the cone does not need electricity.

Sequential sampling

In sequential sampling, insect counts are taken sequentially and the results of each sample determine if additional samples are needed. Sequential sampling is based on the mathematical distribution of insect pests and their predators, the economic threshold, and the level of risk that the farmer is willing to take.

We developed sequential sampling tables for brown plant-

7. Sequential sampling table for planthoppers and beneficial insects.



8. *Lycosa pseudoannulata*, an important spider predator of planthoppers and other insect pests.

hopper pests and predators. The economic threshold for brown planthopper is 1 per tiller or 20 per hill. The risk level is 0.20, so we are 80% sure of making the right decision.

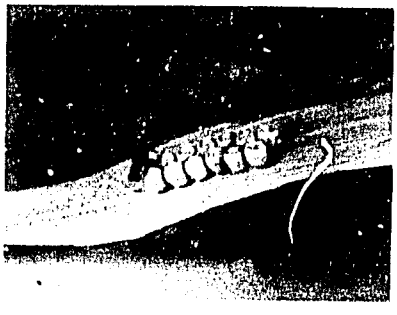
Figure 7 shows how sampling points are accumulated to make a control decision, but a farmer would use a table to count and record planthopper and predator populations. For each major predator (spider, beetle, waterbug) encountered, five hoppers are subtracted from the number of hoppers counted.

Sequential sampling is the first system that takes into account beneficial insect populations when deciding to apply insecticides. It is simple and takes less time than more conventional methods because the sample size is flexible and determined by pest and predator populations. Small or large populations require few samples. An additional benefit is that farmers learn to recognize major predator species, such as spiders (Fig. 8).

Green leafhopper behavior on tungro-infected rice plants

Tungro-infected rice plants have yellow leaves, slight stunting, and low tillering; however, they survive until maturity, thus providing an inoculum source. In a choice test, yellow, tungro-infected plants first attracted more green leafhopper adults than healthy green plants. After 24 hours, however, many leafhoppers had moved to healthy plants.

9. Adult black bug infected with fungus.



10. Parasite *Telenomus cyrus* attacking black bug eggs.

11. Mortality of black bugs treated with different fungi.

12. Brown planthoppers treated with buprofezin do not molt (bottom), while untreated insects molt as shown by cast-off skins (top).

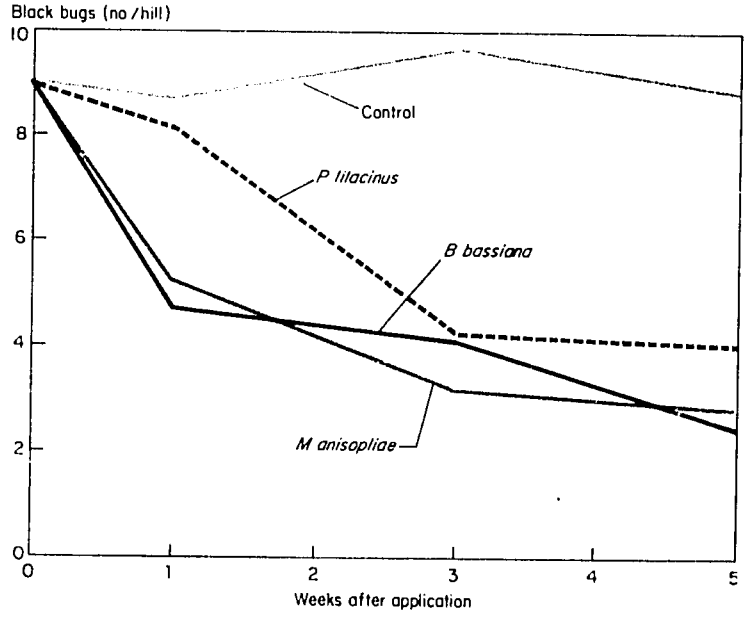
Food intake was less on infected plants than on healthy plants. Insect growth, longevity, fecundity, egg hatchability, and population increase also declined. Tungro-infected plants had significantly more free sugar than healthy plants but soluble protein was lower. The attractive qualities of infected plants plus their poor food quality encourages the spread of disease to healthy plants.

Biological control of the black bug

We are evaluating fungus diseases and native and introduced parasites to control the black bug *Scotinophara coarctata*. The fungi attack the adult stage (Fig. 9) and the tiny wasp parasites are specific to black bug eggs. In Palawan, Philippines, we tested the parasites *Telenomus triptus* from Malaysia and *Telenomus cyrus* from Luzon, Philippines (Fig. 10). Field and laboratory studies will identify the most promising parasite. Fungi that have caused significant black bug mortality include *Beauveria bassiana*, *Paecilomyces* sp., and *Metarrhizium anisopliae* (Fig. 11).

Buprofezin for brown planthopper control

Buprofezin (NNI-750) kills brown planthopper nymphs by inhibiting molting (Fig. 12), but does not otherwise affect adult planthoppers, their eggs, or natural enemies. One application of 0.125 kg ai buprofezin/ha usually suppresses brown planthopper populations on susceptible rices. The planthopper



population must be monitored so nymphs and not adults or eggs are present when buprofezin is applied. When mixed with insecticides such as cypermethrin, deltamethrin, peridrothrin, and phenthoate that cause brown planthopper resurgence, the mixture controlled all brown planthoppers and did not cause resurgence.

Botanical insect controls

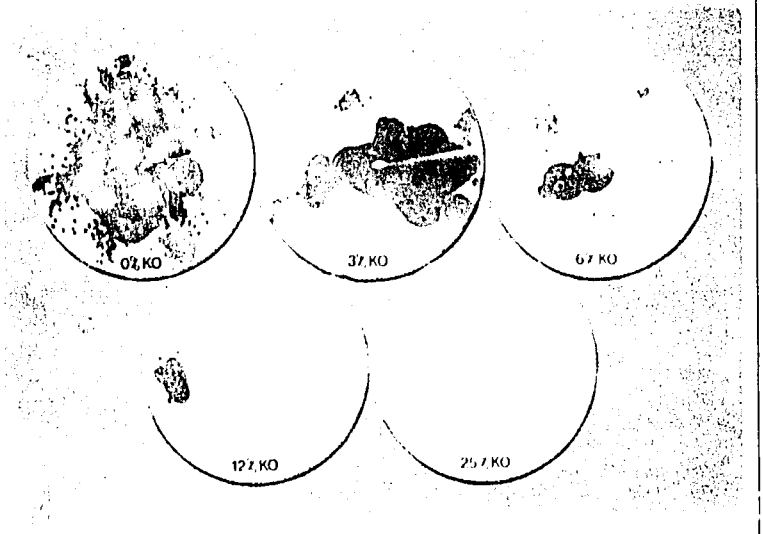
In addition to neem, we evaluated the insect control potential of other tropical plants that are sources of nonedible oils.

Feeding, growth, longevity, and fecundity of rice leafhoppers and planthoppers were significantly reduced on rice plants treated with seed oil or cake of chinaberry *Melia azedarach* and *M. toosendan*. Chinaberry is common in Asia. Custard apple *Annona* sp. seed oil, alone or with neem oil, reduced tungro virus transmission by green leafhopper. Spraying rice with seed oil of karanja *Pongamia glabra*, a common Indian tree, reduced feeding of brown planthopper females (Fig. 13) and caseworm larvae.

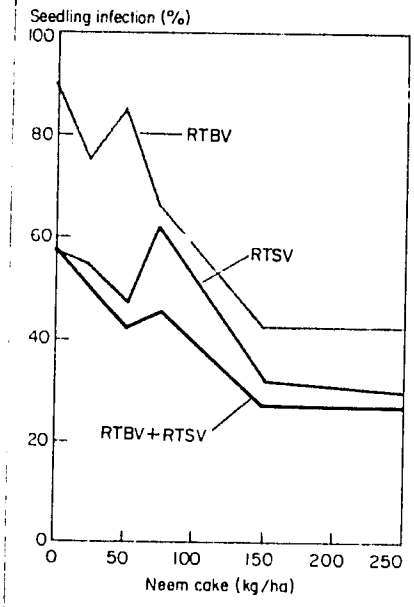
To explore the potential of botanical pest control substances, we organized a research planning Workshop on Indigenous Plant Materials for Pest Control in collaboration with East-West Center, the University of the Philippines at Los Baños, and the Philippine Council for Agriculture and Resources Research and Development.

Applying neem cake to control tungro

Tungro is caused by isometric rice tungro bacilliform and spherical virus particles that are transmitted by green leaf-



13. Filter paper disks on which brown planthopper honeydew was collected when they fed on TN1 plants sprayed with karanja oil.



14. Percent infection with tungro bacilliform virus and spherical virus particles in TN1 seedlings grown in soil with incorporated neem cake

hopper. In greenhouse tests, incorporating ≥ 150 kg neem cake/ha in the soil reduced transmission of both virus particles (Fig. 14).

Neem oil disturbs brown planthopper mating

Brown planthopper males and females communicate by species-specific vibrations produced on rice plants. Males make a croaking sound and sexually mature females on the same plant answer with a drumming sound. Applying 5 μg neem oil/female planthopper alters the pattern of signals and disrupts the mating process.

Insect pest management

Yield loss trials on 80 rainfed and irrigated rice crops from 1976 to 1983 showed significant yield losses in 50% of 337 farms. Based on average insecticide use, Philippine rice production could remain at current levels with half the insecticide now used if it were effectively applied.

Insecticide should be applied only when pest populations threaten losses greater than monitoring and application costs. Local trials should quantify yield losses caused by major pests and be used to develop efficient economic thresholds.

Treatments using economic thresholds to make insecticide application decisions were included in 1976-83 yield loss trials in seven Philippine provinces. Application decisions on 70% of the fields considered economic thresholds. About half of the decisions were to control whorl maggot; 25%, leaffolder; 10%, rice bug and whitebacked planthopper; and less than 5%, yellow stem borer and caseworm. Planting resistant varieties controlled brown planthopper and green leafhopper.

We compared 5 years of yield loss records from 2 sites in Nueva Ecija and Pangasinan Provinces. With high pest incidence, yield loss averaged 1 t/ha per crop. Greatest yield loss (0.5-0.7 t/ha) occurred at vegetative stage, mainly from whorl maggot and early-season defoliators. Leaffolder, whitebacked planthopper, and yellow stem borer were common at reproductive stage but infestations seldom reached economic thresholds. Yield loss was 0.2-0.3 t/ha. Yield loss caused by leaffolder, yellow stem borer, and rice bug was lowest at ripening (0.1-0.2 t/ha).

WEEDS

An herbicide for broadcast-seeded rice

In our evaluations of herbicides for broadcast-seeded, flooded rice, applying 0.3 kg ai BAS514/ha 6 days after seeding was relatively safe, controlled weeds better, and gave significantly

higher IR58 grain yield than thiobencarb + 2,4-D. As more farmers in South and Southeast Asia change from transplanting to broadcast-seeding, selective herbicides are becoming more important for weed control.

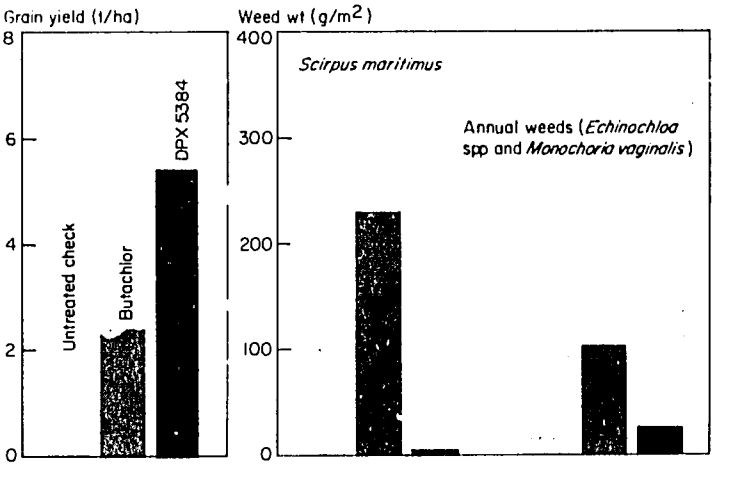
DPX for annual and perennial weed control

We compared herbicides for control of annual and perennial weeds of lowland rice. A granular formulation of DPX5384 at 0.05 kg ai/ha applied soon after weeds emerged (6-8 days after seeding) gave excellent control of annual weeds such as *Echinochloa* spp. and *Monochoria vaginalis* and perennial *Scirpus maritimus*, was not toxic to rice, and significantly increased grain yield of broadcast-seeded, flooded IR36 (Fig. 15).

Herbicide formulations for applicators

Controlled-drop herbicide applicators have a narrow droplet-size spectrum. In the greenhouse, we tested 2,4-D herbicide formulations in birky (a low-volume pneumatic sprayer), micron-herbi (a battery-operated ultralow-volume disc sprayer), and conventional hydraulic knapsack sprayers. 2,4-D was applied as dimethylamine salt (amine), isobutyl ester, and isopropyl ester formulations.

The isobutyl ester and isopropyl ester formulations were more effective than the amine when sprayed from the controlled-drop applicators. Different formulations did not affect the performance of the hydraulic knapsack sprayer. The isobutyl ester formulation performed best when applied by the micron-herbi. Isopropyl ester was best with the birky. Performance of the amine formulation did not vary among sprayers.



15. DPX5384 provided excellent control of annual weeds and perennial *Scirpus maritimus* and significantly increased IR36 grain yield.

IRRIGATION WATER MANAGEMENT

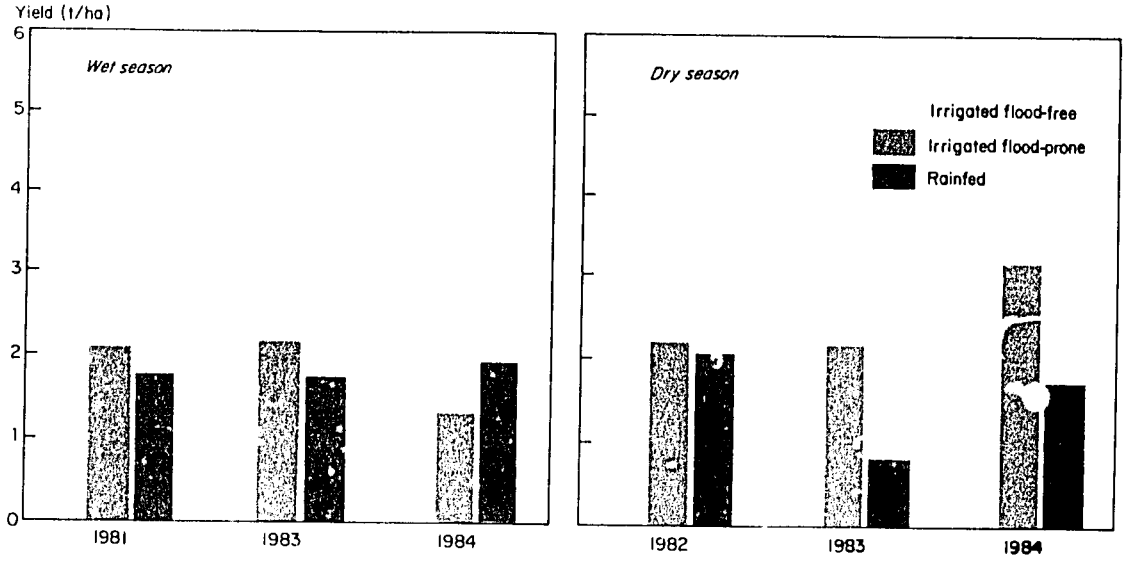
In 1984 we continued research to identify more efficient irrigation technology and management practices for rice farmers. We emphasized studies to minimize the effects of excess water in wet season and to make water available to more farmers in dry season.

Excess water

Excess water in wet season reduces rice production in many irrigation systems. Waterlogged soils may delay or prevent land preparation, and flooding or submergence may reduce yield or destroy the crop. In the Libmanan-Cabusao Pump Irrigation System, collaborative research with the Philippine National Irrigation Administration indicated that yields in flood-affected areas, about 20% of the 3,500-ha system, do not significantly differ from those in adjacent rainfed areas (Fig. 1).

Drainage studies. In Bicol, Philippines, most flooding problems are associated with slow drainage after typhoons. Drains are small and poorly maintained, most coastal fields have low elevation, and many upstream fields are overirrigated.

1. Yield on irrigated flood-free, irrigated flood-prone, and rainfed farms in the Libmanan-Cabusao Pump Irrigation System



Better maintenance and management would reduce the flood-prone area but would not eliminate the risk of flood damage. We are testing submergence-tolerant rices for such areas.

The Bicol data provide a foundation for research to classify regional flood problems, evaluate the effects of drainage water quality on rice growth, and identify floodwater management requirements. We also hope to develop an effective combination of system design and management and flood-tolerant rices for Bicol and similar flood-prone areas.

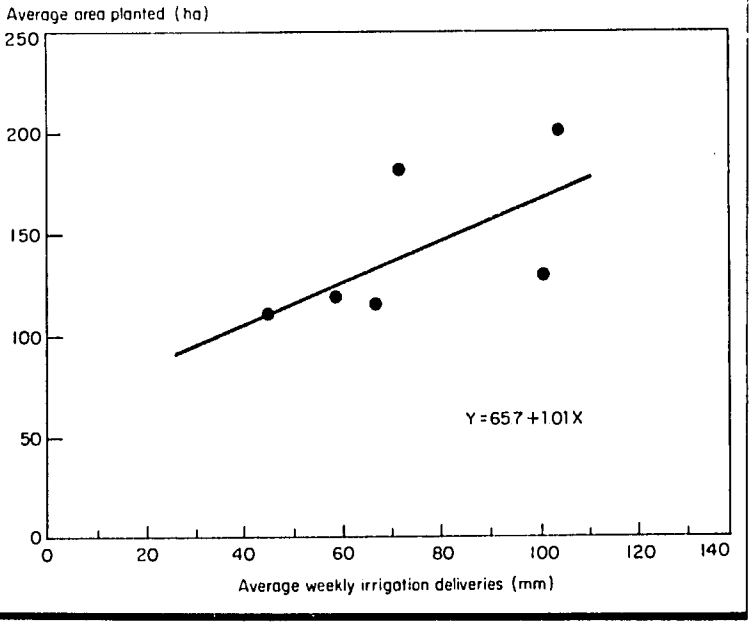
Overirrigation. We have continued to develop methodologies for suspending irrigation deliveries during wet season rainy periods. At Libmanan-Cabusao we found pumping should stop when rainfall reaches 8 mm/day.

Rapid management response to rainfall alleviates downstream flooding and reduces pumping costs. In most systems studied, however, farmers prefer to depend on wet season irrigation water rather than use rainfall efficiently. We will continue to identify constraints to more effective rainfall utilization.

Improving irrigation water access in dry season

Dry season water shortages at the tail-end of irrigation systems limit rice production potential in many countries. We examined two ways to alleviate the problem.

Improving land preparation schedules. Late land preparation extends the irrigation season and contributes substantially to inefficient water use. In Bicol (Fig. 2) and Nueva Ecija,



2. Rate of land preparation in the Libmanan-Cabusao Pump Irrigation System related to irrigation delivered at the beginning of the main channel.

Philippines, we found that technical rather than social or economic factors slowed land preparation.

If more water is distributed more efficiently when land preparation begins, irrigation seasons can be shortened, which benefits water use efficiency and reduces pest problems. Water demand should be reduced during land preparation. Evaluation of soil water requirements, developing low-water land preparation techniques, and improving water distribution early in each irrigation season will increase water use efficiency and encourage synchronous planting.

Alternative cropping patterns. Where water is particularly scarce or expensive, irrigating dry season rice is less efficient than irrigating upland crops. Our work in Bangladesh and the Philippines shows significantly more area can be irrigated and that farmer incomes increase when low water use cropping patterns are adopted. However, diverse dry season cropping patterns cause organizational problems in allocating and distributing water. We are comparing the effect of soil type and soil-water regime on rice and upland crops to identify appropriate land preparation technology and modify farm-level water delivery infrastructures to avoid waterlogging sensitive upland crops.

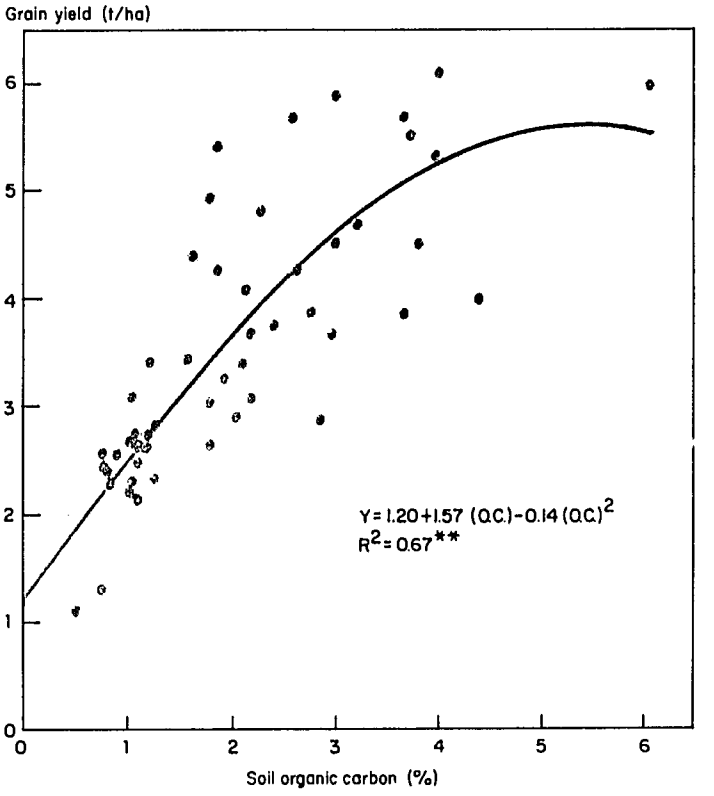
SOIL AND CROP MANAGEMENT

SOIL CHARACTERIZATION

Soil tests can help reduce fertilizer applications. Data from 125 experiments in 1984 show that applying 80 kg N/ha to soils with more than 0.2% total nitrogen rarely increased rice yields and that yields without nitrogen, phosphorus, and potassium fertilizer correlated highly with soil organic matter content (Fig. 1). Organic carbon content is simple to measure, and can be used to determine nitrogen fertilizer requirements

Applying fertilizer to soils with more than 5 ppm available phosphorus, 80 ppm potassium, and 1 ppm zinc is unlikely to improve yields up to about 5 t/ha, especially if nutrient-efficient varieties are planted.

In soil flooded with more than 50 cm of water for most of the season, yield was better with adequate phosphorus. Deep



1. Relationship of yield and soil organic carbon content in no-fertilizer plots in farmers' fields in eight Philippine provinces.

water plants had less nitrogen, phosphorus, potassium, and magnesium than shallow water plants, although the chemical composition of the soils was almost identical. Soil nutrient losses were greatest in deep water. Applying fertilizer aggravated deep water injuries.

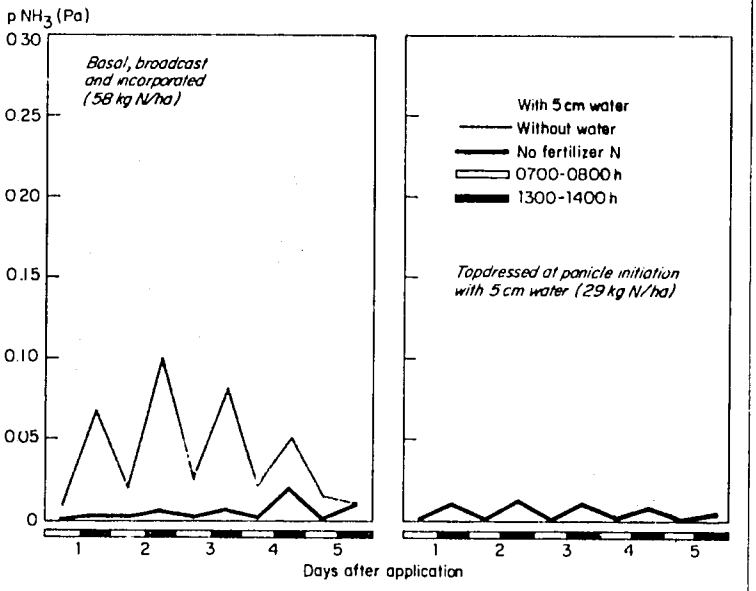
We have evidence that excess potassium and, perhaps, silicon in irrigation water harm rice. Some Philippine soils have very high natural levels of potassium. Adding more than 100 meq K/kg of soil containing 0.7 meq exchangeable K/100 g depressed rice growth and yield.

MANAGEMENT OF SOIL AND FERTILIZER NITROGEN

Effect of water depth on pNH_3

Using NH_3 vapor pressure (pNH_3), we evaluated nitrogen loss during fertilizer application at different water depths.

When urea was broadcast and incorporated with 5 cm standing water, pNH_3 was higher than when urea was broadcast on mud and incorporated (Fig. 2), suggesting that less volatilization loss occurs if there is no standing water.



2. Equilibrium vapor pressure of NH_3 in floodwater as affected by water depth during urea application. Topdressing data are the mean of two treatments.

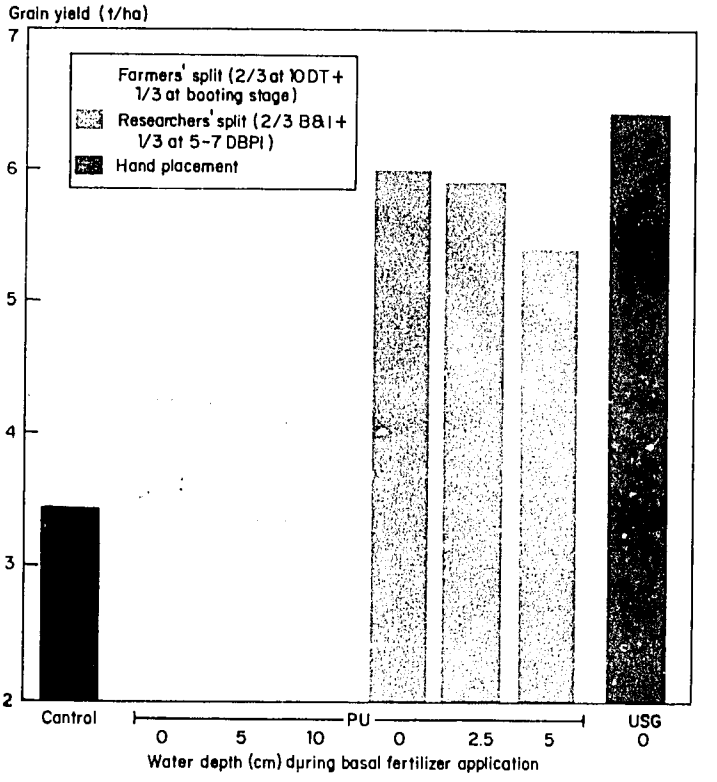
The farmer practice of topdressing equal amounts of urea 10 days after transplanting and 10 days after panicle initiation caused high pNH_3 and therefore high NH_3 losses. At 5 cm, partial pressure was high for 3 days after topdressing, and highest 2 days after topdressing. Partial pressure was lower 10 days after transplanting because the well-developed rice canopy minimized volatilization.

Topdressing urea with 5 cm standing water caused higher pNH_3 than topdressing with 10- and 15-cm standing water but topdressing at 10 and 15 cm is less beneficial to the rice crop.

Efficient nitrogen application with better water management

Broadcasting and incorporating nitrogen fertilizer into mud increased IR58 yields 0.9 t/ha in dry season (Fig. 3) and 0.5 t/ha in wet season over incorporation with 5 cm standing water. Farmers commonly apply nitrogen in equal splits 10 days after transplanting and 10 days after panicle initiation. From many trials we have found that yields are better if two-thirds of the fertilizer is incorporated in mud and one-third is topdressed in 5 cm standing water at panicle initiation. This technology now is part of the revised 16-step recommendations of the Philippine Masagana-99 Program.

In another experiment, we evaluated the effect of water depths and fertilizer application methods on nitrogen use efficiency. Basal nitrogen incorporation without standing water and deep point placement immediately after transplanting produced similar grain yields. Proper fertilizer timing with good



3. Effect of water depth and nitrogen fertilizer (87 kg N/ha) application method on IR58 grain yield. DT = days after transplanting, B&I = broadcast and incorporated, DBPI = days before panicle initiation, PU = prilled urea, USG = urea supergranules.

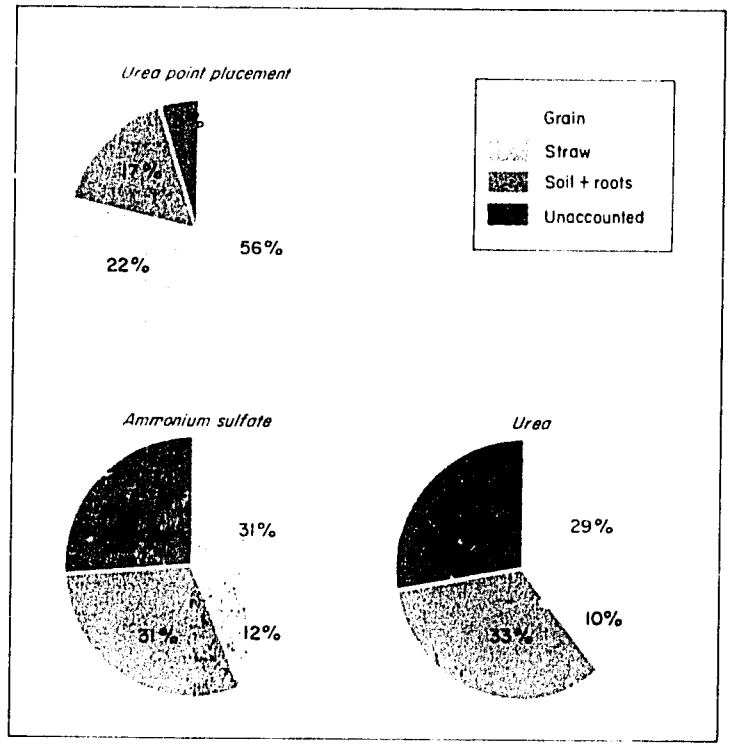
water management may give the same benefits as deep point placement without the extra manufacturing and application costs.

Nitrogen loss and utilization in a calcareous clay loam

We used the ^{15}N balance technique to evaluate the effects of nitrogen source and application methods on nitrogen loss and utilization in a calcareous clay loam. Highest ^{15}N recovery by straw + grain was 78% with dry season (Fig. 4) deep point placement of urea supergranules. At harvest, only 5% of the applied nitrogen could not be accounted for. When prilled urea or ammonium sulfate was split-applied, more than 26% of the applied nitrogen was not recovered. Results showed that urea can be used as efficiently as ammonium sulfate, even in calcareous soil, if it is properly managed to minimize nitrogen losses.

Nitrogen use efficiency in upland rice

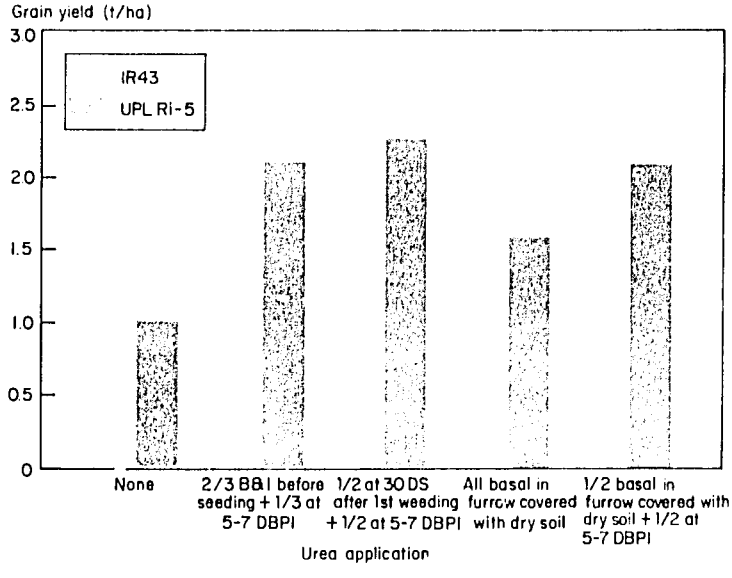
We evaluated different urea application methods in wet season under upland conditions in a farmer's field in Batangas,



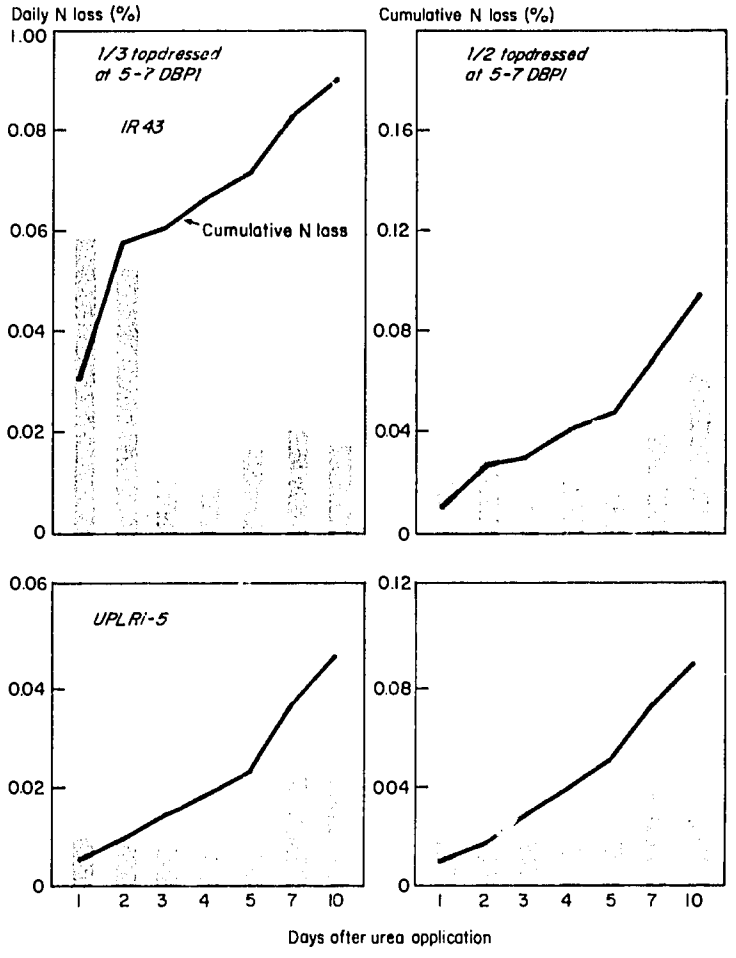
4. Effect of different application methods on ^{15}N balance at harvest.

Philippines. Soil was a Udic Argiustoll with pH 5.4, 2.04% organic matter, and 0.125% total nitrogen.

Applying urea significantly increased yields over those of the unfertilized control (Fig. 5). Yield was highest when urea was



5. Effect of urea application (70 kg N/ha) methods on grain yield of two rices under upland conditions. B&I = broadcast and incorporated, DS = days after sowing, DBPI = days before panicle initiation.



6. Daily and cumulative nitrogen loss in upland rice after topdressing urea at 5-7 days before panicle initiation (DBPI).

applied in equal splits 30 days after seeding and 5-7 days before panicle initiation, but did not differ significantly from urea applied as two-thirds broadcast and incorporated and one-third 5-7 days before panicle initiation. Applying urea in furrows and covering it with dry soil produced the lowest yields.

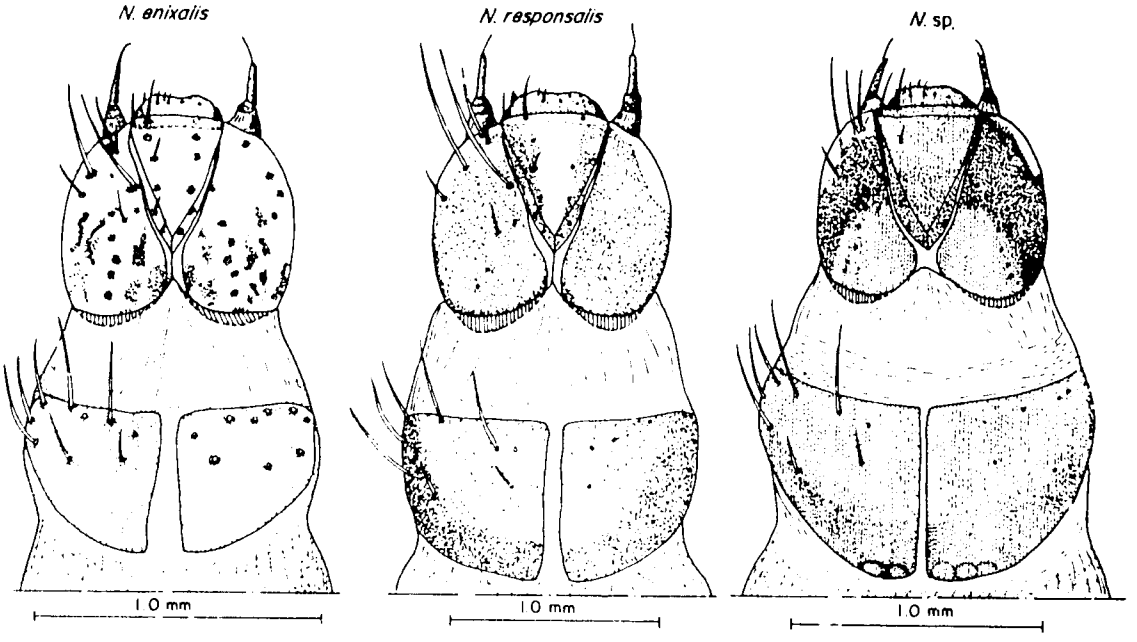
Nitrogen volatilization, measured with an acid trap, was minimal (Fig. 6). Losses were lower with UPL Ri-5 than with IR43.

BIOLOGICAL NITROGEN FIXATION

Under natural conditions, many environmental factors limit nitrogen fixation by different organisms. We are working to develop technologies to overcome those limitations.

Azolla

Phosphorus deficiency and insect damage are major constraints to azolla use. Many Philippine rice growing areas have



7. Fifth-instar larvae of three caseworms that damage azolla.

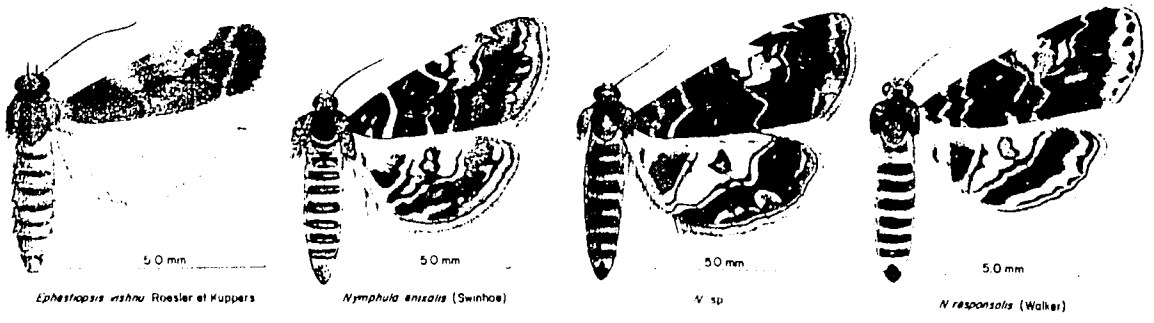
less than the 0.1 ppm phosphorus in floodwater needed for azolla growth. At IRRI, insects reduced azolla biomass production by 20-80%.

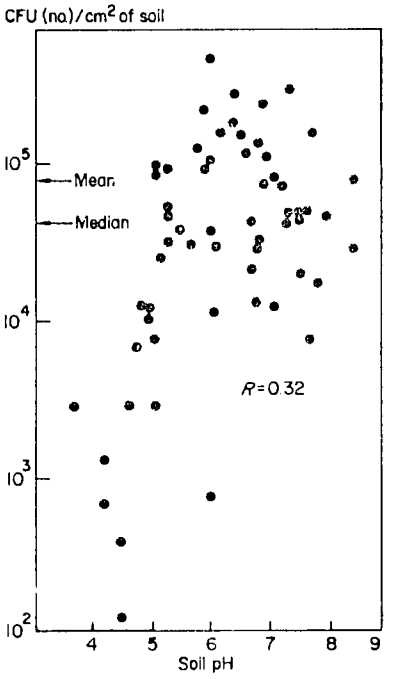
Insect surveys in the Philippines, Thailand, and Indonesia identified caseworms *Nymphula enixalis* and *N. responsalis* (Fig. 7) and webworm *Ephestiopsis vishnu* as major azolla pests (Fig. 8). For azolla use to be expanded, we must develop inexpensive ways to supplement phosphorus and control insect damage.

Blue-green algae

We surveyed 61 wetland rice fields, mostly in the Philippines, and found N.-fixing blue-green algae in all the soils (Fig. 9).

8. Adult females of pyralid pests of azolla.





9. Contrary to indications of previous studies in several countries, we found that N_2 fixing blue-green algae are present in all the Philippine rice soils we analyzed. Additionally, there is a correlation between soil pH and blue-green algae abundance.

Greenhouse experiments with five soils showed that blue-green algae introduced as a soil-based inoculum persisted in the soils, but did not produce agronomically significant biomass. Maximum nitrogen fixation occurred about 2 weeks after soils were flooded and was mainly due to the activity of indigenous strains.

On those soils, controlling invertebrates that feed on blue-green algae (grazers) with crushed neem (*Azadirachta indica*) seeds encouraged N_2-fixing blooms of indigenous (four soils) or inoculated blue-green algae (one soil).

A preliminary survey of invertebrate populations in Philippine fields showed that blue-green algae grazers are always present, and each soil may have 70% of the recorded grazer species. Inexpensive grazer controls may encourage the growth of indigenous or inoculated blue-green algae.

Blue-green algae technologies must be tested in many environments. To initiate collaboration with national programs on algal biotechnology, we sent questionnaires to scientists working on blue-green algae. Of the 177 responses received, almost half were interested in the management of blue-green algae to increase soil fertility and rice yields.

Bacterial N_2 fixation

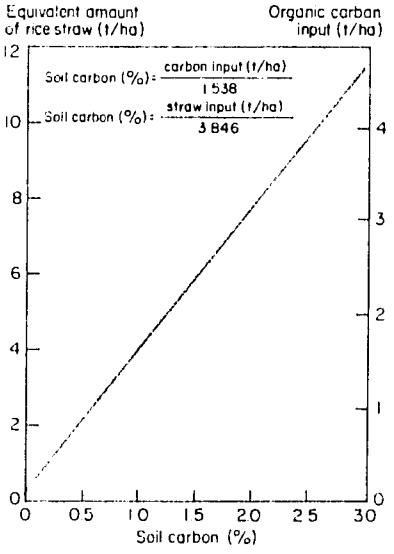
We improved and applied simple acetylene reducing activity (ARA) and ^{15}N dilution techniques to screen rice varieties for N_2-fixing ability. ARA assays can be used for large samples and quick assays. Root and basal shoots (5 cm) of a hill of rice are enclosed in a plastic bag and ARA is measured for 6 hours in the dark, which reduces measurement variability.

In general, the longer the growth duration of a variety, the higher the ARA at heading. ARA is highly correlated with plant growth parameters; root, shoot, and total dry matter; and total plant nitrogen, particularly in dry season.

We used the ^{15}N dilution technique to identify rices that are highly dependent on atmospheric N_2. Labelled ammonium nitrogen was added to flooded soil in concrete tanks and one or two crops were grown to stabilize the ^{15}N before testing. In some trials, rices such as IR42 and Hua-chou-chi-mo-mor, which have high nitrogen stimulating ability, had low ^{15}N grain content, showing that much of the nitrogen was derived from the atmosphere, not the soil. However, ^{15}N content varied by less than 25% between varieties.

MANAGEMENT OF ORGANIC MANURES

Organic matter plays an essential role in soil fertility and organic amendments can be important substitutes for chemical fertilizer.



10. Derived relationship of seasonal straw amendments and soil carbon content in tropical lowland soils (two annual rice crops and dry fallow).

Organic matter decomposition

We used straw decomposition studies with ^{14}C-labelled rice straw in rice fields at Los Baños to establish a linear function between seasonal incorporation of rice residues and soil carbon content (Fig. 10). In a dry fallow - rice - rice cropping system, 4 t rice residue/ha must be added to maintain or achieve 1% soil carbon content, an undesirably low level. More than 4 t is needed to establish a satisfactory level.

Most nutrients from added residues take months or years to recycle, and recycling time is relatively independent of water regime. Decades are needed for measureable changes of soil organic matter content in a dry fallow - rice - rice cropping system.

Lengthening moist aerobic periods enhances mineralization of soil organic matter, and permanent submergence considerably conserves soil organic matter. Substantial research is needed to understand the long-term effects of intermittent flooding on nutrient recycling from organic residues.

Straw incorporation

A 7-year experiment showed that straw and water may be partial substitutes for nitrogen fertilizer. Incorporating 5 t straw/ha followed by flood fallowing between crops increased soil nitrogen content of the Maahas clay at Los Baños from 0.163 to 0.203% and rice yield 0.5 t/ha per season, the equivalent of applying 25-50 kg N/ha per season.

MANAGEMENT OF OTHER NUTRIENTS

Sulfur status of some Philippine soils

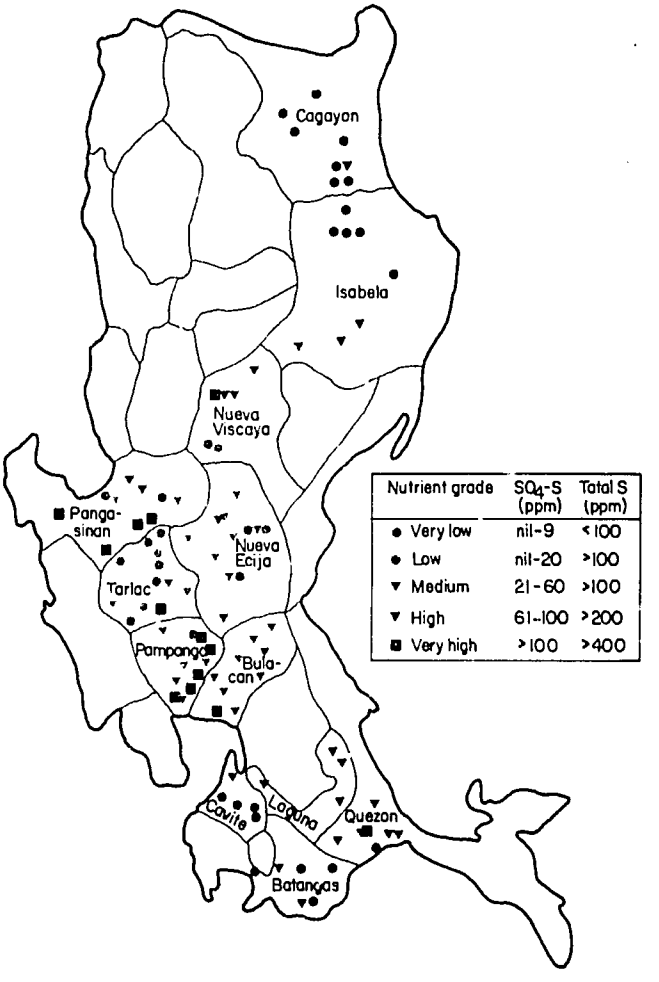
We analyzed Philippine rice soils from 99 sites in 12 Luzon provinces for total sulfur, sulfate-sulfur, and other chemical properties.

Phosphate extractable sulfate ranged from 0 to 1274 ppm. Based on total sulfur and sulfate-sulfur contents, the soils were placed in five categories (Fig. 11). Sites from Cagayan, Isabela, and Tarlac are potentially sulfur deficient.

INTERNATIONAL NETWORK ON SOIL FERTILITY AND FERTILIZER EVALUATION FOR RICE

In response to increasing emphasis on adverse environments, the INSFFER program has added three collaborative trials to evaluate soil fertility and fertilizer management in upland rice soils.

In 1984, INSFFER organized a workshop and field visits to establish procedures for characterizing wetlands so trial results



11. Sulfur status of some rice soils in Luzon, Philippines.

can be effectively extrapolated in similar sites, which will allow INSFFER trials to be effectively translated to other locations (Fig. 12). Among the participants were cooperating INSFFER scientists and pedologists of the Soil Management Support Services of the United States Department of Agriculture.

TILLAGE AND MANAGEMENT OF SOIL PHYSICAL CONDITIONS

Land preparation for lowland rice

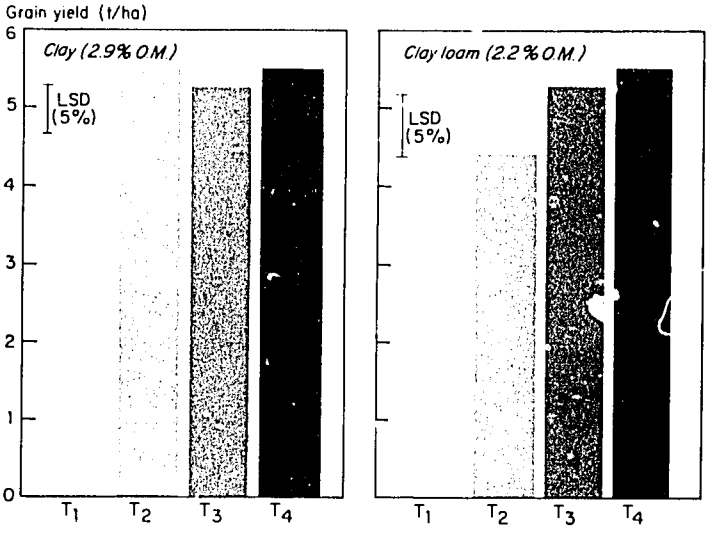
We evaluated the effects of different land preparation methods on grain yields of transplanted IR36. Fields differed in texture, clay mineralogy, percolation and seepage losses, and water tables. Land preparation methods were zero tillage, minimum tillage, shallow puddling, and conventional puddling.

12. Participants on a soils characterization tour following the wetland soils workshop.

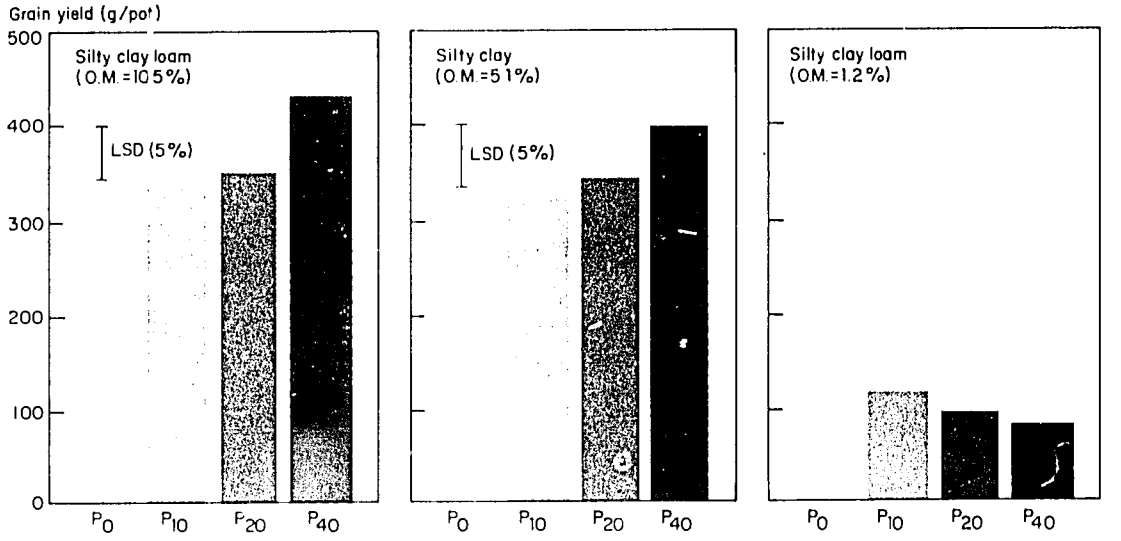
Minimum tillage and conventional puddling gave the same yield in a clay soil dominated by X-ray amorphous alumino-silicates and montmorillonite-like clay minerals, with 47% shrinkage, ·5 mm daily percolation and seepage losses, and 0-20 cm water table (Fig. 13).

Conventional puddling was best in a clay loam dominated by X-ray amorphous alumino-silicates and halloysite-like clay minerals, with 25% shrinkage, ·80 mm daily percolation and seepage losses, and ·150 cm water table. In both soils, grain yields were lowest with zero tillage.

In easily dispersible clays with low permeability, minimum, but not zero, tillage may be an alternative to capital- and energy-intensive puddling.



13. Effect of land preparation methods on IR36 grain yield in two soils at IRRI. T_1 = zero tillage, T_2 = minimum tillage, T_3 = shallow puddling, T_4 = conventional puddling.



14. Effect of percolation rates on IR36 yield in soils with different organic matter (O.M.). P_0 = no percolation, P_{10} = 10 mm percolation/d, P_{20} = 20 mm/d, P_{40} = 40 mm/d.

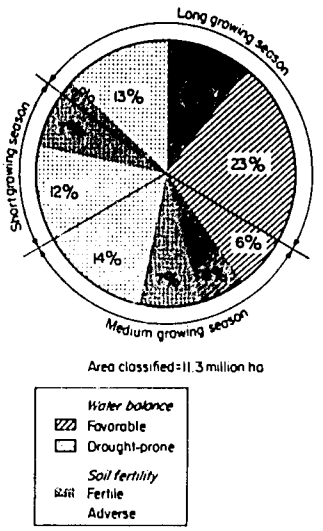
Percolation rates

We studied the effect of different percolation rates on IR36 grain yield in silty clay loam to silty clay soils with 1.2-10.5% organic matter. Percolation rates were 0, 10, 20, or 40 mm/day. Higher percolation rates increased grain yields in soils with 5.1 and 10.5% organic matter, but not in soil with 1.2% organic matter (Fig. 14). This indicates that optimum tillage and puddling methods vary for soils with different organic matter contents, and that organic matter amendments may not be appropriate in soils with limited percolation.

CLIMATIC ENVIRONMENT AND RICE

Rice environments

We refined our classification of Asian rainfed rice growing areas and delineated 10 major ecosystems based on growing season, water balance, and soil fertility. Our evolving classification methodology significantly improves the identification and description of environments for targeting rice improvement strategies.



1. Comparative distribution of upland rice areas by major environments in South and Southeast Asia.

Upland rice. The dominant upland rice ecosystem in Southeast Asia has a long (more than 5 months) growing season, favorable water balance, and infertile, acidic soils (Fig. 1). We are working to develop productive rices for those conditions.

In South Asia, most upland rice areas have a relatively short, drought-prone growing season. Varieties must be very early maturing and drought tolerant.

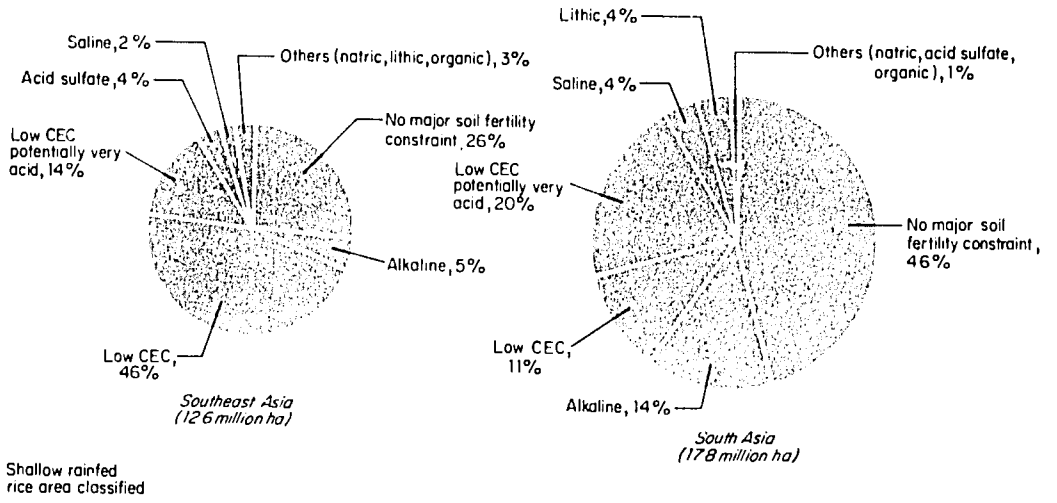
Shallow rainfed lowland rice. Shallow rainfed rice is planted on more than 30 million ha in South and Southeast Asia. The largest ecosystem, 6.6 million ha, has a long growing season, favorable water balance, and fertile soils. Additionally, there are several important rainfed ecosystems with adequate moisture or fertility.

We classified soil constraints to determine their extent and relative importance in Asian shallow rainfed lowlands. About 55% of shallow rainfed rice in South Asia and 74% in Southeast Asia are affected by adverse soils (Fig. 2). Low cation exchange capacity limits production on 7.7 million ha, high phosphorus fixation on 5.3 million ha, and salinity on 1.2 million ha. Smaller areas have acid sulfate soils (0.5 million ha), high organic matter (0.3 million ha), and natric soils (0.1 million ha).

Agrohydrology of upland rice

When upland rice is grown on a gently sloping toposequence growth and yield may depend on its position up the hill. Growth differences may reflect variations in depth to and uptake of groundwater, moisture-related differences in nutrient uptake, or varying soil properties associated with slope position.

2. Comparative distribution of shallow rainfed rice areas by soil fertility constraints in South and Southeast Asia. CEC = cation exchange capacity.



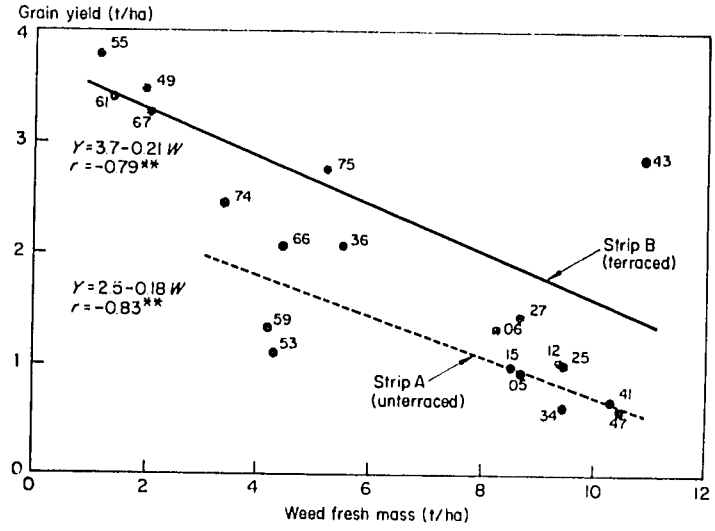
Shallow rainfed rice area classified

3. Layout of an experiment to determine upland rice growth differences on a gently sloping topcsequence. The wooden barriers restrict soil and nutrient movement.

In 1984 wet season we grew dry-seeded IR36 in four 80 × 11 m strips on a 2% incline in an upland field. The strips were crossed (Fig. 3) by a series of wooden barriers (terraces) to restrict aboveground downslope flow of soil and nutrients during heavy rainfall. Soil and crop variables were measured daily or weekly in 10 sections of each strip.

In 1984, June to September had 10% less rainfall but 10% more rainy days than the long-term average. Water tables were deeper than normal, averaging 1.1 m on the upper half and 0.9-1.1 m on the lower half of the toposequence. Rice yield probably was only slightly influenced by groundwater uptake, and was not affected by hillslope position or terracing.

Surface soil remained wet during most of the growing season because rain fell on more than two-thirds of the days, and water stress did not affect rice growth and yield. However,



4. Grain yield (Y) of upland IR36 in 1984 wet season as affected by weed fresh mass (W) at harvest. Mass of weeds removed during early-season weedings is not included. Numbers beside data points indicate distance (m) up the hillslope.

topsoil wetness delayed weeding and promoted weed growth, which reduced grain yield (Fig. 4).

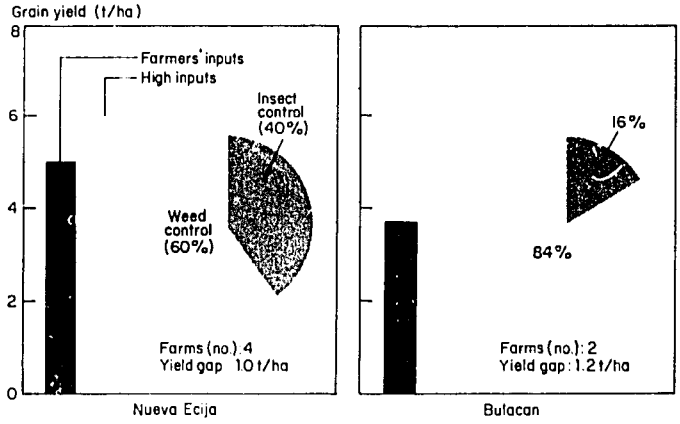
Based on 1984 and previous experiments, we concluded that, in years when the upper soil horizons dry, growth and yield of wet season upland rice may be greater at lower hillslope elevations because of groundwater uptake and nutrient migration. When surface soil remains moist, effects are less consistent and soil hydrological effects on rice growth must be interpreted using a deterministic simulation model of rice growth and yield.

CONSTRAINTS ON RICE YIELDS

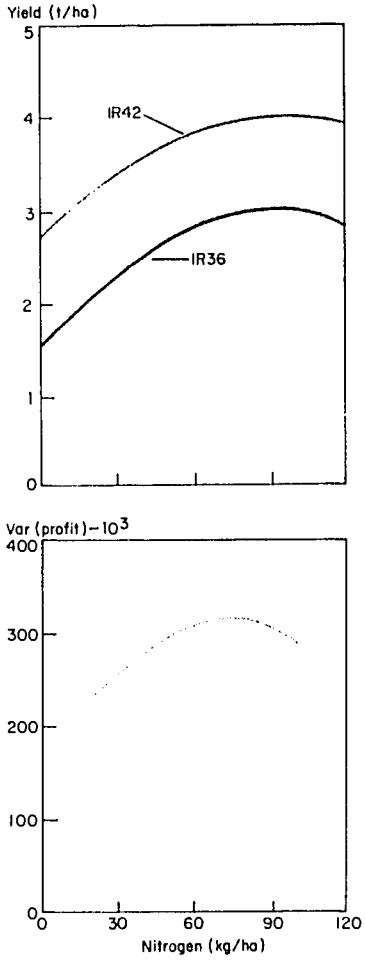
Broadcast-seeded flooded rice

From 1974 to 1983 farm level constraints research emphasized transplanted rice. In 1984 we changed our focus to broadcast-seeded flooded rice because many farmers in Malaysia, the Philippines, and Thailand are broadcast-seeding on puddled fields. In 1984 dry season, we conducted farm-level trials in Nueva Ecija and Bulacan in Central Luzon, Philippines, where more than 70% of rice is broadcast-seeded.

Farmers' seeding rates were high: 185-275 kg seed/ha in Nueva Ecija and 140-230 kg/ha in Bulacan compared with a test



1. Poor weed control followed by insect pest control were major constraints to yield of broadcast-seeded rice at Nueva Ecija and Bulacan. Improved weed control (lightly incorporating 1 kg ai butachlor/ha 3 days before seeding) accounted for 60% of the yield gap in Nueva Ecija and 84% in Bulacan.



2. a) Mean nitrogen response of rainfed IR36 and IR42. b) Profit variation for rainfed rice as affected by nitrogen application.

rate of 100 kg seed/ha. Yield gap between farmer and researcher inputs was 1.0 t/ha in Nueva Ecija and 1.2 t/ha in Bulacan (Fig. 1). Poor weed control was a major economically recoverable yield constraint at both sites. Farmers could substantially increase grain yield of broadcast-seeded rice with effective herbicide application for weed control, and good water and fertilizer management.

Fertilizer use and risk on rainfed rice

It often is argued that the full potential of fertilizer-responsive modern varieties has not been realized in shallow rainfed environments. In those environments, unpredictable rainfall, typhoons, and pests cause fertilizer response to vary each year, and farmers may apply suboptimal fertilizer rates because they risk losing their investment.

We used a random coefficient model to estimate the variability over time of IR36 and IR42 response to nitrogen. In the model, nitrogen response varies each year.

The model was applied to 5 years of nitrogen response experiments at an IRRI rainfed site (Fig. 2a). Maximum yield was at 96 kg N/ha. The marginal product at 60 kg N/ha was 11 kg grain:1 kg nitrogen, which is reasonable for these conditions. IR42 yielded about 1 t higher than IR36. The profit maximizing nitrogen rate was 42 kg N/ha with farmer prices. Profit variance increased with nitrogen application at a declining rate, peaking at 71 kg N/ha (Fig. 2b).

A decision-making model combined measures of farmer risk aversion with the estimated profit distribution. It predicted that moderately risk-averse farmers would apply 32-35 kg N/ha, which is 7-10 kg less than the profit maximizing rate. These results, consistent with other analyses, imply that risk considerations may not substantially affect fertilizer use in shallow rainfed environments.

CONSEQUENCES OF NEW TECHNOLOGY

Changing comparative advantage

We measured the contribution of technological change to increasing the comparative advantage of Philippine rice production. Profitability of producing rice was estimated using social prices, which indicate long-run opportunity costs. Government policies or market imperfections can cause social prices and private prices that farmers pay to differ.

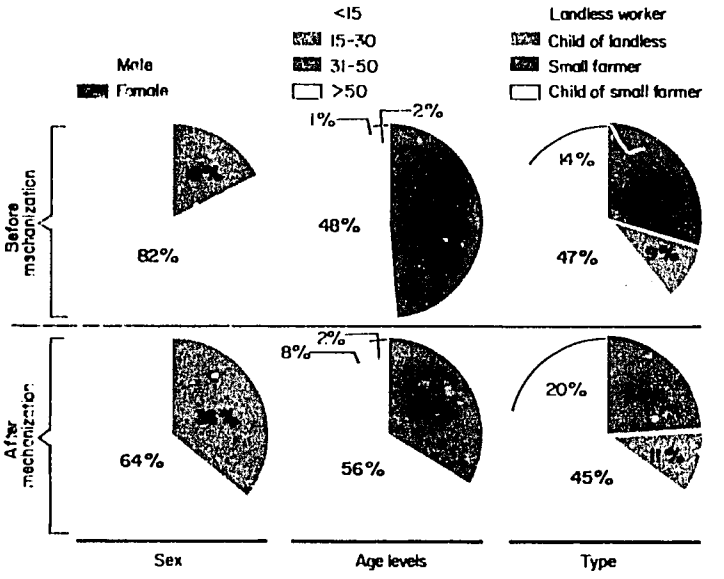
The social profitability of Philippine rice production increased between 1966 and 1982. Technological change contributed to about half the increased social profits. The effect of technological change became apparent after second generation modern rice varieties were introduced in the middle 1970s. They have insect and disease resistance, which encourages sustained yield growth.

Grain quality preferences

We studied consumer demand for grain quality. Different grades of rice were collected from major urban markets in the Philippines, Thailand, and Indonesia and analyzed at IRRI. The characteristics used to determine quality in breeding programs explained 60-90% of rice price variations in the three countries.

Consumers preferred whiter (more polished) rices with few broken grains, making milling quality a very important determinant of price. Head rice recovery is an inherited trait, therefore, it can be improved. For example, IR20, introduced in 1970, has nearly twice the potential head rice recovery of IR5 and IR8.

Amylose determines cooked texture and is the most important chemical characteristic of rice. More amylose gives rice a harder texture, and consumers prefer soft-textured rice. Most IRRI modern varieties have high amylose. Samples collected from the Philippines were mostly IR varieties with high average amylose content (28%). In the Philippines, consumers place a high value on lower amylose content. In Indonesia and Thailand, almost all samples had the preferred intermediate amylose content (20-25%) and consumers did not place any significant value on further reductions.



1. Changes in the composition of labor used in harvesting and threshing rice in Central Luzon, Philippines.

The national rice breeding program in Indonesia has developed several modern rices with intermediate amylose. Many of the Indonesia market samples we collected were locally developed modern varieties with intermediate amylose.

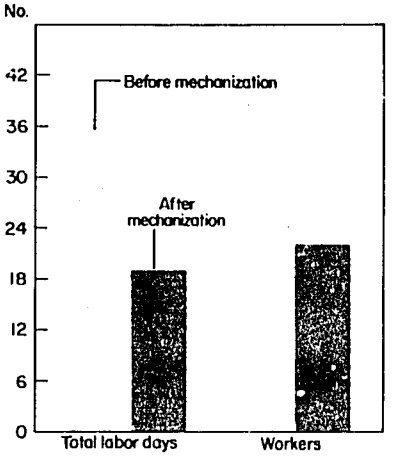
Other grain quality requirements varied among countries. There is considerable scope for international and national rice breeding programs to adapt modern rice varieties to local tastes and preferences.

Small farm mechanization and labor

In Central Luzon, Philippines, mechanical threshing results in less work for landless harvester-threshers than traditional techniques. Manual operations are now limited to cutting and hauling rice to a threshing area. Threshing and cleaning are mechanized.

Almost 100% hired labor is used for harvesting and threshing. Mechanical threshing has reduced labor requirements from 34 to 18.5 labor days/ha (Fig. 1) and the workers needed, from 39 to 21.6/ha. Most savings were in threshing, although mechanization also reduced labor necessary for harvesting and hauling.

Labor force composition changed when the axial-flow thresher was introduced (Fig. 2). Traditionally, more than 80% of the workers were male and less than 1% were younger than 15. Now, 36% versus 18% of the labor force are women, and the number of laborers under 30 years old have significantly increased. Participation of landless workers and their families has not changed.



2. Changes in total labor days and number of workers for harvesting and threshing.

Consequences of cropping systems and irrigation technology

We studied the macro effects on the rural economy of new cropping systems technology and irrigation in Oton and Tigbauan, Philippines.

New technology and irrigation increased the average annual growth of aggregate output to 9% and income to 6%. Employment grew more than population despite rapid farm mechanization. Income distribution changed to favor nonagricultural households and farm households with irrigated land. In general, rural income distribution did not improve.

New technology and irrigation strengthened the production and value-added linkages of the economy and weakened the import linkage. Agricultural employment linkages declined substantially and the production structure shifted from agricultural intradependence to agricultural and nonagricultural interdependence.

Technology and infrastructure changes generated 23% of output and 14% of income in 1979-80 and employment increased 15%. The multiplier effects were so strong that indirectly generated agricultural outputs became almost equal. New cropping systems technology had about twice the production impact of irrigation, but irrigation generated the most employment.

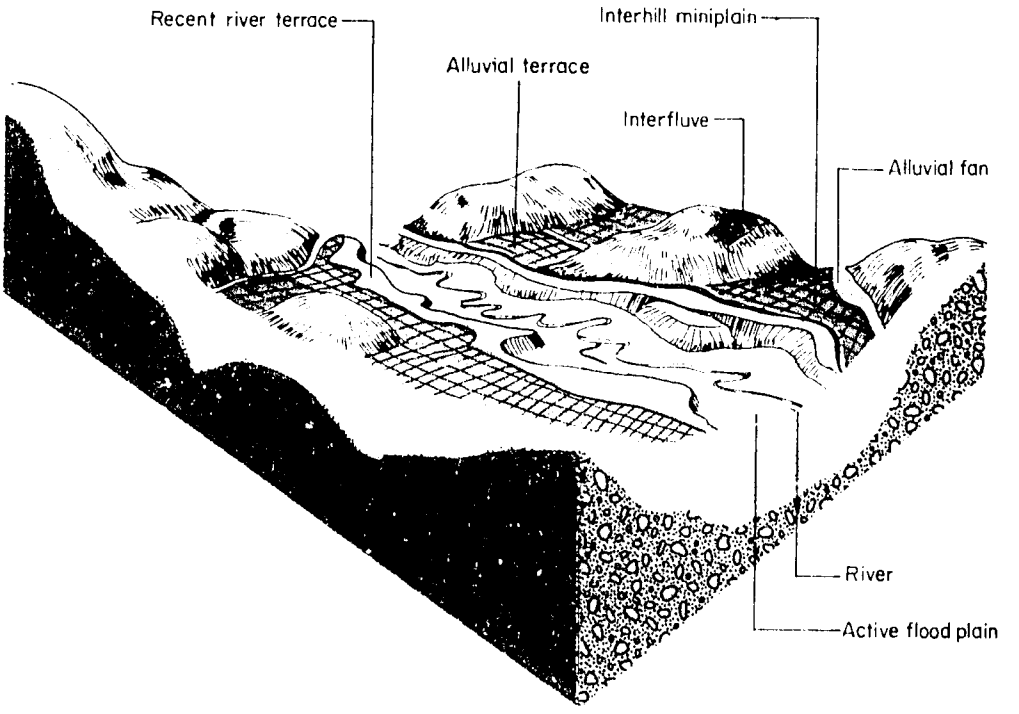
Direct income effects were strongest on irrigated and partially irrigated farms, followed by those on rainfed lowland farms. The income multiplier effects largely benefited nonagricultural households. Equity was adversely affected and the conflicts between growth and equity remain to be solved.

CROPPING SYSTEMS

ANALYSIS OF THE PHYSICAL AND BIOLOGICAL ENVIRONMENT

Environmental and social analyses are integral parts of farming systems research. Landform classification, long-term weather data, and simple social observations often provide a base on which to initiate a project. Refining those data during the project help fine-tune research objectives.

In the Cagayan River Basin of the Philippines we began by developing a land classification system and mapping major landforms in the project area. There are five landforms — alluvial terrace, recent river terrace, interfluve, interhill mini-



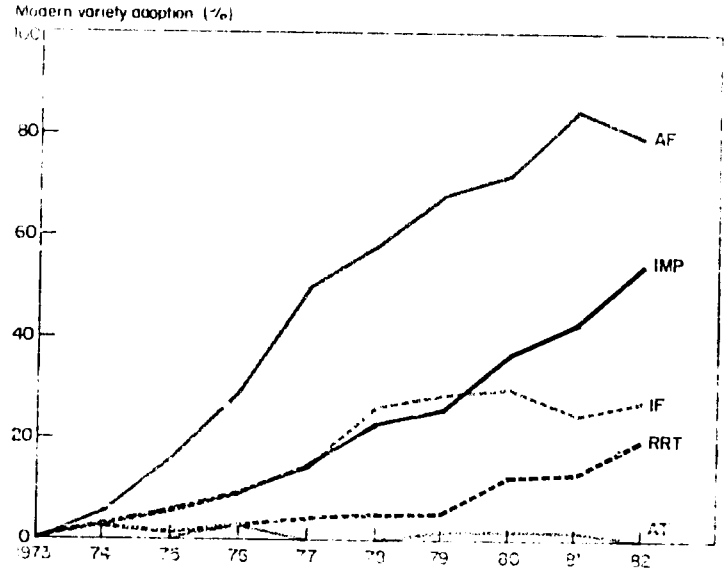
1. Landform units in the Cagayan Valley

plain, and alluvial fan (Fig. 1). The alluvial terrace is the largest and has the most adverse environment. Wet season throughout the area lasts 7 months, with intense periods of rainfall from June to November.

Ricelands on the alluvial terrace are drought- and flood-prone and few farmers plant modern rice varieties (Fig. 2). Most constraints to modern variety adoption derive from the extremely variable water regime. Drought and floods largely determine the timeliness of field operations and crop development and yield.

Although severe drought in 1983-84 caused low yields, crop-cut data from farmer cooperators' fields on each landform properly represent the relative productivities of the landforms and yield differences between modern and traditional varieties.

Largely because of the environment, we found there was little probability of modern variety adoption on unfavorable landforms, even with frequent extension worker contacts. On the more favorable alluvial fan, significant adoption occurred without extension contact. Our analysis showed that extension workers had the most effect on the interhill miniplain, which has an intermediate environment.



2. In the Cagayan Valley, modern variety adoption has been high on alluvial fan (AF) but almost nil on the alluvial terrace (AT). IMP = interhill miniplain, IF = interfluve, RRT = recent river terrace.

Modern rices can perform better than traditional, long-duration, low yielding varieties on the alluvial fan and interhill miniplain. Planting modern varieties will increase farmer options for crops grown before and after rice.

ANALYSIS OF CHANGES IN THE SOCIAL AND ECONOMIC ENVIRONMENT

Modern technology adoption

From 1975 until 1980, IRRI conducted on-farm cropping systems research at the municipalities of Oton and Tigbauan in Iloilo, Philippines. During that time, an irrigation system that services part of the area was constructed, modern rice varieties were adopted, and cropping patterns intensified.

We observed distinct differences in acceptance of modern agricultural technology in the municipalities. We compared the neighboring villages of Cordova Norte and Sipitan in Tigbauan to identify conditions of farmer adoption and consequences of modernization.

At Cordova Norte, almost all farmers grew modern rice varieties in 1984-85. At Sipitan, 52% of the cultivators planted modern varieties, 36% grew traditional varieties, and 12% grew both. At Cordova Norte, 45% of the farmers grew more than 1 rice crop that year; at Sipitan 23% grew more than 1 crop.

Different modern variety adoption is partially explained by dissimilarities in water control. At Cordova Norte, 33% of the farmers have irrigated land and 7% have partly irrigated fields.

At Sipitan, all land is rainfed; therefore, short-duration varieties are valued. Modern varieties, however, are not as popular as in Cordova Norte, where they are appreciated for high yield and good performance.

Dependence on local middlemen. Partly because of attitudinal and adoption differences and partly because of the marked contrast in accessibility between the two communities, we expected Cordova Norte farmers to participate more directly in markets outside their village than farmers from Sipitan, especially because more Cordova Norte farmers (56%) sell rice than Sipitan farmers (32%).

Our expectations were correct for fertilizer purchases. Significantly more Sipitan farmers bought fertilizer from local middlemen than did those from Cordova Norte. Rice sales did not confirm our expectations. All but one Cordova Norte farmer sold rice locally, even though outside markets are easily reached by tricycle, jeepney, and truck. At Sipitan, which is accessible only by a narrow track, more farmers sold rice outside the village.

In both communities, all farmers who sold rice outside had relatively larger farms and said they earned greater profits outside. Farmers who sold locally said they did so to avoid transportation costs and that middlemen were easy to sell to and gave prompt payment. Although most sellers to middlemen were small farms, about 30% had medium or large farms. Most farmers lacked or did not use a business network to sell on outside markets.

Changing labor opportunities for women

Work opportunities for women are at risk during transplanting and harvesting. The amount of transplanted rice is decreasing

Burmese women harvesting rice.

because farmers wet seed modern rices. Because both sexes do transplanting, labor reduction caused by the shift affects both men and women.

We expected sex discrimination at harvesting because farmers tend to prefer hiring men rather than men and women. Male laborers are appreciated because they are allegedly stronger and faster than women. We found that the threat to job opportunities for women was not related to modern rices, but to mechanization. We could establish no statistical relation between modern rice cultivation and mechanization in Cordova Norte and Sipitan. We intend to identify conditions under which changes that are negative for women can be avoided.

PEST CONTROL IN RICE-BASED CROPPING SYSTEMS

Crop intensification increases insect pests

The availability of photoperiod-insensitive, early-maturing modern rices has encouraged farmers to plant second, irrigated dry season crops. Insect populations have increased with cropping intensification.

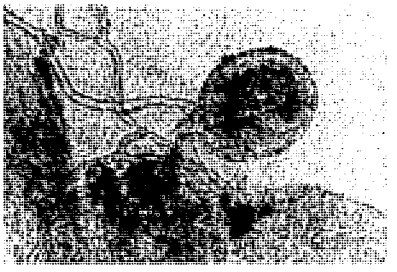
At IRRI, we have measured insect abundance since 1965. Light trap catches reflect insect populations on surrounding farms where improved irrigation in 1967-68 allowed farmers to plant a second dry season rice crop. Yellow stem borer catches are an example of the typical increase and reestablishment of new equilibrium populations of insect pests in response to crop intensification.

Insect carryover from wet to wet season, rather than population buildup within wet seasons, probably causes the higher pest numbers found with double cropping. After 1971, wet season populations decreased in the irrigated fields adjacent to the IRRI farm, probably because of a delayed buildup of natural enemies. Yellow stem borer peaks in dry season were highly correlated with the population in the following wet season, indicating the role of the dry season carryover.

Planting more area to rice and widely varying planting dates also increase insect pest numbers, particularly if nonresistant rices are grown. The least disruptive way to decrease insect problems and produce more food is to grow only two rice crops per year, plant only resistant varieties, and add nonrice crops to the system. A diversified cropping pattern would break the rice cycle and reduce pests. Populations decline further if rice crops are planted synchronously among contiguous farms.

Effect of mycorrhizae on upland crop diseases

Mycorrhizae, or fungus-root associations, exist in most soil-plant systems. They often provide plants with soil-derived



3. Mycorrhizal fungus associated with an upland rice root

nutrients and can alleviate root disorders. Mycorrhizal fungi also decrease infection by plant pathogens.

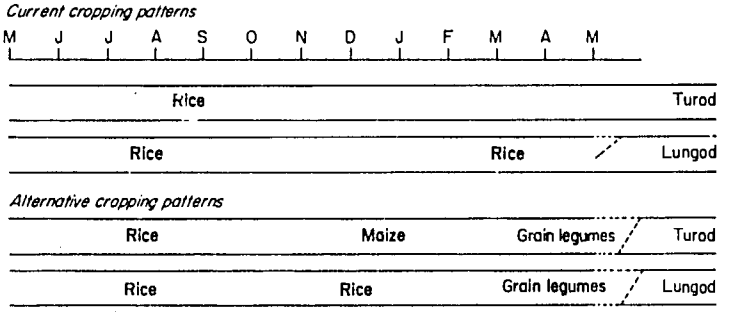
There are diverse plant-fungi interactions in rice-based cropping systems that include upland crops such as maize, mungbean, peanut, and cowpea (Fig. 3). We studied the ecology of mycorrhizal fungi and their relationship with associated crops to determine their proper management. Our evaluation sought to determine the nature and extent of mycorrhizal formation in various crops and the relative effects of specific mycorrhizal associations, particularly on major plant diseases in the cropping system.

A survey of Philippine soils from Manaoag, Pangasinan; Guimba, Nueva Ecija; Claveria, Misamis Oriental; and IRRI that had different cropping histories showed that lowland rice fields have spores of vesicular-arbuscular mycorrhizal fungi, but that they occur less frequently than in upland soils. *Glomus*, *Gigaspora*, and *Sclerocystis* species were found in all samples but their populations varied.

ON-FARM CROPPING SYSTEMS RESEARCH

In 1984 we initiated a cropping systems research site in Nueva Ecija, Philippines. Irrigation water at Nueva Ecija is limited and pumping is expensive. Our goal is to identify the most profitable use of water and to intensify cropping by emphasizing efficient water allocation and distribution. We are cooperating with the Philippine Ministry of Agriculture and Food, the National Irrigation Administration, and the Farmers Irrigation Association.

High water losses in Nueva Ecija adversely affect dry season rice cultivation but favor upland crops. Figure 4 shows the rice sequences farmers now cultivate on upper and lower fields. If irrigation water is available and farmers can perform necessary cultural operations, three annual crops are possible at both terrain positions.



4. Alternative cropping patterns for partially irrigated land in Nueva Ecija. *Lungod* is lower-lying than *turod* and easier to irrigate early in dry season. Water now distributed to 42% of the land for rice must be distributed over the entire command area to irrigate upland crops.

We found that farmers use pump irrigation to supplement rainfall in wet season and to irrigate rice on about 40% of the command area in dry season. We are working to improve water distribution so farmers in the command area can profitably cultivate two or three crops each year.

COMPONENT TECHNOLOGY

Selection and testing of cultivars

Varietal selection and evaluation of upland crops for rice-based farming systems is in collaboration with the Philippine Institute of Plant Breeding, national programs, the International Institute of Tropical Agriculture, the International Center for Research in the Semiarid Tropics, the International Center for Maize and Wheat, and the Asian Vegetable Research Development Center.

IRRI evaluated 127 sorghum varieties from ICRISAT and 30 were selected for more testing. The IRRI-IITA project expanded screening and selection activities in cowpea and soybean. We screened 760 advanced cowpea lines and 1,410 soybean lines.

We are working to identify dual-purpose legume crops, such as cowpea and pigeonpea, that yield grain, produce fodder for livestock, and grow after rice. Ten intermediate-duration cowpea varieties were evaluated. TVx 3671-14C-01D, TVx 2724-01F, TVx 3410-02J, TVx 1948-01F, and TVx 3310-02F yielded 1.4-1.9 t grain/ha and 12-19 t fodder/ha.

Nine vegetable cowpea lines from IITA were evaluated in wet and dry season. IT81D-1228-12 yielded well in both seasons and retained green foliage even after pod production stopped. The lines had multiple resistance to diseases such as powdery mildew, rust, bacterial pustule, and leaf spot.

We tested nine very early-maturing cowpea varieties after lowland rice. IT82E-56 yielded 1.2 t/ha in 62 days. Other promising lines were IT82E-13 and IT82E-77. Ten early-maturing cowpea varieties were evaluated before rice. IT82D-889 yielded highest and matured in 50-55 days.

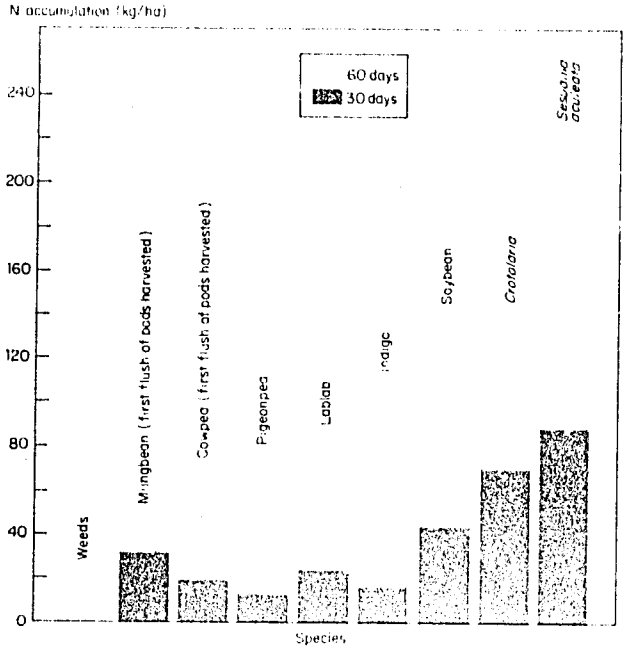
Early-maturing pigeonpea can grow after rice. Pigeonpea can be ratooned after harvesting the grain and a second grain crop will develop before the rice crop must be planted.

We evaluated 10 ICRISAT pigeonpeas. QPL-72 and TC(FC)-1-1 yielded 2.7 and 2.0 t beans/ha. Ratoons yielded less than 0.07 t beans/ha. TCF 6-1-1 produced the most fodder (9.9 t/ha) and QPL-72 the most ratoon fodder (20.1 t/ha).

Green manures

We are intensifying research to minimize the use of nitrogen fertilizer for rice by including legumes in cropping systems. Of

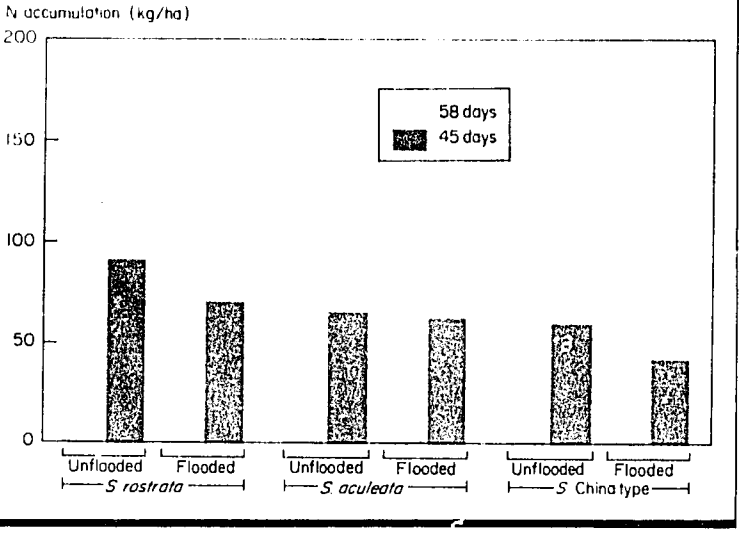
5. *S. aculeata* accumulated more nitrogen than other green manure crops at 30 and 60 days.



nine green manure species tested, *Sesbania aculeata* accumulated the most nitrogen (Fig. 5).

Because green manure crops grown before rice often are flooded, we tested three *Sesbania* species for their performance when flooded during the last 25 days of growth. Stem-nodulated *S. rostrata* accumulated more nitrogen than the other species when planted early or late and with or without flooding (Fig. 6, 7). Incorporating 58-day-old, unflooded *S.*

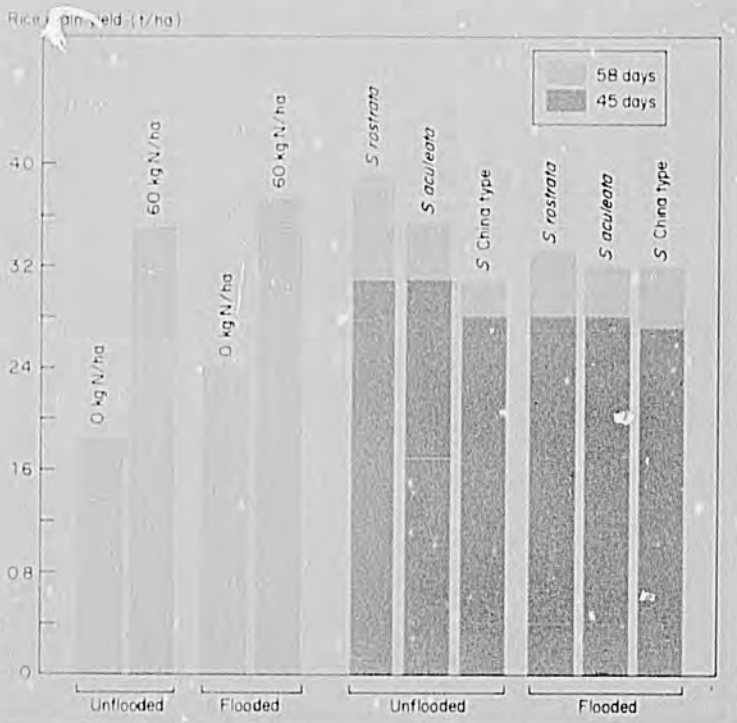
6. *S. rostrata* accumulated more nitrogen than *S. aculeata* or *S.* "China type." Nitrogen accumulation in all species decreased an average 18% when they were flooded during the last 25 days of growth.



7. a) *S. rostrata* roots in standing water. They exhibit fibrous rooting that is typical of aquatic plants. b) Roots removed from soil and water. Root systems were more fibrous on plants in standing water for 25 days.

rostrata produced the highest grain yield (Fig. 8). Rice yield response to green manure and nitrogen fertilizer was highest in plots not flooded before planting.

In 1984, we studied the response of irrigated, wet season rice to fertilizer nitrogen after green manuring, residue removal,



8. Incorporating 58-day-old, unflooded *S. rostrata* produced the highest rice yields.

9. Intercropping cowpea with upland rice increased protein production.

incorporated unweeded fallow, and incorporated fallow plus farmyard manure. *S. aculeata* was incorporated; maize fodder and mungbean residue were removed; unweeded fallow residue was incorporated; and unweeded fallow and farmyard manure were incorporated. Rice yield after incorporating green manure approximately equalled yield with 100 kg N/ha applied to rice after maize fodder and 50 kg N/ha after the other treatments.

Intercropping

Legume crops can improve protein production where upland rice is produced. Total crude protein produced almost doubled when 1 row of cowpea replaced 2 of 10 upland rice rows (Fig. 9). Although most of the increase came from the cowpea grain, protein content of rice grain increased from 6.3 to 7.1%.

Although upland rice + cowpea intercropping increases protein production, the cowpea variety we planted was highly competitive and sharply reduced rice yields. We evaluated several cowpea varieties with different growth habits for intercropping with upland rice. IT82D-889 yielded well but did not sharply depress rice yield. IT82D-889 is a determinate, 60-day variety from the International Institute of Tropical Agriculture.

AGRONOMIC MANAGEMENT IN RICE-BASED CROPPING SYSTEMS

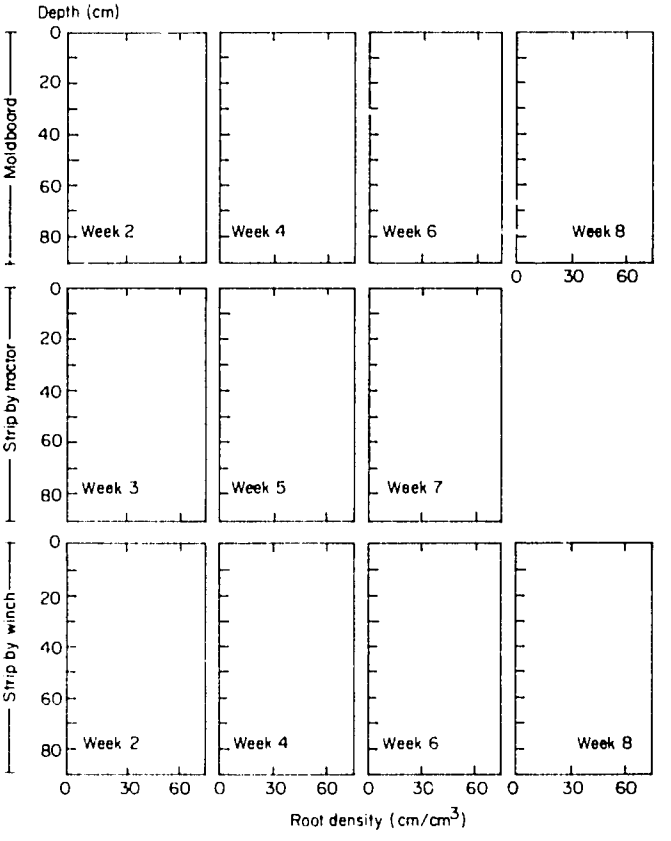
Tillage in a rainfed lowland cropping sequence

Dry bulk density of a puddled rice soil typically varies from 0.4 t/m^3 near the surface to 1.2 t/m^3 or more below 20 cm.

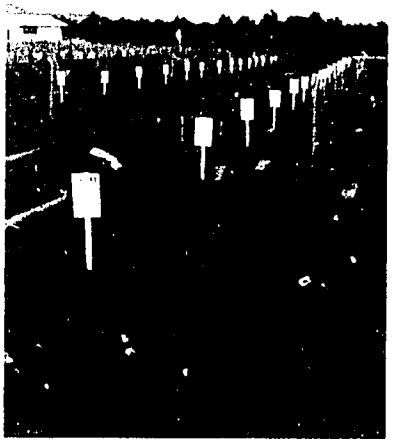
10. Cable-winch tillage implement used for strip tillage in mungbean plots.

Increased bulk density implies a loss of transmission pores, which is desirable for lowland rice because it reduces percolation of water. During the second phase in a rice - nonrice cropping system, the drier soil has increased shear strength, which may restrict or prevent downward root growth.

We disrupted the compacted layer of a Typic Tropaquept clay loam puddled rice soil by tillage to 35 cm along strips 0.4 m apart. As soon after tillage as possible we planted mungbean seeds along the strips. On plots cultivated by a single tine, whether pulled by a tractor or by a cable-winch system (Fig. 10), roots grew to 60 cm 2 weeks earlier than in conventionally tilled plots (Fig. 11). For plantings made 4 days after the field was drained, yields were 2.0 t/ha. For planting at 6 days, yields decreased to 1.6 t/ha. Yields on all treatments at both planting dates were high. Plots were not fertilized or irrigated, but weeds and insects were controlled. There was little rainfall and the plants utilized water stored in the profile, which satisfied about 75% of the potential water requirement of 250 mm. Precision manual seed-planting ensured uniform



11. Effect of tillage on mungbean root distribution.



12. Precision manual planting ensured uniform mungbean density.

13. N. Fortuno and L. Malabayabas measure water infiltration rate in a rice field after 4 years of legume green manure incorporation.

plant density (Fig. 12), which promoted efficient use of sunlight and stored water.

The experiment also showed the importance of depth of soil above natural layers of different structure and higher mechanical strength. Each 13 cm additional soil depth above the natural layers was associated with 100 kg higher yield/ha.

Soil physical effects of green manures and crop residues

It takes about 200 mm depth of water to puddle soil for rice. In some rainfed lowland cropping systems, it may take several weeks to accumulate 200 mm of rain at the beginning of wet season. In those weeks it may be possible and profitable to grow a legume green manure that could provide 80 to 100 kg N/ha for the ensuing rice crop, and could also increase transmission pores and encourage deep rooting.

Four years' incorporation by rototilling of legume green manures and residues of rice and other crops had only slightly affected topsoil porosity and water infiltration rate (Fig. 13). Annual incorporation of much greater quantities of green manure (as in the ongoing sesbania experiments) may cause larger effects on soil physical properties and crop rooting.

ASIAN RICE FARMING SYSTEMS NETWORK

In our collaborative work we emphasize distribution of improved upland crop varieties developed at national and international centers. The Asian Rice Farming Systems Network now includes more than 180 active national research sites, all working to identify ways of increasing production from and profitability of rice-based farming systems. The sites are managed by national cropping systems or farming systems programs. Bhutan, Malaysia, Pakistan, and Vietnam joined the network in 1984.

Currently, animal enterprises are the most profitable components of Asian farming systems. Although the complexities of animal research in rice-based farming systems prevent detailed experiments, the strong interest of network participants led to a workshop to discuss establishing a few research sites where the animal component will be studied as part of the system.

With special support from the International Development Research Centre of Canada, five research sites were identified for the project: Santa Barbara, Philippines; Ban Phai, Thailand; Pumdi Bhumdi, Nepal; Batumarta, Indonesia; and Galnewa, Sri Lanka. The Philippine and Thailand projects began in 1984. Nepalese researchers began monitoring the livestock component in Pumdi Bhumdi and added oats to cropping pattern trials to provide animal feed.

Crop-livestock research in Santa Barbara will emphasize meat and draft cattle (Fig. 14). Crop components include rice, mungbean, cowpea, peanut, and maize. Farmers cooperating in the project are making all management decisions, but

14. Crop-livestock research in the Philippines will emphasize meat and draft cattle.

national researchers have provided for regular feeding of *Leucaena* and mineral blocks and planting of forage crops around the homestead. Component technology research also is conducted by IRRI on crops and the Philippine Institute of Animal Science on animals.

Participants in the Thai project are the Farming Systems Research Institute, the Department of Agriculture, the Office of Agricultural Economics, the Department of Livestock Development, and Khon Kaen University. Ban Phai is representative of northeast Thailand. The area is relatively dry, with rainfed rolling hills where rice fields are terraced and bounded by uplands. In addition to meat and draft cattle, crops include rice, cowpea, peanut, cassava, maize, and fodder.

MACHINERY DEVELOPMENT AND TESTING

Machinery for efficient utilization of inputs

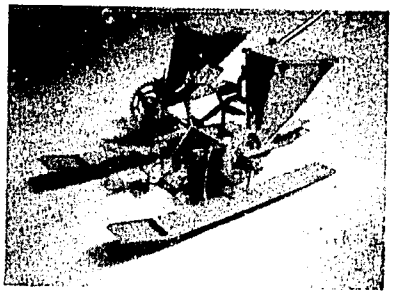
Fertilizer deep placement and direct-seeded pregerminated rice seeds can reduce cash inputs and increase rice yields. In 1984, we worked to develop better fertilizer placement and seeding equipment.

Fertilizer injectors. The spring auger prilled urea applicator developed in 1983 has performed well. We improved its metering accuracy by extensive laboratory and field tests.

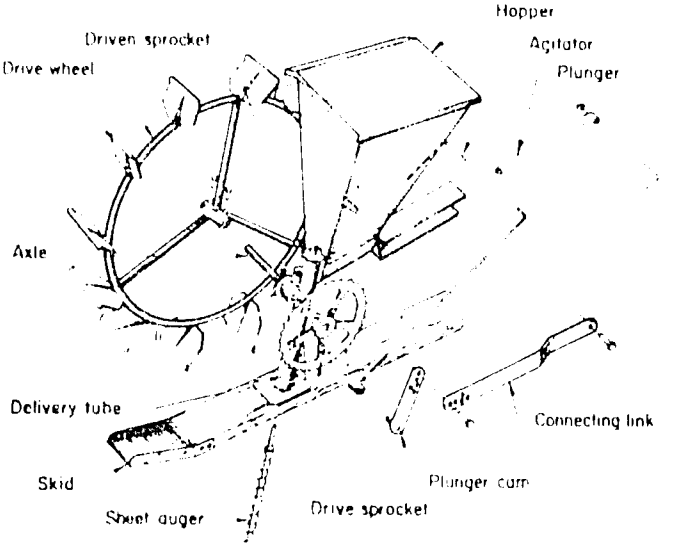
We designed a plunger-auger machine (Fig. 1, 2) that meters fertilizer with a plunger and injects it into puddled soil with a sheet auger.

The plunger-auger applicator performed well with different prilled urea fertilizers and in varying field conditions. It can apply fertilizer at 3 rates in 5-cm-deep flooded soils with 10% accuracy. In 1984 wet season, tests in 24 farmers' fields in Laguna, Philippines, indicated that use of the applicators increased fertilizer use efficiency an average 49% over farmer methods.

We are field-testing the applicators more widely to assess problems, farmer reactions, and machine durability. The information we gather will help introduce the applicators to manufacturers and farmers in Asian rice producing countries.



1. Plunger-auger prilled urea applicator



2. Plunger-auger applicator in use

Direct seeder for pregerminated rice

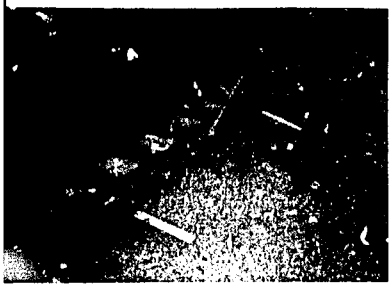
Interest in direct seeding pregerminated rice in puddled soils is increasing as transplanting costs rise. We developed a new 10-row seeder (Fig. 3) based on experience gained with 2 earlier IRRI seeders. The machine uses a roller-type seed metering mechanism. Small protruding pins pull pregerminated seeds for the hoppers. Pin height is adjusted to set the seeding rate.

Because the hardpan varies from field to field and within the same field, wheel-supported machines cannot maintain a uniform relationship with the soil surface, thus causing irregular seed placement. Our seeder has two narrow skids that support it on the soil. The machine glides on the skids, thus maintaining a uniform seed-drop distance and uniform seed placement.

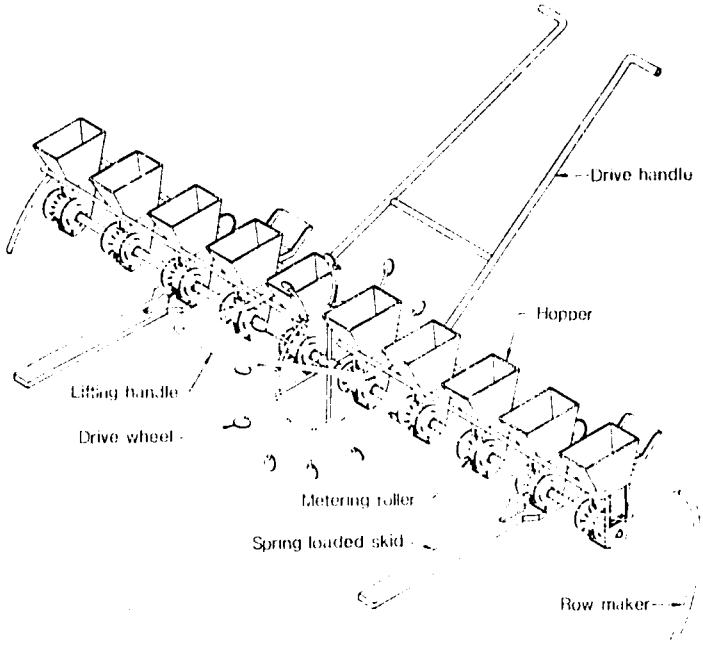
The seeder has a single wheel that drives the metering mechanism and is the transport wheel. The single wheel allows the operator to turn the machine in a sharp U for the next pass through the field. The 10-row seeder weighs 10 kg, and is easy to pull while walking forward or backward. It is being tested in different parts of the Philippines.

Industrial liaison

IRRI works with farm mechanization programs in several countries to help introduce small machinery to farmers and



3. Ten-row seeder for seeding pregerminated rice in puddled soils.



village manufacturers. We initiated a collaborative program at Coimbatore, India, and continued our activities in Burma, Egypt, Indonesia, the Philippines, and Thailand.

In collaboration with the Philippine Ministry of Agriculture and Food, we modified the axial-flow thresher to shell maize (Fig. 4). The modification cost is about $50 and the machine will help in marketing yellow maize.

4. Axial-flow maize sheller.

5. Foot pump for vegetable irrigation

A low-cost manually operated foot pump was developed for rice farmers who grow vegetables in dry season (Fig. 5). The pump, designed in Bangladesh, was introduced to Philippine farmers.

A video tape showing mechanization was produced in Indonesia and Thailand. In Thailand, the tape is distributed in the local language. The mechanization program in Thailand is intended to increase yields and reduce the drudgery of subsistence farmers who depend primarily on human power for crop production.

IRRI reapers, threshers, and transplanters are being introduced in Egypt to farmers who currently use human and animal labor. A farm labor shortage in Egypt requires the rapid introduction of machinery to maintain high production in irrigated areas.

In Africa, 90% of all farm operations use hand labor. To relieve drudgery and make more productive use of land, small suitable machines will be essential. IRRI-designed machines have been introduced in several African countries and collaboration will be developed with several interested national programs and with farming systems programs and scientists at the International Institute of Tropical Agriculture.

TRAINING

Training courses

In 1984, 517 scholars and fellows from 40 nations participated in IRRI training and educational programs. Among them were 55 senior and postdoctoral research fellows, 16 visiting research fellows, 180 MS and Ph D candidates, and 33 nondegree scholars. Additionally, 210 short-term trainees attended regular and special training courses.

Courses included Genetic Evaluation and Utilization, International Network on Soil Fertility and Fertilizer Evaluation for Rice, Cropping Systems Training, Agricultural Engineering, Upland Rice Training, Integrated Pest Management, Irrigation Water Management, Rice Production Training, Agricultural Economics, and Farm Managers.

The first course on *Pest Management for Deep Water Rice* was in Thailand in October 1984. The course, organized by the Thai Rice Research Institute and IRRI, emphasized new methods for pest management in deeply flooded, broadcast-seeded fields. More than half the course was field work and demonstrations. Eleven trainees from Bangladesh, India, Indonesia, the Philippines, and Thailand participated.

New training courses

We prepared three new training courses for 1985. The *Rice Genetic Resources Conservation and Utilization Course* will be a 1-year program. Trainees will spend 3 months collecting indigenous rice germplasm from fields in their home countries, then come to IRRI for lectures on genetic conservation and field and laboratory work to characterize their collections.

Improving Income and Employment in Rice Farming Systems will be a 1-week course for senior research scientists, administrators, and planners working in national rice production programs. The course will include lectures and field visits to learn about productive, input-efficient, rice-based cropping systems; rice farming systems design that considers ecology, economics, and employment generation; preparing value added products from rice straw, bran, and hulls; and post-harvest processing.

Statistical Procedures and Computer Applications in Agricultural Research is a 2-month course that will familiarize working statisticians from national research centers with new

Students in the IRRI Rice Production Training Course learning how to establish a dapog seedbed.

statistical procedures and research techniques as applied to agricultural research.

IRRI also has helped plan and will participate in the course *Systems Analysis and Simulation in Rice Production and Its Use in Research and Technology Transfer.* The course will provide knowledge and practical experience on the application and adaptation of simulation models related to research and extension in national programs.

Developing new country courses

We are intensifying efforts to help collaborating countries build training programs. In 1984, IRRI training specialists visited Bhutan to help develop and offer a 2-week rice production course. Visits also were made to India.

Education symposium

We collaborated with the Committee on Science and Technology in Developing Countries and the Asian Association of Colleges and Universities of Agriculture to sponsor a Symposium on Education for Agriculture. The 36 participants included vice chancellors from agricultural colleges and universities, and senior representatives of ministries of agriculture and education, the agribusiness sector, international agencies that support training programs, and farmer organizations.

Recommendations were drafted to assist international and national agricultural research centers to collaborate with agricultural universities to offer nondegree training programs that will help provide well-trained agricultural personnel to work for government, private sector, and university programs. Computer technology for managing teaching and training programs also was discussed.

COOPERATIVE RESEARCH

Although IRRI has always emphasized cooperative research at many different levels, in 1984 we explicitly recognized the importance of such cooperation by adding program area 1100, Cooperative Research.

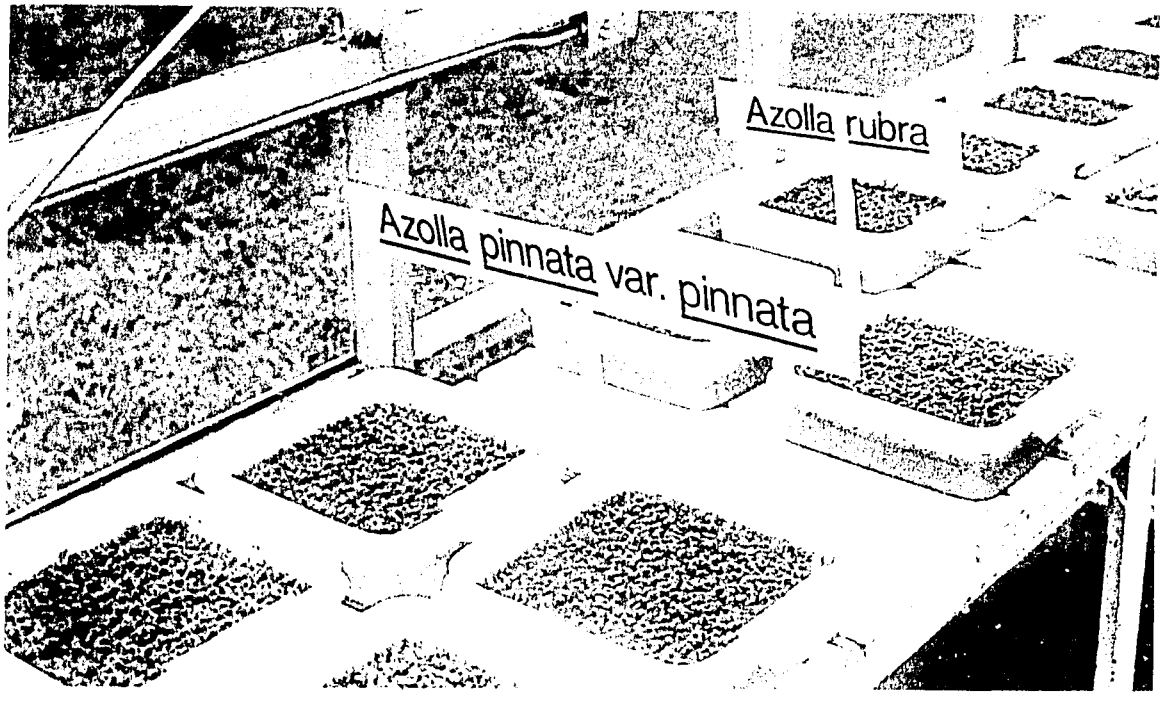
Our research and dissemination programs utilize seven major pathways of cooperation: global research services, networks, country programs, cooperative research, collaboration with advanced institutions, training and technology transfer, and knowledge sharing (Table 1).

Global research services

Germplasm collections. Global services such as the International Rice Germplasm Center and the azolla and blue-green algae collections team with international and national research programs and individual scientists to conquer genetic erosion.

Table 1. Pathways of cooperation between IRRI and other scientists and institutions.

Pathway	Examples
Research services	International Rice Germplasm Center, azolla germplasm
Networks	International Rice Testing Program, International Network on Soil Fertility and Fertilizer Evaluation for Rice, Asian Rice Farming Systems Network
Country programs	Resident scientists Scientist-scientist
Cooperative research	Hot spot screening Shuttle breeding Farm machinery
Collaboration with advanced institutions	Organizations (United States Agency for International Development, Institute for Research in Tropical Agriculture of France, German Agency for Technical Cooperation, Overseas Development Agency of the United Kingdom, etc.) Universities and institutes International centers (International Institute of Tropical Agriculture, West Africa Rice Development Association, International Centre of Insect Physiology and Ecology, International Food Policy Research Institute, International Fertilizer Development Center, etc.) Individual scientists
Training and technology transfer	Los Baños In-country Joint
Knowledge sharing	Seminars, monitoring tours Bibliographic services Publications



The azolla collection includes six species.

In 1984, major rice germplasm collection efforts were made in Bhutan, Sri Lanka, and Indonesia. The azolla collection, which is maintained in controlled growth chambers, contains six species. The blue-green algae collection includes 78 strains. Interested scientists receive samples from these collections at no charge.

Data management. National agricultural research organizations are using more on-farm trials to test new technologies. Because of differing physical, environmental, social, and economic conditions, on-farm trials often are conducted at many sites and information collected may include not only the performance of new technologies but also descriptions of local farming conditions.

Speedy data analysis is essential for on-farm trials be successful. Often, the complex nature and large volume of data slow program implementation because suitable computer facilities and trained personnel are unavailable.

We initiated a cooperative project with the Philippine Ministry of Agriculture and Food to develop a generalized microcomputer-based data management system for on-farm trials in national programs. The system includes

- data entry to facilitate data encoding and editing;
- a data base for information storage and retrieval; and
- a system for data analysis, summarization, and report generation.

By the end of 1984, four Philippine agricultural regional offices were using the system.

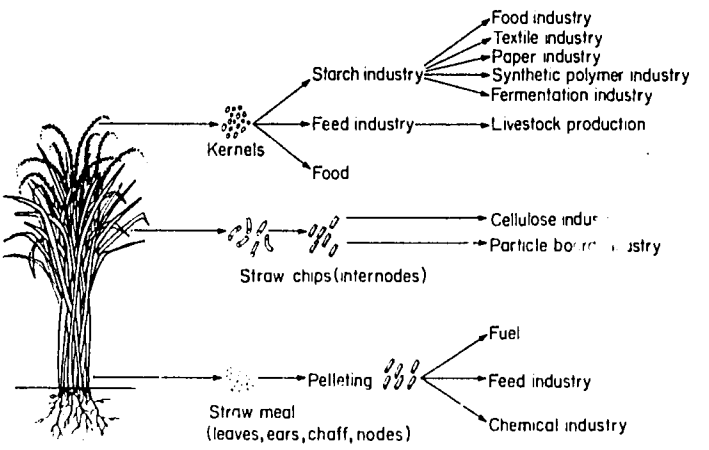
Networks

Networking promotes institutional and individual interaction and communication. The International Rice Testing Program celebrates its 10th anniversary in 1985. Ten years ago, it had 12 nurseries and contact scientists in 46 countries. In 1984, it had 24 nurseries with 2,500 entries and trials in 53 nations. Hundreds of national scientists have participated in meetings and monitoring tours in Asia, Latin America, and, most recently, East Africa, where they observe local conditions, rate nursery entries, and learn more about each other and mutual and special problems.

Our newest network, the Asian Rice Farming Systems Network (ARFSN), concentrates on development and testing of component technologies for farming systems. Goals are to intensify farming and thereby produce more food, income, and jobs in rice growing areas.

In cooperation with the University of the Philippines at Los Baños (UPLB), IRRI has developed a rice farming systems demonstration on the theme *Prosperity Through Rice*. Farm objectives are to demonstrate efficient production and utilization of the rice biomass in irrigated rice-based farming systems and to maximize income and employment through crop intensification, crop integration with livestock and aquaculture, and crop residue utilization for manufacturing value-added products.

Potential utilization of rice by-products to increase income and employment in agriculture.



The farm includes rice-based cropping patterns, livestock, azolla propagation, mushroom culture, compost making, home vegetable gardening, and biogas generation. The biogas generation project is in collaboration with the Korean Office of Rural Development. The biogas generators use rice straw and animal manure.

Cooperative country projects

IRRI has resident liaison scientists working in Africa, Bangladesh, Burma, Egypt, Indonesia-Malaysia, Latin America, the Philippines, and Thailand. They work as members of the national rice research teams and collaborate with extension personnel from national agricultural development programs and universities and facilitate cooperative research between local agricultural centers and IRRI.

Each program focuses on work identified by the host country. In Egypt, for example, there are three main research areas: extension, breeding, and agricultural engineering. Living and working closely with host country scientists also allow us to study special problems, such as deep water rice in Thailand, in their natural environments.

Our program in Madagascar began in 1984. An IRRI rice breeder and an agronomist are working with the national rice research program to develop material and management procedures to help improve rice yield.

Collaborative research

Cooperative in-country research allows us to take advantage of the wide variability in rice growing and socioeconomic environments in different nations. Particularly important is the ability to test varieties for insect pest and disease resistance and adverse soils tolerances at hot spot locations, and to carry on shuttle breeding for more rapid development of varieties suitable for adverse environments.

For example, we have a long-term collaborative breeding program for cold tolerance with Korea. In summer, varieties are screened for cold tolerance in Korea. In winter, their progeny are grown in low-temperature conditions in Banaue, Philippines. Thus, new varieties can be developed and tested twice as fast as they could at only one location.

We also cooperate with several national programs in machinery development and testing. In Burma, we successfully tested and modified the IRRI 6-row transplanter and a reaper, the prototype of which was developed in China. Egypt and Indonesia also are active cooperators in the machinery development and testing program.

A. C. F. Trevitt, Commonwealth Scientific and Industrial Research Organization of Australia, is working with IRRI to quantify nitrogen loss through ammonia volatilization.

Collaboration with advanced institutions

We regularly work with developed country organizations such as the United States Agency for International Development and the German Agency for Technical Cooperation (GTZ) that fund special research and information dissemination programs. In 1984, GTZ helped establish new physical sciences laboratories at IRRI. GTZ is a longtime collaborator in soils related research. The agency also helped sponsor, for the second year, a book exhibition at the Frankfurt Book Fair that included publications of 22 international agricultural research centers (IARCs).

We work with scientists and programs of several national research organizations. These include the Institute for Research in Tropical Agriculture of France, upland rice research; the Asian Vegetable Research Development Center, component crops for farming systems; the International Fertilizer Development Center, chemical fertilizers and nutrient losses; the International Institute of Tropical Agriculture, rice and component crops; the International Center of Insect Physiology and Ecology, planthopper physiology; and the International Food Policy Research Institute, rice policy research in Asia.

We also cooperate with institutes and universities such as UPLB, the University of Reading, the University of Durham, and the University of California at Davis.

Training and technology transfer

Our programs in training and technology transfer have several levels. More than 3,000 national rice scientists have attended IRRI's instruction courses, which are oriented to training in research methodology and rice production techniques. Non-degree courses include agricultural engineering, agro-economics, cropping systems, integrated pest management, plant breeding, and upland rice.

We also assist national programs to set up training programs in areas such as rice production and germplasm collection and maintenance. In 1984, we helped Bhutan set up training for extension workers and worked with Indonesia and other countries in germplasm collection.

In the Philippines, we exchange information with regional representatives of the Ministry of Agriculture and Food at twice yearly, 2-day meetings. The meetings update regional workers on new technologies and help us know how previously discussed technologies are performing and what are significant new field problems.

MS and Ph D students plan their course of study and attend classes at UPLB, and carry out thesis and dissertation research at IRRI. Many of these students return to their home countries to take leadership positions in national programs. General guidance of the degree training program is provided by the IRRI Academic Council, which includes representatives of several academic institutions.

Knowledge sharing

Knowledge sharing is essential to our work, particularly because many of our clients have limited information and communication resources. Regular seminars and conferences at IRRI and in rice growing nations around the world involve country scientists with international scientists, giving both broader perspectives in technology development.

Through IRTP monitoring tours and INSFFER soil classification tours and workshops, scientists and extension workers participate in hands-on evaluation of new varieties and lines and management practices. Conferences such as the Rainfed Lowland Rice Workshop in Bhubaneswar, India, in October 1984, bring international scientists together and, perhaps more importantly, include many local researchers who might not otherwise have the opportunity to interact with such a range of experienced workers.

Bibliographic and library services facilitate the location and dissemination of information that often is unavailable in other libraries. Each year we publish supplements to the *International bibliography of rice research*, which are widely circulated

among libraries in the rice world. Additional bibliographies include the *International bibliography on cropping systems* and that on azolla.

Through its Tokyo office, the IRRI library translates many journal articles and books from Japanese to English, thereby making their contents available to a much bigger audience.

Books and newsletters are important to good communication. In 1984, we distributed more than 6,000 books and released 21 major publications. IRRI educational materials were exhibited in book fairs in China, Germany, Mexico, India, and the United States. To encourage further distribution of books from the IARCs, IRRI, in cooperation with the Consultative Group for International Agricultural Research, published a book catalog that describes more than 1,000 IARC titles and tells how to get them.

Through a survey of translators and publishers of non-English editions of IRRI books, we found that at least 116 editions had been or were being copublished in 34 languages by 48 agencies in 25 countries (Table 2) The most popular titles for copublication were *A farmer's primer on growing rice* and *Field problems of tropical rice.*

P. V. P. Singh, IRRI postdoctoral fellow, and Mrs. Veronica Lasconia of Iloilo, Philippines, comparing iron toxicity symptoms in her fields with those illustrated in Field problems of tropical rice.

Table 2. Copublication status of 19 IRRI books.

Title	Copublished editions (no.) Printed	In press
Farmer's primer on growing rice	25[a]	15
Field problems of tropical rice (1st edition)	10[b]	0
Field problems of tropical rice (2nd edition)	7[c]	21
Production of seedlings	4[d]	0
Rice improvement	4[e]	0
Fundamentals of rice crop science	1[f]	3
Illustrated guide to integrated pest management	0	5
Others	18	7
Total	69	51

[a]Bahasa Indonesian (2 editions), Bahasa Malaysian, Bengali, Burmese, Cebuano, Chinese (2 editions), French, Gujarati, Hiligaynon, Ilokano, Kannada, Nepali, Oriya, Parsi, Spanish (2 editions), Swahili, Tagalog, Tamil, Thai (2 editions), Urdu, Waray. [b]Bahasa Indonesian, Bengali, Burmese, Hindi, Nepali, Tagalog, Tamil, Telegu, Urdu, Vietnamese. [c]Bengali, French, Spanish, Tagalog, Thai, Vietnamese, Waray. [d]Gujarati, Gujarati and Hindi, Hindi, Telegu. [e]Chinese, Korean, Spanish, Vietnamese. [f]Chinese, Japanese, Spanish, Vietnamese.

FINANCES

Summary of financial support to IRRI core and special projects received in 1984[a]

	Core		Special	
	Unrestricted	Restricted	Projects	Total
United States Agency for International Development	$ 5,301,007 00	$ --	$1,760,781 78	$ 7,061,788 78
Japanese Government	--	3,331,320 14	199,959 19	3,531,279 33
United Nations Development Programme	--	1,530,200 00	320,264 57	1,850,464 57
European Economic Community	--	1,412,708 50	--	1,412,708 50
Canadian International Development Agency	1,233,920 00	--	133,157 19	1,367,077 19
International Fund for Agricultural Development	--	1,300,000 00		1,300,000 00
International Bank for Reconstruction and Development	1,120,000 00	--	--	1,120,000 00
Overseas Development Administration, United Kingdom	920,890 00	--		920,890 00
IBM World Trade Americas	--	--	762,582 61	762,582 61
International Development Research Centre	--	148,867 00[b]	489,325 52	638,192 52
Federal Republic of Germany	456,772 50	27,676 00[b]	127,074 85	611,523 35
Australian Government	515,691 00	--	--	515,691 00
Government of Sweden	368,856 95	--	--	368,856 95
Ford Foundation	150,000 00	--	120,633 60	270,633 60
Government of the Philippines	164,532.19	--	45,609 17	210,141 36
Government of Denmark	190,305 02	--	--	190,305 02
Government of Brazil	150,000 00	--		150,000 00
Swiss Federal Council	--	148,526 56[b]	--	148,526 56
Government of Belgium	115,524 75	--	17,773 04	133,297 79
Government of the Netherlands	--	94,951 92	14,432 96	109,384 88
Government of China	100,000 00	--	--	100,000 00
Soil Management Support Services of the University of Hawaii at Manoa	--	--	83,600 00	83,600 00
International Institute of Tropical Agriculture[c]	--	--	78,005 74	78,005 74
International Centre of Insect Physiology and Ecology[c]	--	72,856 09[b]	--	72,856 09
Office of Rural Development, Korea	--	--	59,000 00	59,000 00
International Fertilizer Development Center[c]	--	--	57,917 53	57,917 53
Government of Italy	52,593 00	--	--	52,593 00
Rockefeller Foundation	--	--	52,000 00	52,000 00
International Food Policy Research Institute[c]	--	--	38,550 69	38,550 69
Government of Spain	25,000 00	--		25,000 00
Asian Development Bank	--	--	19,700 00	19,700 00
Government of the Islamic Republic of Iran	--	--	19,315 73	19,315 73
Government of New Zealand	16,605 00	--		16,605 00
Government of India	2,252 00	--		2,252 00
Others[d]	--	--	207,785 11	207,785 11
	$10,883,949 41	$8,067,106 21	$4,607,469 28	$23,558,524 90

[a]Receipts are accounted for on a cash basis. [b]Transferred projects since 1983. [c]Funds received in support of collaborative research. [d]Other donors were Resources Management International, Inc., Indonesia, $72,840; International Board for Plant Genetics Resources, $33,300; Food and Agriculture Organization of the United Nations, $31,778; Norsk Hydro A.S., $17,778; Imperial Chemical Industries, $10,000; International Potash Institute and the Potash Phosphate Institute, $9,000; Hoechst, $5,025.13; Ciba-Geigy, $5,000; Monsanto, $4,020.67; Du Pont Far East Inc., $3,015.08; FMC International, $3,000; SKW Trosberg, $3,000; Stauffer Chemicals, $3,000; Shell Chemicals Co., $2,532.93; American Cyanamid, $2,000; KenoGard, $1,000; Nippon-Kayaku Co., Ltd., $995.09; Wacker-Chemie GmbH, $500. USAID donated excess property of an indeterminable value. Briggs and Stratton Corporation, USA, donated 11 Briggs and Stratton gasoline engines of assorted horsepower. The governments of France (ORSTOM and IRAT) and the Netherlands provided the Institute with visiting scientists, the value of their services cannot be quantified.

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*Left during the year
**On study leave
***Joined and left during the year
****Joined during the year
*****Left and rejoined during the year
˙Cooperative research staff
++Died