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IRRI HIGHLIGHTS 1987

INTERNATIONAL RICE RESEARCH INSTITUTE

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INTERNATIONAL RICE RESEARCH INSTITUTE
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The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today IRRI is one of the 13 nonprofit international research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR). The CGIAR is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 50 donor countries, international and regional organizations, and private foundations.

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". . . to conduct research on the rice plant, and on all phases of rice production, management, distribution, and utilization, with the objective of improving the nutritive and economic advantage or benefit of the people of Asia and other major rice-growing areas of the world . . ." IRRI MANDATE

IRRI is acutely aware of its responsibilities in examining the interdependencies, interactions, synergisms, and impacts of all aspects of rice culture. Our work in 1987 built upon the breakthroughs and steady advancements in increasing the production of rice in the many environments in which it is grown around the world.

We recognize the increases in rice production that are needed in the next 10 years, and beyond. The challenge is to defend earlier gains as we strive for increased gains. In Asia, where land for the expansion of agriculture is limited, this means intensification—increasing both yield per crop and crops per year. This must be achieved within the context of sustainability—conservation of soil, nutrient, and water resources.

We realize that achievements in our research must ultimately result in benefits to people—in food to eat, in income to enhance the quality of life, in relief from subsistence drudgery, in opportunities for personal fulfillment by all members of low-income farm families.

These highlights of IRRI research during 1987 are brief vignettes of some of the interactive programs through which we work to advance knowledge and technology across the cutting edges of the many elements that result in rice productivity.

Earlier achievements of IRRI scientists drew world recognition this year. Two awards in particular must be highlighted.

Two IRRI scientists were awarded the 1987 Japan Prize for their roles in the development of the improved semidwarf varieties that were the breakthrough that dramatically increased rice yield potential. Mr. Henry M. Beachell, former IRRI plant breeder, and Dr. Gurdev S. Khush, head of the IRRI plant breeding department, shared Japan's most prestigious scientific recognition.

Beachell, who joined IRRI in 1963, was honored for his part in developing IR8, the first semidwarf rice variety with the potential to double yields in the tropics. Khush, who joined IRRI in 1967, led the effort that developed IR36, a variety with genetic resistance and tolerance for dozens of diseases, insects, and environmental stresses.

The world rice situation

In 1987, world rice production dropped below requirements, the result of prolonged drought in India, Indonesia, Kampuchea, Laos, Philippines, Sri Lanka, Thailand, and Vietnam and of flooding in Bangladesh. The Food and Agriculture Organization estimates 1987 production to be about 454 million tons, 4 percent (18 million tons) below that of 1986; Asia's output is estimated at 414 million tons, 4.3 percent (19 million tons) below that of 1986.

World trade in rice in 1987 is projected to be 11 million tons, about 0.5 million tons less than in 1986 (the result of a sharp reduction in Brazil's imports and lower shipments to Africa). But Asia's rice imports for 1987, which had been steadily declining over the last five years because of increased self-sufficiency in many countries, are projected at 0.8 million tons, 15 percent higher than in 1986.

In response, the world rice price has risen strongly, from a low of $195/ton at the end of 1986 to more than $300/ton at the beginning of 1988. That price increase marks a sharp turnaround from the previous five years, when nominal rice prices had fallen to their lowest level in more than a decade.

With the 1987 production shortfall, import requirements in 1988 are expected to increase again. But the rice output of many exporting countries has been reduced, and export

supplies are expected to lag behind import needs. Reflecting this, world rice trade is forecast to decline further in 1988, and prices are expected to continue to rise.

Global rice imports had dropped sharply when adoption of modern rice technology shifted the comparative advantage of growing rice in favor of traditional importing countries. Strong agricultural protectionism among developed countries contributed directly and indirectly to the decline in world rice price as well.

With the general slowing of economic growth in major rice-growing countries that resulted from depressed world commodity prices and external debt problems, public support to the rice sector dwindled. The short- to medium-term forecast of continuing low world rice prices contributed in recent years to low priority being accorded output and input price subsidies, investments in irrigation, and support of rice research.

The late 1987 world rice shortfall and price increase may have been caused by weather factors. But a slowdown in public investments in irrigation and rice research, in part a response to the low world rice price trend, is creating conditions for future food shortages. Projections of demand and supply to the year 2000 indicate the possibility of global as well as Asian shortfalls in rice production.

The Japan Prize was presented 14 April 1987 in the presence of Crown Prince Akihito in Tokyo. The Science and Technology Foundation of Japan initiated the Prize in 1985 to recognize persons who have "served the cause of peace and prosperity for mankind through original and outstanding achievements in science and technology." This was the first time the award had been given to agricultural scientists.

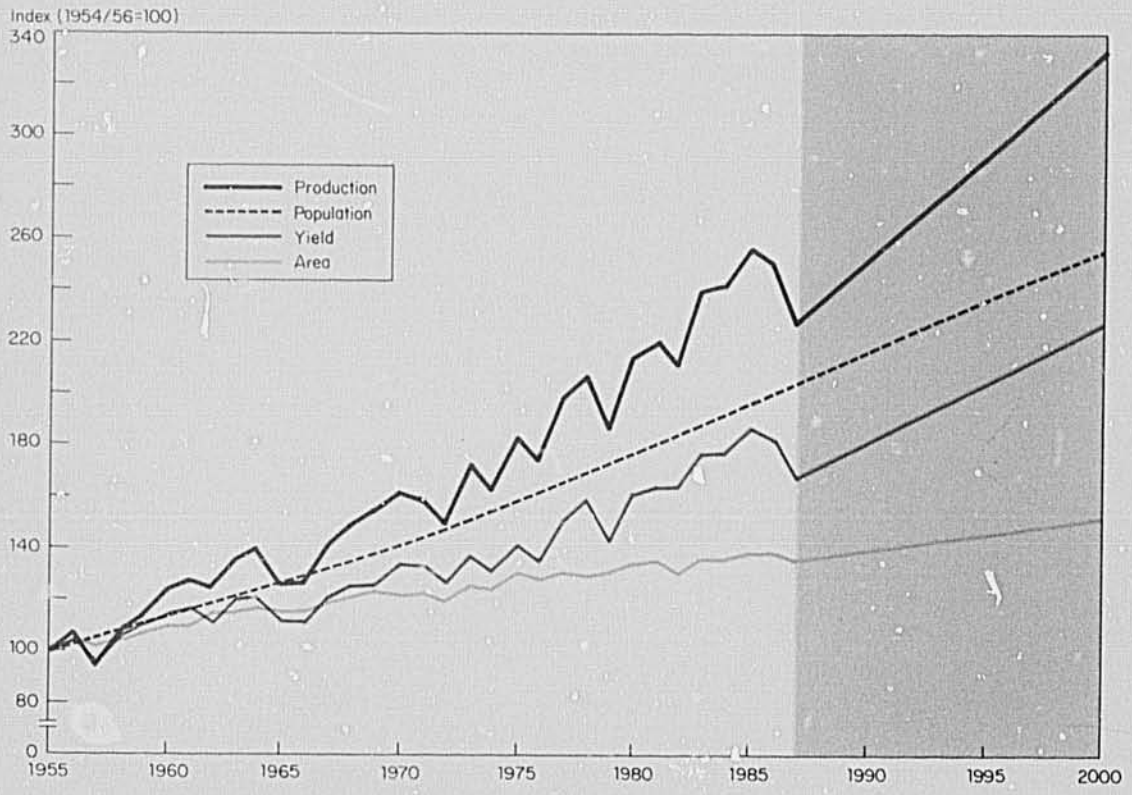
Director General M.S. Swaminathan was named recipient of the first General Foods World Food Prize, established by the General Foods Fund, Inc., to recognize, encourage, and reward outstanding individual achievement in improving and increasing the world food supply. The prize was presented 6 October 1987 in ceremonies at the Smithsonian Institution in Washington, D.C.

The World Food Prize is designed to honor individual contributions to addressing and alleviating hunger and malnutrition. Another purpose is to attract talented, creative, and dedicated young people to careers in the complex and challenging food and agriculture systems.

"The Prize gives recognition to the importance of the production of food and the right of all persons to nutrition security, which includes not only an adequate quantity of food

Less than 5 percent of global rice production is traded internationally; most rice is marketed and eaten within 50 kilometers of where it is grown.

Trends in production, population, yield, and area planted to rice in South and Southeast Asia, 1955-2000.



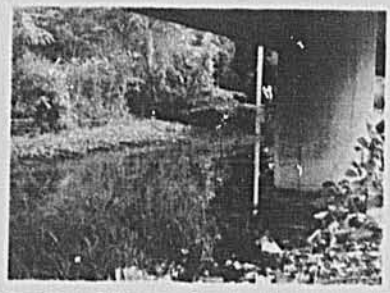
but nutritious food and safe drinking water, so that they may realize their full potential," Swaminathan said.

Swaminathan became Director General of IRRI in 1982 and completed his assignment in January 1988.

GENETIC CONSERVATION AND EVALUATION

The aim of germplasm conservation and evaluation is to provide the building blocks for improved germplasm with higher and more stable yield potential. We are working toward identifying the sources of resistance to diseases and insect pests and of tolerances for a range of adverse growing conditions. In the process, we refine our ability to identify and screen for desirable characteristics and against undesirable traits.

In Kerala, India, a local helper swam to collect a sample of *Oryza rufipogon*. Habitat descriptions are important in documenting the ecologies of different species and in early identification of potential resistances and tolerances.



In one wild rice collection this year, we found a threatened population of *Oryza officinalis* growing amid debris under a viaduct on a road near Bangkok, Thailand.

Genetic resources

Germplasm fuels every aspect of biological research. One of IRRI's distinct advantages in breeding improved rices for many different environmental and cultural needs is the unusually rich germplasm collection maintained in the International Rice Germplasm Center (IRGC). Much of the material conserved is already extinct in the wild, no longer grown by farmers, or no longer available in the original donor countries of the tropics.

During 1987, an Asia-wide collaborative collection of wild species was begun. Exploratory missions with national agricultural research programs netted germplasm of nine wild taxa, with field descriptions of the samples and the ecology of the sites where they were found.

This collection is saving populations of wild rices threatened by urban development and destruction of forest areas. One population of *Oryza granulata* we found in the central plains of Thailand consisted of a single plant with one seed (we collected two tillers and the seed, leaving the plant in

its habitat). A population of the rare *Oryza ridleyi* consisted of two plants with eight seeds.

In addition, the collection missions are pinpointing locations where wild relatives of rice are being conserved alongside other flora and fauna in botanical gardens, forest reserves, and wildlife parks.

The wild species carry an array of genetic resistances and tolerances for many stresses, both biological and ecological. Their distant relationship to domesticated species also provides new insights into rice genetics. Increasing research at the cellular and molecular level has tripled demand for wild species germplasm.

The rice germplasm collection now includes more than 83,000 accessions. A major activity is rejuvenating seed to respond to requests from national programs. In 1987, we did a large-scale seed increase for the Philippine Rice Research Institute (1,286 varieties) and the Philippine Department of Agriculture (576 varieties). This is an important part of IRGC activity, since many indigenous traditional varieties are no longer grown by farmers and may not be found in national germplasm collections.

We also expanded computerization of our operations, working toward fully integrated management. This year, we tested an improved procedure for identifying duplicates in the collection, using computer records in conjunction with field evaluation. So far we have matched 134 duplicates among 39,180 accessions.

Yield potential

Yield ceilings for rice grown in the tropics appear to have reached a plateau. Our research indicates that one way to improve yield is to increase the number of high density grains per panicle. Heavier grains are important in increasing head rice recovery.

We have been working on identifying factors involved in development of high-density grain. Defoliation and spikelet removal studies showed that, although there is competition for carbohydrate, spikelets in the fifth and sixth positions on the primary branches are stronger sinks. They have the highest grain filling rates and final weights; those in the second position have the lowest weights and take longer to fill.

Ideal plant type for producing high-density grain

- Low tillering, with only primary tillers developing.
- Large panicles, to compensate for low tillering.
- Thick culm, with more vascular bundles to lessen lodging, support a larger panicle, and promote carbohydrate accumulation.
- Panicles with only primary branches, to increase the percentage of filled grains.
- Larger pedicelled vascular bundle, to promote transport of assimilates.
- Medium-size grains (about the size of IR8 grains), with less white belly.

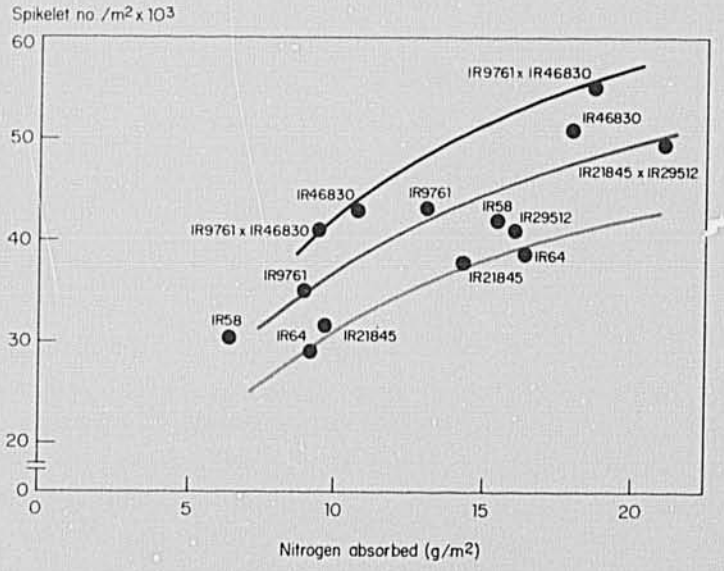
Varieties vary widely in their production of high-density grain, indicating that breeding to increase percentage of heavier grains would improve yield. Early crosses resulted in substantial heterosis in number of primary branches, spikelets on primary branches, and inner and outer vascular bundles—characters associated with higher numbers of high-density grain. High light intensity and lower temperatures during heading also resulted in more high-density grain.

These factors indicate that a modified plant type would be ideal for producing high-density grain. We have started developing the idealized plant type to test this hypothesis.

In the tropics, high temperatures after heading increase maintenance respiration loss and hasten senescence, leading to poor ripening. High temperature during the vegetative stage leads to reduced sink size and lower yield.

For short-duration varieties, increasing the biomass through higher nitrogen uptake in initial growth stages could further improve yield. But in medium- and long-duration varieties, the scope for biomass improvement is limited. Yield usually is improved by increasing the partitioning of stored energy to the grain. To do this, overgrowth must be controlled by lowering dry weight at heading.

An important physiological characteristic for higher yield potential is sink formation efficiency (larger sink size per



Relationship of spikelet no./m^2 and nitrogen absorbed before heading. IRRI, 1986 dry season.

absorbed nitrogen unit). A significant variation in sink formation efficiency among varieties indicates a potential for improving sink capacity.

While increased yield potential is important in reaching total production goals, resource-poor farmers need technology to help them achieve stable, relatively high yields with low cash inputs. We have found that modern varieties yield more than traditional varieties, even without added nitrogen. But varieties do differ in their nitrogen absorption ability, particularly at the tillering stage. Yield and yield stability are higher in medium-duration than in short-duration varieties. Varieties with more panicles have higher yield stability than varieties with heavier panicles.

Grain quality and nutritional value

Incorporating improved grain quality and nutritional value into a variety without added inputs would benefit both farmers and consumers. The achievement of self-sufficiency in rice production by many countries has led to increased demand for rices with better milling and eating quality.

Although head rice yields have been improved by breeding for completely translucent, nonwaxy endosperm, some varieties show extreme susceptibility to cracking when overripe or overdry. Fissuring resistance contributes to stable head rice yields after milling. Differences in resistance to fissuring in IR breeding lines are correlated with brown rice properties, rather than with hull tightness. Percentage cracked grains after brown rice was soaked in water for 5-10 minutes correlated with head rice yield of rough rice soaked for 3 hours. Translucency correlated with fissuring resistance in brown rice better than did amylose content or gelatinization temperature.

In addition to whole grain, consumers in tropical Asia prefer intermediate-amylose rices with intermediate gelatinization temperatures or low-amylose rices with low gelatinization temperatures. Amylose content (linear fraction of starch) is the major factor determining cooked rice texture. We analyzed the grain quality of parents and breeding lines designed for different environments. In general, rainfed lowland, deepwater, and tidal swamp rices had high amylose; upland rices had intermediate amylose. Gelatinization temperatures were intermediate.

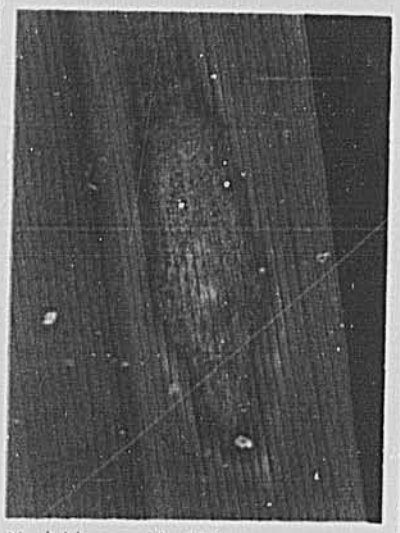
- Erect, thick leaves, to give better light distribution and higher photosynthetic rate.
- Higher photosynthesis under low photosynthetically active radiation, so that carbohydrate supply will not be limited during rainy season.
- Low maintenance respiration, to increase net assimilation rate; higher shoot:root ratio might decrease root maintenance respiration.
- Medium growth duration; carbohydrate accumulated before heading can be used to produce larger panicles and heavier grains.
- Intermediate plant height; a harvest index of 0.55 will make the plant lodging resistant, decrease maintenance respiration, and provide optimum partitioning of carbohydrate to the grain

Consumer surveys indicate that the grain characteristics consumers prefer vary considerably among nationalities and cultures.

We tested thiamine and riboflavin in the brown rice of 30 IR varieties grown in the wet and dry seasons. Thiamine and riboflavin differed significantly among the varieties. Thiamine levels correlated across seasons, as did riboflavin levels. Riboflavin levels tended to be higher in the wet season. Pigmented traditional rices had similar thiamine levels, but higher riboflavin, than nonpigmented improved rices.

Biological stresses

Pathogens and insects can evolve rapidly, making it necessary to keep a constant stream of germplasm with resistance genes available to national breeding programs. Research is also focusing on how to obtain more durable resistance to pests.



Neck blast and leaf blast symptoms.

Disease resistance

Bacterial pathogens cause at least a dozen different rice diseases. Bacterial blight (*Xanthomonas campestris* pv. *oryzae*) and bacterial leaf streak (*X. c.* pv. *oryzicola*) are perhaps the most serious in Asia. Sheath brown rot (*Pseudomonas fuscovaginae*) is distributed all over the globe. Glume blight or bacterial grain rot (*P. glumae*) reported in the tropics also causes seedling blight.

Bacterial diseases are distinguished on the basis of tissue specificity and modes of transmission. The pseudomonads are seed transmitted and cause grain discoloration, but *P. fuscovaginae* colonizes both the leaf sheath and the grain, while *P. glumae* attacks seedlings and the grain. Bacterial blight is systemic, bacterial leaf streak infects primarily the leaf blades and is seed transmitted.

Some IR lines that have the *Xa-4* gene for resistance to bacterial blight appear to have only background resistance. On another parameter, background resistance expressed in some varieties at the seedling stage may carry over to mature plants; in others, it is expressed only in the adult plant. The effect of background resistance appears to be partial and not race specific.

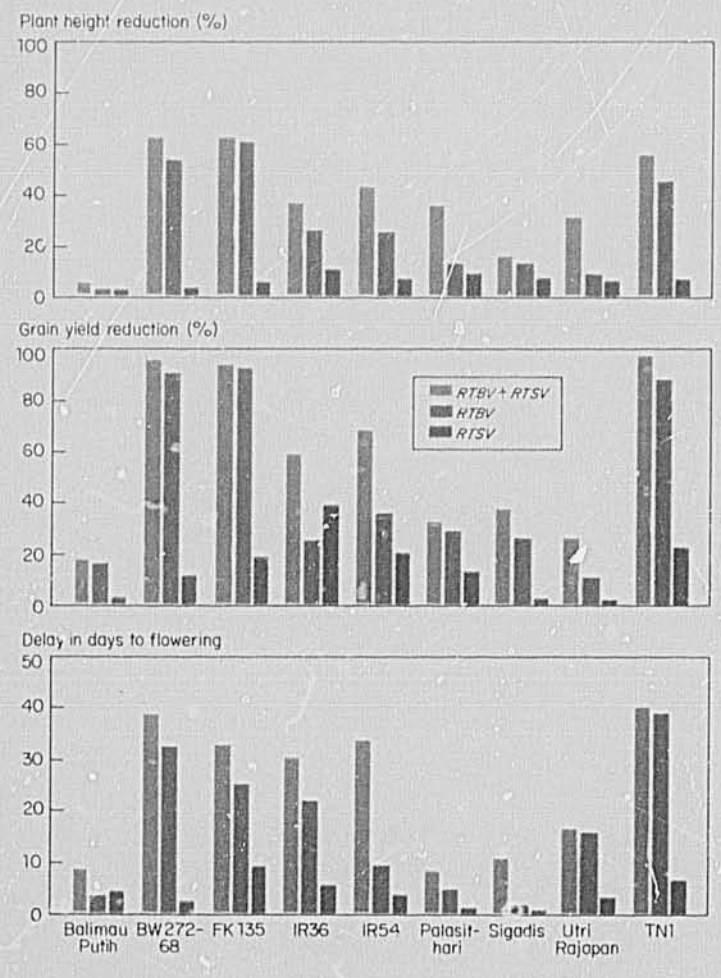
The upland sheath blight nursery has increased our capacity to screen for resistance; most of the 7,614 entries in 1987 rated moderately resistant to highly susceptible.

A great number of fungi attack rice—more than 50 species have been identified so far. Knowledge about resistance varies

with disease. For some pathogens, no resistance has been identified; for others, the low levels of resistances identified cannot be easily selected for in segregating populations.

Resistance to blast has been used by breeders, and can be highly effective. But that resistance has been short-lived because of the evolution of new pathogen races. Some forms of partial resistance to blast appear to be more durable.

We compared leaf and neck blast resistance of a set of elite lines. In general, lines resistant to one type are resistant to the other, although there are exceptions, and some lines appear relatively susceptible to leaf blast, but resistant to neck blast.



Plant height reductions, grain yield losses, and delay in days to flowering in plants of nine varieties infected with both forms of rice tungro virus.

Rice tungro is a composite disease caused by bacilliform and spherical viruses. Varieties react differently to each virus, depending on the type of resistance in their genes. We have identified some varieties that are resistant to virus infection, others that are tolerant. It appears that resistance to green leafhopper (the vector insect) and tolerance for virus infection are rather common; virus resistance is rare.

In general, tungro symptoms are severe in plants infected with both bacilliform and spherical viruses, milder in plants infected with the bacilliform alone, and not clear in plants infected with the spherical virus alone. Plants of Balimau Putih variety infected with both viruses showed no clear symptoms, Utri Rajapan plants showed very mild symptoms, Sigadis and Palasithari plants showed distinct symptoms at early growth stages but milder symptoms later. Other varieties showed severe symptoms.

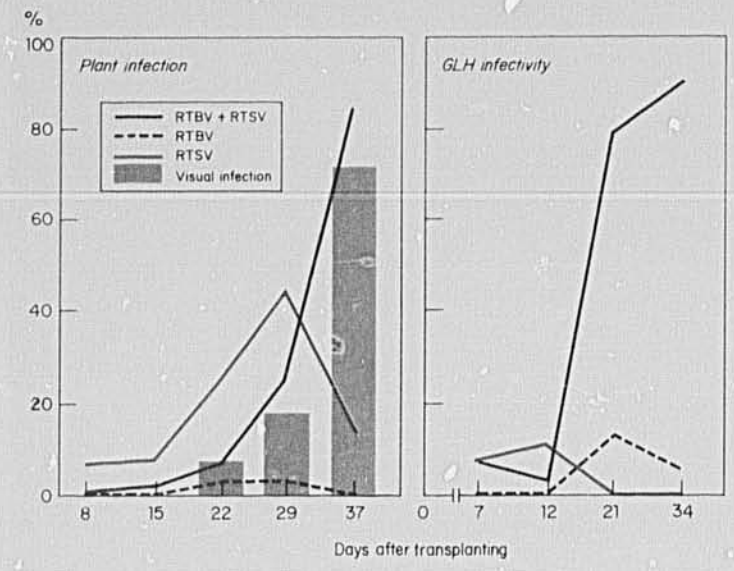
Virus concentration in infected plants was determined by enzyme-linked immunosorbent assay (ELISA). Bacilliform virus concentration especially was lower in plants of tolerant varieties.

The correlation between symptom severity 3 weeks after infection and grain yield reduction was significant in seedlings infected 7 days after soaking, showing that tolerance can be scored at the seedling stage. We developed a new scoring method based on plant height reduction and leaf discoloration. Inoculated seedlings are scored individually. Resistance level is indicated by low average scores. The screening method also was modified to obtain higher infection and to increase our capacity. We can now test 2,000 entries a month.

We have screened more than 40,000 germplasm accessions so far; those with consistently low infections have been evaluated further, and resistant cultivars categorized into four types of resistance and tolerance.

Tolerance can be useful in managing virus diseases. We used the correlation between symptom severity and yield reduction among varieties infected with ragged stunt to develop new infection scoring systems based on incidence and symptom severity.

We studied disease onset and development in a tungro-endemic experimental field. In green leafhopper-susceptible TN1, seedbed infection was very low. In transplanted fields, spherical virus infection occurred first. Double infection began



Tungro incidence by visual symptoms and tungro bacilliform and spherical virus infection by ELISA from 8 to 37 days after transplanting and infectivity of green leafhoppers collected at 7, 12, 21, and 34 days after transplanting.

to increase about 2 weeks later, tungro symptoms also appeared then. More of the vector leafhoppers collected in the fields 1-2 weeks after transplanting were infective for the spherical virus; those collected 3 weeks or later were mostly infective for both viruses.

In moderately resistant varieties, spherical virus infection occurred first; double infection developed slowly. In resistant varieties, double infection was very low.

Insect resistance

More than 100 species of insects attack rice—20 are major pests, some also transmit viruses.

In our screening trials, we found two accessions of the wild species *Oryza minuta* that are highly resistant to white-backed planthopper and the virulent Mindanao brown planthopper. Eight accessions of the wild species *O. brachyantha* are highly resistant to yellow stem borer, three to leaffolder.

Increased susceptibility to tungro virus has been reported in IR36, IR42, IR64, and IR66 planted in the Philippines, indicating possible shifts in the virulence of green leafhopper vector populations. We screened 19 varieties and 5 lines with known green leafhopper resistance or tungro tolerance and identified 8 that had consistently lower insect populations and tungro incidence.

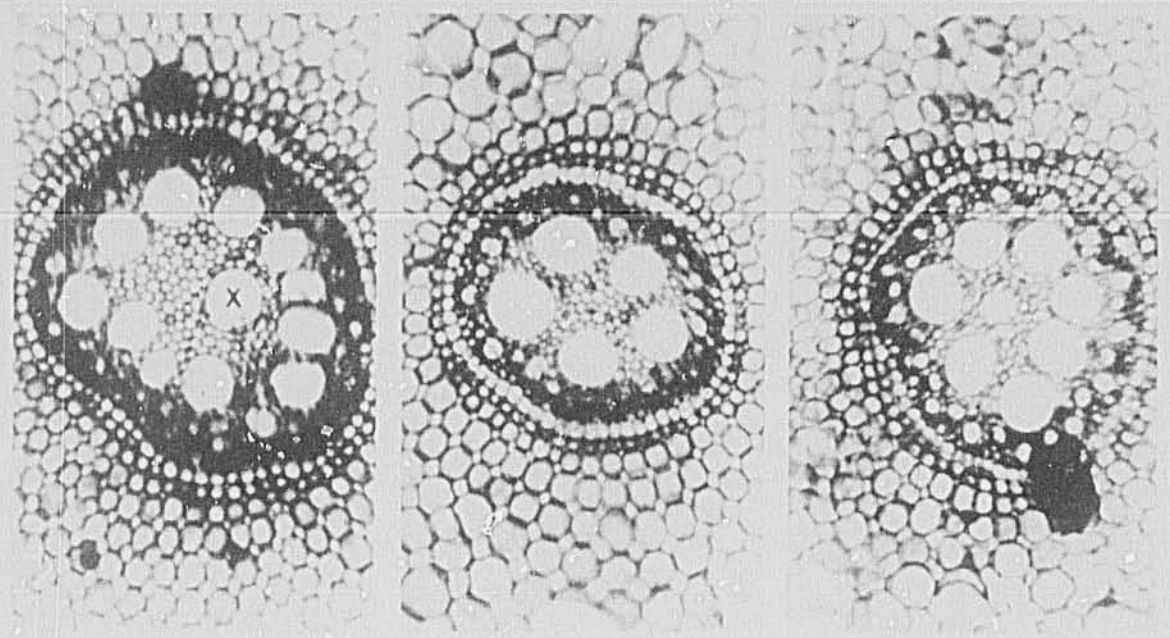
The green leafhopper nymphs used as vectors in varietal screening are easy to rear. We use second- to third-instar nymphs fed overnight on tungro-infected TN1 plants to inoculate 7-day-old test seedlings. Screening output was doubled by reducing inoculation time from 8 to 4 hours, by increasing the number of nymphs per seedling, and by disturbing the insects at 1-hour rather than at 2-hour intervals. The large number of adults that develop in inoculation cages can be collected to produce more test nymphs.

Physical stresses

Drought tolerance

Although no plant—and especially not rice—will grow without water, the progeny of some of our recent crosses have excellent ability to withstand root zone soil moisture tension as high as 10 bar. The cross IR47686 for adverse upland rice soils produced 16 lines with excellent drought tolerance; IR49718

Highly drought-tolerant lines produced from cross IR47886, compared with drought-susceptible IR20, at 10 bar soil moisture tension.



A major portion of the drought-avoidance mechanism in rice can be attributed to a large xylem vessel number and area that provide more effective water and nutrient conductivity from the roots to the shoot.

for rainfed lowlands produced 8 lines with superior tolerance; and IR38692 for deepwater areas produced 9 highly drought-tolerant lines.

Rice is most sensitive to drought at the flowering stage. If soil moisture tension increases only 0.8-1.0 bar, yield losses may reach 100 percent; the same drought stress at the vegetative stage may cause only a 10 percent yield loss. Screening and selecting for flowering stage tolerance are proving difficult, because flowering of different varieties is not synchronized.

Rice roots transport water through the xylem vessels. A large part of the drought avoidance mechanism in rice can be attributed to high xylem vessel numbers and area that provide more effective water and nutrient conductance from the roots to the shoot. We analyzed the F_1 and F_2 populations of crosses of four female parents (an upland variety from Africa and two hill varieties and one Aus variety from Bangladesh) with drought-susceptible IR20 as the common male parent and obtained moderately high to high broad sense heritability estimates. Root xylem vessel number and area were positively associated with root diameter and root length in several crosses. We are using root length and root diameter at transplanting as selection indices in breeding for drought tolerance.

We also observed a positive correlation between leaf area and root diameter, root length, root dry weight, shoot dry weight, and the root:shoot ratio in a cross of hill rice Mimidim Alang and IR20. In upland Moroberekan/IR20 progeny, leaf area correlated positively with root volume and dry weight. These co-adapted complexes of traits found in traditional varieties are related to drought tolerance.

Problem soil tolerance

Climatically, physiographically, and hydrologically, about 58 million hectares of problem soils in South and Southeast Asia are more suited to rice than to any other crop. To plant those lands to rice without costly amendments, it is necessary to exploit varietal tolerance. Tolerance for soil stresses such as salinity also supports sustainable rice cropping in favorable soils. We screen about 10,000 cultivars a year for adverse soil tolerance.

Seedling survival is a good measure of salt tolerance. Susceptible varieties are severely affected by salinity up to 7

Screening for breeding lines tolerant of problem soil conditions is done in several stages, both in the greenhouse and in the field.

days after germination, but gradually gain tolerance with age; tolerant varieties are not affected at any age. Tolerant varieties like Pokkali also have higher embryo weights than susceptible varieties. High embryo weight appears to be an index of more vigorous growth.

Mineral analysis showed that resistant varieties usually have lower Na:K ratios in shoot and roots. Susceptible M1-48 accumulated the highest level of sodium in the shoot but the lowest in the roots. Resistant Pokkali had very low sodium in the shoot, which is attributed to dilution due to rapid vegetative growth.

Visual symptoms of nutrient stresses sometimes are poor criteria for tolerance and yield response. For zinc deficiency, analysis of nutrient ratios (Zn:Fe, Zn:P, Mg:Zn) is a useful adjunct. High Fe:Zn ratios can induce zinc deficiencies even when zinc content of leaves is in a normal range.

With the assistance of the Asian Development Bank, we have established key sites for problem soil tolerance screening

in Iloilo, Philippines. All problem soils except alkali and peat soils and a wide range of rainfall regimes are found within a relatively small area.

IR8192-200-3-3, repeatedly found tolerant of multiple soil toxicities and nutrient deficiencies, has been released as a variety in Sabah, Malaysia.

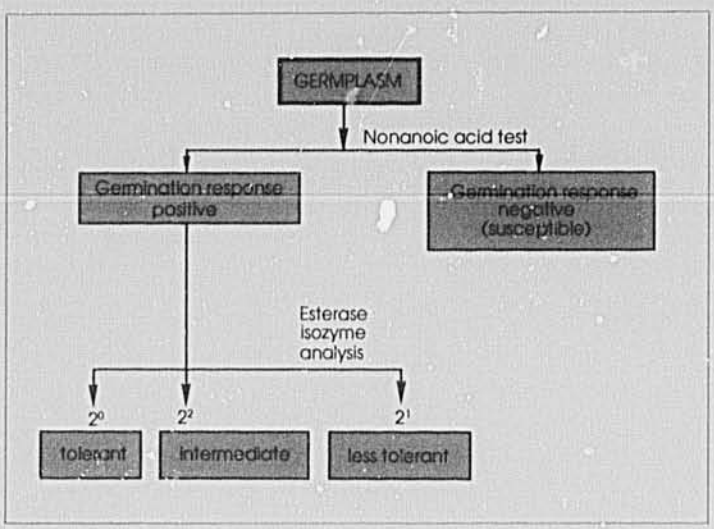
Cold temperature tolerance

High-yielding breeding materials tolerant of low temperature have been developed in several locations. The best entries in the International Rice Cold Tolerance Nursery at 23 locations in 15 countries in 1987 were JKAU(K)450-126-100, JKAU(K)450-126-2, JKAU(K)450-172-10, Ching Hsi 15 (acc. 36852), Z-Yah-Tsan (acc. 04648), Akiyudaka, and Suweon 303.

Evaluating materials at Chuncheon, Korea (a 10-year-old program) has been effective. In a seedling nursery test of 969 entries with continuously flowing cold water (17 °C), the best entries were SR12212-T4, HR6441-B-B-11, HR7381-AC7, and Z-Yah-Tsan. Among International Rice Cold Tolerance Nursery entries screened for tolerance at anthesis, Akiyudaka, H231-85, Stejaree 45, and Barkat had less than 40 percent spikelet sterility.

Low temperature is a problem in many African rice-growing areas, particularly in the Sahel region. Among 65

Most traditional rices in low temperature areas of South and Southeast Asia are bulu types. We selected 24 bulus from 600 cultivars screened for cold tolerance at the seedling stage. The varieties with an acceptable level of tolerance are of relatively short duration at high altitudes.



Two-tier screening for cold-tolerant genotypes.

entries from Tanzania screened at the seedling stage, panicle initiation, and anthesis, ES076 and ES078 (Zira) were tolerant. Afaa Kilombelo 1-196 was most tolerant at panicle initiation. ES053 (Ringa), Lindi Safari, ES018 (Straw), and ES042 showed very low sterility during anthesis. Afaa Kilombelo 1-196, ES010 (Supa India), and ES059 (Bishore) were outstanding at both stages.

Of 1,331 entries from 16 other African countries screened at the seedling stage, only 4 percent were tolerant of low temperatures; most tolerant were Wacee, Yetigbi, Baihiway Gbayawgi, and Baihiway Willingi from Liberia.

The roles of lipids in cold tolerance and of nonanoic acid in germination have been clarified; we used that knowledge to develop a novel two-tier approach to screening for cold tolerance and dormancy in the laboratory. Polar lipids of cold-tolerant rice genotypes have high linolenic acid (C18:3) content under both low and normal temperatures. They also show a null allelic situation at Esterase 2 isozyme locus (Est-2^0).

Less tolerant or susceptible genotypes had either Est-2^1 or Est-2^2 alleles. We found that Est-2^1 and Est-2^2 isozymes compete for the choline-ester precursors of polyunsaturated fatty acids (PUSFA) to convert them to free unsaturated fatty acids (USFA), reducing the formation of PUSFA. The free USFA are metabolized to short chain saturated fatty acids (SCSFA), resulting in higher levels of SCSFA in Est-2^1 and Est-2^2 genotypes.

Because the SCSFA, especially nonanoic acid (C 9:0), are involved in seed dormancy, the amount of acid needed to impose dormancy on seeds would be relatively less for Est-2^1 and Est-2^2 genotypes.

Rice genotypes can be screened for cold tolerance on the basis of germination response at a given level (5 mM) of nonanoic acid and their Esterase-2 allelic situation.

Deep water and flood tolerance

Basic research on internode elongation was emphasized during 1987 with experiments on morphology and hormonal regulation. Internode elongation was found to be the result of an increase in cell length and cell numbers, with cell numbers the most important in accounting for total increase in internode length. Two or three genes for elongation ability were identified among 4 crosses between floating rices from the Indian subcontinent and Thailand and modern varieties. Crosses with the Bangladesh wild floating rice *O. rufipogon* also appear to be good sources of superior elongation.

We screened more than 21,000 IRGC entries for submergence tolerance. Adalat, Jagai, Kusumkatki, and Tanki were outstanding.

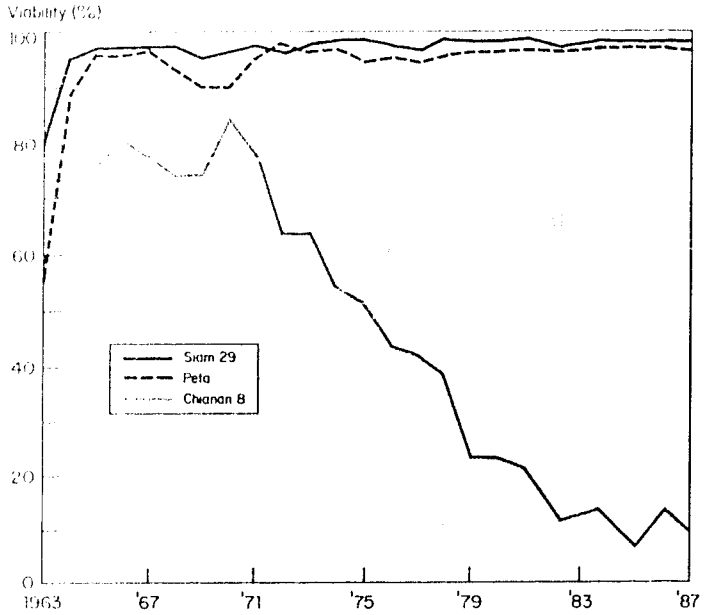
Seed science and technology

Seed vigor is extremely important in realizing the full genetic potential of a variety. Yield losses due to poor seed quality are estimated to be as high as 30 percent.

We identified some varieties that maintain seed vigor. Traditional varieties Dharial and Habiganj Boro IV and improved lines IR39379-90-2 and MTU5410-14 showed tolerance for accelerated aging.

Speed of germination correlated positively with oxygen uptake, total dehydrogenase activity, alpha amylase activity, and free amino acid content. Embryo weight correlated positively with embryo:endosperm ratio, shoot length, and seedling dry weight and negatively with germination rate. Varieties differed in embryo weight.

Senescence in rice embryos starts with the coleoptile, followed by the epiblast, lateral and vertical scales, coleorhiza, plumule, radicle, mesocotyl, and scutellum.



Seed viability of three rice varieties across 24 years' storage in the medium temperature room of the IRGC (2°C, 50% relative humidity, 8.5% moisture content). IRRI 1963-87

Seeds of tropical varieties Peta and Siam 29 that have grain dormancy maintained their viability after storage at 2°C and 8.5 percent moisture for 24 years; viability in nondormant Chianan 8 dropped to about 10 percent.

GERMPLASM ENHANCEMENT

To enhance the germplasm available for improved rice breeding lines, IRRI is adapting and applying the most current biotechnology methodologies in its laboratories. Appropriate tools in tissue culture, molecular biology, and genetic engineering are being used to improve breeding methods. This work dovetails with advances in germplasm improvement to make available materials that can be tailored for the different environments within which rice is grown. The goal is a continuous stream of improved materials available for national rice breeding programs to adapt to their local conditions.

Breeding techniques

Most advances in rice improvement so far have occurred through conventional breeding. We are supplementing our conventional breeding program with emerging biotechnology techniques for further gains in yield stability and potential. Genetic engineering techniques are being used to move genes for disease and insect resistance and stress tolerance across sexual barriers.

Tissue culture

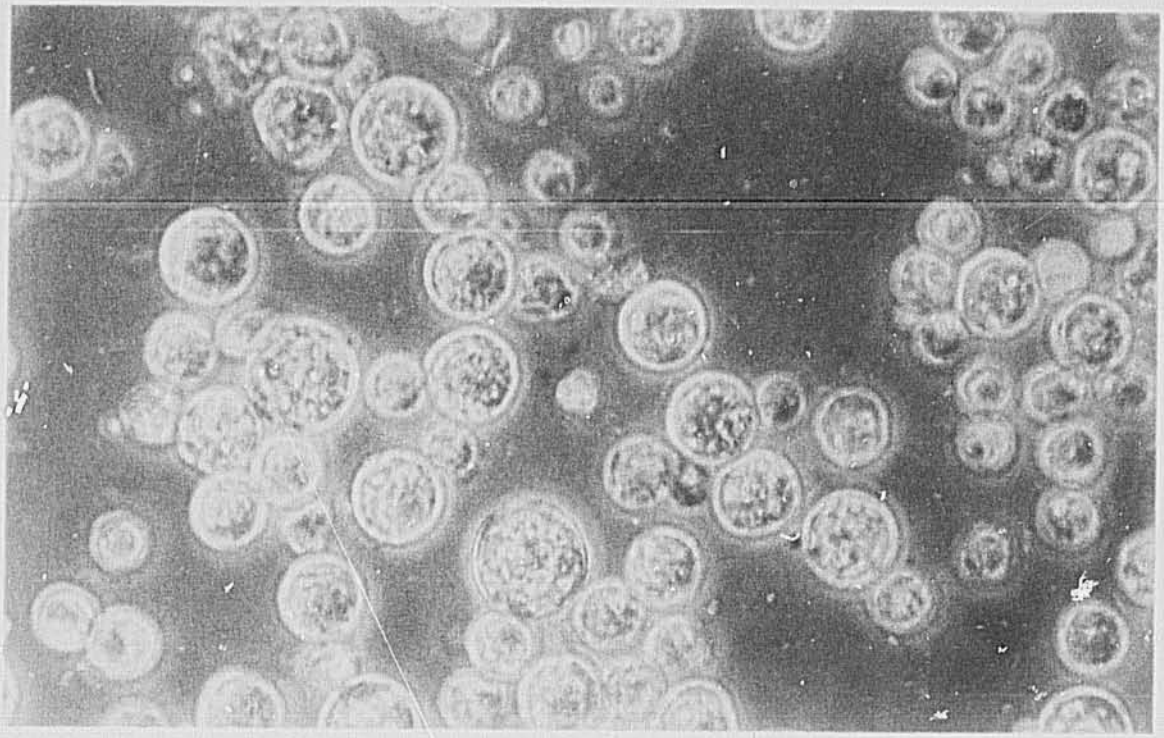
Most of the work in anther culture has been in immediate development of homozygous lines with tolerance for and resistance to such stresses as water deficit, salinity, cold temperature, and blast. Basic studies are emphasized in our research on somatic cell culture, isolated pollen culture, and protoplast culture.

We investigated the inheritance of anther culturability to improve our ability to incorporate anther culture efficiency from highly responsive varieties into recalcitrant varieties. Genotypes from a 4-parent diallel set were used. Callus induction was significantly affected by genotype. Genotype by media interactions indicate that different genotypes need different media for callus production. Callus induction ability appears to be a highly recessive character with large genetic variation due to additive gene effects. Green plant regeneration has similar patterns of inheritance. With careful selection of parents, it appears possible to transfer the high culturability of japonicas into indicas.

We are using anther culture to routinely produce plants for adverse conditions. In field tests of 1,544 lines from diverse sources for salt tolerance, only those derived from anther culture survived the highly saline conditions.

We have regenerated 1,622 green plants in this project. We also have regenerated 11,450 green plants for cold tolerance. One line had shorter duration, shorter plant height, more panicles, and higher blast resistance than the check variety. So far, 1,988 green plants have been produced from 107 crosses bred for upland conditions.

In isolated pollen culture, we established a routine for callus induction and green plant regeneration. Preculturing



Taipei-309 protoplasts

anthers before pollen isolation and adding proline to the callus induction medium. Nearly increased callus induction and subsequent plant regeneration.

Grading the grain used as explants in anther cell culture according to seed specific gravity increased reliability. High density grains have higher callus production and green plant regeneration.

This year, we achieved callus induction and plant regeneration from Taipei 309 protoplasts. Protoplast-derived calli and sustained cell division also have been achieved from two genotypes, each of japonica and indica varieties.

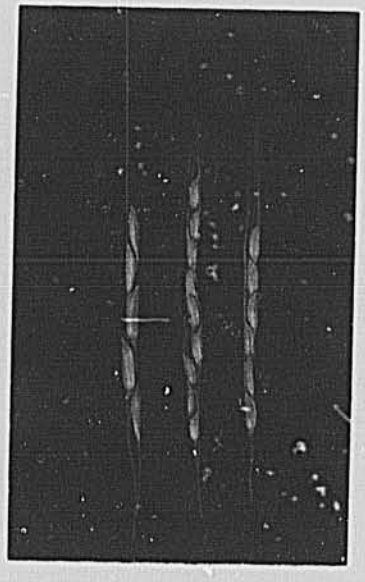
Wide hybridization

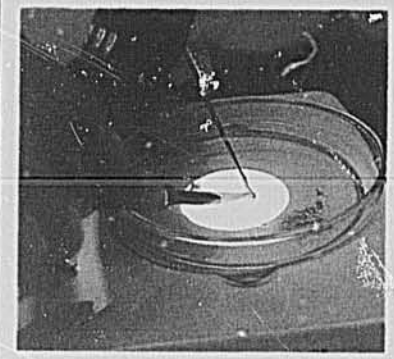
Wild species of rice are a rich source of genes for rice improvement. Wild species carry genes and genetic combinations for disease and insect resistance, tolerance for such stresses as adverse soils and excess water, and increased biomass. Until recently, those genes were not within the reach of plant breeders because of interspecific barriers such as cross incompatibility, hybrid sterility, lack of chromosome recombi-

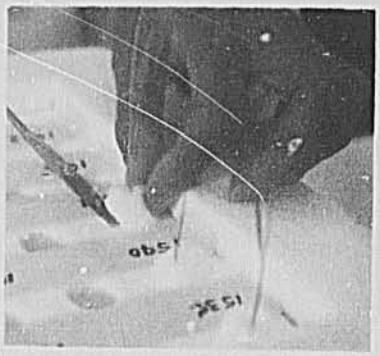
nation, and linkage drag. We are using biotechnology to overcome some of these barriers.

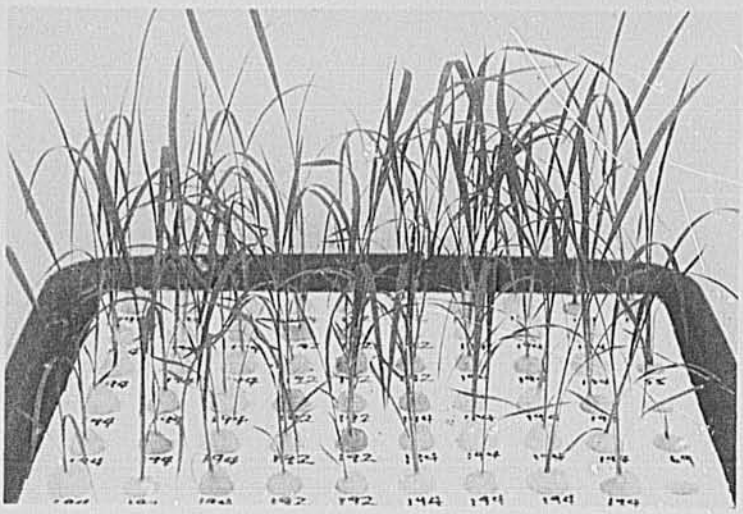
O. minuta, a tetraploid species with a genomic constitution of BBCC, is a rich source of resistance to pests and diseases. We selected four accessions of Philippine origin with bacterial blight, blast, brown planthopper, and whitebacked planthopper resistance and crossed them with susceptible IR31917-45-3-2 (AA genome). Seed set was 0-4.2 percent; hybrid seed development was slow because of premature embryo and endosperm degeneration.

We crossed *Oryza sativa* with *O. latifolia*. The F_1 hybrid was an intermediate plant type. Panicles were similar to those of *O. latifolia*; spikelets were somewhat larger.







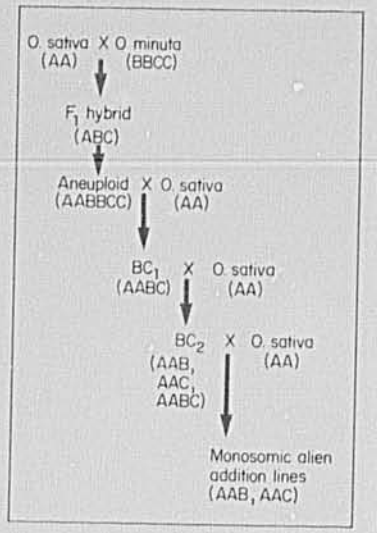


To ensure survival, we rescued 14-day-old embryos. The F_1 hybrids were intermediate in plant type, with panicles similar to those of *O. minuta*. All hybrids were triploid with ABC genomic composition and completely male sterile.

Backcrosses with *O. sativa* produced low numbers of BC_1 seeds. Using embryo rescue, two BC_1 tetraploid (AABC) plants were obtained.

Wide hybridization laboratory

Wide hybridization begins with the *O. sativa* plant. It is emasculated and pollinated with pollen from the selected wild species. Immature 14-day-old hybrid seeds are harvested and their embryos rescued. That microscopic process is carried out under sterile conditions in a laminar flow cabinet. The rescued embryo is transferred to a solid growth medium in a test tube and cultured in the dark. The newly germinated embryo is moved into the light. When the plantlet is green and has a fairly well-developed root system, it is transferred to a nutrient solution and grown in the phytotron. When early vigor is established, the seedlings are transplanted to soil. The mature hybrid plant is backcrossed with *O. sativa* to carry through the gene transfer process.



Scheme for transferring traits from *O. minuta* into *O. sativa*.

BC_1 production was limited by the high female sterility in the F_1 hybrids. To overcome hybrid sterility, ABC hybrids were treated with colchicine to try to produce amphiploids (AABBCC). The nine partially fertile hybrids produced were backcrossed and nine embryos extracted, yielding four BC_1 plants.

Resistance of the hybrids to bacterial blight and blast has been confirmed; testing for brown planthopper and white-backed planthopper resistance is in progress.

We also are exploring using wild *Oryza* species as sources of genes capable of increasing yield potential. Two approaches are being pursued.

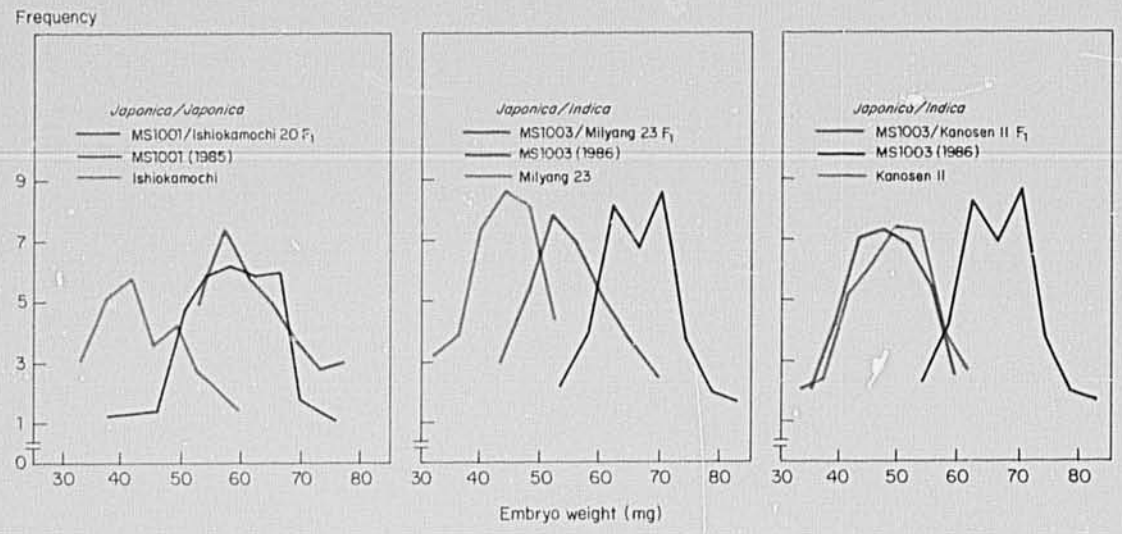
The first is the transferral of genes from species having high biomass and leaf area but different genomic constitution to *O. sativa*. We crossed four accessions of *O. latifolia* (CCDD genomic composition) with IR36 and IR64. Addition line production and the induction of translocations will be used to facilitate introgression of genes influencing yield potential characters.

In the second approach, traits are transferred from the AA genome species *O. nivara* and *O. rufipogon* into *O. sativa*. Crosses were made between IR64 and five accessions of *O. nivara* and between IR54 and IR64 and four accessions of *O. rufipogon*. Gene transfer should result from interspecific chromosome pairing and recombination in the F_1 and later generations.

Hybrid rice

More rice from the same land and the same effort continues to be needed to feed growing populations. F_1 hybrids grown in China have about 15 percent higher yields than the best available modern high-yielding varieties. Hybrids suitable for different agroecological regions, using locally adapted improved parental lines, and hybrid seed production techniques suitable for the different agroecological and socioeconomic conditions are needed.

Some IRRI-bred hybrids tested during 1987 in Korea, India, Indonesia, Malaysia, and Vietnam yielded 0.5-2.9 t/ha more than check varieties. But at IRRI and Maligaya, Philippines, yields were inconsistent. The problem appears to be proportion of sterile plants; 10 percent sterility reduced yield 15 percent.



Frequency distribution of embryo weights in F_1 hybrids and parent varieties.

Seven new cytoplasmic male sterile lines and 73 restorer lines have been developed or identified. Seed yields of cytoplasmic male sterile lines had been very low because of unsatisfactory synchronization of flowering with the male parent and low outcrossing rates. Increasing the planting density of female plants increased seed yield.

Initial growth vigor has been considered the principal trigger of heterosis in rice. Although higher initial growth in F_1 hybrids is related to larger embryo size, such a relationship is not found in indica/japonica crosses. In those crosses, higher leaf area expansion is considered the primary factor. Leaf area correlates significantly with higher respiration rate. Higher yields in heterotic hybrids in Korea were attributed to higher total dry matter and higher harvest index.

F_1 hybrids had better nitrogen absorption ability at tillering than the parents, and consequently had larger sinks. But they showed greater sink degeneration.

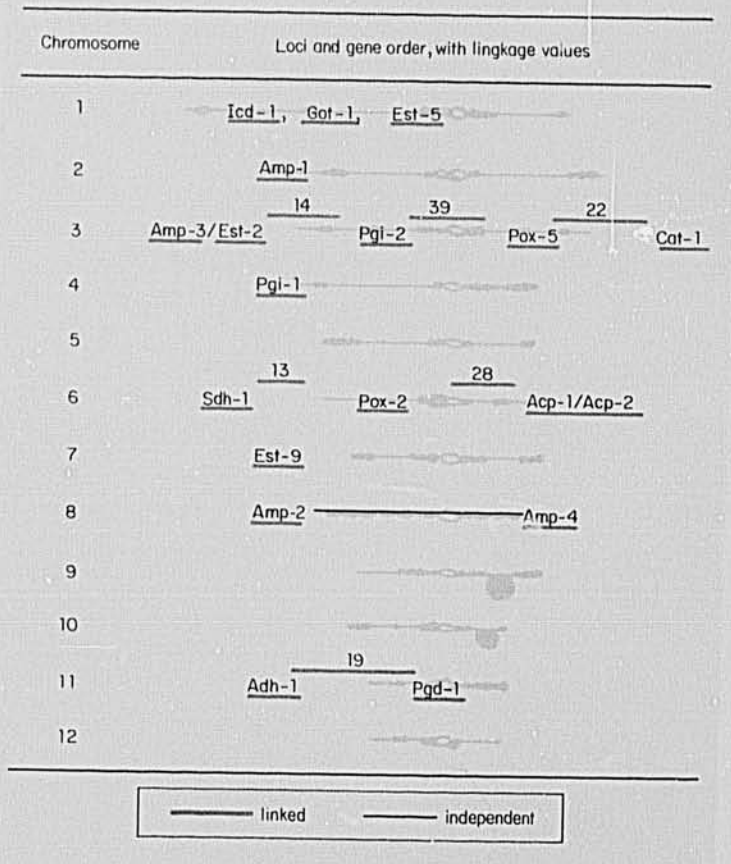
The wide compatibility varieties (WCVs) that produce fertile F_1 progenies in indica/japonica crosses were first identified in Japan, but their seeds were not readily available because of strict regulations relating to plant breeders rights. We have identified eight varieties—BPI 76, N22, Lambayeque 1, Dular, Moroberekan, PBMNI, Palawan, and Fossa HV—that possess wide compatibility genes. They are being made available to interested hybrid rice breeders around the world.

Rice genetics

Genetics and molecular maps

To utilize emerging techniques in molecular genetics and biology in rice improvement research, we need a more detailed understanding of the genetic architecture of the rice plant. On the basis of work at IRRI and by national program scientists, pachytene maps of rice chromosomes have been prepared and the 12 chromosomes numbered in descending order by length. Using primary trisomics, associations between 12 linkage groups and chromosomes have been determined. During 1987, we located four new marker genes to their chromosomes. Fourteen isozyme loci were associated with their chromosomes; 18 of the 25 known isozyme loci have now been assigned to linkage groups.

Chromosome location of linked isozyme loci and known linkage values.



A restriction fragment length polymorphism linkage map has been prepared with Cornell University, USA. It has 120 DNA markers arranged in linkage groups.

Genetics of disease and insect resistance

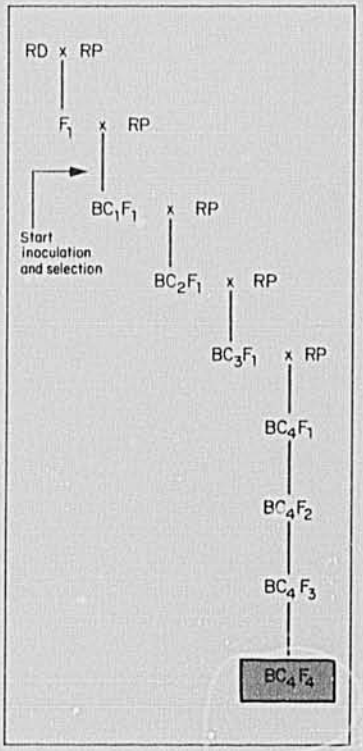
Systematic studies of different genes for resistance and analysis of the nature of resistance help us identify durable and stable genes to use in the breeding programs. We have been examining the genetics of bacterial blight and blast pathogens and vector insects and of resistance in rice to these problems.

The numbering of bacterial blight resistance genes identified at IRRI and in Japan was revised and two new genes identified: the *xa-13* gene in BJ1 conveys resistance to Philippine race 6, *Xa-14* in TN1 conveys resistance to race 5. We have 22 near-isogenic lines carrying 8 identified bacterial blight genes that can be used as differentials in monitoring race distribution, as testers for studying genetics, as donors in breeding programs, and as material for basic research on the mechanisms of resistance.

Near-isogenic lines with single true resistance genes for blast were developed through six backcrosses to susceptible indica CO 39. Preliminary studies suggest six resistance genes. A genetic study of partial resistance to blast in indica rice suggests that this form of resistance is polygenic, with low, narrow-sense heritability. By selecting for partial resistance in the F_2, we were able to develop F_3 lines with increased resistance.

We also identified two new genes for resistance to brown planthopper (seven identified so far). Genes for resistance to brown planthopper and whitebacked planthopper were transferred from *O. officinalis* to *O. sativa* by backcrossing; allelic relationships to known genes for resistance are being determined.

We have produced isogenic lines for the resistance to whitebacked planthopper in the background of IR1561-228-3-3 and have started work on isogenic lines for resistance to brown planthopper. Genetic analysis of 12 varieties with resistance to green leafhopper showed that single dominant genes convey resistance in six varieties; two varieties have single recessive genes, four have two genes governing resistance. We are analyzing those allelic relationships.



Procedure for breeding near-isogenic lines to use in identifying disease resistance gene types. RD = resistant donor, RP = recurrent parent, BC = backcross, F = segregating generation.

Genetics of pathogenicity

In the first phase of our research on host-pathogen relationships, we are focusing on the genetics of the blast fungus *Magnaporthe grisea*, imperfect state = *Pyricularia oryzae*, and the bacterial blight pathogen *Xanthomonas campestris* pv. *oryzae*. In collaborative work with the University of Wisconsin and Kansas State University, USA, we are investigating the molecular mechanisms controlling pathogenesis. Knowledge of the critical steps of pathogenesis can be used to design rice genotypes that disrupt the normal pathogenesis pathway of the pathogen, providing a long-term solution to the problem of resistance breakdown.

Using the perfect state of the blast fungus, we have determined the genetic control of cultivar specificity in the pathogen; five single genes have been identified so far. Our genetic analysis has identified a pigment mutation (buff) that acts epistatically to virulence—the buff mutant cannot attack rice, even though the fungus has the correct combination of virulence genes. This control of the biosynthesis of melanin, required for successful penetration of the host cell, is a critical step in the pathogenesis pathway that determines whether the fungus can be a parasite.

A conjugal gene transfer system has been developed in the bacterial blight pathogen and gene libraries of different pathogen races have been constructed. We now have a genetic system to study genetic and biochemical determinants of pathogenesis.

Radioisotope labeling is an indispensable tool in molecular genetic studies, but reliable supplies of radioisotopes (32-phosphorus, in particular) are difficult to get in developing countries. We are exploring nonradioactive labeling and have succeeded in using biotin-labeled DNA probes in analyzing bacterial genomes.

Genetic improvement

Since the initial breakthrough in increasing yield potential, major attention has been devoted to incorporating other desirable traits into improved varieties. Because stable resistance to diseases and insects is difficult to achieve, breeders must work continuously to incorporate new genes for

resistance into improved varieties to increase and maintain yield stability.

Irrigated rice

More than 70 percent of the world's rice is produced from irrigated and favorable rainfed lowland environments, where rice also is more vulnerable to changes in races and biotypes of pathogens and pests. Our goal is to maintain and to defend current rice production against diseases, insect pests, and adverse growing conditions. At the same time, we work toward higher yield potentials and more stable forms of resistance to and tolerance for adversity.

Progress in improving rice for irrigated and favorable rainfed lowlands has a direct bearing on improving rice for other environments. A useful gene for disease resistance from a wild species transferred to rice for irrigated conditions immediately becomes available to programs breeding rice for other environments.

Some elite breeding lines

- IR28224-3-2-3. High yield potential. 130 d duration. Long slender translucent grains with high milling recovery, high amylose and low gelatinization temperature. High field tolerance for tungro. Resistant to blast, bacterial blight, green leafhopper, and all brown planthopper biotypes.
- IR28228-12-3-1. 130 d duration. Medium-long translucent grains with high amylose and intermediate gelatinization temperature. High field tolerance for tungro. Resistant to blast, green leafhopper, and all brown planthopper biotypes.
- IR32453-20-3-2. Good yield potential. Medium duration. Long slender grains with high amylose and low gelatinization temperature. High field tolerance for tungro. Resistant to blast, grassy stunt, green leafhopper, and all brown planthopper biotypes.
- IR34686-179-1-2. Very high yielding. 135 d duration. Long slender grains with intermediate amylose and low gelatinization temperature. High field tolerance for tungro. Resistant to blast, bacterial blight, green leafhopper, and all brown planthopper biotypes.
- IR31802-48-2-2. Excellent yield potential. 105 d duration. Long slender translucent grains with intermediate amylose and intermediate gelatinization temperature. Field tolerance for tungro. Resistant to blast, bacterial blight, green leafhopper, and brown planthopper biotypes 1 and 2.
- IR32429-47-3-2. Good yield potential. 107 d duration. Excellent grain quality with intermediate amylose and intermediate gelatinization temperature. Field tolerance for tungro. Resistant to blast, bacterial blight, green leafhopper, and all brown planthopper biotypes.
- IR35366-90-3-2. High yield potential. 110 d duration. Long slender grains with high amylose and intermediate gelatinization temperature. Resistant to bacterial blight, blast, green leafhopper, and all brown planthopper biotypes.
- IR42000-211-1-2. Excellent yield potential. 105 d duration. Excellent grain quality with intermediate amylose and intermediate gelatinization temperature. Excellent field tolerance for tungro. Resistant to blast, bacterial blight, green leafhopper, and brown planthopper biotypes 1 and 2.
- IR41996-50-2-1. Good yield potential. 100 d duration. Long slender grains with intermediate amylose and intermediate gelatinization temperature. High field tolerance for tungro. Resistant to blast, bacterial blight, green leafhopper, and all brown planthopper biotypes.

This year we selected several lines from crosses of *O. sativa* and *O. officinalis* that have superior yield potential. New genes for resistance to brown planthopper and whitebacked planthopper derived from crosses of *O. officinalis* and a new gene for resistance to bacterial blight from *O. longistaminata* have been transferred to *O. sativa* breeding lines by backcrossing. We have made progress in selecting for durable resistance to blast. We made crosses to combine the cold tolerance and short stature of temperate japonica varieties with the intermediate amylose content and slender grains of tropical japonicas.

The number of IRRI breeding lines named as varieties worldwide increased to 178, with 23 additional lines named in 9 countries.

Rainfed lowland

Rainfed lowland rice covers more than 35 million hectares in South and Southeast Asia. Tolerance for drought and flooding, resistance to disease and insect pests, and yield stability are important breeding objectives.

IRRI research workers examine progress of promising breeding lines at a farmers' field rainfed lowland testing site in Solana, Cagayan, Philippines.

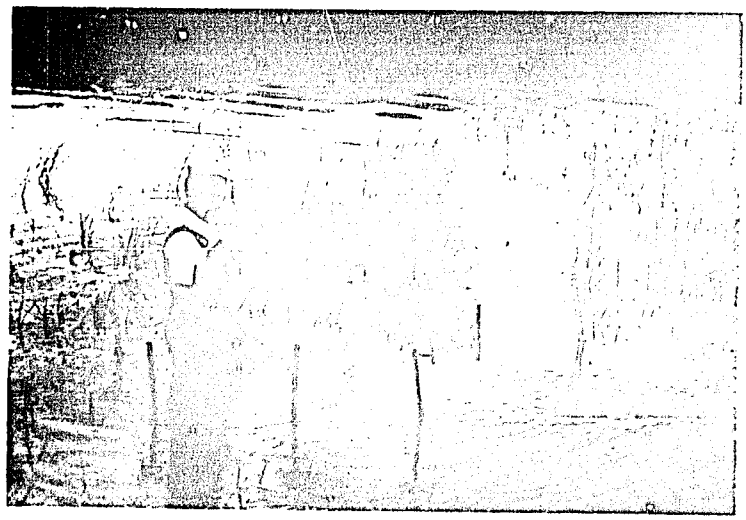
We select for drought resistance at all growth stages. Early generations are grown under water stress, later generations are screened in dry season nurseries. Advanced lines are evaluated in the field in a range of drought-prone environments.

Replicated yield trials in five drought-prone Philippine sites were used to screen 20 short duration and 30 medium to long duration improved lines. Water deficits ranged from mild to severe. Average yields were as high as 2.5 t/ha. IR13240-108-2-2, IR19431-72-2, and IR21567-9-2-2 consistently performed well.

We also evaluated several hundred breeding lines with improved plant type for flood tolerance at the seedling stage in greenhouse tanks. Those that equaled tolerant check FR13A also had higher survival under severe stress in the field.

In many rainfed areas, dates of seeding and transplanting are affected by the time of onset of the rainy season, which can vary widely from year to year. Desirable harvest date is influenced by the time rainfall decreases and floodwaters recede, by the onset of low temperatures in higher latitudes, and by the seeding date of the dry season crop. In these cases, photoperiod sensitivity is important. We are evaluating breeding lines with improved plant type and strong photoperiod sensitivity under different rainfed lowland conditions.

Cultivars and breeding lines were tested for yield in farmers' fields in three unfavorable environments found in Solana, Cagayan, Philippines. Conditions were drought prone, drought and submergence prone, and submergence prone.



Flooding was severe and yields were low in submergence-prone fields. Even so, IR28930-5T, IR26724-246-1-1, and BR118-3B-17 did very well. Several improved breeding lines with submergence tolerance yielded higher than the checks.

We evaluated 48 entries at IRRI's medium deepwater research site. Materials were exposed to three flooding regimes, with different depths, timing, and severity of flooding. IR19319-5-3-3 had particularly high and stable yields across water regimes. Local check Wagwag Faire performed well. IR24705-11-3-2, IR13149-43-2-P1, IR13149-71-3-2, and IR26760-27-1-3 have performed well in these tests for several years.

We distributed more than 5,000 seed samples of advanced breeding lines, donors for various traits, and F_2 populations to breeders in 16 countries.

Upland rice

Some 100 million subsistence farmers and their families, among the most underprivileged rice growers in the world, cultivate rice on about 20 million ha of upland fields. Most traditional upland cultivars possess tolerance for difficult soil and climatic stresses, but have low productivity due to a plant type that has low response to nitrogen and is susceptible to lodging and pests. We are working to retain their desirable traits in improved cultivars that also are responsive to low fertilizer inputs.

A wide range of tropical japonicas is used for donors of major traits, recombined with the best indica donors. In 1987 observational and yield trials, several progenies demonstrated clear advantage over traditional and improved checks.

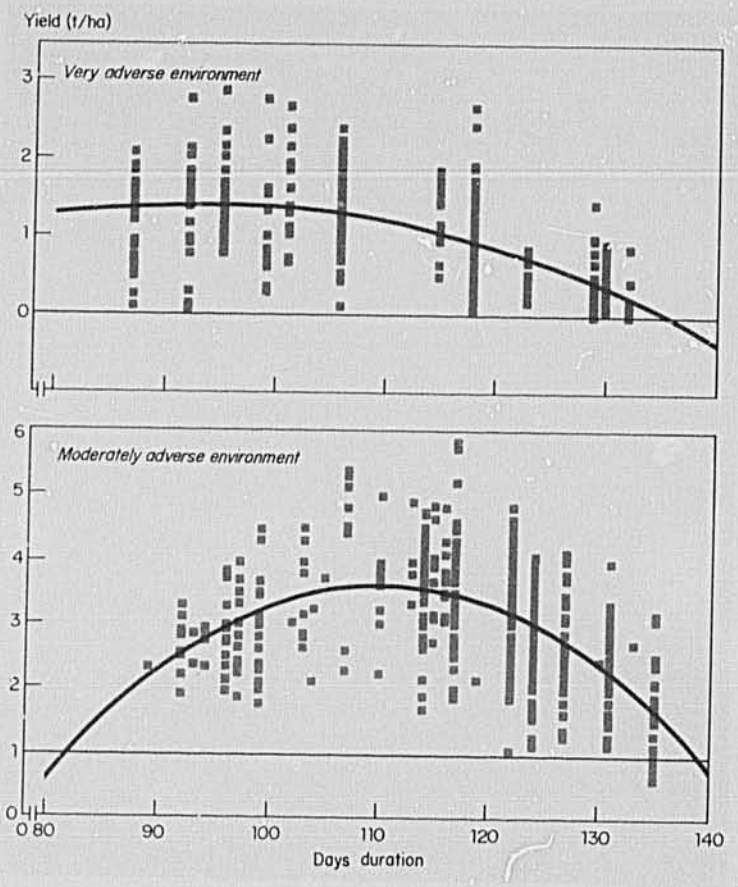
Indications are that yield potential is 3.5 t/ha in very adverse environments with low inputs and 4.5 t/ha in moderately adverse environments with moderate inputs. Intermediate plant height is insurance for weed competition at the early vegetative stage. Resistance to lodging is another major advantage. It is possible to combine yield potential, drought tolerance, and adaptation to poor soils—an example is IR47686-6-2-2. IR44716-6-2 combines durable resistance to blast and tolerance for acid soil.

We developed a computer model, using the integrated database from the International Rice Testing Program international trials, to cluster genotypes with similar responses to

Modified plant type for upland areas

- Intermediate height with moderate tillering, to improve nitrogen responsiveness.
- Droopy lower leaves, to shade out weeds and conserve soil moisture.
- Erect upper leaves for efficient light penetration.
- Deep, thick root system, for drought resistance.
- Blast resistance and acid soil tolerance.

We tested the yield potential of 500 upland rice entries at two sites in the Philippines, one with very poor (pH 4) and one with moderately poor (pH 5.2) soils. Yield potential was 3.5 t/ha in very poor soils and 4.5 t/ha in moderately poor soils. Best growth duration was 95 ± 10 days for very poor soils, 110 ± 10 days for moderately poor soils. Best plant height was around 100 cm.



the complex interaction of site-soil-crop-weather-management. Six of 18 short-duration cultivars included in the upland yield nursery exhibited similar responses to temperature, daylength, and water availability. Such modeling techniques should be useful in devising breeding strategies.

Deepwater rice

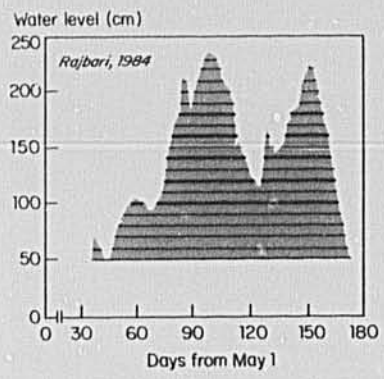
Many rice-growing countries in the world have areas where deepwater rice could be grown, and whose farmers are interested. But it takes 10 years for a national program to breed a deepwater variety tailor-made for local conditions.

We are collaborating with Thailand and several other countries to evaluate procedures for farmers' field testing of early-stage breeding materials. Bulk mixtures of populations derived from donors and with the desired submergence tolerance or elongation ability are planted across a range of

water depths. Segregating populations survive differentially. Bulked seed will be adapted to different water depths in a few seasons. Such admixtures could be used as base populations for line selection by breeders; farmers would have a crop in the meantime.

The dominant factors that determine the success of a deepwater rice crop are the rate at which floodwater rises and its maximum depth. Many deepwater rice research stations have been keeping daily records of water levels to use in interpreting varietal performance. A computer model to categorize floodwater patterns using 20 sets of data from Thailand gave a quantitative measure of depth stress for each flood. Now we will try to classify deepwater cultivars by depth stress and rate of water level increase.

Eastern India has more than 3 million hectares of deepwater rice—more than any other country in Asia. We helped establish a network to train the pest management specialists who are surveying pest and disease incidence to describe farmer cultural practices as well. The data will be mapped by environment type.



We developed a simple computer model to compare floodwater patterns, using data from Bangladesh and Thailand, and used it to evaluate conditions in areas of Kampuchea where deepwater rice will be introduced.

Tidal wetlands and problem soils rice

Asia's 50 million hectares of cultivated land includes about 5 million hectares of tidal wetlands, where soil problems limit rice yields. In addition, as much as 50 million hectares of uncultivated land could be used for rice production; perhaps 23 million hectares, mostly tidal wetlands, could be planted to problem soil-tolerant varieties. But different soil and climatic stresses occur in different geographical areas.

A research cooperative enables prebreeding work on site-specific soil problems. This year we evaluated a wide range of breeding materials in national program cooperative research sites representing saline (India), alkali (Pakistan), acid sulfate (Thailand), peat (Indonesia), and iron-toxic (Sri Lanka) soils. Three advanced breeding lines with adaptability to coastal saline soils were identified.

F_1 anther culture derivatives of crosses involving highly salt-tolerant varieties were found to have good adaptability to saline and alkaline-saline soils. Several traditional varieties from Indonesia and West Africa were found to possess tolerance for multiple soil stresses.

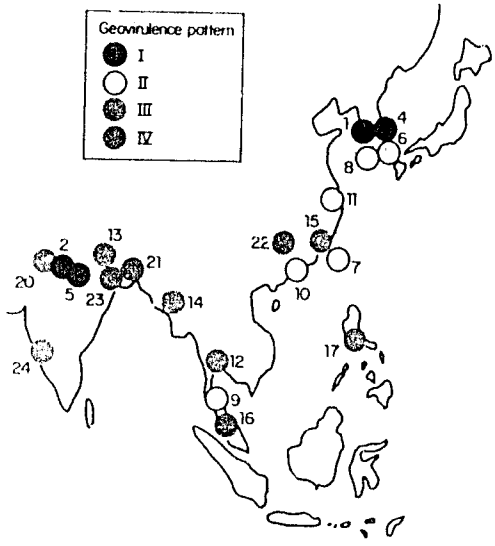
International Rice Testing Program

IRTP provides rice scientists around the world access to a wide spectrum of varietal diversity and a mechanism through which breeding lines can be tested under a wide range of agroclimatic conditions within a short time. This helps identify varietal adaptability to diverse environments and genetic variability among major insects and pathogens. Hot spot locations for screening against selected stresses also are identified.

In 1987, 1,550 sets of 29 types of nurseries consisting of 1,291 entries were composed and distributed to 50 countries; 136 entries were used as genetic donors in various breeding programs and 17 were advanced for yield testing. This year, 19 IRTP entries were released as varieties in 10 countries in Asia and Latin America. Four monitoring tours were organized: drought in South and Southeast Asia; deepwater rice in Thailand, Vietnam, Bangladesh, and India; ufra in Bangladesh and India; and rice in Ivory Coast, Gambia, Senegal, and Nigeria.

Analysis of IRTP data provides knowledge beyond cultivar performance. Using 1985 IRTP blast nursery data, we found a close association between virulence pattern and geographic proximity, indicating coevolution of blast populations and rice genotypes. Four distinct interaction patterns were identified--

Geovirulence patterns of blast at 24 IRTP test locations (based on Ward's cluster analysis of leaf blast reaction). The star indicates places not shown on the map.



Pattern I
1. Suweon, Korea
2. Parwanipur, Nepal
3. Mortara, Italy*
4. Icheon, Korea
5. Kankal, Nepal

Pattern II
6. Milyang, Korea
7. Chia-Yi, China
8. Iri, Korea
9. Kuan Gut, Thailand
10. Guangzhou, China
11. Hangzhou, China

Pattern III
12. Bangkhen, Thailand
13. Bhur, Bhutan
14. Yezin, Burma
15. Fuzhou, China

Pattern IV
16. Bumbong Lima, Malaysia
17. Los Baños, Philippines
18. Goiania, Brazil*
19. Villavicencio, Colombia*
20. Almora, India
21. Shillong, India
22. Changsha, China
23. Joydebpur, Bangladesh
24. Lonavala, India

patterns I and II, common in East Asia, Nepal, and Italy, have narrow ranges of virulence; patterns III and IV, found in South and Southeast Asia, Latin America, and some parts of China, have wider ranges. Geovirulence patterns help in designing pan-national blast management strategies.

CROP AND RESOURCE MANAGEMENT

The overall goal in crop and resource management is to develop methods by which soil, nutrients, and water can be used to produce rice and other crops grown in rotation with rice more efficiently, while maintaining and improving those resources. With integrated, safe control of pests and with the development of appropriate farm machinery and improved postharvest management, the result should be more efficient use of resources, generating increased production, income, and employment opportunities.

Soil characterization and management

Chemical aspects

The crop yield potential of an acid sulfate soil depends on the chemical and physical properties of the topsoil, on the water regime, and on management. We characterized five acid sulfate soils in the Philippines—Sulfaquepts and Tropaquepts developed in marine floodplains and tidal marshes and Sulfaquepts developed from sediments associated with volcanic sulfur emanation—and tested amelioration methods. The soils had the following characteristics:

- Very low soil pH and elevated lime needs.
- Low soil solution pH with flooding.
- Toxic levels of Al^{3+} immediately after flooding, water-soluble Fe^{2+} thereafter.
- Fe:Mn imbalance and Mn deficiency.
- N and P deficiency.

Lime and manganese applications were beneficial. But when sulfidic minerals or jarosite are present in the upper

20-30 cm of soil, rice growth is limited. Amendments are labor and capital intensive.

We compared the effect of leaching Sulfaquept topsoil with brackish and with demineralized water, accompanied by application of phosphorus and lime, on soil solution kinetics and on nutrient uptake by rice. Leaching before transplanting removed toxic concentrations of iron and high amounts of sulfate. Water quality made no difference. Leaching increased nutrient uptake and yield, but decreased concentrations of almost all ions in the soil solution. Only high rates of lime appreciably increased rice growth and yield.

The reduction of soil caused by flooding and the production of CO_2 by fermentation of organic matter are important factors in determining soil pH. The increase in pH above 6.8 of flooded acid soils is limited by precipitation of either iron or manganese carbonates.

To better understand soil transformations under flooding, we studied the solution kinetics of four soils. At the Eh and ionic concentrations found in most flooded soils, $FeCO_3$ and $MnCO_3$ control solubility of Fe^{2+} and Mn^{2+}. Pure minerals are not likely to be formed. Coprecipitation of iron and manganese can lead to manganese deficiency when Fe:Mn ratios and the partial pressure of CO_2 are high.

In acid sulfate soils, iron and manganese concentrations in the soil solution are controlled by mineral phases of ferrous sulfide and manganese sulfide. Coprecipitation can cause manganese deficiency.

The only pure mineral phase that controls zinc solubility in flooded soils is zinc sulfide, but this phase accounts for only a small proportion of the solid phase. Coprecipitation of zinc with iron or manganese as carbonates or sulfides seems to be the major process causing decreased availability of zinc.

Physical aspects

Puddling rice soil before planting lessens water percolation and retains standing water in the field, promoting several features that are favorable to rice production. But for rainfed rice farms or where irrigation is unreliable, puddling uses sometimes scarce water. It also takes time.

We studied the time needed with various puddling implements and power sources to achieve a standard,

acceptably low water infiltration rate of 2 mm per day. The procedure took baseline measurements of energy input per unit time per unit ground area for different implements and power sources, then compared infiltration rates with a standard amount of energy.

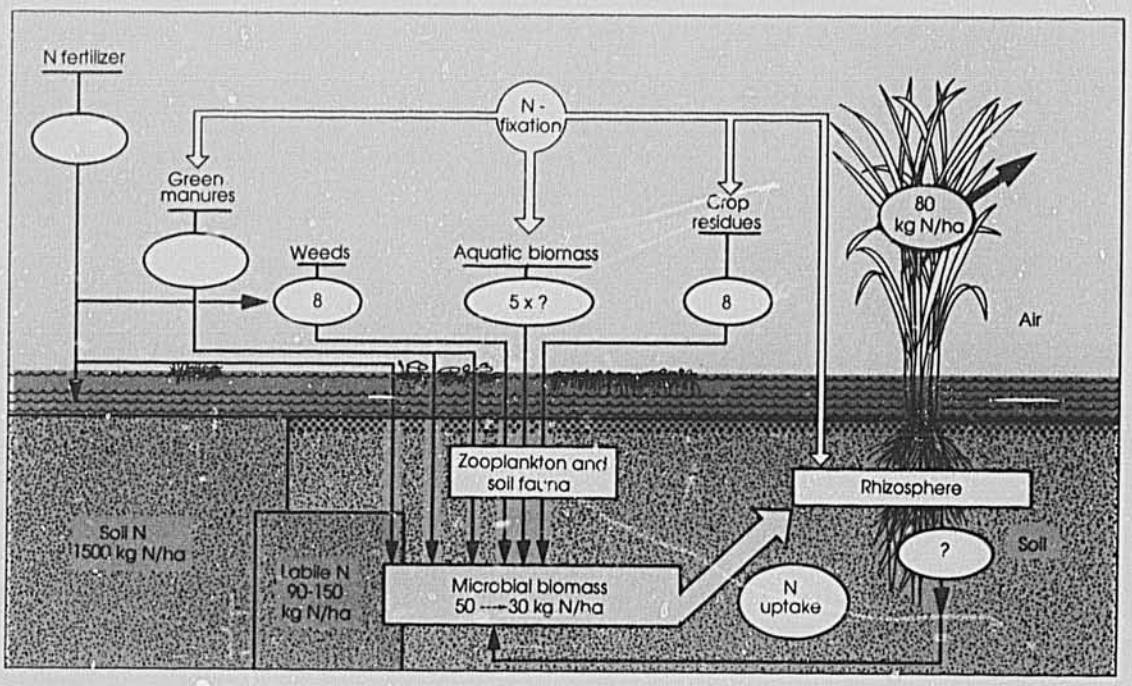
Gasoline-powered rototillers took only 25 percent of the time for the same energy input, but animal-powered plowing or harrowing was more effective in lessening water percolation. The net result was that engine power saved half the puddling time using animal power.

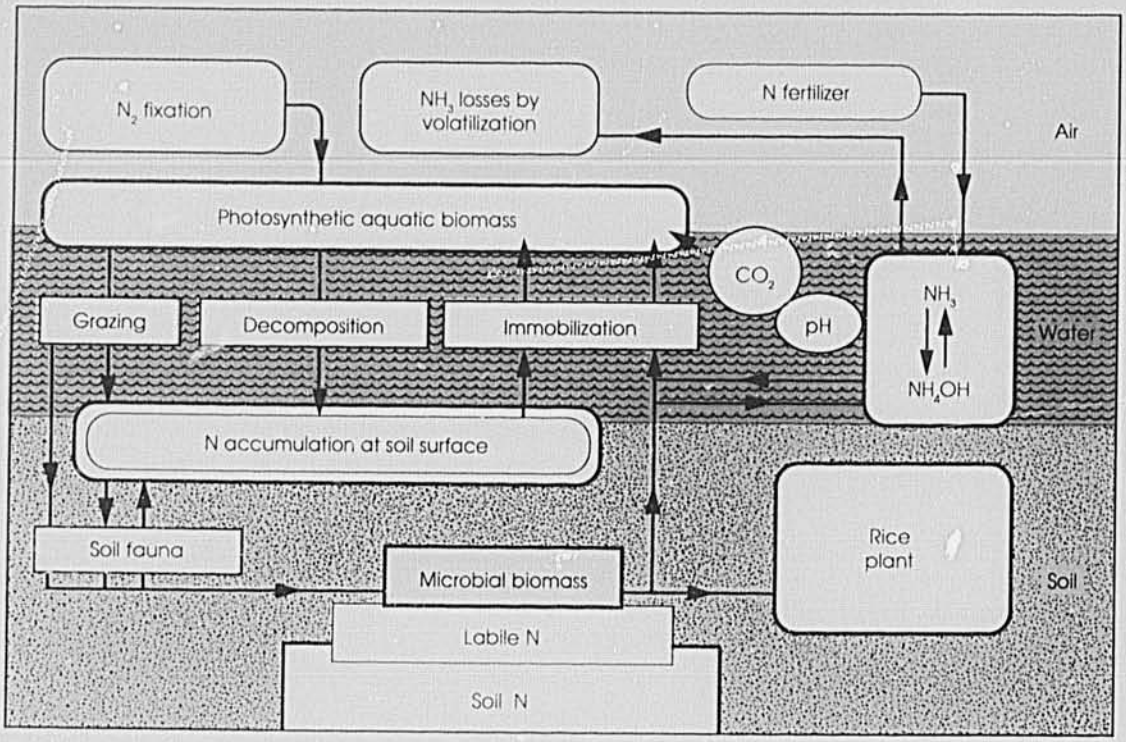
Biological aspects

A wetland ricefield ecosystem is characterized by two features: the presence of floodwater, where biological activity is high and organic matter accumulates, and instability because of frequent disturbances by cultural practices. The microbial biomass of that system is a major channel through which nutrients are transferred to cultivated plants.

In our studies, the microbial biomass in Maahas soil decreased from 50 to 30 kg N/ha during a crop cycle, while rice

The origin of soil nitrogen absorbed by rice.





Activities of the photosynthetic aquatic biomass in flooded ricefields.

was absorbing 80 kg N/ha. If most of the soil nitrogen available to rice originates from the microbial biomass, soil nitrogen is being replenished by a microbial biomass turnover two or three times a crop cycle.

This year, we studied the composition, standing crops, and photosynthetic and N_2-fixing activities of the weeds, algae, and aquatic plants that develop in the floodwater of a ricefield, and their role in providing carbon, nitrogen, and other substrates that allow the replenishment of soil-available nitrogen. The 65-plot experiment measured the effects of different applied nitrogen fertilizer levels, applied phosphorus, and blue-green algae inoculation, with neem applied to control grazers. We collected data throughout the rice crop cycle on the composition (carbon, nitrogen, phosphorus, ash, dry weight) of the photosynthetic aquatic biomass, the weed biomass, and the standing crop; the photodependent N_2-fixing activity and photosynthetic activity in the floodwater; and the pH and nitrogen and phosphorus content of the floodwater.

Average acetylene-reducing activity ranged from 2 to 42 kg nitrogen fixed/ha per crop. Weeds contributed 3-19 kg; other aquatic plants contained up to 19 kg N/ha. Broadcast urea caused a very rapid and short blooming of unicellular green algae, resulting in high nitrogen losses by ammonia volatilization. Those algae blooms disappeared rapidly with the development of ostracods, whose grazing pressure decreased photosynthetic activity and reduced N_2 fixation by blue-green algae. Deep placement of urea did not inhibit photodependent biological nitrogen fixation.

Development of significant N_2-fixing activity in plots where urea was broadcast seems to be an index of low fertilizer efficiency, as was shown by negative correlations between acetylene-reducing activity and yield.

High nitrogen fixing activities and highest yields were obtained in plots where urea was deep-placed. The absence of correlation between yield and acetylene reducing activity in those plots and control plots showed delayed availability of the fixed nitrogen. That can be shortened by incorporating the photosynthetic aquatic biomass.

Surface-applied N fertilizer inhibits development of N_2-fixing blue-green algae; deep placement permits algal bloom to contribute an average 22 kg N/ha per crop.

Nutrient management

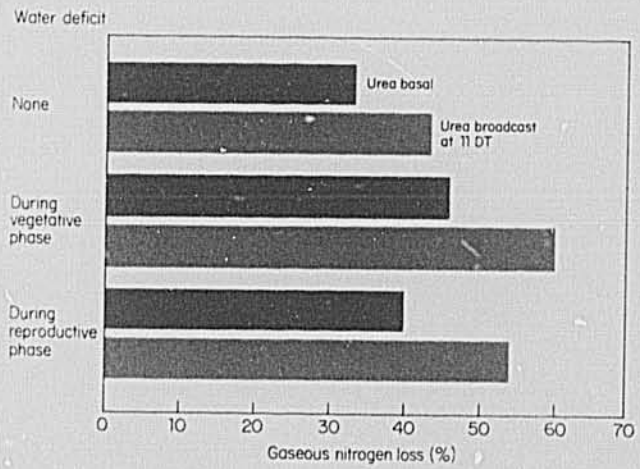
Nutrient transformation and utilization

Ammonia volatilization is a major nitrogen loss mechanism that affects the efficiency of urea and other inorganic fertilizers in flooded rice. Under continuous flooding with no water deficit, gaseous nitrogen losses from 40 kg urea/ha, either basal incorporated or broadcast at 11 days after transplanting, were very high. Water deficit during vegetative or reproductive stages increased the loss.

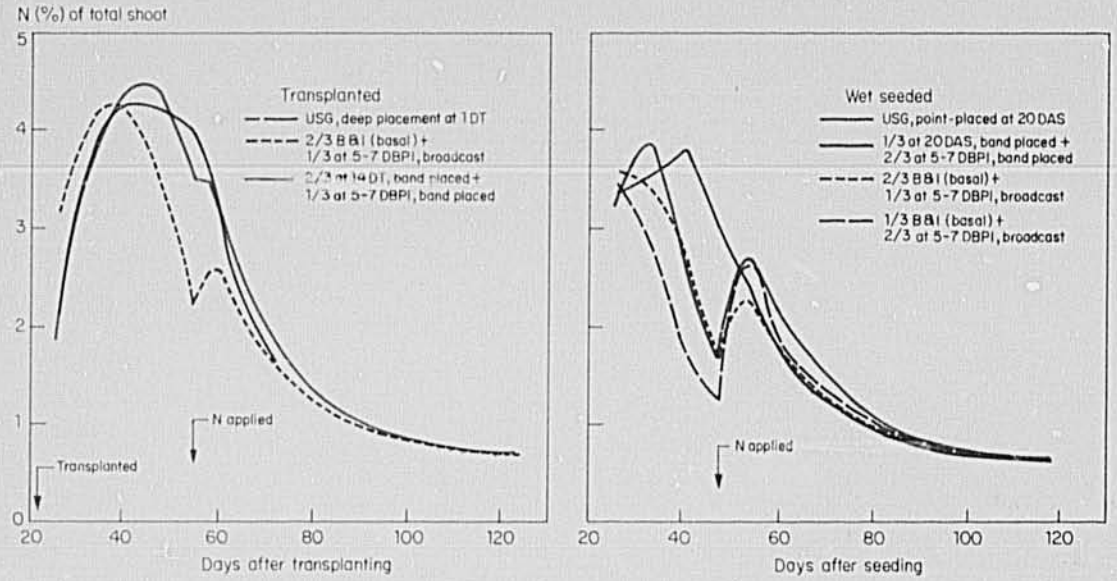
We used micrometeorological techniques to measure nitrogen gas in the soil and nitrogen gas flux from the soil, confirming that the nitrification-denitrification process from water deficit followed by reflooding was responsible for the increase in nitrogen loss.

Denitrification has long been recognized as a mechanism of nitrogen loss in flooded rice soils. However, its magnitude and importance has been unclear because a suitable method for field measurement was not available. International Fertilizer Development Center scientists developed a method for estimating denitrification and refined it in tests at three sites in the Philippines, in collaboration with IRRI.

Nitrogen gas loss from urea fertilizer at each site was only 1% or less of the nitrogen applied. The nitrogen losses by denitrification measured directly are much lower than those estimated by indirect techniques. These findings show that



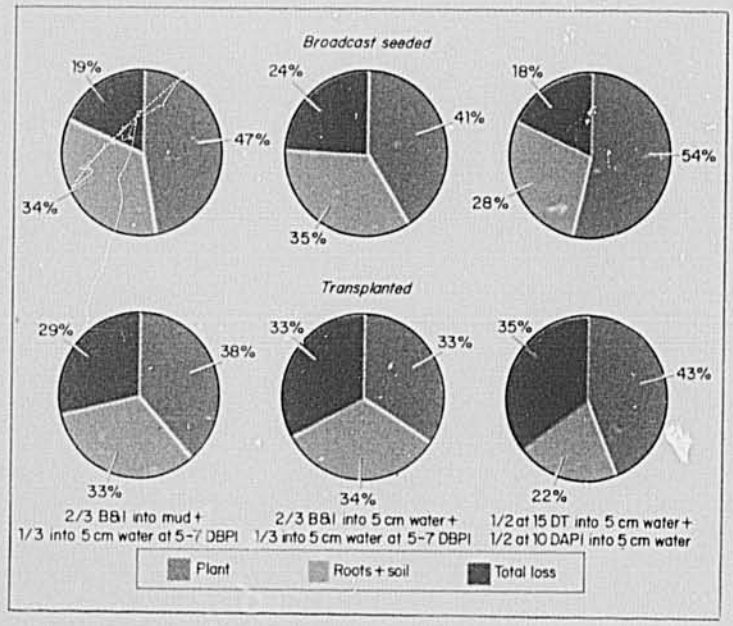
The effect of water deficit and fertilizer application method on gaseous nitrogen loss.



Effect of time and method of fertilizer application on nitrogen content in the rice shoot at different crop growth stages of transplanted and wet seeded IR64. Muñoz, Nueva Ecija, Philippines, 1987 dry season. B&I = broadcast and incorporated, DAS = days after seeding, DBPI = days before panicle initiation, DT = days after transplanting, USG = urea supergranules.

considerable scope still exists for improving field techniques to measure nitrogen loss.

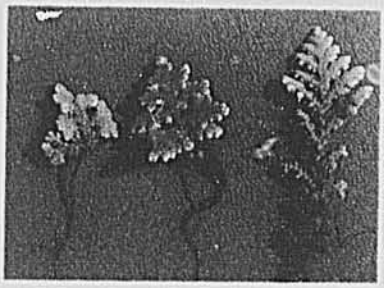
Recovery of inorganic nitrogen is higher in broadcast seeded rice than in transplanted rice, regardless of fertilizer application method. In our study, the amount of nitrogen recovered from the soil and from the rice plant roots did not



Recovery of ^{15}N-labeled urea at harvest in broadcast seeded and transplanted flooded rice. Nueva Ecija, Philippines. Mean of 1985 and 1986 dry seasons.

differ significantly, so that high plant recovery in broadcast seeded fields resulted in low total nitrogen loss. Nitrogen recovery also was higher when urea was broadcast and incorporated into mud than into 5 cm standing water.

We also examined differences between split applications. Although half the fertilizer into water at 15 days after transplanting and half into water 10 days later gave high plant N recovery, yields were considerably lower than with other split applications.



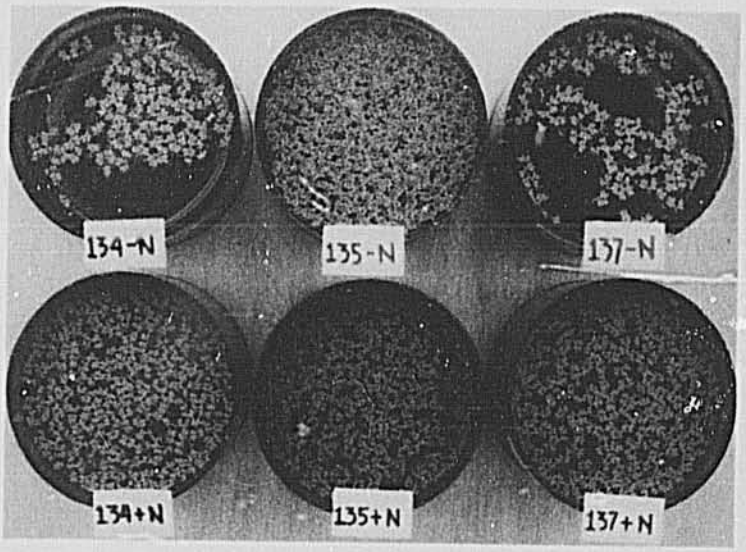
Morphology of azolla parents and hybrids. Right, *A. filiculoides*; center, hybrid; left, *A. microphylla* (female parent).

Microbial management and biological nitrogen fixation

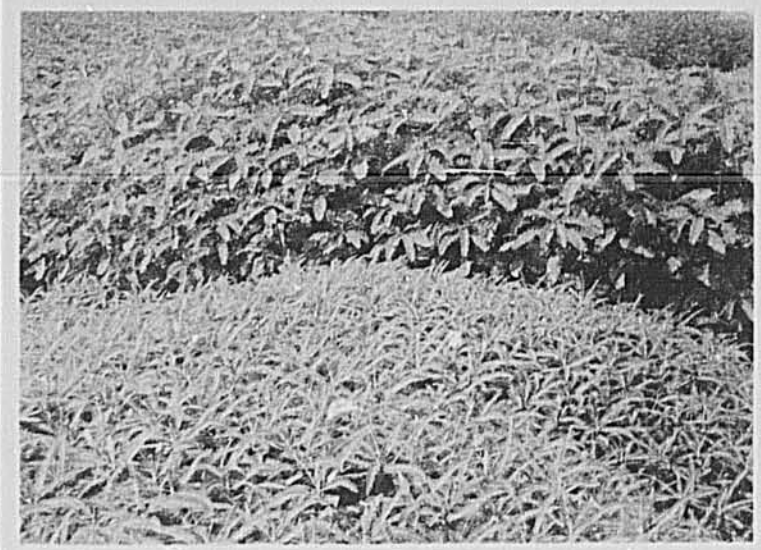
Algae symbionts appear to determine the response of azolla to temperature. Symbiotic algae from *Azolla microphylla*, which tolerates high temperature, were introduced to *A. filiculoides*, which is susceptible. *A. filiculoides* with *A. microphylla* algae grew well at 37 °C day, 29 °C night temperatures. Original *A. filiculoides* turned yellow.

We also were able to breed sexual hybrids of azolla. *A. microphylla* was crossed with *A. filiculoides*. The hybrids had enzymes from both species; their vegetative morphology was intermediate and heterosis was high. In the field, hybrids grew better than *A. microphylla* and had higher N_2-fixing activity under high temperature.

The azolla germplasm collection increased to 375 accessions with the addition of duplicates from the collection at the Université Catholique de Louvain, Belgium.



Azolla filiculoides with symbiont algae introduced from *A. microphylla* (pot 135) grew better than original *A. filiculoides* (pots 134 and 137). Adding nitrogen suppressed growth because of weak N_2-fixing activity.



Green manure crops *Sesbania rostrata* (top) and *Aeschynomene afraspera* contribute equally to increased rice yields, but *A. afraspera*, with less biomass, is easier to incorporate.

Biofertilizers

We evaluated two stem-nodulating legumes as green manure with and without applied inorganic fertilizer for flooded rice on two soils: Maahas clay, 0.123% N, 15 ppm Olsen P, CEC 32 meq/100 g, pH 6.3; and sandy loam, 0.063% N, 7 ppm Olsen P, CEC 8 meq/100 g, pH 5.6. *Aeschynomene afraspera* and *Sesbania rostrata* from ORSTOM, Dakar, Senegal, were grown for 49 days, then incorporated 3 days before transplanting IR64.

S. rostrata produced significantly more biomass and was taller. However, *A. afraspera* had higher nodulation, N_2 fixation, and N content. Both green manure species increased rice yield as much as did 60 kg urea N/ha. *A. afraspera* gave the same yield increase with less, more easily incorporated biomass. The experiment was in collaboration with the University of Giessen.

We studied the effect of adding rice straw with green manure or with inorganic fertilizer on nutrient kinetics and uptake in flooded rice soils. Nitrogen availability and uptake were similar with equivalent amounts of green manure and inorganic fertilizer. Adding straw depressed nitrogen availability and uptake. Net immobilization of nitrogen persisted throughout rice crop growth.

Grain yields were lower with straw incorporation except with 75 kg or more of inorganic N/ha. Organic manures increased the availability of iron, manganese, and potassium, but lowered the availability of zinc and, initially, phosphorus.

Water management

Coastal saline areas

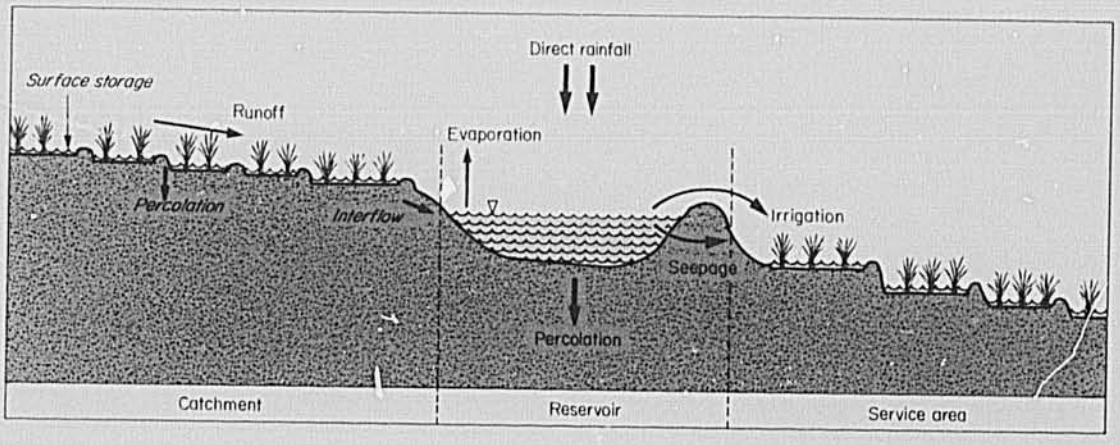
Where adequate supplies of good quality irrigation water are available, coastal saline areas are being brought into irrigated rice production. However, that rice production environment is very delicate; if water shortages occur, as is the case during the dry season in many irrigation schemes, salinity buildup is rapid and yields drop.

We studied the effects of water shortage in such an area—1,400 hectares serviced by a gravity irrigation scheme in Camarines Sur, Philippines. In the 1987 dry season, rice farms that did not receive adequate irrigation suffered severe yield losses, more severe in areas that are salinity prone. In 1986, the upper half of the upstream area used 77 percent of the total irrigation water supply. That anomaly was a major reason for water inadequacies and associated salinity problems on farms in the lower reaches.

A modified water allocation-distribution scheme tried in collaboration with the National Irrigation Administration was challenged by a severe drought halfway through 1987. Even so, grain yields and net returns were higher in areas using the improved method; the benefit was highest for farmers with saline soils.

On-farm rainwater conservation

Farm reservoirs can provide a supplementary irrigation capacity that stabilizes wet season rice production and makes possible a dry season crop, while adding income from



Schematic of catchment area, farm reservoir, and service area with inflow-outflow components for on-farm supplementary irrigation.

reservoir fish production. The reservoirs are water storage ponds excavated on the farm to collect runoff and direct rainfall.

We used a sample of five farm reservoirs in Tarlac, Philippines, to develop a methodology for water balance analysis. Average farm size was about 3 ha, average reservoir size was 2,300 m^2, average depth was 1-2 m. About 45 percent of the inflow to the reservoirs is from direct rainfall, 55 percent from runoff from the catchment slopes.

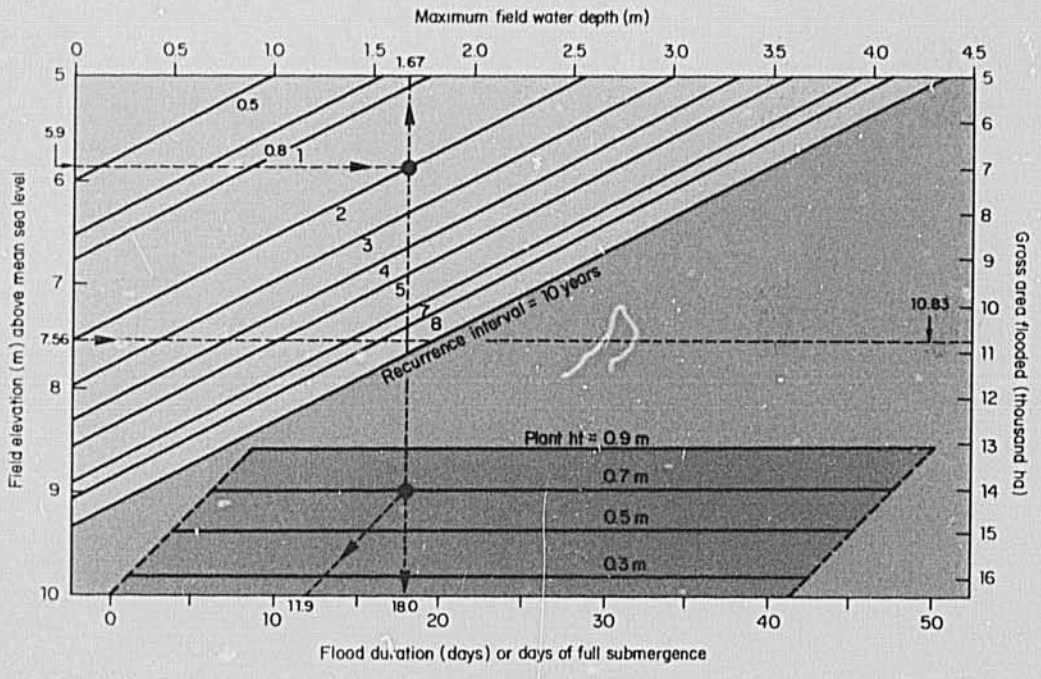
Water losses were estimated as 30 percent through evaporation, 30 percent through seepage and percolation. About 40 percent of the total outflow was used for irrigation, including land preparation.

With continuous use of water by the farmers, the farm reservoirs stored 2 to 3 times more water during the year than their maximum capacity. At the beginning of the dry season, the reservoirs were full.

Hydrology of flood-prone rice environments

We developed a computer model to identify flooding depths and durations for fields of different elevations, areas that would

Nomograph for determining extent of flooded area caused by flooding events at different intervals, with maximum water depths, flooding duration, and period of crop submergence at given field locations. Based on data from the Bicol River basin, Philippines.



be flooded, and submergence time of crops of different heights, given different severities and recurrences of flooding. The model was used to characterize the flood-prone environment of the Bicol River basin, Philippines, where some 40,000 hectares of riceland is often flooded, with heavy crop damage.

A nomograph provides a way to manage the information generated by the model. Using hydrologic parameters, it can predict how a recurring flood will affect an area and can be expanded to estimate rice production losses caused by flooding.

Crop management

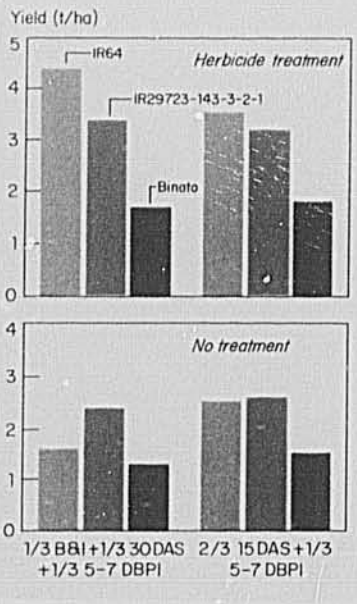
Component technology for rice

Physiological and agronomic components of crop growth and their impacts on grain yield were studied in wet seeded and transplanted rice (IR64) during the dry season. We monitored canopy CO_2 assimilation, nitrogen uptake, nitrogen distribution in plant parts, and leaf area index.

Wet seeded rice had higher nitrogen uptake, but lower concentration in shoot tissues, than transplanted rice. The direct seeded crop showed more vigorous growth and tillering during the vegetative stage, which led to dilution of absorbed nitrogen in the tissues. When inorganic fertilizer was applied 1/3 broadcast and incorporated before seeding and 2/3 broadcast 5-7 days before panicle initiation, the crop showed nitrogen deficiency and low photosynthetic rates before panicle initiation.

We found that this effect could be partially overcome by deep placement of nitrogen, either with point placement of urea supergranules or with band placement of liquid urea (using a newly developed manual, push-type injector). Band placement in particular led to high nitrogen concentration in the tissues during and after panicle initiation, resulting in significantly higher yields. Liquid urea band placement at 87 kg/ha in fields seeded by dibbling or with a drum seeder at 20-× 20-cm spacing produced 8.5 t grain/ha.

That high yield was the result of high cumulative canopy CO_2 assimilation, which depended largely on leaf nitrogen content and leaf area index. Fertilizer deep placement increased assimilation throughout crop growth.



Yield of broadcast seeded flooded rice as affected by cultivar and fertilizer management. IRRI, 1986 dry season. Mean of four replications and two seeding rates. B&I = broadcast and incorporated, DAS = days after seeding, DBPI = days before panicle initiation.

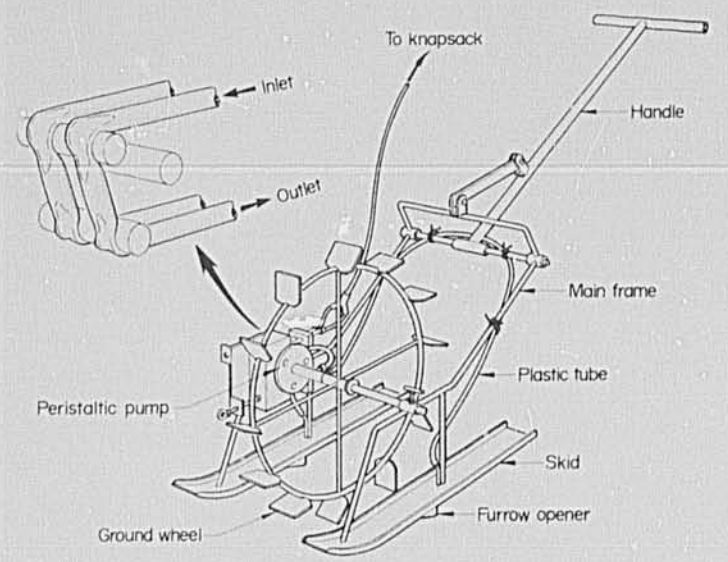


Fig. 40. Liquid fertilizer injector for deep-placement efficiency.

Liquid fertilizer injector for deep-placement efficiency.

Farm machinery and postharvest management

Liquid fertilizer injector

Studies consistently show that deep placement is effective in increasing fertilizer efficiency. But machines to deep place granular fertilizer have performed inconsistently. Recent experiments have shown that deep placement of liquid urea solutions results in more uniform effects. We designed a liquid injector equipped with a peristaltic pump and narrow furrow openers and closers. It requires substantially less force to push.

Upland weeder

For upland rice farmers, manual weeding using traditional tools requires as much as 120 labor hours per hectare. Herbicides are too expensive for these poor farmers.

In interrow cultivation, two operations are effective in suppressing weed growth: hilling up removes the topsoil between plant rows and uses it to cover the plant base; off-barring removes the topsoil near the plant base to uproot weeds. Hilling up also enhances growth and promotes tillering.

We developed a double-bladed and reversible hand push

device for hilling up and off-barring. It can be used in upland rice and legume crops.

Sun drying rough rice

Rotary dryers can be used to predry the rice harvest to a critical moisture level to prevent spoilage during the rainy season. Predried rough rice can then be sun dried to the final 12-14 percent milling moisture. But sun dried rice sometimes shows uneven drying. Overdried grain results in less head rice and lower milling recovery.

We developed a computer model to determine the solar radiation requirement for rice layer thicknesses of 1, 2, 4, and 6 cm. It uses historical solar radiation data to compute the daily solar radiation probability on a weekly basis.

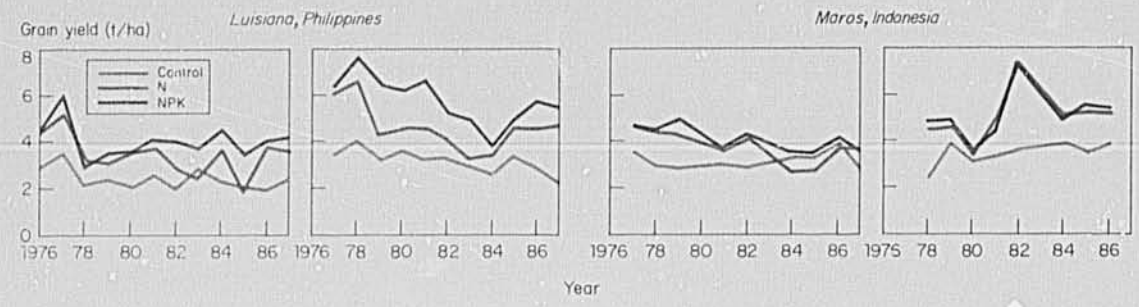
Nonuniform layer thickness and not enough turnover during sun drying also could be part of the problem. We are developing a walking tractor-mounted implement to mechanize some of the spreading, turning, mixing, and piling operations involved in sun drying rice on concrete pavement.

The International Network on Soil Fertility and Sustainable Rice Farming (INSURF)

After a decade of work on fertilizer efficiency, the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) began to confront additional vital issues, such as sustainable rice cropping and increased cultivation of adverse environments. Social equity and environmental quality issues also were being considered as IRRI and national program scientists began to develop relevant soil fertility management technology for various rice environments.

A holistic view of the entire rice and related cropping patterns production process is being taken, with sustainable soil fertility the central concern. During 1987, the network's name was changed to recognize this contemporary focus. INSURF will continue to strengthen the research capabilities of national programs. Some national programs will act as lead centers for different network activities.

Increasing emphasis has been given integrated nutrient management studies and long-term fertility trials to determine management technologies for sustained productivity. Integ-



Long-term grain yields at sites in the Philippines and Indonesia, with and without fertilizers.

rated use of inorganic and organic nitrogen fertilizers in irrigated rice was studied in 36 trials at 13 sites in 5 countries. Azolla combined with best-split prilled urea or deep-placed urea supergranules was as effective as urea alone in most sites; in six sites, it was better. Rice straw with urea gave lower yields than urea alone or combined with azolla, probably because straw plus inorganic nitrogen leads to greater nitrogen immobilization.

Ten sites in four countries continued long-term fertility trials in 1987; sites in the Philippines and Indonesia have conducted continuous trials since 1976. Although nitrogen continues to be the limiting nutrient, phosphorus and zinc are beginning to exert some influence on yield.

PEST MANAGEMENT

Pests are a major threat to food production stability. Losses due to insects, diseases, and weeds range from 10 to more than 30 percent in different rice environments. Pest resurgence, emerging insect biotypes and pathogen races, new weed problems, and secondary pest outbreaks haunt rice production, particularly in the humid tropics where rice is grown throughout the year.

Integrated pest management

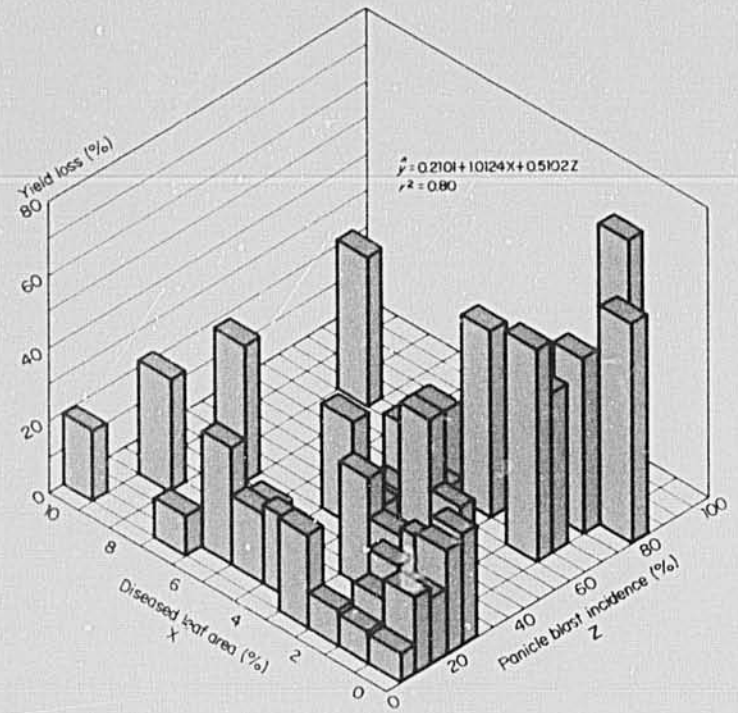
Long-term pest management relies on ecological methods to lower the carrying capacity of rice ecosystems: planting different cultivars in the wet and dry seasons, introducing

A wolf spider in a rice hill can account for up to 10 planthoppers, reducing the need for insecticide treatment. In fact, insecticides would kill the spider, too.

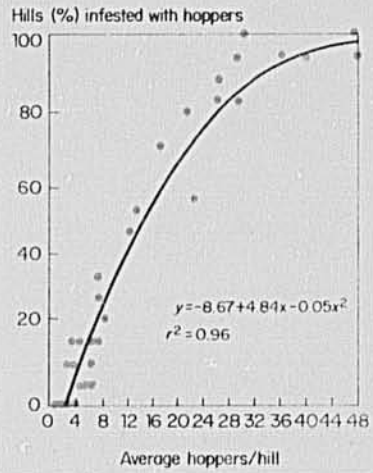
within-stand cultivar diversity, and planting nonrice crops to break pest cycles. We are using a systems approach to analyze pest problems, disease epidemics, insect outbreaks, and weed infestations in rice and rice-based cropping systems in different environments.

Disease epidemiology and management

When cultivar resistance is ineffective, knowledge about disease epidemiology and yield losses helps in designing control strategies.The effects of key environmental factors (such as drought, temperature, relative humidity, and rainfall) on blast development are being quantified and the data synthesized into computer simulation models to help us analyze why some parts of the world are particularly blast-prone. Blast damage at different plant growth stages is being examined in field studies and incorporated into a computer-simulated crop growth model.



Relationship between leaf blast severity, panicle blast incidence, and yield loss.



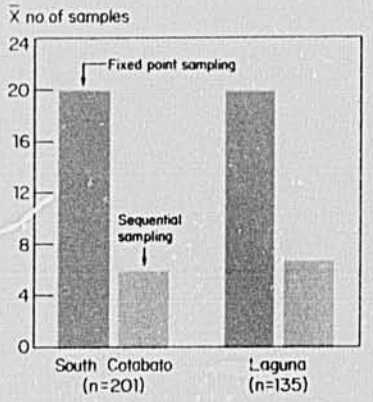
Relationship of percentage hills infested with 10 or more hoppers and hopper density. Victoria, Laguna, and South Cotabato, Philippines, 1987.

Insect bionomics and tactics

We developed a sequential sampling model for planthoppers and insect predators. The model is based on binomial distribution, or sampling for presence or absence (10 or fewer hoppers is considered 0; more than 10 is considered 1). The decision to treat also takes into account the presence of major predators, such as spiders and predatory beetles and crickets.

Sequential sampling saved two-thirds the number of samples needed for a treatment decision. Agreement on threshold level was close to perfect. Considering predators in the scheme allowed the economic threshold to be adjusted up.

We also are developing methods to measure the action of biocontrol agents. Laboratory studies of predator feeding have defined the consumption capacity of major predator groups against selected insects.



Number of samples needed as basis for insecticide treatment decision. Fixed point sampling vs sequential sampling. Philippines, 1987.

Echinochloa spp. weed seedlings look so much like rice seedlings they are often transplanted into the main field. Herbicide control is needed in the rice nursery.

Weed management

Planting modern semidwarf rice varieties that respond to high fertilizer rates is resulting in a considerable buildup in perennial weed populations in irrigated ricefields. *Paspalum distichum* and *Scirpus maritimus* sometimes cause total yield loss in the Philippines and some other tropical Asian countries.

In our long-term trials on controlling these weeds with tillage, varietal selection, and herbicides, we have identified the following factors:

- Increasing tillage from one to three harrowings significantly reduced *P. distichum* but increased *S. maritimus* populations.
- IR29723-143-3-2 competed more successfully with *P. distichum* than IR64, but not with *S. maritimus*.
- Herbicides were effective in controlling *S. maritimus*, but not *P. distichum*.

One problem in controlling weeds in transplanted rice is weedy nurseries. We found that seedlings of *Echinochloa* spp. look so much like rice seedlings, they are often transplanted into the main field. If only 5 percent of the hills are infested, yield losses are about 7 percent. But when 50 percent of the hills are infested, yield losses go over 85 percent.

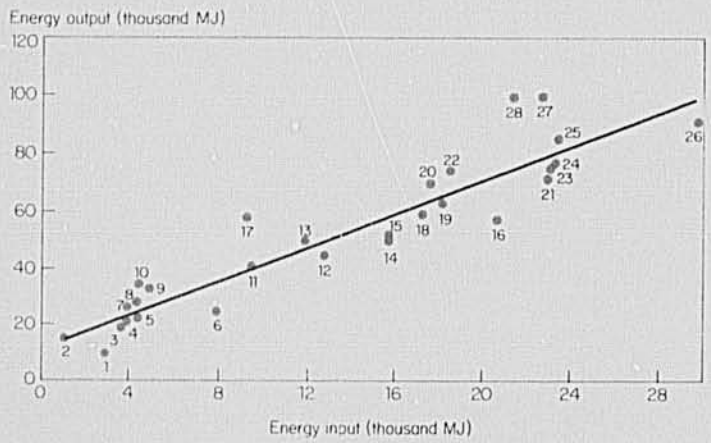
Echinochloa spp. can be controlled with herbicides; the cost to treat a nursery large enough to plant one hectare is only about US70 cents.

Herbicides are necessary to control weeds in broadcast wet seeded rice. But sprayers need large amounts of water, and not all farmers have them. We found that weeds can be controlled by pouring concentrated herbicide into the standing water at the edge of the field or into irrigation water inlets.

Good stand establishment helps minimize weed competition. We tested the effect of herbicide treatment under two fertilizer application regimes on yield of broadcast wet seeded IR64, IR29723-143-3-2, and Binato. When nitrogen was applied in three splits, IR64 yielded higher in weeded plots, IR29723-143-3-2 higher in unweeded plots. With two splits, yields were similar. Both improved cultivars yielded higher than traditional Binato, regardless.

RICE FARMING SYSTEMS

Simulation and systems analysis (or computer modeling) is a tool that can lead to greater efficiency in research and faster application of knowledge. Modeling helps expand interpretation of experimental results, improve experimental design, and generalize results over wider ranges



Response of rice to level of inputs, measured as energy input and energy output.

Traditional varieties
1 = acid upland (Philippines)
2 = upland (Latin America)
3 = unfavorable rainfed
4 = upland (Philippines)
5 = unfavorable rainfed
6 = broadcast upland
7 = unfavorable rainfed
8 = favorable rainfed
9 = favorable rainfed
10 = deepwater
11 = semifavorable rainfed (wet season)

Modern varieties
12 = irrigated (Philippines wet season)
13 = irrigated (Philippines wet season)
14 = irrigated (rice garden)
15 = irrigated (Philippines)
16 = irrigated (Japan)
17 = irrigated (with azolla fertilizer)
18 = irrigated (Philippines dry season)
19 = irrigated (Philippines dry season)
20 = irrigated (Philippines dry season)
21 = irrigated (Philippines dry season)
22 = irrigated (Philippines dry season)
23 = irrigated (Philippines dry season)
24 = irrigated (Philippines dry season)
25 = irrigated (Philippines dry season)
26 = irrigated hybrid rice (China)
27 = irrigated (with organic fertilizer, China)
28 = irrigated (Mabrouk-4 program, Egypt)

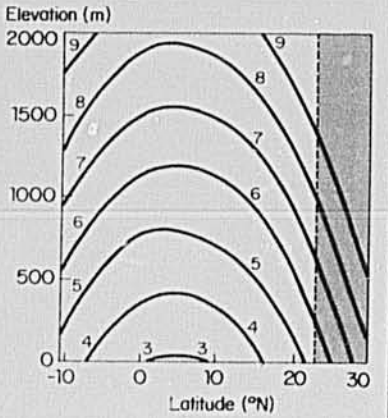
Input energy:energy harvested

We examined the amount and composition of the energy used in rice production by constructing a series of energy budgets. The correlation is clear. Higher yields are tied to higher energy inputs, at least for now.

The 28 systems considered range from low-input slash-and-burn cropping techniques used in the uplands in Latin America to input-intensive irrigated systems used in Asia. The comparison is energy units harvested (the food value of the crop) against energy units used (the labor, fuel, fertilizer, crop management inputs).

Traditional upland farming systems have the highest output:input efficiency. But they also have very low yields, and therefore low human carrying capacity. The significant finding is the near-linear relationship for the range of production systems studied. Even at the highest levels of energy input, there is no evidence of a decline in the energy output:input ratio.

This suggests that for rice, we have not yet reached the flexion point of declining returns to increased inputs.



Isoquant (equal yield) lines of simulated wheat yields in Southeast Asia, expressed as a function of latitude and elevation. (Shaded portion outside Southeast Asia for comparison.) Numbers on lines are yields, in t/ha.

of time and space. We are rapidly expanding our use of this tool in many projects.

One application responded to a farming systems question. Interest in cultivating wheat is growing in Southeast Asia. We used a crop growth model to identify trends in potential yields of rainfed wheat following rice in different environments of the region.

Yield potential of irrigated wheat is projected at 3 to 6.5 t/ha between 10 degrees south and 23 degrees north latitude, up to 500-meter elevation. Such yields should be stable and relatively insensitive to sowing date. The gap between potential and water-limited yield is small if wheat is sown toward the end of the rainy season in deep, well-drained soil.

Simulated yields are close to actual yields.

Component technology integration

Unfavorable production environments

Upland rice commonly is grown on low fertility acid soils, with no purchased inputs. We studied the nitrogen added by intercropping with grain or forage legumes. Indeterminate cultivars of cowpea and lablab were tested as intercrops and as sources of green manure to rice. Incorporating clippings of cowpea added 21 kg N/ha; lablab added 93 kg N/ha. Rice yields in the intercrop were similar to yields of rice alone.

Intercropping cowpea and lablab with rice did not affect rice yields, but did increase nitrogen available to rice. In addition, the intercrop yields added to total production.

Nitrogen uptake increased. Cowpea yielded an additional 1 t grain/ha; lablab, 0.5 t/ha. When plowed down at the end of the dry season, lablab supplied 19 t fresh green manure/ha, the equivalent of 100 kg N/ha.

Sustainable production on gentle hills

Long-term soil erosion on nonbunded gently sloping ricefields can be controlled using contour bands of vegetation. Grass bands also can add the short-term benefit of more favorable soil and water conditions for upland rice and other crops. But in very wet sites and during very wet seasons, when crops other than rice run the risk of waterlogging, bunding and puddling the soil for rainfed lowland rice might be a better cropping strategy. In the same locations, rainfall during dry years could be insufficient for puddling and transplanting.

A livelihood and soil conservation strategy could be to combine the alternatives: establish parallel along-slope strips of land, devoted as appropriate to nonbunded rice, bunded rice, and nonbunded upland crops, with the nonbunded land protected by grass bands.

Contour bands of vegetation can help control soil erosion and conserve soil moisture on nonbunded hill ricefields.

In the 1987 wet season, grass bands retained rainwater on their upslope sides, increasing the soil moisture available to nonbunded rice and mungbean. Mungbean production was five times more valuable than upland rice. Because the rainfall pattern was insufficient to allow puddling and transplanting (1987 wet season was unusually dry), production from bunded strips was zero.

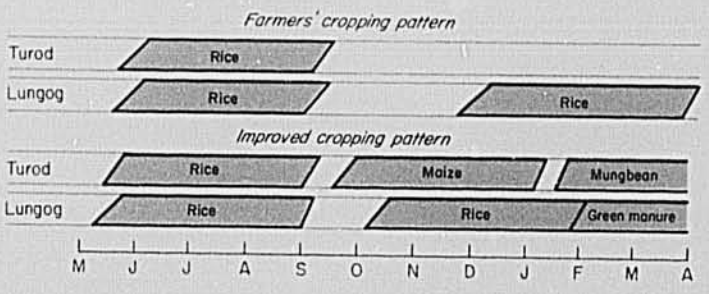
Favorable production environments

Land that is not cropped in the dry season after harvest of wetland rice could be planted to legumes. But puddling and flooding for the rice crop create seed zone and root zone soil structures and redox regimes that are not suitable for a legume crop. We are studying the physical conditions of soil in the seed zone and root zone and the land preparation needed to turn a flooded ricefield into an upland crop field with low cost and low energy.

For root zone conditions, we manually excavated puddled soil to 1-meter depth and replaced it with nonpuddled soil. The consequential low soil strength and more rapid aeration resulted in a short-duration, nonfertilized, nonirrigated mungbean yield of 2.6 t/ha, more than four times higher than the Southeast Asia average.

When we loosened soil strips with chisel tines to 0.35-m depth, mungbean yields were about 2 t/ha. The chemically reduced soil conditions that persisted after rice adversely affected early growth of the succeeding mungbean.

Those reduced conditions can be avoided if mungbean planting is postponed several days, until the soil reoxidizes. But attendant soil drying hinders seedling emergence, cutting yield in half. Some mungbean cultivars are more tolerant of reduced soil conditions.



Improved cropping patterns for partially irrigated fields in Nueva Ecija, Philippines. Lungog has lower-lying fields than turod that are easier to irrigate for rice in the dry season.

Limited water in the dry season in deep well irrigation areas with light-textured soils makes crop diversification important on land grown to rice in the wet season. In the IRRI cropping system research site in Guimba, Philippines, farmer participation helped us evaluate a rice - maize - mungbean pattern designed to more profitably use water and to intensify cropping by increasing water use efficiency among crops and farms. Maize after rice yielded up to 6 t/ha with moderate fertilizer.

With uncertain rainfall, farmers may plant overaged rice seedlings, reducing the yield potential. Dry seeding can avoid that problem and allow time for a short-duration upland crop to follow a short-duration rice crop. Field preparation for the rice crop does need new implements.

Farmers in Guimba, Nueva Ecija, Philippines, traditionally use a lithao wooden plow. We compared the IRRI-developed inverted "T" seeder (with tillage and with no-till) and plow seeders with drilled seeding and with the lithao plow, at 100 kg seeds/ha. More seedlings emerged with the inverted "T" and full tillage, resulting in a higher number of productive tillers and 6.3 t yield/ha.

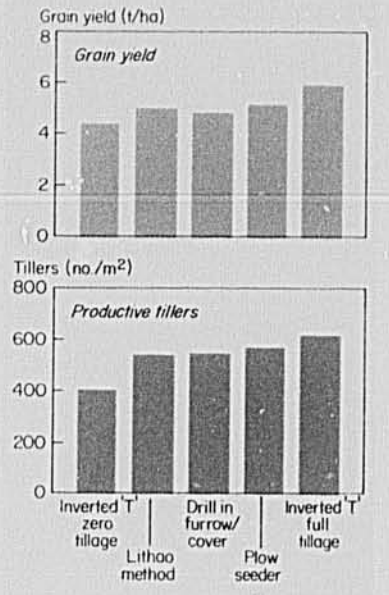
We also used no-till land preparation for a prerice sesbania crop in farmers' fields in a favorable rainfed area. The *S. rostrata* crop planted before the onset of rains produced a total fresh biomass of 12.8 t/ha. That was incorporated and rice grown. Rice yield was comparable to that with 80 kg inorganic N/ha.

Deepwater rice for herbage

Livestock production in deepwater rice and rainfed lowland rice areas has been limited by a shortage of pasture and fodder. Deepwater rice, with a more than 200 day duration, produces as much as 19 t biomass/ha. The biomass produced before flowering could be used as herbage.

In our experiments, cutting deepwater rice at the vegetative stage did not significantly reduce yield. In similar trials in Huntra, Thailand, during the 1986 and 1987 cropping seasons, herbage yields were 1.03 t/ha, with a 0.2 t increase in grain yield/ha. Foliage may be cut from 40 to 100 days after seedling emergence.

Goats at the Dairy Training and Research Institute, University of the Philippines at Los Baños, were fed rice forage



Effect of method of crop establishment on direct seeded rice yields in Guimba, Philippines, 1987 wet season.

hay, rice forage silage, and rice straw. Hay and silage contain much higher amounts of crude protein and lower cell wall fractions than straw. Hay and silage have similar nutrient composition, but hay showed lower dry matter intake as percent of body weight.

Food crop + forage intercropping is a way to increase animal feed, especially during the dry season. The food crop can be a cereal or food legume, the forage crop normally is a legume. Soil fertility is improved when legumes are used in the system.

We tested four combinations of the food legumes cowpea and mungbean and the forage legumes siratro and sunn hemp after rainfed flooded rice harvest on the IRRI farm. Cowpea + sunn hemp gave the best combination yield.

For upland conditions, we tested maize + one of five legumes during the dry season after wet season rice. Maize yields and fodder yields were not significantly affected by different combinations; maize yields were highest with high plant density.

Women in rice farming

This year we followed up our survey of gender-specific tasks and decisionmaking in Santa Barbara, Pangasinan, Philippines. Processing glutinous rice is a major traditional activity, and a significant source of income, for the women in Carosucan, a village with rainfed fields. The traditional glutinous rice varieties commonly grown have low yields and long growth durations. Techniques for processing the grain are strenuous and inefficient.

We introduced IR65, a high-yielding, short-duration glutinous variety. In 1986, 22 farmer-cooperators tested IR65 on 0.9 hectare in fields parallel to 1.5 hectares of fields planted to local varieties. IR65 yielded nearly 1 t/ha more than traditional varieties, with shorter duration. It had higher tillering and better quality grain. In 1987, 30 farmers planted IR65 on 2.85 hectares; 15 farmers planted local varieties on less than 1 hectare.

Despite the small area planted to glutinous rice, women in farm-owned and landless households generate considerable income selling rough and processed glutinous rice. Total cash

Hand pounding parboiled glutinous rice with charcoal is one of the arduous steps in preparing the sticky black rice that is a seasonal income-producing activity in Pangasinan, Philippines.

sales of four landless families in October 1986 was $1,275, almost all of it earned by women selling processed rice.

The method of processing glutinous rice is unique to this region. Black grains are preferred by Pangasinan customers as the main ingredient in rice delicacies prepared for All Saints Day (1 November, a Filipino holiday).

The processing is in three steps: boiling and drying, dehulling and mixing with charcoal, and winnowing. Rough

rice is boiled, stirring constantly, 40-50 minutes per 12-kg rice, until it is dry. The parboiled rice is cooled, hand pounded six times in a boat-shaped mortar with a wooden pestle, and winnowed to remove bran, husks, and charcoal fragments.

Cooking is mostly done by women; pounding by men, women, and children; winnowing by women. Several batches are processed a day, by groups of neighbors and friends. Some tools developed by IRRI engineers (a wooden rotary stirrer, a portable wooden mechanical dehuller, and a portable parboiler-dryer unit) are being modified to make them more comfortable and efficient for women to use.

Equity impact analysis

Adoption of modern rice technology, particularly modern rice varieties, is constrained by environmental conditions such as water control. As a result, the productivity gap between favorable and unfavorable rice production environments throughout South and Southeast Asia has widened during the last two decades.

The fear that modern rice technology has created large disparities in regional income distribution is widely expressed. But our analyses indicate that, at least as far as wage income is concerned, the location specificity of modern rice technology has not worsened regional income distribution.

We examined the impact of modern rice technology on demographic change and wage rates across different production environments, using data collected in an extensive survey of 50 villages in the Philippines. If adoption of modern varieties and construction of irrigation facilities increased labor demand, wage rates in favorable production environments would have increased. In response to that, interregional migration would have occurred, with more in-migration to favorable areas from unfavorable areas and less out-migration from more favorable areas to urban areas, for a net population growth in more favorable areas.

Regression analyses for 1970-80 and 1980-86 show significantly positive coefficients for adoption of modern varieties and for the person:land ratio. Coefficients for the adoption of irrigation are significant only for 1970-80, but irrigated area expanded in only three locations during 1980-86.

It seems clear that adoption of modern varieties and construction of irrigation attracted migrants to favorable areas during the 1970s. There is a slight indication that changes in mechanical technology and direct seeding affected demographic change.

The extent to which such adjustments have contributed to the equalization of wage income was explored by analyzing the regional wage differential. We found that no technology had any significant effect on wage differentials except adoption of transplanted modern varieties (which had a negative coefficient). These findings strongly suggest that wage rates are largely equalized between favorable and unfavorable environments.

We have established collaborative research with China, Indonesia, Thailand, Bangladesh, Nepal, and India to extend this analysis of the linkage between rice technology and farmer income.

Asian Rice Farming Systems Network

More than 250 rice-based cropping/farming systems research sites in 16 countries use methodology developed by network collaborators and at IRRI. In 1987, most focused on testing cropping patterns and crop-livestock systems in rainfed lowland, irrigated lowland, and upland rice environments.

EDUCATION AND COMMUNICATION

IRRI's training and educational programs are broadly organized as primarily research based and as short-term courses on research and crop production methodologies. The objective is to provide the type and level of instruction needed to build groups of well-trained and highly motivated scientists working on various aspects of research and development of rice and rice-based farming systems in the developing countries of the world.

In 1987, 304 visiting scientists, research fellows, and scholars from 50 countries participated in research-based

Titles published in 1987

- *World rice statistics*
- *Global aspects of food production*
- *Progress in rainfed lowland rice*
- *Physical measurements in flooded rice soils*
- *Strengthening national wheat and rice research systems* (for IFAD)
- *Upland rice: a global perspective*
- *Efficiency of nitrogen fertilizers*
- *1986 supplement to publications of the international agricultural research and development centers*
- *Weather and rice*
- *Azolla utilization*
- *A farmer's primer on growing soybean on riceland*
- *A farmer's primer on growing cowpea on riceland*
- *IRRI annual report for 1986*
- *IRRI highlights for 1986*
- *A farmer's primer on growing rice* (Lao language)
- *Insights of outstanding farmers* (Tagalog language)
- *Helpful insects, spiders, and pathogens—friends of the rice farmer* (English, French, Iloko, and Tagalog languages)
- *Field problems of tropical rice* (Sinhala, Malagasy, and Khmer languages)

(does not include translations printed in other countries)

programs at IRRI. The 170 degree scholars were enrolled at 34 different universities; 53 came to IRRI to conduct their dissertation research.

We also offered 25 short-term training courses to 355 participants. A highlight was a special course on the basics of rice production for 13 Kampucheans. Several special courses were conducted completely or partially away from IRRI. For example, the Azolla Utilization course was offered in China, the Deepwater Integrated Pest Management course in India and Bangladesh, part of the Varietal Improvement course in Indonesia, and the Deepwater Rice Genetic Evaluation and Utilization course in Thailand.

We continue to develop course materials with particular emphasis on encouraging self-learning. And we are establishing relationships with training institutes in national systems to help develop in-country programs.

Since the education and training programs were initiated, nearly 6,000 scientists from some 80 countries have returned from IRRI to the rice research programs in their home countries. The first issue of the IRRI Alumni Newsletter was published recently, with a primary goal to encourage communication and collaboration across national boundaries.

Library and documentation

By the end of the year, the Rice Literature Search System had 113,205 rice literature entries covering 1961-87. All the original documents represented by those citations are in the IRRI Library book and periodical collection and are being used to respond to requests worldwide for information about rice.

We also released the 1986 supplement to the *International Bibliography of Rice Research*. That 808-page volume contains 8,011 bibliographic citations arranged by subject matter, with author and keyword indexes.

Communication and publications

IRRI published 23 books in 1987 and distributed 102,000 copies of those and past-year titles. At least 1 million copies of 110 editions of 27 IRRI books have been published in 42 languages in 25 countries.

One free copy of each new book goes to about 800 key developing world agricultural libraries. Of the total distribution, 95 percent went to developing countries; 38 percent was distributed free to libraries. In addition, we mailed 7 issues of the *International Rice Research Newsletter* and 4 issues of the *IRRI Reporter* to 11,500 individuals and 3,050 libraries in 151 countries, 77 percent of them in developing countries; 8 issues of the *IRRI Research Paper Series* were sent to 3,050 libraries; and 7 issues of *Rice Abstracts*, published jointly with C·A·B International, were sent to key agricultural libraries in developing countries.

The fifth Editing and Publication training course in the 3-year program cosponsored by IRRI and the International Development and Research Centre, Canada, brought the number of EdPub graduates now working in national communication and publications activities to 45 editors in 16 countries. Graduates have helped conduct follow-up short courses through national programs in China, Indonesia, Malaysia, Tanzania, and Kenya. Courses are planned in Thailand and Nigeria. The EdPub training materials will be published in 1988 as a text for developing country science editors.

INTERNATIONAL COOPERATION

A major role of IRRI is fostering the growth of a global family of rice research institutes and scientists dedicated to improving the productivity, profitability, stability, and sustainability of rice farming systems. IRRI has formal or informal relationships in both research and training in nearly all the rice-growing countries of the world. Support comes largely from special projects funding.

East and Southeast Asia

Philippines

Collaboration between IRRI and Philippine scientists was strengthened with the signing 29 May 1987 of a Memorandum

of Understanding between IRRI and the Philippine Rice Research Institute (PhilRice). The first work plan proposes collaboration in varietal improvement, planting and fertilizer management, farm mechanization, postharvest engineering, integrated pest management, rice farming systems, social science and policy research, and technology transfer.

PhilRice, on behalf of the Philippine Department of Agriculture, led planning for the 10th and 11th Department of Agriculture-IRRI Technology Transfer Workshops. The 10th workshop, on increasing income and employment, was followed by two special Prosperity through Rice short courses conducted for 65 trainees by the Department of Agriculture, PhilRice, the University of the Philippines at Los Baños, and IRRI.

During the 11th workshop, on increasing rice production after an abnormally dry wet season, 120 participants debated options for increasing rice availability to offset an anticipated 500,000 tons milled rice production shortfall. The kice Production Enhancement Program to provide subsidized

nitrogen fertilizer had reached 245,000 farmers planting more than 365,000 ha rice in 70 provinces by the end of 1987.

The Varietal Improvement group of the Philippine Seed Board has recommended release of IR28224-3-2-3 and IR28228-12-3-1 as IR68 and IR70.

Burma

This year's collaboration with Burma focused on cropping patterns; varietal improvement of rice, food legumes, edible oil crops, and small grains; and small-scale mechanization. Promising cropping patterns identified in 1986-87 trials include maize - rice - soybean or peanut, cotton or sesame - rice, cotton - rice, and rice - wheat in central Burma and rice - cowpea in south-central Burma.

Five IR elite breeding lines were among the 10 varieties recommended for release in five rice environments: IR18269 Yn 5, IR18048 Yn 5, and IR18048 Yn 15 for rainfed lowland; IR8845-10-3-3 and IR13155-60-3-1 for cool regions.

China

The 1987 International Rice Research Conference (IRRC) was held in Hangzhou, on the occasion of the dedication of the Huang Tian Fan campus of the China National Rice Research Institute. Facilities there include plant growth chambers, experimental fields, a main laboratory building, a biotech building, greenhouses, a germplasm bank, library and computer center, and guesthouses and trainee dormitories. The Hangzhou campus, to be completed in 1988, will include headquarters, reception areas, and scientist housing.

Participation at IRRC included about 100 scientists from 22 countries and international research institutes around the world and about 100 Chinese rice scientists.

Indonesia

Particular attention in the Agency for Agricultural Research and Development (AARD)/IRRI collaborative research program focused on rice tungro, prosperity through rice, rice policy and food demand/supply prospects, agricultural engineering, and water management. In three rice cropping monitoring tours through West, Central, and East Java, plantings in general appeared to be well-managed, with farmers following recom-

mendations of the Ministry of Agriculture for varietal choice and pest control. Where water is available, farmers are harvesting a rice crop every 90 to 100 days.

The 8th annual AARD/IRRI collaborative research planning meeting was held in Bogor 29-30 June.

Malaysia

The first Malaysian Agricultural Research and Development Institute (MARDI)/IRRI collaborative research planning meeting took place in Penang in late March. Mechanized rice production, stimulated by a shortage of labor, is a major concern. Collaborative work is underway in hybrid rice, rice soil physics, and rice grain quality.

In Sabah, the area under rice had been decreasing. In 1987, the Ministry of Agriculture reordered priorities in rice to emphasize production in upland, rainfed, and problem soils with the goal of producing 60-70 percent of the rice needed. In coastal areas, popular IR42 is yielding more than 7 t/ha at high seeding rates and with no weed pressure. IR8192-200 and IR54 were released as recommended varieties in June.

Kampuchea, Laos, and Vietnam

The IRRI-Indochina program began in March 1987 with funding from the Australian International Development Assistance Bureau. Funding has been extended to 1991.

The focus of the work plan with Kampuchea is on human resource development, assistance in applied research, technology transfer, and development of a training and research infrastructure. In mid-year, 13 Kampuchean agricultural officers attended a special 4-month rice production course at IRRI, after a 2-week English language course in Phnom Penh. An applied research program designed in conjunction with the Ministry of Agriculture began at three regional research centers, with some on-farm testing of modern and traditional varieties.

The IRRI-Laos work plan, signed 17 December 1987, focuses on developing sustainable technologies for rice-based farming systems. The primary rice-growing environments are upland and rainfed lowland. More stable farming systems are needed in the upland areas, where crop management is primarily slash-and-burn.

Collaborative work priorities in Vietnam are varietal improvement and management for specific agroecological

With population increases, slash-and-burn farming leads to declining yields and environmental degradation. Collaborative research in Laos will identify sustainable alternatives.

environments, integrated nutrient management, cropping intensification, integrated pest management, and water management. During 1987, 33 Vietnamese scientists and scholars participated in training and education programs at IRRI. Promising lines for acid sulfate conditions have been identified at the Cuu Long Rice Research Center in the Mekong Delta.

Thailand

Two major collaborative, core-funded projects in Thailand are deepwater rice research in flooded areas of the central plain and rainfed lowland research in problem soils of the northeast. Both have a regional collaborative research component with other countries. Technology resulting from research in Thailand is directly applicable in Laos, Vietnam, and Kampuchea and, to some extent, in Burma.

South Asia

Bangladesh

The Bangladesh Rice Research Institute (BRRI) and IRRI scientists collaborative work pattern is integrated; research

projects are carried on as mutual efforts. The program is now focusing on rainfed lowland rice, rice-based farming systems, prosperity through rice, grain quality, botanical pest control, and differential impact studies.

BRRI researchers are shifting to integrated farming systems research, with the focus on increasing family income. The impact of rice farming systems research is being studied in two sites, with all income, expenditure, and crop production activities monitored to provide insights into the benefits families have derived from the adoption of new technologies.

Using data from the Soils Resource Institute, the Rice Farming Systems Division has delineated eight rainfed environments with associated primary land uses. Cropping systems recommendations have been developed for lowland favorable, lowland drought prone, and deep water. Collaboration with the Water Development Board is developing improved water and crop management practices for selected irrigated systems.

Bhutan

Only 5 percent of Bhutan's 46,500 km^2 is cultivated; 90 percent of its 1.2 million people depend primarily on agriculture for their livelihood. Rice is grown on about 35,000 hectares of mainly irrigated or rainfed fields. Average yield is 2 t/ha.

The most progress in the IRRI-Department of Agriculture collaboration continues to be in the medium altitude (600-1,800 m) zone. IR36 and IR64 have shown excellent adaptation to this environment. In 10 farmers' field trials with only farmyard manure fertilizer, IR64 yielded 4.7 t grain and 11.9 t fresh straw/ha. Preliminary experiments indicate the feasibility of two rice crops per year, under specified conditions. Ratooning also appears promising. In one trial, the main crop yielded 6.6 t/ha, the ratoon crop 4 t/ha.

In the lower altitudes in the south, the research capability of Bhur Farm substation of the Centre for Agricultural Research and Development is being strengthened. Two breeding lines—BR153-2B-10-1 and BG379-2—are showing excellent performance. Trials confirmed the potential of *Sesbania aculeata* as green manure. A pilot area has been identified to demonstrate integrated pest management technology.

In the high altitude zone (above 1,800 m), shuttle breeding has helped identify a few genotypes with potential;

they have been selected for a pedigree nursery. Popular local varieties (japonica types) were crossed with selected IR varieties.

India

Two special Indian Council of Agricultural Research (ICAR)-IRRI collaborative rice research projects for development of rainfed rice in eastern India were initiated in 1987—pest management in deepwater rice and rainfed rice production. The deepwater areas have been mapped, with detailed studies of the primary pest population dynamics. In the rainfed areas, 4 research centers and 11 associate centers have enlisted the cooperation of more than 1,500 farmers to conduct on-farm trials representing specific agroecological environments.

Africa

Egypt

New rice research facilities were dedicated at Sakha in January 1987. Major research effort concentrates on developing high-

yielding, nonlodging, relatively early varieties with improved resistance to blast and stem borers and tolerance for salinity. Grain quality is a top priority. Short-duration varieties tried in a two-crop intensification yielded less than one main crop.

Madagascar

Work at the National Center for Applied Research for Rural Development (FOFIFA) included screening about 1,200 introduced cultivars and Malagasy traditional varieties for cold, phosphorus deficiency, and iron toxicity tolerance. Sixteen IRCTN lines had cold and iron toxicity tolerance and 13 Malagasy varieties had phosphorus deficiency tolerance. F_1 seeds from 82 crosses made at IRRI using Malagasy and elite germplasm are under test. Nearly 800 introductions are being field tested in the major ecologies of the island; 124 are in advanced trials.

Upland and lowland cropping systems research in four major rice-growing areas is nearly three-fourths on-farm trials and farmer problem focused.

West Africa

IRRI's activities in West Africa involve collaboration with other international organizations, particularly the International Institute of Tropical Agriculture (IITA) and the West Africa Rice Development Association (WARDA), and with national agricultural research systems through the International Rice Testing Program (IRTP). IRTP-Africa now constitutes the core of many national breeding programs. In African countries, interest in sending students to various IRRI training programs is increasing. The commitment of many African countries, IITA, WARDA, and IRRI to work together as a team is intensifying.

IRTP-Africa has identified 58 varieties with superior performance in irrigated and upland ecologies. IRTP-Latin America sent 75 observational nursery sets and 115 global nursery sets to requesting national programs.

Latin America and the Caribbean

The Caribbean Rice Improvement Network is sponsored by the Centro Internacional de Agricultura Tropical (CIAT) with funding through IRRI-IRTP. Belize, Cuba, Dominican Republic, Guyana, Haiti, Jamaica, Trinidad and Tobago, and Surinam are

participating. Improved germplasm introduced from CIAT, IRRI, and national programs is evaluated in the Dominican Republic to form observation nursery sets for the different production systems and environments of the network countries. Nearly 200 promising entries in 29 nursery sets were distributed in 1987; 214 have been selected for distribution in 1988.

A package of agronomic practices developed to control red rice, reduce production costs, and increase productivity is being demonstrated in farmers' fields in Bonao, Dominican Republic. A newsletter, *Rice in the Caribbean*, is being published twice a year.

Research and support for Latin America are coordinated through CIAT. In regional IRTP activities, 76 nursery sets were distributed in 1987; they included materials containing tolerances for several disease, insect, and soil problems. National programs released as new varieties 13 lines originally distributed in IRTP nurseries and 11 lines developed in their own crossing and selection programs.

The precision of hot spot site evaluations at Villavicencio (Santa Rosa station), the current CIAT rice program evaluation site, is under study. Long-term data suggest that hot spot screening has increased the program's ability to predict overall disease reaction 15-20 percent of the time; the Santa Rosa station can predict leaf blast and scald reactions in Central America 80-90 percent of the time. Brown spot pressure appears to be unreliable.

FINANCES

Summary of financial support to IRRI core and to special and collaborative projects received in 1987.[a]

	Amount (US$)			
	Core		Special and collaborative project	Total
	Unrestricted	Restricted		
Details of sources of support from grants				
International Bank for Reconstruction and Development	2,100,000			2,100,000
Japanese Government		5,586,934	994,182	6,581,116
Overseas Development Administration — United Kingdom	1,389,113			1,389,113
Canadian International Development Agency	1,351,440			1,351,440
United States Agency for International Development		4,050,140	1,447,235	5,497,375
Asian Development Bank			664,600	664,600
Federal Republic of Germany	708,738		195,818	904,556
United Nations Development Programme		2,289,300	6,075	2,295,375
European Economic Community		2,044,292		2,044,292
Australian Government	646,185		390,711	1,036,896
International Development Research Center		58,047	562,167	620,214
Government of Sweden	502,358			502,358
Government of Denmark	370,112		63,122	433,234
Swiss Development Cooperation		250,000	50,000	300,000
Rockefeller Foundation		355,400	343,000	698,400
Ford Foundation	**300,000**	**80,000**	244,000	624,000
Government of The Netherlands		**291,754**	200,897	492,651
Government of India	**246,782**			246,782
Government of Finland	233,481			233,481
Government of Norway	116,669			116,669
Organization of Petroleum Exporting Countries			154,329	154,329
Government of France		130,760		130,760
Office of Rural Development, Korea			98,000	98,000
Government of the Islamic Republic of Iran			83,030	83,030
Government of the Philippines	53,530		29,132	82,662
People's Republic of China	50,000			50,000
Government of Spain	30,000			30,000
Government of Mexico	**19,446**			19,446
Government of New Zealand	15,025			15,025

	Amount (US$)			
	Core		Special and collaborative project	Total
	Unrestricted	Restricted		
Miscellaneous research grants			48,611	48,611
Funds reimbursed under collaborative research program				
International Food Policy Research Institute			89,441	89,441
International Center of Insect Physiology and Ecology		**81,637**		81,637
Resources Management International, Indonesia			65,107	65,107
University of Giessen			62,712	62,712
Istituto per la Chimica Del Terreno			50,000	50,000
International Fertilizer Development Center			45,514	45,514
International Center for Living Aquatic Resources Management			33,845	33,845
University of Hamburg			21,163	21,163
Consortium for International Crop Protection			16,553	16,553
International Institute of Tropical Agriculture			15,642	15,642
USDA/University of Minnesota			13,814	13,814
Total	8,132,879	15,218,264	5,988,700	29,339,843

*Receipts are accounted for on a cash basis. Amounts shown in boldface differ from 1987 pledges by grantors in that they may reflect 1986 or 1988 pledges received in 1987 or may not reflect the full amount of 1987 pledges which are anticipated to be received in 1988. Also, the Government of France (through the research organizations ORSTOM and IRAT) provided IRRI the services of three resident scientists; the value of their services cannot be quantified.

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[1]Left during the year
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