IRRI RESEARCH HIGHLIGHTS 1988

International Rice Research Institute

1989
INTERNATIONAL RICE RESEARCH INSTITUTE
Los Baños, Laguna, Philippines
P.O. Box 933, 1099 Manila, Philippines

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.

IRRI receives support, through the CGIAR, from a number of donors including the Asian Development Bank, the European Economic Community, the Ford Foundation, the International Development Research Centre, the International Fund for Agricultural Development, the OPEC Special Fund, the Rockefeller Foundation, the United Nations Development Programme, the World Bank, and the international aid agencies of the following governments: Australia, Belgium, Canada, China, Denmark, Finland, France, Federal Republic of Germany, India, Italy, Japan, Mexico, The Netherlands, New Zealand, Norway, the Philippines, Saudi Arabia, Spain, Sweden, Switzerland, United Kingdom, and United States.

The responsibility for this publication rests with the International Rice Research Institute.

ISSN 0115-1142

Table of contents

A strategy for the 1990s

The year 1988 was another watershed in IRRI's evolution. The task: preparing for IRRI's fourth decade, toward the year 2000.

The world of rice and rice science continues to change, at an ever-accelerating pace. The physical and economic characteristics of rice production and consumption–and their long-term prospects–are posing new challenges. Rice research and scientific advances of potential relevance to rice have created new opportunities.

In 1988, we addressed ourselves to developing a vision of the future, to better anticipate tomorrow's problems and to define our search for innovative solutions over the next decade. Extensive debate and interactive thinking by IRRI staff and expert international consultants culminated in October with the endorsement by the IRRI Board of Trustees of the strategy document *IRRI toward 2000 and beyond*.

The challenge

The world is becoming ever more complicated. Concerns about the future–the availability of food, conservation of resources, and sustainability of the environment–highlight increasingly complex problems. The solutions to these problems must be sought now.

We designed a research strategy for IRRI that aims at minimizing the problems related to adequate rice production on an equitable and sustainable basis by maximizing the potential to solve the problems.

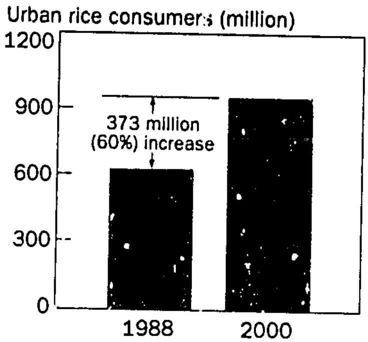
Each year, the world must feed 80 to 100 million more people, most of them in the less developed and poorer countries. Virtually all the people who depend on rice as their primary food live in the less developed countries. Half the world's rice is consumed by those who produce the crop, most of them resource-poor farm households.

IRRI toward 2000 and beyond

The goal
Improved well-being of present and future generations of rice farmers and consumers, particularly those with low incomes.

The objectives
To generate and disseminate rice-related knowledge and technology of short- and long-term environmental, social, and economic benefit and to help enhance national rice research systems.

The strategy
To increase rice production efficiency and sustainability in all rice-growing environments through interdisciplinary research and to ensure the relevance of IRRI research and the complementarity of international and national research efforts through close collaboration with national programs.



Current and projected number of urban rice consumers in 14 major rice-growing countries of Asia (from 1988 World Population Data Sheet).

Increasing urbanization in rice-consuming countries is putting pressure on national food security.

To meet the projected growth in demand for rice, we estimate that the world's annual rough rice production must increase–by an astronomical 65% (from today's 458 million tons to 758 million tons) by 2020. For the leading rice-growing countries of South and Southeast Asia, production will need to double.

We identified five important issues to consider in devising IRRI's research strategy for the 1990s.

- Current forecasts of rice supplies do not take into account factors that could adversely affect the long-term security and stability of rice production.
- Factors that affect production apply equally to both favorable and unfavorable rice ecosystems.
- In the foreseeable future, the world will continue to rely heavily on the favorable rice-growing ecosystems, particularly to feed urban consumers. The vulnerability of these systems to degradation demands continuing and, in some aspects, increased attention.
- Rapid scientific advances in many fields have potential to help IRRI and its partners find solutions to continuing and emerging problems.
- A wide range of interrelated factors–political, economic, institutional–will contribute to increasing and sustaining rice production, protecting the environment, and improving the well-being of farmers.

Designing the strategy

Many of the development issues related to rice are interdependent. The range of entry points for research is extensive. Two aspects of strategic decisionmaking guided our decisions–research policy and research resource allocation priority.

Policies

Research relevance. Broad-based research, including research on socioeconomic aspects of rice production, is needed to characterize the rice ecosystems in terms of people and their environment, to improve understanding of the farming systems within which rice is produced, and to refine the definitions of the kinds of technologies that should be developed. IRRI will intensify its dialogue with national partners, to improve our understanding of farming systems and the needs of prospective users and beneficiaries of rice research results.

Environmental sustainability. Attention to the impact of high yield-producing technologies becomes more urgent as cropping intensifies. All our programs will be driven by, and many will be specifically directed to addressing, concerns about the effects of rice production systems on the environment.

Efficiency and equity. An efficient research system would allocate resources to return the same marginal social benefits per unit of research input, regardless of where that input was made. It would not be concerned with who received the benefits. But equity demands that IRRI be concerned with how the benefits from research investment are distributed. We will direct IRRI research toward improving both production efficiency and

The role of women in rice research and rice farming has both efficiency and equity implications.

equitable returns to all rice-dependent groups, particularly those in the less favorable ecosystems.

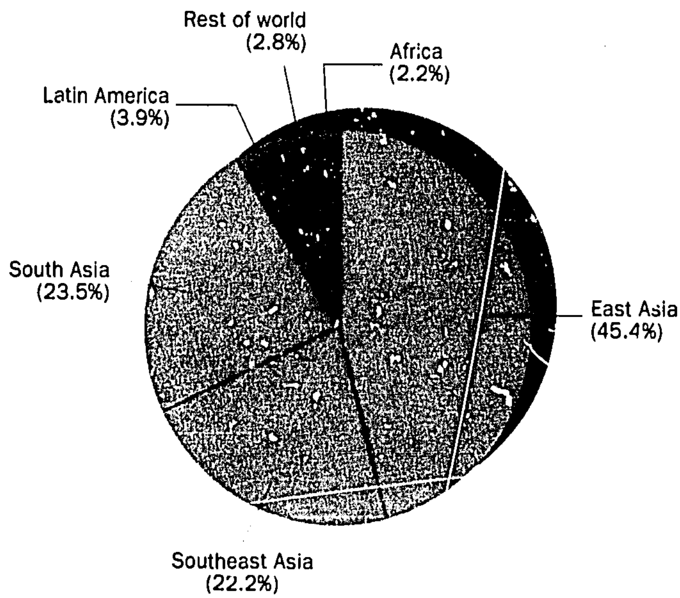
Women and rice. The role of women in rice research and rice farming has both efficiency and equity implications. Analysis of the contribution of women to rice production, marketing, and consumption; identification of technologies that reduce the burden of women without displacing their income-earning capacity; and development of processing techniques that conserve the level of essential nutrients in rice will help focus research on the ultimate beneficiary of rice research: the whole family.

Disciplinary strength and interdisciplinary focus. A recurring dilemma in research management is how to integrate the strengths of different scientific disciplines toward seeking solutions to complex problems. IRRI is instituting a new program structure to facilitate the pursuit of excellence in both disciplinary and interdisciplinary research.

Priorities

The strategy is to strike an optimum balance of effort devoted to several alternatives. IRRI's programs will be oriented to the major rice ecosystems and to the farming communities and consumers dependent on them.

Regional distribution of world rice production of 298 million tons milled rice in 1987.



Collaborative research on the less favorable ecosystems will increase. Consistent with environmental enhancement and sustainability, efforts will be directed toward securing yield gains in favorable ecosystems and seeking new yield potentials in all ecosystems. Our research efforts will move toward strengthening IRRI's scientific base, using results and techniques emerging from the frontiers of scientific discovery.

We are committed to helping strengthen national rice research programs and will be increasing collaborative work and knowledge sharing with all IRRI's partners. We look toward a mutually supportive global rice research system.

While IRRI will continue to focus on Asia, its worldwide responsibilities cover all regions. We will contribute to research and to strengthening national programs in Africa and Latin America in the context of the activities of other international agricultural research centers.

Programs

IRRI's strategy will be implemented through research and international programs.

Research programs

The types of ecosystems that must supply rice are important in planning research. Water regime is the primary determinant of the types of rice cultivars and production practices needed. In our planning for IRRI's future, we considered the broad ecosystems for rice: irrigated, rainfed lowland, upland, deepwater, and tidal wetlands.

Interdisciplinary research programs for the major rice ecosystems will include a thorough characterization of each ecosystem in terms of agroecology; people and their environment; and the historical, socioeconomic, and technical aspects of rice production. This will refine the definitions of the kinds of technologies that should be developed for the farming systems within which rice is produced. It also will define the conditions and criteria for evaluation that will ensure that the technologies developed will maintain or improve the natural resource base.

Irrigated rice ecosystem.

Irrigated rice ecosystem. The goal is secure and increased rice productivity, with enhanced efficiency and sustainability of irrigated rice farming systems. The objectives are

- To raise irrigated rice yield potential to higher plateaus to meet the needs of the increasing number of urban rice consumers.
- To develop crop and resource management techniques that will reduce production costs, increase yields, and sustain land productivity.
- To secure yield gains.
- To reduce the gap between potentially attainable yields and actual farm yields.

Rainfed lowland rice ecosystem. The goal is increased productivity and yield stability and ensured sustainability

Rainfed lowland rice ecosystem.

of rice farming systems, particularly in the less favorable environments vulnerable to flooding and drought. The objectives are

- To develop rice breeding lines capable of higher, more sustainable yields for the different rainfed environments, with particular emphasis on tolerance for submergence and drought.
- To develop improved production practices and farming systems for the less favorable rainfed lowland rice environments.

Upland rice ecosystem. The goal is rehabilitation and increased stability and sustainability of upland rice farming systems. The objectives are

- To design a range of rice production practices that will help rehabilitate the uplands and transform them into sustainable agroecosystems.
- To develop techniques and technologies for increasing and stabilizing upland rice yields.

Upland rice ecosystem.

Deepwater rice.

Deepwater and tidal wetlands rice ecosystems. The goal is high and stable rice production in deepwater and tidal wetland areas. The objectives are

- To develop rice breeding lines capable of higher and more stable yields, with improved tolerance for floods, drought, pests, and problem soils.
- To develop rice-based cropping systems that increase land use efficiency.
- To develop crop and resource management practices for currently unused areas with a potential for growing rice.

Cross-ecosystems research. The challenges of the future are likely to be much more complicated than those we have had to address in the past. Anticipatory research, in which IRRI adopts a futuristic role toward sustaining gains in rice science, is needed. Such research will make use of new techniques and newly developed tools. It will bridge basic research done elsewhere and the work done in the ecosystem-specific programs and in national rice research systems to increase rice yield potential.

Tidal wetlands rice.

The objectives of such research are to increase understanding of rice ecosystems; to develop modern scientific tools, methods, and knowledge for addressing current and anticipated rice production problems common to several ecosystems; and to make available to programs in countries worldwide promising technologies arising from more basic research.

International programs

Since its founding, IRRI has played a major role in fostering the growth of a global family of rice research institutions and scientists. International programs during the 1990s will support and strengthen the rice research capacity of national systems and will serve the international rice research community.

Germplasm conservation and dissemination. A continuous supply of diverse germplasm, including traditional varieties, improved breeding lines, wild relatives, and grasses in rice-related genera, is crucial to raising rice yield potential, stabilizing yields, and enhancing the sustainability of biotic ecosystems. Our objective is to collect, preserve, document, and study the world's rice germplasm and to provide free access to it, worldwide, for rice research and rice crop improvement.

Information and knowledge exchange. IRRI's mandates to disseminate the research findings of the institute, to make available literature on rice worldwide, and to organize conferences and workshops will be no less important in the future than they were at IRRI's founding. The library and documentation center will continue to collect and provide access to the world's literature on rice. We will publish scientific information and promote the flow of current rice research knowledge to scientists. We will compile, evaluate, interpret, and disseminate current primary and secondary data on rice and the physical, biological, and socioeconomic environments of the rice ecosystems and establish linkages with other relevant databases. We will facilitate the participation of scientists from all collaborating institutions in setting program priorities, planning research, sharing results, and promoting dialogue on institutional and policy issues. We will work to create an accurate understanding of rice, rice research, and

IRRI's goal, objectives, programs, and approaches among donors, policymakers, and the general public in both developed and less developed countries.

Networks. Three major networks link national program scientists with each other, with IRRI, and with other international and regional centers. Collaborators in the International Rice Testing Program (IRTP) exchange and evaluate improved genetic materials in different rice-growing countries. The International Network on Soil Fertility and Sustainable Rice Farming (INSURF) generates technologies relevant to nutrient management and soil conservation problems in specific areas, with emphasis on renewable resources. The Asian Rice Farming Systems Network (ARFSN) facilitates identification of more productive and sustainable rice-based small farming systems. All these collaborations will be strengthened to facilitate the exchange of new knowledge worldwide.

Training. IRRI offers postgraduate training and non-degree training and develops short-course materials to facilitate the transfer of training techniques to national programs. The objective is to develop a critical mass of professionals working to advance rice science and to solve rice production and utilization problems.

Regional and country programs. IRRI responds on a limited basis to the specific needs of some rice-growing countries whose current rice research capacity is insufficient.

Toward 2000

Both quantitative and qualitative change will occur as IRRI's new strategy is implemented. Scientific disciplines will be grouped into divisions. Carefully designed interdisciplinary projects will be implemented through the research and international programs. The strategy calls for increasing the range and degree of collaboration with many different types of research organizations and systems. All IRRI's work will continue to relate directly to the two primary objectives: conducting research and helping to enhance national rice research systems.

Highlights of 1988

Even as planning for redirection and change took place, IRRI scientists continued their work to stretch the limits of current rice knowledge, to devise ways to conduct research more precisely and efficiently, and to apply current knowledge to designing improved technology. Highlights of 1988 work are presented here, within the structure of IRRI's organization during the 1980s.

Genetic evaluation and utilization

A continuous supply of improved germplasm anchors increases of rice production all over the world. Higher yield potential and long-lasting pest resistances and stress tolerances demands research into sources of valuable characters and into breeding techniques for incorporating those sources into ever-better lines.

Genetic resources

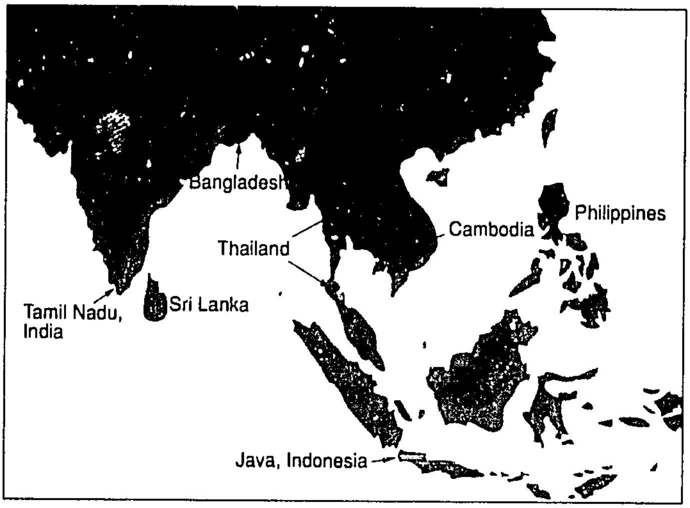
The varietal improvement programs of IRRI and its national cooperators rely on the collection of some 84,000 cultivated and wild rices maintained in the International Rice Germplasm Center (IRGC), for sources of desirable characters. Advances in biotechnology, with its potential for wide hybridization, have increased the emphasis on collection of wild rices and the wild relatives of rice.

Conserving wild rices. Natural habitat destruction has been increasing dramatically, and IRGC has stepped up its program to collect wild species of *Oryza*. Wild *Oryza* species collected during 1988 included *Oryza nivara*, *O. rufipogon*, *O. "spontanea"*, *O. officinalis*, *O. eichingeri*, *O ridleyi*, and *O. granulata*.

In addition, we are increasing our efforts to collect wild relatives of rice such as *Hygroryza aristata* and *Leersia* sp. In one case, biotechnology workers in Europe requested *H. aristata*. Within two months, populations

***Hygroryza aristata*, a wild relative of rice, is one of several wild genera that could be crossed with rice through advances in biotechnology.**

Areas of collaborative exploration for wild *Oryza* species and genera in 1988.



were discovered, collected, and samples dispatched for their use in comparative DNA studies.

Restocking rice collections. IRGC continued its support of national rice research efforts by supplying several countries with collections of their traditional rice varieties. National breeding programs use these varieties in adapting improved breeding lines to local conditions. Requests this year came from the Philippines, Senegal, and Karnataka State in India. In the Philippines, IRGC provided the Philippine Rice Research Institute (PhilRice) with 647 upland rice varieties.

Complete sets of germplasm data were provided leaders of rice germplasm collections in several national programs, to help them in their varietal improvement research.

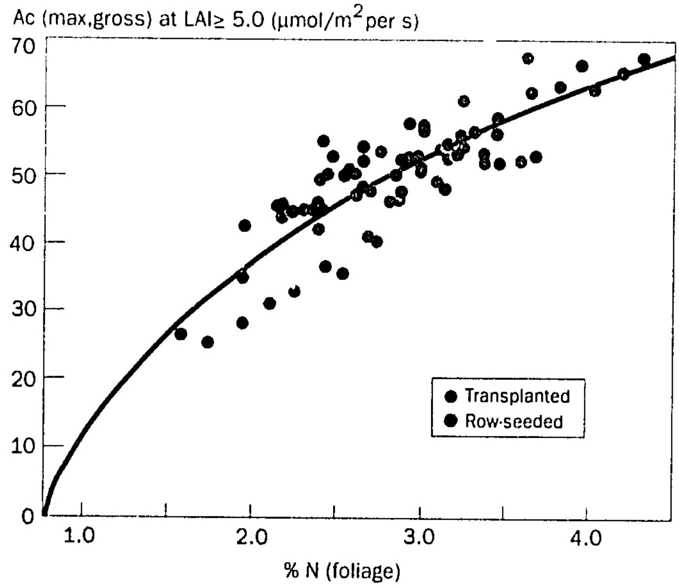
Agronomic and physiological characterization

Studies on the fundamental bases of higher yield potential in the rice plant continue. We are characterizing a new plant type for direct seeded flooded rice and identifying donors for component traits.

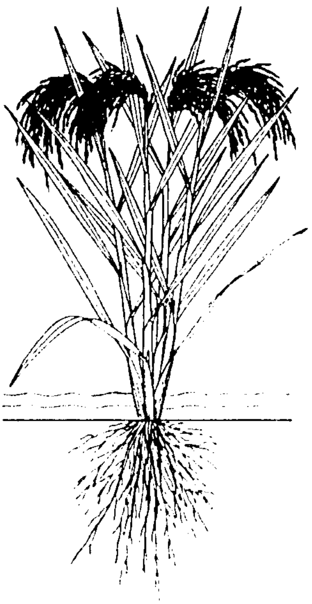
New plant type for direct seeded flooded rice. When modern, high-yielding semidwarf rice is direct seeded and grown under favorable nutritional and climatic conditions, overgrowth of the crop canopy results in substantial yield reductions. We studied growth, canopy carbon dioxide assimilation kinetics, nitrogen economy, and yield formation of transplanted and direct seeded IR58, IR65, and IR29723-143-3-2-1 in the 1988 dry season at Muñoz, Nueva Ecija, Philippines.

Direct seeded rice was more productive at the vegetative growth phase than transplanted rice, primarily because of the absence of transplanting shock. Transplanting normally delays crop establishment, canopy carbon dioxide assimilation, foliage expansion, and tillering by 2 weeks. That early growth and vigor, however, were followed by growth reduction during the reproductive stage, because of higher-than-optimal leaf area index (LAI). And regardless of total nitrogen uptake by the crop, foliage nitrogen concentration was critically low during the ripening stage—the result of nitrogen dilution through foliage expansion. At LAI of 5 and above, nitrogen concentration in the foliage—not LAI or total plant nitrogen uptake—limited carbon dioxide assimilation.

We conclude that under the climatic and soil conditions at the experimental site, the maximum grain yield of 9.1 t/ha for both transplanted and direct seeded IR64 could be raised through plant type improvement, to 10.5 t/ha for transplanted and 11.8 t/ha for direct seeded rice.



Relation between foliage nitrogen concentration (% N) at LAI of 5 and above, and maximum canopy gross photosynthesis (Ac).



Ideal plant type for direct seeded flooded rice

- short to medium stature with erect leaves
- medium to long duration
- low-tillering ability
- early growth vigor and improved seedling anchorage
- high N uptake rate
- limited foliage expansion during reproductive stage
- maintenance of high foliage N concentration
- high storage capacity of assimilated N in stems and leaf sheaths
- strong vertical senescence gradient and delayed senescence of flag leaves during ripening
- high spikelet number per panicle

Yield potential. One way to increase yield potential is to increase the number of high-density grains, which occur mostly on the primary branches of the rice panicle, and to increase the number of spikelets per panicle. We studied the panicle characteristics of 60 varieties and lines to identify possible donors of high-density grains.

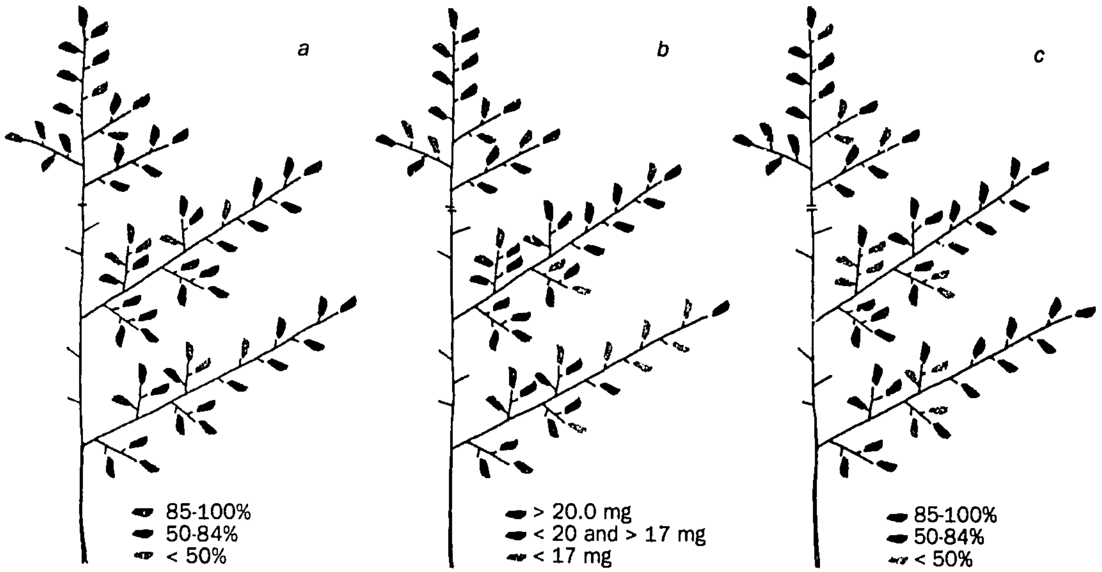
To increase the number of primary branches, we made several crosses of *Oryza sativa* with *O. glaberrima*. Lines with thick culms and more vascular bundles were selected from the anther culture-derived upland cross Moroberekan Palawan. Selections from traditional variety Rewa 353 were used to increase the number of filled spikelets per panicle. In two of the *O. sativa O. glaberrima* crosses, the number of primary branches increased to 18 (IR varieties have about 10 primary branches). Spikelet number ranged from 320 to 380 in Rewa 353-3 IR47705-AC4.

Environmental conditions during panicle initiation and development affect spikelet development. Spikelets develop on the lower panicles first. Development proceeds from the base to the apex of the panicle. At flowering, however, development of grains begins at the topmost branches of the panicle and proceeds downward.

In the tropics, spikelets on the upper primary branches are better filled, and their chances of occuring and being filled are higher than those on the lower and secondary branches. A plant with more spikelets on the primary branches and fewer spikelets on secondary branches could improve grain yield potential.

We compared growth and yield of direct-seeded crops in both the wet and dry seasons using low-tillering, large panicle IR25588 and high-tillering, small panicle IR58. Low-tillering IR25588 had better grain yield performance at close plant spacing in both seasons.

The heaviest panicles in both IR25588 and IR58 were on the first six tillers that developed. These tillers flowered earlier and had bigger culms and more leaves per tiller to support many spikelets. All spikelets had better grain filling. This suggests that a rice plant with six tillers may be ideal for increasing grain yield potential in direct-seeded rice.



Development of spikelets and grain filling on a panicle. *A*, chances of spikelet occurrence on different positions in a panicle; *B*, grain weight at different locations in a panicle; and *C*, chances of filled grains at different locations in a panicle.

Grain quality and nutrition

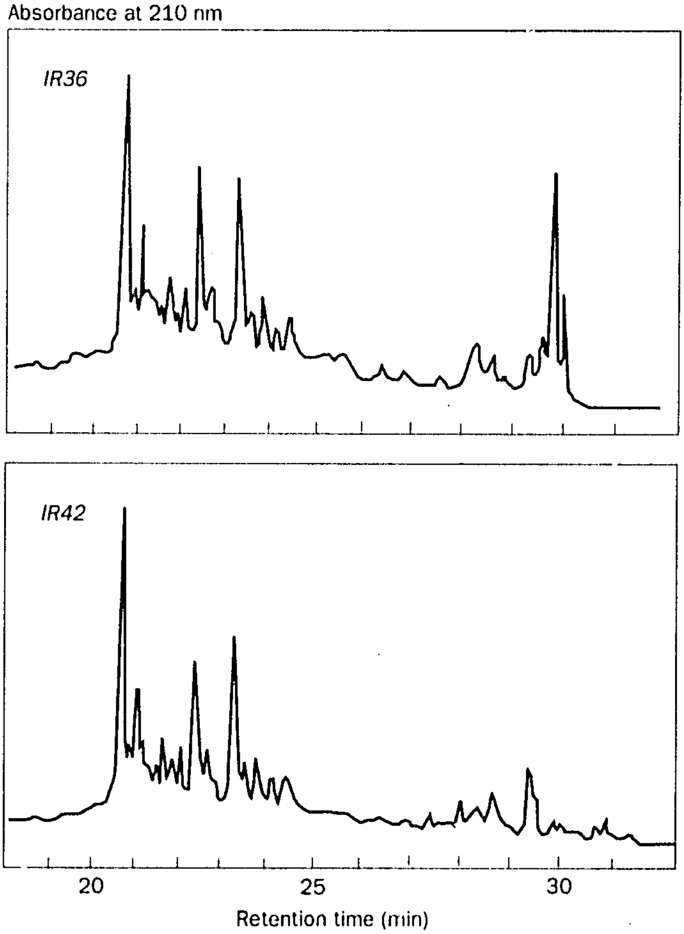
Work to identify the grain characteristics related to the most commonly-preferred cooked quality—soft texture—continues. Even though they have the same amylose content, rices can vary in their cooked quality. The relative amount of residual protein in rice starch granules can be used to distinguish between nonwaxy grains of indica (Wx^a) and japonica (Wx^b) alleles. Residual protein may be determined by the amounts of waxy gene product, 60 K polypeptide, or bound starch synthase.

We found that indica starch has about three times more waxy gene product than japonica starch at the same apparent amylose content, which differs from the identical regression lines for both alleles reported earlier. Our study suggests that the developing grain of japonica rice has less bound starch synthase than that of indica rice, but has more soluble starch synthase, which accounts for its ability to synthesize the same amount of amylose.

In collaborative studies with Kagoshima University, Japan, we found that the increase in iodine affinity of starch over an amylose content range of 16 to 18% was due to a corresponding increase in the affinity of amylopectin for iodine rather than an actual increase in amylose content. Higher iodine affinity increases cooked rice hardness, regardless of the reason for the affinity.

A problem in the milled rice market and in the rice seed market is consistent varietal identification. We successfully identified 11 varieties, including sister lines IR36 and IR42, on the basis of their soluble proteins using reversed-phase high-performance liquid chromatography. This work was done in collaboration with the University of Manitoba, Canada.

Reversed-phase liquid chromatography elution profile of acetic acid-soluble proteins of IR36 and IR42. The identical profile up to 25 minutes retention time revealed their common cross (IR2071); their differences show up in the 26-30 minute region.



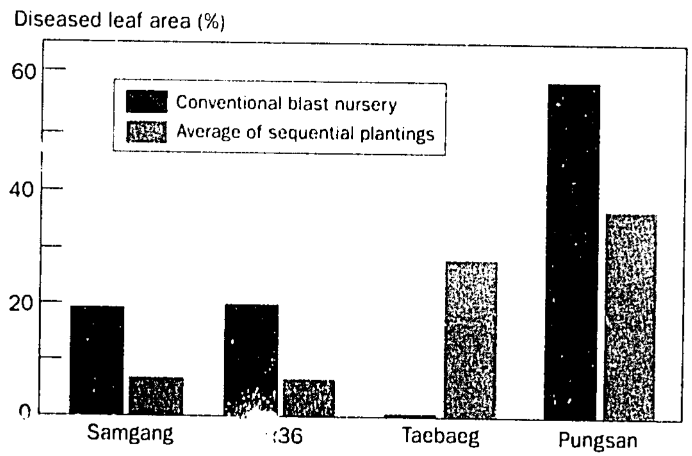
Disease resistance

The race to keep ahead of rapidly-evolving biotypes of the important diseases of rice demands continual attention to identifying and developing sources of resistance.

Field evaluation for partial resistance to blast. Partial resistance to rice blast is an important genetic ability to reduce blast damage, and might contribute to durability of resistance. We developed a field evaluation technique to screen for partial resistance. Sequential planting allows ample time for multiplication of virulent isolates of the blast pathogen *Pyricularia oryzae*. This technique can be readily combined with conventional blast nursery evaluation that screens for more basic resistance.

Cultivars Samgang and IR36 had a low level of blast severity, as measured by diseased leaf area, in the conventional blast nursery and in the sequential planting trial, indicating a high level of partial resistance. Taebaeg was highly affected by blast in the sequential plantings, indicating low partial resistance.

Blast susceptibility and soil properties. In upland areas, blast is an important constraint to rice production. The susceptibility of rice to blast is thought to be related to soil properties and mineral nutrition, particularly silica content. We grew rice variety C22 on two Philippine soils–a weathered soil from Cavinti, Laguna (Si content 15 ppm), and a young, volcanic soil from Santo Tomas,

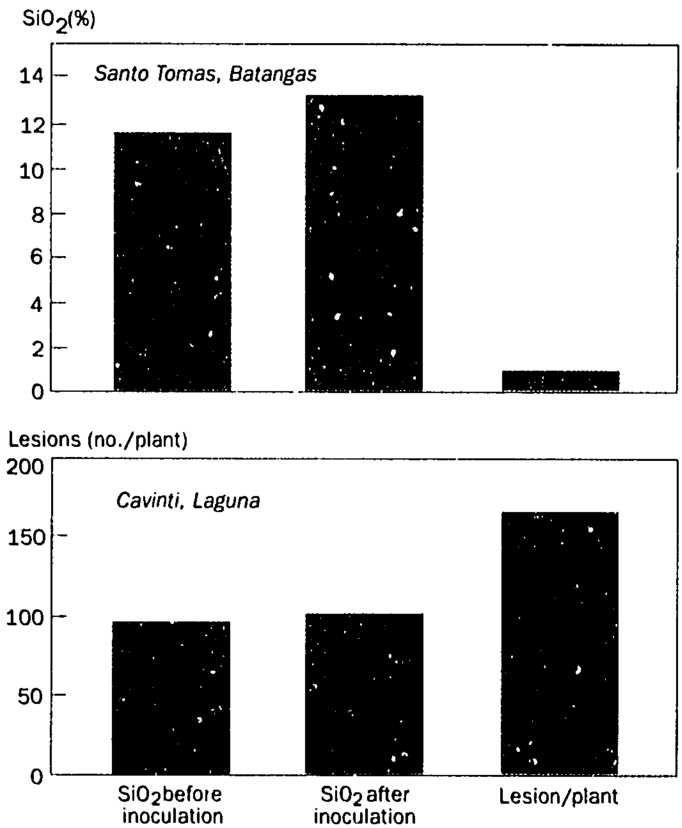


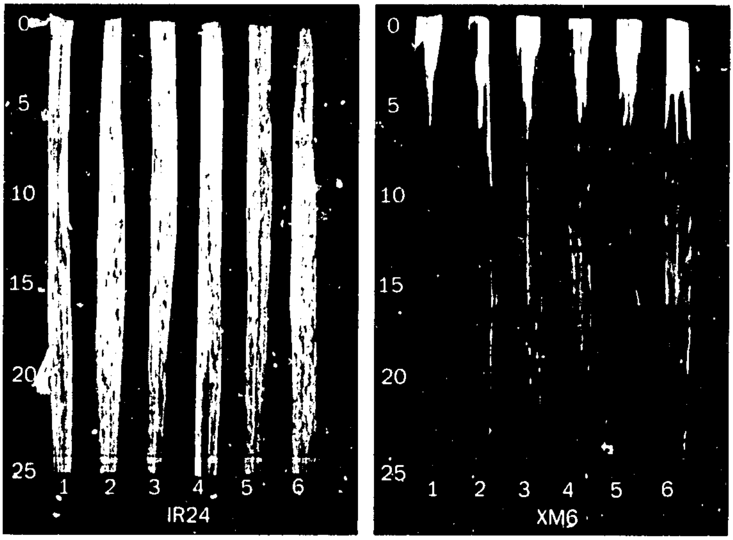
Blast disease severity in four cultivars 28 days after seeding in the conventional blast nursery and in sequential plantings.

Batangas (Si content 61 ppm). The rice plants grown on the soil higher in silica content contained more silica in the topmost leaves both before and after blast inoculation, and developed fewer blast lesions.

Mutation breeding for resistance to bacterial blight. A bacterial blight-susceptible variety, IR24, was treated with 1 mM MNU as a chemical mutagen. Two resistant mutant lines (selected from 2,739 M_2 lines) were resistant to all bacterial blight races in the Philippines. To clarify the inheritance of resistance in these mutants, they were crossed with IR24. The reaction of F_1 and F_2 plants suggested that they had a single recessive gene. Allelism tests with three known recessive genes showed that the mutant gene is independent of these three genes and is a new recessive gene. This provides an new source of bacterial blight resistance for breeding programs.

Silica content of topmost leaves and degree of blast infection of rice cultivar C22 grown on two Philippine soils, one with high silica content (Santo Tomas) and one low in silica (Cavinti).





Reaction of induced mutant line XM6 and cultivar IR24 to six races of *Xanthomonas campestris* pv. *oryzae* at 18 days after inoculation.

Transfer of disease resistance from wild rice to O. sativa. Wild species of rice represent a rich source of useful traits for rice improvement. *O. longiglumis*, *O. minuta*, and *O. ridleyi* are resistant to blast and bacterial blight. By backcrossing and embryo rescue, BC_1, BC_2, and BC_3 plants have been produced from crosses between a susceptible *O. sativa* cultivar and *O. minuta*. Some of the BC_1 and BC_2 plants are resistant to bacterial blight. Since *O. longiglumis* and *O. ridleyi* are not sexually compatible with *O. sativa*, attempts are being made to introduce genomic DNA from these two species by pollen-tube pathway transformation.

Wild rice *Oryza minuta* (right) which is resistant to blast and bacterial blight, was crossed with domesticted rice *O. sativa* (left) to produce the F_1 (middle).

Insect resistance

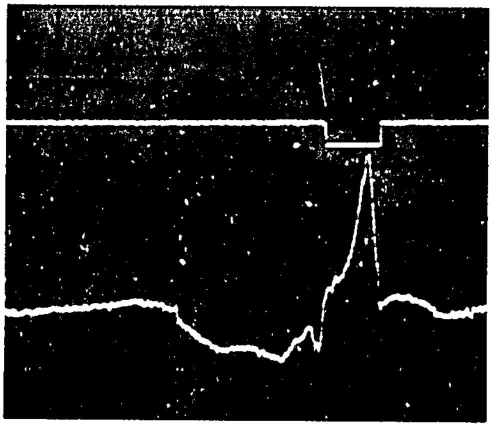
Identification of the volatile compounds from rice plants that attract or repulse insect pests is expected to open new avenues for insect pest management. Moreover, these volatiles could serve as indicators in breeding for resistant varieties.

Bioassay of rice volatiles. We isolated volatiles from rice genotypes with different degrees of resistance to insect attack. Susceptible variety Rexoro consistently produced higher quantities of volatiles than resistant variety TKM6 and an *O. perennis* accession.

Rice leaffolder susceptibility. We studied the reaction of rice leaffolder *Cnaphalocrocis medinalis* moths to the volatiles from resistant and susceptible plants. Their reaction was measured by electroantennogram (EAG), which measures the drop in electrical potential across an insect's antenna in response to a stimulus–in this case, the volatile extracts. The extracts of susceptible plants generally evoked a higher response than the resistant ones.

Rice bug resistance. Almost all rices are susceptible to the rice bug. We evaluated selected accessions of the traditional variety Sathi, whose panicles normally are completely enclosed within the flag leaf sheath, for resistance to the rice bug. Although oviposition did not vary on the different accessions, nymphal survival, weight, and insect feeding significantly decreased on accession 24033. This held true whether or not the panicles remained naturally enclosed or were forced open. The short feeding time of rice bugs on accession 24033 led us to conclude

Antennal preparation for electroantennogram measurement of *Cnaphalocrocis medinalis* moth response to rice volatiles (left). Glass micropipets with saline and Ag-AgCl electrodes are placed touching the tip and the base of the antenna. Oscilloscope shows a negative potential of 2.5 millivolts recorded in response to hexanol produced by susceptible plants.



that resistance is conferred by chemical factors, which might be incorporated into improved lines through conventional breeding.

New breeding lines for leaffolder resistance. Present high-yielding varieties have weak resistance to leaffolders. From greenhouse-selected F lines deriving resistance from TKM6, Mathumanikam, or Ptb 33, we screened F progenies in farmers' fields. Twenty-one percent of 976 TKM6 lines and 4% of 247 Mathumanikam lines were consistently resistant to rice leaffolder.

Drought tolerance

Wide variations in rainfall and the extension of rice farming into more adverse environments are increasing the need for germplasm carrying wider tolerances.

Drought stress index for rice. We developed a drought stress index that will enable comparing results of drought stress tolerance screening trials from different sites in different years. The index resulted from greenhouse experiments begun in 1987 to compare the effects of the duration of water deficit at different growth stages on the transpiration and yield of rice. Drought tolerance scoring is based on the finding that grain yield decreases in direct proportion to the amount that cumulative transpiration of stressed plants is less than that of well-watered plants.

Inducing drought stress. We found that rice plants respond to some chemical desiccants, such as atrazine and magnesium chlorate, in the same way they respond to drought stress. These chemicals function as drought simulators, allowing us to induce drought stress without having to actually stress plants in the field. This enables more control of the research variables and more rapid experimentation.

Flowering stage drought tolerance. Genotypic differences in drought resistance changed when water deficit occurred at different growth stages. These results agree with those of previous experiments, that stress during flowering reduces rice yields. The results also showed that genotypic differences in drought resistance at flowering are strongly related to differences in accumulation of assimilates (starch) in vegetative tissues before stress and their remobilization to panicles during stress.

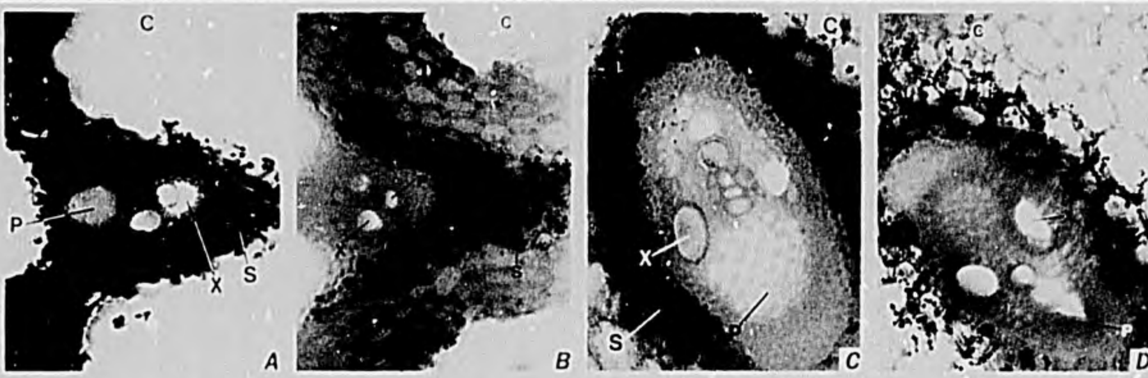
The traditional variety Sathi (showing panicles forced from the flag leaf sheath).

Indices for reduction of rice grain yield by water deficit

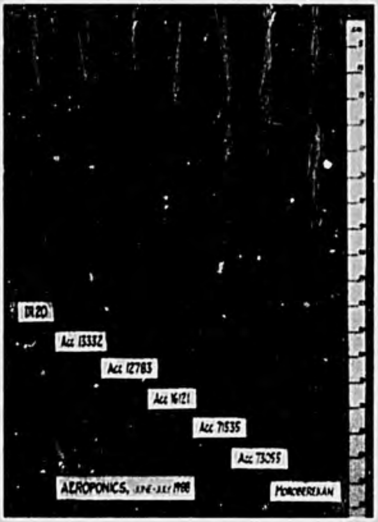
Cultivar	Grain yield loss/kg transpiration reuction	
	Vegetative phase	Reproductive phase*
IR64	5	5
Kinandang Patong	5	10
Salumpikit	1	6

* from panicle initiation through panicle emergence

Drought stress index



Photomicrographs comparing accumulation of starch (dark stain) in drought-tolerant and drought-susceptible rice. Drought-tolerant IR46 accumulates much starch in lower culm internodes when it is well-watered (*A*), which is depleted through translocation to panicles under water deficit (*B*). Drought-susceptible IR52 accumulates little starch under well-watered conditions (*C*) and only weakly translocates starch out of the culms during stress (*D*).



Roots of seven cultivars sampled from aeroponic culture. Drought tolerant cultivars have longer, thick roots.

Aeroponic culture. We used the aeroponic culture system to compare the root development of drought-tolerant cultivars. Those that headed and produced good grain filling after prolonged drought stress at the reproductive stage in the dry season were examined. Accessions 16121 and 67750 have thick and moderately long roots, similar to those of the drought tolerant check variety Moroberekan.

Drought tolerance screening. Of 5,861 varieties and lines tested for drought tolerance in the 1988 dry season, 111 performed better than the drought-tolerant checks Salumpikit and IR442-2-18; 14 showed outstanding drought tolerance.

Adverse soil tolerance

As rice cultivation continues to move onto less-advantageous soils, including tidal wetlands, improved cultivars are needed to increase yields over the traditional, adapted varieties.

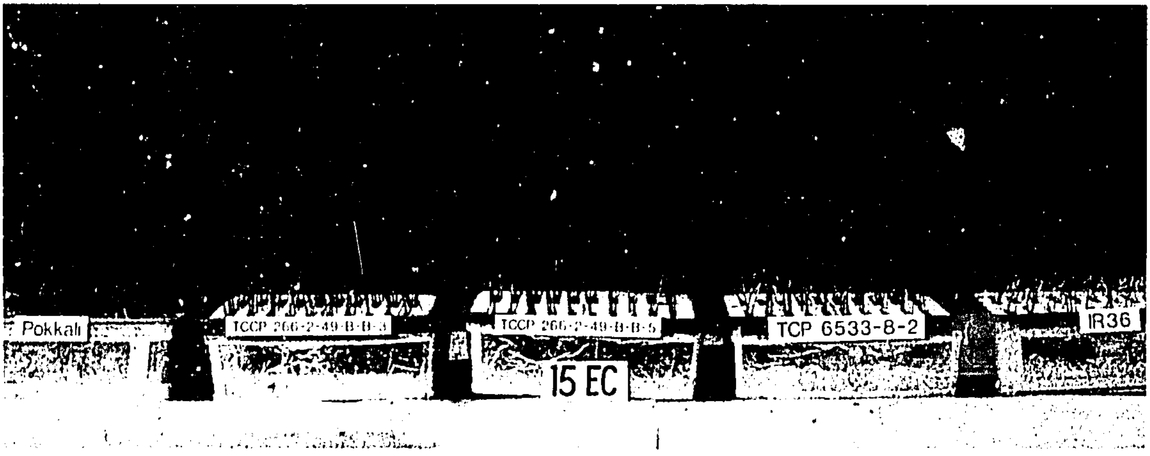
Salt tolerance. A semidwarf genotype with a high level of salt tolerance was developed through somaclonal variants of the highly salt-tolerant rice variety Pokkali. The new genotype has agronomic traits associated with improved plant type. This removes a major constraint–the lack of semidwarf genotypes with high level of salt tolerance for use as donors. Tolerance of varieties such as Pokkali normally decreases when they are combined with plant type characteristics.

A study of the characteristics of six varieties with known reactions to salinity showed that salt tolerance is related to the ability of the plant to absorb more nutrients, limit sodium uptake, and prevent excessive salt entry into younger leaves by maintaining sodium in the culms and older leaves. Tolerant rices are also able to reduce their transpiration rate as salinity increases. These findings will help guide breeding programs for problem soils and tidal wetlands.

Zinc difficiency tolerance. Zinc deficiency is commonly associated with peat soils. Plant zinc concentration alone does not discriminate cultivar tolerance or susceptibility. In 1988 screening trials, we measured plant zinc concentration of 12 rices representing the range of reaction to peat soil conditions. All the cultivars, whether tolerant or susceptible, had zinc concentrations below the critical limit of 20 mg kg. It was the iron:zinc ratio that discriminated the cultivars; tolerant varieties had lower iron:zinc ratios. This provides another factor to use in screening breeding lines for this important character.

Hot spot screening. We tested a series of cultivars and advanced breeding lines at five Philippine sites representing tidal wetlands and problem soils. Twenty bulu varieties performed well at all sites, including saline soils. (Bulus are tropical japonica types that are adapted to very harsh conditions. They have not yet been exploited extensively in breeding programs.) Upland varieties did not perform well under saline- or iron-toxic conditions, but were tolerant of phosphorus deficiency. Seven of 468 advanced breeding lines with adaptability across most of the sites showed promise for use in developing improved germplasm.

Three semidwarf F_1 tissue culture lines with salt tolerance comparable with that of the parent Pokkali.



Deep water and flood tolerance

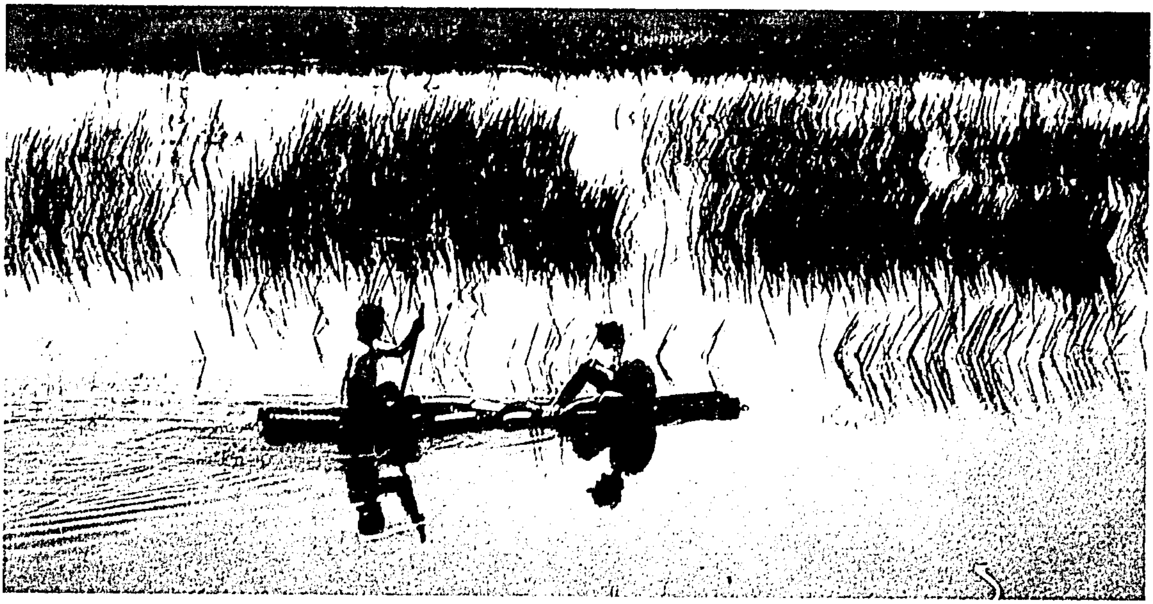
Improved germplasm for cultivation in deep water would increase the contribution of areas subjected to these conditions to needed production increases.

Low temperature tolerance. Low water temperature at the onset of flooding inhibits elongation of deepwater rices and may affect survival and yield. We exposed 6-week-old plants of 270 deepwater rice cultivars to constant water temperature of 15 and 25 °C for 8 days. Internodes in some cultivars elongated at the lower temperature. Hansa, ARC10657, and Bhujon Korpur showed better elongation at 15 °C than at 25 °C; Dal Katra, Chanda Amon, Digha, Goirol, and Dhal Pata elongated well at both temperatures.

Total submergence. Floating rices from the Indian subcontinent elongate rapidly in the early seedling stage, and can emerge from total submergence brought about by flash floods. With the Rice Research Institute of Thailand, we developed lines from IR parentage that combine fast elongation ability with grain quality and maturity acceptable to Thailand. These lines were tested in farmers' fields for the first time in 1988.

Multiple characteristics. We have crossed deepwater cultivars with *O. rufipogon* and *O. longistaminata* and have obtained some combinations with improved

Supachai Taengsuwan, Thailand, and Dirk HilleRisLambers, IRRI, inspect breeding lines that survived 2-meter flooding in a farmer's field trial near Parchantakam, Thailand.



elongation ability, perennial growth habit, and resistance to bacterial blight. In some cases, these traits are combined with acceptable panicle size and modern variety type. We identified several *O. glaberrima* rices from West Africa as floating rices.

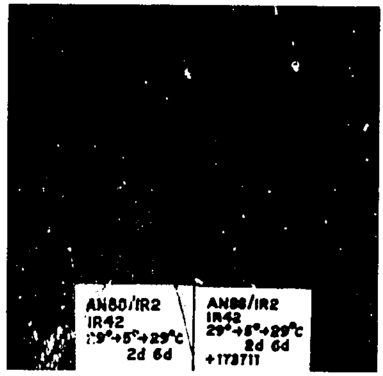
Adverse temperature tolerance

Another adverse environment for rice cultivation is the higher altitudes, where crops are subjected to lower temperatures than desirable for optimal productivity.

Transfer of cold tolerance. Many cold-tolerant rices are bulu (tropical japonica) type, combining cold tolerance, adaptability to low soil fertility, and disease resistance. These characteristics have been difficult to transfer to indica rices because of the high sterility of the hybrids. We have found, however, that the high grain sterility in bulu indica crosses is not a drawback, because selection for fertility in subsequent segregating generations is successful. Bulu japonica crosses do not show sterility problems, and we expect that many desirable genotypes could be obtained in segregating populations of these crosses.

Abscisic acid analogue. Chemical treatment is one way to minimize chilling injury which limits the growth and yield of rice. In collaboration with the University of Hamburg, Federal Republic of Germany, we studied the protective effect of the synthetic abscisic acid (ABA) analogue on chilling and transplanting stress. Spraying seedlings with ABA before chilling stress may guarantee plant survival. Root-dipping before transplanting increases survival rate and speeds up crop establishment.

Screening for cold tolerance. Screening for cold tolerance was done in cooperation with the Rural Development Administration, Republic of Korea (ROK). We screened 969 cultivars and breeding lines from IRRI, ROK, and other national programs in the cold water-irrigated fields in Chuncheon. The best entries, based on spikelet fertility, phenotypic acceptability, and panicle exsertion, were Fu-Men-Huan, Bir-Zi-Goo, IR20913-B-60, SR11842-9-1-3, and Unbong 3. Fu-Men-Huan and Bir-Zi-Goo had been identified as tolerant in earlier screening of germplasm from China; Unbong 3 was developed at the high-elevation Unbong Substation, Honam Crop Experiment Station; and



The protective effect of abscisic acid analogue LAB 173711 on chilling tolerance in rice seedlings.

IR20913-B-60 came from the cross IR7149-51-1-3/IR36// Paro White.

The 1988 International Rice Cold Tolerance Nursery (73 entries) and 59 other materials were tested for cold tolerance at flowering. The plants were subjected to 19 °C air temperature for 10 days at panicle emergence. Fourteen entries showed sterility of less than 50%. IR15579, a line from the cross K78-76-B*2/Kn-1b-214-1-4-3, showed good fertility.

Five of 35 promising entries in the observational yield trial yielded more than 7 t/ha: Pungsanbyeo, YR6488-ACP36 and YR6488-ACP39 (both anther culture-derived), SR13618-9-3-2, and SR10649-B-285-2-2. All were developed in ROK.

Rainfed lowland rice breeding

The genetic improvement program for rainfed lowland rice emphasizes the generation of improved breeding lines and populations with stress resistance, and the development of collaborative programs with national agricultural research systems in target environments to develop more productive rainfed lowland rices.

In the Philippines, we tested more than 400 breeding lines and cultivars in 5 drought-prone rainfed lowland sites and more than 200 breeding lines in 5 medium deepwater (stagnant flooding up to 50 cm) sites. IR43485-40-2-42-2 performed well at all rainfed lowland sites. At the medium deepwater sites, IR33360-5-1-3-1 yielded an average 4.1 t/ha over all sites, compared with 2.6 t/ha for the highest yielding check.

We again tested several hundred lines in farmers' fields in Solana, Cagayan, Philippines. Severe drought stress delayed transplanting of most nurseries, resulting in severe transplanting stress on the older seedlings. The local Wagwag cultivars are well adapted to these stresses and yielded better than almost all other entries. Three IRRI improved breeding lines (IR19319-5-3-3-2-1, IR24705-11-3-2-3-3, and IR43485-22-2-2-2), however, matched the yield of Wagwag at transplanting ages ranging from 61 to 82 days after seeding.

We also tested entries from the collaborative Thailand-IRRI breeding program at four research stations and a farmer's field in northeast Thailand. Three improved breeding lines yielded higher than local checks.

More than 3,000 seed packets were distributed to scientists in nine countries. IRRI rainfed lowland breeding lines were advanced to local yield trials in several countries, including Myanma (formerly Burma), India, Cambodia, and Malaysia (Sabah).

Irrigated rice breeding

Twenty improved IRRI breeding lines were released as varieties by the national programs of nine countries. Seven were released in Vietnam, four in the Philippines, two each in Cuba and Bhutan, and one each in Venezuela, Bolivia, Peru, India, and Pakistan. Eight of the 20 had been released earlier in other countries. IRRI breeding lines named as varieties worldwide now total 198.

We continued to share elite germplasm with cooperators worldwide. We supplied 37,005 seed packets in response to 332 requests from 61 countries. An additional 40,234 seed packets of IRRI breeding lines were sent to rice scientists in 46 countries through the IRTP nurseries.

Innovative breeding methods

We have increased our attention on ways to use emerging biotechnologies in the enhancement of rice germplasm.

Tissue culture. Tissue culture techniques have the potential to complement conventional breeding programs by shortening the breeding cycle, increasing variability, and achieving hybrids from sexually incompatible crosses.

Although the anther culturability of indica rices is still considered low, anther culture can be used to produce homozygous lines from F_1 hybrids. More than 1,800 plants were regenerated from 167 F_1 crosses made in 1988. More

Callus formation and plant regeneration from isolated pollen cultures of rice *Oryza sativa* cv. Taipei 309. *A*, dimorphism of freshly isolated pollen grains; *B*, division of isolated pollen grains; *C*, plant regenerated from pollen.

than 800 anther culture-derived lines from F_1s regenerated previously were sent to IRRI scientists and cooperating institutions for testing. They included lines developed for uplands, blast resistance, or cold or salinity tolerance.

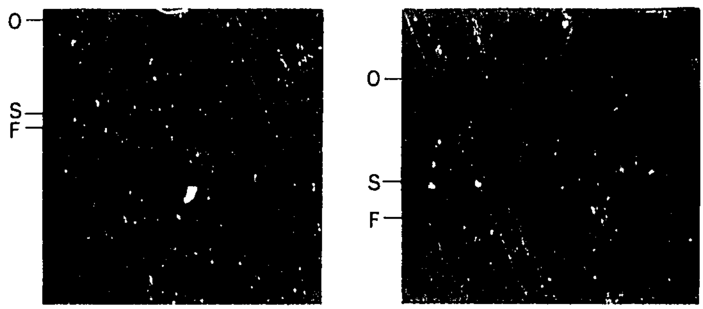
The ability to regenerate plants from isolated pollen is crucial to successful research in genetic engineering. Transformation of individual pollen would yield genetically modified true breeding lines.

The existence of pollen dimorphism and preculture of anthers before pollen isolation affect isolated pollen culture efficiency. We found that relatively larger pollen grains (50-58 um diameter) are the viable ones with the capacity to divide. Preculture of anthers for 8 days at 8 °C is required.

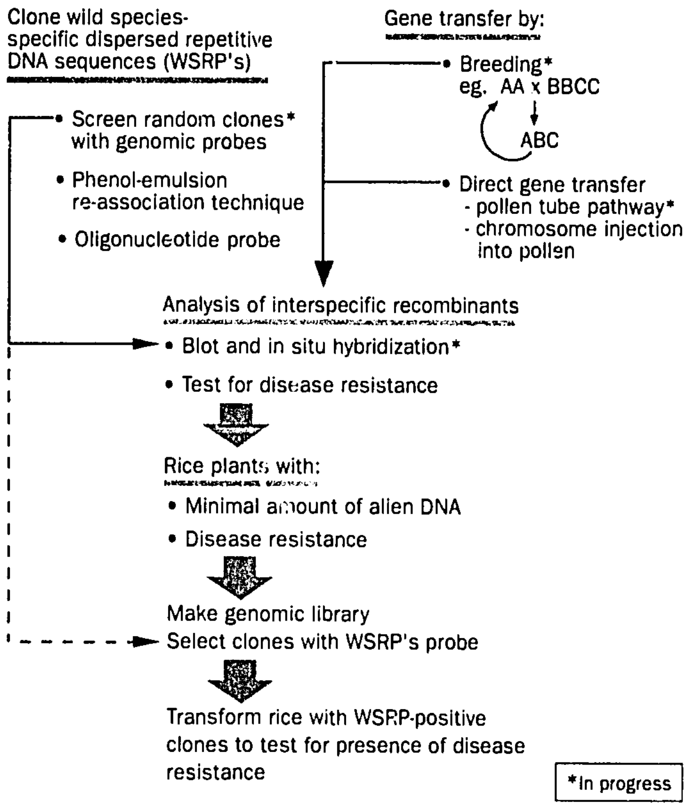
Although the efficiency of isolated pollen culture is still low compared with that of anther culture, we have been able to regenerate plants from isolated pollen of japonica (Taipei 309) and indica (IR43) rices.

Using protoplast culture, we have regenerated plants from protoplasts of japonica (Taipei 177, Taipei 309, and RAC3) and indica (Tetep) rice varieties, with plating efficiencies ranging from 0.8 to 1.8%, depending on the variety. Cell suspension cultures as sources of protoplasts for fusion with cultivated rices have been initiated or maintained in several wild rice species, including *Oryza ridleyi, O. perennis, O. eichingeri,* and *O. australiensis.*

Genetic and molecular maps. Work to fill in the gaps of current knowledge about the genetic architecture of rice continues. We identified three new isozyme loci, *Fdp*-1, *Xdh*-1, and *Dia*-1, in rice germplasm using starch and polyacrylamide gel electrophoresis. We are in the process of locating these isozyme loci to their respective linkage groups.



Polyacrylamide gel zymogram showing polymorphism for two new isozymes in cultivated rice: *A, Xdh*-1 (S band); *B, Fdp*-1 (S band).



General cloning procedure for isolating disease resistance genes in wild rice species for transfer to well-adapted varieties.

In continuing research for saturating the linkage maps of rice, we were able to associate four morphological markers with their respective linkage groups through trisomic tests. Two markers, a gold hull mutant (*gh-2*) and a brittle node mutant (*bn*) were located on chromosome 2. Two chlorophyll mutants (*chl-8* and *chl-9*) were located on chromosome 8, a heretofore poorly marked chromosome.

This basic genetics work will enable more extensive use of emerging techniques in molecular genetics and biology in rice improvement research. To date we have located 18 isozyme loci to 8 of the 12 chromosomes of rice. We are continuing the survey of additional isozyme loci to identify loci for the remaining four chromosmes.

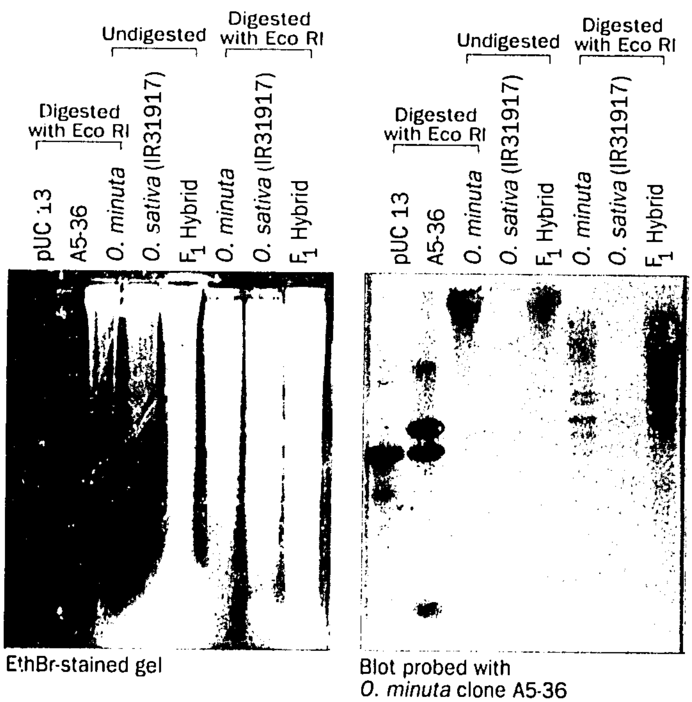
Isolating genes from wild rices. Although wild rices are a rich source of desirable traits, they also carry undesirable traits that must be bred out before the interspecific recombinants become agronomically useful.

Repeated backcrossing to eliminate these traits is time-consuming and large segments of alien DNA often remain in advanced backcross generations. We are working on a general cloning procedure to physically isolate genes of interest in wild rice and transfer them into well-adapted rice varieties.

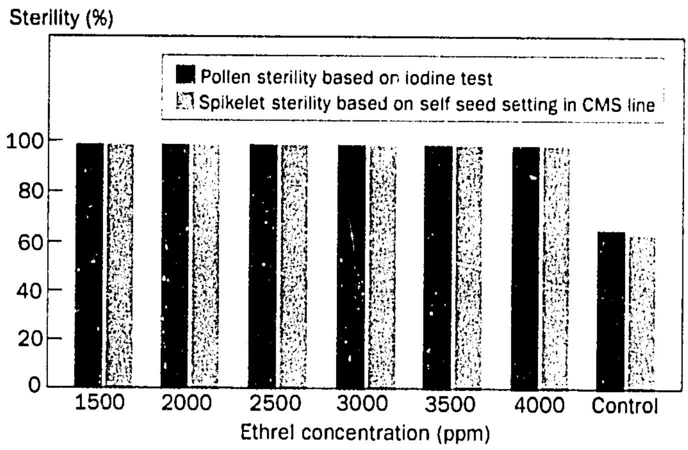
We have been working toward the isolation of dispersed repetitive DNA sequences specific to *O. longiglumis*, *O. minuta*, and *O. ridleyi*. Some species-specific clones have been achieved and are being tested for their usefulness in following the introgression of alien chromosomes in wide crosses.

Hybrid rice studies. An important constraint to developing hybrid rice production in the tropics is the lack of cytoplasmic male sterile (CMS) parents. Achieving heterotic hybrids depends on complete pollen sterility of the CMS line. When sterility is incomplete, there is partial selfing of the CMS line and the seed produced is a mixture of F_1 seeds and selfed seeds. An example is the CMS line IR54752 A.

To make IR54752 A completely pollen sterile, we used the male gametocide ethrel, which induces partial



Use of DNA probe specific to wild species to follow the introgressions of *O. minuta* chromosomes. Note that only the *O. minuta* parent and the F_1 hybrid show signals.



Effect of ethrel sprayed at flag leaf development stage on percentage of fertility.

pollen sterility in a normally fertile cultivar. When sprayed at a concentration of 1,500 to 4,000 ppm at flag leaf or booting stage, ethrel induced complete pollen and spikelet sterility in the CMS line.

Three hybrids developed in the Korea-IRRI hybrid rice project–IR54756 A/S294, IR54756 A/S332, and IR54756 A/Iri 362–outyielded the best check cultivar Suweon 294 by 1.1 to 1.7 t/ha in trials at three sites in Korea. Other IRRI-developed hybrids outyielded local check varieties (Jaya, 6.7 t/ha, and Mangla, 6.6 t/ha) at Bangalore, India. The IRRI hybrids were IR54752 A/IR46 R (9.8 t/ha), IR54752 A/IR28178 (8.8 t/ha), IR54752 A/IR54 R (8.3 t/ha), and IR46830 A/IR9761-19-1 R (8.2 t/ha). In a 1988 dry season trial at IRRI, IR46830 A/IR9761-19-1 R yielded the equivalent of 13.2 t/ha, compared with the highest yielding inbred cultivar IR9723-113-3-2-1 (10 t/ha). IRRI physiologists, who conducted the trial, found that F_1 hybrids show the best combination of factors for larger sink size and better grain filling.

Seed science and technology

Improved rices are only of use to farmers if the seeds they plant germinate and produce vigorous seedlings. Viability (an integral component of vigor), dormancy, and tolerance for low temperature were shown to be interrelated. Cold-tolerant, nondormant cultivars rapidly lost seed viability, but highly dormant cultivars that retained their viability tended to be susceptible to cold. Moist heat treatment was found more effective than dry heat treatment in breaking dormancy, without adversely affecting subsequent seedling vigor.

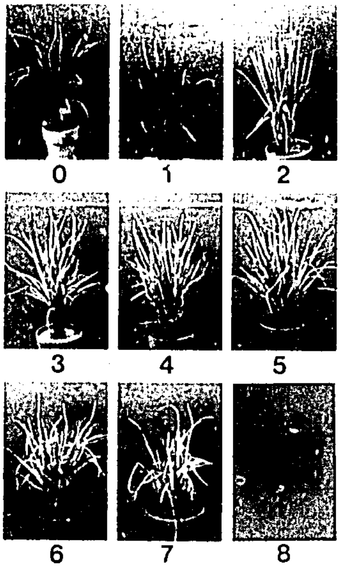
We screened 254 entries from various International Rice Testing Program (IRTP) nurseries for seed vigor: 15% showed high vigor, 22% moderate vigor, and 63% low vigor. Among those showing high vigor were improved lines IR13240-108, IR21178-39-P1, IR25588-7-3, IR29723-143-2, and IR39357-91-3, all of which were the highest yielding entries in the 1986 yield nurseries.

Pest Management

Losses of rice crops to pests—diseases, insects, weeds—heavily impact production in some regions and some environments. The problem is complicated by the interactive nature of pests. Multiple infestations are difficult to control. IRRI's pest management work is being focused on integrated management—on identifying natural control mechanisms; on understanding the ricefield disease, insect, and weed ecology; on establishing economic thresholds of pest infestation (when the costs of control can be recouped through saved harvest); and on environmentally safe control methods.

Diseases

Rice tungro virus. Knowledge of how rice tungro virus (RTV) spreads in farmers' fields is needed to develop sound methods for assessing disease severity. We developed a pictorial key with nine grades to assess disease severity and used it to study the relation between disease incidence and disease severity at six rice growth stages.



Pictorial key to assess disease severity in plants infected with rice tungro virus.

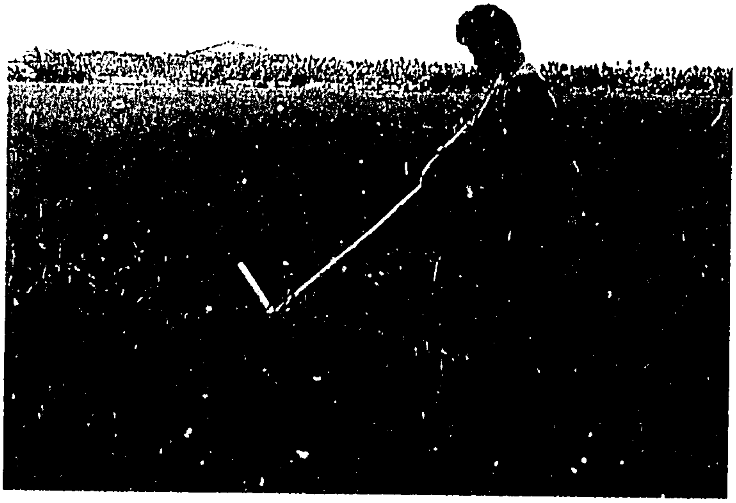
We then developed regression equations to predict severity from percent incidence at each growth stage studied. These equations will enable more accurate assessment of disease loss in farmers' fields.

In the same experiment, we monitored the distribution pattern of the disease and plotted it on field maps. Initially, infected plants were distributed in a random pattern. That changed to a clustered pattern, and finally to a regular pattern. The results indicate that in RTV scouting, the investigator should make a large "X" or "W" path through the field to obtain an accurate disease assessment.

Blast disease. Quantitative models would be useful for predicting yield losses caused by blast. We used path coefficient analysis to clarify how leaf blast and panicle blast influenced growth components (plant height and biomass of leaf, stem, and panicle) and yield components (number of effective tillers, 1,000-grain weight, number of filled grains per panicle, and percent unfilled grains). The yield components most directly related to yield loss are the number of filled grains and the percentage of unfilled grains. Leaf blast reduced the number of filled grains more than panicle blast, but panicle blast had a greater effect on the percentage of unfilled grains. We are evaluating several empirical equations for predicting yield losses caused by blast.

Insects

Yellow stem borer. Of all rice insect pests, stem borers cause the greatest yield loss annually and remain one of the most difficult groups to control. We developed a simulation model of the population dynamics of the rice yellow stem borer for use in pest management. The model simulated satisfactorily the timing of egg, larval, and pupal population density peaks in two trials. Pest control, through release of egg parasites or application of insecticides on larval populations, was evaluated with the model.

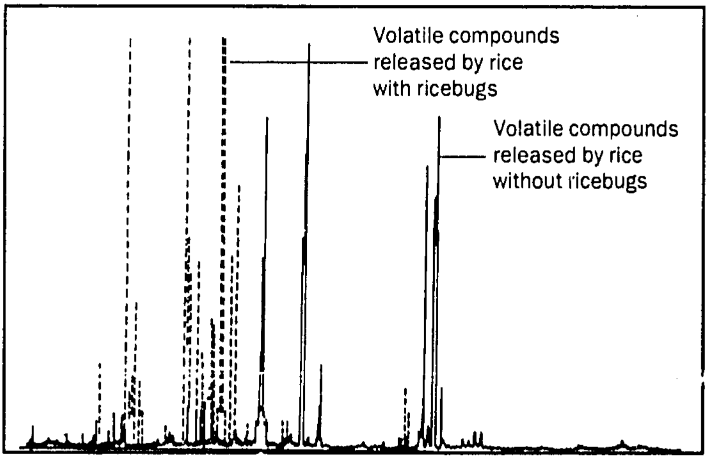


Scouting for stem borer moths by sweeping weedy ricefield borders with an elbowed stick. Walking the field borders is easier than field sampling for eggs. Egg densities in the field can be determined from the number of moths flushed from field borders.

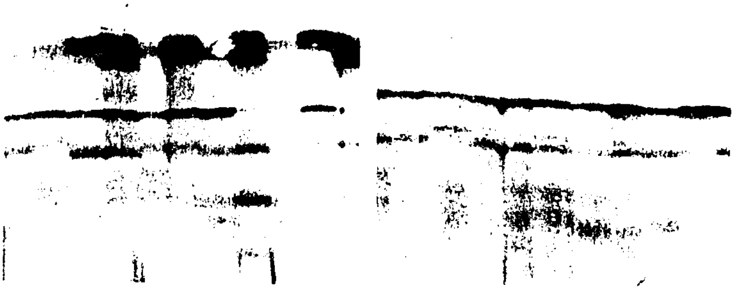
Current methods of determining critical threshold values for timing treatment are either inaccurate or too time-consuming. Insecticide application must be timed at peak egg densities in the field, just before newly hatched larvae tunnel into tillers. We developed a method to determine when to sample for eggs in the field by scouting for stem borer moths in weedy field borders. Moths hide from bird and dragonfly predators during the day and can be flushed from their hiding places by stroking foliage with an elbowed stick. Moths flushed from weedy field borders serve as an early warning of egg laying in the field.

Rice bug pheromones. The characteristic odor of rice bugs is produced by a blend of volatile compounds, which attract other rice bugs but may repel predators. Understanding these compounds could lead to new control methods. We are trying to identify the sexual and feeding attractants emitted by the rice bug to attract populations from nearby fields. We hope to provide farmers with attractants that mimic the natural ones emitted by the bug and to design better traps.

Rice leaffolder. Two species of rice leaffolders, *Cnaphalocrocis medinalis* and *Marasmia patnalis*, are usually found in association on rice plants. Studies on the comparative biologies and population dynamics of the two species are difficult because the larvae and pupae are similar in morphology, as are their spinning and feeding behavior. Yet their differentiation is important in



Chromatographic profile of rice at heading with and without rice bug infestation. Several signals are characteristic of infected plants.

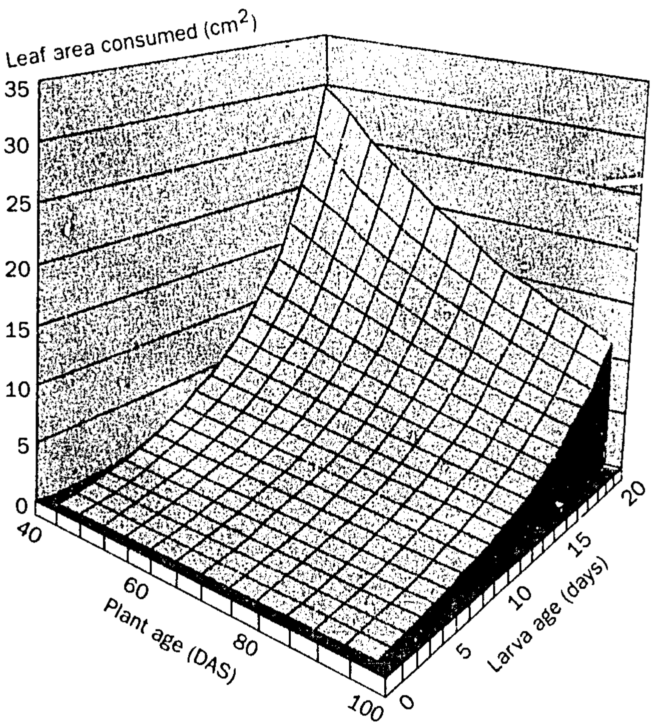


Electrophoretic differences in esterases of *Cnaphalocrocis medinalis* and *Marasmia patnalis* pupae.

developing a more thorough understanding of insect ecology and in designing control mechanisms.

We used horizontal starch gel electrophoresis of soluble isozymes to accurately and rapidly distinguish the species. Consistent electrophoretic differences found in 2 of 10 enzyme systems studied–isocitric dehydrogenase and esterase–permitted accurate differentiation between second- to fifth-instar larvae and pupae.

Rice leaffolders attack the rice plant by feeding on the leaves, directly reducing photosynthesis and ultimately



Relations between rice leaffolder leaf consumption, larval age, and plant age. DAS = days after seeding.

yield. Leaf area removed is dependent on insect age, plant age, and rice variety. The fourth and fifth larval instars consume more than 90% of the larva's total consumption. There is substantial reduction in feeding with plant age. On 100-day-old plants, larvae consume only 80% of what they would consume on 40-day-old plants. We developed a computer simulation model that incorporates leaf area consumption rates with insect and plant age. Insect feeding can now be characterized by a single parameter, the feeding coefficient, thus simplifying relating this model to the establishment of economic thresholds.

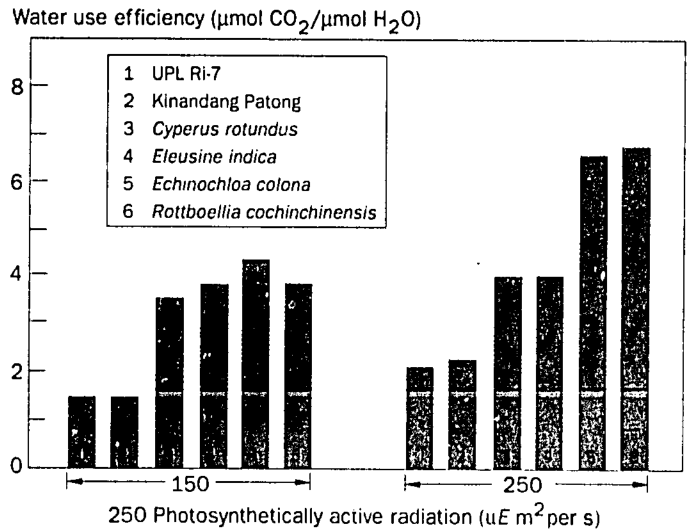
Community ecology of arthropods in rice. In rice ecosystems, populations of all species coexist in relation to one another. When pest populations are studied independently, they reveal only fluctuations with time. Yet environmental factors and rice cultural practices influence the entire community, not just a single species. Rice arthropods are natural pest control agents, and it is useful to understand how rice arthropod communities are structured.

Using the Shannon-Wiener information index, we found that species diversity increases with crop age to a plateau about 3 weeks after transplanting and remains unchanged until harvest. Perturbations in the form of pesticide applications may cause a drop in diversity (such as a weakened arthropod community), which in turn may lead to an extreme dominance or outbreak of a pest species.

Botanical insecticides. Derivatives of the neem tree *Azadirachta indica* are among a group of biological pesticides that could be used to control crop insect pests without harming beneficial predators. A 6% crude neem seed water extract sprayed three times at 10-day intervals controlled rice leaffolders in ricefields. The insecticide triazophos was more effective than the neem extract but, unlike neem, it also destroyed natural enemies of the leaffolders.

Weeds

Ecophysiology of rice weeds. An important breakthrough in weed control will be the understanding and integration of changes that occur in the demography, ecology,



Water use efficiency of rice and weeds at different light levels.

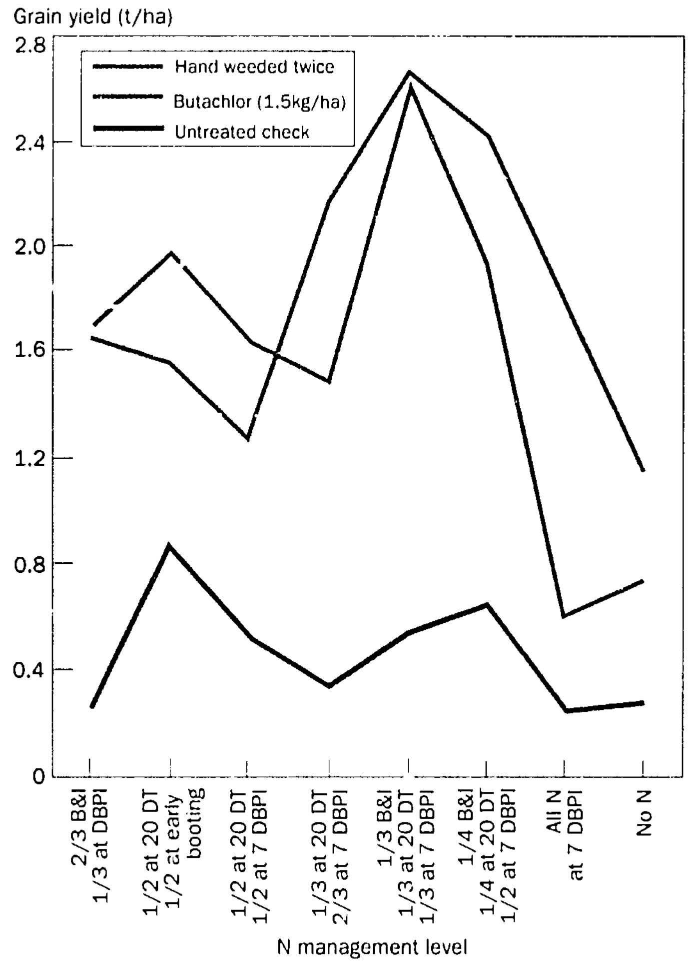
physiology, and morphology of weeds as they interact with the environment and with each other.

We studied the water extraction capacity of weeds and rice under upland conditions, at different levels of light. Water use efficiency was higher in weeds than in rice at all light levels. The high water use efficiency of weeds was associated with their high photosynthetic rates, low stomatal conductance, and relatively low transpiration rate. These characters enable weeds to tolerate drought stress better than rice and to remain aggressive when water is in short supply.

Nitrogen management and weed control. Entirely weed-free conditions do not often exist in farmers' fields. How can a farmer manage nitrogen fertilizer application to favor crop growth over weed growth, and when should he weed the field? We studied the effects of the timing of nitrogen application and weed control in broadcast seeded flooded rice and in transplanted rainfed rice.

In broadcast seeded rice, there was no significant difference in nitrogen uptake and yield when nitrogen was broadcast and incorporated basally or broadcast at 15 days after seeding (DAS), suggesting that nitrogen application up to 15 DAS is feasible. The timing of weed control was more important. Nitrogen uptake was not significantly different between weed control at 3, 10, or 20 DAS, but grain yield was highest when weeding was done 20 DAS.

With good weed control, three-split nitrogen applications produced higher grain yields in IR64. Without weed control, nitrogen application timing had little effect. B&I = broadcast and incorporated, DBPI = days before panicle initiation, DT = days after transplanting.



Grain yields from plots treated for preemergence weed control were generally low because of high weed resurgence.

In transplanted rainfed rice, we studied the timing of 80 kg N/ha in plots with different weed pressures. Without weed control, grain yields were similar regardless of nitrogen management practice. When weeds were controlled, however, three-split nitrogen applications consistently produced higher yields than two splits or single applications.

Stress interactions

When rice suffers simultaneously from more than one growth limiting stress–as it often does–the stresses may interact. And the combined effect can be larger than the product for stresses acting alone. Management that eliminates one stress could have an even greater benefit, by lessening the decrease in growth and yield caused by associated interactions.

We conducted three stress interaction experiments. Five stresses (water deficit, nutritional deficiency, insects, pathogens, and weeds) were imposed on IR62 rice at realistic field levels. Nonstressed plants yielded 5.9, 5.7, and 5.5 t/ha in the three experiments. The combination of all stresses decreased yields by 84%, 57%, and 67%. In the experiments in which an individual stress decreased yield by 9% or more, we detected interactions among water deficit, weeds, simulated stemborer damage, and pathogens. For example, pathogen stress decreased yield of fully irrigated plants by 9%. But when plants were also subjected to water deficit, which by itself caused a yield loss of 55%, yield loss from pathogen stress increased to 17%.

These preliminary experiments show that management techniques are needed not only to prevent any given physical or biological stresses, but also to guard against two or more stresses occurring simultaneously.

A multidisciplinary team of agronomists, entomologists, plant pathologists, statisticians, soil chemists, and soil physicists conducted this multifactor experiment to detect interactions among various biological and physical stresses on transplanted rice.

Crop and resource management

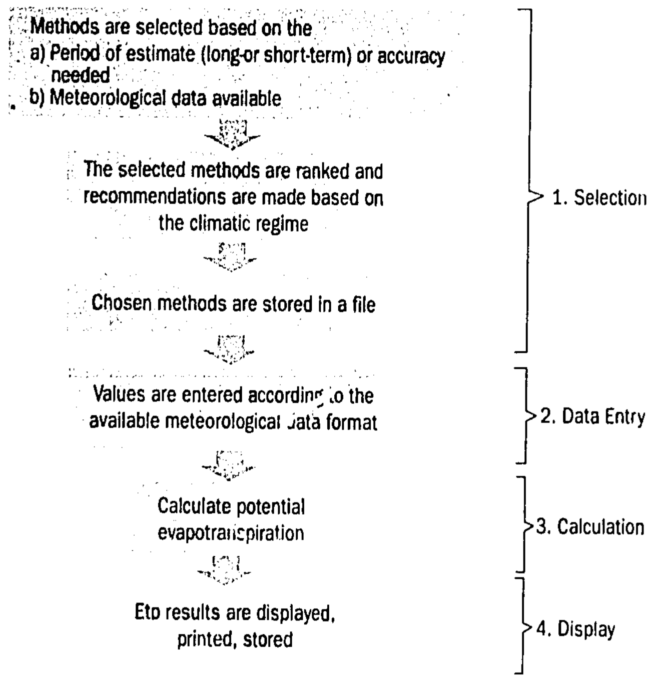
Soil, nutrients, and water are the critical elements in rice production. These resources must be managed, for the crop season, the cropping year, and future cropping, if rice production is to be increased at the same time that resources are conserved and farming is sustained.

Water management

Small farm reservoirs. We conducted water balance studies on small farm reservoirs in Tarlac, Philippines, and analyzed runoff characteristics of catchment areas with different land uses. We found that the minimum size of catchment area for each 1,000 m^3 of reservoir storage capacity is 0.2 ha for catchments planted to rice and 1.1 ha for grass catchments.

Farmers have difficulty estimating the rice area that available reservoir water will support during the dry season. We devised a simple formula based on the estimated amount of water retained in the reservoir at the

Typical small farm reservoir for growing a dry season rice crop in Pampanga, Philippines.



Conceptual flow chart of PET, an expert system for selecting appropriate evapotranspiration equations and performing the calculations.

beginning of the season and the water requirement for the crop. For example, if dry season rice is transplanted as early as possible after the wet season harvest, we estimated that a 110-d variety would need about 300 mm water. If 65% of the storage capacity of a typical 2,000 m^3 reservoir is available, a dry season rice area of 0.4 ha can be grown.

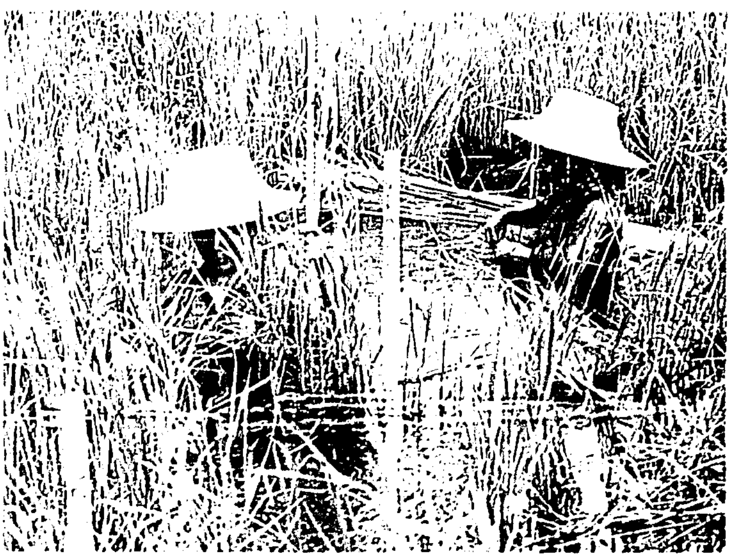
Estimating potential evapotranspiration. Knowledge of potential evapotranspiration (E_{tp}) is essential for planning, designing, and operating irrigation systems. The equations commonly used for E_{tp} estimation present a bewildering choice. We developed PET, an expert computer model for potential evapotranspiration evaluation, to rapidly select appropriate E_{tp} estimation methods and execute the corresponding calculations.

Basin irrigation for upland crops. Establishing upland crops in irrigated ricefields is a formidable undertaking. The heavier texture of rice soils restricts drainage and promotes waterlogging. We developed an irrigation method for maize following rice that involves frequent applications of low volumes of water, never exceeding 50 mm. The method provides adequate water to the maize crop, but requires application efficiencies greater than 90%. In tests in 3 maize fields in Guimba, Nueva Ecija, Philippines, we applied 330, 336, and 379 mm of water in 8, 7, and 10 low-volume irrigations. The quantities of water applied were close to the seasonal evapotranspiration requirements for maize, half the 600-800 mm usually required or less.

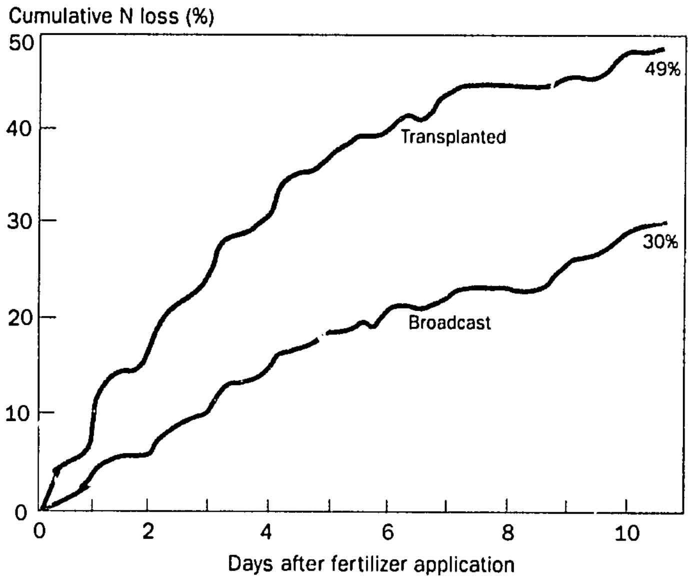
Soil and fertilizer management

Nitrogen is the major input for rice, and the highest cost factor in rice production. We are studying nitrogen and other fertility aspects of rice soils on several fronts, such as better understanding of soil chemistry, examining ways to reduce nitrogen losses in flooded ricefields, evaluating cultivars for nitrogen response, and using nitrogen fixation abilities of green manure plants. For resource-poor farmers, organic sources of nitrogen are particularly important.

Soil characterization. To better understand chemical conditions in the soil near rice roots–the rhizosphere-we developed a computer simulation model of iron diffusion and oxidation, in collaboration with the University of Oxford. The model predicts that under normal conditions, large quantities of iron may be transferred into the rhizosphere. Rhizosphere pH may be lower than that in the surrounding soil by more than two units. This magnitude of such effects had not been recognized previously. These



Sampling deepwater rice for nitrogen uptake in Thailand.



Cumulative nitrogen loss of transplanted and broadcast seeded IR64 rice, Calauan, Philippines, 1988 dry season.

findings have major implications for work to select germplasm with more efficient nutrient uptake and for work on biological nitrogen fixation in the rhizosphere.

Nitrogen sources for deepwater rice. Much of the nitrogen supply of deepwater rice is thought to come from the floodwater itself or from biological fixation. Our field studies indicate, however, that soil type may be a more important determinant of nitrogen supply than had been thought. On acid sulfate soils, the uptake of nitrogen by deepwater rice plants is suppressed at the onset of flooding, then is maintained at very low levels during the flooded period. But on less acid soils, the rate of nitrogen uptake increases to quite high levels after the initial suppression at the onset of flooding. Through surveys of fields for available nitrogen, we are identifying soil and floodwater conditions where yields are sustained naturally and other areas where improved fertility could give economical yield increases.

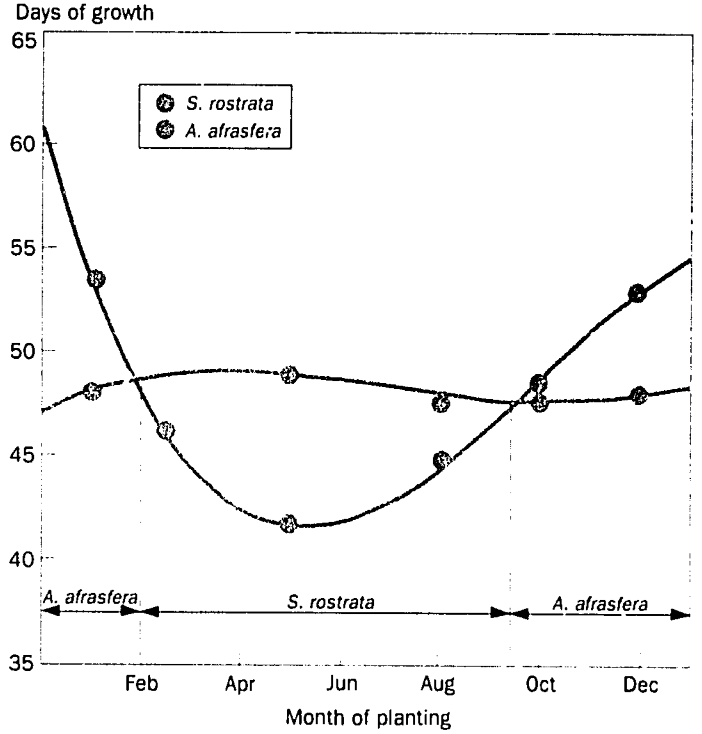
Ammonia volatilization and nitrogen use. We compared ammonia volatilization losses from broadcast seeded and transplanted rice in a two-year field study. Applying urea into the floodwater at 11 d after broadcast seeding reduced ammonia volatilization losses by 20-35% compared with applying nitrogen to transplanted rice.

Broadcast seeded rice also has higher nitrogen recovery than transplanted rice. In the 1988 dry season at Calauan, Laguna, Philippines, broadcast seeded rice recovered 27% of nitrogen applied at 21 days after establishment compared with 6% for transplanted rice, which may have suffered from transplanting shock.

Green manure and inorganic nitrogen. The relative efficiency of nitrogen in green manure and in inorganic fertilizers is a major issue in developing legumes as nutrient sources. We applied 0, 30, 60, 90, and 120 kg N/ha to rice as green leaf manure (GLM), urea, or equal combinations of the two. All nitrogen was applied at transplanting, regardless of source, to eliminate the effect of different timing. Yield differences were not significant for any treatment, suggesting that inorganic nitrogen can be used interchangeably with GLM. Maximum grain yield was estimated at 4.4 t/ha when nitrogen was applied at 116 kg/ha, whatever the source.

Nutrition requirement for Sesbania rostrata. We studied the effect of applying nitrogen, phosphorus, and potassium fertilizers on nitrogen accumulation of *Sesbania rostrata* in a field experiment in San Manuel, Tarlac, Philippines. Urea basal applied to 45-day-old *S. rostrata* significantly increased nitrogen accumulation. Phosphorus and potassium fertilizer applied at 40 kg/ha stimulated growth, nodulation, and nitrogen accumulation. However,

The application of nitrogen, phosphorus, and potassium fertilizers increased the growth, nodulation, and nitrogen accumulation of *Sesbania rostrata*.



Seasonal changes in growth duration requirement of *Sesbania rostrata* and *Aeschynomene afraspera* to accumulate 100 kg N/ha.

yields of the subsequent rice crop were no higher for any of the green manure treatments than with urea application. Farmers may increase nitrogen accumulation intended for the subsequent rice crop by applying phosphorus and potassium fertilizers to their green manure crop.

In a greenhouse experiment in which *S. rostrata* was grown in nine Philippine soils of various fertility, available phosphorus was the major growth limiting factor in both upland and flooded lowland soils. Dry matter and nitrogen uptake were higher in flooded soils, however, because of higher phosphorus and nitrogen supply. *S. rostrata* showed no symptoms of zinc deficiency on soils low in available zinc. It may be a suitable green manure crop for growing on saline soils before rice when water is available but salinity levels are still too high for rice.

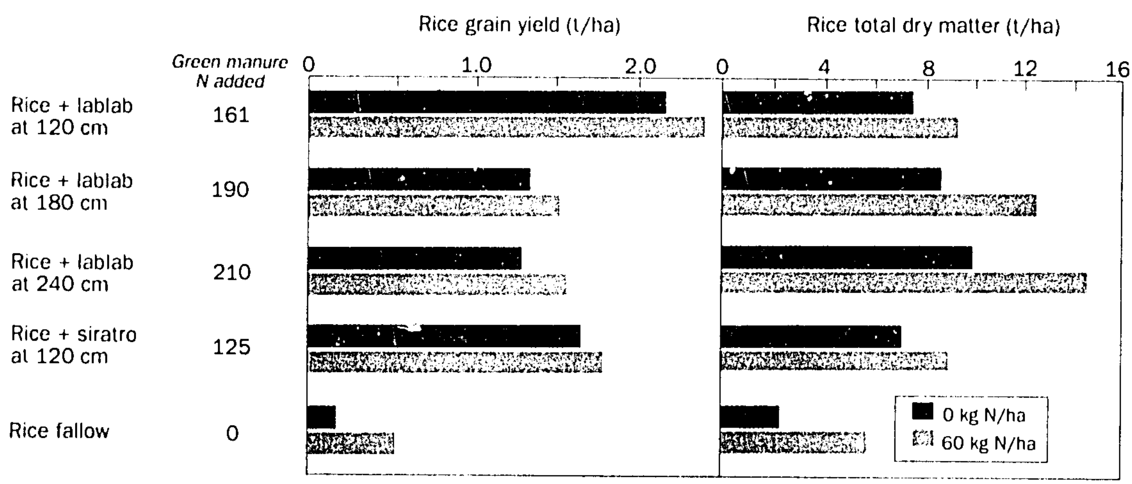
Nitrogen production by green manure crops. Another stem-nodulating legume, *Aeschynomene afraspera*, was compared with *S. rostrata* for growth, nitrogen fixation, nitrogen accumulation, and time of flowering over six

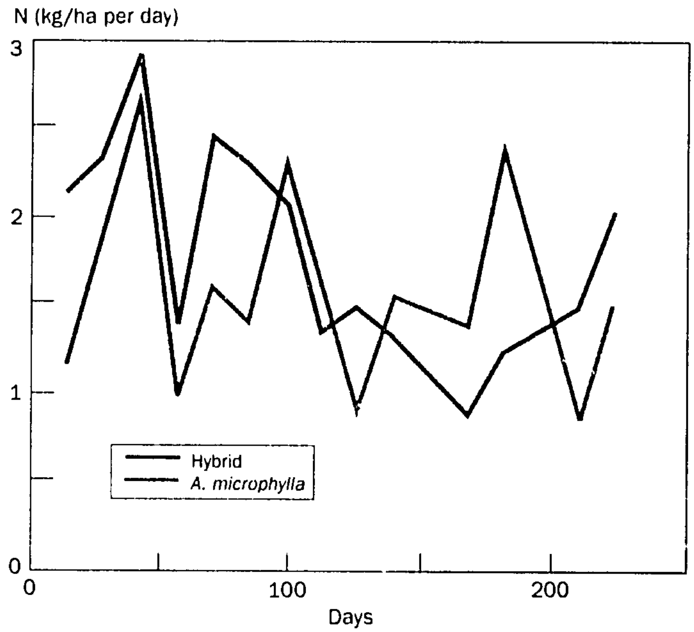
Upland rice grain yield and dry matter are substantially increased when the rice crop is intercropped with lablab or siratro. Values in centimeters (cm) indicate the distance between rows of the forage crop.

cropping seasons, in collaboration with the University of Giessen. *S. rostrata* exhibited higher seasonal variability than *A. afraspera*. Eight-week-old *S. rostrata* accumulated about 100 kg N/ha in the December harvest and about 230 kg N/ha in the July harvest. *A. afraspera* accumulated 150-200 kg N/ha in all 6 crops. To accumulate about 100 kg N/ha, *S. rostrata* may be a more suitable crop in March-September (daylength >11.5h), *A. afraspera* in October-February (daylength <11.5h).

Intercropping legumes. Indeterminate legumes are known to enhance nitrogen recycling in cropping systems. The challenge is to integrate them with grain crops so they do not compete for field time or labor. We found that by intercropping lablab (*Lablab purpureus*) or siratro with upland rice, and plowing down the dry season biomass accumulation before planting the succeeding rice crop, 120-210 kg nitrogen per hectare was made available to the rice crop. Grain yields increased by as much 1 to 2 t/ha and total dry matter by more than 6 t/ha on a nutrient-poor soil. The application of inorganic nitrogen did not significantly increase rice yields when the green manure was plowed in.

N fixation and azolla management. *Azolla* continues to show promise as an organic fertilizer. Our work with the *azolla* germplasm collection at IRRI is investigating the





Comparison of nitrogen production of hybrid *Azolla filiculoides* and *A. microphylla* and the parent *A. microphylla* from December 1987 to June 1988.

nitrogen fixation abilities of the different species and improvement of nitrogen fixation in hybrids.

The growth and nitrogen fixation of hybrids between *A. filiculoides* and *A. microphylla* were better in the cool season (December-March) in IRRI's field than that of parent *A. microphylla*, but the opposite was observed in the hot season (April-May). Concentration of nitrogen was always higher in hybrids than in *A. microphylla*.

Azolla strains were classified by electrophoresis patterns of nine enyzmes, in collaboration with Washington State University. *A. filiculoides* is distinctly separate from other species. *A. microphylla*, *A. caroliniana*, and *A. mexicana* are chemotaxonomically similar. *A. japonica* from Japan belonged to *A. filiculoides*. Using this and other morphological and physiological characteristics, some New World accessions labeled as *A. filiculoides* were shown to be members of other species.

Tillage and soil physical condition

Soil physical management for legume production. In many rice-growing countries, a legume could be grown in the dry season on ricelands that are left uncropped after harvest of wet season rice. But soil preparation for wetland rice creates seed zone and root zone structures unsuitable for legumes. We are developing low-cost, low-energy soil physical management methods to promote rapid seedling emergence and profuse and deep rooting of legumes grown after rice.

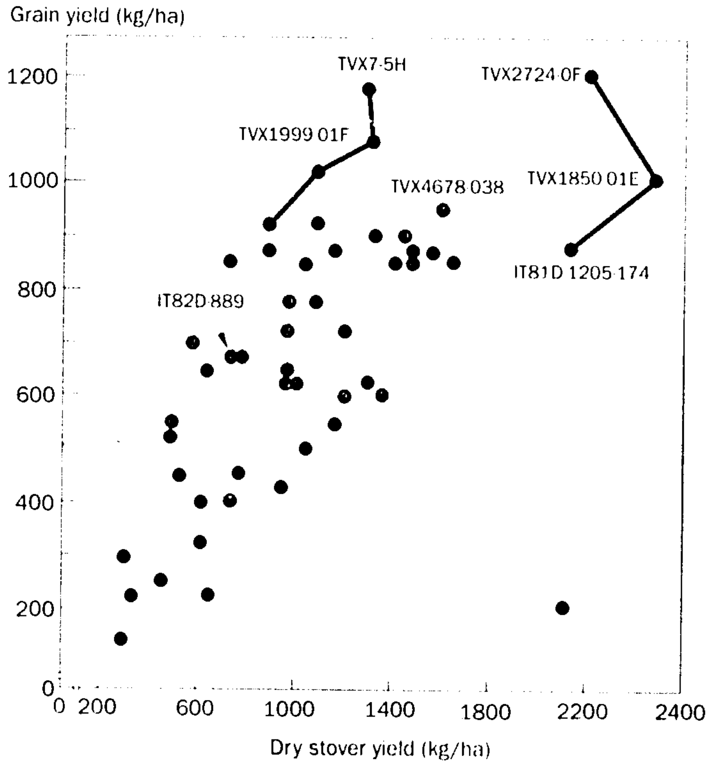
We used a new system of rice - legume management in which rice seedlings were transplanted at 22 cm intervals along dual rows spaced 7 apart, with a 28-cm space between each pair of rows. Immediately after rice harvest, we used a prototype interrow tillage implement to prepare a seedbed for mungbean in the 28-cm space between the dual rice rows, without disturbing the rice stubble. Mungbean yield with this system was 2.1 t/ha.

Effect of tillage on water retention. One purpose of wetland tillage of rice soil is to lessen percolation and retain standing water in the field. Soil compaction (as that done by animal hoof) is an important component of tillage. In experiments at IRRI, yields of irrigated rice were 3 t/ha in untilled soil, 4.2 t/ha in mechanically prepared soil, and 5 t/ha in water buffalo-puddled soil.

Cropping systems

A problem in rice - legume cropping systems is selecting appropriate legume varieties for the agroclimatic environment. We are attempting to select two radically different types of cowpea cultivars for different niches in upland rice-based cropping systems: an early-maturing cultivar for intercropping with rice and a late-maturing cultivar to grow after rice. The cowpea for intercropping with rice should combine high yield with low stover weight to minimize competition with rice. We have identified the cultivar IT82D-889 from the International Institute of

By transplanting rice in rows spaced alternately at 7 and 28 cm (left), the 28-cm space can be tilled immediately after rice harvest without disturbing the stubble (center), and a mungbean crop can be grown (right).



The search for cowpea germplasm for upland rice-based cropping systems seeks two types of cultivars: an early-maturing, less competitive type for intercropping, and a late cultivar with high green manure biomass.

Tropical Agriculture as the prototype of the plant type we seek. The cultivar for the postrice crop ideally should combine high yield with high biomass to provide nitrogen for the subsequent rice crop.

Climatic environment and rice

We developed a simulation model to estimate potential grain yields of transplanted and dry seeded rice for irrigated and rainfed conditions on the IRRI farm. The information provided serves as a reference for current field trials and can help to interpret differences in growth and yield on a yearly or seasonal basis.

The model is based on physiological and physical processes such as photosynthesis, respiration, transpiration, and movement of water in the soil. Crop and soil parameters are taken from specific experiments; weather data are from actual observations over a 24-year period.

Social and economic environment

Equity impact analysis. There is widespread concern that the differential adoption of modern rice technology between favorable and unfavorable rice production environments will increase regional income disparities. In an earlier study in the Philippines, we found that wage rates tended to remain equal because the higher labor demand of modern technology encouraged both seasonal and permanent migration of labor from unfavorable to favorable areas. But the adoption rate of modern technology is particularly high in the Philippines.

We extended the study to Nepal, where modern varieties (MVs) occupy less than 40% of the riceland. Similar labor migration in Nepal tended to equalize wage rates. The adoption of MVs also increased the demand for land as well as for labor, thereby raising returns to land from rice production. This in turn contributes to widening the gap in returns to land from rice production. A comparative study of villages in irrigated and nonirrigated areas in Nepal showed that crop diversification in nonirrigated areas tended to equalize income distribution.

Results from only two countries do not permit drawing definitive conclusions about wage and income distribution in favorable and unfavorable areas. But these preliminary results do indicate that labor migration to favorable areas and crop diversification in unfavorable areas tend to equalize wage and income distribution.

Farmers training farmers. A major goal of socioeconomic research is to help national programs develop methods by which they can work with farmers in introducing new technology. One method is to enlist farmers to train other farmers. At a key on-farm research site in Claveria, Philippines, a farmer participatory model was developed to address soil erosion in upland rice systems. It involved

- farmers identifying the problem and seeking a solution,
- farmer experimentation, adaptation, and adoption of contour hedgerow systems,
- agronomic research that built upon farmers' experiments,

Lao agricultural officials visited the IRRI upland on-farm research site in Claveria, Philippines, to see how farmer-derived research and technology transfer methods developed there might be applied in Laos. From right: Samuel Fujisaka, IRRI visiting scientist; Soukaseum Bhodisane, director, Lao Department of Agriculture; Emelita Jayson, IRRI field aide; and Khamsing Saya Kone, Lao senior vice minister of agriculture.

Machinery development and testing

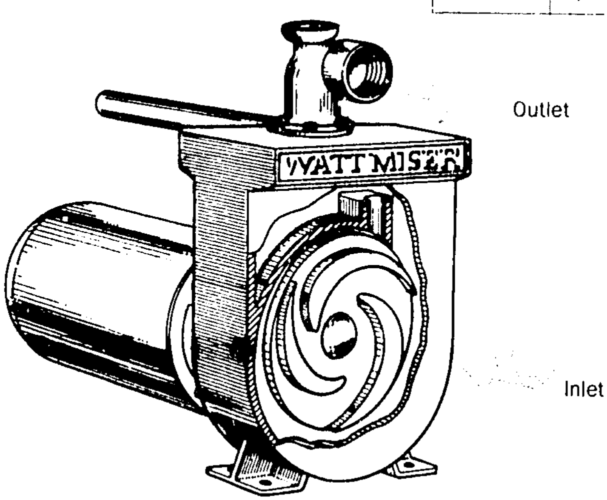
IRRI engineers, in collaboration with the Bureau of Plant Industry of the Philippine Department of Agriculture, developed small electric pumps to help small farmers in the rainfed lowland areas tap groundwater during dry periods at less cost. The IRRI Watt-Miser self-priming electric pump series can provide supplemental irrigation for 1-3 hectares of rice using a matching single-phase electric motor from 0.37 to 1.13 kW. The pump's impeller is 115 mm in diameter, but can be supplied in varying widths to suit different flow rates and different sizes of electric motors.

In a test in northern Luzon, a 0.56-kW IRRI Watt-Miser operating in a tubewell cost about US$0.10 per hour to operate; a pump driven by a gasoline engine consuming 1 liter per hour cost about US$0.32 for the same water output. One Manila manufacturer has started mass-producing IRRI Watt-Miser pumps.

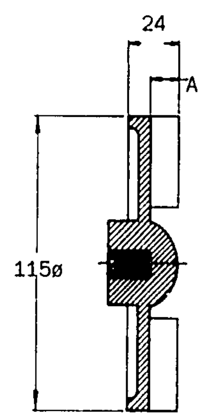
In cooperation with the University of Hohenheim, Federal Republic of Germany, we developed and tested a

Philippine Department of Agriculture-IRRI electric pump can supply supplemental irrigation for 1 to 3 hectares, depending on impeller width and motor size.

A (mm)	7	9	12	18
Motor HP	1/2	3/4	1	1-1/2



Pump



Impeller section

solar tunnel dryer for drying paddy. The unit reduced moisture content from 26% (wet basis) to 14% in 6-8 hours. Milling recovery of dried paddy was close to potential. Although drying with the solar unit is more efficient than sun-drying, the initial cost is relatively high.

International Collaboration

IRRI has formal or informal relationships in both research and training in nearly all the rice-growing countries of the world. These activities help in meeting the goal of strengthened national research capabilities.

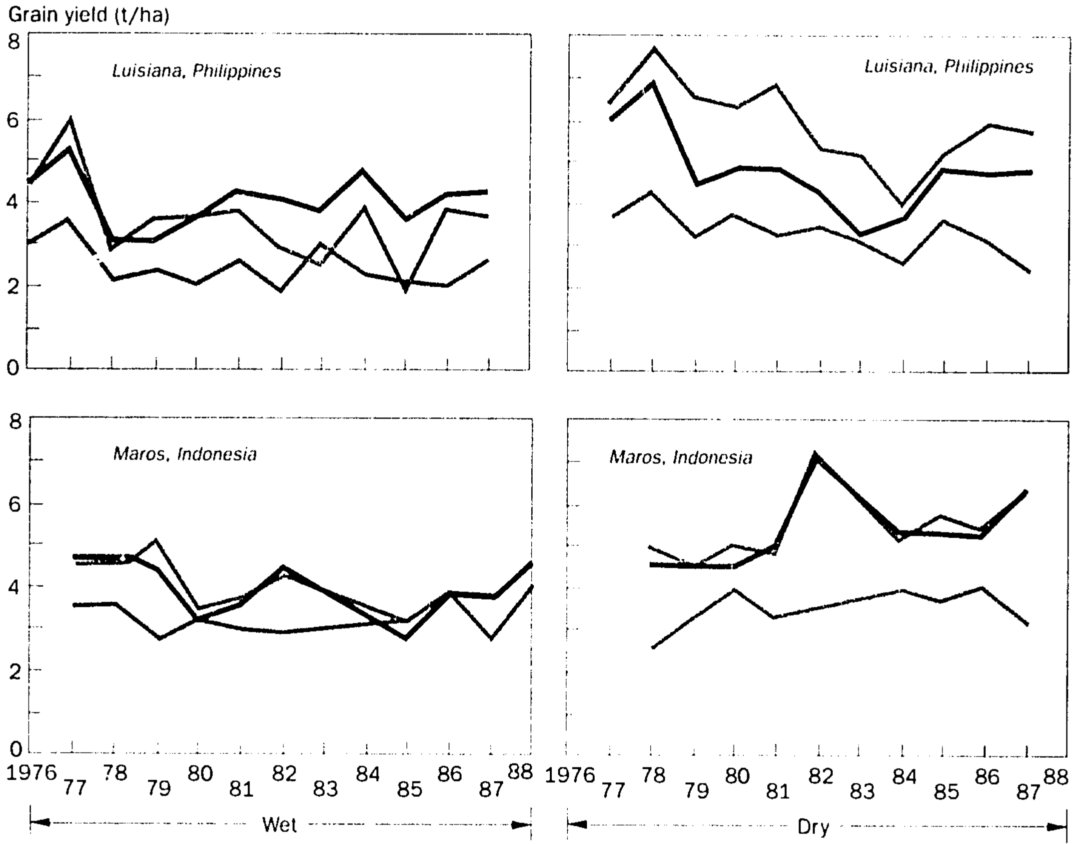
Networks

Networks link scientists and research organizations involved in activities of mutual concern within a country, within a geographic region, and across continents.

INSURF. In 1988, the International Network on Soil Fertility and Sustainable Rice Farming (INSURF) initiated subnetworks. The subnetwork concept is premised on the fact that certain national systems have attained sufficient strength and maturity that they have a comparative advantage in some research areas. Lead centers were established in China, India, Indonesia, the Philippines, and Thailand. Relevant technologies developed in subnetworks will be shared throughout INSURF.

Integrated nutrient management trials test promising organic materials and cropping patterns to provide greater flexibility in studying site-specific problems. Important findings in 1988 show that

- Combinations of inorganic and organic fertilizer performed as well as inorganic fertilizer alone at most sites.
- Among organic materials, azolla and straw gave comparable yields.
- Soil properties and other environmental factors peculiar to a site are major factors in assessing integrated nutrient management strategies.
- Green manure performs better than azolla or farmyard manure at some sites.



Long-term grain yields are declining in both the wet and dry seasons, even with complete nitrogen, phosphorus, and potassium treatment. INSURF, 1976-88.

Rainfed lowland and upland rice trials now include site-specific soil problems and related factors, such as crop residue management and rice-based cropping systems. We found that

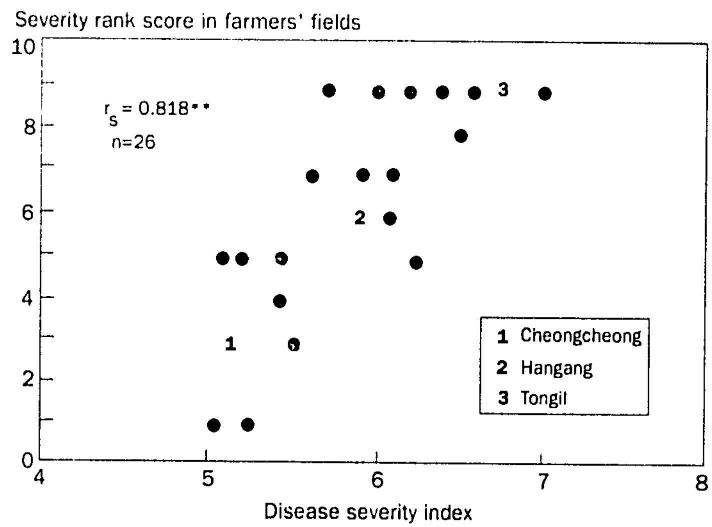
- Nitrogen continues to be a major limiting nutrient, although other nutrients such as phosphorus and zinc are beginning to exert an influence on yield.
- Yields at most sites are gradually declining in both the wet and dry seasons, even with complete nitrogen, phosphorus, and potassium treatment.
- Changing varieties, climatic factors, and biological stresses account for year-to-year yield fluctuations.

IRTP. In the 1988 International Rice Testing Program (IRTP), more emphasis was given to genetic diversity and efficient utilization. A total of 1,217 sets of 25 types of IRTP nurseries were distributed to 16 countries in Asia, Africa, Latin America, and Europe. Several countries used IRTP entries in their rice hybridization programs; 198 entries were advanced for field testing at local, state, or national levels.

The blast disease severity index (DSI) used in the International Rice Blast Nursery (IRBN) is useful to determine quantitative resistance to rice blast. We found a close correlation between DSI in the blast nursery and the severity ranking of Tongil-type varieties in farmers' fields and in the leaf blast nursery at IRRI.

We used simulation modeling to determine the potential productivity of cultivars at different IRTP yield-testing sites. When actual yields at 65 sites were compared with potential yields, actual yields were as high as simulated values in only about half the trials. In the remaining trials, actual yields were less than 60% of potential. Reasons for this yield gap appear to vary from year to year and from site to site.

ARFSN. In 1988, the Asian Rice Farming Systems Network concentrated on crop - livestock and rice - fish farming systems, the role of women in rice farming systems, and the impact of farming systems research. A four-country study demonstrated how maximizing rice yields per unit of land, time, water, and energy and postharvest management contributes to increased income and employment. We also investigated how the benefits of



Relation between disease severity index of Korean indica varieties from the International Rice Blast Nursery and blast severity ranking in farmers' fields.

Peanut is one of several crops being evaluated for growing before or after rice in upland environments in a project coordinated by the Asian Rice Farming Systems Network.

improved technology accrue to farmers in terms of nutrition, capital assest accumulation, and education of children.

We introduced farmer participatory research methods within ARFSN, particularly in Bhutan, Madagascar, and the Philippines, and evaluated IRRI-designed seeding and rice transplanting machines.

Cooperative country projects

Since its inception, IRRI has provided direct technical support to some rice-growing countries with specific needs. These projects are covered by Memorandums of Agreement; support usually comes from special funding.

Asia

Bangladesh. Two successive years of severe flooding during the main rice season (transplanted aman) have led to modifications in cropping systems to avoid the consequences of flooding. The Bangladesh Rice Research Institute (BRRI) has released two improved photoperiod-sensitive varieties that can be transplanted after floods. Even when planted as late as the end of September, they will flower before cold weather and yield 2-3 t/ha.

Studies on irrigation management have focused on increasing cropping intensity and more efficient use of irrigation water in nonflooding areas of central Bangladesh. Improved varieties released in these areas have a 17-26% grain yield advantage and a 5% straw yield advantage over farmers' varieties.

Bhutan. Emphasis continued on strengthening Bhutan's human resources in rice research and development. Two IRRI training staff members spent a month in Bhutan to assist the Bhutanese Department of Agriculture in planning and conducting rice production refesher courses for 138 senior and field-level extension workers. The in-country training itself was done by five Bhutanese graduates of the 1986 IRRI Training and Technology Transfer Course. We also conducted a training program on growing mustard after rice, and began collaborative studies on integrated pest management. The IRRI-Bhutan Rice Farming Systems Project is supported by the International Development Research Centre.

Three rice varieties (introduced, tested, and evaluated with IRRI support) were released by the National Variety Release Committee: BR153-2B-10-1-3 (released as BR153) for low-altitude southern foothills, IR64 (released as IR64) for medium-altitude valleys, and Takanenishiki (released as No. 11) for high-altitude areas.

IRRI training staff helped the Bhutanese Department of Agriculture plan rice production refresher courses for senior and field-level extension workers.

Cambodia. The Cambodia-IRRI project addresses three areas considered crucial to the success of Cambodian agriculture—the development of human resources, research infrastructure, and effective technology transfer mechanisms. Thirteen agricultural officers completed a special rice production training course at IRRI in 1988.

We gave the development of the Cambodian Rice Research and Development Institute (CARRDI) at Prateah Lang high priority, assigning an experiment station development specialist to help produce the CARRDI site master plan. IRRI projects in Cambodia are supported by the Australian International Development Assistance Bureau.

China. IRRI's collaborative work with China involves the Chinese Academy of Agricultural Sciences; the Chinese Academy of Agricultural and Mechanization Sciences; Academica Sinica; the National Laboratory for Plant Genetics Engineering; Development Research Institute, Research Center for Rural Development of the State Council of the People's Republic of China; 14 provincial academies; and 6 agricultural colleges and universities.

A farmer threshes rice near Prateah Lang, proposed site of the Cambodian Rice Research and Development Institute.

Collaborative research priorities are integrated pest management, sustainable agriculture, hybrid rice, biotechnology, and germplasm conservation and utilization.

India. Collaborative research with the Indian Council of Agricultural Research (ICAR) concentrated on rainfed rice environments in eastern India: deepwater, rainfed shallow, drought prone, rainfed shallow, submergence-prone; and upland. In an attempt to integrate experiment station and on-farm research into a coherent program, we conducted on-farm research (varietal improvement, crop establishment, nutrient management, and manual irrigation) on 500 farmers' fields during the 1988 wet season. At an upland site in Ranchi, Bihar, the test line RAU 4045-10 (100-day maturity) yielded 3.4 t/ha compared with the local check Brown Gora (97-day maturity) yield of 1.8 t/ha. At a rainfed lowland site, NC492, a tall indica selection from local germplasm, yielded 4.1 t/ha, compared with a 2.1 t/ha yield for Sno Kalma, a popular local variety.

We studied the traditional rice - fish culture system practiced by farmers in deepwater rice areas in West Bengal. Multilocational trials in farmers' fields were used to standardize and improve the culture of important fish grown along with deepwater rice. We experimented with several plot designs and devised a suitable fish sampling procedure.

Indonesia. Staff of the Agency for Agricultural Research and Development and IRRI collaborated in the collection of germplasm from West Java: 30 populations of *Oryza rufipogon*, 12 of *O. officinalis*, 2 of *O. granulata*, and 11 varieties of *O. sativa*. In irrigated rice improvement, we evaluated elite breeding lines with multiple resistance to diseases and insects in replicated yield trials. Emphasis was on superior grain quality conditioned by intermediate amylose and intermediate gelatinization temperature. Breeding lines originating from crosses of *O. sativa* and *O. officinalis* are being evaluated.

In breeding for peat soils, two locations in South Kalimantan were used: Unit Tatas for potential acid sulfate soils and Belandean for acid sulfate, direct tidal wetlands. We screened traditional varieties from West Africa and advanced IR lines. In Unit Tatas, eight West African varieties were better than local check varieties;

Farmers in West Bengal, India, netting fish in a deepwater ricefield.

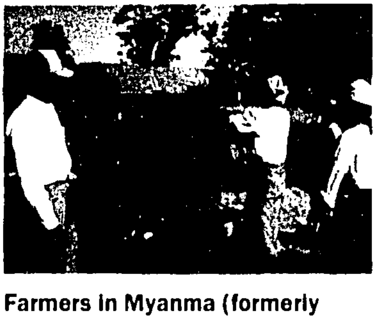
in Belandean, 15 West African varieties performed well. Seven West African varieties were selected for hybridization. IR26708-2-2-3-1-1, IR30217-4-3-2-3, and IR31376-1-2-1-1 were selected for further testing.

Although Sukamandi soil (Vertic Tropacults in association with Typic Plinthaquox) is low in available phosphorus, continuous application of TSP has gradually increased its accumulation—trials on phosphorus sources in the wet and dry seasons showed no response to application.

Evaluation of hybrid rices was hampered by the high frequency of sterile plants due to the instability of IR54752 A. However, populations of IR54752 A grown at 500 m above sea level in Kuningan were more uniform than those grown at Sukamandi. Success in developing rice hybrids now seems to depend primarily on the availability of a stable CMS line, high outcrossing rate, and resistance to major pests and diseases.

Laos. We did a project identification and design study in anticipation of a major country project. Several IRRI scientists visited Laos to discuss rice research and development priorities with the Lao Government and to identify the possible role of IRRI. We identified development of appropriate low-cost technologies for upland and rainfed lowland rice-growing areas and staff training as priority activities for the Laos-IRRI project. The collaboration with Laos is supported by the Australian International Development Assistance Bureau.

Myanma. The Myanma (formerly Burma)-IRRI Farming Systems Project (MIFS), funded by the Canadian International Development Agency, conducted research at 19 sites in collaboration with 60 national agricultural scientists. Eleven promising cropping patterns were identified at four sites. We demonstrated to farmers that *Sesbania rostrata* is an effective green manure crop for rice if it is incorporated within 60 days after emergence.



Farmers in Myanma (formerly Burma) using the IRRI TH-8 thresher under the guidance of an agricultural officer.

In the small-scale mechanization program, we modified the IRRI-designed rice drum seeder to sow upland crops after rice, and designed a gear drive mechanism to operate the IRRI TH-7 by animal power.

Ten new rice varieties were recommended for release in four ecosystems. We evaluated 27 International Rice

Testing Program nurseries at 13 sites and conducted 4 International Network on Sustainable Rice Farming Systems trials at 8 sites.

Philippines. We participated in the Technology Transfer Workshop sponsored by the Department of Agriculture, PhilRice, and IRRI. The most important result was the design of a special national rice production program to offset the yield reduction anticipated due to severe drought during the year.

In collaboration with the Dairy Training and Research Institute, we evaluated methods for ensiling rice forage for cattle feed and determined the optimum harvest time. Rice forage cut earlier than 40 days after transplanting (DT) requires pretreatment with molasses or maize before ensiling. Forage cut 50-80 DT requires no pretreatment.

We continued work with the Philippine Institute of Plant Breeding (IPB) to accelerate the development and selection of upland crop cultivars for growing before and after rice in upland environments. The Asian Rice Farming Systems Network coordinates the distribution of trials that include mungbean, cowpea, bush sitao, soybean, peanut, pigeonpea, maize, and sorghum. Through this collaborative effort, we hope to increase the productivitiy of millions of hectares of ricelands where a prerice or postrice crop is possible.

Thailand. Several new projects, including socioeconomic research and biological agents for the control and management of rice pests, were initiated. In deepwater rice, significant progress has been made in introducing early-maturing crops for preflood production. Methods to establish upland or early rice intercrops with deepwater rice were evaluated. Fertilizer management, weed control, and yield evaluation techniques also were assessed.

A small plot technique to test responses of deepwater rice to fertility is comparable to trials in farmers' fields. Variability of yield measurements are tested using border effect experiments. The aim is to make early generation yield trials more efficient. Using plant samples and N analysis gives more satisfactory results in nitrogen uptake studies than using normal yield measurements. The technique shows the pattern of response to flooding under different soil conditions.

This was the sixth year for Thailand-IRRI breeding nurseries for rainfed lowland rice, and 84 advanced lines were evaluated in six stations in the northeast. Advanced lines from the shuttle breeding program were grown in farmers' fields in Ban Khu Kad. Alternative methods of direct seeding, including using small hand-operated planters, were evaluated in experiment station and farmers' fields. Both wet and dry seeding are being compared to transplanting.

Interpretations of the soils and landscape of one village were carried out using four topographical transacts. Soils and hydrology were mapped in relation to farmer cropping practices and yields. This work will help to identify constraints to higher yields and to more intensive cropping systems. Soil fertility work focused on phosphorus nutrition of rice in acid and acid sulfate soils, and the effect of phosphorus sources with varying citrate solubility. The research design involved P-sorption isotherms and soil chemical properties in relation to phosphorus sources. The results will be used to develop a cost-efficient, low input technology for rainfed lowland rice production.

Africa

Egypt. The scarcity of arable land in Egypt means that agricultural research must focus on increasing yields and cropping intensity. IRRI works with Egyptian rice researchers through the Rice Research and Training Center at Sakha to exchange germplasm and breeding lines and to provide technical help and training for Egyptian scientists.

Two high-yielding, blast-resistant varieties were recommended for cultivation in 1988: Giza 175 (GZ1394-10-1) and Giza 181 (IR1625-203). We identified several breeding lines that have some salinity tolerance in addition to high yielding ability, blast resistance, and good grain quality. One of them, GZ2175-5-6, gave average yields of 11.3 t/ha in large-scale demonstrations in farmers' fields in 1988.

Madagascar. On the Madagascar High Plateau (1,000-1,800 m), rice yields are low because of poor water control and low soil fertility, including iron toxicity and phosphorus deficiency. Crosses between Malagasy varieties and introduced elite lines have resulted in several lines that

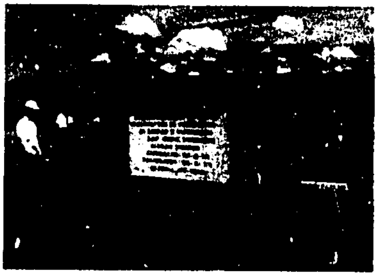
In the High Plateau of Madagascar, poor water control and low fertility keep rice yields low.

tolerate those stresses as well as cold; three have been recommended for prerelease generation advance. The phosphorus-deficient soils bind the phosphorus applied as fertilizer so that it is not available to the rice plant. Dipping seedling roots in a slurry of soil, water, and triple superphosphate is about 30% more efficient than broadcasting and incorporating the fertilizer.

We are identifying deepwater varieties that could be grown in the fallow season on the Marovoay Plain. That would permit about 12,000 hectares to be double-cropped to rice.

Latin America and the Caribbean

In areas where rice harvest is delayed because of lack of labor or poor weather, head rice recovery (yield after milling) can be as important to the farmer as rough rice yield. (Head rice recovery tends to decrease with delays in harvesting rice after peak maturity.) Although some differences in head rice recovery can be ascribed to seasonal effects, we are studying genetic differences, in cooperation with the International Center for Tropical Agriculture (CIAT). Based on head rice recovery after delayed harvest, we have classified rices as resistant to delayed harvest, moderately resistant, moderately susceptible, and susceptible. We expect that these milling evaluations will also permit more accurate assessment of varietal performance at the farm level.



The Caribbean Rice Improvement Network evaluates improved germplasm introduced from IRRI and from the International Center for Tropical Agriculture.

CIAT also sponsors the Caribbean Rice Improvement Network, which evaluates germplasm introduced from CIAT and IRRI.

Education and Communication

IRRI's training program is aimed at increasing the capability of human resources in national rice research systems. IRRI also plays a major role as a facilitator of the worldwide flow of rice information.

Training

IRRI training programs are designed to meet the needs of its cooperators in developing countries. They include regular training courses conducted at IRRI, professional advancement through graduate study at cooperating universities or visiting scientist appointments at IRRI, and courses organized to meet specialized training needs.

In 1988, 497 scientists from 43 countries were enrolled in various IRRI training programs. Among them were 20 visiting scientists, 29 postdoctoral scientists, 12 collaborative research scientist, 87 Ph D and 49 MS scholars, and 22 nondegree scholars and fellows.

We have formal collaborative graduate training agreements with 30 universities, having concluded agreements with Assam Agricultural University, India; Universidad Federal de Pelotas, Brazil; and Colegio de Post-Graduados, Mexico, in 1988.

The first international course on seed health testing in rice was conducted for 19 trainees in cooperation with scientists from the Denmark Institute of Seed Pathology for Developing Countries.

We held 20 group training courses (9 regular, 11 special) for 260 trainees from 38 countries. Included in the group training courses were special rice production courses for field and extension personnel of Cambodia and Laos, and the first international course on rice seed health testing.

We started an IRRI Alumni Newsletter and published two issues for distribution during the year.

Library and documentation

We broadened the scope of our literature dissemination program through expanded linkages with the International Network on Soil Fertility and Sustainable Rice Farming, the International Rice Testing Program, and the Asian Rice Farming Systems Network. This permits the Library to directly answer the information needs of an additional 350 key rice scientists and 375 research workers at 217 sites operated by national agricultural research systems in 104 countries.

Communication and publications

At least 84,000 copies of major IRRI publications were distributed during 1988. Of these, 45,846 were in English; the others were translations generated through our copublication program.

Of the English publications, 41% were distributed free, mostly to key Third World libraries. Almost all translations were sold or sponsored by donor funds.

Ten books in English were released. An additional seven translations of IRRI publications were copublished by national programs.

Four issues of the *IRRI reporter*, 6 issues of the *International rice research newsletter* (IRRN), and the IRRN Subject index for 1987 were distributed to 9,500 rice workers and 1,500 libraries in 140 countries. Eight IRRI research papers were issued.

Recognition

Early achievements of IRRI administrators and scientists continue to draw worldwide recognition. Two of those who have contributed to improvements in the world food situation since 1960 were recognized this year.

The 1988 World Food Prize

Dr. Robert Flint Chandler, Jr., the first Director General of IRRI, was awarded the World Food Prize in October, in ceremonies at the Smithsonian Institute in Washington, D.C. He was honored for his decades of work toward improving the world food situation.

Dr. Chandler established IRRI in 1960 and served as its head until 1972. During the first decade, he molded IRRI into an international center of excellence to help alleviate hunger worldwide—he defined its research directions, built its physical plant, and assembled the nucleus of its international research staff.

He also served as the first Director General of the Asian Vegetable Research and Development Center in Taiwan, China, 1972-1975. The World Food Prize is sponsored by General Foods Funds, Inc.

The Rank Prize

The prestigious Rank Prize for Agronomy and Nutrition was conferred on Dr. Te-Tzu Chang, principal IRRI geneticist and head of the International Rice Germplasm Center (IRGC), together with Dr. P.R. Jennings, former IRRI rice breeder, and Prof. Yuan Long-Ping, director of the Hybrid Rice Research Center, Changsha, Hunan, China. The award was presented in London in March.

Dr. Chang introduced Dee-geo-woo-gen, a Chinese dwarf rice, into IRRI's breeding program in 1962. That led

Traditional variety Peta and first high-yielding semidwarf variety IR8.

to the development of the first high-yielding semidwarf IRRI variety, IR8, released late in 1966.

Dr. Jennings was honored for his role as an IRRI breeder during the early development of modern rice varieties; Prof Yuan developed the first F_1 hybrid rice varieties, in China in the 1970s.

The Rank Prize Funds were established by Lord J. Arthur Rank to recognize contributions to human and animal nutrition and to the science of optoelectronics. The 1988 prize is only the sixth agronomy and nutrition award given since the fund was established.

Finances

IRRI's budget

Summary of financial support to IRRI core and to special and collaborative projects received in 1988.[a]

	Amount (US$)			
	Core		Special and collaborative project	Total
	Unrestricted	Restricted		
Support from grants				
Asian Development Bank			450,600	450,600
Australia	629,644		966,378	1,596,022
Belgium			135,235	135,235
Canadian International Development Agency	1,482,421		20,085	1,502,506
Denmark	405,175		142,092	547,267
European Economic Community		2,050,830		2,050,830
Finland	249,180			249,180
France		206,120		206,120
Federal Republic of Germany	564,462	169,339	53,262	787,063
India	**111,921**			111,921
International Bank for Reconstruction and Development	1,950,000			1,950,000
International Development Research Centre		79,459	427,569	507,028
International Fund for Agricultural Development			2,117	2,117
Iran			83,065	83,065
Italy	**387,402**	**800,000**	220,000	1,407,402
Japan		5,691,103	2,049,564	7,740,667
Republic of Korea Office of Rural Development			98,000	98,000
The Netherlands		150,756	110,974	261,730
Norway	127,684			127,684
Organization of Petroleum Exporting Countries			108,671	108,671
Philippines	**137,196**		28,951	166,147
Rockefeller Foundation		**136,600**	249,183	385,783
Spain	29,990			29,990
Stabilization Mechanism Fund (CGIAR)	1,150,000			1,150,000
Sweden	552,787		21,959	574,746
Swiss Development Cooperation		**671,282**		671,282

[a] Receipts are accounted for on a cash basis. Amounts shown in boldface differ from 1988 pledges from grantors in that they may reflect 1987 or 1989 pledges received in 1988, or may not reflect the full amount of 1988 pledges, which are anticipated to be received in 1989. Also, the Government of France (through the research organizations ORSTOM and IRAT) provided IRRI the services of four resident scientists; the value of their services cannot be quantified.

Summary of financial support to IRRI core and to special and collaborative projects received in 1988 (continued).[a]

	Amount (US$)			
	Core		Special and collaborative project	Total
	Unrestricted	Restricted		
United Kingdom Overseas Development Administration	1,546,396		21,600	1,567,996
United Nations Development Programme		**1,815,200**		1,815,200
United States Agency for International Development		**4,128,028**	1,757,856	5,885,884
Miscellaneous grants			66,782	66,782
Funds reimbursed under collaborative research programs				
Food and Agriculture Organization			23,000	23,000
International Center of Insect Physiology and Ecology		**44,926**		44,926
International Fertilizer Development Center			45,086	45,086
International Food Policy Research Institute			107,393	107,393
United States Department of Agriculture/University of Minnesota			9,080	9,080
University of Giessen			35,030	35,030
University of Hamburg			23,610	23,610
Total	9,324,258	15,943,643	7,257,142	32,525,043

[a] Receipts are accounted for on a cash basis. Amounts shown in boldface differ from 1988 pledges from grantors in that they may reflect 1987 or 1989 pledges received in 1988, or may not reflect the full amount of 1988 pledges, which are anticipated to be received in 1989. Also, the Government of France (through the research organizations ORSTOM and IRAT) provided IRRI the services of four resident scientists; the value of their services cannot be quantified.

Trustees

DR. YOOKTI SARIKAPHUTI[1]
Deputy Permanent Secretary
Department of Agriculture
Ministry of Agriculture and Cooperatives
Bangkok
Thailand

DR. HOWARD A. STEPPLER[4]
Emeritus Professor
Department of Plant Science
MacDonald College of McGill University
21, 111 Lakeshore Road
St. Anne de Bellevue, P.Q.
Canada H9X 1CO

DR. M. S. SWAMINATHAN[1]
Director General
International Rice Research Institute
P. O. Box 933
1099 Manila
Philippines

PROF. ZHANG YIHUA
Director
Institute of Crop Germplasm Resources
Chinese Academy of Agricultural Sciences
30 Bai Shi Qiao Road
Beijing
China

Personnel

Office of the Director General

M. S. SWAMINATHAN, Ph D, director general[1]
KLAUS LAMPE, Ph D, director general[1]
FERNANDO A. BERNARDO, Ph D, deputy director general
MANO D. PATHAK, Ph D, director, research and training
ROBERT L. BOURQUEIN, MBA, director, administration
FAUSTINO M. SALACUP, BS, CPA, director, protocol and liaison
EDWARD N. SAYEGH, BBA, director, finance
PURITA M. LEGASPI, BBA, CPA, special assistant to the director general
KHIN WIN, MS, visiting scientist

Administrative Staff

REBECCA C. PASCUAL, MS, manager, food and housing services
ZOSIMO Q. PIZARRO, LLB, manager, legal office
PEDRO G. BANZON, LLB, manager, security, safety, and shipping
B. P. GHILDYAL, Ph D, IRRI liaison scientist, India[5]
I. TANAKA, D Agr, part-time IRRI liaison scientist, Japan[5]
WALTER C. TAPPAN, BS, IRRI liaison scientist, Indonesia and Malaysia[5]
DIOSCORO L. UMALI, Ph D, IRRI liaison scientist, China (consultant)[5]
EDWARD D. SPRATT, Ph D, project manager, Egypt[5]
SUDHAMOY BISWAS, Ph D, project director, India, (consultant)[1,5]

Cooperative Research Staff

Africa

KRISHNA ALLURI, Ph D, IRTP liaison scientist for West Africa

K. Gopalakrishna Pillai, Ph D, IRTP coordinator for East Africa

Bangladesh
Jerry L. McIntosh, Ph D, research systems specialist/IRRI representative
Noel P. Magor, M Agr, cropping systems agronomist

Cambodia
Harry J. Nesbitt, Ph D, agronomist and team leader[1]
Ram Chet Chaudhary, Ph D, plant breeder[1]
Ernest W. Nunn, Ph D, research development specialist[1]
Gregor J. Wells, Ph D, consultant, IRRI-Indochina Program

China
Dioscoro L. Umali, Ph D, IRRI liaison scientist (consultant)

Egypt
Edward D. Spratt, Ph D, project manager
A. P. K. Reddy, Ph D, plant pathologist

India
B. P. Ghildyal, Ph D, IRRI liaison scientist
Sudhamoy Biswas, Ph D, project director[1]
H. David Catling, Ph D, entomologist[1]

Indonesia/Malaysia
Walter C. Tappan, BS, IRRI liaison scientist

Japan
I. Tanaka, D Agr, part-time IRRI liaison scientist

Latin America
Manuel J. Rosero, Ph D, IRRI liaison scientist[1]
Federico E. Cuevas-Pérez, Ph D, IRTP coordinator for Latin America

Madagascar
B. B. Shahi, Ph D, plant breeder
James R. Hoopper III, Ph D, agronomist

Myanma *(formerly Burma)*
Rosendo K. Palis, Ph D, farming systems agronomist

Thailand
Donald W. Puckridge, Ph D, agronomist

Agricultural Economics
John C. Flinn, Ph D, agricultural economist and head[2]
Cristina C. David, Ph D, agricultural economist
J. Bart Duff, MS, agricultural economist
Leonardo A. Gonzales, Ph D, agricultural economist
Prabhu L. Pingali, Ph D, associate agricultural economist
J. Samuel Fujisaka, Ph D, visiting scientist
Yujiro Hayami, Ph D, visiting scientist[3]
Robert E. Huke, Ph D, visiting scientist[1]
Keijiro Otsuka, Ph D, visiting scientist
Nimal F. C. Ranaweera, Ph D, visiting scientist

Agricultural Engineering
Graeme R. Quick, Ph D, agricultural engineer and head[1]
Joseph K. Campbell, MS, visiting scientist[1]

Agronomy
Surajit K. De Datta, Ph D, principal agronomist and head
Cezar P. Mamaril, Ph D, agronomist
Keith Moody, Ph D, agronomist[2]
Donald W. Puckridge, Ph D, agronomist[5]
Keith T. Ingram, Ph D, associate agronomist
Roland J. Buresh, Ph D, visiting scientist
James E. Hill, Ph D, visiting scientist[1]

Cereal Chemistry
Bienvenido O. Juliano, Ph D, chemist and head

Communication and Publications
Thomas R. Hargrove, Ph D, editor and head
Stephen J. Banta, Ed D, editor
M. LaRue Pollard, Ph D, editor
William H. Smith, BS, editor

Lloyd R. Bostian, Ph D, visiting scientist[3]
Ian Montagnes, MA, visiting editor[1]
Vrinda Kumble, MA, consultant[3]
Devinder Sharma, MS, consultant[1]

Computer Center

George C. Krajcsik, Ph D, software coordinator and head
Sean E. O'Connor, BS, computer hardware coordinator[1]

Entomology

B. Merle Shepard, Ph D, entomologist and head[1]
James A. Litsinger, Ph D, entomologist[2]
Osamu Mochida, D Agr, entomologist[1]
Ramesh C. Saxena, Ph D, entomologist
H. David Catling, Ph D, entomologist[1,5]
Z. R. Khan, Ph D, associate entomologist
Wendell L. Morrill, Ph D, visiting scientist[4]
Peter A. C. Ooi, MS, visiting scientist[4]

Integrated Experimental Farm and Grounds

Orlando G. Santos, MPS, senior farm and grounds superintendent

International Rice Germplasm Center

Te-Tzu Chang, Ph D, principal geneticist and head
Duncan A. Vaughan, Ph D, associate geneticist

International Rice Testing Program

V. Seshu Durvasula, Ph D, plant breeder and global coordinator
Muhammad Akbar, Ph D, plant breeder
Sang Won Ahn, Ph D, associate plant pathologist
Krishna Alluri, Ph D, liaison scientist for West Africa[5]
Manuel J. Rosero, Ph D, IRRI liaison scientist[1,5]
Federico E. Cuevas-Pérez, Ph D, IRTP coordinator for Latin America[5]
K. Gopalakrishna Pillai, Ph D, IRTP coordinator for East Africa[5]

Library and Documentation Center

Lina M. Vergara, MS, librarian

Multiple Cropping

Virgilio R. Carangal, Ph D, agronomist, officer-in-charge
Dennis P. Garrity, Ph D, agronomist
Ram Kumar Pandey, Ph D, visiting scientist[1]
F. W. T. Penning De Vries, Ph D, visiting scientist

Plant Breeding

Gurdev S. Khush, Ph D, principal plant breeder and head
Derk HilleRisLambers, Ph D, plant breeder
Ryoichi Ikeda, Ph D, plant breeder[4]
Tsugufumi Ogawa, D Agr, plant breeder[1]
Dharmawansa Senadhira, Ph D, plant breeder
Sant S. Virmani, Ph D, plant breeder
Ram Chet Chaudhary, Ph D, plant breeder[4,5]
B. B. Shahi, Ph D, plant breeder[5]
Francisco J. Zapata, Ph D, tissue culture specialist
Darshan S. Brar, Ph D, associate plant breeder
David J. Mackill, Ph D, associate plant breeder
Lesley Ann Sitch, Ph D, associate plant breeder
Michel A. Arraudeau, MS, visiting plant breeder
Emmanuel Guiderdoni, MS, visiting scientist
Bert J. Hoff, Ph D, visiting scientist[1]
Chong-Ho Kim, Ph D, visiting scientist

Plant Pathology

Twng-Wah Mew, Ph D, plant pathologist and head
Hiroyuki Hibino, D Agr, plant pathologist[1]
Paul S. Teng, Ph D, plant pathologist, epidemiologist
Ankireddy P. K. Reddy, Ph D, plant pathologist[5]
John Michael Bonman, Ph D, associate plant pathologist
Hei Leung, Ph D, associate plant pathologist

Hisatoshi Kaku, Ph D, visiting scientist
Jean-Claude Prot, Ph D, visiting scientist[4]

Plant Physiology

Benito S. Vergara, Ph D plant physiologist and head
Shigemi Akita, D Agr, plant physiologist[1]
Genshichi Wada, D Agr, plant physiologist
K. Takahashi, D Agr, visiting scientist[1]
John M. Wilson, Ph D, visiting scientist[1]

Rice Farming Systems Program

Virgilio R. Carangal, Ph D, agronomist and head[2]
Jerry L. McIntosh, Ph D, research systems specialist IRRI representative[5]
James R. Hoopper III, Ph D, agronomist[5]
Noel P. Magor, M Agr, cropping systems agronomist[5]
Rosendo K. Palis, Ph D, farming systems agronomist[5]
Donald G. Faris, Ph D, visiting scientist[4]
Nicolas Mateo, Ph D, visiting scientist[1]
Clive W. F. Lightfoot, Ph D, associate visiting scientist[4]

Soil Microbiology

Iwao Watanabe, D Agr, soil microbiologist and head
Jagdish K. Ladha, Ph D, associate soil microbiologist
Pierre A. Roger, D Pedologie, visiting scientist

Soils

Heinz-Ulrich Neue, Ph D, soil chemist and head
Terence Woodhead, Ph D, physicist
Guy J. D. Kirk, Ph D, associate soil chemist[4]

Statistics

Kwanchai A. Gomez, Ph D, statistician and head

Training and Technology Transfer

Dan R. Minnick, Ph D, training specialist and head
Glenn L. Denning, Ph D, scientist (international collaboration)
Harry H. Nesbitt, Ph D, agronomist and team leader[4,5]
Ernest W. Nunn, Ph D, research development specialist[4,5]
Jill M. Sullivan, MA, consultant[1]
Gregor J. Wells, Ph D, consultant[1,5]

Water Management

Sadiqul I. Bhuiyan, Ph D, agricultural engineer and head
George J. Moridis, Ph D, associate agricultural engineer

---

[1]Left during the year.
[2]On study leave training.
[3]Joined and left during the year.
[4]Joined during the year.
[5]Cooperative research staff.
[6]Died during the year.