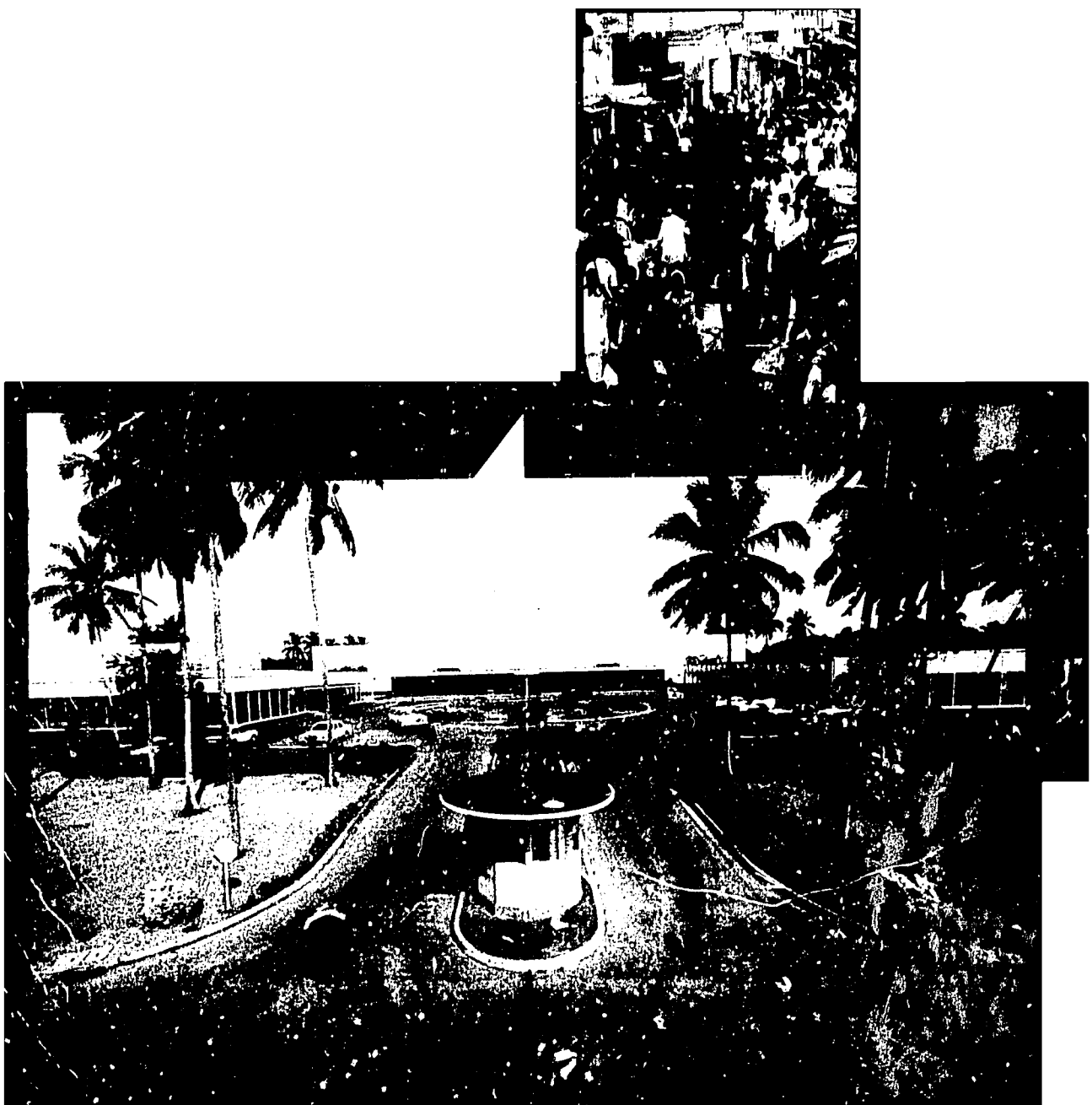
Research Highlights for 1979



International Rice Research Institute

PN-AAN-622/62
ISN-31805

Research Highlights for 1979

1980
INTERNATIONAL RICE RESEARCH INSTITUTE
LOS BAÑOS, LAGUNA, PHILIPPINES, P.O. BOX 933, MANILA, PHILIPPINES

The International Rice Research Institute receives support from a number of donors including the Ford Foundation, The Rockefeller Foundation, the European Economic Community, the United Nations Development Programme, the OPEC Special Fund, the Asian Development Bank, the International Development Research Centre, the World Bank, and the international aid agencies of the following governments: United States, Canada, Japan, United Kingdom, Netherlands, Australia, Federal Republic of Germany, New Zealand, Belgium, Denmark, and Sweden.

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

Contents

1 OUR 20th YEAR OF RICE RESEARCH
4 Major progress in 1979
17 MAJOR RESEARCH RESULTS
17 Genetic evaluation and utilization program
17 *Integration of appropriate varieties*
23 *Agronomic characteristics*
25 *Germplasm conservation and dissemination*
26 *Computerized data management*
27 *Disease resistance*
32 *Insect resistance*
39 *Grain quality and nutrient content*
41 *Drought resistance*
48 *Adverse soils tolerance*
50 *Deepwater and flood tolerance*
53 *Temperature tolerance*
56 *International Rice Testing Program*
59 Control and management of pests
59 *Diseases*
61 *Insects*
70 *Weeds*
71 Irrigation water management
77 Soil and crop management
77 *Efficiency of nitrogen utilization*
81 *Biological nitrogen fixation*
83 *Soil characterization*
86 *Crop culture*
89 Environment and its influence
90 Constraints to increased yields
95 Consequences of new technology
97 Cropping systems
98 *Environmental description*
103 *Cropping pattern design*
105 *Cropping pattern testing*
108 *Insect pests and continuous rice production*
110 *Component technology*
117 *Preproduction evaluation of cropping systems*
119 *Asian Cropping Systems Network*
121 Machinery development
123 International activities
125 Associated formal training
127 Finances

dia's No... eplaced by IR-8

...dia's highest yielding variety — Taichung ...ive No. 1—has been re...ced in Indian ricelands ...the Philippine IR-8 "mi...er rice" variety, accord... to advisers Prakash, depu... ...ities to secretary of the min... ...ns to bid and agricul... ...olars at the of... ...chairman-gene... ...RCA, 304 ...boulevard exten... ...ya City.

...er Gathered that re... ...purchase "miracle" seeds from the ...pines was made by the ...Asian Bank for In... ...Development and ...ment. It requested ...assistance of the Pil... ...Development Corp. of ...Philippines to arrange ...simple purchase for ...al purposes to Liberia. ...In his letter to Roberto ...Almuneva, PDCP presi... ...ent, P. Clarence Parker ...Jr., general manager of ...the Liberian bank, said rice ...is the staple ... of Li... ...tion today ... 120,000 ...metric tons of which 30,000 are ...imported.

In promoting a rice de... ...velopment program, in Libe... ...ria as with ... ...the conversion of the Li... ...berian farmer. It said it is in... ...terested first of all in ex... ...perimenting with high... ...yielding rice varieties. ...

...Andres that although IR-8 was introduced in Indi... only last year, it al... has occupied about ... 945 hectares.

"This sho... people like ... Prakash ... of sey ... outside the ...

...Proof of January slow... ...ing has never been possible. How can ...we showing of time be measured if all ...the available timing devices on earth ...are similarly affected by relatively ...slow motion, when the regularly beeping sig... ...nals of pulsars were first detected com... ...ing from outer space, Queens College ...astronomer Lou Hoffmann has filed that ...question with answers. There ab... ...out 1/100th of a second per year. The pro... ...posed radio pulses coming from ...lowears away seemed to be the clo... ...clock needed to measure earth time. ...Hoffmann sug... ...letter to Nature. Hoffmann sug... ...d that the pulse rate of pulsars be ...regularly from January through ...when the earth is farthest from ...in and slows to its maximum speed. ...time the pulse rate could be com... ...with an accurate timing device ...

...Bugs in the miracle.

...Scientists ...pulsar ...a rice ... ...century ...than an ...thousand ...doubling ...their ... ...week ...vested ...first ... ...rice ...ing ... ...seed ...has ...new ...the ...rice ...V...

export rice

RCA calls for bids

...Seed ...to ...cation, ...the United ...Canada, Japan and ...Philippines to observe ...ed programs, es... ...researchers, ...

High-yielding rice st...

One of the most significant events of the century has taken virtually unnoticed over the past five years some 40 scant miles outside Manila.

The site is the International Rice Research Institute (IRRI) in Los Baños where they have produced new strains of fast growing, high yielding rice strong enough to survive typhoons and monsoon rains.

The significance of this achievement is best appreciated when viewed against Asia's dizzying population increase and diminishing per capita food production.

For a country like the Philippines, which now spends nearly $70 million a year in precious foreign ...clusive interview with UPI: "I think I am right in saying that the greatest single achievement in this century in the Orient is what the IRRI has done..."

By using the newly developed seeds, Haraldson said per hectare rice yields in the Philippines ... to im... ...creased ... ...per ...

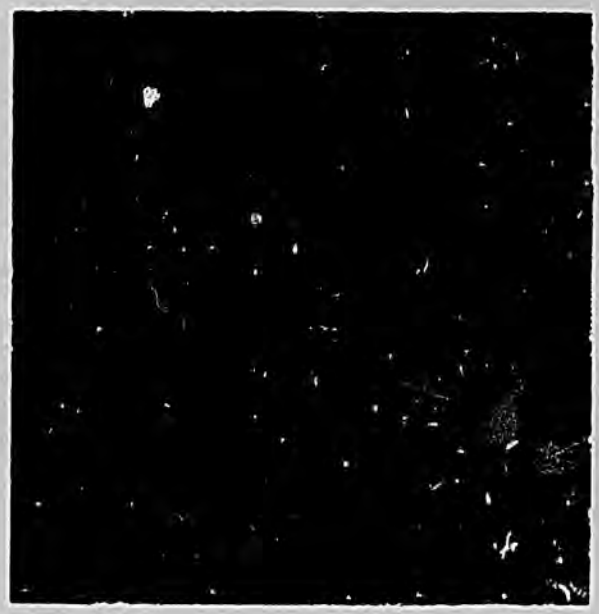
The Phil... ...three mill... ...rice land ... but only ... irrigated ... water, ... productiv... ...growing ... (one ca... ...ent of ...

As ... ...pines ... ...fens ...

...there will be enough of these high yielding seed varieties to plant 150 hectares," Haraldson said. Only ...that 150 hectares will have produced enough seed to plant 13,000 hectares. By next spring, if we can get the right kind of seed farmers, we will have enough seeds for 1,200 and the fall plant...

'Miracle' in Vietnam: New Rice May Be Key To Economic Stability After War Ends in Land

High-Yield Hybrid Is a Big Hit With the Farmers, Despite Its Unappetizing Taste



...ondas & a 'Perfect Food' ...

World Food ... Declined 2% ...

...ed Res... ...IGON-... ...but th... ...ent N... ...t, A Ste... ...because ...Americ... ...Most Ar... ...miracle ...De scrap...

...(UPI) — World food production fell for more than two percent for the first time in seven years in ... due mainly to a 17 percent drop in Soviet output ... the United ... population ... President ... Nations Food and Agriculture ... Monday ... ...ryone agr... ...so-called ...strain dev... ...national Ri... ...nes. It has ... and a half ...planted by ... in the ... ...holehearts ...4 U.S. off... ...the ric... ...food ... ...

...racle' in Vietnam: New ...Key to Land's Economic

World Rice Product... At Record Hig...

MANILA (UPI) — World production of rice — food for more than one billion people — reached a record high of 193 million tons in 1968, according to the United Nations Food and Agriculture Organization (FAO).

...rice varieties now being ...vated extensively in the Philippines and other Asian countries.

In Manila, Lopez, Philippine vice president and also agriculture secretary, in his address ... delegates, stressed the ... tance of tackling problems ... rice production and trade ... said the cereal was "pr... the kitchen, the ... staple, of more than ... people largely in A... Pacific."

In its position pa... before the confer... ...ippine delegation ... it was able to ... ric tons of lo... rice in 1968 ... followed by ... ply into ... year 1967 ...

The 19... losses ... expected ... said it ... rice to ... ments ... social ...

...rld's population...

(From Page 1)

...0,000 every day, 7.5 ...every minute and 60 ...every year.

...ation and rate of ...ed on data from the ...ns and the U.S. census ...rate of increase reflects ...r births minus the ...

The United Nations Environment Program has estimated that by the turn of the century, one third of all arable land at present will have been destroyed while there may also be two billion more people.

Justin Blackwelder, president of the Fund, said that only dozens of years, ...ps as three successive years of ... will stop the ...

24 scholars train at int... rice research institute,

Dr. Robert F. Chandler Jr., director of the ... Rice Research Institute ... ...ted at Los Baños, Laguna, ...are proud that the training ...program of the institute had ...been ... with the ...cooperation of ... research ...institutes in the Philippines.

The institute's training ...program ... from farming ...families ... the ... ...of the world ...for the guidance ...of ... specialists in all ...fields of rice research ...

...Chandler said ...

IR-8 discovery of this decade

Asia made major economic ... this week ...

The major steel compa... ...nies of Japan announced ...they would ... their ... ...a joint steel venture in ... ...United States in a move ... ...Co. ... ...oil, ...Will ... ...

OUR 20th YEAR OF RICE RESEARCH

On 14 April 1979 the International Rice Research Institute entered its 20th year. The Institute was formally established on that date in 1960 by a group of farsighted, innovative men who recognized the need to match food production with massive increases in population taking place in the tropics. It is fitting that we pay tribute to those farsighted men as we briefly review IRRI's accomplishments in 1979.

Those early progressive leaders fully understood the significance of the rice plant in feeding the world. They knew it was the primary staple food for most of the world's low-income people, especially those in the tropics. And from experience, they were convinced that tropical rice yields would not increase merely by adopting the rice technology of the temperate areas. Only by rice research in the tropics could improved varieties and better technology be developed for the tropical rice farmer. The group envisioned an international research institute, free from the political and geographic constraints of national governments but attuned to the needs of these countries, to take the leadership in doing that research.

The founding members of the IRRI Board of Trustees are listed on a permanent marker at the entrance to IRRI. At the time of this Board meeting in early 1962, a few changes had occurred. Those at the 1962 meeting were (from the left) Dr. V. G. Sinco, Dr. T. H. Shen, Dr. K. R. Damle, Dr. H. Kihara, Dr. M. C Chakrabandhu, Dr. J. G. Harrar, Dr. R. F. Chandler, Dr. B. Gozon, Dr. F. F. Hill, and Dr. P. Garcia. Dr. C. P. Romulo replaced Dr. Sinco on the Board later in 1962.

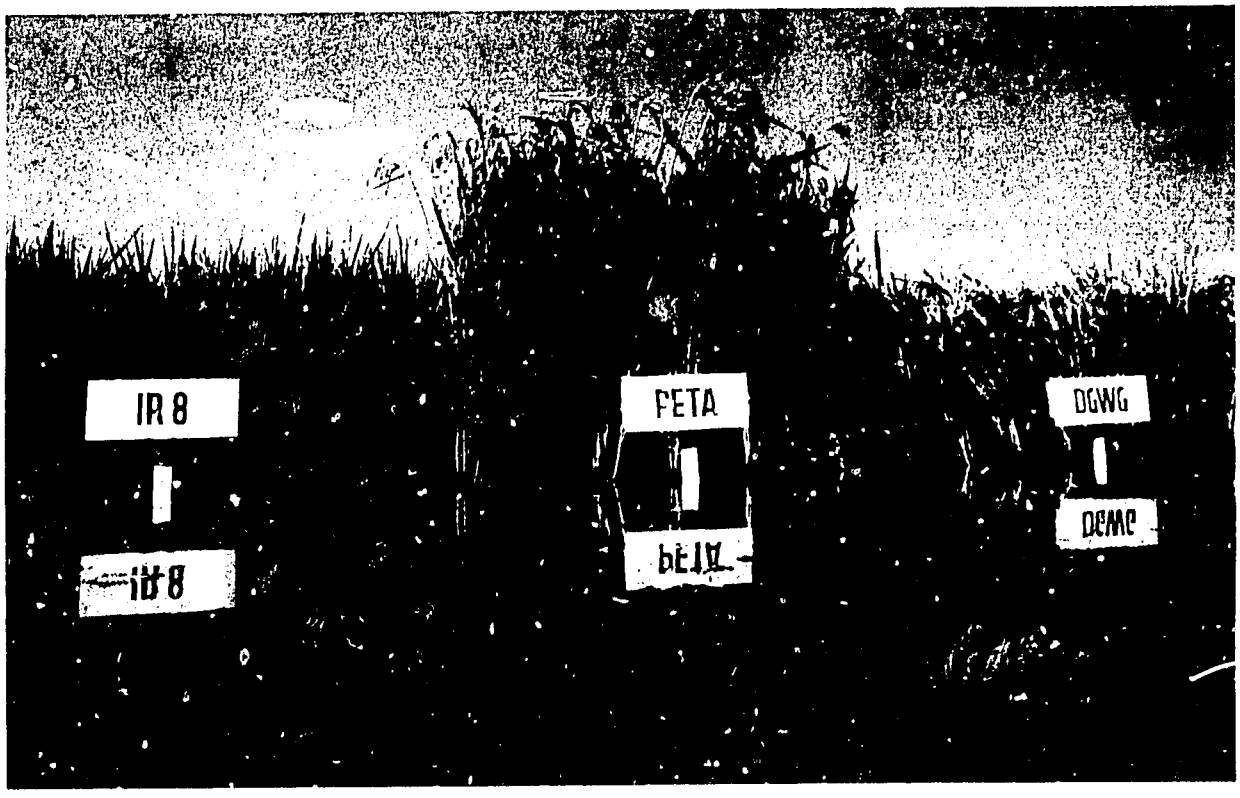
IRRI Director Robert F. Chandler, Jr. (right) and H.M. Beachell (left), the IRRI plant breeder who made the selection of IR8, showed IR22 to United Nations Secretary General U Thant of Burma during his visit to IRRI in 1970.

IR8 was selected from a cross, made in 1962, of the tall traditional variety Peta and the semidwarf variety Dee-geo-woo-gen. In 1972 Dr. Chandler said: "Although many further advances in rice production will be made, probably no other discovery will have such an impact on yield potential as the redesigning of the rice plant from a tall, droopy-leaved, lodging-susceptible one, to a short, upright-leaved one."

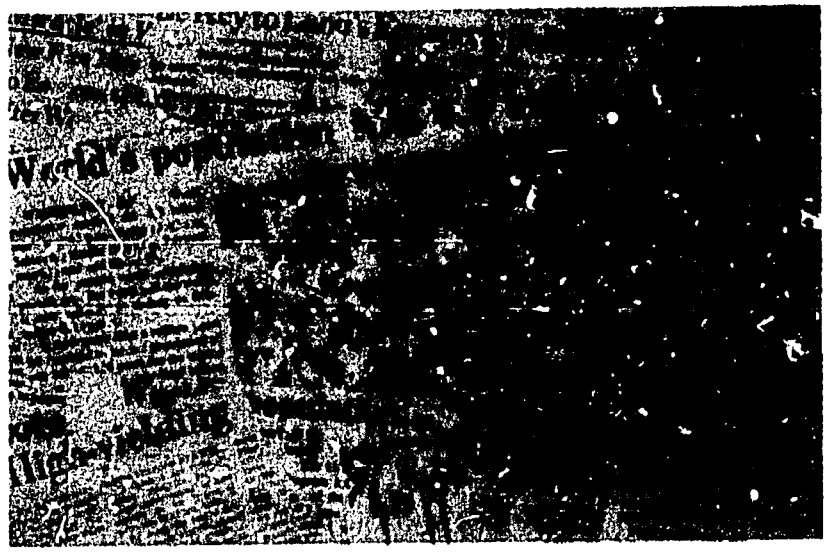
The early success of IRRI is well documented. In only 2 years, the main Institute facilities were constructed and dedicated, and an impressive team of senior rice researchers from around the world had been formed. More than 7,000 rice seed samples had been collected from 65 countries and were being tested. Twenty-four scholars had been invited for training. Under the able and aggressive leadership of Dr. Robert F. Chandler, a truly international research and training effort quickly got under way.

But it was the development of IR8, soon to be dubbed *the miracle rice,* that electrified the rice-growing world and gave evidence of the potential for rice research. For the first time, the tropical farmer had a sturdy, fertilizer-responsive rice with the practical potential of producing yields as high as those of its temperate zone counterparts.

The new rice was short and tough like its *Chinese* father and a high producer like its *Indonesian* mother. Coupled with improved technologies of water management, and fertilizer and pesticide usage, this new variety elevated practical rice production in the tropics to a new level. It was no wonder that terms such as *Rice of the Gods* and *Green Revolution* were soon coined. The vision of IRRI's creators became clear to doubters and supporters alike. Skeptical political leaders and



The early modern rices had an impact on rice production in Asia. But as the 1970s closed, the news headlines still implied problems to come from the food-population balance.



scientists saw the potential in mission-oriented research; soon, companions to IR8 began to appear from national programs. The green revolution in rice was truly under way.

Within a few years, the impact of the new technology was widespread. By 1968, the Philippines, a chronic importer of rice, announced that it had rice to export. The new rices – IR8 and IR5 – joined similar varieties in other Asian countries to help provide rice for populations that were growing at nearly 3% annually. Dr. Chandler's prediction that "the whole face of rice-growing Asia is going to change" was coming true.

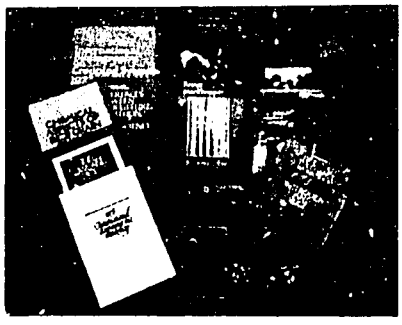
Without the genius and the remarkable successes of those who organized and led IRRI during its formative years, today's rice researchers would be greatly handicapped. The organizers' high standards have left a challenge, not only to their successors at IRRI but to cooperators in national programs as well.

1979's challenges

The challenges to rice researchers and farmers in 1979 have many elements in common with those faced by scientists and rice producers in 1960. Even though worldwide production levels are markedly higher than had been predicted by the pessimists of the 1960s and early 1970s, they barely keep pace with population increases. Worldwide production of rice in 1979 was estimated at only 375 million tons – about 3% less than in 1978, a record year. The sizable production decreases were due to dry weather in India and Bangladesh, and were not fully compensated for by production increases in China, the Philippines, and Korea, and in countries outside Asia. As a consequence, world trade in rice increased in 1979 as did its international price.

Two newspaper reports early in 1980 illustrate the long-term problem we face. On 20 February, the World Food Council reported that world food output declined by 2% in 1979. This gloomy report was followed by an announcement from the Environmental Fund that on 14 March the world population had reached the 4.5 billion mark. Most of the 90 million people added in 1979 live in Asia where 90% of the world's rice is produced and consumed. It is obvious that continued success in rice research and production will be needed.

A collaborative bacterial blight experiment at the Bangladesh Rice Research Institute (BRRI) is checked by T.W. Mew, IRRI plant pathologist (left), and BRRI scientists Abu Taher Mia, Aminul Haq, and Anwar Hossain.



Fourteen major IRRI publications were released in 1979. They serve as a channel for communication of research information throughout the rice-growing world.

Major progress in 1979

The five primary activities that have characterized IRRI's programs continued in 1979:

- *Research* at IRRI headquarters covered problems that cannot be conveniently handled by counterpart scientists in national research organizations.
- *Training* helped develop expertise on research and production methodologies related to the rice plant and to the rice farmer.
- *International networks* expedited cooperation among scientists and educators concerned with rice and rice-based cropping systems.
- *Collaborative research* with scientists from both developed and developing countries improved and extended the capabilities of IRRI scientists to solve rice production problems.
- *Communication* of our findings and those of our cooperators through conferences, workshops, symposia, and through the publication of research findings increased.

Each of these activities required effective cooperation with colleagues in national programs in both the developing and the more developed countries.

International networks

For both research planning and program implementation we continued to rely heavily on networks of cooperating scientists in rice-growing countries, especially in Asia. The major networks through which much of our research is accomplished include:

- International Rice Testing Program (IRTP)
- International Cropping Systems Network (ICSN)
- International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER)

The first INSFFER training course was held at IRRI early in 1979. Each trainee took part in all phases of conducting an experiment relating to fertilizer efficiency – including land preparation.

- International Rice Agroeconomic Network (IRAEN)
- International Farm Machinery Network (IFMN)

The IRTP provides an effective research linkage for the world's rice improvement programs including our Genetic Evaluation and Utilization (GEU) program. In 1978, seventeen types of field nurseries were composed, and one or more types went to scientists in 52 countries.

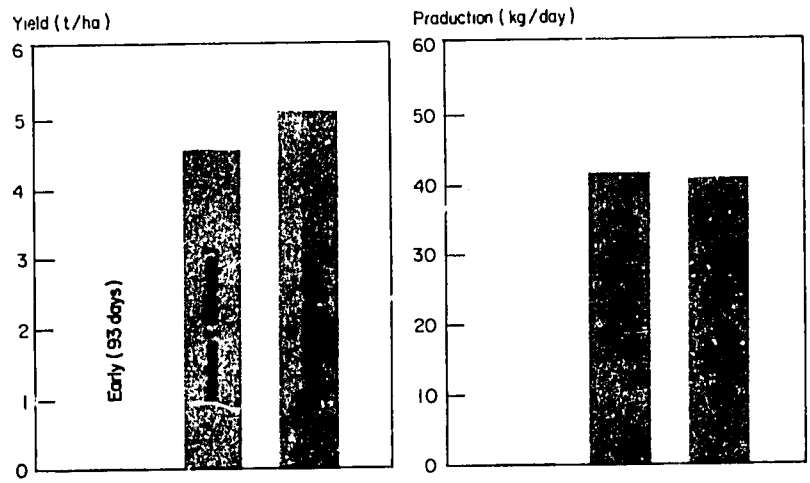
We received data from 431 individual trials of 17 types of 1978 IRTP nurseries. These data were compiled, analyzed, and published in 1979.

The performance of early-maturing rices in yield nurseries was most encouraging. These rices performed almost as well on a per-crop basis as their medium- and late-maturing counterparts (Fig. 1). On the basis of yield per day, however, they produced about 20% more rice than the medium- and later-maturing rices.

The ICSN has research at 22 sites in 8 countries. Fifteen of the sites have rainfed wetland conditions. In addition to these network sites, national researchers in the 8 countries have cropping systems work under way at an additional 27 sites. We expedited communication among these scientists by holding a workshop in Nepal in May, a special workshop for economists, and a cropping systems study tour in October and November.

The INSFFER network, which had been set up initially to determine means of increasing fertilizer efficiency, was broadened to include other aspects of soil fertility and rice production. Experiments on azolla were included and special tests were planned for fertilizing rice in deepwater areas.

The results of the work on constraints, implemented through the IRAEN, were summarized and published. The farm machinery network gave priority to helping manufacturers in



1. The top entries in the international rice yield nurseries were the late-maturing rices. They yielded more per crop than did the corresponding medium- and early-maturing entries. But production per day was higher for the earlier-maturing varieties.

S.S. Virmani, visiting plant breeder from the International Institute of Tropical Agriculture, works with hybrid rice in IRRI plots.

developing countries to test, fabricate, and produce appropriate machines for the small farmer and to training of young engineers at IRRI headquarters.

Collaboration with other centers and research organizations

For several years we have steadily increased our collaboration with rice scientists and educators from other countries. Some of the collaboration is formalized through institution-to-institution agreements. Others are handled on an informal basis, mostly through scientist-to-scientist contacts.

Formal cooperative arrangements have been made to encourage exchanges with institutions and scientists in:

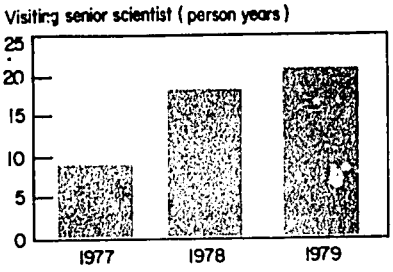
- Burma
- China
- Cuba
- France
- India
- Indonesia
- Philippines
- Thailand
- Vietnam
- Russia

Exchanges of seed, publications, and scientific personnel are expedited through these formal arrangements.

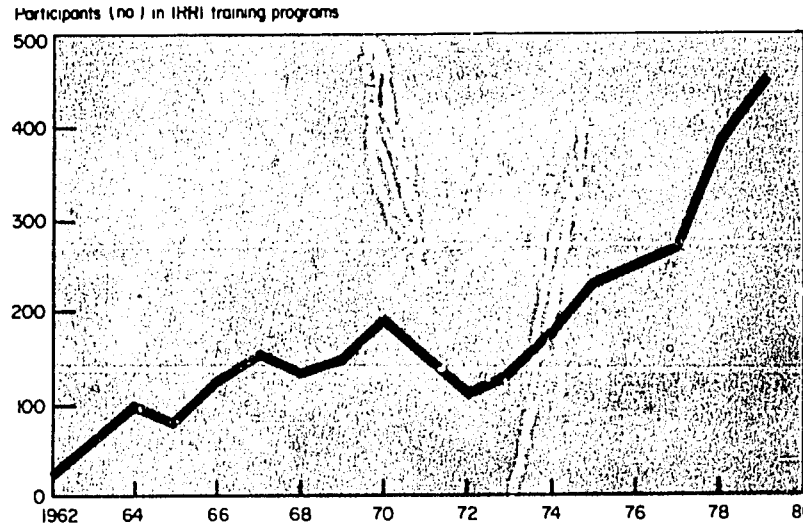
Active cooperation in research with several sister international agricultural research centers and with national counterparts already exists. Such rice research is being accomplished with international and regional centers and with national, state, and private institutions.

- Centro Internacional de Agricultura Tropical (CIAT)
- International Centre for Insect Physiology and Ecology (ICIPE)
- International Fertilizer Development Center (IFDC)
- International Food Policy Research Institute (IFPRI)
- International Institute of Tropical Agriculture (IITA)
- West Africa Rice Development Association (WARDA)
- Boyce Thompson Institute in the United States
- Centre for Overseas Pest Research (COPR) in the United Kingdom
- Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM) in France
- Tropical Agriculture Research Center (TARC) in Japan
- Tropical Products Institute (TPI) in the United Kingdom
- Research institutes in developing countries
- Universities in several countries

Tangible evidence of the cooperation that has been established are the visiting scientists and senior research fellows from these cooperating institutions who worked at IRRI in 1979 (Fig. 2). These cooperators provided more than 20 scientist-years of service at IRRI headquarters. Coming from 11 countries they helped us develop new research methodologies



2. The number of visiting senior scientists including senior research fellows has increased greatly in the past 3 years. These visitors perform sophisticated research while at IRRI, teach new methods to our junior researchers, and continue to collaborate with IRRI when they return home.



3. Number of participants in IRRI training programs has increased sharply since 1972.

and introduced our scientists to other modern research techniques. They participated in our training programs and implemented basic research of importance to IRRI. Furthermore, they provide a linkage for cooperative relations with IRRI when they return to their home institutions.

Training, conferences, and communication

Participation in our training programs, workshops, and conferences in 1979 set new records. More than 425 scientists and educators from 33 countries took part in various training programs – a doubling of participation in 5 years (Fig. 3).

Twelve major workshops and conferences with more than 600 participants were held at IRRI headquarters in 1979. Research planning was a major component of each.

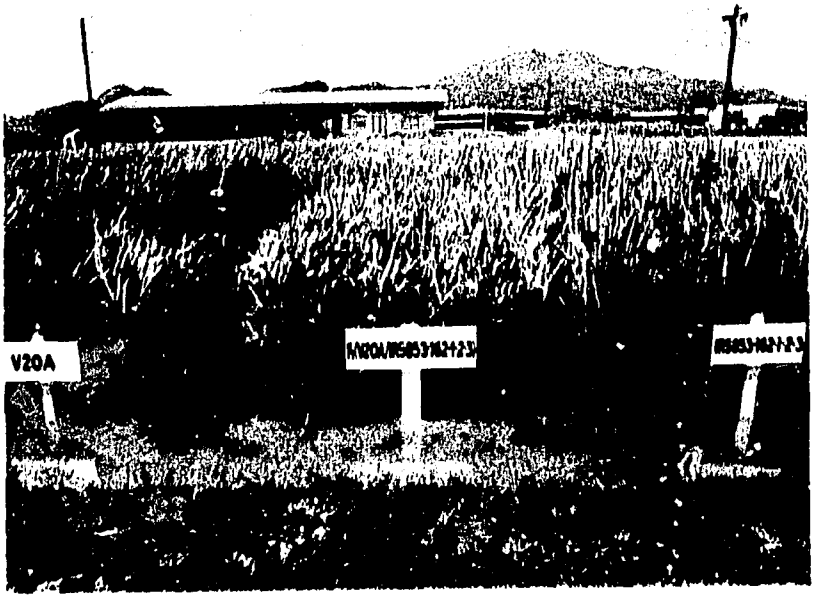
Reports or proceedings of each meeting are published by IRRI. In 1979, eight such books were published and made available to cooperators and to libraries and research centers in the developing countries. These books provide a relatively low cost means of communication among rice scientists around the world.

Small-group discussions are a planned part of each IRRI conference. During these sessions we get answers to the questions "So what?" and "Where do we go from here?" for framing conference recommendations.

Innovative breeding techniques

Research on innovative breeding techniques was greatly expanded in 1979. Our plant breeders and those in national research programs made considerable progress in the last two decades in incorporating genetic resistance to disease and insect pests and tolerance for adverse environmental conditions into modern rices. They have taken advantage of the remarkable genetic variability in the 50,000 accessions found in IRRI's

Hybrid vigor is being tested in IRRI trials. We are taking advantage of the experience of Chinese scientists who have used IRRI varieties as parents for successful production of hybrids in China. The hybrid in the center plot resulted from a cross with V20A as the female parent and IR5853-162-1-2-3 as the male parent.



M.C. Rush, visiting plant pathologist, watches the removal of anthers from developing rice panicles in an IRRI laboratory. Anthers cultured in the laboratory produce callus, which in turn produces a homozygous plant (bottom). When transplanted, the plants grow normally and will reproduce sexually to form populations of genetically identical plants.

germplasm bank and in germplasm collections in national programs. Progress has been made mostly through the use of time-consuming traditional breeding methods.

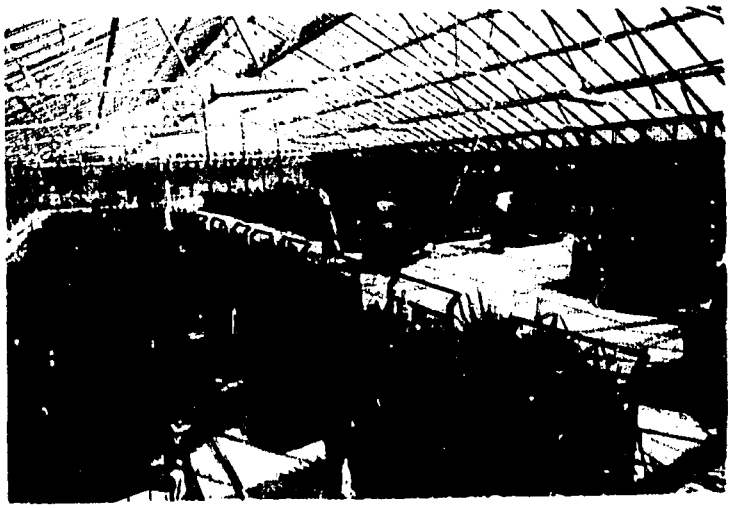
To supplement the traditional plant breeding methods, we started, often in cooperation with scientists in national programs, to test and use techniques for:

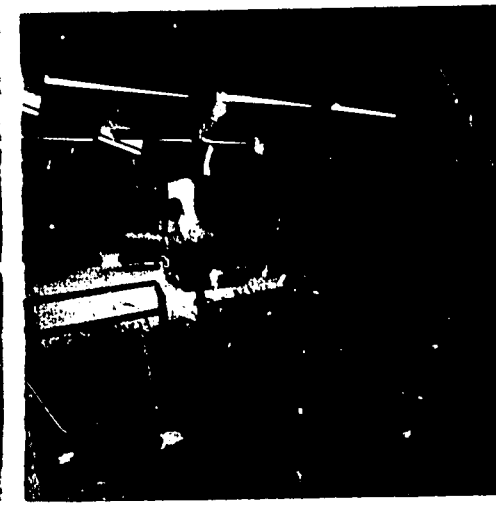
- hybrid rice,
- anther culture,
- mutation breeding, and
- rapid generation advance.

Hybrid rice. Taking advantage of 1970–72 research at IRRI on cytoplasmic male sterility and outcrossing mechanisms, we began to evaluate the heterosis or hybrid vigor of F1 rice hybrids. Utilizing techniques developed by scientists in the People's Republic of China, where hybrids are being successfully produced on about 5 million ha, we made appropriate crosses at IRRI. Fortunately, the IRRI varieties IR24 and IR26 have been used extensively as the fertility restorer parents for hybrids in China.

We already have Chinese scientists working on hybrid rice at IRRI. In cooperation with the Hunan Academy of Agricultural Sciences, we started plans for a special 6-week training course for scientists in other rice-growing countries of Asia. About 1 month of that training will be in China.

Anther culture. We began research on anther culture in 1979, drawing on the expertise of scientists from China, Japan, India, and the United States. Anther culture shows considerable





This special rapid generation advance (RGA) darkroom at IRRI can create artificial day lengths for 205,200 plants at one time. Carts of plants are quickly moved from artificial daylight to the darkroom, thereby reducing the day length and inducing flowering. The RGA system can produce 3 generations a year of day length-sensitive rices that normally would flower once a year. Thus, it cuts the time needed to get an F5 generation from 4 years to less than 2 years.

promise for the rapid development of genetic material with resistance to disease and insect pests and to different environmental stresses such as salt tolerance.

Mutation breeding. We also initiated research on mutation breeding, with the objective of modifying the characteristics, such as height and growth duration, of otherwise suitable traditional varieties. Initial research is being done on tidal swamp rice from Indonesia. The preliminary results look promising.

Rapid generation advance. Using a newly constructed greenhouse-darkroom, we speeded the reproduction of day length-sensitive progeny of crosses made by, or for, our cooperators in national research programs. The new facility grows two or three generations a year of lines that normally produce only one crop annually. In 1979 we grew 293,000 plants from 189 crosses using this technique.

The role of chemicals in pest management

For several years we have placed primary emphasis on host-plant resistance as a means of managing rice pests and we will continue to do so. But the rapid emergence of new races of disease organisms and biotypes of insect pests highlights the need to supplement host resistance with pesticides and other pest management tools. Consequently we sought effective chemical control to complement host resistance.

Several systemic fungicides applied as seed treatments at low rates gave good control of leaf blast for as long as 6 weeks (Fig. 4). The seed treatments were easy and economical. Likewise, we were able to obtain effective control of sheath blight with several chemicals.

4. Treatment of rice seeds with 8 g of a systemic fungicide/kg seed gave good control of leaf blast in 1979 tests.

We evaluated insecticides in the greenhouse and in the field for control of the brown planthopper and found some to be highly effective (Table 1). At the same time, we confirmed earlier observations of serious resurgence of the brown planthopper following treatment with selected insecticides. In some cases, the resurgence appeared to be related to the elimination of parasites and predators by the chemicals (Fig. 5), but for other chemicals the reasons for the resurgence remained obscure. Pesticide use must be a component of integrated pest management, which includes biological control methods as well.

The effect of a naturally occurring chemical on larvae of the corn borer is seen here. The larva on the left was treated with 0.2 µg of the chemical; the larva on the right was not treated.

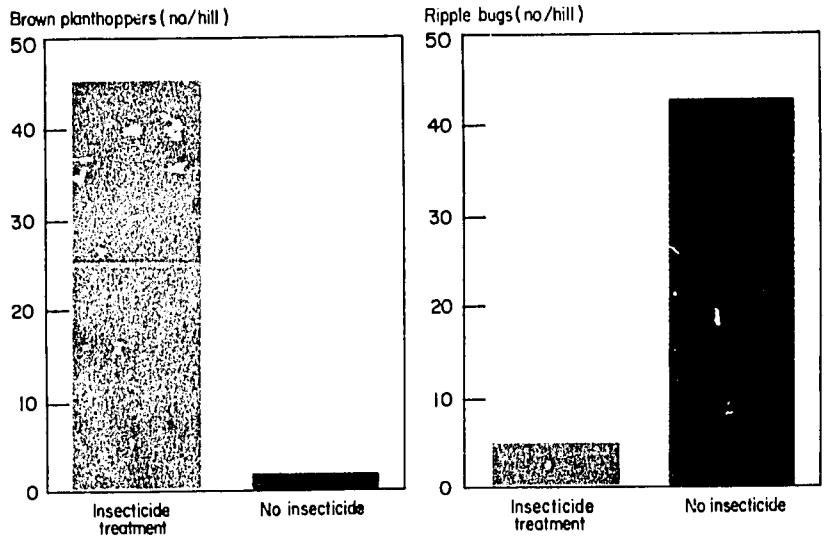
Natural plant products

Research was intensified and expanded in 1979 to ascertain the biochemical basis of varietal resistance to disease and insect pests. Naturally occurring chemicals, which deter oviposition and have juvenal hormonal as well as pesticidal effects were separated from resistant varieties. The compounds are being

Table 1. Several chemicals were effective as foliar sprays in controlling the brown planthopper (BPH). The rate was 0.75 kg active ingredient/ha. IRRI, 1979 wet season.

Chemical	BPH reduction[a] (%)
Perthane	83 a
EXP 5469	75 a
MK 501	71 a
R677	62 a
M8174	−24 b
No treatment	3 b

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

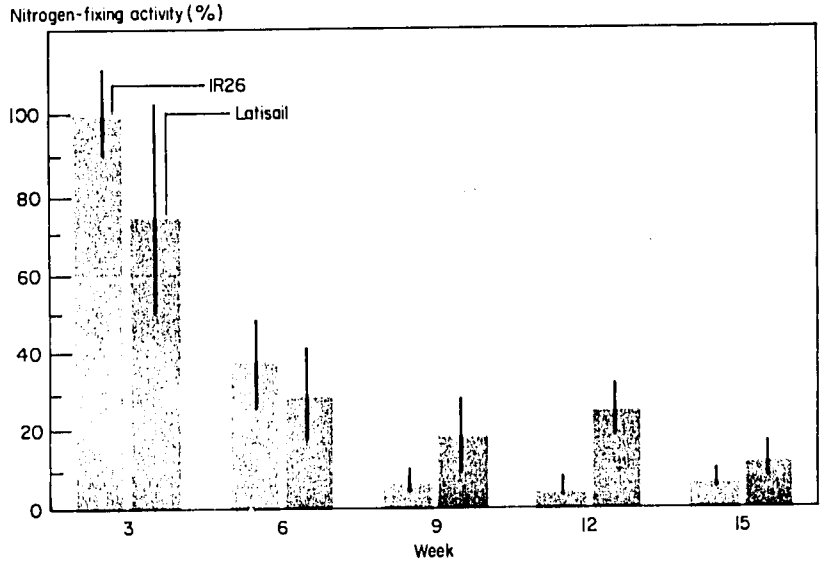


5. Treating a susceptible variety with 0.75 kg diazinon active ingredient/ha followed by 3 sprays of decamethrin at 8 g a.i. resulted in a marked increase in the brown planthoppers and a drastic reduction in the number of ripple bugs, a predator.

characterized and identified, and we will explore their potentials for practical use. By gaining an understanding of nature's defense mechanisms, we should be in a better position to provide the farmer with tools to manage pests.

Naturally occurring chemicals with pesticidal or other adverse effects on both rice insects and disease organisms were also found in plants other than rice. Working in cooperation with scientists from the International Centre on Insect Physiology and Ecology, we extracted from a common indigenous plant chemicals that had adverse effects on the embryo and larvae of the brown planthopper and decreased survival and oviposition of this pest. The same extract also inhibited the growth of pathogens causing several rice diseases.

P.A. Roger (left), visiting soil microbiologist from the Office of Overseas Scientific and Technical Research (ORSTOM) in France, and S.A. Kulasooriya, postdoctoral fellow from Sri Lanka, check an IRRI laboratory study of blue-green algae.



6. The figure shows the N_2-fixing activity of the stems relative to that of intact plants with roots, at various stages of growth in IR26 and Latisail. As the plant grew, the relative rate of N_2 fixation of stems decreased. Latisail showed a higher relative rate of N_2 fixation of the stems. The vertical bars indicate the standard deviation.

Nitrogen fixation and use

We learned in 1979 that nitrogen fixation associated with wetland rice took place not only in the root zone but at the basal part of the shoot as well (Fig. 6). With some varieties, fixation in the basal shoot zone at the early seedling stage exceeded that in the root zone. This may partly account for unexplained nitrogen fixation in wetland soils.

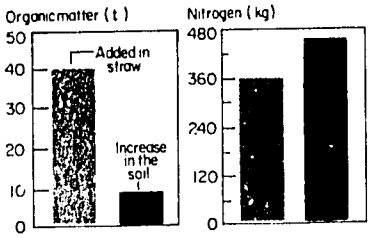
By measuring heterotrophic nitrogen fixation in long-term fertility plots, we learned that past applications of nitrogen, phosphorus, and potassium did not depress nitrogen fixation in the soil but rather accelerated it. In contrast, however, autotrophic fixation of nitrogen by algae was drastically reduced when urea fertilizer was applied to the paddy surface.

Root zone placement of supergranules of urea gave remarkably high apparent recovery of the applied nitrogen. Recovery was lowest from topdressed treatments that farmers commonly applied. Practical means for placing the urea in the root zone are being sought.

The burning of rice straw in the field throughout Asia results in large losses of nitrogen and other elements. Working the straw into the soil can produce significant amounts of additional soil nitrogen.

Nitrogen conservation through soil and crop management

In 1979 we gained further evidence that proper management can conserve nitrogen and make it available for further use by the rice crop. By incorporating rice straw in a field soil, we not only conserved the nitrogen in the straw but obtained an additional increase in soil nitrogen (Fig. 7). Over a 6-year period we incorporated about 360 kg N/ha into the soil as straw. But at the end of the 6 years, the soil nitrogen content had increased to 456 kg/ha.



7. Incorporating straw residues in a rice soil for 6 years gave a dramatic increase in the nitrogen content of the soil – an increase even greater than the nitrogen added in the straw. Other studies suggest that straw may stimulate nitrogen fixation.

In a supplemental greenhouse test, scientists from Boyce Thompson Institute and IRRI found similar results. The increase in soil nitrogen resulting from straw incorporation ranged from 2.2 to 4.0 μg N/g straw added. Extrapolated on a field-crop basis, this suggests a nitrogen increase of 6.6–12 kg/ha per crop. The straw residue may be providing energy for organisms capable of fixing nitrogen.

The practical significance of these findings is apparent. Straw incorporation not only conserves the nitrogen contained in the straw but also brings about an even greater increase in soil nitrogen. This soil nitrogen is important in rice production because two-thirds of the nitrogen taken up by rice plants comes from the soil.

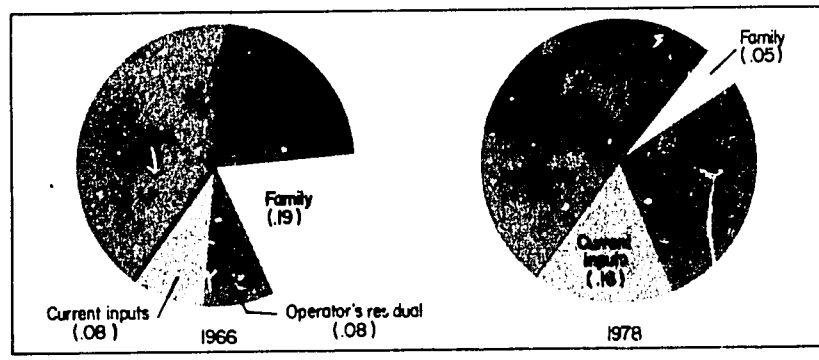
Improved irrigation water management

Studies in the Philippines, Thailand, and Bangladesh highlighted a general inefficiency of water use in irrigation schemes in the tropics. Water use efficiencies were as low as 25–30% in areas where unimproved water distribution and management practices were followed. It was also found that farmers in larger systems tended to have lower water use efficiency than those in smaller systems. This was due to the greater flexibility in the smaller systems and to the farmers' lack of confidence in the ability of the larger systems to provide irrigation water when it is needed.

Consequences of new technology

Hired labor required per hectare increased after the adoption of modern rices and their associated technology. In 1979 we studied data on the labor requirements in a portion of Laguna province, Philippines, that had been similarly surveyed in 1975. The total labor requirement per hectare had not changed appreciably, but hired labor hours increased from 51 to 68, while family labor hours declined from 33 to 17. Hired labor for weeding and other preharvest operations increased while labor for harvesting and threshing declined. The sharp increase in labor for weeding was likely due to the adoption of the system of crop sharing that requires hired labor to weed the crop in exchange for the privilege of harvesting.

We also studied the distribution of the increased earnings among landowners, hired labor, and the farmer and his family (Fig. 8). Due to changes resulting from land reform the landlord's portion of earnings decreased sharply between 1966 and 1978 as did the proportion of earnings for family labor. Hired labor's share increased slightly while much of the increase was from return on current inputs and the operational residual earnings.

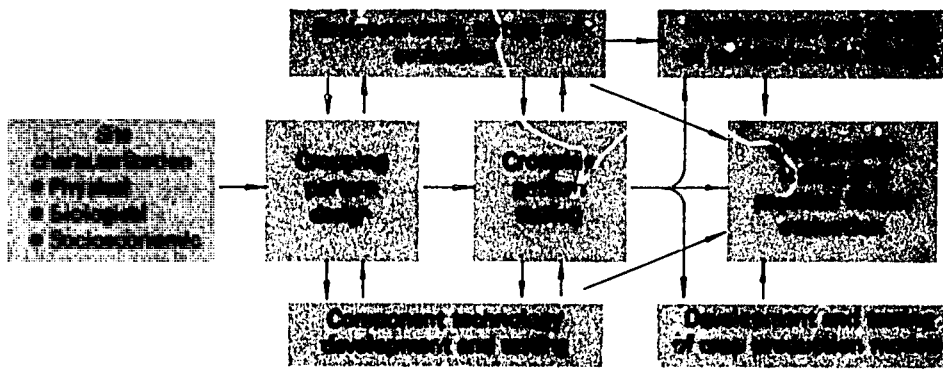


8. Relative share of earnings for rice farms in Laguna province, Philippines. The same farms were surveyed in 1966 and 1978.

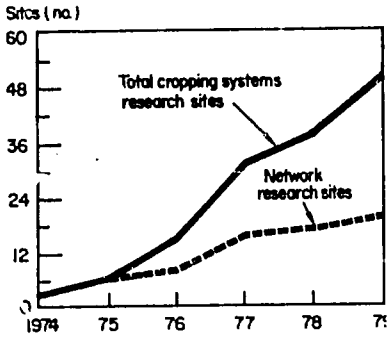
Cropping systems

By far the most significant contribution we have made in cropping systems research during the past 5 years is the development and testing of a farm-based research methodology (Fig. 9). We select sites with probable potential for improved cropping systems and identify their environmental characteristics. Cropping patterns potentially superior to those being used are designed and then tested in farmers' fields. Weaknesses in existing technology and in socioeconomic acceptability are discovered, and research to remove these weaknesses is initiated. The farmer is an omnipresent cooperator, as are representatives of national programs who have the primary responsibility for multilocation testing and for encouraging farmer adoption.

The farm-based research methodology has been adopted by scientists in national research programs (Fig. 10). In 49 research sites in South and Southeast Asia, cropping systems research is



9. A simplified diagram of the on-farm research methodology developed and used by IRRI cropping systems scientists and cooperators in 8 Asian countries.



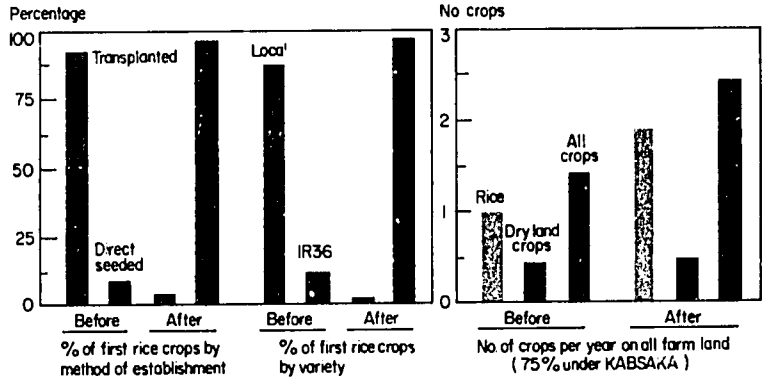
10. The number of cropping systems research sites in 8 cooperating Asian countries has increased dramatically over the past 5 years. About 40% of these sites in 1979 were in the IRRI-established cropping systems network.

being implemented. At 22 of these sites, the research is a component of the research network that we helped establish.

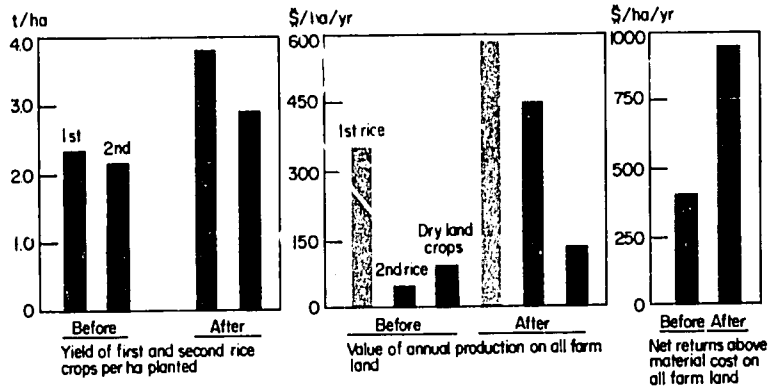
International agencies and donor organizations have studied the research methodology and are increasingly using it in integrated rural development projects or agricultural research programs they sponsor.

The on-farm research pioneered by IRRI staff has led to farmer adoption of early rice crop establishment and to an increase in double rice cropping and overall cropping intensity. The most dramatic results were noted in 9 barrios of Iloilo province, which we surveyed in 1979 – 5 years after the first IRRI cropping systems results were obtained. The farmers had not only adopted improved cropping patterns and increased their cropping intensities but also benefited financially from the adoption (Fig. 11 and 12). They were financially better off. They had paid debts, initiated home repairs, and purchased both household and field equipment. The farmers had responded quickly to the extension-type program not only because it was well presented but because it provided them a new technology that worked and helped them improve their quality of life.

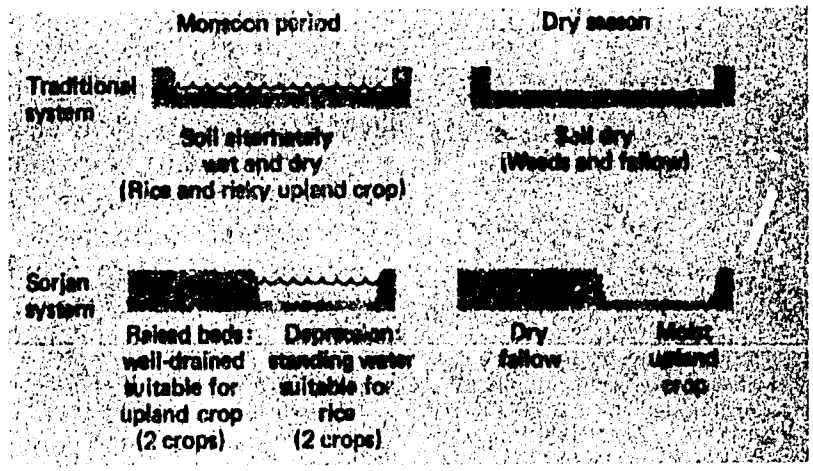
Two innovative intensive cropping systems were studied



11. Under guidance of the KABSAKA program, farmers switched from transplanting a traditional rice variety first crop to dry seeding of the early-maturing IR36. This enabled them to double the number of rice crops grown each year and still grow dryland crops after rice.



12. Increased cropping intensity combined with higher yields led to higher farm production and returns to farm resources. Net income to farm land, labor, and management has more than doubled to about $2300/yr on these 2.5 ha farms.



13. We tested the *sorjan* system used in Indonesia, which permits the production of 2 upland crops on raised, well-drained beds and 2 rice crops in depressions during the rainy season and an upland crop in the depressions during the dry season.

further in 1979. Continuous rice cropping was tried without the use of insecticides to determine if pest buildup would occur. We found instead an increase in natural enemies of the insect pests, which reduced the danger of the buildup of brown planthopper and other rice pests.

The continuous cropping system was tried in several provinces in the Philippines in sites varying from 1 to 365 ha. Yields were generally as good as or better than those produced at IRRI headquarters. One farmer in Batangas province produced 33 t/ha using this system in 1979.

We experimented with the *sorjan* system of raised beds and depressions used in parts of Indonesia (Fig. 13). Yields of 2 upland crops on the raised beds during the wet season were surprisingly high: 5.7 t soybean/ha, 2.9 t mung bean/ha, 9.0 t sorghum/ha, and 100,000 marketable ears of maize per hectare. Net returns per hectare for the upland crops during the monsoon period varied from US$3,100/ha for soybean to US$70/ha for sorghum. Rice yields in the depressions were low (3.8 t/ha) because the crop was grown on exposed subsoil. The preliminary results look very promising as a means of providing upland crops during the monsoon season.

Our insect pest management studies at cropping systems sites showed that:

- Prophylactic pesticide treatments for rice generally did not provide the desired benefit-cost ratio of 2.0 or more in 3 out of 4 years of testing;
- The benefit-cost ratio of pesticides for mung bean was high (3.1 to 17.5), making pesticide usage on this crop most profitable; and
- Insect populations in continuous rice culture with no chemical protection were actually less than those in comparable fields.

Major research results

Genetic evaluation and utilization

Our Genetic Evaluation and Utilization (GEU) program sustained its momentum during 1979, with a tremendous amount of on going research among the multidisciplinary GEU teams. During the year the teams' progress in developing genetic materials for a wide range of environments was reflected in:

- development of new lines for rainfed wetland and dryland areas. These lines combine drought resistance, insect and disease resistance, and other characteristics that make them attractive modern varieties for the farmer without irrigation.
- full use of rapid generation advance facilities at IRRI to grow nearly 300,000 plants from crosses of photoperiod-sensitive rices and get bulk quantities of seed of F3-F5 generations back to cooperators in several countries.
- initiation of the use of tissue culture techniques for varietal improvement.
- selection of 11 varieties from 9 IR lines for use as named varieties in 7 countries, plus release to farmers of 2 new varieties developed by the Thailand-IRRI collaborative project.
- identification of rates at which new biotypes of insects might develop on resistant varieties, and identification of moderate plant resistance as stable and practical for brown planthopper control.
- development of a program for disease race prediction and gene rotation to provide new resistant varieties before new races of a disease develop.
- formal participation of scientists from the People's Republic of China in the International Rice Testing Program (IRTP), and the holding of a workshop and monitoring tour in China late in 1979.

INTEGRATION OF APPROPRIATE VARIETIES

During 1979 drought ravaged much of the rainfed rice crop in a wide arc from eastern India through Indochina, and yield losses of 30% were projected for much of the region. Yet, earlier in the same growing season, many of those drought-struck areas had serious flooding. With such variation and risk, farmers in

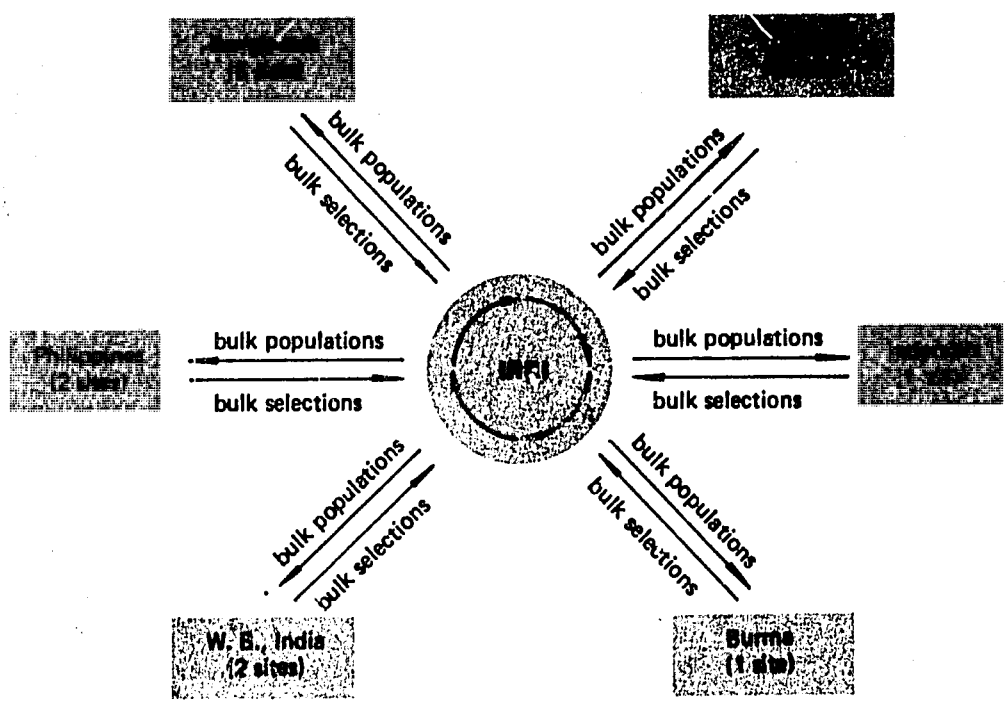
the rainfed areas are reluctant to invest scarce resources in the modern rice varieties – or in any aspect of their improved technology.

For the rainfed wetland areas, appropriate improved varieties must differ greatly from the rices now widely grown in well-irrigated areas. The selling point of modern rices for rainfed farmers will be *yield stability*, not high yield potential, which is the forte of the modern semidwarf rices. Essentially, the rainfed farmer needs a guarantee that regardless of weather he will have some rice to harvest.

Rainfed wetland collaboration

We have developed a collaborative approach that should allow us to identify genotypes with both the obvious (flood tolerance, for example) and less obvious factors that contribute to yield stability for rainfed wetland rice. Our collaborative work in rainfed wetland rice involves a network of rice scientists in six different countries throughout South and Southeast Asia.

Through the network we shuttle early generation breeding material through several national sites (Fig. 1) in sequential years. The parents for the crosses that are selected through the system are chosen by the collaborating scientists. The crosses



1. Breeding material flows through a 6-country network in an international collaborative program on rainfed wetland rice. This breeding system will impart a high degree of yield stability to the rices eventually selected for release to farmers.

are made at IRRI and first distributed to the collaborators in the F2 generation. Outstanding lines that are eventually selected from this system will be distributed for testing in the International Rainfed Lowland Rice Observational Nursery (IRLRON).

Sukumar Mallick of the Chinsurah Rice Experiment Station, West Bengal, India, inspects IR4219-35-3-3 in a multiplication plot. The variety is tall (compared to semidwarf in the background), sturdy (compared to the traditional varieties in the foreground), responsive to nitrogen fertilizer, and tolerant of submergence, and represents a first approximation of the varietal type required for rainfed wetland farmers.

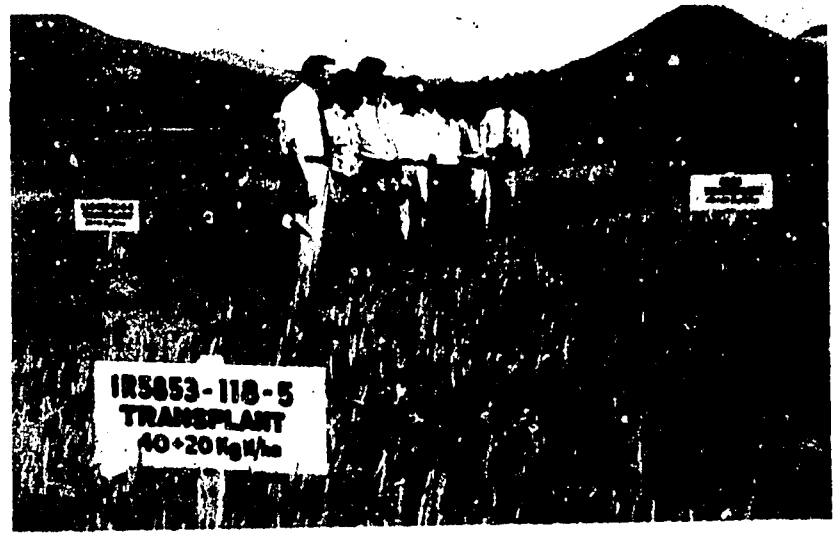
New lines with multiple attributes

Our breeding program for irrigated rice continued to incorporate diverse genes for disease and insect resistance, shorter growth duration, and improved grain quality into new lines. Two new genes for brown planthopper resistance (*Bph 3* and *bph 4*), which convey resistance to all biotypes at IRRI and some other biotypes in South Asia, were added to numerous breeding lines. Many of the lines mature in less than 100 days and yield as well as varieties that mature 2 weeks later. Two recently identified genes for resistance to whitebacked planthopper were incorporated into improved plant types as were genes for green leafhopper resistance.

Numerous breeding lines with intermediate amylose content are available, and we have incorporated genes for aroma into the best improved lines.

Rainfed wetland. In our rainfed wetland breeding program, drought resistance has been combined with multiple disease and insect resistance and resistance to other physicochemical stresses. An outstanding example is IR5853-118-5 (Fig. 2), which is highly resistant to drought and also has all the other characteristics that make the modern varieties attractive.

Dryland rice. IR6115-1-1-1, from the cross IR1529-680/Moroberekan, yielded more than 4 t/ha for 3 consecutive years in dryland replicated yield trials in a farmer's field in Batangas



2. IRRI Director General N. C. Brady and some of the GEU team scientists that worked to develop IR5853-118-5 check its performance in long-term fertility plots at IRRI. To Dr. Brady's left are S. K. De Datta, agronomist; W. R. Coffman, plant breeder; T. T. Chang, geneticist; J. S. Nanda, plant breeder; S. Yoshida, plant physiologist; and M. D. Pathak, director, research and training coordination.

province, Philippines. This line has an elastic growth duration (which increases its tolerance for drought) and good recovery ability (which means it can benefit from the late rains). IR6115-1-1-1 is highly resistant to bacterial blight and has exhibited some resistance to blast and biotypes 1, 2, and 3 of the brown planthopper.

Among the breeding lines for dryland farmers IR5260-1 and IR5931-110-1 are early maturing and perform well in relatively dry conditions; both lines recover well from drought. Another line, IR5716-18-1, reacts early to drought stress by rolling its leaves, but it has excellent resistance at the reproductive stage. In a test where severe stress occurred at the reproductive stage, this line was one of the few entries that produced grains.

IR50, which is highly resistant to tungro disease, shows its resistance in the green and healthy plants at the center of these tungro test plots in Zamboanga del Sur, Philippines. IR50 was named and released to farmers in late 1979 by the Philippine Seed Board.

IRRI lines named in national programs

Eleven varieties from nine IRRI lines were named in national programs in 1979 (Table 1). That brought the number of national varieties named from IRRI sources to 75. Eleven varieties named directly by IRRI prior to 1975 makes the grand total 86.

- Sinshwethwe, released in Burma, and IR34, released in India for Tamil Nadu state, are identical to IR34, which was first named in the Philippines in 1975.
- IR36, which is identical to its Philippine counterpart, is recommended for the dry and wet seasons in Orissa state, India.
- Rajinder Dhan 201 is a high yielding variety with excellent grain quality and resistance to bacterial blight. It is recommended for areas with good water control in Bihar state, India.
- Laxmi and Sabitri have multiple disease and insect resistance, short growth duration, and excellent grain quality. They are recommended for the terai region of Nepal.
- IR1529 is a medium-duration variety with very high yield potential. It was released in Niger and Upper Volta.

Table 1. Seven countries in Asia and Africa named IRRI lines as varieties in their national rice production programs in 1979.

Variety name given	IRRI line	Where named
Sinshwethwe	IR2061-213-2-17	Burma
IR34	IR2061-213-2-17	India
IR36	IR2071-625-1-252	India
Rajinder Dhan 201	IR579-97-2-2-1	India
Laxmi	IR2061-628-1-6-4-3	Nepal
Sabitri	IR2071-124-6-4	Nepal
IR1529	IR1529-680-3-2	Niger
IR48	IR4570-83-3-3	Philippines
IR50	IR9224-117-2-3-3-2	Philippines
IR2053	IR2053-206-1-3	Sudan
IR1529	IR1529-680-3-2	Upper Volta

• IR48 was the first IRRI line with intermediate amylose content to be named in the Philippines. It has medium growth duration (135 days) and multiple disease and insect resistance.

• IR50 is a very early-maturing variety (107 days) with multiple resistance to diseases and insects. It is resistant to the tungro virus in southern Philippines, where IR36 and other widely grown varieties have become tungro susceptible.

• IR2053 has intermediate stature and long slender grains. It is the first rice variety to be named in the Sudan.

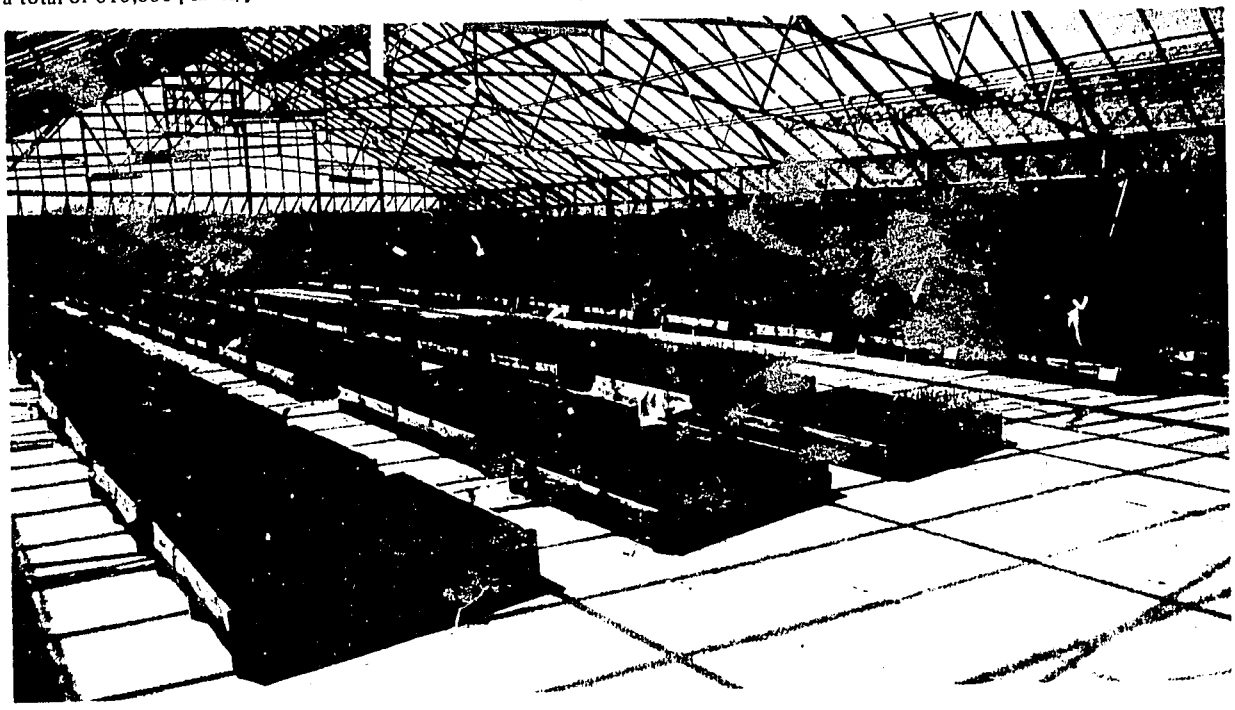
Rapid generation advance for photoperiod-sensitive rices

Breeding to improve photoperiod-sensitive varieties for flood-prone, rainfed rice areas has been neglected, mostly because those rices take much longer to develop than the photoperiod-insensitive varieties – which include the modern high yielding varieties.

We used a rapid generation advance (RGA) system to grow two to three generations of crosses in a year. Thus, to get from F2 to F5, which normally takes 4 years, RGA shortens the time to 1–2 years. RGA is especially useful with photoperiod-sensitive crosses because they produce only one generation a year in the field.

Almost 293,000 plants involving 189 crosses from F2 to F5 generations were grown in our RGA facilities in 1979 (Fig. 3). Crosses of cold-tolerant rices were included. Most of the crosses were made by cooperators in Thailand, India, Sri Lanka, and

3. Rapid generation advance (RGA) greatly shortens the time required to develop photoperiod-sensitive varieties for rainfed flood-prone wetland areas. This RGA facility at IRRI can accommodate 205,200 plants/planting, which is equivalent to 1.3 hectares or a total of 616,000 plants/year.



Bangladesh, but certain crosses were made by IRRI at the request of plant breeders from these and other countries. We provide bulk quantities of seed of the F3 to F5 generations of the photoperiod-sensitive materials to the cooperators who made the original crosses, or to scientists in any other interested national program.

Mutation breeding

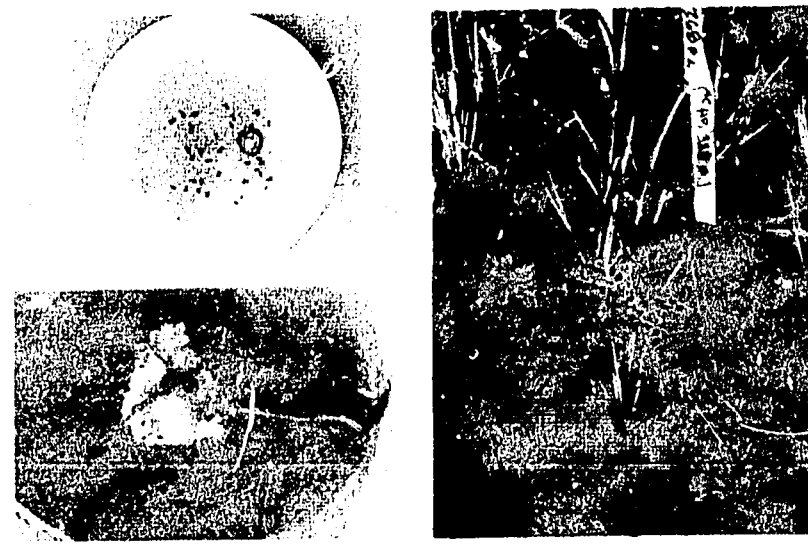
Many traditional rices throughout the world are highly adapted to areas where the modern semidwarf rices fail. But many traditional rices have low yield because they are excessively tall and take very long growth periods. Through chemical mutation we were able to decrease the height and shorten the growth duration.

We treated the Indonesian tidal swamp varieties Siyam Halus and Siyam Kuning with the chemical mutagen ethyleneimine and identified both early and short-statured mutant derivatives (Fig. 4). The variety Intan, which has a relatively long growth duration but is otherwise well adapted to medium elevations, was also treated. Some attractive, early-maturing mutant derivatives were recovered. The Siyam Halus and Siyam Kuning derivatives will be tested in the tidal swamps of Kalimantan during 1980, and the Intan derivatives will be tested in selected medium-elevation areas.

Innovative breeding – tissue culture

Anther or pollen culture produces normal rice plants that are homozygous and will reproduce sexually to form populations (lines) composed of genetically identical individuals. Using the technique, rice breeders can make conventional crosses and

4. M. Mahadevappa, IRRI postdoctoral fellow (right), examines early-maturing chemically induced mutant derivatives of Siyam Halus, a photoperiod-sensitive variety grown in the tidal swamps of South Kalimantan, Indonesia. These early derivatives should result in more productive cropping systems in the tidal swamps.



5. Three stages in tissue culture experiments to produce homozygous plants from anthers from F1 plants at IRRI during late 1979. Callus is produced by pollen growing from the side of an anther (left). A haploid plant grows from the callus (middle) and the plants are later transferred to nursery beds (right). From pollen selection to transfer of 20- to 30-cm plants takes about 60 days.

produce F1 hybrid plants. By plating anthers from the F1 plants, the breeders establish genetically homozygous lines (Fig. 5), which can immediately be screened for resistance to pests, or tolerance for nutrient deficiencies or toxicities, salinity, drought, or other plant-growth constraints. Plants within lines are also homozygous for maturation, height, grain quality, cold tolerance, photoperiod response, and other agronomic and physiological characteristics.

Tissue culture research for rice was a key topic at our 1979 International Rice Research Conference. Rice researchers in China, India, and Japan pioneered in tissue culture work in Asia. In September 1979 we began a series of experiments to evaluate the applied aspects of rice tissue culture research as it relates to varietal improvement. The initial work sought rice germplasm with high inherent capability to produce callus and homozygous plants through anther culture.

Seventy-four varieties and breeding lines from the hybridization block were evaluated for such capability. Fifty-five of those cultivars produced from 2 to 40 calluses from different pollen grains in each anther that produced callus. Plants produced from callus of several of the cultivars tested were successfully transferred from a tissue culture medium to soil in screenhouse beds.

AGRONOMIC CHARACTERISTICS

We now have rices with very short growth duration and high yield potential that will meet an increasing demand by Asian farmers. We evaluated several hundred entries with a growth duration of less than 100 days in 1979 replicated yield trials.

Table 2. Eleven early-maturing entries in the 1979 replicated yield trials had daily yields higher than those of the popular IR36.

Selection	Cross	Growth duration (days)	Yield (t/ha)	Yield (kg) per field per day[a]
IR9752-71-3-2	IR28/Kwang-Chang ai//IR36	99	5.08	66.8
IR9729-67-3	BG34/IR28//IR36	99	4.57	60.1
IR19728-9-3-2	IR8608-298-3/IR10179-23	98	3.99	53.2
IR19743-25-2-2	IR9129-192-2/IR10176-79	98	4.12	54.0
IR19743-46-2-3	IR9129-192-2/IR10176-79	98	3.99	53.2
IR19746-28-2-2	IR9129-192-2/IR10183-7	98	4.20	56.0
IR13204-3-3-3	IR28/CO39//IR36	98	4.52	60.2
IR19795-17-3-2	IR9703-41-3/IR10185-68	98	4.35	58.0
IR19819-31-2-3	IR9715-4-2/IR10176-79	98	4.29	57.2
IR9708-51-1-2	ADT26/IR1561-228-3//IR28	98	3.99	53.2
IR10179-2-3-1	IR747B2-6-3-2/Ai-nan tsao 1	93	3.66	52.3
IR36	IR1561-228-1//IR24[4]/*O. nivara*/// CR94-13	109	3.81	44.3

[a]Does not include 23 days in the seedbed.

Out of 368 entries in the wet season, 47 or 12.7% matured in less than 100 days. Many of them matured 10–15 days earlier and yielded as well as or slightly better than IR36 (Table 2).

Nitrogen response of irrigated and rainfed rice

We evaluated 36 varieties and breeding lines in nitrogen response trials at IRRI and at 3 Bureau of Plant Industry stations in the Philippines. IR42 continued its superior performance, but IR48 performed equally well. IR50 performed well at all sites and was the highest yielding entry at the Visayas Rice Experiment Station, Iloilo. Other promising selections that performed well were IR5853-162-1-2-3, IR9129-209-2-2-2-1, and IR4568-86-1-3-2.

In trials as irrigated crops in a farmer's fields, IR42 and IR48 were the highest yielding entries during the wet season. IR46 was the highest yielding entry during the dry season.

Twelve entries at IRRI plus eight in farmers' fields were evaluated as a rainfed crop. IR9217-58-2-2, closely followed by IR48 and IR42, had the highest yield at IRRI. In farmers' fields IR13419-113-1 and IR42 were the best performers.

Sources of semidwarfism

Because most of the short-statured high yielding rice varieties were derived from Dee-geo-woo-gen or another Chinese dwarf, we continued to seek new genetic sources to maintain the short stature and to broaden the genetic base. During 1979 we evaluated 36 F2 populations that involved a new semidwarf or dwarf source, and a tester that has the recessive dwarfing gene from Dee-geo-woo-gen. In each of 10 dwarf/semidwarf crosses,

The ability of a variety to consistently and productively ratoon will be a valuable asset in many rainfed cropping systems. Differences in ability to ratoon are seen here. IR9852-19-2 (left) had outstanding ratoon growth (rated 2 on a 1-9 scale) following harvest of the main crop. The relatively poor growth of a sister line in the adjacent plot (rated 8) suggests genetic differences in the ability to ratoon.

the F2 plants showed distinct segregation, indicating different height genes. Among 26 semidwarf/semidwarf crosses, 5 distinct sources were found.

Ratooning ability

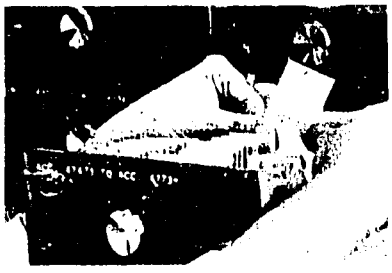
When the stems of a rice plant are cut at harvest, a ratoon, or regrowth, may occur. For some varieties proper management may produce a ratoon crop within 60 days after harvest of the main crop and yields may exceed 2 t/ha. Ratooning of rice as a crop is a common practice in some countries. With appropriate varieties, it might be useful in many rice-based cropping systems in Asia. During the 1979 wet season we evaluated the ratooning ability of nearly 2,000 varieties and breeding lines in our replicated yield trials and observational yield trial. The tests involved an extraordinary effort to treat each plot in a uniform manner after harvest of the main crop. Although the main crop had sheath blight, 303 cultivars were excellent ratooners and 139 of them exhibited synchronous flowering.

GERMPLASM CONSERVATION AND DISSEMINATION

As the high yielding modern rices spread into areas previously planted to traditional varieties, the world faces the threat of these old gene-rich rices being lost forever. Although traditional varieties have a generally low yield potential, they are rich in genes that provide tolerance for pests or adverse growing conditions.

Field collections

To conserve the world's irreplaceable traditional rices, we continued to collaborate with different Asian countries. A



Our germplasm bank continued to provide a large volume of seed samples to IRRI and other scientists. During 1979 it supplied about 26,700 samples of O. sativa *for various GEU tests at IRRI. About 3,700 samples of the Asian cultivars, 688 samples of wild species, 270 African rices, and 128 genetic testers were sent to rice workers all over the world.*

sixth joint venture with Sri Lanka essentially completed a canvass of the local germplasm in major production areas. Intensive collection was also implemented in germplasm-rich areas of Bangladesh and Indonesia's Kalimantan Island. East Kalimantan was explored by a collection team for the first time. Local workers, with our technical or financial assistance, or both, collected rices in remote areas of Bangladesh, India, Indonesia, the Philippines, Sri Lanka, and Thailand.

Since 1972 we have directly collaborated in the collection of about 10,000 seed samples from farmers' fields in 7 Asian countries. At the same time we assisted 7 other countries in gathering 33,000 samples. Our germplasm bank now holds 47,743 registered accessions of the Asian rices plus about 9,500 unregistered samples.

Seed longevity patterns checked

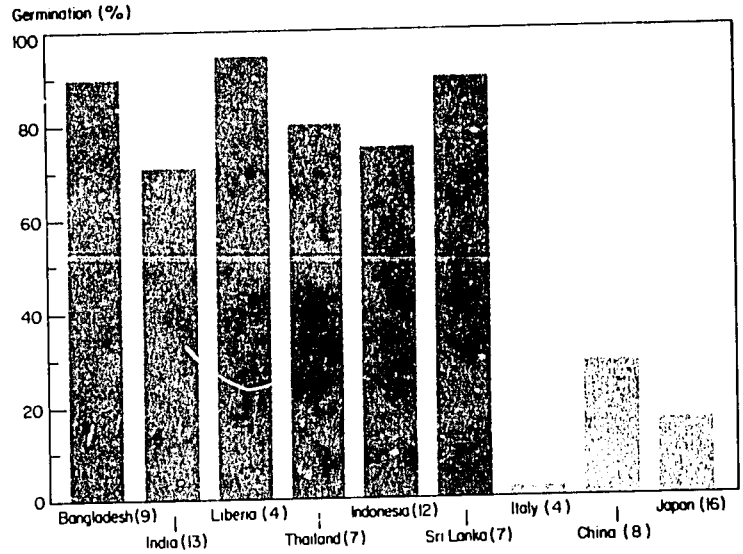
The collected rices that go into the germplasm collection represent diverse backgrounds, and have different seed longevity patterns. Several years ago we found that varieties with strong grain dormancy had a high viability level (94–96%), but a nondormant variety's viability dropped rapidly to 63% after 8 years of storage at 2–4°C.

During 1979 we tested a large number of 3.5-year-old seeds in short-term storage (19°C) and found even more striking differences in longevity (Fig. 6). The test results suggest we must closely monitor different types of seeds in storage and devise appropriate seed rejuvenation schedules.

COMPUTERIZED DATA MANAGEMENT

Computer-based data management allowed IRRI scientists and their collaborators in national and network programs to handle about 20 million computer records in 1979.

We added 2,233 registered accessions of *O. sativa* to the IRRI germplasm computer data bank and updated the data bank with 133,157 new records. At the end of 1979, the bank contained 1,448,027 records representing all existing information on the 38 basic morphoagronomic characters and the 37 GEU traits of 40,768 rices in the collection. A computer program for sorting



6. Viability patterns of 3.5-year-old seed samples of different origin in short-term storage (19°C, 50% relative humidity) at IRRI, 1979 wet season. The varieties that lost viability fastest were nondormant japonica rices from temperate-zone countries; the highly viable samples were indica varieties from high-rainfall areas in the tropics. The bars represent mean viability for the number of samples in parentheses after a country name.

the germplasm data bank based on the alphabetical-numerical arrangement of the variety names was developed in 1979. It provided our GEU scientists an alternative to use of accession numbers for visual searching for desired accessions and greatly facilitates their work.

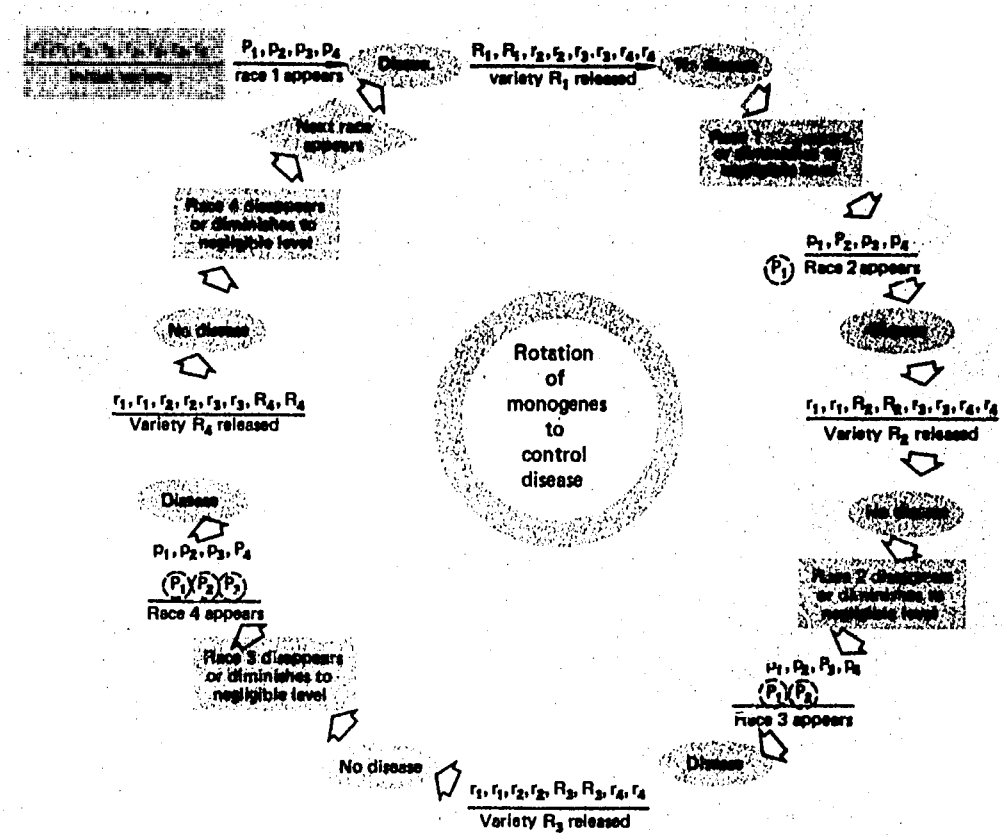
We developed a computerized data management system to handle data generated in the International Cropping Patterns Monitoring Project of the Asian Cropping Systems network. These data consist of both the environmental factors and the performance of the cropping patterns at each test site. About 250,000 records of such data collected from the outreach sites in Iloilo and Pangasinan, Philippines, for crop years 1975–79 are in our computer files.

DISEASE RESISTANCE

Disease as a limiting factor in attaining stable, high rice yields has become increasingly obvious during the 20 years that IRRI scientists have devoted to intensifying rice production and increasing rice yields. The inherent variability of rice pathogens and their ability to adapt to attack the modern high yielding rice varieties were obvious in 1979. Bakanae was epidemic in the Philippines and threatened the existence of IR42 in Luzon and Mindanao. Tungro and bacterial blight were epidemic in several Asian countries, and around the world rice varieties formerly resistant to blast were repeatedly found to be susceptible.

Control of new pathogen races

Horizontal and monogenic disease resistance are two types of resistance available in rice. Monogenic resistance, when it is



7. This diagram shows a proposal for race prediction and gene rotation to keep development of new disease-resistant varieties for farmers ahead of the development of new races of disease organisms. Follow the diagram by starting with the release of variety R_1 (top).

effective, provides complete protection from disease. Horizontal resistance is not effective when epidemics occur, but it can provide protection against loss from diseases in non-epidemic conditions.

To capitalize upon the total freedom from disease conferred by monogenic resistance, we proposed a program of *race prediction* and *gene rotation* in 1979 (Fig. 7). Steps in controlling the evolution of new pathogen races by race prediction and gene rotation in a disease management system follow:

1. Identify the monogene for resistance that is effective against races of the pathogen present in a specific cropping area.

2. Use the monogene for resistance (identified in step one) to develop varieties of each agronomic type required for the

specific cropping area and release these varieties for farmer use. This will reduce, and possibly eliminate, the presently occurring races in the cropping area.

3. Test the resistant monogene at sites remote from the specific cropping area concerned, primarily through the International Rice Testing Program. The race of the pathogen that overcomes the monogene in one or more of the remote areas will be representative of the race that will eventually evolve in the cropping area following the introduction of the new varieties containing the monogene (step 2 above).

4. Identify, based upon results obtained from the testing program (step 3), a monogene for resistance to the race predicted to occur in the cropping area and use it in the variety development program.

By the time the predicted race develops, new varieties containing the monogene for resistance should be available for distribution to farmers, and the cycle continues.

Genetics of resistance and pathogenicity

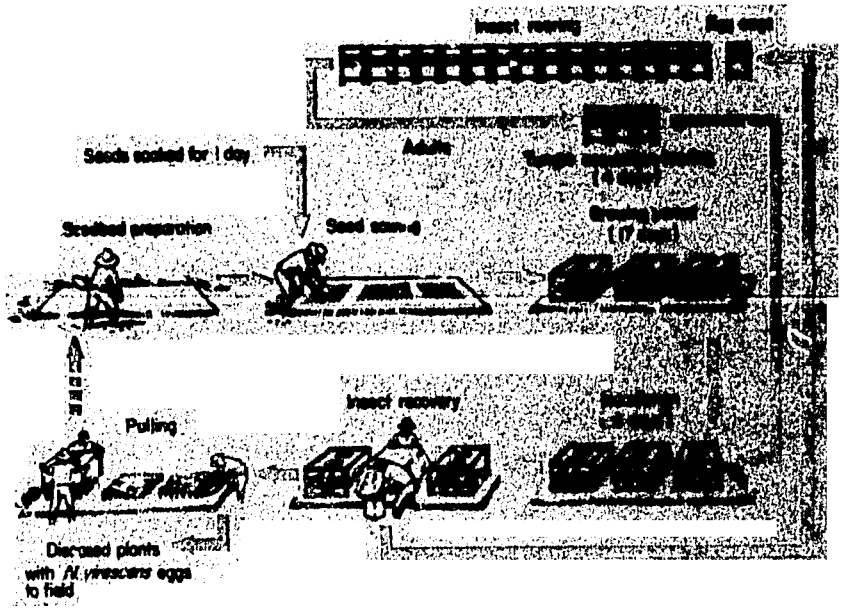
An essential component of all disease control programs based upon plant resistance is the identification of genes for resistance in the rice plants. We have identified monogenic resistance in rice that is effective against blast, brown spot, narrow brown spot, leaf scald, bakanae, and bacterial blight.

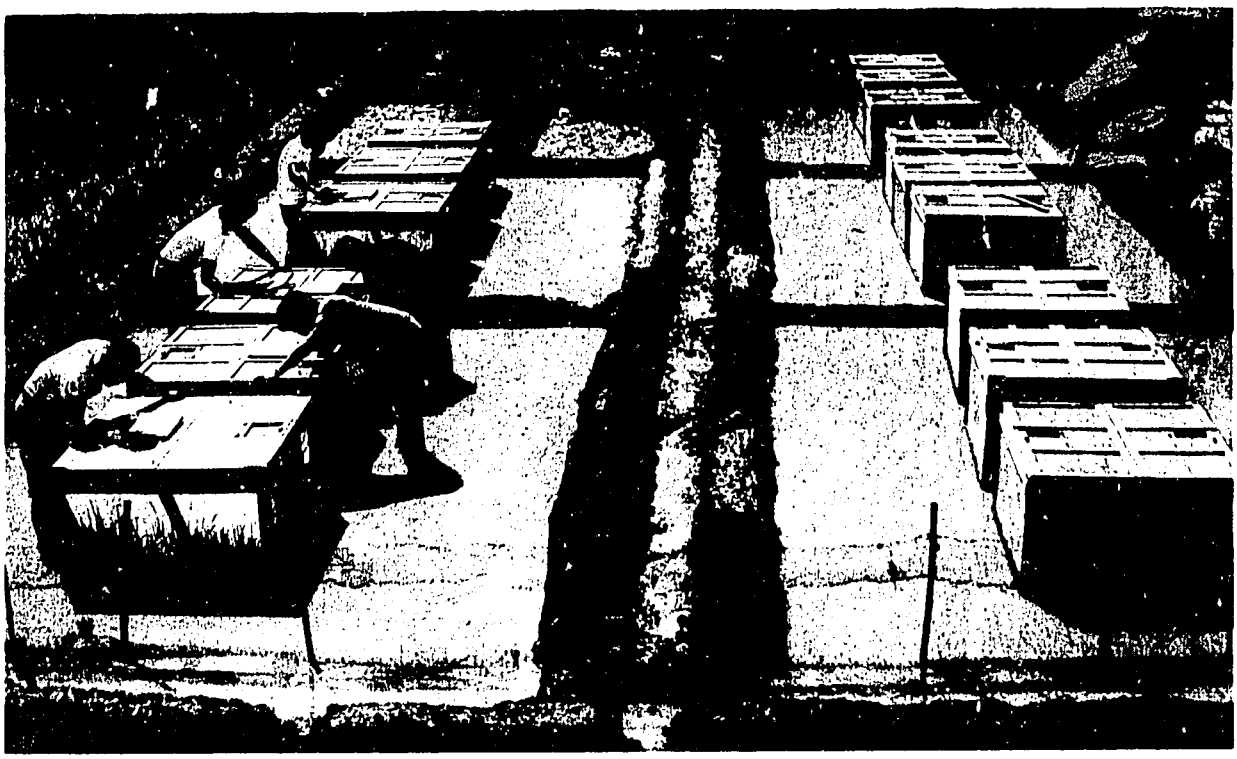
Fungus diseases. We developed new inoculation techniques for use in studying the genetics of resistance to blast, brown spot, narrow brown spot, leaf scald, sheath rot, and bakanae. Resistant and susceptible parental lines were identified, crosses made, and tentative pathogen races identified for each of the diseases. Four monogenes controlling resistance to specific races of blast were tentatively identified and evidence for the existence of several others was obtained.

Bacterial blight. We had preliminary evidence in 1979 of a new monogene for resistance to bacterial blight. In 38 of 43 varieties tested, resistance was governed by a dominant monogene allelic to *Xa 4*. Resistance in five varieties was conferred by a recessive monogene, three of which were allelic to *xa 5*. In the variety Khao Lay Nhay the recessive monogene was nonallelic to *xa 5* and its allelic relationship with *xa 8* is being evaluated.

Virus diseases. A method for propagating tungro-infected rice seedlings and tungro vectors was developed. The method (Fig. 8) involves:

- rearing tungro vector *Nephotettix virescens* with Taichung Native 1 (TN1) plants as feeding material and source of a constant supply of viruliferous insects,
- raising TN1 seedlings in seedbeds covered with cages,





8. These cages cover seedbeds on which viruliferous insects are released to inoculate the seedlings with tungro. Nearly 700,000 tungro-inoculated seedlings were produced for IRRI plant breeders' use in 1979. The production c[illegible] insects and seedlings is [illegible] (top).

- inoculating the seedlings by releasing viruliferous insects into the cages, and
- transplanting the seedlings in field plots after they have been exposed to the viruliferous insects.

This method produces 30,000 seedlings containing *N. virescens* eggs weekly, 90% of which are infected with tungro.

About 64% of the nymphs developed are capable of causing tungro infection. From April to November 1979, we supplied a total of 697,000 inoculated seedlings to the IRRI plant breeders for use in the pedigree and rice tungro virus nurseries.

In an IRRI greenhouse, we tested 9,688 entries for resistance to tungro and 5,393 for grassy stunt. Basmati and Habiganj DW8 consistently showed a low percentage of tungro infection. Field scoring of the tungro reactions of 43,793 entries, including 2,625 entries in the rice tungro virus nursery, was done at Molave, Zamboanga del Sur. Among the entries, 471 had a score of 3 or lower.

Breeding for tungro resistance

In the dry season of 1979 tungro was reported in farmers' fields in Mindanao. Some fields were totally infected. IR36 and IR42, which were bred as tungro-resistant varieties, had severe infection.

Both varieties have the PTB 18 source of tungro resistance, which proved effective during the severe tungro outbreak of 1972–75. But in the 1979 outbreak the PTB 18 resistance was not effective against tungro in Mindanao.

During June–October 1979 we tested all the entries of our replicated yield trials in a farmer's field in Zamboanga del Sur, Mindanao. The incidence of tungro was so high that many farmers' fields in the area were abandoned. Among 400 entries, 123 were resistant, 10 were moderately resistant, 13 were segregating, and 254 were susceptible. All entries originating from crosses involving PTB 18 were susceptible. However, we found many resistant lines and varieties (including IR29 and IR34), which originated from crosses involving Gam Pai 15 and Pankhari 203. Whether the change in tungro resistance is due to a change in the virus or the vector is not clear. Gam Pai and Pankhari sources are still highly resistant, and many elite lines involving them as parents remain resistant. One highly resistant line, IR9924-117-2-3-3-2, was recommended for varietal status by the Rice Working Group of the Philippines, and seed distribution to seed growers in Mindanao started.

Screening for disease resistance

We screened a total of 208,656 lines and varieties for resistance to 11 diseases in 1979, and several new sources of resistance to bacterial blight, blast, bakanae, brown spot, narrow brown spot, leaf scald, sheath rot, tungro, grassy stunt, and ragged stunt were identified. Nearly 7,000 varieties and lines were screened for sheath blight, but no good source of resistance was found.

INSECT RESISTANCE

Although wide-area insect attacks subsided somewhat in the rice-growing regions of Asia in 1979, the potential for crop devastation by insects remained high. Most rices widely grown by farmers still lack resistance to one or more of the major insects that threaten. And threat of development of new biotypes – insects within a species that develop capability to overcome a variety's genetic resistance to attack – looms over the rice farmer.

We evaluated thousands of rice varieties in 1979 to find sources of genetic resistance to eight major insect pests. Plant breeders concentrated on genetic studies of the varieties pinpointed by our entomologists. The goal was to find new gene sources that can be used to develop newer, better insect-resistant varieties, and to cope with the eventuality of new biotypes.

Identification of resistance sources

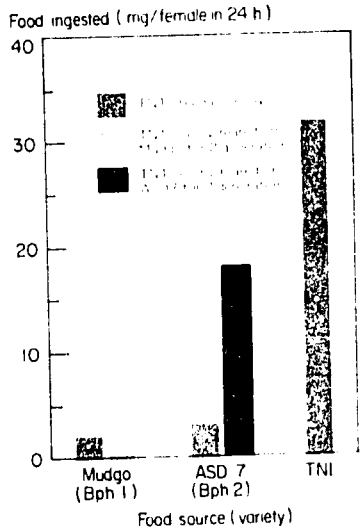
From the world germplasm collection we identified 58 varieties with resistance to the whitebacked planthopper, 19 with resistance to all three biotypes of the brown planthopper, and 3 with moderate levels of resistance to the yellow stem borer. Leaf folder rearing and screening techniques developed in 1978 facilitated the identification of three rices with leaf folder resistance. Because we have not been able to find high levels of resistance to stem borers and whorl maggots in *Oryza sativa,* we started systematic evaluation of wild rices in the germplasm collection. No stem borer and whorl maggot resistance was found, but we did identify some wild rices with resistance to three brown planthopper biotypes and to green leafhopper and whitebacked planthopper.

The possibility that rice insect pests can develop a capability to overcome a rice variety's resistance remains a threat to rice production. IR26 (right) succumbed to the brown planthopper 3 years after release. IR36 (left) has maintained its resistance.

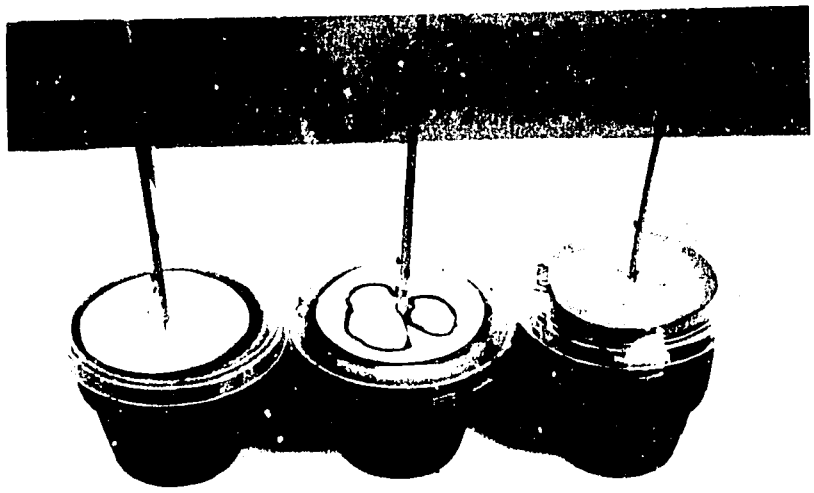
Biotype selection studies

In 1979 we started biotype selection studies for the brown planthopper and the whitebacked planthopper. The objective was to determine the rate at which a new biotype might develop on a resistant variety.

Brown planthopper. Brown planthopper biotype 1 colonies, which had been reared on the susceptible variety TN1, were cultured on the resistant varieties Mudgo (*Bph 1* gene for resistance) and ASD7 (*bph 2* gene for resistance). By the ninth generation the insects reared on resistant plants could kill Mudgo and ASD7. This appeared to be due to adaptation of these insects to feed on resistant plants. The biotype 1 insects reared on the susceptible variety TN1 did not show such adaptation.



9. Brown planthoppers from TN1 reared for 8 generations on ASD7 adapted to this variety and greatly increased their feeding rate. But the adaptation of the TN1 colony for Mudgo was much lower.



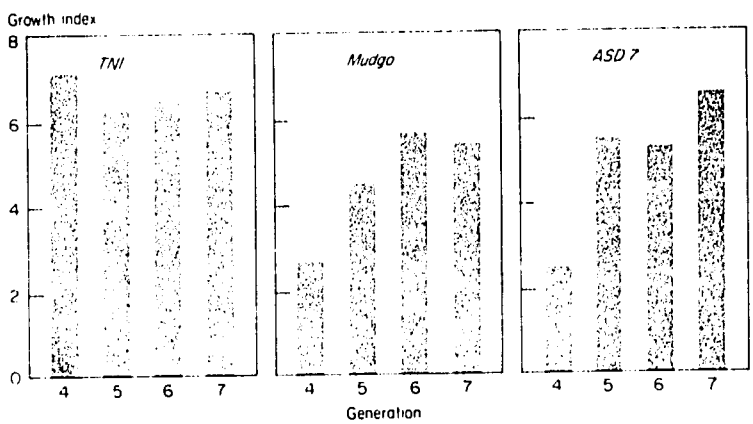
A rapid technique for determining the amount of feeding by brown planthoppers. The bromocresol green-treated filter paper changes color on contact with the insect honeydew. Size of the spot is a measure of the amount of feeding (above, right).

The adaptation of these insects to the resistant varieties appeared to be due to changes in their feeding activity, growth, and fecundity.

- *Feeding.* The ASD7 colony had a high level of adaptation by the eighth generation as indicated by feeding activity. The Mudgo colony increased feeding only slightly (Fig. 9).
- *Growth index.* The growth index is a measure of the adaptation of insects to the resistant varieties:

$$\text{Growth index} = \frac{\%\ \text{survival of nymphs to adult stage}}{\text{nymphal period in days}}$$

An increase in the survival percentage and shortening of the nymphal period increases the growth index and, in turn, the susceptibility of the rice to the planthopper. The growth index of biotype 1 on Mudgo and ASD7 increased rapidly from the fourth to the fifth generation. By the fifth and sixth generations, the growth index was almost equal to that of hoppers feeding on the susceptible TN1 (Fig. 10).



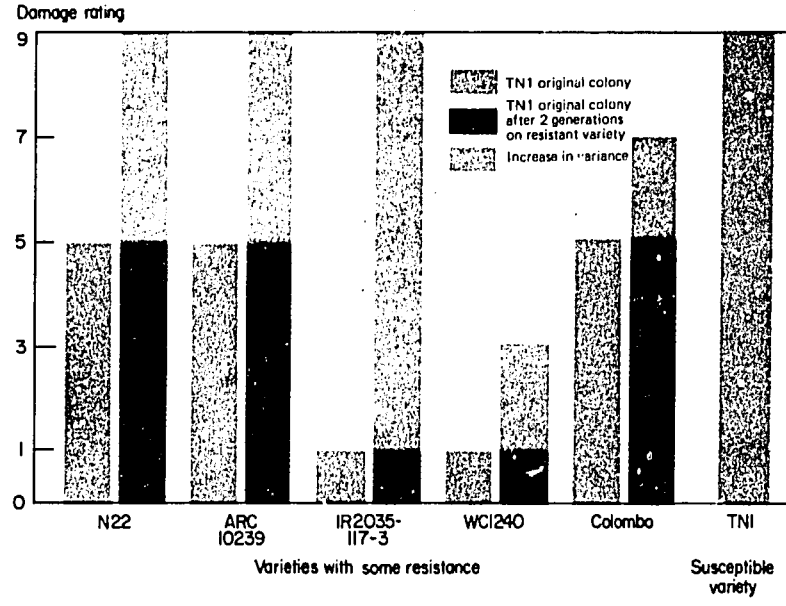
10. The growth index of biotype 1 on TN1 (susceptible), Mudgo, and ASD7 (resistant) from the 4th to the 7th generation indicates that Mudgo and ASD7 colonies adapt to survive and grow on the resistant varieties by the 5th and 6th generations, even though their feeding level is low.

• *Fecundity.* Although the ASD7 colony had a high feeding rate on ASD7, it had a low fecundity rate on ASD7, Mudgo, and even TN1, as compared to the Mudgo colony on Mudgo, ASD7, and TN1. The Mudgo colony had adapted for egg laying on Mudgo by the ninth generation, even though it had not developed for feeding by the eighth generation. Apparently the small amount of food ingested is efficiently used for egg production.

Whitebacked planthopper. The whitebacked planthopper threatens the rice crop in certain areas. We modified the system for forcing brown planthopper biotype selection and used it to study the possibilities of biotype selection occurring with the whitebacked planthopper. After two generations had fed on a resistant variety, the hoppers were placed on susceptible TN1 for one generation to produce sufficient insects for testing. Following that they were tested on varieties with genes for whitebacked planthopper resistance.

When the insects were tested for virulence on the same variety on which they had been reared for the two previous generations, it was evident that virulence in all selection colonies had increased (Fig. 11).

The possibility of development of a new whitebacked planthopper biotype has important implications for breeding for resistance to this insect. In 1979 our plant breeders studied the inheritance of resistance in 21 varieties. They found 19 with one dominant gene *(Wbph)*, and 2 with one dominant *(Wbph 1)* and 1 unidentified recessive gene.

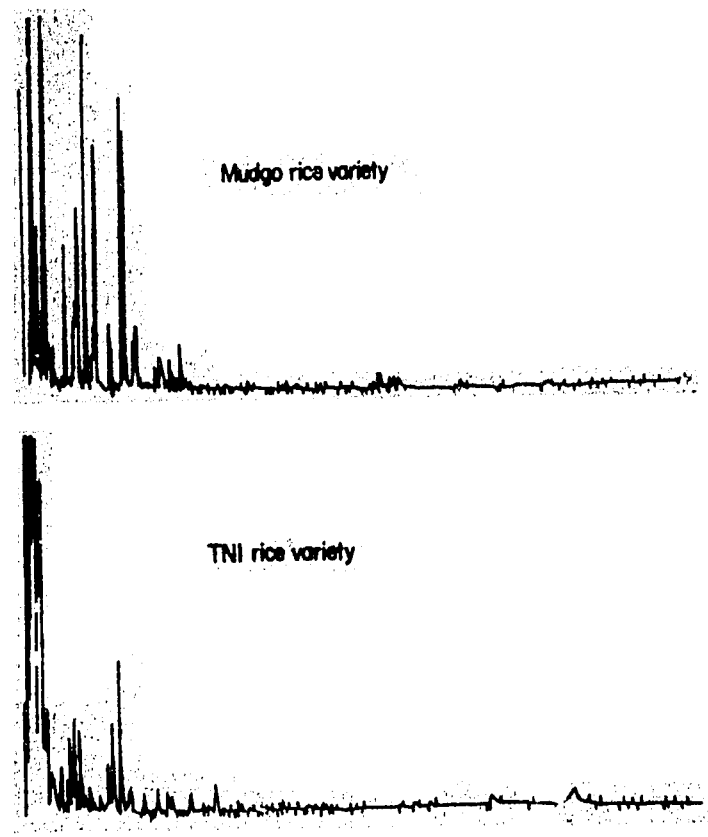


11. The whitebacked planthopper resistance of 5 varieties decreased after 2 generations of the insect were reared on these varieties. The original colony was reared on TN1, a susceptible variety.

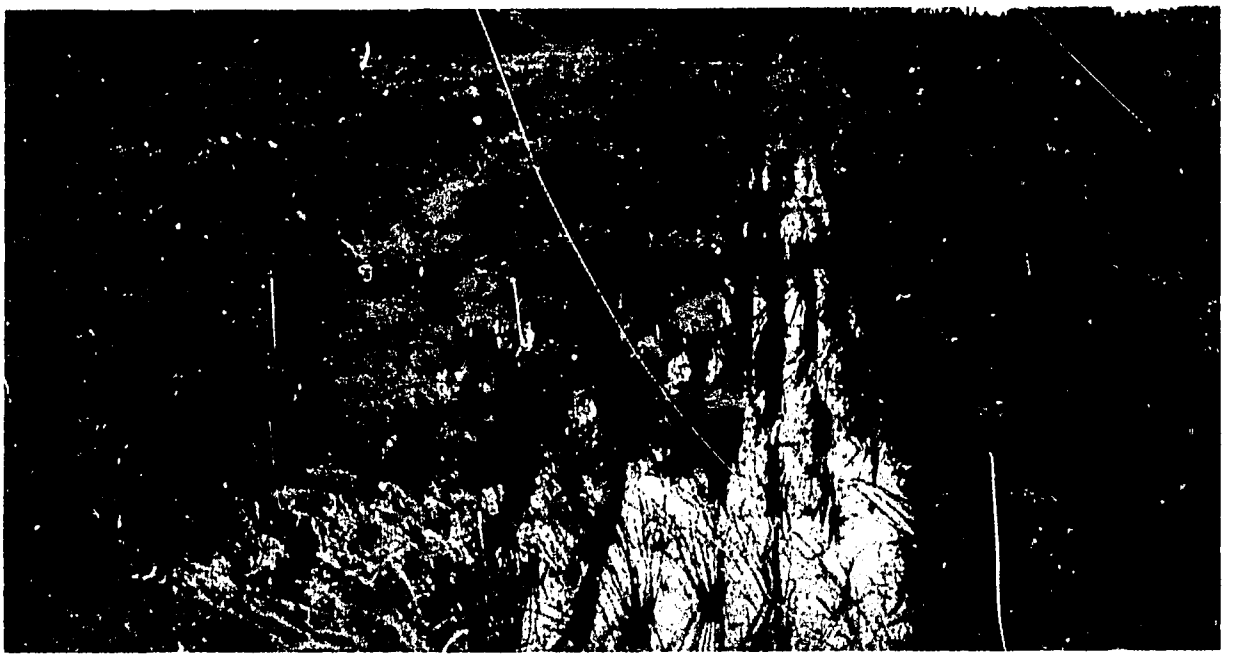
Levels of a feeding inhibitor in resistant varieties

It has been demonstrated that resistance to the brown planthopper in certain varieties is governed by chemicals in the phloem tissues, which inhibit the sucking action of the insect. A visiting scientist from the Tropical Agriculture Research Center in Japan found that oxalic acid at certain concentrations inhibits sucking by the brown planthopper. Chemical analysis of rice varieties with and without resistance genes in 1979 indicated that although all varieties have oxalic acid, its levels in resistant varieties are generally higher than those in the susceptible varieties. The average concentration of oxalic acid in susceptible varieties was 0.24 mg/g fresh tissue, but in 5 groups of resistant varieties it ranged from 0.45 to 0.59 mg/g fresh tissue.

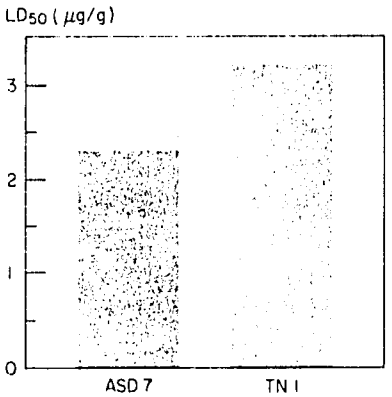
Our 1979 studies also showed that volatile oils present in rice plants are important allelochemic factors in determining susceptibility or resistance of varieties to insects. A gas chromatographic analysis of the steam distillates of a susceptible (TN1) and a resistant (Mudgo) variety showed distinct qualitative and quantitative differences among their volatiles (Fig. 12). These *fingerprints* of the steam distillate



12. These gas chromatograms show the essential oils in steam distillates of leaf sheaths of biotype 1-resistant Mudgo and susceptible TN1 rice varieties.



To identify varieties with moderate resistance to the brown planthopper in the field, susceptible plants in border rows are sprayed with insecticides to induce a resurgence of the brown planthopper. The photo shows hopperburn of susceptible borders. Insects from the borders move to the test entries (green plants between borders) when the border plants are killed. Results are seen in Figure 15.



13. The LD_{50} values for brown planthopper biotype 2 cultured on a susceptible (TN1) and a moderately resistant variety (ASD7) showed that hoppers feeding on the resistant variety were killed by lower doses when topically treated with carbofuran. LD_{50} = mean lethal dose.

volatiles illustrate basic chemotaxonomic differences between the susceptible and resistant rice varieties.

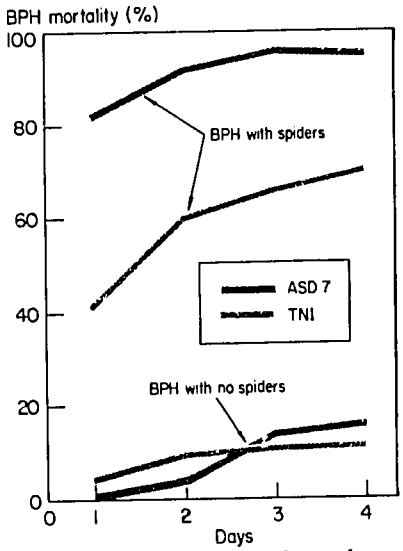
Moderate resistance to the brown planthopper

Because of the rapid adaptation of the brown planthopper to feeding on varieties with major resistant genes, we did studies to determine if a more stable type of resistance could be found. We feel that moderately resistant varieties may provide a more stable type of resistance and could, with chemical and biological control, serve in an integrated pest management approach to brown planthopper control.

ASD7 has moderate resistance to biotype 2. Some brown planthoppers feed on ASD7 and survive to the adult stage, but the survivors are small and lack vigor. If such insects are weaker and more susceptible to insecticides, chemical control of the brown planthopper could be more attractive with a moderately resistant variety because lower rates of insecticide would provide effective control.

Studies in 1979 indicated that carbofuran is more toxic to biotype 2 hoppers feeding on ASD7 than to those on the susceptible variety TN1 (Fig. 13).

We also found that spiders are more effective predators when feeding on hoppers growing on a moderately resistant variety (Fig. 14). In 4 days spiders had completely eliminated the hoppers feeding on ASD7 plants, but only 70% hopper mortality occurred on the susceptible plants. Thus a moderately resistant variety can increase the effectiveness of biological control.



14. The spider *Lycosa pseudoannulata* predation of biotype 2 brown planthoppers feeding on a susceptible (TN1) and a moderately resistant (ASD7) rice variety was highest among hoppers feeding on the moderately resistant variety ASD7. Because of the ASD7 resistance the planthoppers are smaller and move around the plant more, resulting in increased predation.

Moderate resistance to the brown planthopper plus more effective biological control, with use of low rates of insecticides when the planthopper population reaches the economic threshold, appear to be a practical and ecologically attractive means of brown planthopper control.

Identification of moderately resistant varieties. We found detection of moderate resistance difficult in the common seedbox screening techniques using 7- to 10-day-old seedlings. The seedlings were usually rated as susceptible. However, in fields where planthopper attacks occur in older plants, moderate resistance was easily detected. Several varieties from the International Rice Brown Planthopper Nursery, which are killed in the seedbox screening for biotype 2, showed a moderate level of resistance in field screening where biotype 2 was predominant (Fig. 15). The moderately resistant varieties were:

Variety	*Origin*	*Variety*	*Origin*
Triveni	India	IR46	IRRI
Mudgo	India	ADT32	India
Utri Rajapan	Bangladesh	Kencana	Indonesia

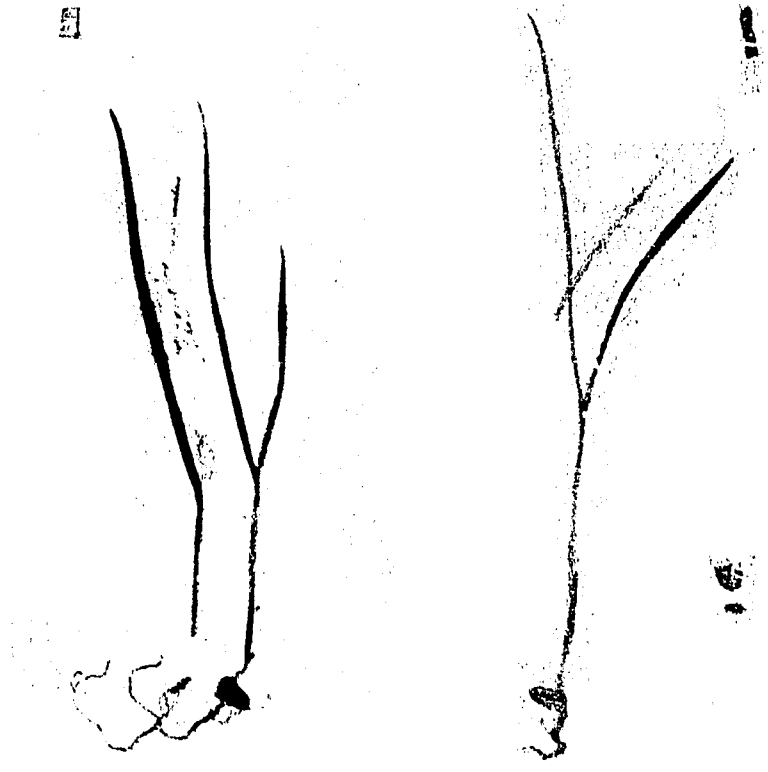
15. Through field screening of varieties from the International Rice Brown Planthopper Nursery moderately resistant varieties have been identified. Triveni, shown here, is susceptible in the seedbox screening technique as a 10-day-old seedling. But in the field, it stands well, while other varieties nearby have been killed or have decomposed as indicated by the surrounding bare soil.

Further evaluation of the moderately resistant varieties Triveni and Mudgo against a mixture of biotype 1 and 2 hoppers in a screenhouse verified our field results. Under intense insect pressure the moderately resistant varieties were damaged but still survived, but IR26 and TN1 were killed.

Nature of moderate resistance

We have observed that moderately resistant varieties may tolerate high insect populations without showing as much damage as do more susceptible varieties. Despite similarities in insect populations, Triveni and Mudgo had lower damage ratings than the susceptible varieties. Plant tolerance, the ability of the plant to continue to survive and grow in spite of insects feeding on it, may contribute to moderate resistance.

To compare the plant tolerance of moderately resistant and susceptible varieties we exposed the plants to feeding by hoppers until they were almost killed. The plants were then grown in a solution containing ^{14}C and the amount of radioactivity was measured by exposing to X-ray film. The resulting autoradiographs showed high levels of radioactivity in plants of the moderately resistant varieties Mudgo and Triveni, including continued photosynthetic activity. The susceptible varieties IR26 and TN1 had low levels of radioactivity (Fig. 16).



16. Varieties Triveni and Mudgo, which have tolerance for biotype 2 brown planthopper feeding, are capable of continuing photosynthesis even after severe insect attacks; susceptible varieties TN1 and IR26 have very low photosynthetic activity. This is shown in this autoradiograph. The moderately resistant variety took up a large amount of radioactive carbon in the form of ^{14}C as shown by the intensity of the black color; the susceptible varieties took up very little.

GRAIN QUALITY AND NUTRIENT CONTENT

Consumers of rice continue to show preference for certain rices in the marketplace. Cooking quality (mainly the texture as affected by amylose content), taste, and aroma are among the main consumer measurements of quality. Nutritive value, especially the protein so essential to small children, gets less of the consumers' attention.

Lines with intermediate amylose

We made a large number of crosses involving breeding lines with intermediate amylose content during 1979, and the number of intermediate-amylose lines in our various nurseries was much higher than in previous years. IR4570-83-3, named IR48 in the Philippines, was the first intermediate-amylose IRRI line named as a Philippine variety. IR48 has grain similar to that of the popular C4-63G, but the acceptability of its raw and cooked milled rice equals that of C4-63G's. Filipino consumer panels showed a definite preference for the cooked dryland rices IR43 and C171-136 over the intermediate-amylose rices C4-63G and BPI-121-407 and a high-amylose rice, IR46 (Table 3). Previous consumer panel tests had reflected a preference for the softer texture of cooked rice with 18–20% mean amylose content

Grain quality work in 1979 included scoring of rices by trained taste panels at the University of the Philippines at Los Baños. The panelists' scores helped correlate human preferences with instrument measurements of grain quality made in IRRI laboratories.

Table 3. During 1979 collaboration continued with the Institute of Human Ecology, University of the Philippines at Los Baños, to determine consumer preferences for raw and cooked rice. The panel indicated a preference for dryland rices with low to intermediate amylose content.

Variety or line	Mean preference score[a]		Amylose (% dry basis)	Alkali spreading value	Cooked rice Instron reading for hardness (kg)
	Raw	Cooked			
BPI-121-407	−0.50 c	−0.38 c	23.7	7.0	7.8
C4-63G	0.62 a	−0.22 c	23.3	4.7	7.9
C171-136	0.08 b	0.27 b	22.9	4.2	5.6
IR43	−0.16 bc	0.73 a	15.8	7.0	5.5
IR46	−0.04 b	−0.40 c	28.6	5.1	9.7

[a]By 40 panelists at Bucal, Lemery, Batangas, who rated the samples 1st = 1.16; 2d = 0.50; 3d = 0; 4th = −0.50; and 5th = −1.16. Means in the same column followed by a common letter are not significantly different at the 5% level.

characteristic of dryland rice over the typical intermediate (22–24%) amylose rices such as C4-63.

Protein content

We cooperated with scientists in the Philippines and in India in evaluating rices of average and high protein contents for their comparative nutritional value for children. Growth studies on preschool Indian children on an 80%-rice diet typical of South India indicated that replacing average-protein (7%) rice with high-protein (10%) rice gave no improvement in the children's height and weight (Table 4).

In a feeding trial involving preschool Filipino children on a diet in which about 40% of the protein was from rice,

Table 4. The height and weight of preschool children fed rice-based diets adequate in protein was improved by simultaneous replacement of average-protein (7%) rice with high-protein (10%) rice and addition of zinc. The study was in collaboration with the Christian Medical College and Hospital, Vellore, India, and the Food and Nutrition Research Institute, Manila, Philippines.

Children and diet	Increase in[a]		Mean lysine in diet (g/16 g N)
	Ht (mm)	Wt (kg)	
Indian children (1-year study, 11 children, 80% rice diet)			
Average-protein rice	71.3 a	1.32 a	4.3
High-protein rice	69.8 a	1.13 a	4.1
Filipino children (6-mo study, 27 children, 40% rice diet)			
Average-protein rice	42.1 b	0.84 b	5.3
Average-protein rice + 5 mg zinc	43.9 ab	0.99 b	5.3
High-protein rice + 5 mg zinc	48.3 a	1.38 a	4.7

[a]In the same group of children, means in a column followed by a common letter are not significantly different at the 5% level.

supplementation with zinc (5 mg) together with substitution of high-protein (10%) rice for average-protein (7%) rice resulted in significantly faster height and weight increases. Zinc supplementation alone did not improve the growth of the children.

The energy intake of the Indian children was higher but the quality of the protein reflected in lysine content (5.5 g lysine/16 g N = 100%) and growth were better for the Filipino children. Both diets were more than adequate in protein. The nutritional advantage of the high-protein rice would probably be more dramatic if the diets had been deficient in energy and protein, conditions common in tropical Asia.

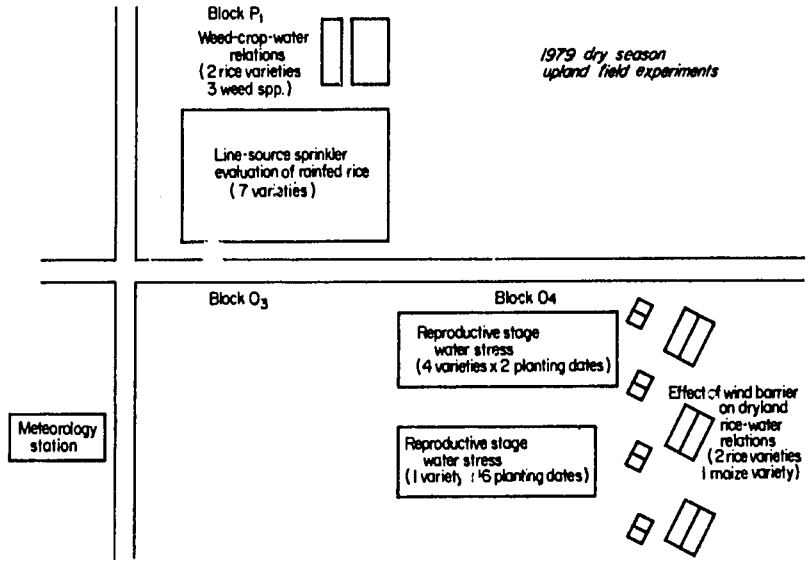
DROUGHT RESISTANCE

Drought devastated the rice crop on thousands of farms across Asia during 1979. The loss spelled hardship and hunger for the small rainfed rice farmer and dealt a severe blow to national rice production programs. But technology exists, and more is being developed, to assure farmers in drought-prone areas of a reasonable chance of a good crop in dry years.

In the 1979 dry season we greatly increased the scope of field studies of drought resistance. Because drought at the reproductive stage is a serious and more prevalent type of stress

The devastation of drought is seen in the hands of these Indian women who seek the few surviving panicles of ripe grain in the field in Bihar. The photograph was taken October 1979. The region suffered from prolonged drought during the main cropping season.

The diagram (right) pinpoints 5 major studies as part of expanded drought resistance research early in 1979. The photo (top) is an infrared aerial view that shows the effect of drought on research plots. The severity of the effect of drought on crop growth is seen in the lighter red areas.

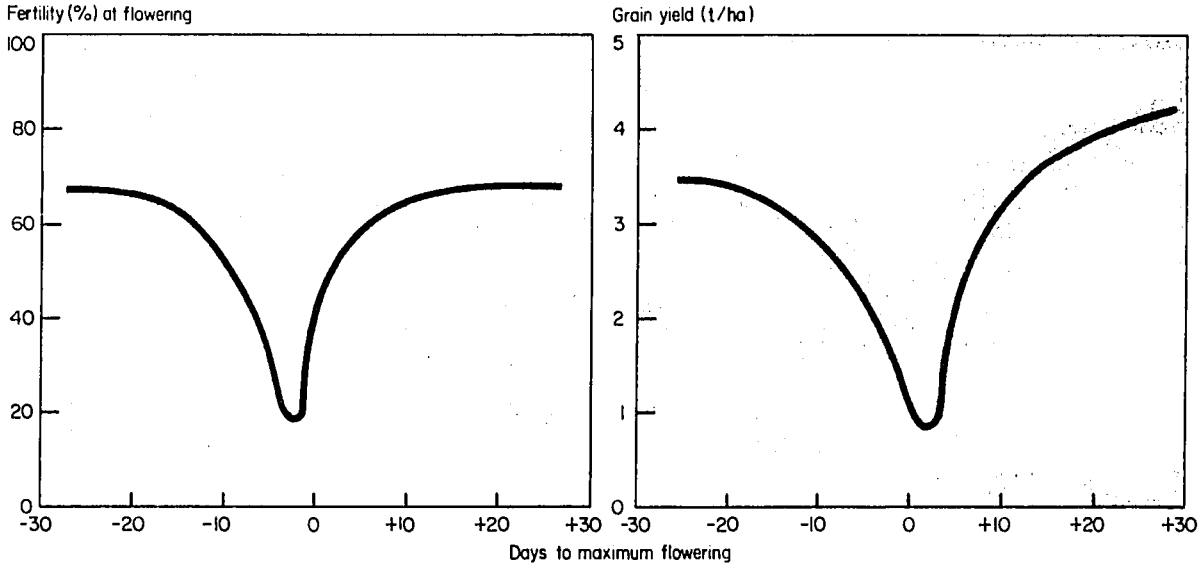


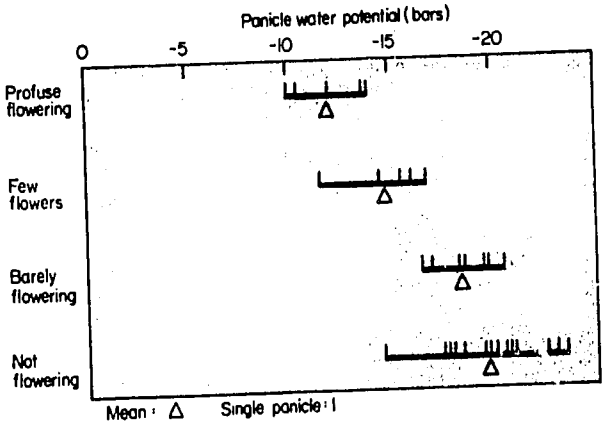
affecting rice yields, a major shift in field research – from the vegetative stage of plant growth to the reproductive stage – was made. We also tested a significant new field research technique – the line-source sprinkler.

Reproductive stage water stress

The reproductive growth stages of rice are reportedly the most sensitive to drought. Among them flowering is the most sensitive. Figure 17 illustrates this sensitivity. A 1979 study suggested that the water-potential threshold for flowering is between -13 and -10 bars (Fig. 18). We measured the panicle water potentials of IRAT 13 and IAC 1246, both dryland varieties, in a drought-stressed crop during the normal flowering

17. The sensitivity of a rice crop to drought at the flowering stage is seen in the sharp drop in grain yield of IR36. Each dot is one test plot. Maximum drought stress was on 2 May – the 0 point in the scale. Note the agreement of the yield curve with the percentage of fertility curve.



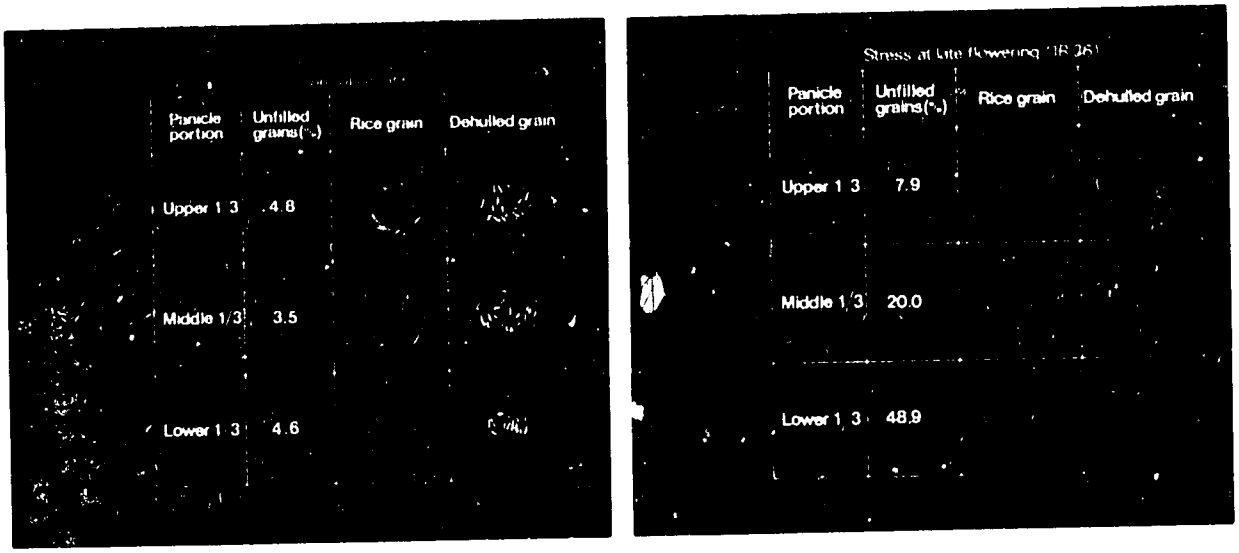


18. Flowering of the dryland varieties IRAT 13 and IAC 1246 decreased at a mean panicle water potential of −15 bars. All panicles were from the same plot. Note the sharp increase in panicles not flowering at −15 to −20 bars of water potential. The low points in the curves in Figure 17 were at about −20 bars.

time, 0930–1100 hours. Among panicles selected for the same degree of exsertion, those suffering from severe water stress (-14 to -24 bars) did not flower. Those that had only a mild stress (-10 to -13 bars) flowered profusely.

Drought stress not only reduces yield by increasing spikelet sterility (Fig. 19) but also decreases the grain weight if it occurs during grain filling. We observed that drought stress also predisposed the panicles to the sheath rot fungus *(Acrocylindrium oryzae)*, which caused darkening or discoloration of the grains and reduced grain yield and quality.

Additional studies focused on the frequently observed occurrence of whitehead or sterile spikelets on a panicle. The panicle does not appear to be able to regulate water loss by



19. The effect of drought is seen in the grains from the stressed panicle of IR36 (right). Note the effect of stress on the grains, which are discolored, small, and shriveled.

20. Sterile spikelets, called whitehead, result when the rice plant suffers from prolonged drought at the reproductive stage.

closing its stomata or by rolling as the leaf does. Thus unabated water loss during drought periods leads to sterile panicles. Figure 20 illustrates the characteristic symptoms of panicle stress.

Pinpointing rices with drought resistance

In 1975 we began field screening of rices for drought resistance during dry season. Among those initially identified as drought resistant were IR442-2-58, Salumpikit, and Carreon. They were used to incorporate drought resistance into the genetic makeup of varieties with high yield potential. Several lines that resulted had drought resistance and five of them – IR5853-118-5, IR8103-120-3, and IR9669 Sel. from IRRI; and BKN6986-108-2 and KU 86 from Thailand had consistently high resistance (Table 5). Four other IRRI-bred lines had good drought ratings in 1978 and 1979.

Table 5 gives the drought scores of parents suggested as possible sources of drought resistance of the selected lines. The parents showed consistent resistance only to relatively moderate stresses but their progenies were excellent even at 10 bars of soil moisture tension. This finding suggests the need for studies

Table 5. Drought resistance bred into 7 IRRI lines stayed consistently high at IRRI in the 1978–79 dry season. Note that in 3 lines drought resistance was as high as or higher than that of the resistant check for 3 consecutive years. Nam Sagui 19, Leb Mue Nahng 111, and Khao Dawk Mali 105 were reported in 1974 and 1975 as resistant to prolonged (10 days) moisture stress in the phytotron.

Designation	Possible source of resistance	Drought score[a]				
		1977		1978		1979
		4 bars	10 bars	5 bars	10 bars	5 bars
IR5853-118-5	NS 19	3	3	1	3	3
IR8103-120-3	Aus 197	3	3	1	1	3
IR9669 Sel.	Carreon	4	4	1	3	1
IR5624-110-2	KDML 105	–	–	1	3	3
IR8154-95-1	KU 70-1	–	–	1	3	3
IR8234-174-3	NS 19	–	–	2	3	3
IR9995-96-2	NS 19	–	–	1	3	3
BKN6986-108-2		3	3	2	3	3
KU 86		2	2	1	3	1
Nam Sagui 19		7	7	3	7	3
Leb Mue Nahng 111		3	3	3	5	3
Khao Dawk Mali 105		3	3	2	4	3
KU 70-1		3	6	3	6	3
Carreon		4	5	–	–	–
IR442-2-58		4	5	1	5	3
Salumpikit		4	5	1	4	3
IR20		7	8	5	8	5
IRAT 9		7	8	6	9	7

[a]Scoring is on a 1–9 scale: 1 = no to negligible effect of soil moisture stress, 9 = all plants apparently dead. Bars are units of soil moisture tension. Dashes indicate no test during the year.

IR5853-118-5, shown here as the only apparently live entry in 1979 dry season drought screenings at IRRI, has had consistently good drought resistance ratings since 1977.

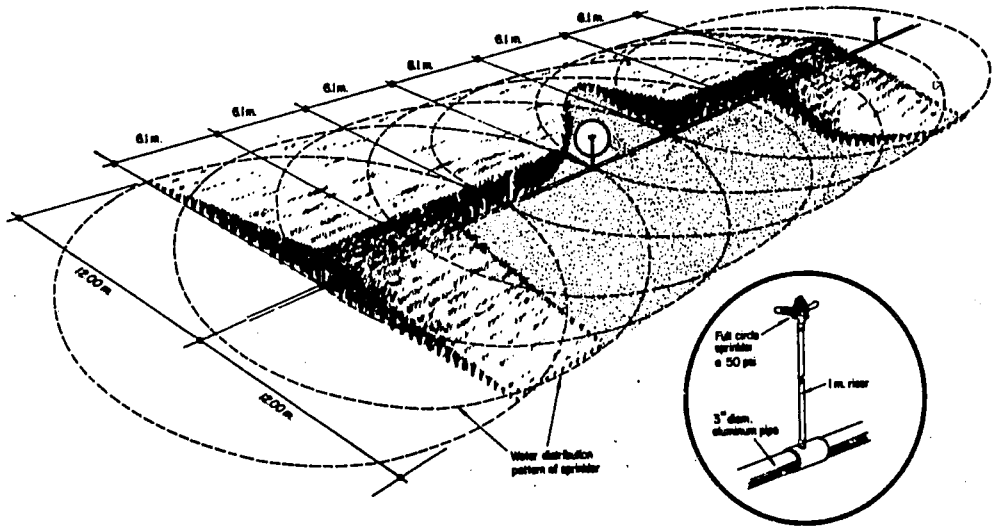
on mode of inheritance of drought resistance. Information on inheritance could speed the incorporation of desired drought character into improved rices.

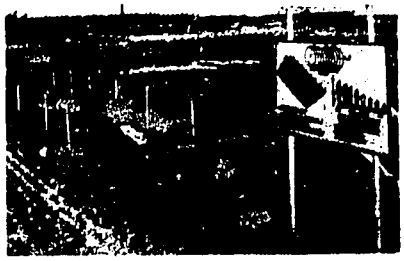
Screening for drought resistance

During the 1979 season, mass screening for field resistance to drought involved 2,449 accessions from the germplasm bank and 1,314 breeding lines from IRRI and the International Institute of Tropical Agriculture (IITA). As in previous screening tests, a large number of accessions from Africa, India, Laos, and Pakistan showed moderate to high levels of drought resistance at the vegetative growth phase. We also found a large number of accessions with high levels of drought resistance at the reproductive growth phase. They included TOX lines from IITA, traditional varieties from Laos, and Assam varieties from India. Dryland breeding lines of IRRI – IR5440-1-1-3, IR5987-25-1, IR621-3-5, and IR6254-27-1 – also showed moderate to high levels of drought resistance at the reproductive phase.

Drought performance of 25 rices in Central Luzon

In tests of promising lines in farmers' fields at Talavera, Central Luzon, Philippines, the crop had 28 drought stress days that started 18 days after transplanting (DT). Only 122.4 mm of rain fell after the stress period and the field had standing water for only 3 days. A second stress period began 54 DT and continued until harvest time with only light showers – total of 57.1 mm of rainfall – falling at 4- to 10-day intervals. Yields ranged from 1.3 to 2.4 t/ha. Entries that yielded more than 2 t/ha were





21. This sprinkler system, tested in the 1979 dry season, permits precise creation of drought situations at any stage of plant growth. Use of the new system will cut several years off the time needed to fully test the drought resistance of breeding lines.

IR36, IR5853-118-5, and IR10168-52-4-2 in the early-maturing group and IR44, IR10781-75-3-2, C166-133, B865C-Mr-144-3-1-2, and B1141C-Kn-43-1-8 in the late-maturing group.

Line source sprinkler

A major new field research technique – a line-source sprinkler developed at Utah State University – was tested in the 1979 dry season to see if we could use it to screen breeding lines for response to varying levels of water deficit (Fig. 21). Use of the sprinkler system in dry season screening for drought resistance was a significant breakthrough: it gave us the means to control a systematic application of water and to evaluate the responses of cultivars and breeding lines. The system also allowed us to select the growth stage for drought testing and instead of visual scoring the evaluation of entries was based on the growth and yield.

The sprinkler system significantly improved our capability to screen breeding lines for drought response. By incorporating this controlled irrigation technique into the drought resistance program, we can determine, within 1 or 2 years, the yield response of a breeding line. Previously this information could only be obtained through multilocation testing and many years of waiting for drought to occur naturally at the desired growth stages.

Deep root systems and other agronomic characteristics

Because we cannot easily examine root systems of growing rice, any correlation between root growth and top growth would be

Table 6. These coefficients show the correlation between root growth and top growth of the rice plant.[a] The results support the common observation that dryland rice varieties are usually tall, low tillering, and deep-rooted.

	Correlation coefficient		
	Plant ht	Tiller no.	Deep-root score
Days to flowering	0.134**	0.156**	0.113*
Plant ht		−0.463**	−0.453**
Tiller no.			0.391**

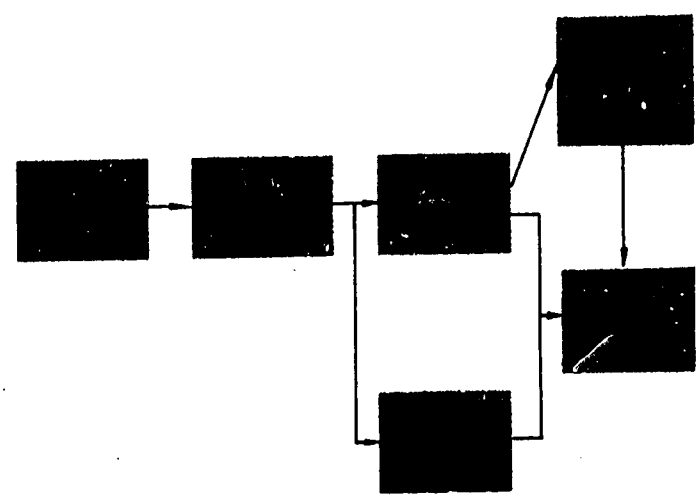
[a]*Significant at 5% level. **Significant at 1% level.

helpful in research on drought. During 1976–79 we examined 1,081 lines or varieties for the relationship between deep root-to-shoot ratio and plant height, tiller number, and days to flowering. Simple correlation coefficients between deep root score and those agronomic characteristics are summarized in Table 6.

Growth duration is not correlated with deep-root score. Based on the IRRI scoring system, in which a low score indicates deepest rooting, deep-root score is correlated negatively with plant height but positively with tiller number. The correlation between plant height and deep root system is not genetically linked.

Aluminum toxicity and drought resistance

Aluminum toxicity is suspected to be a major limiting factor for growth of dryland rice on acid soils and wetland rice on acid sulfate soils. In a moist soil, a toxic level of aluminum affects rice growth and yield by affecting total root length. A series of 1979 experiments indicated that aluminum toxicity affects the drought resistance of rice through an effect on root growth (Fig. 22).



22. A series of 1979 experiments established the mode of aluminum toxicity in rice growth. Growth and nutrient uptake of rice are closely related to total root length. Water uptake rate per unit length of root is not affected by aluminum toxicity, but with drought, aluminum-affected plants suffer more water stress because their maximum root length is shorter. Thus, aluminum toxicity is considered an important factor affecting drought resistance of rice.

ADVERSE SOILS TOLERANCE

Farmers on millions of hectares of rice land fail to get good yields with modern rice varieties because of adverse soil conditions. In densely populated South and Southeast Asia alone, where there is an increasing scarcity of arable land, about 100 million ha that could grow rice lie uncultivated largely because of soil problems. Many soils could be amended to grow rice – but at high cost. The goal of our adverse-soils tolerance research is rice varieties that will give farmers a reasonable yield on problem soils without making costly amendments.

In 1979, we screened nearly 25,000 rices (Table 7). Among 4,562 rices found tolerant, 3,275 were from the general breeding program and had not been specifically bred for adverse soil tolerance. Tests in farmers' fields pinpointed IR rices suited to various adverse soil conditions:

Salinity	: IR42, IR4595-141-1, IR4530-22-2, IR9884-54-3
Alkalinity	: IR36, IR42, IR46, CSR 1, CSR 3
Iron toxicity-acid sulfate soil	: IR36, IR42, IR46, IR4683-54-2
Peat soil	: IR36, IR38, IR42, IR50
Boron toxicity	: IR40, IR42
Aerobic soils	: IR36, IR43, IR48

Multiple stress tolerance in IR rices

Tolerance for multiple soil stresses in some recently developed IR rices that have disease and insect resistance gives them a great advantage over the earlier IR varieties. Our 1979 tests indicated that:

Table 7. Screening for adverse soils tolerance in 1979 covered 10 soil conditions and nearly 25,000 entries.

Soil condition	Screened rices (no.)	Tolerant rices (no.)	
		Total	From general breeding program
Salinity	16,058	3,542	2,405
Alkalinity	1,733	260	236
Iron toxicity-acid sulfate soil	932	125	112
Peat soil	165	12	12
Boron toxicity	24	7	7
Phosphorus deficiency	1,605	183	152
Zinc deficiency	3,703	388	309
Aerobic neutral soil	317	22	22
Aerobic acid soil	331	23	20
Total	24,868	4,562	3,275

Rices such as IR36, IR42, and the newly named IR50, as well as other salt-tolerant advanced breeding lines perform better and mean higher income to many small farmers in coastal areas.

- IR36, by virtue of its tolerance for salinity, alkalinity, and zinc and iron deficiencies, should do well on salt-affected soils of arid regions.
- IR42 and IR44, which have tolerance for salt, iron toxicity, and phosphorus deficiency, should be adapted to strongly acid soils and acid sulfate soils.
- IR43, because of its tolerance for deficiencies of phosphorus and iron as well as toxicities of aluminum and manganese, should do better than other rices as a dryland rice in acid soil areas.
- IR50, released in the Philippines in 1979 and tolerant of salt, zinc deficiency, and organic soil problems, is a good rice for farmers on coastal organic soils.

There are indications that multiple soil stress tolerance made IR36 and IR42 two of the top yielders in 1979 international tests.

Genetics of adverse soils tolerance

An analysis of the data from our mass-screening of rices for adverse soils tolerance suggests that the genes imparting tolerance for different mineral stresses are nearly independent in behavior. Heritability studies in 1979 showed that tolerance for zinc deficiency is dominant and under polygenic influence.

DEEPWATER AND FLOOD TOLERANCE

Almost 2,000 crosses made in 1979, with many of the progeny run through a special rapid generation advance system (*see* Integrated GEU section), underscored our efforts to produce better varieties for the deepwater rice areas. Screening lines and varieties for tolerance for complete submergence became a routine procedure in developing lines and varieties for the flood-prone areas, and screening for elongation ability continued.

Improvement and modification of the various screening techniques for deepwater rice continued at IRRI headquarters and at our cooperative project site in Thailand. Fertilizer trials with the newly developed lines in farmers' fields gave encouraging results. The trials included RD17 and RD19, the first Thai deepwater varieties developed by hybridization and released to farmers in deepwater areas.

Response of medium-deepwater rice to nitrogen fertilizer

Fertilizer application at sowing is rare for deepwater rice and becomes impractical after the water starts to rise. In addition, the response of floating rice to nitrogen fertilizer is low or even negative. Thus, floating rice will continue to produce low yields unless the plant type is improved.

In 1979 we examined the grain yield increase due to fertilizer applied to semidwarf medium deepwater rice lines. Nitrogen application increased the grain yield of all entries by an average of 35%, ranging from 14% in MRC505 to 62% in IR587-3-2E-1-33.

We found that:

- The role of basal nitrogen application in producing higher

The newly released deepwater variety RD19 is on the right in these deepwater trials at Huntra, Thailand. The variety on the left is Pin Gaew 56, a parent of RD19.

grain yields was limited to increasing the panicle number per unit area. Nitrogen application increased the number of panicles per square meter by 47%, but did not affect the number of spikelets per panicle, percentage of fertility, and 1,000-grain weight.

- Plant height was significantly increased by nitrogen fertilizer, which promoted internode elongation. Increased plant height also resulted in more crop canopy above the water level. At flowering time there was a 99% increase in leaf area index due to nitrogen application.

Slow-release fertilizer for medium-deepwater rice

With the introduction of modern varieties such as IR42 in the Philippines, and RD17 and RD19 in Thailand for medium deepwater use, fertilizer management practices are essential for efficient, high-yield rice production in these areas. Experiments at IRRI in the 1979 dry season evaluated slow-release nitrogen fertilizer for medium-deepwater rice.

We increased water depth starting 30 days after transplanting until a depth of 40 cm was reached. That depth was maintained until near harvest time. We obtained 2.75 t/ha response to fertilizer nitrogen as one-half prilled urea and one-half forestry grade sulfur-coated urea broadcast and incorporated. Urea supergranules placed 10–12 cm deep gave yields similar to those by SCU alone or SCU plus prilled urea broadcast and incorporated (Table 8).

Thailand-IRRI collaborative project

RD17 and RD19 were recommended for release to Thai farmers by the government of Thailand in 1979. They represent Thailand's first deepwater rice varieties of hybrid origin. Both varieties are selections from BKN6986, the cross between the semidwarf IR262 and the floating rice Pin Gaew 56. RD17 and

Table 8. Slow-release fertilizers gave significant yield increases for IR42 grown in medium deepwater (max depth 40 cm). IRRI, 1979 dry season.

Forms and mode of urea fertilizer[a] (54 kg N/ha)	IR42 yield[b] (t/ha)
No nitrogen	0.75 f
1/2 PU + 1/2 SCU (FG)	3.07 ab
SCU (FG)	2.49 abc
1/2 PU + 1/2 SCU (ordinary)	2.09 abcde
SCU (ordinary)	2.22 abcd
Urea supergranules (10–12 cm)	3.18 a
Prilled urea	1.81 cdef

[a]PU = prilled urea, SCU = sulfur-coated urea, FG = forestry grade. [b]In the column, any two means followed by the same letter are not significantly different from each other at the 5% level.

Table 9. RD17 in 1979 fertilizer trials gave an indication of a minimum 3 t/ha yield at an 80-cm water depth but no consistent response to nitrogen.

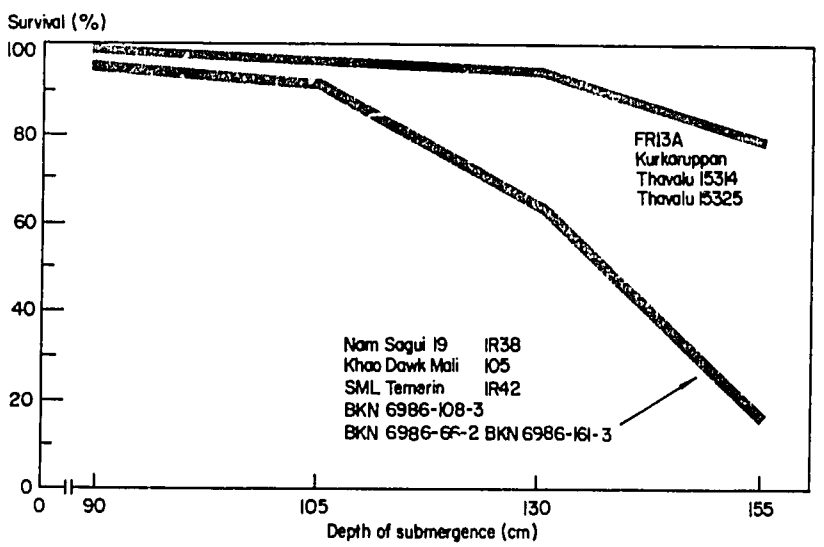
Spacing (cm)	Yield (t/ha)		
	No fertilizer	25-25-0 kg NPK/ha	60-25-0 kg NPK/ha
25 x 12.5	3.3	3.3	4.0
25 x 25	3.8	3.3	3.8
25 x 40	2.4	2.9	3.2

RD19 possess dwarfing genes, but can withstand flooding as deep as 1 meter during the vegetative phase because they then form longer-than-usual internodes. Both varieties are only moderately susceptible to bacterial blight, and have long grains and acceptable cooking quality.

- RD17 (BKN6986-66-2) matures in 140 to 150 days, regardless of the photoperiod prevailing in Thailand. It can therefore be grown in the dry and wet seasons.
- RD19 (BKN6986-147-2) is photoperiod sensitive; if planted early it flowers in mid-November in Thailand and is ready for harvest in mid-December. RD19 is intended for the vast areas immediately east and north of Bangkok, where traditionally tall, photoperiod-sensitive varieties are grown in the wet season. RD19 has the added distinction of being Thailand's first photoperiod-sensitive semidwarf rice variety.

RD17 was tested at three levels of fertilizer and three spacings (Table 9). The result indicated a possibility of reaching 3 t/ha in 80 cm of water. At that depth the ordinary modern semidwarf rices usually give no yield. The data indicate that wide spacing reduces yields.

Water level and submergence tolerance. In an experiment in a deepwater pond we found survival after a period of total



23. Survival after submergence of the 4 varieties (top) indicates the great potential for developing rices that will survive the prolonged submergence common in deepwater areas. Each entry was tested at water depths indicated by the data on the curves.

submergence decreased drastically as water depths increased. With plants submerged in 155 cm of water for 9 days at 44 days of age (20 days after transplanting), average survival rate went down to 78% for the known tolerant varieties and 17% for susceptible varieties (Fig. 23).

These findings confirm our previous results, and clearly demonstrate an extraordinary potential to develop rices with tolerance for submergence or deep flooding. There is a need to screen rices at water levels sufficiently deep to pinpoint differences in submergence tolerance.

TEMPERATURE TOLERANCE

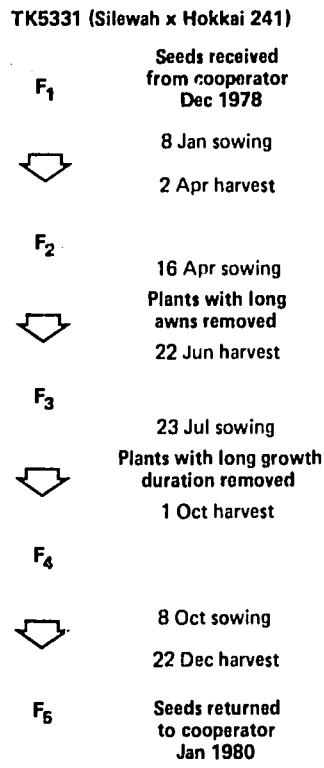
Temperature extremes, ranging from below 20°C in many mountainous areas to about 35°C in some arid areas where tropical rice is grown, continued to suppress yields from the modern rices. In 1979 we expanded research on temperature extremes through cooperation with scientists in areas where such extremes affect the rice crop.

Low-temperature tolerance

Cold tolerance research continued in collaborative studies with scientists from the Office of Rural Development (ORD) in Korea. More than 1,500 entries were screened by an IRRI-ORD team at special facilities provided by ORD at Chuncheon, Korea. The best entries were:

SR3049-58-1-5-1	CI 11043	Tatsumi-mochi
SR3049-58-1-5-2	Fuji 269	Von Ja 2
SR3054-55-1-2-3	Wase Toramochi	Hwanghaedo
CI 11041	Somewake	

Entries in cold tolerance screening at the ORD rice research substation, Chuncheon, Korea, are checked by Moo Sang Lim, ORD Suweon (left); Jong Doo Yea, ORD Chuncheon; and Romeo Visperas, IRRI senior research assistant (right). Varietal differences in cold tolerance are clearly seen.



24. With rapid generation advance of the cold-tolerant rice TK5331 at IRRI in 1979, we delivered F5 seed to a cooperator in a year. To have gotten the same F5 with field handling would have required 4 years.

In addition, the fertilizer response of the rice plant at low temperature and protective measures against plant damage by low water temperature were studied. Only the adding of compost had any significant effect in reducing the sterility of Suweon 264 irrigated with cold water (17°C) at the meiotic stage. The addition of nitrogen, phosphorus, or silica did not improve the fertility of the spikelets.

Genetics of cold tolerance at the seedling stage

We did a genetic analysis of 13 crosses involving cultivars tolerant of and susceptible to low water temperature at the seedling stage. The seedlings were subjected to water temperature of 12°C 10 days after sowing. In 11 crosses, the F2 populations segregated in the ratio of 3 resistant to 1 susceptible to low water temperature, indicating simple monogenic inheritance of cold tolerance at the seedling stage.

Rapid generation advance

The advantage of rapid generation advance in breeding of cold-tolerant rices is similar to that in breeding of photoperiod-sensitive rice. It provides a speedup of the breeding process (Fig. 24).

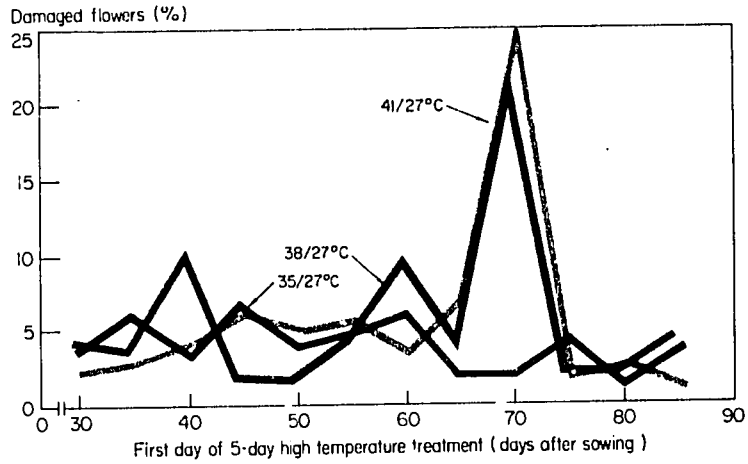
In 1979 lines from 48 crosses made specifically for cold tolerance were grown in rapid generation advance facilities at IRRI. Those crosses, for low-temperature areas in India, Nepal, Korea, and the high-altitude areas of Indonesia and the Philippines, were distributed in bulk for selection at specific sites.

High temperatures and white-tipped panicles

White-tipped panicles are occasionally seen in farmers' fields. Because the number of affected panicles is usually small and the degree of crop damage appears slight, farmers and researchers have not given the symptom much attention.

But in 1977, white-tipped panicles were widespread in Palawan, Philippines. The symptoms were conspicuous on improved varieties such as C4-63G and IR26, but were not seen on traditional varieties.

The cause of white-tipped panicles in farmers' fields was attributed to high soil temperatures at panicle initiation time. We demonstrated in 1979 studies in the IRRI phytotron that white-tipped panicles are caused by high temperature at the panicle initiation stage (Fig. 25). Thus, high sterility was induced by the high temperature at flowering time. A large varietal difference in proneness to white-tipped panicles was found.



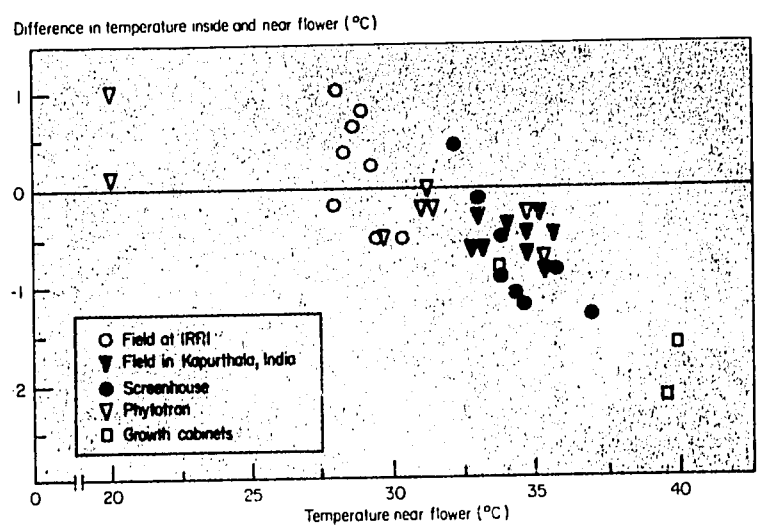
25. Effect of high temperature on the growth of flowers. At panicle initiation, a growing panicle is only 1–2 mm long and is located on the short culm, which puts the panicle near the soil surface. If the temperature of the soil surface rises to 38°C or higher, which is likely with intense sunshine and shallow or no standing water, white-tipped panicles may occur.

High temperature inside the rice flower

High percentages of sterility occur when rice flowers are exposed to high air temperature at the time of opening. But temperature inside the rice flower should have the greatest effect on sterility.

In 1979 we measured temperature inside and outside the rice flower under various growing conditions. We found that temperature inside the flower was as much as 1°C higher than the outside temperature when the ambient temperature was 30°C and below. When the ambient temperature went above 30°C, however, temperature inside the flower remained lower than that outside (Fig. 26).

The lower temperatures inside the flower were attributed to increased transpiration. Further measurement of temperature inside the flower clearly showed that the temperature differences were greater when ambient air was drier and more transpiration had occurred.



26. Effect of air temperature on flower temperature in the rice plant. IRRI, 1979.

INTERNATIONAL RICE TESTING PROGRAM

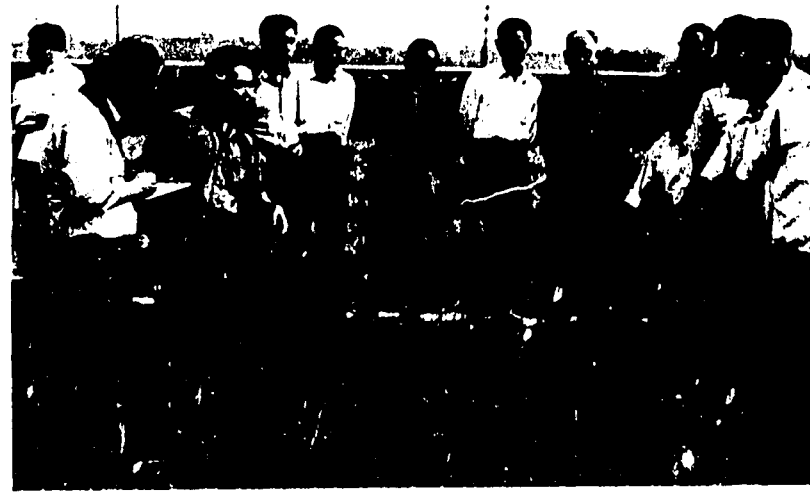
The International Rice Testing Program, already easily identified throughout the rice-growing world by its acronym IRTP, provides a unique unit for collaboration among the world's rice scientists. IRTP provides scientists of all disciplines a chance to participate in a systematic evaluation and development of the diverse rices required to better fit the needs of their farmers.

Five years of IRTP growth

In 1979 IRTP completed its fifth year. During the 5 years it made significant gains – types of nurseries increased from 12 to 16, the number of nursery sets dispatched rose from 457 to about 900, and the number of participating countries, from 40 to 75. The IRTP for Latin America, coordinated from the Centro Internacional de Agricultura Tropical (CIAT), dispatched about 150 sets of 7 nurseries to 21 countries in Latin America. In Africa, the West Africa Rice Development Association (WARDA) tested many of the IRTP materials and disseminated the best entries in its trials. In the large rice-growing countries of Asia IRTP material continued to be integrated into the national rice improvement programs.

Varieties and breeding lines from national rice improvement programs now represent more than half of the test entries in

Rice scientists talk with a Venezuelan farmer during a 1979 IRTP monitoring tour in South America. Such on-farm contact helps increase the effectiveness of IRTP.



A 1979 IRTP monitoring tour in the People's Republic of China brought large numbers of Chinese and Asian rice scientists together for the first time.

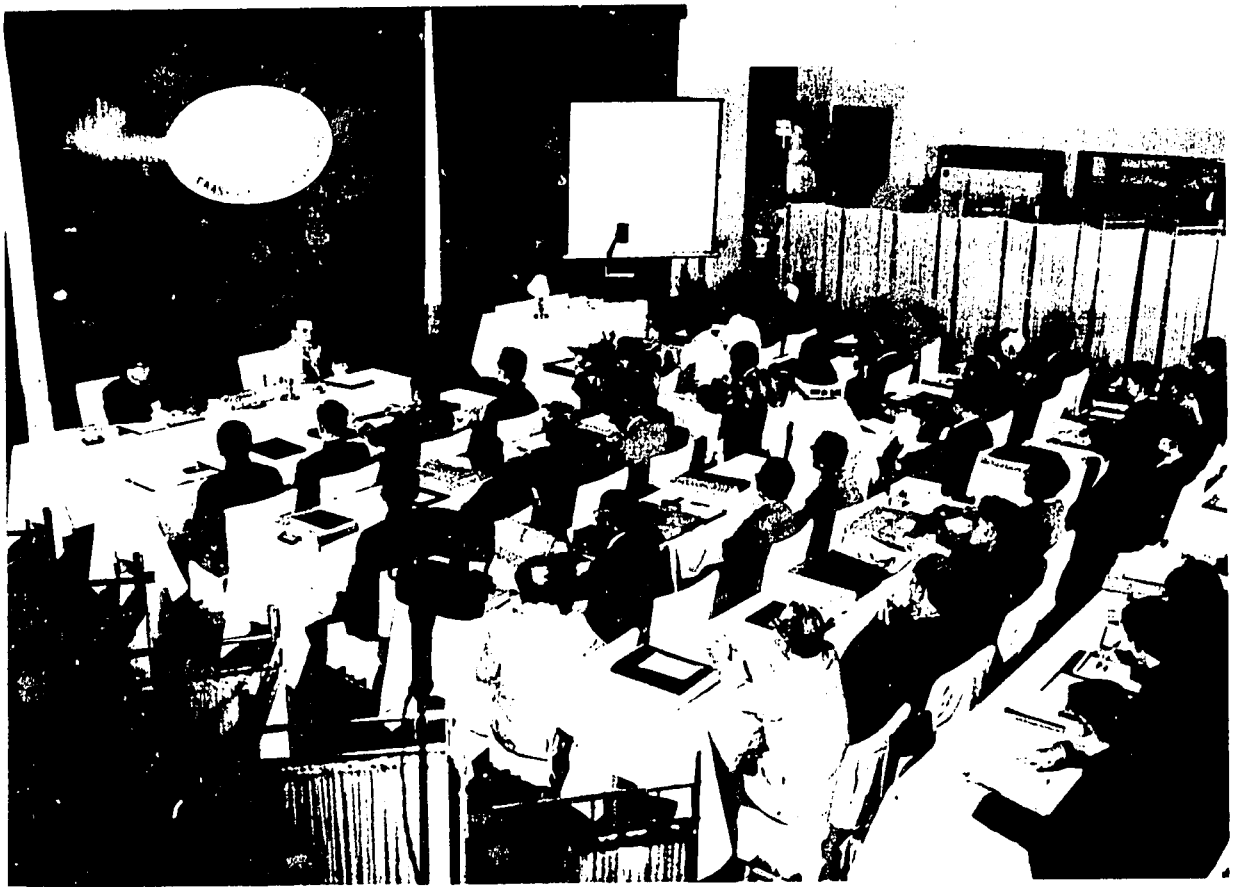
the IRTP nurseries, and many of the national entries performed well in several countries. But the impact of IRTP has been felt most through cooperating scientists who have identified and used the best IRTP entries in the diverse environments of their respective regions.

We made significant progress in improving the analysis of the wealth of data collected from IRTP trials worldwide. In 1979 we analyzed all data from 1978 nurseries and got reports quickly to cooperating scientists, which gave them valuable information for planning next season's experiments.

During 1979 seeds for more than 1,000 test nurseries were dispatched from two central points: 923 nurseries from IRRI to 55 countries around the world, and 150 nurseries from CIAT to 21 Latin American countries. For the first time, scientists from the People's Republic of China participated in trials of nurseries (Fig. 27). Some highlights of the nursery results are in Table 10.

Table 10. These promising entries from some of the IRTP nurseries tested in 1978–79 indicate the enormous pooling of rices from a broad range of environments for testing in IRTP. Only those with an IR designation originated at IRRI. The parentheses enclose recently named varieties.

Nursery	Promising entries
IRYN-Early	IET4094 (CR156-5021), IR5853-118-5, IR9093-216-3, IR36, B541b-Pn-58-5-3-1, MRC603-303
IRYN-Medium	BR51-46-5, IET6073 (RP825), IR2058-78 (IR46), IR4570-83 (IR48), IR42, IR5853-162-1-2-3, BR51-282-8
IRYN-Late	CR1002, CR1009, IET5656 (RP975), RP1064-14-2-2, IR4625-132-1-2
IURYN	IR1529-430-3 (IR43), IR9669 Sel., IET1444, IR36, IR2035-242-1 (IR45), IR3839-1, B541b-Kn-19-3-4
IRBN	IR1905-PP-11-29-4-61, IR3259-8-172-5, IR4547-2-1-2, IR4547-16-1-5, IR9660-00948-1, IR9852-18-1
Sheath blight	IET4699 (RP967-11), IR4422-98-3-6, Suduwee, Tadukan
IRTN	ARC11554, BKNBR1031-7-5-4, BKNBR1031-41-2-6, DWA8, Gam Pai 30-12-15, IR8158-44-2-1, IR8608-298-3-1, Utri Merah, Utri Rajapan, Pankhari 203, Habiganj DW8
IRBPHN	PTB33, Sinna Sivappu, Hondarawala, Mudu Kiriyal, Suduru Samba
IRGMN	BG404-1, W1263, RPW6-17
Stem borer	IR1820-52-2 at vegetative stage, IR4227-28-3-2 at heading stage



An international rice research workshop was held in October 1979 at the Guangzhou branch of the Chinese Academy of Agricultural Sciences. The workshop, which brought together 30 rice scientists from 8 Asian nations, was jointly sponsored by the Academy and IRRI.

Monitoring tour remains key to IRTP planning

We continued IRTP monitoring tours and workshops as keys to broadening the base of IRTP planning and other international GEU activities. Four monitoring tours were conducted in 1979. The first was in South America, following a Latin American IRTP Workshop held at CIAT. Tour participants visited Ecuador, Colombia, Venezuela, Guyana, and Surinam to observe research activities and on-farm conditions for dryland and irrigated rice.

Two problem-area tours were held in Asia: one on diseases with focus on bacterial blight and one on insects with focus on brown planthopper and gall midge.

The fourth tour was associated with the first International Rice Research Workshop in the People's Republic of China. Workshop participants discussed integrated pest control with focus on the use of resistant varieties and cultural control. The monitoring tour covered research institutes and rice production communes in Guangdong and Hunan provinces.

Control and management of pests

The development of rices with resistance to diseases and insects in our GEU research helps to reduce the toll taken by rice pests in farmers' fields. But we also seek improved cultural, biological, and chemical means to reduce that toll. The goal is development of simple, inexpensive, environmentally acceptable techniques for pest control – including weeds – to serve the needs of the small-scale Asian farmer.

DISEASES

Serious outbreaks of diseases in rice fields around the world make it increasingly evident that the modern disease-resistant rice varieties must be backed up by other disease control programs if maximum yields are to be obtained. This is especially true in areas of intensive crop production.

Effective management of rice diseases requires the integration of resistant varieties into control programs based upon the use

Even with the advent of rices resistant to diseases and insects, the use of chemical pesticides is required. IRRI research continues to seek more effective, lower cost pest control techniques that fit the needs of the Asian farmer.

of cultural practices, biological control, mandated regulatory practices, and chemical pesticides. We intensified research on disease control with cultural practices and chemicals in 1979.

Cultural control of fungus diseases

Sheath blight is the major disease of irrigated rice in the world. We found the sheath blight fungus *Rhizoctonia solari* to cause disease on 11 weed grasses in dryland and wetland fields. The weed hosts provide a continuous source of sheath blight inoculum in the tropics, and all growth stages of the pathogen are abundantly present in fallow or idle rice fields. Survival of the sheath blight pathogen on rice straw in paddy fields was reduced when the fields were continuously flooded. In dryland rice fields, sheath blight survival was affected by other soil microorganisms, especially bacteria and *Trichoderma* sp.

We found that the leaf scald fungus *Rhynchosporium oryzae* is a seed-borne pathogen of rice. Infected seeds appear to be a source of primary inoculum in disease development in the field. The pathogen survived for more than 7 months in air- and sun-dried seed stored at temperatures of 20, 25, 30, or 35°C.

Seedling blight, caused by Sclerotium oryzae, *is the most serious disease problem in rice seedling beds in the tropics. The seedlings on the right grew from seed slurry-treated with Vitavax 75 WP at the rate of 50 g/100 kg of seed. Seed in the middle tray were treated at the rate of 25 g/100 kg; those on the left were not treated.*

Cultural control of bacterial diseases

Survival of *Xanthomonas oryzae,* the causal agent of bacterial blight, was highly variable, depending upon its growth stage in the disease cycle. In the resting stage, either in pure culture or in diseased leaves or husks of seeds, *X. oryzae* was highly tolerant of temperatures as high as 50°C. In the growth stage, however, the bacterium could not survive at temperatures of 40°C for 5 hours.

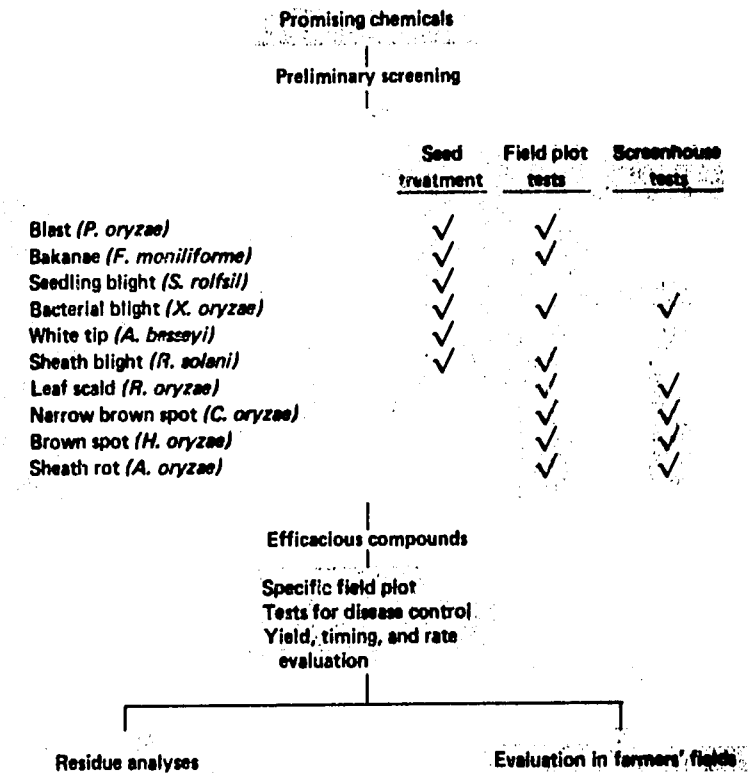
Cultural control of virus diseases

We tested and confirmed a method of predicting or forecasting the incidence of tungro. The number of tungro vectors and percentage of infective vectors present in Luzon rice fields in April–June 1979 were shown to be directly related to the incidence of tungro disease occurring in rice fields from June to November. This tungro forecasting system was proposed in 1978 after several years of study.

Chemical control of rice diseases

Research on chemical control of diseases was expanded in 1979. We emphasized the development of chemical control measures for rice diseases, including seedling and seed-borne diseases, leaf and seedling blast, and sheath blight (Fig. 1) – diseases that cannot be controlled effectively with resistant varieties or cultural practices.

I. Diagram of procedures commonly used for screening and evaluating chemicals for disease control. At IRRI, special emphasis is given to control of diseases for which host resistance is weak or nonexistent.

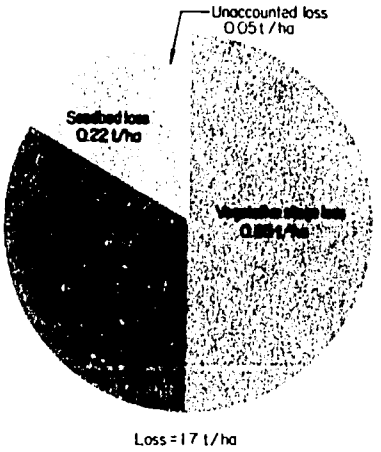


- The use of systemic fungicides applied as seed treatments appears to offer a safe and economical means of controlling several diseases. These chemicals can be easily and conveniently utilized by both small- and large-scale rice farmers.
- Effective control of bakanae, blast, narrow brown spot, and sheath blight was obtained with several systemic chemicals applied as seed treatments. Chemical treatment is the only effective control measure for sheath blight at the present time.

INSECTS

The continuing need for on-farm control of rice insect pests is underscored by the results of a simple test of insect losses in farmers' fields in 1979. We used insect-resistant and susceptible varieties and determined losses caused by insects by comparing yields in fields with maximum chemical treatment for insect control with those in fields with no treatment.

Where IR22, which is susceptible to most of the major insect pests, had no treatment, yield losses were about 34%. This suggests that major insect pest pressures were only moderate. Losses for varieties resistant to those pests averaged 18%. IR22



2. IR22, which is not resistant to most major insect pests, yielded 4.9 t/ha with complete insecticide protection in a farmer's field but had a loss of 1.7 t/ha when no insecticide was applied. Insecticide omitted only in the seedbed caused 13% of the loss; omission of insecticide at the vegetative stage gave 50% loss, and omission at the reproductive stage gave 34% loss.

had a 1.7 t/ha yield loss, 50% of which occurred when the vegetative stage (transplanting to panicle initiation) was not protected with insecticide (Fig. 2).

Integrated pest management

We examined an integrated pest management (IPM) approach to insect control, where insecticide is applied only when an insect population or damage reaches an economic threshold.

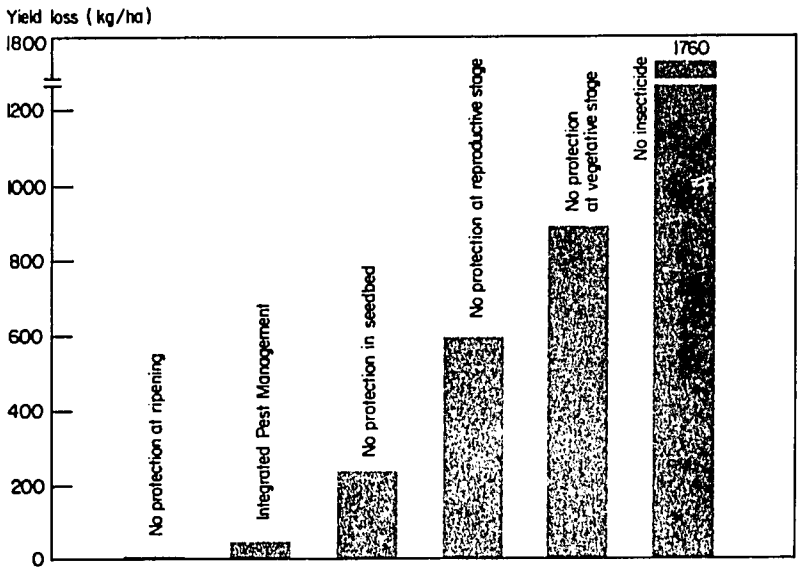
Yield losses with IPM were low and yields were almost equal to those with maximum protection (Fig. 3). Profit was higher for IPM than for other control techniques because of the higher cost of insecticides used for maximum crop protection. But even though the benefit-cost ratio for insecticide use in IPM was highest, it was not sufficiently high to be attractive to farmers.

The low attractiveness of IPM called for development of techniques to improve its effectiveness and decrease the cost of its various components. We started testing new techniques in farmers' fields in Nueva Ecija province in cooperation with Philippine Government agencies.

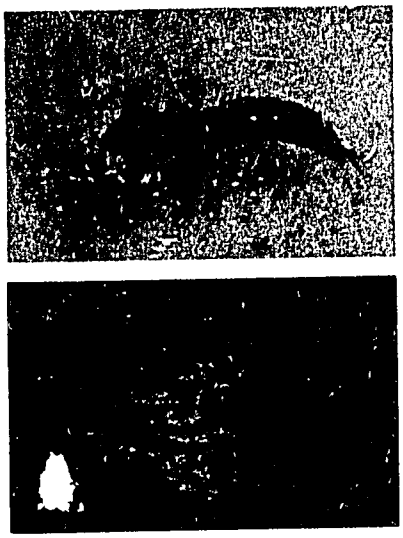
Insecticide evaluation

A new technique for rearing the rice bug facilitated the development of a laboratory procedure for insecticide evaluation against this pest. For the first time we identified several commercially available insecticides for rice bug control. We also identified several coded compounds that provide effective brown planthopper control in field tests.

3. Yield losses when insecticides are applied based on economic threshold and when various rice growth stages are not protected.



Integrated pest management techniques were developed and tested in farmers' fields in Nueva Ecija province, Philippines, in 1979. This group of farmers was at a pilot program clinic run by entomologists from IRRI and the Regional Crop Protection Center of the Bureau of Plant Industry.



Extracts from an indigenous tropical plant were lethal when applied topically to larvae of the green hairy caterpillar. The larva on the top shows the effects of the extract. A healthy larva is at the bottom.

Plant chemicals for pest control

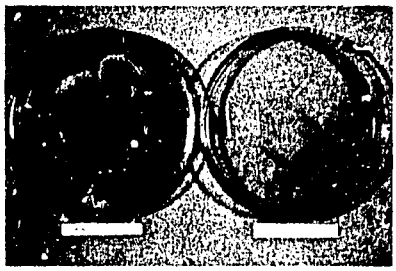
Because of rapidly increasing costs of petroleum-based insecticides, we started a search for commonly occurring insect-resistant plant species that might be useful in an integrated pest control program.

In cooperative studies with the International Centre of Insect Physiology and Ecology (ICIPE), the extract of an indigenous plant was found effective against numerous insect pests (Table 1). Even extremely small quantities of the extract repelled insect pests, reduced their feeding, disrupted embryonic and larval growth, and decreased survival and oviposition. Sprays of the plant extract reduced BPH nymphs and adult populations in the field.

We also tested the extract against common rice pathogens and found that it inhibited the growth of causal organisms of bacterial blight, leaf streak, leaf rot, and wilt, and the fungal leaf scald, narrow leaf spot, blast, and sheath rot. Further tests

Table 1. Examples of selected rice insect pests against which the extract of an indigenous plant was effective in laboratory tests. IRRI, 1979.

Insect pest	Effect of extract
Brown planthopper	Adult and nymphal mortality increased
Whitebacked planthopper	" " " " "
Green leafhopper	" " " " "
Rice bug	Egg hatchability reduced, nymphal mortality increased
Whorl maggot	Egg hatchability reduced, adult mortality increased
Striped borer	Egg hatchability reduced, larval growth disrupted
Leaf folder	Repellent, antifeedant, growth disrupted, oviposition inhibited, egg hatchability reduced
Caseworm	Egg hatchability reduced
Green hairy caterpillar	" " "



In tests of an extract from an indigenous plant, 1 mg extract/cm² on nutrient agar inhibited the growth of the rice blast organism Pyricularia oryzae.

against the rice blast fungus showed that the extract inhibited mycelial growth and spore germination.

The plant extract had negligible or no toxicity on the rice insect predators common in the rice fields – spiders, mirid bugs, and *Microvelia*.

Another natural product that showed promise in pest management is the seed oil from the neem tree. It was highly effective against the rice leaf folder from egg to adult stages. In laboratory studies larval feeding was significantly reduced on leaves sprayed with 12% or higher concentrations of emulsified crude neem oil. On plants treated with neem oil, leaf folder moths laid only about one-third the number of eggs laid on plants sprayed with water. Hatchability of eggs on treated plants was 25–50%, that on nontreated plants was about 80%.

Neem oil also had a synergistic effect on parasitization of leaf folder larvae. Rice fields sprayed with 50% neem oil had about 35% larval parasitization, nearly twice as high as that in control plots.

Insecticide application methods

The size of insecticide droplets has an important effect on the efficacy of an insecticide spray. Insect control with a spinning-disc ULV (ultra-low-volume) sprayer, which produces small droplets, was compared with control by the common knapsack sprayer. When spraying was done after the rice canopy had closed, the ULV sprayer deposited more insecticide on the leaf sheath where the brown planthopper feeds.

A combination row marker-insecticide injector developed by IRRI engineers was tested as a means for root-zone application. Field plots treated with a low rate of carbofuran matured about 2 weeks before the untreated rice (Fig. 4), but because of the

4. The center plot was treated with a low rate of carbofuran (200 g a.i./ha) applied with an experimental row marker-insecticide injector. The treated crop matured 2 weeks earlier than the same variety in untreated adjoining plots. Early maturity is common in carbofuran-treated plots.

Table 2. Greenhouse experiments were conducted in 1979 to determine whether plant growth stimulation by carbofuran would also occur in the absence of insects. Plant weight, height, tillering, and grain weight all increased in the carbofuran-treated plants, and days to flowering decreased.[a]

Treatment	Seedling weight (mg) (21 days old)		Plant height (cm)	Tillers (no.)	Productive tillers (%)	Days to flowering	Grain weight (g/plant)
	Stem and leaves	Root					
Carbofuran	32.2 a	9.9 a	101 a	17.3 a	58 a	76 b	8.3 a
Check	25.8 b	4.5 b	87 b	11.2 b	36 b	83 a	4.2 b

[a]Within a column, numbers followed by a different letter are significantly different at the 5% level.

low insect population we were unable to attribute the early maturity to insect control.

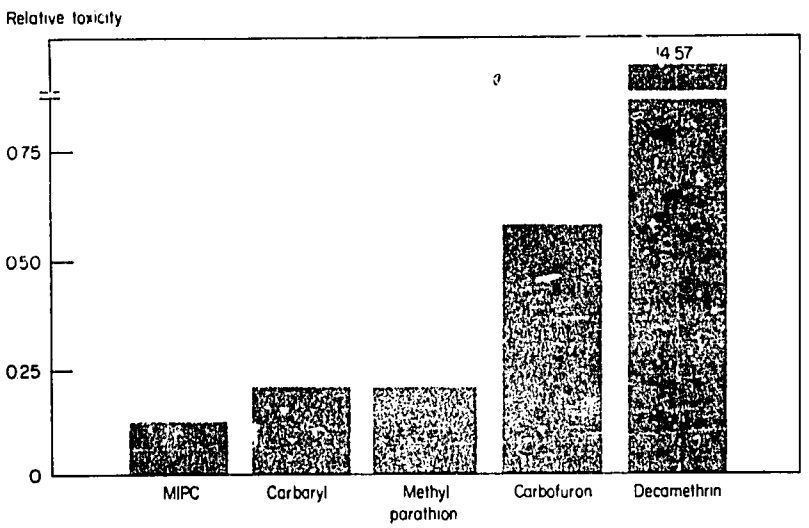
Early maturity and increased tillering and height are common characteristics of carbofuran-treated plants (Table 2).

Brown planthopper resurgence

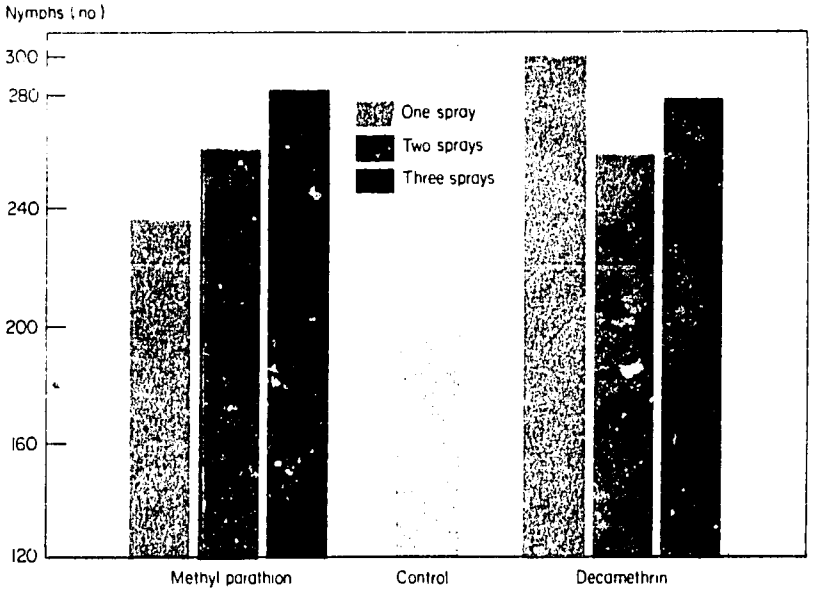
We continued studies to better understand why brown planthopper numbers tend to increase to outbreak proportions when some insecticides are applied. This phenomenon, called resurgence, was investigated in the laboratory and the field to determine the role of natural enemy destruction.

We found that insecticides had no effect on parasitization of brown planthopper eggs, but in some cases affected predators. Studies to determine the relative toxicity of resurgence- and nonresurgence-inducing insecticides on the mirid predator *Cyrtorhinus lividipennis* and the brown planthopper indicated that MIPC, a nonresurgence insecticide, was much less toxic to the predator than decamethrin, a resurgence-inducing insecticide (Fig. 5). But methyl parathion, which also causes resurgence, had a low relative toxicity.

Studies continued to determine the role of resurgence-inducing



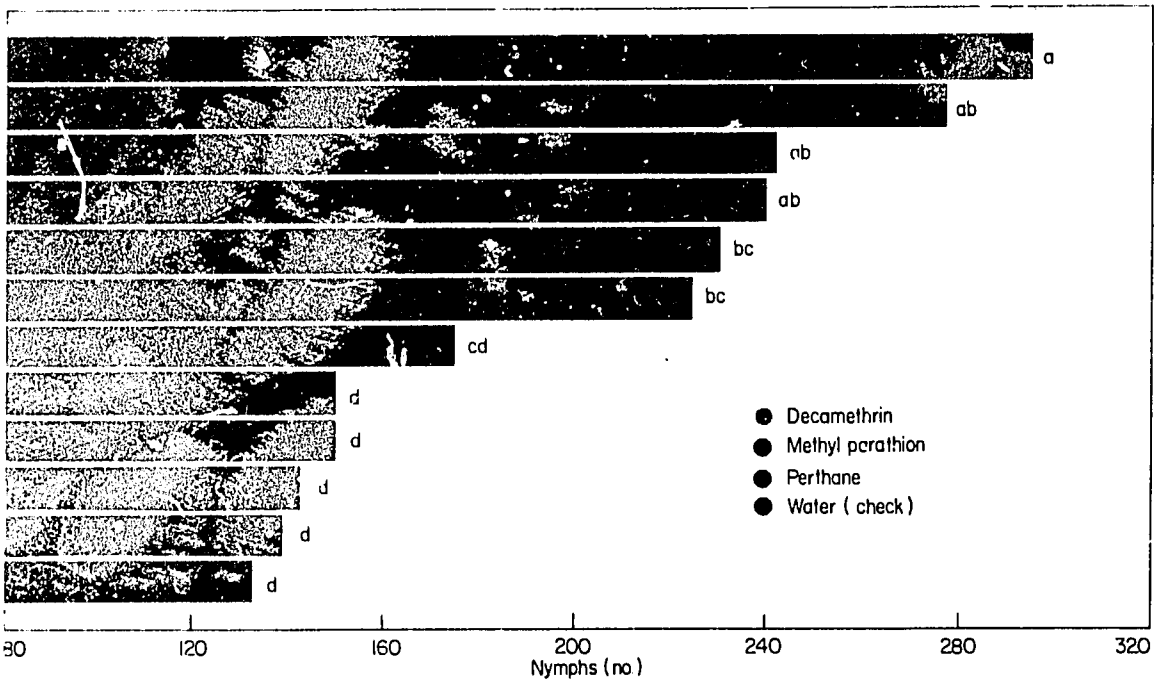
5. Decamethrin, an insecticide that induces resurgence of the brown planthopper, is highly toxic to *Cyrtorhinus lividipennis*, a predator of the planthopper. MIPC, an insecticide relatively nontoxic to the predator, does not cause brown planthopper resurgence but methyl parathion, which is also relatively toxic to the predator, causes resurgence.



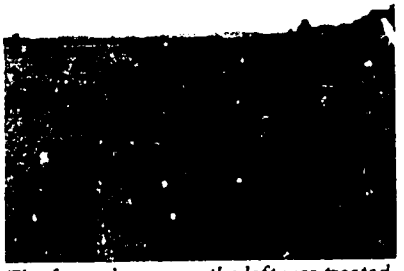
6. In 1979 laboratory tests, a single spray with resurgence-inducing insecticides increased the reproductive rate of brown planthoppers. The bars represent nymphs that hatched from eggs laid on rice plants by 2 females in 7 days. The count was made 15 days after the last spray.

insecticides on insect reproductive stimulation. Laboratory tests indicated that one application is sufficient to cause a significant increase in the reproductive rate (Fig. 6).

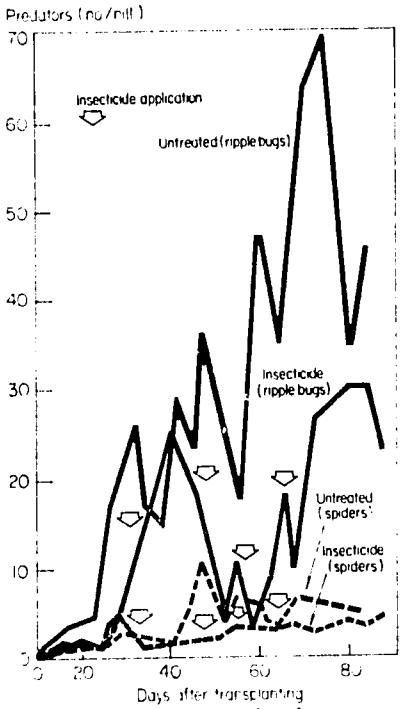
When we used different insecticides in a spray sequence and released brown planthoppers on the sprayed plants after the last application, the level of resurgence depended on which insecticides we sprayed last (Fig. 7).



7. The reproductive rate of brown planthopper as influenced by insecticides used in a spray sequence was tested. When Perthane, a nonresurgence insecticide, was applied after two sprays of decamethrin or methyl parathion, both resurgence insecticides, there was no increase in number of nymphs produced.



The farmer's crop on the left was treated with insecticides but later was hopperburned and lodged. The crop on the right received no insecticides and brown planthoppers were scarce. Careful pesticide management is needed to prevent undesirable side effects.



8. Brown planthopper outbreaks may be caused by reductions in the populations of predatory ripple bugs and spiders following sprays with decamethrin at 47, 56, and 66 days after transplanting.

Ecology of the brown planthopper

Outbreaks of the brown planthopper have been attributed to agronomic practices associated with high rice yields. But susceptible varieties grown at IRRI in 1979 according to such recommended practices but without application of insecticides rarely had brown planthopper damage.

To understand the mechanism, or mechanisms, of outbreaks, we monitored the survival of natural field populations of brown planthopper in several susceptible varieties at IRRI and in nearby farmers' fields. Use of a new suction sampler provided data never before obtained in the tropics.

Survival of brown planthopper eggs and nymphs was low, and the average survival from the egg through the nymphal stage was usually less than 10%. Reproduction did not appear to compensate for these death rates, and the populations naturally declined. Evidently natural control by predation and parasitization suppressed the pest population.

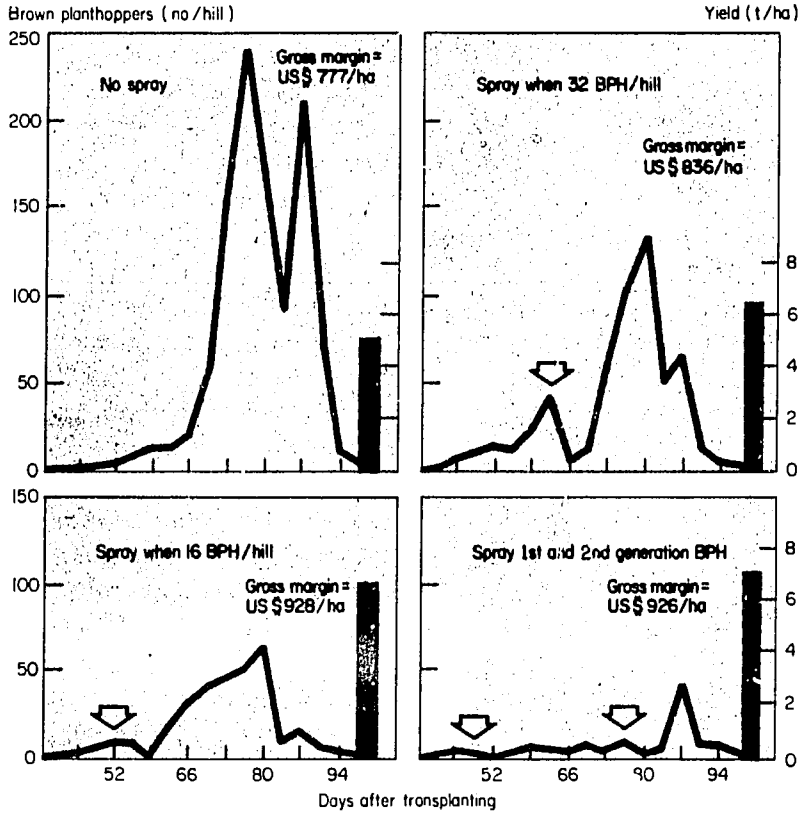
We compared the abundance and survival of brown planthopper and two important predator species in two IRRI fields – one was treated with insecticide and one nearby was left untreated. The brown planthopper population in the untreated field remained small and survival was very low as expected, but in the treated field pest density and survival increased, ultimately causing hopperburn. Because of insecticide treatment, the abundance of natural enemies such as predatory spiders and ripple bugs decreased (Fig. 8). The decrease was a possible major cause of the increase in brown planthopper survival and a pest population explosion. Trials in greenhouse cages indicated that decamethrin, the main insecticide applied in this experiment, kills the important spider *Lycosa pseudoannulata* within 1 day.

Timing of insecticides for brown planthopper control

Perthane application for brown planthopper control was timed considering the life cycle of the insect, its number, light trap catches, and a calendar schedule. Yields – and profits – were highest when Perthane was applied at the peak of the first and second generations (based on the life cycle) or when the number of planthoppers reached 16/hill (Fig. 9). Calendar-based sprays without regard to abundance or insect generation were less effective and less profitable.

Brown planthopper migration

Transoceanic migration of the brown planthopper occurs in Japan, and on the basis of meteorological events and the extent of the immigration, relatively accurate predictions on the need



9. Timing of insecticide (Perthane) application for brown planthopper control was tested on a susceptible variety (IR42) in the 1979 dry season after we had applied decamethrin to all plots to increase brown planthopper populations. The benefit-cost ratio for insecticide was highest with 1 application/crop at the time the insects numbered 16/hill. This study confirms previous results, which established an economic threshold of 20 hoppers/hill or about 1 hopper/tiller.

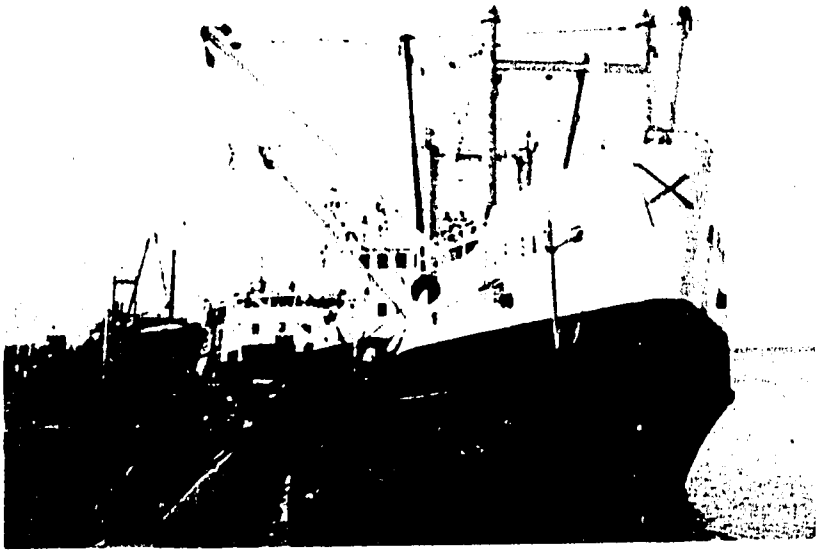
for control have been made. To better understand the extent and role of short-distance (farm-to-farm) and long-distance (interisland) movement in outbreaks in the tropics, a cooperative study was started with scientists of the Centre for Overseas Pests Research in London and ICIPE in Nairobi.

Daily monitoring of hoppers at IRRI showed that immigration activities occurred mostly during the vegetative stage of crop growth. Studies on short-distance movement in farmers' fields showed a correlation between aerial activity and the arrival of long-winged adults on the rice crop.

Studies also showed interisland movement of the brown planthopper and other hoppers in the Philippines. During two interisland voyages during the rainy season (June–October), planthoppers were collected in nets and on sticky board traps aboard ships (Fig. 10). This is the time of the year when the southwest monsoon originating in the Indian Ocean flows toward the Philippines. These warm and very moist air currents are ideal for transporting insects over long distances.

Sampling planthoppers and predators

Until 1979 research on the ecology of insects in wetland rice fields had been hampered by the difficulty of obtaining accurate



10. The MV Surigao, a cargo-passenger ship, was used for the first interisland voyage for monitoring long-distance migration of brown planthopper in the territorial waters of the Philippines during June–July 1979. The nets for catching hoppers are seen at the top of the forward masts and on the bow.

IRRI researchers use the newly developed FARMCOP suction device in the field. After carefully placing a covered, square, transparent-plastic and wire-frame enclosure over a rice hill, the operators vacuum animals into the FARMCOP container with a transparent rubber hose.

estimates of planthopper and predator populations. To overcome that problem we developed a simple new suction device, the FARMCOP sampler.

The new sampler consists of a small automobile vacuum cleaner and a collecting container. With the sampler, insects and other animals on plants and the surface of paddy water can be collected. After collection, water sucked into the container is drained and alcohol is added to preserve the animals in a bottle.

Cost of the FARMCOP, including two 12V automobile batteries, is about US$150. A comparison of samples obtained in flooded rice by FARMCOP, large D-VAC, and UNIVAC showed that greater numbers of brown planthopper nymphs and predators, such as ripple bugs and spiders, were nearly always recovered per hill by the FARMCOP (Table 3).

Table 3. Among sampling techniques for transplanted rice, the FARMCOP most accurately measured the populations of brown planthopper nymphs, and predatory juvenile ripple bugs and spiders.[a]

Sampling technique[b]	Brown planthoppers (no./5 hills)		Predators (no./5 hills)	
	Nymphs	Adults	Ripple bugs	Spiders
FARMCOP	22 a	24 b	216 a	68 a
D-VAC	8 b	48 a	51 b	28 b
UNIVAC	2 c	25 b	20 c	19 b
Visual count	1 c	14 b	32 bc	9 b
Mouth aspirator	2 c	17 b	0 d	15 b

[a]Within columns, means followed by a common letter are not significantly different at the 5% level. [b]Uncovered enclosure was used with all techniques except visual count.

11. The three trays of IR36 seedlings in front illustrate the increase in herbicide damage as seeding depth decreases. Seeding depth was 1 cm for the tray on the left, 3 cm for the center tray, and 5 cm for the right. Note also the marked effect of the herbicide antidote naphthalic anhydride in the 1-cm depth seeding. The three trays at the back had the antidote applied as dry powder at 1% of seed weight.

WEEDS

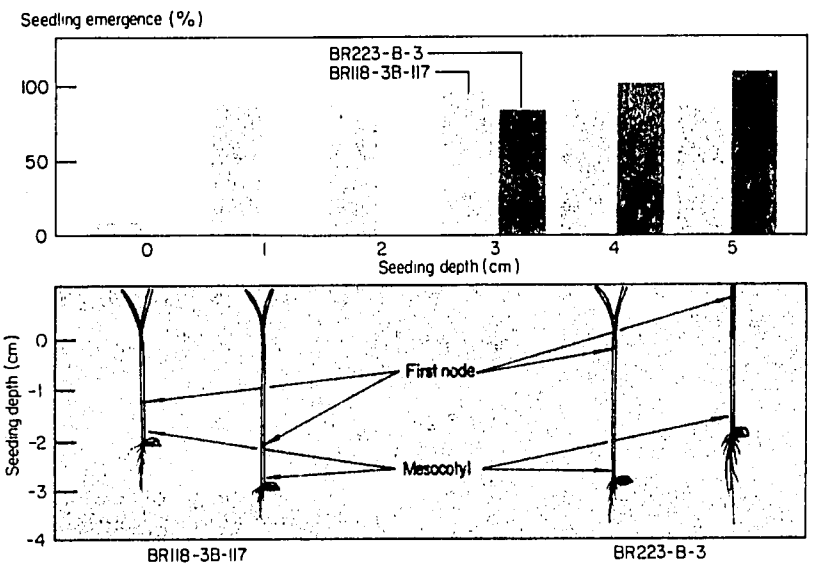
Problems of weed control and management continue to face tropical rice farmers, especially where rice other than irrigated transplanted is grown. We continue to seek both cultural and chemical means of managing weeds.

Some effective herbicides also have toxic side effects on rice. For example, butachlor and thiobencarb may cause damage to dry-seeded rice when used at rates necessary to kill weeds. The herbicide tolerance of two rices, IR36 and Salumpikit, increased as the depth of seeding increased. Figure 11 shows the tolerance of IR36. The use of the herbicide antidote naphthalic anhydride gave IR36 greater protection against butachlor than against thiobencarb, but for Salumpikit the reverse was observed.

Cultivar tolerance for herbicides

Injury of rice seedlings by preemergence herbicides, which are applied to the soil surface, is influenced by location of the plant's first node in relation to the treated soil layer. Rices with a long mesocotyl and their first node near the soil surface are susceptible to herbicide damage. Rices with short mesocotyls are herbicide tolerant.

We previously identified BR118-3B-17 as tolerant of butachlor, pendimethalin, and thiobencarb. It has a short (6 mm) mesocotyl. BR223-B-3 is susceptible to those herbicides and has a long mesocotyl (26 mm). Figure 12 shows the response of the two cultivars and their parents to thiobencarb for different seeding depths.



12. The effect of thiobencarb on seedling emergence when applied to the soil surface at a rate of 2 kg active ingredient/ha differs depending on seedling mesocotyl length. BR223-B-3 has a long mesocotyl and BR118-3B-17 has a short mesocotyl. Because the first node of BR223-B-3 is near the herbicide-treated soil surface, the plant is damaged by the herbicide.

Table 4. Butachlor followed by 2,4-D or bentazon controlled both *Scirpus maritimus* and annual weeds in transplanted rice at IRRI, 1979 dry season.

Herbicide treatment[a]	Rate[b] (kg a.i./ha)	Weed weight[c] (kg/m²)		Rice yield[c] (t/ha)
		S. maritimus	Annuals	
No treatment	1.0	112 d	196 c	2.6 c
2,4-D	1.0	18 b	135 c	3.7 b
Butachlor	1.0	108 d	33 b	3.9 b
Butachlor fb bentazon	1.0 fb 1.0	11 b	37 b	5.1 a
Butachlor fb 2,4-D	1.0 fb 1.0	24 bc	20 b	5.1 a
Butachlor fb 2,4-D	1.0 fb 0.5	42 c	33 b	4.7 a
Weed-free check		0 a	0 a	5.1 a

[a]fb = followed by. [b]a.i. is active ingredient. [c]Within a column, values followed by the same letter are not significantly different at the 5% level.

Weed control in transplanted rice

We continued our search for chemicals to control both *Scirpus maritimus* and broadleaf weeds. Butachlor followed by either 2,4-D or bentazon provided such control of weeds in transplanted rice (Table 4).

Irrigation water management

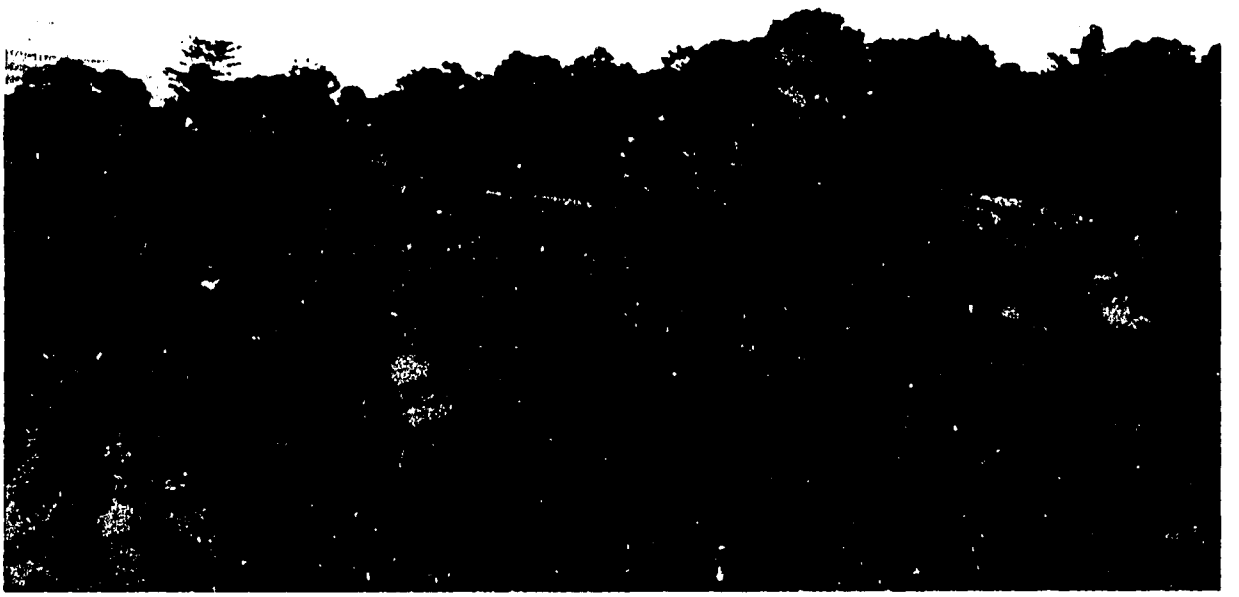
Massive investments in irrigation systems have greatly increased the areas of irrigated rice in South and Southeast Asia since the mid-1960s. The types of irrigation systems that developed differ because of the physical and socioeconomic environments of the different areas and because of the increasing scarcity of easily exploitable water sources.

Unfortunately, many of the existing irrigation systems are not performing at expected levels of efficiency. Our research emphasis in 1979 remained on the performance of irrigation systems and the development of techniques to better utilize their potential to irrigate rice farms.

Evaluation of pump systems

Pump irrigation systems, which include lifting water from surface sources as well as tube wells, are important for Bangladesh and India and are becoming increasingly important in countries such as the Philippines and Thailand. But such systems demand high operating efficiency because of high initial investments and costs to run the pumps.

We evaluated the pumping schedules and water-use patterns of surface-water pumping systems of three different scales in



One of the medium-scale irrigation systems evaluated in 1979 served this isolated farming area in Bulacan, Philippines. Energy costs for pumping water into such systems underscore the need for high operating efficiency.

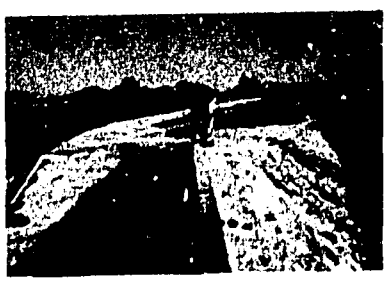
Bulacan province, Philippines, for two consecutive seasons and of two large systems in Bangladesh during the dry season. Two large-scale systems selected in the Philippines each irrigated an average of 480 ha. Three medium-scale farmer group-owned systems irrigated between 22 and 135 ha. Three individually owned small systems irrigated between 2 and 6 ha each.

Generally, all systems were effective in providing farmers with irrigation water supplemental to rainfall. But a comparison of certain aspects of the three systems suggests that farmers in the small systems may have been somewhat more efficient in the use of water (Table 1).

- Farmers in the large systems took longer to prepare their land for planting than did those in the medium and small sized systems. Least land preparation time was taken by farmers in the small systems.
- Farmers in the large systems kept paddy spillway levels an average of nearly 20 mm higher than did small farmers in the small systems. This suggests that farmers in the larger systems may have been somewhat unsure of water supply, and felt a need to keep the water at a higher level in their paddies.
- Even though the effective rainfall was about the same for farms in the three systems during both the wet and dry seasons,

Table 1. Farmers in small pump systems took less time to prepare their lands, used less pumped water, and maintained lower water levels in their fields than farmers in large and medium systems.

Characteristic	Large system (275–685 ha)	Medium system (22–135 ha)	Small system (1–6 ha)
Days (no.) used to prepare land			
Wet season	46.8	40.3	34.0
Dry season	43.3	37.8	35.8
Paddy spillway height (mm)			
Wet season	99	87	79
Dry season	97	88	79
Effective rainfall (mm)			
Wet season	1005	1045	918
Dry season	166	148	196
Water pumped (mm)			
Wet season	232	277	172
Dry season	1080	840	618



Canals such as this, required for pump irrigation systems serving areas of 400–500 ha, are indicative of high initial investment and the need for high operating efficiency.

water pumped by farmers in the small systems was decidedly less than by those in the medium and large system areas.

We found a unique example of good system performance in one medium-scale system serving 25 farmers (27 ha). The average land preparation time per farm was only 22 days in the wet season and 21 days in the dry. The total water used for land preparation amounted to only 321 mm in the wet season and 268 mm in the dry season. The farmers in this system used 50% less water than those in the other medium-scale systems in the wet season and 27% less water in the dry. Comparisons with the large systems showed about 33% less water use in the private system in both seasons. Farmers in the system paid 15% of yield as irrigation water fee; farmers in the large-scale pump systems, which were operated by a government agency, paid an average fee of 200 kg/ha per season.

In a 1978 dry-season study of irrigation in Bangladesh, we found a contrasting picture of the performance within two large pump systems – one serving about 26,000 ha and the other more than 4,000 ha. Both systems suffered from water distribution inequity problems, but the larger system had a higher degree of inequity, especially when water supply was low, because of uncontrolled delivery in the secondary and tertiary canals, and diversion of excessive water by farmers close to the water source. The larger Bangladesh system pumped 108% more water into its tertiary canals than was actually required for evapotranspiration plus seepage and percolation losses. Consequently the water use efficiency (WUE) was only 31%. In contrast, the smaller system had 72% WUE, because it had delivered only about 30% more water than was actually required into its secondary canals.

Table 2. Mean seasonal water use efficiency (WUE) percentage in the Lower Talavera River Irrigation System, Philippines, from the 1975 wet season to the 1979 dry season.

Cropping season	Period	WUE (%)
1975 wet	July–August	43
1976 dry	January–February	51
1977 wet	July–August	60
1978 dry	January–February	60
1978 wet	August–September	50
1979 dry	March–April	73
1979 wet	August–September	70

Evaluation of irrigation system management

During 1979 we evaluated a project, started in 1976 in collaboration with the National Irrigation Administration (NIA), to develop integrated system-management techniques for the 2,500-ha Lower Talavera River Irrigation System.

During the course of the project the efficiency of water use at the farm level improved by almost 30% (Table 2). The major improvement was at the tail end of the system, and resulted from the more equitable distribution of water. The water saved through improved management represented a low-cost additional water supply for use in other irrigated areas of Central Luzon.

An irrigation calendar with a monthly local language message on good irrigation practices was given to farmers before the 1978–79 cropping season, and the calendar's effectiveness was surveyed in 1979. We found that the message of the calendar helped reduce farmers' negative behavior toward irrigation practices. The calendar survey also showed that farmers considered the NIA a highly credible source of irrigation information.

The project evaluation provided clear evidence that simple application of rational management techniques can make marked differences in farmer irrigation behavior, water use efficiency, and rice yields in a large-scale irrigation system.

Problem identification in large irrigation systems

Two large-scale reservoir and three intermediate-scale tank irrigation systems were intensively studied in cooperation with Thailand's Royal Irrigation Department (RID) during 1977–79. The study provided benchmark information about the water and land use in crop production.

In the Nam Phong-Nong Wai Irrigation Project near Khon Kaen, land consolidation, including land leveling and ditch improvement, resulted in increased yields and doubled the dry season mean cropping intensities. Extensive ditch improvements did not increase cropping intensity but gave a water-use

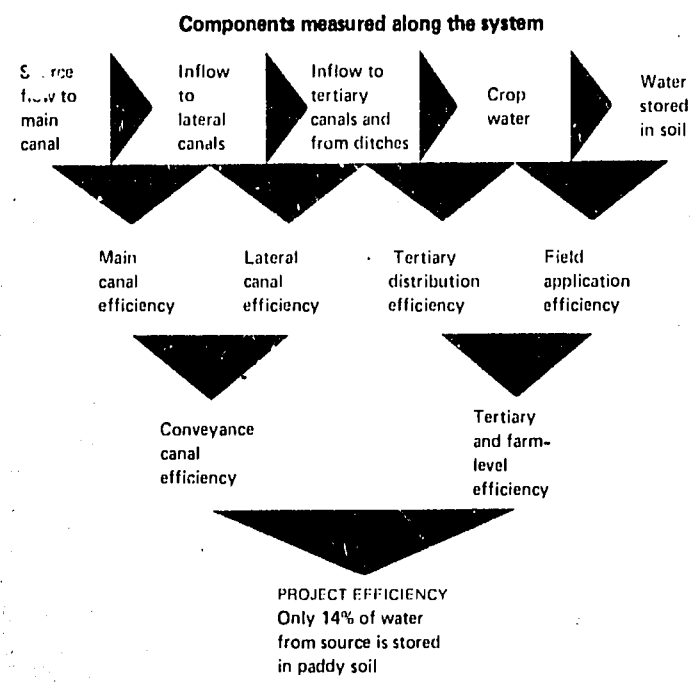
Table 3. Land consolidation provided greater overall benefits than ditch improvement in the Nam Phong-Nong Wai Project, Thailand (1978 dry season–1979 wet season).

	Water utilization efficiency (%)		Seasonal cropping intensity (%)		Rice yields (t/ha)	
	Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
Intensive land consolidation	59	58	80	100	2.61	2.96
Extensive ditch improvement	61	57	20	100	1.94	2.62
Unimproved	24	67	9	100	1.81	2.34
Overall project weighted mean	55	63	36	100	2.36	2.55

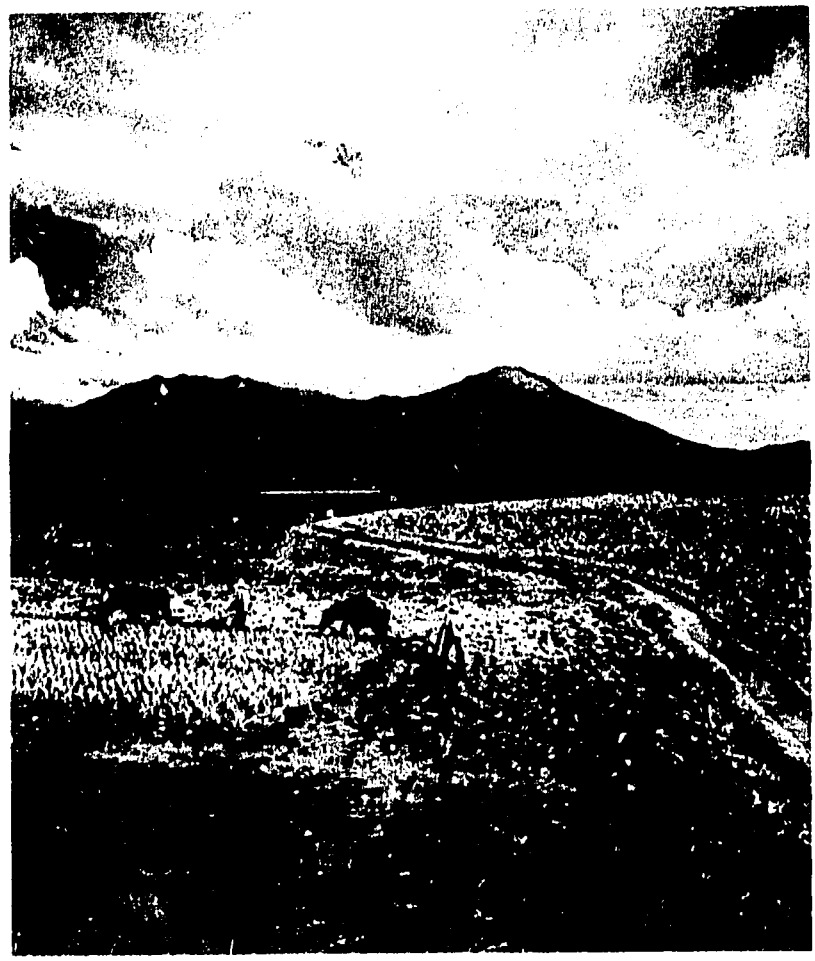
efficiency level equivalent to that from intensive land consolidation (Table 3).

In the Lam Pao Irrigation Project near Kalasin, we found the dry season conveyance efficiency to be 45% for the main system and 32% for the tertiary system. Figure 1 diagrams the components used to determine overall system performance (14%).

The efficiency values for the two Thai systems are not uncommon in systems throughout the world where water is abundant and inexpensive. The low efficiency indicates potential future problems as the total area to be served by the system is brought under irrigation.



1. These components of efficiency were observed for the 1978 dry season in the Lam Pao Irrigation Project, Thailand.



Effective irrigation calls for good management of the system and improved communication between farmers and system managers.

The three tank irrigation systems evaluated in northeastern Thailand have a unique set of problems. Although water is available, no appreciable area is cropped in the dry season because farmers perceive a shortage of water at their farms. A history of poor water delivery in dry seasons significantly affects the willingness to try dry season cropping.

In the 1978 dry season the water released for cropping ranged from 4.4 to 10.2% of the reservoir's capacity, and 22 to 40% of the capacity remained unused at the end of the season. The ratio of unused capacity to released water indicated that 3.5–5.5 times more water could have been used for dry season irrigation. There was, however, lack of communication between farmers and the RID gatekeeper.

Our study showed that land and water resources in the five systems are not effectively used in the dry season. A need for intensification of tertiary irrigation facilities, better management of water deliveries, and improved communication between farmers and irrigation system managers was clearly indicated.

Soil and crop management

Modern rice varieties often do not perform as well in farmers' fields as in research plots. Differences in soil characteristics, and in the soil and crop management practices followed by farmers, are known to account for much of this performance gap. Rising input costs, especially for fertilizers, dictate more detailed attention to rice-growing soils and their management, as well as to crop culture. In 1979 we gave particular attention to nitrogen fixation and to the characterization of rice soils.

EFFICIENCY OF NITROGEN UTILIZATION

We sought ways to increase the efficiency of nitrogen fertilizer utilization using different sources and placements of nitrogen materials.

Plow-sole application of nitrogen fertilizer

We know that placement of nitrogen fertilizer 10–12 cm deep in the paddy soil can greatly reduce nitrogen losses. But one of the greatest challenges for soil scientists, agronomists, and agricultural engineers is to make the concept of placement of fertilizer nitrogen relevant to the farmer. An IRRI-designed plow-sole applicator that attaches to the ordinary plow combines land preparation with fertilizer nitrogen application and increases fertilizer efficiency (Fig. 1). A side benefit is the reduction of labor needed to apply a basal dose of fertilizer.

We initiated a number of field trials using the new placement equipment. Performance was generally satisfactory where the soil was kept flooded after the nitrogen was applied. Data from

1. This plow-sole applicator, driven by the large-spoked wheel (behind plow), meters fertilizer directly into the bottom of the furrow where it is covered by the next pass of the plow.

Table 1. Nitrogen fertilizer applied for IR36 in the 1979 wet season with a plow-sole applicator and as a split application – 2/3 broadcast and incorporated before transplanting and 1/3 applied a week before panicle initiation – showed significant yield benefit from the plow-sole method.

Method of application	Grain yield[a] (t/ha)
No fertilizer nitrogen	3.11 d
28 kg N/ha	
Plow-sole applicator	4.21 b
Split application	3.54 c
55 kg N/ha	
Plow-sole applicator	5.14 a
Split application	4.00 b

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

one such trial (Table 1) show that nitrogen applied in the plow sole as urea gave significantly higher rice yields than urea nitrogen applied by the split-dose system commonly used by farmers.

Fertilizer source and placement studies

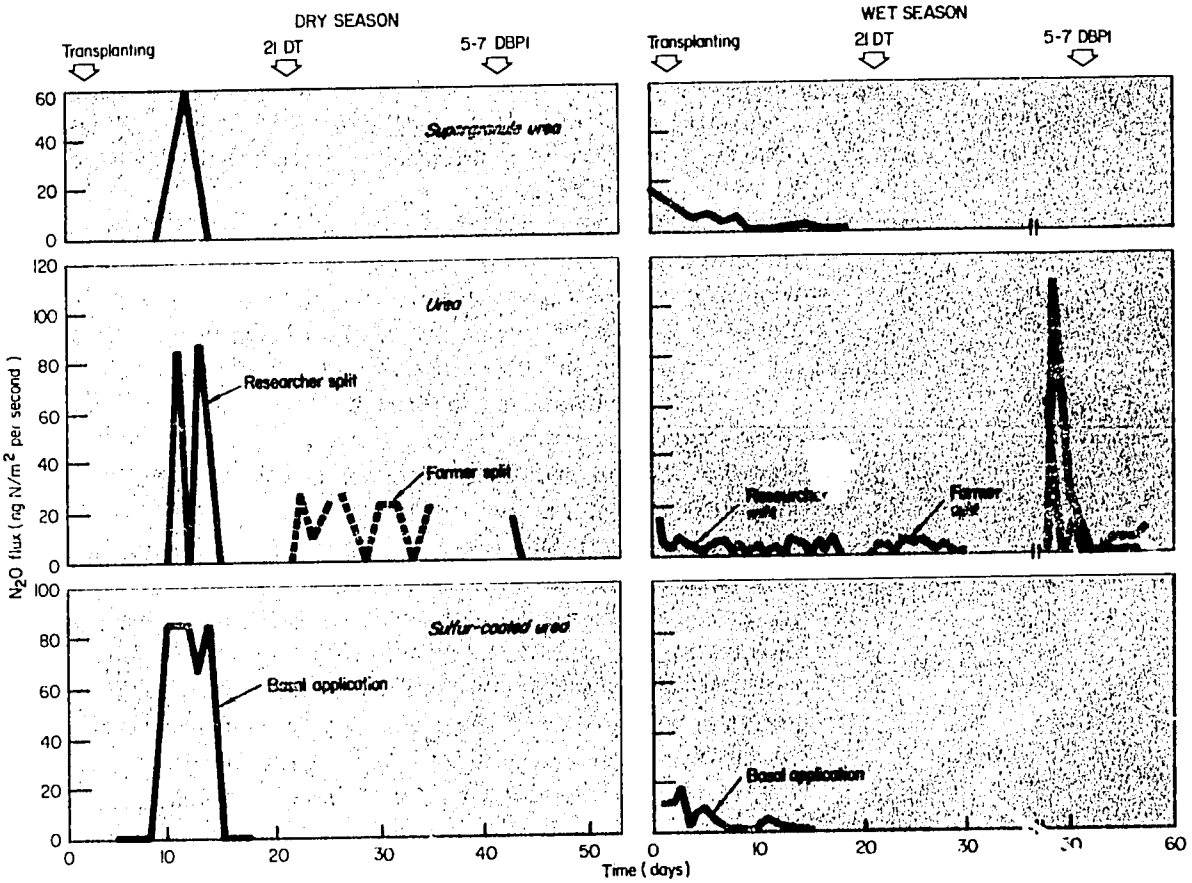
Much of the fertilizer nitrogen applied by farmers is as a broadcast application 2–3 weeks after transplanting. In 1979 we compared the farmers' method with another split application and deep placement using, in addition to prilled urea, supergranules and sulfur-coated area.

Supergranules placed in the root zone and slow-release sulfur-coated urea generally gave the highest yields and highest recovery of the nitrogen applied (Table 2). The farmers' method of applying nitrogen as a topdressing 3 weeks after transplanting generally gave the least satisfactory results. Nitrogen recovery from supergranules placed in the root zone was at least twice as high as that for the farmers' method of application.

Table 2. The differential response of rice to basal and delayed split applications of prilled urea, and to slow-release and root-zone placement fertilizers. In both 1979 dry and wet seasons at IRRI, the most effective was root-zone placement of urea supergranules, followed by sulfur-coated urea applied just before transplanting.

Form of urea	Fertilizer timing[a]			Dry season (IR36, 87 kg N/ha)[b]		Wet season (IR44, 54 kg N/ha)[b]	
	0 DT	21 DT	PI	Grain yield (t/ha)	Apparent N recovery (%)	Grain yield (t/ha)	Apparent N recovery (%)
No nitrogen	0	0	0	4.1 e		3.1 e	
Prilled (researcher split)	2/3	0	1/3	5.7 b	44 b	4.0 b	35 c
Prilled (farmer split)	0	2/3	1/3	5.4 c	23 c	3.8 b	36 c
SCU[c] (soil incorporated)	All	0	0	5.8 b	46 b	4.9 a	78 ab
Supergranule (root zone)	All	0	0	6.2 a	75 a	5.1 a	85 a

[a]DT = days after transplanting, PI = panicle initiation. All basal (0 DT) fertilizers were broadcast and incorporated, except that the supergranules were placed 10 cm deep, 1/4 hills. All 21 DT and PI applications were broadcast directly on the floodwater. [b]In a column, means followed by the same letter are not significantly different at the 5% level. [c]Sulfur-coated urea, forestry grade.



2. Nitrous oxide flux is affected by time and mode of fertilizer nitrogen application. Measurement of nitrous oxide in these IRRI trials gave the first field evidence of nitrification-denitrification in tropical wetland soils. IRRI, 1979 dry and wet seasons. Differences in urea form and methods of application are seen in Table 2, page 78.

We measured dissolved nitrogen levels in the paddy water as well as the evolution of nitrous oxide in this trial. Treatments in which urea was surface broadcast produced high concentrations of urea in the floodwater, particularly in the dry season. Deep placed and slow-release urea fertilizers produced relatively low concentrations of dissolved nitrogen in the floodwater. In the wet season, such low concentrations corresponded with the higher crop recovery of the nitrogen applied.

Measurement of nitrous oxide evolution from the fertilizer test plots provided the first field evidence that nitrification-denitrification occurs in tropical wetland soils (Fig. 2). Because nitrous oxide is one of the products of the process, the relatively low rates of evolution do not represent the total loss due to denitrification. The data, however, show that so far as pollution of the stratosphere is concerned, nitrous oxide from rice soils may not constitute a major environmental hazard.

The relatively high rates of nitrous oxide evolution in the dry season and the flush of nitrous oxide from the panicle initiation dose of split urea applied in the wet season conform with high

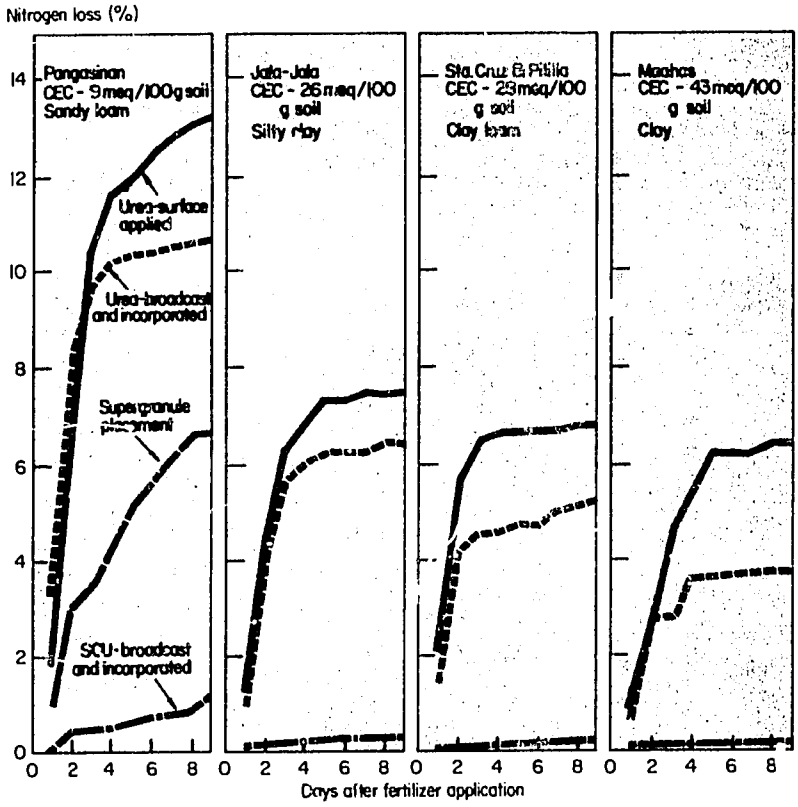
concentrations of fertilizer nitrogen in the floodwater of these treatments. Our 1979 tests suggest that any fertilizer treatment that produces high concentrations of dissolved nitrogen in the floodwater will lead to low recovery of nitrogen by the crop because of high loss from ammonia volatilization and nitrification-denitrification.

Ammonia loss studies

We continued efforts to minimize the loss of nitrogen as ammonia gas, which commonly occurs when nitrogen fertilizers are added to rice paddies. Losses from prilled urea and sulfur-coated urea broadcast and incorporated were compared with those from urea applied on the surface or as supergranules placed in the root zone. The treatments were compared on four soils with various textures.

For all soils ammonia losses from the surface-applied urea were highest (Fig. 3) and those from sulfur-coated urea were lowest. Losses from the sandy loam soil were consistently higher than from the finer textured soils. Even with the root-zone placement of supergranules, significant quantities of ammonia were lost from the coarser textured sandy loam. Luckily most paddy soils are medium to fine textured.

The pH of the floodwater after fertilizer application was not



3. Ammonia volatilization losses with different forms of urea were affected by cation exchange capacity and texture of the soil. Supergranule placement led to negligible loss of nitrogen as ammonia in the silty clay, clay loam, and clay soils. We increased research on the behavior of nitrogen in flooded soil because the behavior of the fertilizers under various soil and floodwater environments may partly explain the low fertilizer-use efficiency.

greatly affected by soil texture. But the pH values were higher with surface application of urea than with broadcast and incorporated sulfur-coated urea. Also the nitrogen content of the floodwater after surface application exceeded 150 μ N/ml compared with less than 10 μ N/ml after application of sulfur-coated urea. The high nitrogen content and high pH of the floodwater undoubtedly aggravate nitrogen loss through ammonia volatilization.

BIOLOGICAL NITROGEN FIXATION

Biological nitrogen fixation – mainly by algae and bacteria serving as intermediaries in removing nitrogen from the air and putting it in a form the rice plant can use – offers tremendous benefits to the rice farmer faced with rising costs of fertilizer nitrogen. Trials in 1979 indicated that it is practical to increase rice yields with azolla alone.

Azolla's potential

The *Anabaena-azolla* complex can fix as much as 450 kg atmospheric nitrogen/ha per year if the azolla is the only crop and is allowed to grow throughout the year. In 1979 we grew azolla between rows of rice (Fig. 4). Adjustment of row spacing permitted 5 crops of azolla during the growth period of one

4. IRRI field workers mix azolla with the paddy soil. Rice in the these plots has a 50-cm space between pairs of rows and 15 cm between paired rows. In 1979, 5 crops of azolla incorporated with the paddy soil added about 100 kg N/ha. Yields on the azolla plots averaged 2 t/ha higher than those on plots (background) with no azolla.

5. IRRI scholar B. P. Rao Subudhi checks azolla growth in phosphorus culture solutions. These trials got a phosphorus solution with 0.03 ppm P. Note the poor growth of *Azolla mexicana* in the far dish. Best growth was by *Azolla pinnata* collected from Thailand (center dish).

crop of rice and about 100 kg N/ha was accumulated. In the test plots the azolla was incorporated into the soil each time the fern covered the surface between the rice rows. The azolla treatment increased rice yield 2 t/ha over plots with no azolla. No plot received nitrogen fertilizer.

Phosphorus nutrition of azolla

Because phosphorus is the nutrient most critical for azolla growth, phosphorus fertilizer is essential for high yield.

We used a continuous flow culture with minimum concentration of phosphorus in water to identify azolla strains that grow better where phosphorus in floodwater is limited. A strain of *Azolla pinnata* collected from Thailand grew without visible phosphorus deficiency symptoms at 0.06 ppm P, but showed some phosphorus deficiency at 0.03 ppm. In tests of various azolla strains and species at 0.03 ppm P, *A. filiculoides* and *A. mexicana* showed severe phosphorus deficiency symptoms, while some strains showed slight effects (Fig. 5).

Nitrogen fixation vs chemical nitrogen fertilizers

It is generally believed that chemical nitrogen fertilizer is incompatible with biological nitrogen fixation in a paddy soil

and that surface broadcast urea depresses nitrogen fixation by algae in floodwater and on surface soil. Our studies in 1979 showed that biological nitrogen fixation remains an important process – even in a fertilized paddy – when proper techniques for deep placement of fertilizer are applied.

In cooperative research with scientists from the International Fertilizer Development Center, we found that deep placement of urea did not depress the activity of nitrogen-fixing algae. Surveys of long-term fertility trials at IRRI showed that continuous application of nitrogen fertilizer did not depress heterotrophic nitrogen fixation in the soil and the rice rhizosphere.

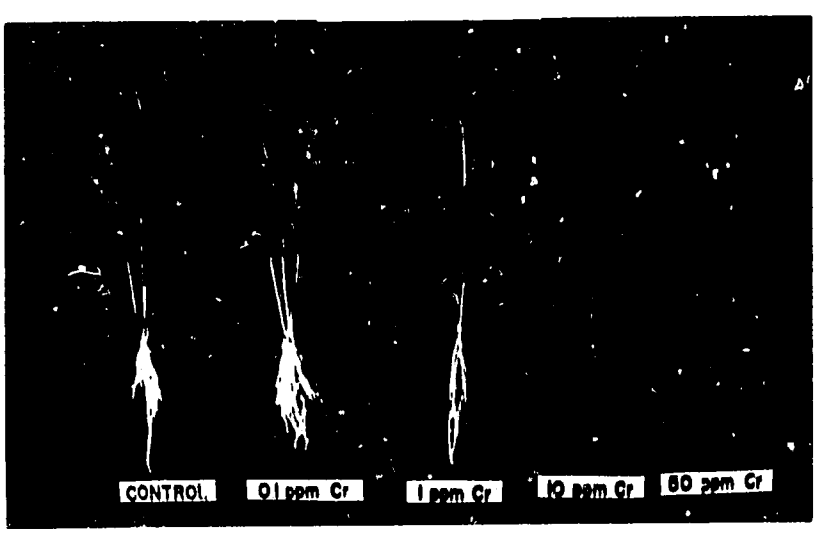
A new type of nitrogen-fixing bacteria

Through a technique that used a nitrogen-containing medium for the isolation of nitrogen-fixing bacteria, we found a type of bacterium on the wetland rice root, which had not been observed before. The bacteria were widely distributed on the roots of wetland plants including rice and weeds. They were not found on dryland plants.

SOIL CHARACTERIZATION

Potassium dynamics in wetland rice soils

Traditionally the potassium fertility of wetland rice soils is studied by determining total and exchangeable potassium. In 1979, we studied the potassium dynamics of wetland soils by electro-ultrafiltration (EUF), a technique that has shown promise in potassium studies in dryland soils. EUF is water extraction of soils under an external electrical field, which approximates those portions of the total extractable soil



Chromium at 1 ppm had marked toxicity for 4-week-old IR42 seedlings in 1979 tests at IRRI.

Table 3. Electro-ultrafiltration (EUF) for determination of potassium content in wetland soils appears to be a better technique than the conventional method of determining exchangeable potassium. In 1979 the relationship between total EUF-K fractions, EUF-K fraction I, and exchangeable K and grain yields were determined in long-term fertility studies at two Philippine experiment stations.[a]

Site	Correlation coefficient between grain yield and		
	Total EUF-K fraction	EUF-K fraction I	Exchangeable K
Bicol	0.89**	0.95**	0.84*
Maligaya	0.83*	0.82*	0.87*
Bicol and Maligaya combined	0.87**	0.63*	0.42

[a]**Significant at 1%; *Significant at 5%.

potassium which are water soluble and those which are exchangeable with different bonding energies.

For the determination of soil potassium dynamics, two EUF parameters are important: the EUF-K fraction I and the total EUF-K fractions. In tests with two Philippine soils, we found those parameters more closely related to grain yields and better indicators of potassium availability than the traditionally determined exchangeable potassium (Table 3). The EUF-K fraction I and exchangeable K were poorer indicators of potassium availability than the total EUF-K fractions.

Our results suggest that the potassium dynamics of wetland rice soils can be evaluated better by the EUF technique rather than by the conventional method using exchangeable K.

Available zinc in rice soils

For several years zinc deficiency has been widely known as a factor limiting yields in wetland rice fields. During 1979 we continued research on the character of soils low in available zinc. We found that some zinc-deficient soils were very high in chromium. With 0.1 ppm chromium in a culture solution rice plants grew well; 1 ppm chromium was toxic.

In our zinc studies we found a high correlation (r = .98**) between zinc weakly bound to soil organic matter and zinc extractable by electro-ultrafiltration. Each of these analyses of zinc in soils was correlated highly (r = .82**) with zinc uptake by the rice plant.

Clay mineral composition of soils

We established a clear relationship between the phosphorus and potassium characteristics and the clay mineral composition of 160 Philippine soils (including 140 wetland rice soils).

We found halloysite, kaolinite, and amorphous materials as the dominant minerals in phosphorus-deficient soils. In soils

containing more than 0.2 meq/100 g exchangeable potassium, vermiculite and beidellite were always absent and montmorillonite was always present.

Potential of coastal saline soils

We analyzed soils from 14 test sites in farmers' fields in coastal saline areas of the Philippines. Most of the soils were slightly acid or slightly alkaline and moderately well supplied with nitrogen and phosphorus. All were well supplied with potassium, but seven were deficient in zinc.

Yields from salt-tolerant rices, such as IR42, grown at some of the 14 sites were as high as 6 t/ha with moderate amounts of fertilizer.

Influence of residue incorporation on soil characteristics

When we analyzed soils into which straw had been incorporated twice a year for 6 years at IRRI, the following were noted:

- organic matter increased by 0.47%,
- nitrogen content increased by 0.023%,
- available phosphorus increased by 4 ppm, and
- exchangeable potassium increased by 0.26 meq/100 g.

The nutrients accumulated per hectare averaged 38 kg nitrogen, 0.8 kg phosphorus, and 17 kg exchangeable potassium per crop.

Straw piles dot the countryside at the time of rice harvest. Organic matter and nutrients are lost because much of the straw is burned. In IRRI tests, the incorporation of straw since 1974 has resulted in significant increase in soil fertility.

CROP CULTURE

Effects of seedling age and planting date on yield

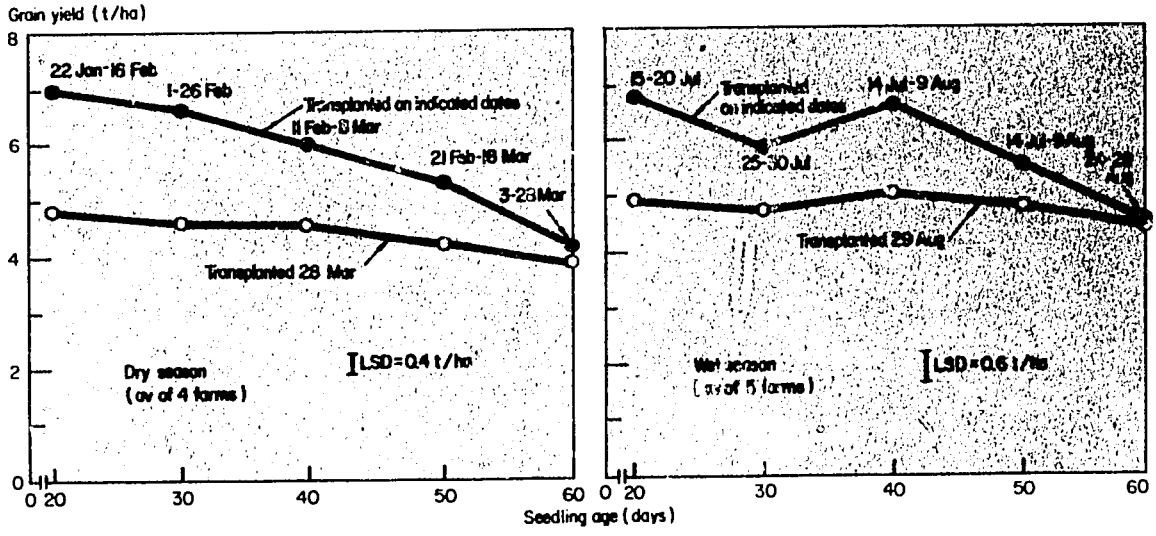
There is continued interest in decreasing the field duration of rice, primarily to increase production per day of transplanted rice under intensive cropping. Transplanting older seedlings can decrease field duration, but even with them it is essential to maintain high yields.

We ran tests on four farms in Nueva Ecija province, Philippines, to determine how age of seedlings influences rice yield. Seedlings at five ages – 20 to 60 days with 10-day intervals – were transplanted simultaneously late in each planting season and on staggered dates starting 1 to 1.5 months earlier. Examination of the average yields from the four farms for both seasons (Fig. 6) emphasized that:

- for simultaneous plantings made late in the season, yields declined slightly during the dry season with increased age of seedling but remained essentially unchanged in the wet season; and
- early planting of young seedlings in both seasons produced higher yields than later plantings of older seedlings.

These results indicated that grain yields of early-maturing IR36 are affected not solely by age of seedlings but, more importantly, by time of transplanting. Environment in the main field has greater influence on the yield performance of rice than does environment in the seedbed.

The performance of seedlings of different ages will depend on the growth duration of a variety, among many other factors. An experiment at IRRI compared the 20- and 40-day-old seedlings of early-maturing IR36 and intermediate-maturing IR42.



6. Grain yields of IR36 under staggered (seedlings from seedbed on range of dates shown) and simultaneous (all seedlings at all ages planted same day) transplanting as influenced by age of seedlings grown. The lower yield from simultaneous transplanting indicates an environmental effect of the main field.

The age of seedlings used for transplanting differs widely among rice farmers. For an early-maturing variety like IR36, use of young seedlings is important. Farmers who grow rices of long growth duration can transplant older seedlings without the yield loss they would have with early-maturing varieties.

For IR36, the grain yield of the 20-day-old seedlings was significantly higher (0.7 t/ha) than that of the 40-day-old. For IR42, the difference in grain yields between the two seedling ages was not significant. The data suggest that with optimum water, fertilizer, and pesticide treatment, varieties with longer growth duration suffer less yield loss from older seedlings than varieties that mature early. This means that wherever a farmer plants a longer-duration variety that yields higher, any lost time due to increased field duration can be compensated for by planting relatively older seedlings, thereby maintaining about the same level of productivity per hectare per day as that with shorter-duration rice.

Effect of crop residues on rainfed rice soils

Better land preparation will help rainfed rice farmers achieve increased cropping intensity. But that will require more information on the physical and chemical properties of rainfed rice soils. In 1979 field experiments at IRRI, we examined the effect of crop residue management on the physical and chemical properties of rainfed rice soils.

Soil consistency denotes the degree of soil firmness and reflects in the workability of soil. Consistency limits such as shrinkage limit, plastic limit, and liquid limit are used extensively in the engineering sciences. Our 1979 study showed that these consistency limits can be used to determine when to prepare the land to get good stand establishment.

Table 4 shows that the preceding crop and crop residue management on a silty clay loam did not significantly affect the moisture content at plastic and shrinkage limits and the range of optimum soil moisture for ease of tillage. On a sandy clay loam, however, the preceding crop and crop residue management

Table 4. Soil moisture content at plastic and shrinkage limits of silty clay and sandy clay loam soils after two cropping sequences at IRRI in the 1979 wet season. The silty clay plots were planted to IR28 before cowpea and sorghum cultivation. The sandy clay loam plots were planted to soybean and corn before cultivation of cowpea and sorghum.

Preceding crop and crop residue management	Soil moisture contents (%)		Range of soil moisture content for tillage (%)
	At plastic limit	At shrinkage limit	
		Silty clay[a]	
After cowpea with			
Rice straw incorporation	38 a	25 a	13 a
Rice straw mulch	38 a	24 a	14 a
After sorghum with			
Rice straw incorporation	40 a	23 a	17 a
Rice straw mulch	38 a	25 a	13 a
Weedy fallow with			
Residue incorporation	38 a	24 a	14 a
		Sandy clay loam[a]	
After soybean fb[b] cowpea with			
Residue incorporation	31 a	30 a	1 a
Residue mulch	32 a	30 a	2 ab
After corn fb sorghum with			
Residue incorporation	32 a	29 a	3 ab
Residue mulch	32 a	28 a	4 ab
Continuously weedy fallow with			
Residue removal	32 a	27 a	5 b

[a]Means followed by the same letter are not significantly different at the 5% level.
[b]fb = followed by.

significantly affected the range of optimum soil moisture for ease of tillage.

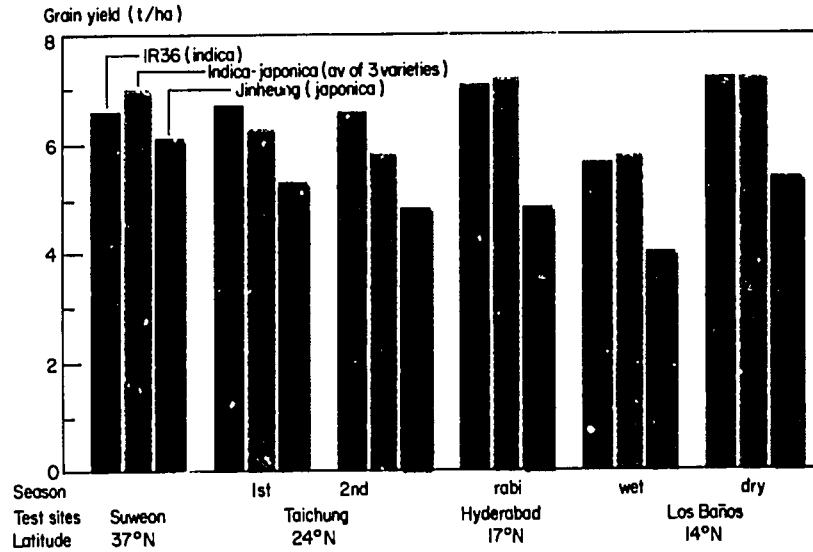
Essentially, a farmer has a long optimal period of time to plow heavy-textured soils after they get moist with rain, but medium-textured soils should be plowed as soon as they are moist.

Environment and its influence

Crosses of indica and japonica contributed greatly to Korea's recent achievement of record average rice yields and self-sufficiency in rice production. Such crosses are highly resistant to lodging and hence respond to high nitrogen levels. And they may be more widely adapted to geographic regions than indica or japonica rices.

Climatic adaptability of indica-japonica rices

Collaborative research in 1979 at four sites – Suweon, Korea; Taichung, Taiwan; Hyderabad, India; and Los Baños, Philippines



1. The 1979 grain yields of indica, japonica, and indica-japonica crosses at 4 sites indicate the wide adaptability of indica-japonica crosses and of IR36, an indica variety.

– demonstrated that both IR36, an indica, and elite indica-japonica crosses have wide adaptability to different climates (Fig. 1). The yield of Jinheung, a japonica, was consistently lower at all sites. The poor yield performance of Jinheung is attributed to its low harvest index at Suweon, and to short crop duration and slow leaf growth at sites with high temperature.

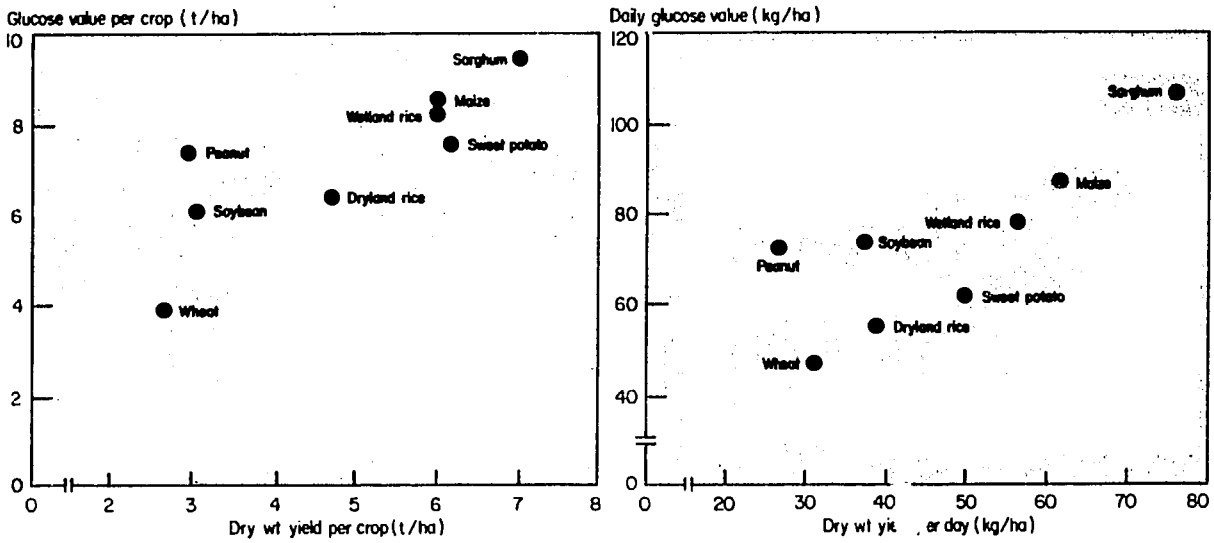
A regression model analysis indicates that grain yields of rice varieties grown at different sites are primarily determined by crop duration, harvest index, and mean daily solar radiation.

Bioenergetics of crop yields

Agronomically, crop yields can be compared in several ways – yield per crop, yield per day, and yield per year – but such yield measurements of different crops are not based on the same water content. For example, rice yield is expressed at 14% moisture, whereas sweet potato yield is as fresh weight. This indicates that a straight comparison of crop yields is not possible. Furthermore, different crops have different chemical composition, which in turn implies different energy content.

In 1979 we took a bioenergetical approach to comparison of different crops' yields. In that approach, crop yield was converted to the amount of glucose used to produce the harvested portion of a crop (Fig. 2). We grew eight crops with no nutrient and water limitations at Los Baños and compared their yields.

Agronomic yields of maize, rice, sweet potato, peanut, and soybean differed greatly, ranging from 3 to 6 t/ha. Bioenergetic yields differed much less. But on a daily basis, the bioenergetic



2. The bioenergetic yield of eight crops at IRRI showed that peanut, soybean, and wetland rice use the same energy and give the same yield per day.

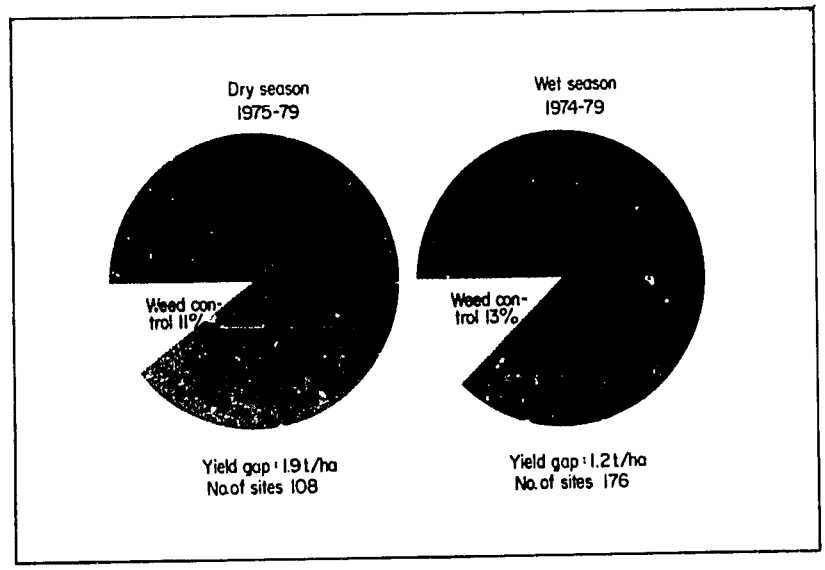
yields of wetland rice, soybean, and peanut were almost comparable despite large differences in agronomic yields. In other words, the three crops are equally efficient in terms of energy use for yield.

Constraints to increased yields

Since 1974 rice scientists – working in teams composed of agronomists, economists, and statisticians – have identified factors limiting rice yields in farmers' fields in six Asian countries. We published the findings of this research – coordinated by IRRI scientists – in *Constraints to High Rice Yields on Asian Rice Farms: An Interim Report* in 1977 and *Farm-Level Constraints to High Rice Yields in Asia: 1974–77* in 1979. From an agronomic viewpoint – as typified by our experiments in the Philippines – the yield gap was larger in the dry than in the wet season, and the most important managed factors were fertilizer and insect control (Fig. 1).

The economics of reducing the gap between the farmers' yields from their fertilizer, insecticides, weeding, etc., and what they could have obtained with higher levels of those inputs in the same field varies by season and by country. Nevertheless, we have found that:

- environment is a major factor in determining the productivity of the farmers' input levels;



1. Low level or improper use, or both, of fertilizer and insecticides made the major contribution to the gap between yields farmers obtained and what they should have obtained in four Philippine provinces, 1974–77.

- yield and profit gains from moving the farmers' technology to a higher level are generally substantial in the dry season but smaller in the wet;
- currently recommended insect control practices are expensive and frequently unattractive to the farmers; and
- there is potential for increasing the efficiency of fertilizer, particularly nitrogen.

Environment and management constraints

There is a great deal of variability in the performance of modern inputs in different environments and attention must be given to measuring the magnitude of that variability between sites. More important, we must identify the source of that variability.

In 1979 we used specific data from the 1974–77 constraints studies in Nueva Ecija, Philippines, to quantify the causes of variability in rice yields between farms. We fitted a crop response function (using data summarized in Table 1) to the experimental data and so were able to relate rice yields to managed (fertilizer, insecticide, weed management) and nonmanaged (moisture stress, solar radiation, typhoons) factors of production. We then examined the reasons for the yield differences between the high (top 25%) and low (bottom 25%) yielding farms by employing the total differential of the production function. The yield difference between high and low yielding farms is directly attributed to the differences in environments and in the levels of managed inputs quantified in the production function.

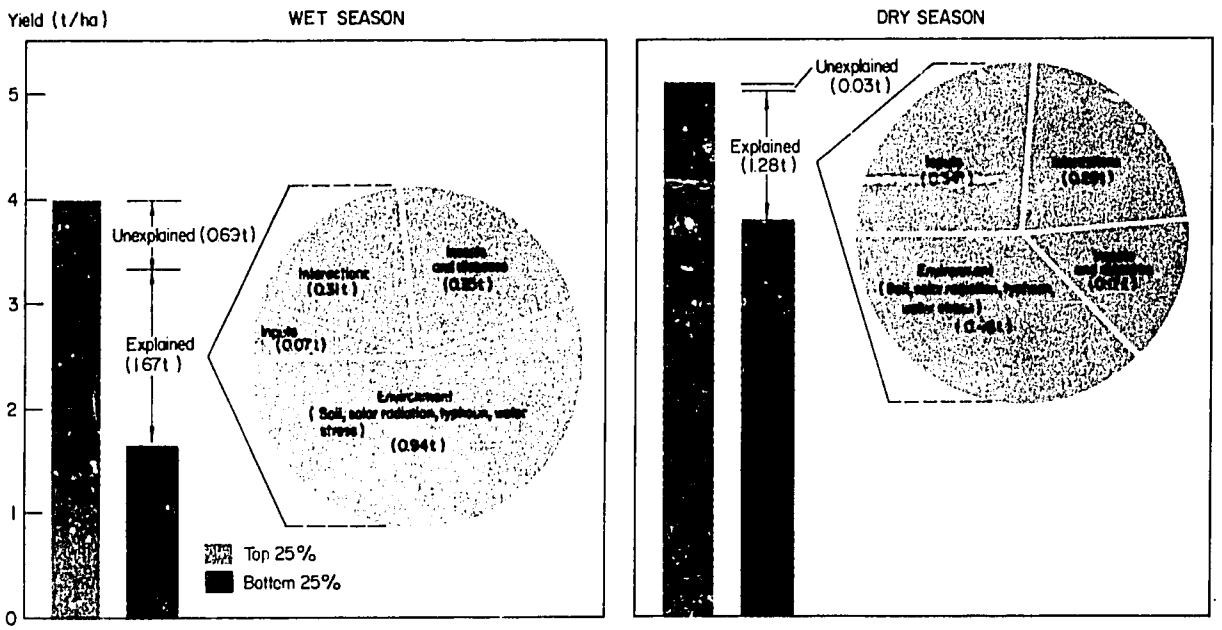
Table 1. Estimated rice production function based on experiments conducted in farmers' fields in Nueva Ecija, Philippines, 1974–77.

Independent variable	Partial regression coefficients[a]
Fertilizer (quadratic term) (F^2)	−0.029
Insecticide (I)	0.472
Weed control (W)	0.691
Seedling age (A)	−10.144
Fertilizer X pest interaction (FP)	−0.115
Disease damage (D)	−25.769
Fertilizer X disease interaction (FD)	−0.251
Organic matter (M)	184.068
Soil phosphorus (H)	2.455
Fertilizer X water stress interaction (SF)	−0.207
Solar radiation (R)	99.492
Fertilizer X radiation interaction (RF)	0.829
Typhoon dummy	−416.371
Av fertilizer efficiency	−1.996
Av insecticide efficiency	−0.469
Constant	1,248
$\bar{R}^2$	0.640
F ratio (n1 = 15, n2 = 3260)	388.934
Standard error of estimate	990.109

[a]All factors other than weed control (W) are significant at the 1% level or better. W was significant at 5%.

2. An analysis of data from 1974–77 constraints studies showed that in the wet season the yield differences between high and low yielding farms are due largely to environment, diseases, and insects. Inputs by the farmer and their interaction with environment assume major importance in the dry season.

Contributions to yield differences. The factors contributing to the yield differences in the wet and dry seasons were identified as shown in Figure 2. The production function helped us explain the factors causing the yield differences for the dry season crop more fully than for the wet season crop.



In the wet season, the managed inputs – fertilizer, insect control, weed control, and seedling age – contributed little to explaining the difference between the low and the high yield crops. Physical environment parameters – a combination of weather-related factors and soil – along with insects and diseases were the major factors causing the yield differences among farms and accounted for some 80% of such differences.

The dry season results were in marked contrast with those of the wet season: the nonmanaged factors accounted for 40–50% of the yield differences, and the remainder were attributed to the levels of managed inputs used and their interaction with environmental variables.

Options for economically increasing yields. To determine the possibilities for economically increasing yields in the high and the low yield farm environments, we substituted the mean values of the environmental factors of the two groups in the production function to derive equations for fertilizer response with the farmers' and researchers' efficiency. From these equations, the optimal fertilizer and expected yield levels were calculated assuming

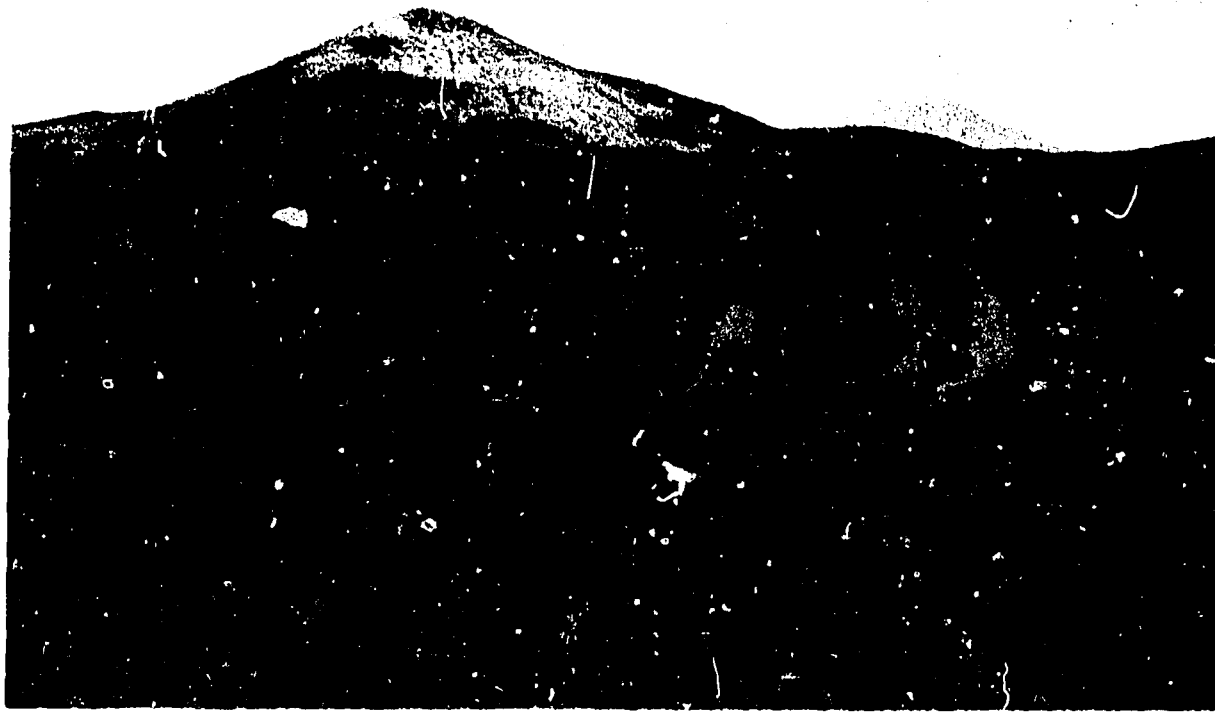
- no cash constraint,
- and a cash constraint that the farmer required a rate of return of US$1.00 from the last dollar invested (Table 2).

For the unconstrained situation (λ=0), the optimal level of fertilizer is higher than what farmers currently use (except for low yielding farms in the wet season). However, the resulting yield and profit gains from raising fertilizer from actual to optimal levels are small with both the researchers' and the farmers' efficiency in the wet season. For the cash constraint

Table 2. Estimated optimum fertilizer input and resulting yield at two rates of discount and farmers' fertilizer use of different farm yield groups.[a]

Season	Yield group	Optimal fertilizer (F) λ = 0	Optimal fertilizer (F) λ = 1	Farmers' fertilizer level	Predicted yield (Y) λ = 0	Predicted yield (Y) λ = 1	Predicted yield (Y) Farmers'	Yield diff.[b] Δ0	Yield diff.[b] Δ1
				Farmers' efficiency					
Wet	Low	0	0	42	1.7	1.7	1.8	-0.1	0.0
	High	116	51	81	3.6	3.2	3.4	0.2	-0.2
Dry	Low	153	84	90	4.5	4.1	4.2	0.3	-0.1
	High	211	142	147	5.8	5.4	5.4	0.4	0.0
				Researchers' efficiency					
Wet	Low	14	0	42	1.8	1.7	1.9	-0.1	-0.2
	High	150	85	81	3.9	3.7	3.7	0.2	0.0
Dry	Low	187	119	90	5.1	4.6	4.2	0.9	0.4
	High	245	177	147	6.5	6.1	5.8	0.7	0.3

[a] Rough rice at US$0.14/kg, fertilizer at US$0.52/kg in the wet season and US$0.54/kg in the dry. [b] λ is the return on the last dollar invested in fertilizer. Δ0 is the yield difference between the estimated optimal level of fertilizer and that achieved by the farmer, Δ1 is the yield difference for the cash constraint situation.



Analysis of 1974–77 data from research on factors limiting rice yields in farmers' fields indicates that the potential of the modern varieties is not being realized in the dry season.

situation (λ=1) in the wet season (other than for the low yield environment – farmers' efficiency), the yield differences between the farmers' and the cash-constrained optima are likewise minimal.

In contrast, yield gains from raising farmers' fertilizer use are somewhat more substantial in the dry season – an increase of almost 0.4 t/ha with farmers' efficiency and up to 0.9 t/ha with researchers' efficiency for the noncash constraint situation. But for the cash constraint situation (λ=1), it is only in the dry season at the researchers' level of efficiency that it appears clearly profitable for the farmer to raise his level of fertilizer use.

Our analysis demonstrates two points:

1. The response to farm inputs, such as fertilizer, is greater in the dry season when there is higher solar radiation, fewer typhoons, and low insect damage and disease incidence.

2. For the farmer facing a cash constraint, the yield and profit difference is small between his level of fertilizer use and that identified through the production function analysis of the constraints trials.

In the less ideal environment of the wet season, the time of the year when the majority of the world's rice crop is grown, the researchers' technology was clearly not superior to the farmers'. But it appears that in the dry season the economic potential of modern varieties is not being realized.

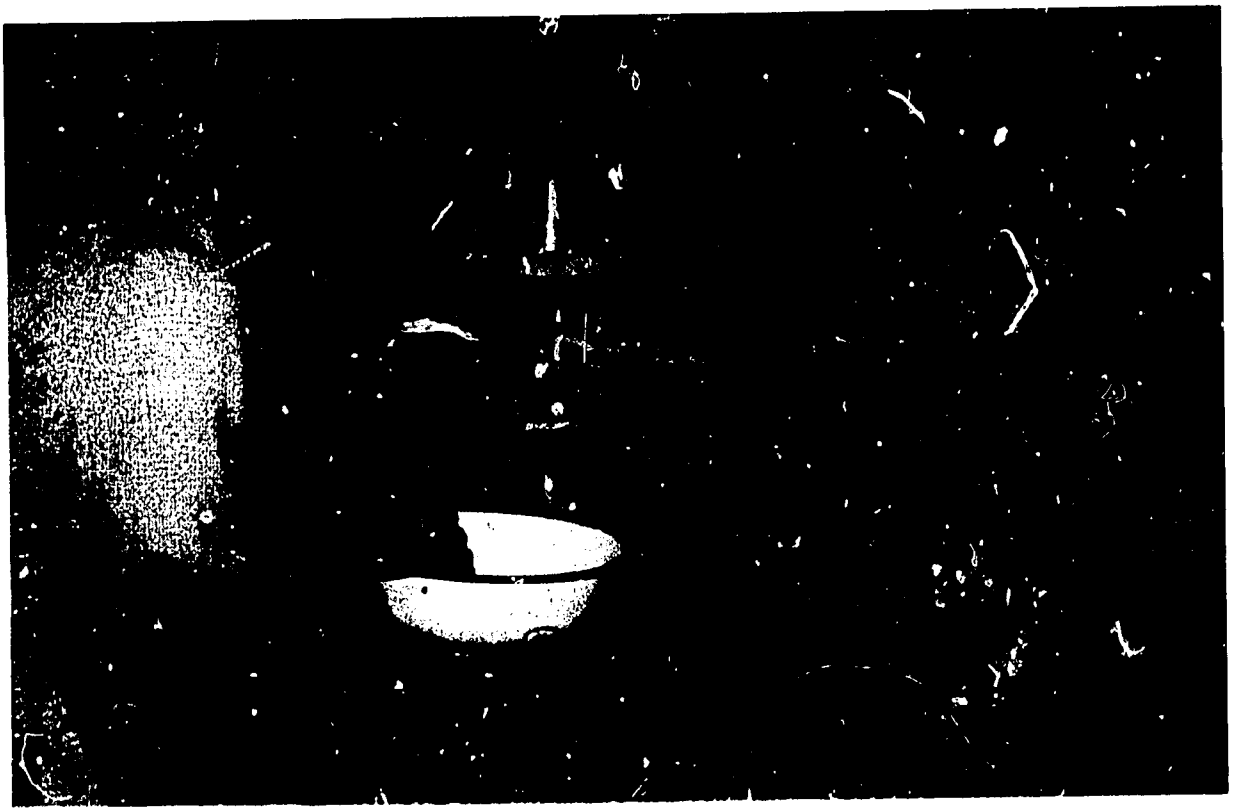
Consequences of new technology

Traditional rice varieties do not respond well to insect and disease control inputs; thus it is uneconomical for farmers to apply them. But farmers have adopted modern high yielding rice varieties that do respond to pesticides, and as a consequence of the new rice technology, farmers who want maximum profits must learn to recognize when pest situations arise.

Even with the modern insect- and disease-resistant varieties, farmers must learn to identify a dozen or more pests that remain enemies – each one in all of its different life stages. Farmers must also:

- predict which part of the plant will be most vulnerable at different growth periods;
- evaluate frequently and quickly the severity of pest infestation in a given field to determine whether to apply insecticides;
- match each pest with its appropriate pesticide, measure the correct concentration of dozens of pesticides on the market, and apply each effectively, economically, and safely.

As a consequence of adoption of the new rice technology, these farmers had to learn to use a simple light trap in their fields and to make decisions on appropriate insect control methods, based on insects found in the trap.



• collaborate in managing pests over a wide field area, because both rats and insects -- many of which spread diseases -- can simply move to a neighboring field when they encounter protective measures.

The sociological challenge of farmers working together tc control pests over a broad area is as critical as the technical challenge they must meet.

IRRI and farmers develop pest management approach

Our approach to integrated pest management (IPM) for small rice farmers in the tropics is to offer them a low-cost effective system of monitoring pest dangers and of applying the necessary measures to offset such dangers. Because rice problems are too varied to allow for simple *package application* of the technology, the farmers virtually must make the quantum leap from tradition to science.

To help farmers make the tradition-science leap, IRRI scientists and farmers in several Filipino barrios jointly developed a 13-week training course in IPM (Table 1). During

Table 1. This chart outlines the salient lessons in a 13-week course for farmers and shows how recommended practices improve upon traditional ones in one area of the Philippines. Because the farmers were highly pragmatic, course emphasis was on what works, what saves money, and what to avoid.

Introduced technology	Farmers' customary practice	Changes required
• Large area synchronous planting of early-maturing varieties and early destruction of rice stubble after harvest to create rice-free periods of more than a month.	• Nonsynchronous planting of early-maturing varieties and allowing harvested stubble to ratoon.	• Organization among farmers tilling a continuous area of the size serviced by an irrigation turnout.
• Avoiding overexposure to insecticides by choosing safer insecticides, using nonleaky sprayer; avoid spraying more than a half day at a time; change and wash clothes after spraying; avoid smoking or eating while spraying.	• Using dangerous insecticides, spraying with leaky sprayers, spraying continuously for several days, reusing insecticide-contaminated clothing, smoking and eating while spraying.	• Understanding the dangers involved in using insecticides, particularly insecticides that can penetrate the skin; fixing leaky sprayers.
• Observing the field weekly to assess the need for insect control.	• Applying insecticide at the wrong time.	• Recognizing insect pests and economic thresholds.
• Considering insecticide specificity to range of insect pests.	• Often applying the wrong insecticide.	• Learning which insecticides are specific to each pest.
• Applying insecticide at minimum lethal dosages.	• Underdose of insecticide which does not kill insect pest but kills its natural enemies.	• Learning to calculate insecticide dosages by using charts.
• Using insect-resistant varieties.	• Using insecticide for insect pests controlled by resistant variety.	• Learning which insect pests are controlled through resistance.
• Managing natural enemies to help contain rice pests.	• Mistaking natural enemies for pests.	• Learning to recognize the important natural enemies.
• Sustained baiting to control rats.	• Acute baiting that produces bait shyness.	• Learning correct techniques of placing bait holders in the field.

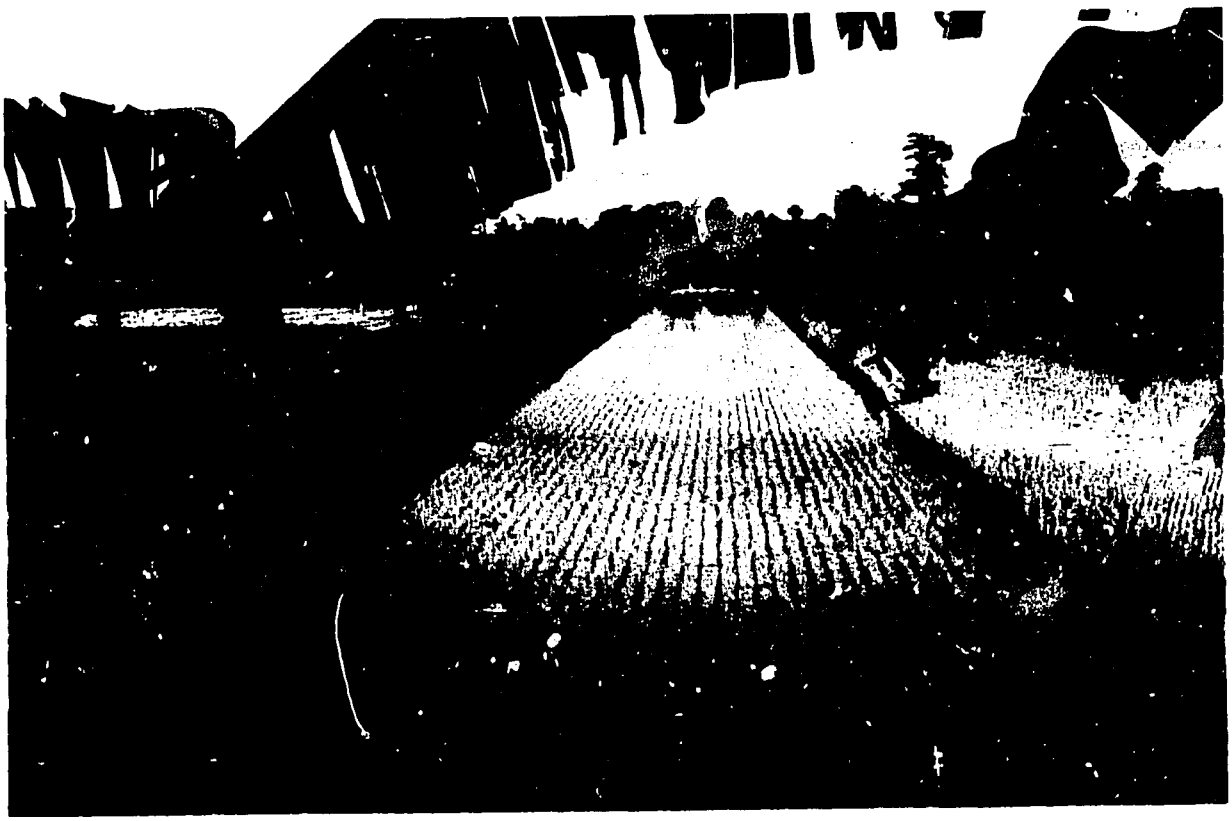
the course the farmers criticized the technology and the teaching materials week by week and evaluated the course's usefulness before graduation. An IRRI anthropologist complemented the farmers' suggestions with insights gained as a participant in the classes and as a *fellow villager* acquainted with their attitudes, practices, and pest problems through living in the barrio.

Cropping systems

Once the rainfed rice farmers of Asia had adopted the modern short-growth-duration rices, they found they had time and soil moisture left for an extra crop – sometimes two extra crops. Our cropping systems research is aimed at helping the rainfed farmer select and grow the most profitable crops in a rice-based cropping pattern.

As of 1979, agricultural research institutions in all Asian countries had enthusiastically adopted on-farm cropping systems research methods – methods developed in collaboration with national researchers, through the Asian Cropping Systems Network.

These 800-m² plots on a rice farm in Batangas province, Philippines, show the many stages of rice growth among the 13 plots in a 1-ha continuous rice production system. The farmer reported average weekly harvests of almost 700 kg for 1979.



Our 1979 work continued to support national cropping systems research teams in methodology development and in research on production problems commonly encountered.

- Our environmental classification research focused on better methods for target area delineation for the extrapolation of research results.
- Ratoon cropping potentials were evaluated in collaboration with plant breeding and other departments.
- Experimental labor-absorbing production systems were evaluated for use in areas with high labor-to-land ratios.
- Double rice cropping in rainfed areas continued to spread rapidly, especially in the Philippines. A computer simulation, using long-term historical rainfall records, helped us predict yield and yield stability.
- Expansion of plant pathology research in our program now helps us cope with diseases, particularly soil-borne diseases that affect upland crop establishment after wetland rice.
- Continuous intensive rice production was successful without insecticides and showed that the availability of rice in all stages of growth and in close proximity allows the buildup of predators that help keep insect pests at tolerable levels.

ENVIRONMENTAL DESCRIPTION

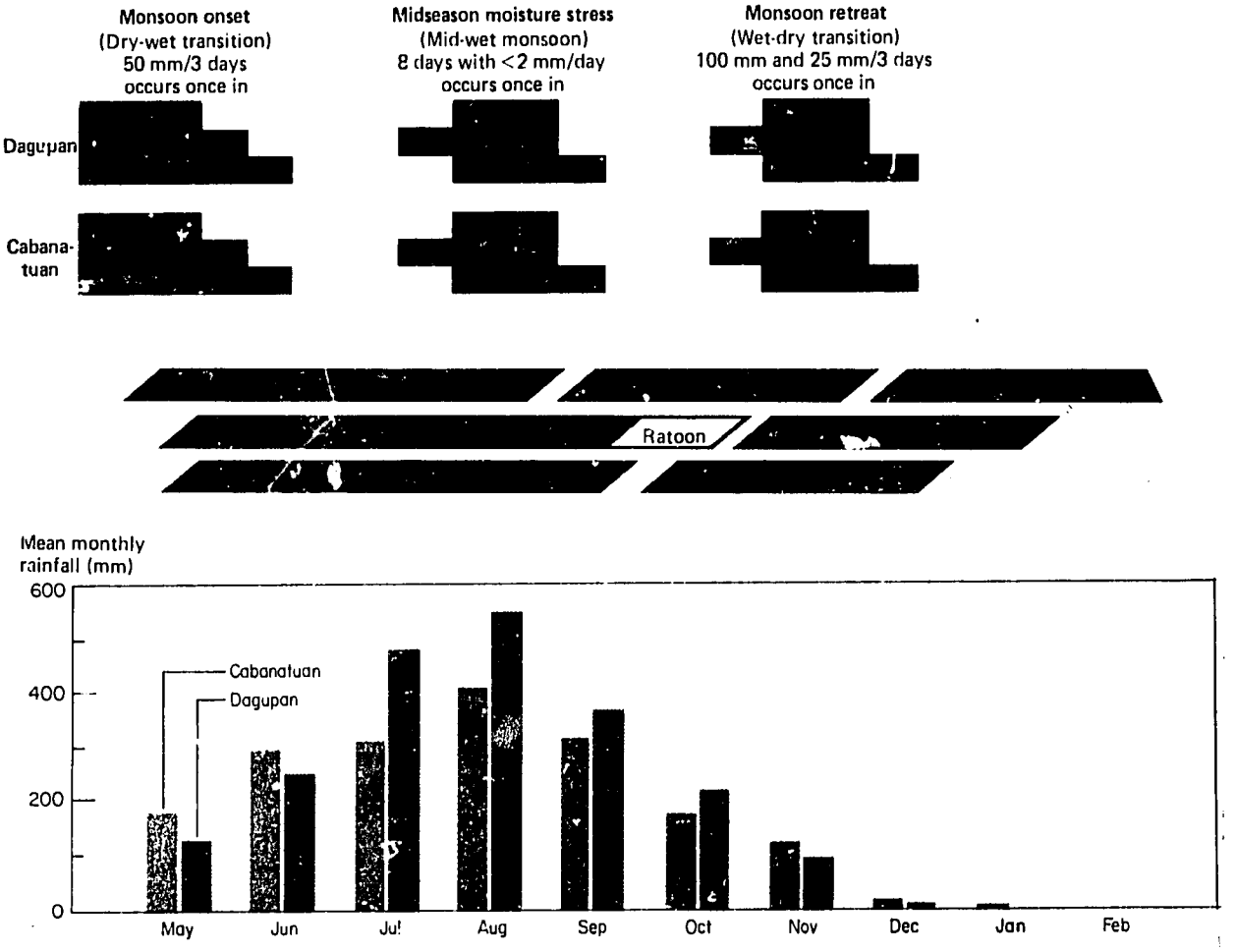
Target area delineation

Cropping systems research determines cropping patterns and the associated component technology for a target area, an area much larger than the research site. A problem, however, is determining the limits of the target area. We need methodical procedures to determine the area limits. For area delineation, four questions must be answered:

- What are the key environmental variables that dominate pattern adaptation?
- What are the limits of these variables within which adaptation will not vary appreciably?
- Where are the limits of these variables located?
- And – as a logical extension of the first three questions – what minor cropping pattern adjustments can be made to broaden the area of pattern adaptation?

Associated with delineation of a target area, the agronomic adaptation of patterns over many areas must also be considered.

To explore a general approach to target area delineation, we started studies in Central Luzon in 1979 to identify areas with physical conditions similar to those of our Manaoag cropping systems network research site. Dry-seeded rice (DSR)-transplanted rice (TPR)-mung bean and DSR-mung bean were



1. Crop varieties and field durations, dry-wet and wet-dry monsoon transition rainfall criteria and return periods, and mid-wet monsoon consecutive dry day criteria and return periods, and mean monthly rainfall for Dagupan and Cabanatuan. Rainfall of 50 mm/3 days was regarded as a lower critical limit for planting DSR, 8 consecutive days with rainfall less than 2 mm/day was regarded as upper critical limit for stress on a rice crop, and 100 and 25 mm/3 days were regarded as upper and lower critical limits for planting mung bean. The periods in the boxes are the average times between the recurrences of the critical limits during the periods covered by the boxes.

the main promising adapted cropping patterns identified for the Manaoag research site. The field durations of these patterns, and a DSR-ratoon rice-mung bean variant, are shown against mean monthly rainfall for two stations in Figure 1. The field water regime was regarded as the key factor governing adaptation of these patterns. In turn, the field water regime is controlled largely by the rainfall pattern, although it is modified naturally by soil properties (and their associated landforms) and artificially by irrigation systems.

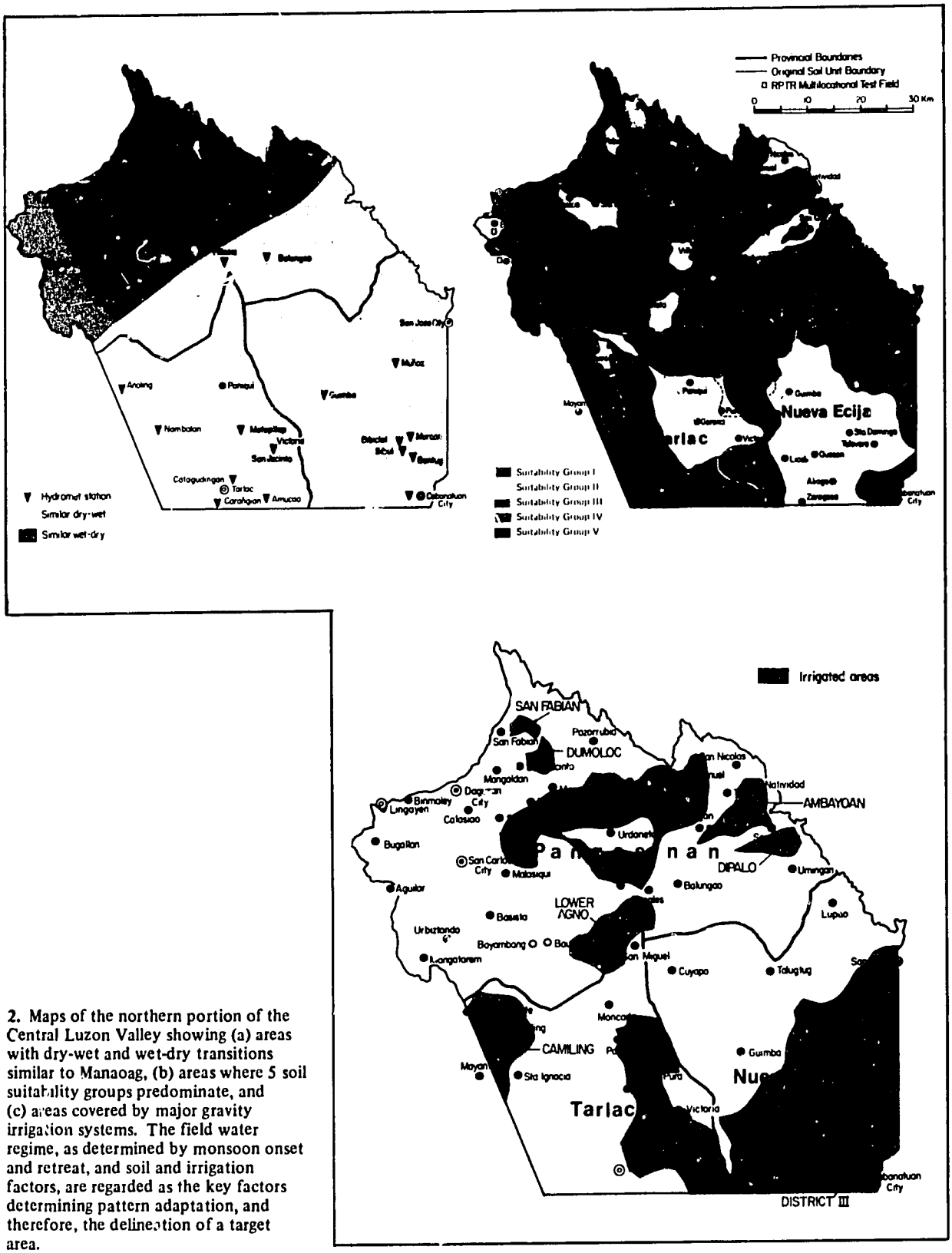
Rainfall pattern. Length of the growing season, as governed by monsoon rainfall, is a major determinant of cropping pattern adaptation. To determine the reliability of rain during monsoon transition periods, long-term rainfall records were used to calculate times between recurrences of critical rainfall limits

during intervals when key pattern operations (tillage and planting) would be performed. Recurrence frequencies for two stations are shown in Figure 1.

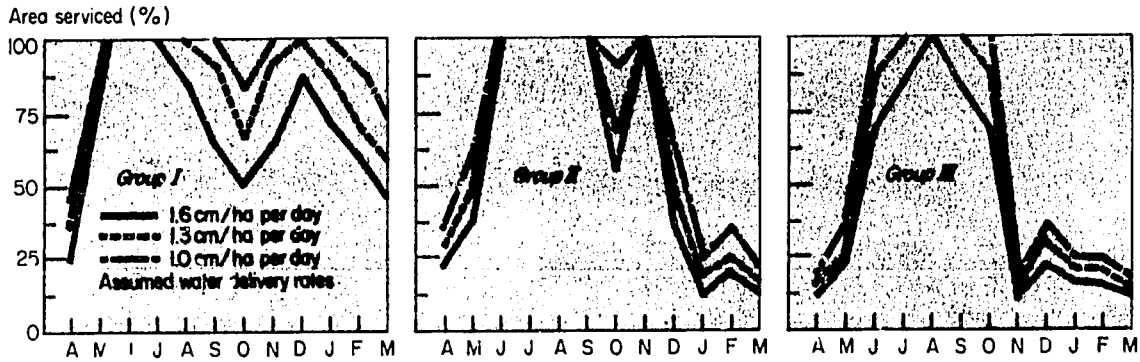
Soils. To locate areas with soils similar to those in the Manaoag site, analytical and descriptive data were obtained from reconnaisance-level studies conducted by government agencies in Pangasinan, Tarlac, and Nueva Ecija. Five soil suitability groups for rainfed rice-based cropping patterns were defined.

- *Suitability Group I:* light-textured, well to excessively drained soils. They do not accumulate water, even at the peak of the wet season. These soils therefore are generally not suitable for rice-based cropping systems.
- *Suitability Group II:* medium light-textured, well-drained soils. They require considerable rainfall to become fully saturated and they remain saturated or flooded during the peak of the rainy season. In this group, DSR (IR36) can be planted between late May and mid-June. Toward the end of the wet season, mung bean (or peanut) can be planted after deep, rough plowing to increase soil infiltration capacity.
- *Suitability Group III:* medium light-textured, moderately well-drained soils. These soils will flood earlier than soils in Group II. Although the same cropping pattern described for Group II is suggested for this group, peanut planted shortly after rice harvest risks damage by late heavy rains. Rice crops grown on Group III soils should be less subject to drought damage than those grown on Group II soils.
- *Suitability Group IV:* medium heavy-textured, poorly drained soils. They will flood earlier than Group III soils and will remain excessively wet for upland crops. The suggested basic pattern is DSR-mung bean, and a rice variety with a duration somewhat longer than IR36's can be used. If the DSR crop is established early and a good stand is obtained, a ratoon crop can be grown while the field is still too wet for mung bean.
- *Suitability Group V:* heavy-textured, poorly and very poorly drained soils. These soils will remain excessively wet with respect to upland crops for a long period. Furthermore, their heavy and poorly structured subsoils will often be unfavorable for the extensive root development important to upland crops. A DSR-TPR pattern can be planted on these soils, with the first crop planted in late May, after early rains have soaked the surface 20–30 cm.

The distribution of the soil suitability groups is shown in Figure 2. The boundaries enclose the predominating suitability group, but other suitability groups may be found within the same area, sometimes in high proportion.



2. Maps of the northern portion of the Central Luzon Valley showing (a) areas with dry-wet and wet-dry transitions similar to Manaoag, (b) areas where 5 soil suitability groups predominate, and (c) areas covered by major gravity irrigation systems. The field water regime, as determined by monsoon onset and retreat, and soil and irrigation factors, are regarded as the key factors determining pattern adaptation, and therefore, the delineation of a target area.



3. Estimated percentage of areas serviced in irrigation system groups during 1978 in the Central Luzon Valley, Philippines.

Irrigation. Because they affect field water regimes, we examined water deliveries in irrigation systems in relation to typical field schedules of cropping patterns for rainfed and partially irrigated crops. In Manaoag, we found that irrigation was necessary to obtain moderate to high TPR and mung bean yields in the DSR-TPR-mung pattern. In the DSR-mung pattern, satisfactory yields of both crops can probably be achieved with rain alone, but irrigation would likely be needed to assure a high mung bean yield potential. The objective of our study was to identify systems with regimes similar to the Lipit-Pao communal system regime. The Lipit-Pao system delivers water from June to December, but deliveries become progressively less reliable from September to December.

Data on command areas and monthly delivery rates were obtained from the National Irrigation Administration (NIA). The seven major gravity irrigation systems operated by NIA (Fig. 2) were grouped on the basis of delivery patterns:

- Group I: Upper Pampanga River Irrigation Systems (RIS), Districts I, II, and III.
- Group II: Camiling RIS, Agno RIS, San Fabian RIS, and Domuloc (extension of San Fabian RIS).
- Group III: Tarlac RIS, Ambayoan RIS, Dipalo (extension of Ambayoan RIS), and Lower Agno RIS.

The seasonal water delivery patterns are averaged in Figure 3.

Water delivery patterns in Group I systems will support 2 rice crops/year for the entire system and 3 rice crops for much of the system. In the southern area of Group I systems, however, light soils predominate and comparatively high conveyance and percolation losses can be expected, especially in the dry season. During the dry season, upland crops would be well adapted to these lighter soils, and therefore the DSR-TPR-mung pattern is an attractive alternative to continuous rice in this area.

In Groups II and III, both DSR-TPR-mung and the DSR-mung would be effective alternatives to present cropping

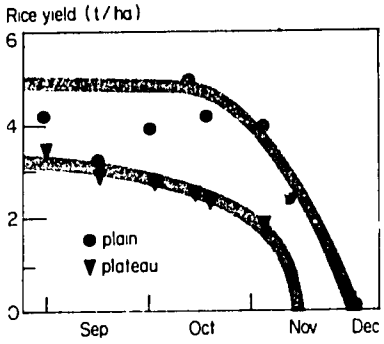
patterns. Most of the soils in Groups II and III systems are of medium texture, and high conveyance and percolation losses are expected to contribute to low water use efficiency in dry season rice, especially in fields far away from main canals. Therefore, the DSR-TPR-mung pattern should be an effective alternative in fields close to main water turnouts, where water is available beyond late October. Fields beyond the reach of regular water deliveries by mid-September would be best suited to DSR-mung bean. Fields receiving occasional water deliveries to mid-October may be too wet for mung bean before late October or early November, and a rice ratoon crop can be grown before the mung bean crop to use field time effectively.

This 1979 approach with a focus on the field water regime can be profitably used in other cropping systems projects. With the focus on rainfall characteristics, which gives emphasis to the pre- and post-monsoon transition periods, on soils (and their associated landforms) and on irrigation systems, key variables within the components can be identified, the limits of the variables can be defined, and the boundaries of the target areas set.

CROPPING PATTERN DESIGN

A second rainfed wetland rice crop

Double-cropping of short-duration varieties in rainfed wetland areas of central and southern Philippines has proved to be a viable system for some farmers. The major drawbacks are lower and more variable yields of the second crop (Table 1). Figure 4 illustrates yields obtained in planting-date experiments. There was more than 1 t/ha difference in yield between crops on the drier, less fertile plateau and on the more fertile water-adequate plain. Late planting also caused declining returns to nitrogenous fertilizer application.

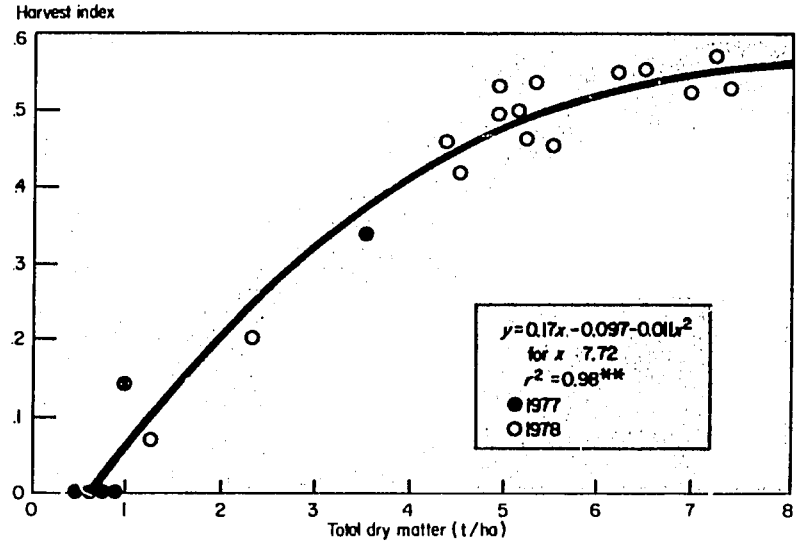


4. To provide base data for our yield simulation of the second rainfed rice crop, we planted IR36 at several planting dates. At the critical period, yield losses reached 140 kg/ha for each day of delay in rice planting. For the first three planting dates on the plain, there was yield loss due to leaf scald and flooding.

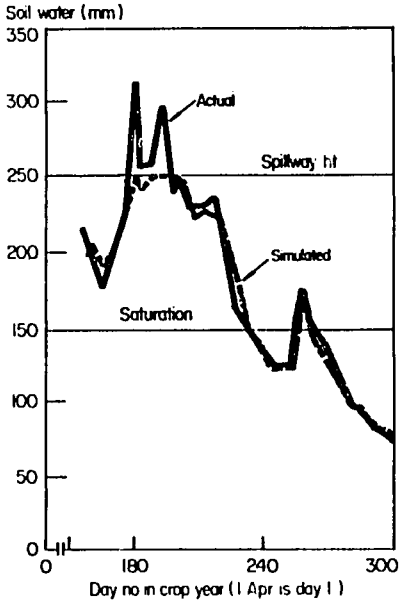
To make appropriate management decisions on the variable second crop, rainfall patterns for a much longer run of years should be considered. From 3 years of crop and soil water data, we utilized a crop simulation model that relates soil water and

Table 1. Yields in experiments with double-cropped rainfed rice in Iloilo, Philippines, 1975–78.

Crop year	Yield (t/ha)	
	1st crop	2d crop
1975	4.3	4.4
1976	4.9	2.2
1977	5.2	1.5
1978	5.3	3.7
Av	4.9	2.9



5. The curve shows the relationship between harvest index and total dry matter for IR36 that we used in yield simulation of the second rainfed wetland rice crop for Iloilo, Philippines, 1978–79. Harvest indexes dropped from 0.56 to 0 as a consequence of increasing drought stress.



6. Actual (black line) and simulated (red line) soil water balance for the plateau position from 4 Sep 1978 to 31 Jan 1979, Iloilo, Philippines.

yield variations. Through this model we estimated crop transpiration from a wetland rice field water balance model and calculated dry matter yields for each day by multiplying crop transpiration by a transpiration ratio. Yield was then calculated by multiplying dry matter yields by the harvest index (Fig. 5).

The actual and simulated yields for 1975–76 are compared in Table 2. Figures 6 and 7 show the water balance for plateau and plain sites in 1978–79. The simulated values were generated from field data for each of the components.

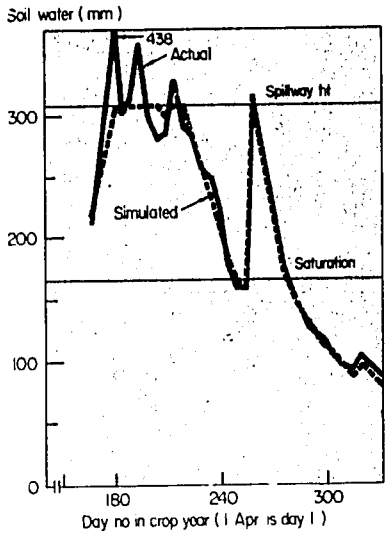
After further validation we will use the simulation to generate yield estimates across years and planting dates and use them for economic analysis. The end product of the research will be decision-making rules for managing the second rainfed rice crop in rainfed wetland areas.

Wide row spacing for upland crops

In the dry season many rice farmers grow upland crops after rainfed rice, but yields are often limited by drought. Research in semiarid regions has shown that the adverse effects of drought can be reduced by decreasing crop populations usually through wider row spacing.

Table 2. Simulated and actual yields of the second rainfed rice crop in Oton-Tigbauan, Iloilo, in 1975 and 1976.

Landscape position	Fields (no.)	Planting date	Planting method	Yield (t/ha)	
				By simulation	Actual
Plateau	3	15 Oct 1975	Wet seeded	0.3	0.5
Plateau	2	13 Sep 1976	Transplanted	3.3	3.4
Plateau	14	21 Sep 1976	Wet seeded	1.2	1.9
Plain	2	15 Sep 1976	Wet seeded	2.9	3.2



7. Actual (black line) and simulated (red line) soil water balance for the plain position from 10 Sep 1978 to 9 Feb 1979, Iloilo, Philippines.

Table 3. Yield for sorghum and peanut (as kernel) in wide and narrow rows following a rice crop. Apparently there was sufficient soil water to permit the sorghum to yield well even with the higher crop density (narrow rows).

Row spacing (cm)	Yield (t/ha)	
	Peanut	Sorghum
250	1.2	1.1
50	0.9	2.2

In many rice-growing areas the weather and soil-water regimes for an upland crop following rainfed rice meet the criteria for successful wide-row technology. We did an exploratory field experiment in the 1978–79 dry season to test wide (250 cm) and narrow (50 cm) row spacings of sorghum and peanut following rice on a dryland site at IRRI.

The results (Table 3) show that at wide spacing sorghum yields were depressed but peanut yields increased by 33%. The increase for peanut was associated with larger kernel size, suggesting that soil water was conserved for transpiration during the pod-filling phase. Apparently there was adequate soil water to meet the needs of sorghum even at conventional spacing.

CROPPING PATTERN TESTING

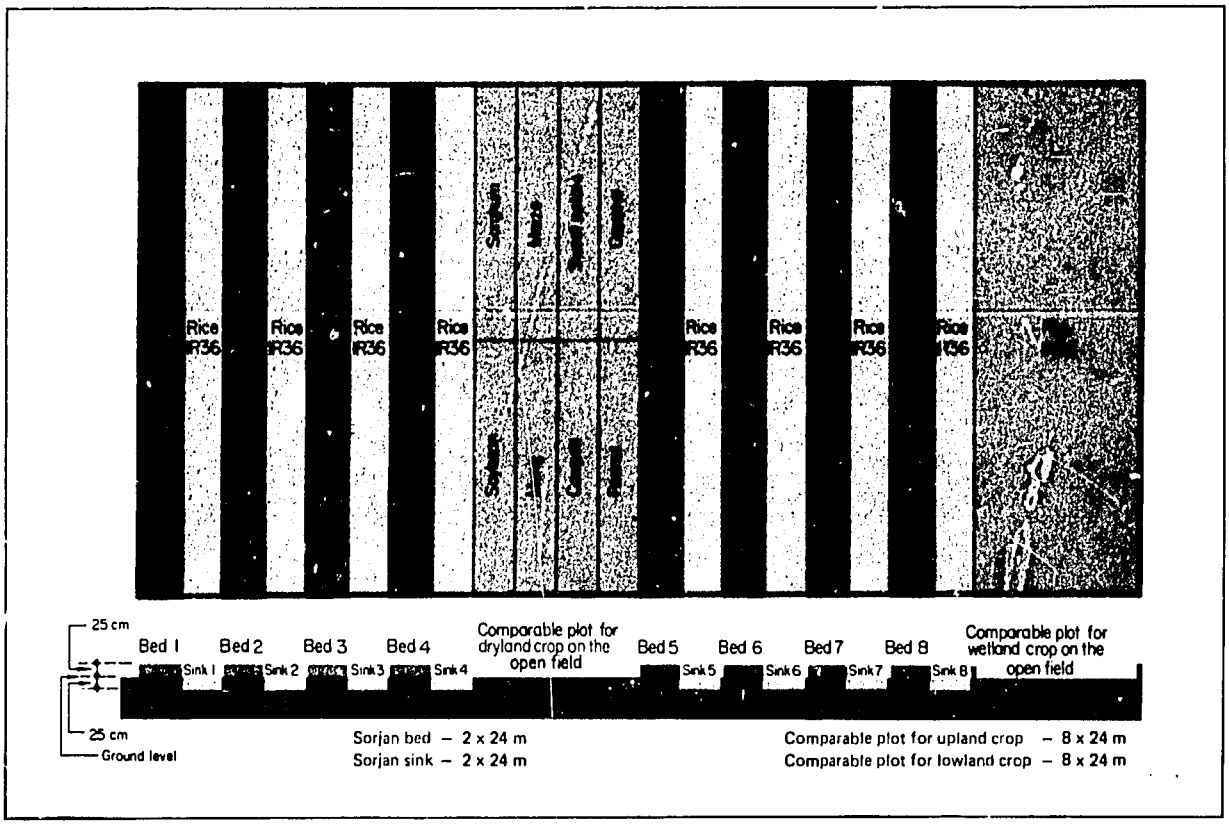
Labor-absorbing, high-intensity crop system for rainfed land

For many of the world's farmers who grow rainfed rice, the availability of enough water for two rice crops is problematic and risks of crop failure are high. Likewise the production of a dryland crop after wetland rice is hampered by the puddled soil conditions in the paddy. Rainfed farmers often face this no-win situation.

Farmers in Java have for centuries used a cropping system to accommodate water excesses and deficiencies in rainfed areas. Called *sorjan*, the system permits the growing of dryland crops on raised beds adjacent to wetland rice in flooded depressions.

We began experiments with a similar system in 1979. Beds were constructed by adding 25-cm-deep soil from adjoining depressions, or sink areas, resulting in a 50-cm difference between bed and sink surfaces (Fig. 8). During the rainy season, our objective was to grow at least two dryland crops in sequence on the beds and two wetland crops in the sinks. Using residual moisture after the second rice crop, we grew an upland crop in the sinks during the early part of the dry season.

Our first and second crops of soybean grown on the raised beds were outstanding (Table 4). Second crops of mung bean, cowpea, and maize (green ears) also performed well, as did a 5-month cassava crop. The raised beds apparently provided



8. Sorjan system trial on the IRRI farm showing the first crop. Note the alternate raised and depressed beds that provide differences in water regimes.

excellent drainage for these crops, even during periods of high rainfall.

Yields of rice crops in the sinks were low, which was not surprising because topsoil on those areas was removed to raise the beds for the dryland crops. Incorporation of crop residues and application of more fertilizer should improve rice yields

After initial trials at IRRI the system was tested in farmers' fields in Pangasinan province. We planted several dryland crops

Table 4. The rainy season yields of upland crops on the raised beds of the *sorjan* system were exceptionally high. In contrast, rice yields in the depressions were low, probably due to low fertility of the exposed subsoil on which rice grew.

System and crop	Crop yields			
	IRRI		Farmers' fields	
	Jun–Sep	Oct–Dec	Heavy soil	Light soil
Raised beds				
Soybean (t/ha)	3.2	2.5	3.9	1.3
Mung bean (t/ha)	1.2	1.7	2.0	1.7
Maize (thousand marketable ears)	15.8	86.5	31.0	27.3
Cassava (t/ha)	21.0		----	
Depressions (mostly subsoil)				
Rice (t/ha)	2.1	1.7	2.8	1.2

to identify those most suited to the system. By rotating the crops among the beds from season to season, we took advantage of the nitrogen fixed by grain legumes and avoided yield reduction of these crops, which often results from successive plantings. The farmers' yields on a heavy soil were about as high as what we obtained at IRRI. Yields on a light soil were low, however (Table 4).

Construction of the 2-m-wide beds and sinks at IRRI required about 4,500 hours of labor/ha for which we assumed relatively high market wage rates. The total construction cost of US$1,380/ha apportioned among six successive rice and dryland crops for each of 2 years gave a construction investment of about US$230/ha per crop.

In Pangasinan where local labor was employed and supervised according to local practices, the construction cost was a third lower – US$150/crop. If a farm family constructed the system, the labor cost might be even lower, particularly for construction during the off-season.

Using these construction costs, we calculated the gross and net returns for each crop grown in the system (Table 5). For all crops except rice, which was grown in the sinks, the net returns were good.

Several crop combinations appear highly profitable in a given season. Rice and soybean, for example, should give about US$620 profit/ha in the first season, and the following maize and rice, an additional US$570. Returns on a third crop planted near the end of the rainy season should provide additional profit. We expect the profitability to improve with refinement of management practices.

The *sorjan* type system has some drawbacks:

- Removal of the topsoil from depressions adversely affected the rice crops; however, higher yields should be possible after the soil is conditioned through further cultivation.

These photographs of the sorjan *trial at IRRI show soybean, rice, and mung bean growing in July (left), and cassava, rice, and sweet potato in December. See Figure 8 for the plot plan for beds and sinks.*

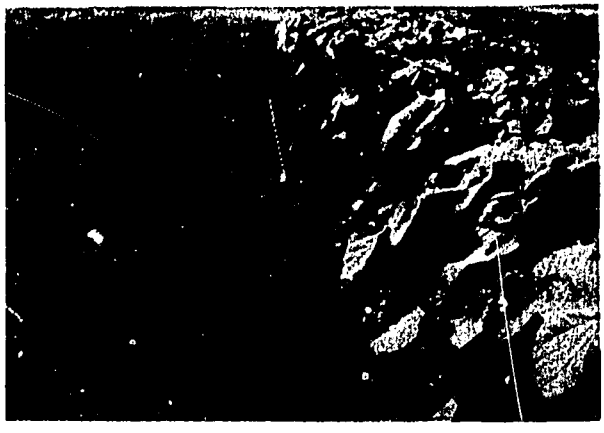


Table 5. Gross and net returns from different crops using the *sorjan* system at IRRI and from one farmer's field, 1979.

System and crop	Returns[a] (US$/ha)			
	IRRI farm		Farmer's field[b]	
	Gross	Net	Gross	Net
Raised beds				
Soybean	4690	3100	1840	1230
Mung bean	3350	1270	1600	990
Maize	2720	1520	840	320
Cassava	3160	2280	–	–
Depressions				
Rice	610	–820	490	120

[a]Share of construction costs included as follows: IRRI = US$230/ha, farmer's field = US$150/ha. [b]Heavy soil.

- Rats caused an estimated 20% yield loss on the first crop of rice and 60% on the second. Sweet potato appeared to harbor rats and was deleted from further trials at IRRI.
- A rice yield of 4.5 t/ha would be necessary to break even on rice considered alone. But all dryland crops, except the first crop of sorghum, achieved sufficiently high returns to pay for an appropriate share of the labor invested in construction plus other labor and material costs.

The system is designed for the small rainfed farm where additional opportunities for employment of labor and management resources are needed. The additional employment and compensation of 4,500 hours of labor/ha for bed construction alone may prove an important benefit to smallholder agriculture. It represents a noncash investment in infrastructure on a scale suitable for a single farm. Areas with partial irrigation may benefit as well.

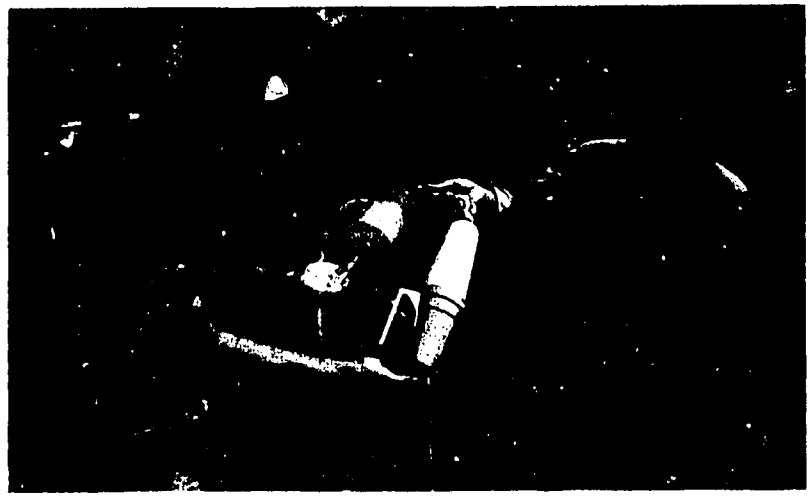
An increased and more evenly distributed supply of vegetable protein throughout the year will benefit farm families and consumers alike.

INSECT PESTS AND CONTINUOUS RICE PRODUCTION

The development of irrigation systems in Asia during the past 20 years, which allowed a rice crop in the dry season, is cited as having contributed to the recent brown planthopper and green leafhopper epidemics. With the added dry season crop, those insects which are specific to rice, can multiply throughout most of the year. The recent introduction of a continuous rice production system, which maximizes rice cropping intensity, is feared by some as a harbinger of even greater insect pest problems than now exist.

To explore this possible increase in insect problems, we monitored a continuous weekly rice planting system at IRRI

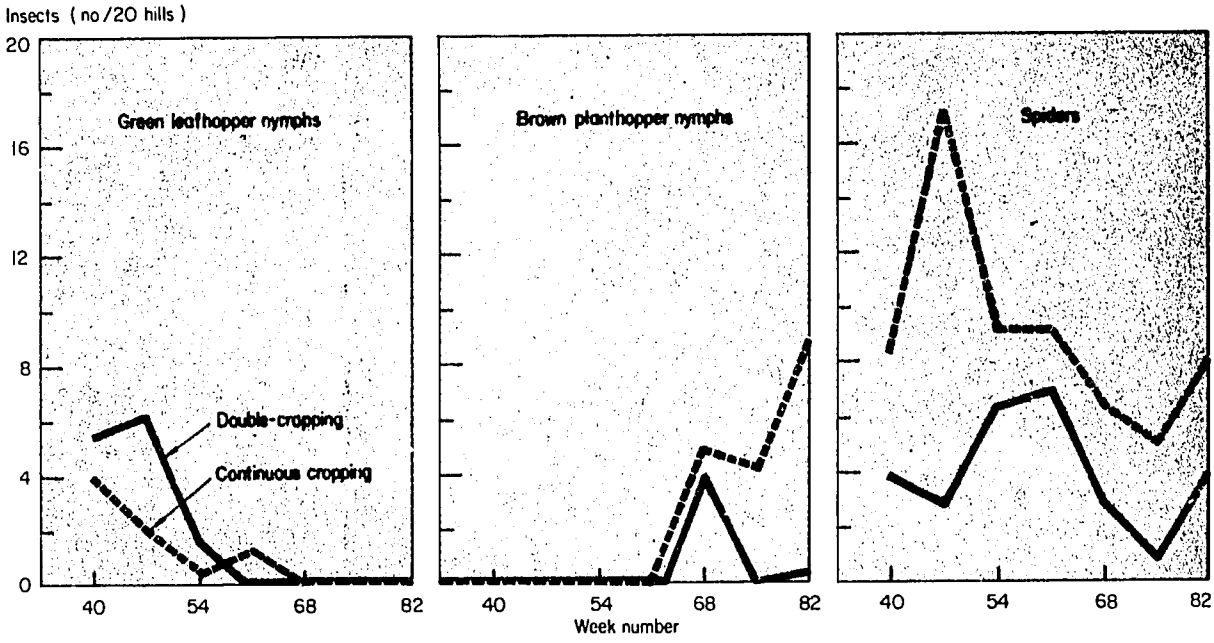
Patrocinio Pantua, IRRI research assistant (left), checks numbers of hoppers and their predators in the collection vial of a FARMCOP suction sampler. Sampling was done weekly for 1.5 years on an 8.5-ha plot in an IRRI continuous rice cropping trial. Intensification of cropping did not lead to insect pest buildup in the rice crop.



for three seasons during 1978–79. We grew a variety that was insect-susceptible, but was resistant to virus diseases. No insecticides were used. A double-crop system was also established in addition to the continuous planting. The double-crop system had the same cultivars and used no insecticides.

Our counts of insect pests and their natural enemies did not support the belief that continuous cropping intensifies insect pest problems. In fact continuous cropping was more favorable to natural enemies, such as spiders, than the common double-crop system. Hopper populations were low in both systems, but the predatory spiders were more abundant in the continuous cropping (Fig. 9). There is good reason to believe that

9. Weekly FARMCOP suction sampling in the 1979 wet season shows low brown planthopper and green leafhopper populations in both the continuous and double-cropped rice production systems, but indicates that spider predators may be favored by the continuous availability of hopper prey.



continuous cropping represents favorable conditions for natural enemies because their hosts (insect pests) are present year-round.

Other rice pests encountered, such as whorl maggot, leaf folder, and rice bug, were well below economic injury levels in both the continuous and double-cropped systems.

While our research on insect pests and their natural enemies supports the contention that some insect pests were favored when the cropping pattern changed from single to double-cropped rice with the advent of irrigation, we have not found that further intensification of cropping leads to greater insect buildup.

COMPONENT TECHNOLOGY

The rapid adoption of a double-rice-crop system by farmers in rainfed areas also increased demands for better adapted varieties of wetland and dryland rice and the upland crops that fit into cropping patterns before or after rice.

Testing of upland crops

During 1979 we continued to screen promising rices from our GEU program. We also tested upland crop varieties at IRRI and the three Philippine sites in the Cropping Systems Network. The upland varieties – mung bean, soybean, cowpea, sorghum, maize, sweet potato, and peanut – were selected in collaborative screening by the University of the Philippines at Los Baños. The screening identified several upland crop varieties for use after wetland rice or as a premonsoon crop. The screening program also resulted in certification of several varieties by the Philippine Seed Board.

Testing of varieties in a cooperative IRRI-University of the Philippines at Los Baños project identifies promising upland crops for use throughout the cropping systems network. V. R. Carañgal, IRRI agronomist and cropping systems network coordinator (right), and A. A. Gomez, UPLB professor of agronomy, check a cowpea variety in 1979 tests.

Determining fertilizer rates

During 1979 we developed a 5-step method to determine fertilizer rates that are within the financial and management capability of farmers and are also compatible with our experimental cropping systems. Objections to the traditional field method of determining fertilizer rates were that the experiments were large or complex, or both, which limited the number of fields used and thus made it difficult to determine variation in response across fields. In addition, the precision level of large designs exceeds the requirements of practical agronomists who, for simplicity, define rates in multiples of 10 or even 25 kg/ha.

With the new method we:

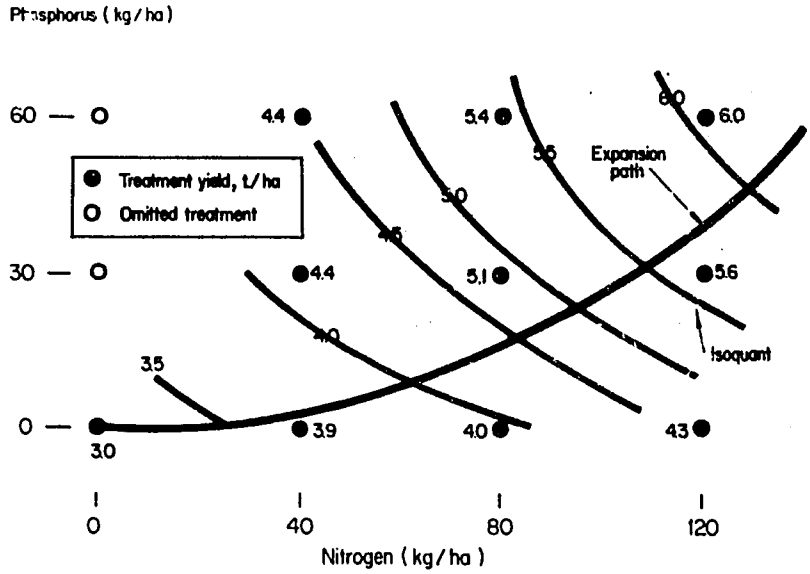
- determined experimental fertilizer ranges and selected test levels using as criteria soil tests, or previous experiments on similar soils, or both;
- determined rational treatment combinations on the basis of fertilizer prices and crop nutrient requirements, eliminating treatment combinations that will obviously be uneconomical;
- located experiments in fields within recognized land units, using 2 replications/field and 10–12 fields to sample yield variability;
- reviewed our data from each experiment statistically; and
- determined economically dominant fertilizer rates by plotting benefits against costs.

We evaluated the 5-step approach in a field in an irrigated area of Napnapan, Iloilo, with wet-seeded IR36 planted in June and September as the test crop.

First crop. For the first crop, upper fertilizer limits were set at 120 kg/ha, 60 kg P_2O_5/ha, and 30 kg K_2O/ha. The three nutrient elements were applied in six treatment combinations. Nitrogen was considered the primary limiting element, and all treatments except the check contained nitrogen at some level, thereby eliminating treatments with phosphorus alone. Likewise, because phosphorus is probably the second limiting element, all treatments to which potassium was applied contained both nitrogen and phosphorus.

Crop yields with and without potassium showed no significant response to this element. Furthermore, interactions between potassium and either nitrogen or phosphorus were not important. A sight-drawn response surface and expansion path, using treatment means, is shown in Figure 10.

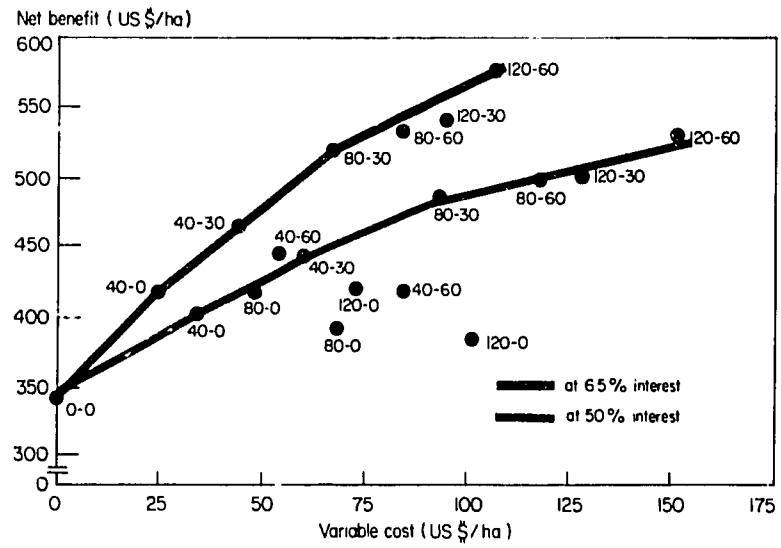
Benefit-cost curves at high and low interest rates, based on the treatments in Figure 10, are shown in Figure 11. Fertilizer rates 80-0-0, 120-0-0, and 40-60-0 were certainly not good choices because for each of them, there was another treatment with a



10. 1978 rice grain yields from different nitrogen and phosphorus combinations (solid dots) and sight-drawn isoquants and an expansion path for a first crop at Iloilo, Philippines. The mean yields from 20 fields with 2 replications per field were included.

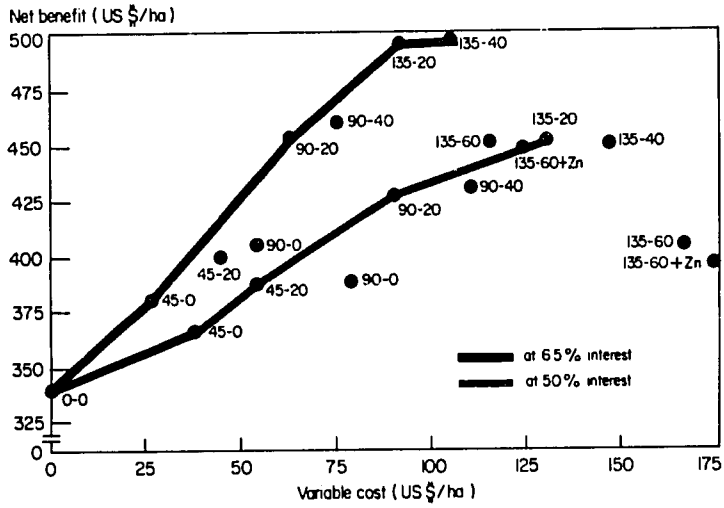
higher net benefit but a lower variable cost. Similarly, net benefits for fertilizer rates 80-60-0 and 120-30-0 fell slightly below a line connecting the values for the 80-30-0 and 120-60-0 treatments. This suggests the N and P balance for the 80-60-0 and 120-30-0 fertilizers would not optimize profits.

Second crop. For the second crop, the maximum nitrogen was increased to 135 kg/ha, potassium treatments were eliminated, and an additional phosphorus level was inserted. Nine N-P treatment combinations and 1 N-P-Zn treatment were planted in 20 fields. There was no response to the zinc treatment and the N-P-Zn treatment was deleted from subsequent analysis. As in the first crop, a sight-drawn response surface and expansion path showed agreement with expected



11. Net benefits as related to variable costs for 10 N and P fertilizer treatment combinations, at two interest rates, first crop at Iloilo, Philippines, 1978. All points below the lines identify fertilizer combinations that are economically unfavorable. Numbers joined by a hyphen indicate kilograms N and P per hectare.

12. Because the price of rice was lower at the second harvest, net benefits were lower from 10 fertilizer treatment combinations, at two interest rates, for the second crop at Iloilo (see Fig. 11).



behavior. Benefit-cost curves assuming high and low interest rates are shown in Figure 12.

Examination of variance components indicated that the number of fields required can be reduced to 10–12 to obtain a standard deviation that is within 4% of the mean of treatments near the middle of the response surface.

The 5-step method appears promising for use by cropping systems agronomists. With it they can quickly determine fertilizer levels that are applicable in simple units of 10–20 kg of nutrient elements/ha. This information can be used by economists in formulating total input packages that are within the financial and management capability of small farmers.

Soil water extraction by upland crops

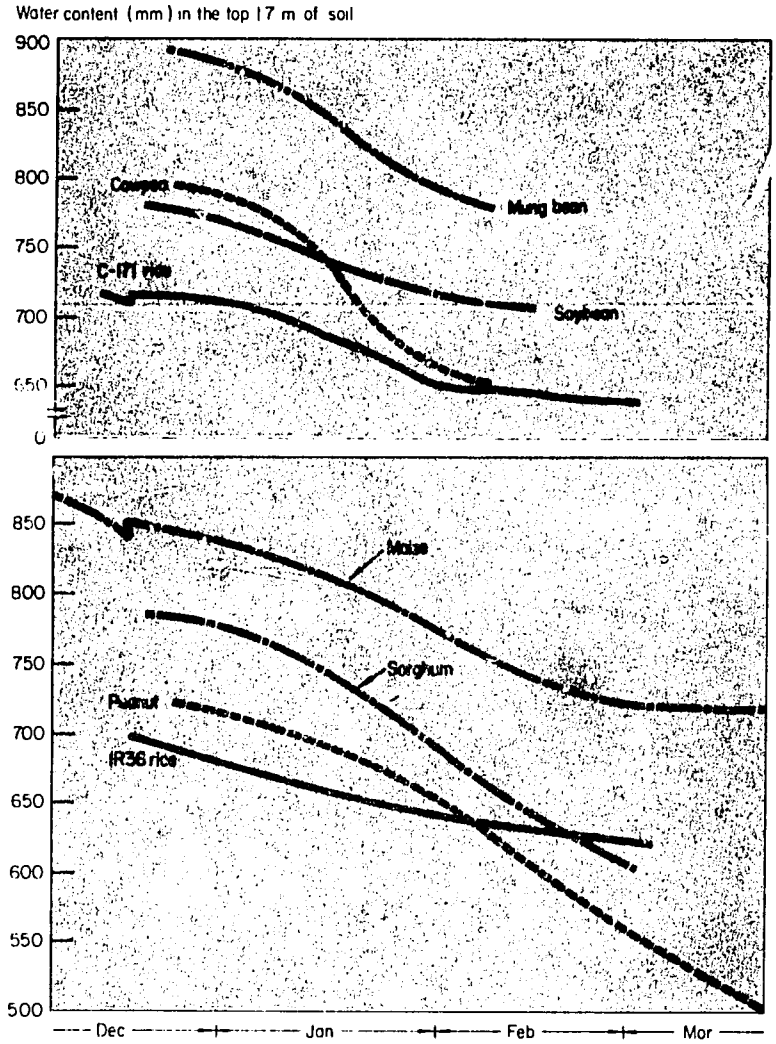
For many farmers who grow rainfed rice the wet season is too short or the rainfall too erratic for growing a second rice crop; however, there may be sufficient soil water for growing an upland crop with little risk.

We compared the ability of crops to extract soil water at a rainfed dryland site at IRRI. Soil water depletion by eight crops was checked. Starting values of soil water differed because the soil was heterogenous (Fig. 13). The crops showed great differences in the amount and pattern of water extraction.

The results suggest that ability to extract soil water explained the success of sorghum, peanut, cowpea, and mung bean as dry-season crops. Maize, soybean, and rice need more than stored soil water if they are to avoid water stress.

Weeds in dry-seeded rainfed rice

Weeds are a greater problem in rice grown in dry-seeded rainfed paddies than in wetland irrigated paddies mainly because more



13. Soil water extraction by the crops was checked in the 1978–79 dry season. Cowpea showed rapid extraction during its brief (66 days) life cycle, but the total extracted (140 mm) was much less than that extracted by peanut (236 mm in 102 days), or by sorghum (178 mm in 78 days). Soybean and the two rice varieties extracted the least (75 mm) and extracted no water below 60 cm from the soil surface.

weed species occur in the unpuddled rainfed soils (Table 6).

We found that weed species growing in association with the rice crop were affected by land preparation methods and weeding regimes. In terms of weed weight, broadleaf weeds and sedges predominated in puddled soils, while grasses dominated in unpuddled rainfed soils.

Weed variation in transplanted rice

Variations in rice yield losses due to weeds in transplanted rice occur across fields and between seasons. Differences in the weed communities growing in association with the crop partially explain the variations. In trials in which all cultural practices except weeding were the same, yield reductions caused by weeds varied from 10 to 100% (Table 7) depending on the weed community types.

Table 6. The number of weed species and weight of weeds at maturity of a rice crop are affected by method of land preparation and water availability. IRRI, 1979 wet season.[a]

Field condition	Weed species[a] (no.)				Weed wt[a] (g/0.5 m²)
	Broadleaf weeds	Grasses	Sedges	Total	
Puddled irrigated	3	1	2	6	5.2
Puddled rainfed	5	3	5	13	17.3
Unpuddled irrigated	6	4	4	14	54.2
Unpuddled rainfed	9	6	4	19	81.3

[a]Av of 3 replications.

Plant pathogens in rice and component upland crops

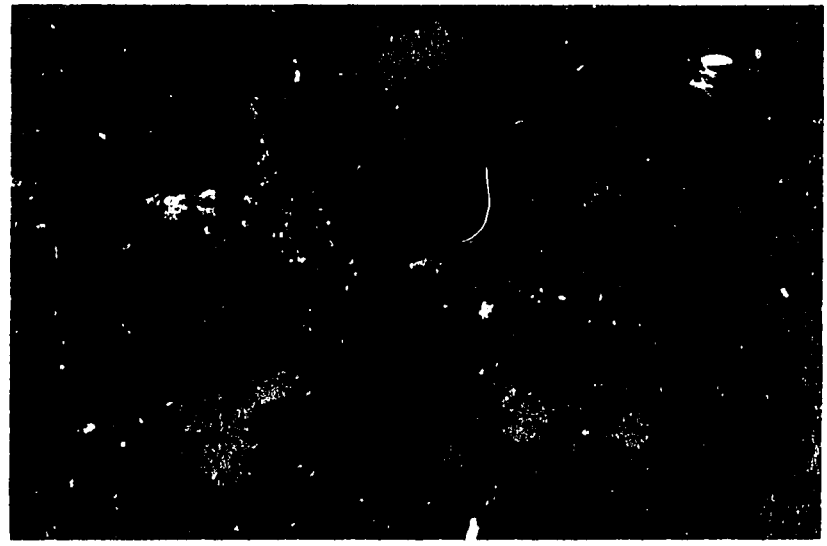
Many plant pathogens are known to have a wide host range that includes rice, maize, sorghum, and grain legumes. The sheath blight and damping-off caused by *Rhizoctonia solani*, and sclerotium stem rot or damping-off caused by *Sclerotium rolfsii* are examples of diseases with such a wide host range. Occurrence of a disease on any component crop in a cropping system could perpetuate inoculum for crops that follow.

We found that *R. solani* strains causing preemergence damping-off on rice, maize, sorghum, cowpea, mung bean, and soybean were equally effective in attacking each of these crops. Among the strains causing postemergence damping-off, however, the cowpea strain differed significantly from the others, causing less disease on rice, maize, and sorghum than on grain legumes. On mature plants, the cowpea strain induced a distinct short lesion on the sheaths of all crops.

S. rolfsii strains from rice, cowpea, mung bean, and peanut were compared through cross-inoculation. All strains caused damping-off on grain legumes and seedling blight on rice and sorghum. The rice strain appeared to be the most aggressive and caused more disease on all crops than did the other strains. On mature plants, the pathogen caused stem rot on grain legumes, maize, and sorghum as well as on rice.

Table 7. The relationship between yield reduction and weed weight for different weed communities in transplanted rice at IRRI, 1978–79.

Weed community	Yield reduction (%) with weed wt of					Weed wt (g/m²) required for 50% yield reduction
	100 g/m²	200 g/m²	300 g/m²	400 g/m²	500 g/m²	
Echinochloa crus-galli ssp. *hispidula-Scirpus maritimus*	42	80	100	–	–	123
Monochoria vaginalis-Echinochloa glabrescens-Fimbristylis littoralis-Scirpus maritimus	21	42	63	84	95	239
Monochoria vaginalis-Scirpus supinus	15	31	46	62	77	333
Monochoria vaginalis	15	31	46	61	75	366
Echinochloa glabrescens	10	20	30	40	51	497



Increased problems with weeds are faced by farmers who direct-seed a first crop of rainfed rice.

Disease and ratoon rice. Soil-borne rice diseases such as sheath blight and stem rot could be important biological constraints in establishment of ratoon rice. We found that stem rot was more common than sheath blight on rice stubble that failed to produce ratoon tillers. Sheath blight was observed on the main crop, but not on tillers produced from ratoon. Fields with standing water, which favored ratooning, also favored stem rot development.

Ratoon cropping of rice

Areas with growing seasons of only 120 to 160 days are generally not suited to double rice cropping. But with shorter-duration modern varieties, many such areas have a 60- to 100-day period after rice harvest when fields remain at or above saturation. Such fields can be used for a ratoon rice crop (Table 8). Because a ratoon crop does not require land

Table 8. Approximate days required for rice-rice and rice-ratoon cropping patterns with a short-growth-duration (100 days) rice variety.

Cropping pattern[a]	Crop duration (days)	Turnaround time (days)	Growing season offset[b]	Total growing season requirement
DSR-TPR	100 + 80	20	0	200
WSR-TPR	100 + 80	20	20	220
TPR-TPR	80 + 80	20	40	220
DSR-Ratoon	100 + 60	0	0	160
WSR-Ratoon	100 + 60	0	20	180
TPR-Ratoon	80 + 60	0	40	180

[a]DSR = rice seeded into dry soil, WSR = rice seeded into puddled soil, TPR = transplanted rice. [b]Days that elapse between the start of the growing season and planting time.

Table 9. The sink (panicle)-source (leaves) relationship in production of ratoon tillers is evident here. Clipping half of each panicle substantially increased ratooning, but clipping the leaves resulted in reduced ratooning of IR36 and IR42.

Treatment	Tillers produced[a] (no.)			
	IR36		IR42	
	Basal	Nodal	Basal	Nodal
Clip 50% panicle length just after flowering	2.0 a	40.0 a	7.5 a	17.3 a
Clip 50% leaf area just after flowering	1.0 a	4.4 c	3.7 b	5.7 c
No clipping	1.0 a	15.0 b	7.6 a	8.8 bc

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

preparation, seedlings, and transplanting, it saves 30% of the cost of production of a transplanted crop.

We evaluated the potential of ratoon cropping of rice in 1979 as a way of providing more flexibility to farmers in the choice of cropping sequences for their land. Results show that the number of ratoon tillers varies greatly from experiment to experiment and is associated with temperatures at harvest time and sink-source relationship during the main crop (Table 9).

Among 400 IRRI breeding lines tested for ratooning ability in the dry season, only 19 showed normal or vigorous ratooning. We evaluated those for dry matter production per day. The six best – IR13471-57-3, IR15315-26-3-2, IR8608-183-2-3-3-1-3, IR9802-50-1-2-2, IR9784-52-2-3-2, and IR9852-19-2 – had less than 5% missing hills, at least 16 tillers/hill, and excellent vigor.

PREPRODUCTION EVALUATION OF CROPPING SYSTEMS

Research at experiment stations, and even formal research that produces promising results in farmers' fields, must still be widely tested on farms. Such testing requires a more informal approach and is commonly done in cooperation with extension specialists. Evaluation of a method of extending cropping systems technology to farmers' fields in rainfed areas received high priority in 1979. We focused on increased cropping intensity – growing two or even three crops where farmers had grown only one before.

Success for rainfed farmers

Using research results and experience gained since 1974, we encouraged the Philippine Government in 1976 to establish a pilot crop production project in Iloilo province. Named KABSAKA, the project involved extension of new rice technology from research plots to rainfed rice farmers' fields. Project farmers planted their first project crop in early 1977.

Testing of new rice technology in farmers' fields brought together IRRI Scientist L. D. Haws (left) and Regional Bureau of Agricultural Extension Specialist Paul Sotomil. The KABSAKA project started in these Santa Barbara, Iloilo, farmers' fields in front of Haws and Sotomil. In 1979 Sotomil had more than 700 farmers enrolled in KABSAKA.

In 1979 we surveyed the KABSAKA project to get an indication of its impact – social, economic, and institutional. In 1977 about 90 farmers had direct-seeded an early first rice crop. By 1978 nearly 320 farmers had asked to join the project. In 1979 more than 700 farmers in the region elected to follow the KABSAKA lead.

Table 10 shows some socioeconomic benefits that accrued to a sample of 23 farmers financed through KABSAKA. The benefits include increase in farm and household assets, house improvements, and education for their children. Financial gains include payment of previous debts to fellow farmers and the banks.

Farm implements acquired included hand tractors, water pumps, rice mills, threshers, sprayers, plows, harrows, and work animals (Table 11). The survey excluded implements bought before the KABSAKA project.

Household items were purchased and house improvements were made by the KABSAKA farmers. Ten farmers renovated their houses. Another change in the study area was increased higher education for farm children. Fourteen farmers were able to send their children to college, vocational school, or high school.

Table 10. Of 23 bank-financed farmers surveyed, most reported increased farm assets and major changes after joining KABSAKA in Santa Barbara, Iloilo, Philippines.

Change	Farmers (no.) reporting
Increase in farm assets	17
Increase in household assets	8
House improvement	8
Education of children	7
Payment of debts	4

Table 11. Farm capital assets acquired by 23 bank-financed farmers after joining KABSAKA in Santa Barbara, Iloilo, Philippines.

Asset	Farmers (no.) reporting	Quantity acquired
Sprayer	11	11
Plow or harrow	5	8
Thresher	5	7
Hand tractor	4	4
Pump irrigation	4	4
Work animal	2	6
Livestock for market	2	7
Rice mill	1	2

The farmers unanimously attributed the improvements in their living standards to double-cropping of rice. Their income more than doubled. Before KABSAKA the 23 farmers surveyed had average gross returns of about US$462/ha; after KABSAKA, the average was US$1,000.

Continuous rice cropping

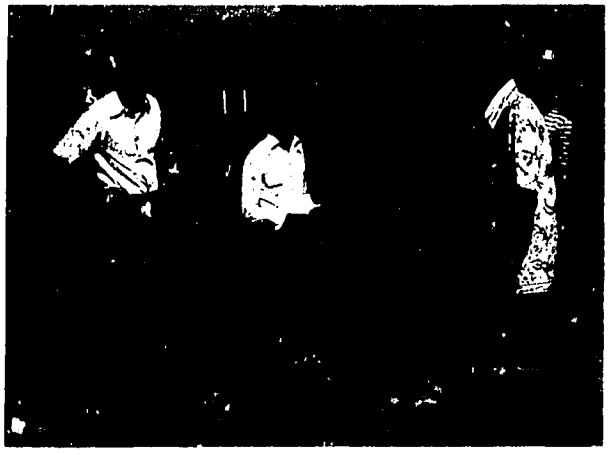
A continuous rice cropping system tested at IRRI in 1976–78 was advanced to multilocation testing in the Philippines in 1979. We also gave Indonesian extension workers training in operation of the system.

By the end of 1979 we had encouraged the start of 12 continuous rice cropping systems on 405 ha in 12 provinces. One system alone covered 350 ha. Rice production per year had nearly doubled in all systems and farmers had started expansion of their continuously cropped areas.

An immediate conclusion from on-site testing is that the system is easily adapted to the whole range of farm sizes. When annual rice production increases from 10–12 t/ha to 25–30 t/ha, the farmer with 1 ha has 15–18 t of added rice to sell and the farmer with 20 ha has as much as 400 t added rice to market. The possibility of an insect buildup in the continuous system was checked by IRRI researchers in 1979. Predator insect populations became more stable (*see* section Insect pests and continuous rice production).

ASIAN CROPPING SYSTEMS NETWORK

The Asian Cropping Systems Network continued to focus on cropping systems research in different rice environments in Asia – Philippines, Indonesia, Thailand, Sri Lanka, Bangladesh, Nepal, Malaysia, and South Korea. Our research sites represent a broad range of climatic zones, soil type, soil texture, and socioeconomic conditions in major rice countries in Asia. The



Activities to review, guide, and improve cropping systems work in Nepal during 1979 were typical of the network approach. The Asian Cropping Systems Working Group met in Nepal and a study tour covered network research sites in Nepal and Thailand late in 1979. Cropping systems research in Nepal is supported by the International Agricultural Development Service (IADS), which sent a team to visit research sites in 1979. Dr. Clarence C. Gray, chairman of the IRRI Board of Trustees, was a member of the IADS team.

number of test sites and kind of rice land involved are shown in Table 12.

In addition to the 22 network sites, 27 cropping systems research sites operated by national teams were associated with the network.

The Asian Cropping Systems Working Group, which provides

Table 12. Cropping systems research was active at 22 Asian Cropping Systems Network sites in 1979. Fifteen sites had research on rainfed wetland cropping systems.

Country	Sites (no.)	Rice land (no.) involved at sites				
		Rainfed wetland	Partially irrigated wetland	Dryland	Irrigated wetland	Deep-water
Thailand	4	4	–	–	–	–
Philippines	3	2	2	1	–	–
Indonesia	3	2	–	2	–	1
Sri Lanka	3	2	1	–	–	–
South Korea	3	–	–	–	3	–
Bangladesh	2	1	1	–	–	1
Nepal	2	2	1	–	1	–
Malaysia	2	2	–	–	2	–

guidance and support to the network, had its eighth meeting in Nepal. The group includes program leaders and selected resource persons from network countries.

A cropping systems study tour for coordinators, regional and national supervisors, and scientists responsible for cropping systems component technology visited research sites in Thailand and Nepal late in 1979.

Machinery development

Turnaround time – the period between harvest of one crop and the planting of a following crop – is constantly cited as a bottleneck to increased cropping intensity. Factors contributing to longer turnaround time are many, but lack of labor at peak periods, lack of water control, and speed of tillage are most often cited.

To help overcome such production bottlenecks, we developed an efficient, low-cost water pump, and a rotary tiller attachment for the highly popular IRRI power tiller. We also put a simple, manual transplanting machine in final field tests in 1979.

Axial-flow pump

Farmers in many developing countries use relatively expensive centrifugal pumps to lift water only 1 or 2 m. Such a low lift is below the efficient operating head of centrifugal pumps. An axial-flow pump of the same horsepower input provides water at a much lower operating cost.

We designed and developed an axial-flow pump with which farmers can handle irrigation water at low cost, low head, and

The self-priming axial-flow pump will pump as much as 1,500 liters of water per minute at a lift of 4 meters. The simple, low-lift pump was designed for fabrication in small shops in developing countries. Its efficiency is higher than that of many axial-flow pumps already on the market.

Salvador Labro, IRRI senior research assistant (left), times a planting trial with the new manual transplanter. The machine requires 30–35 hours of labor/ha. Seedling mats slide into trays on the machine. Seedling production requires special frames (right). The transplanter went into on-farm tests in 1979.

high capacity. The new pump, driven by a 5-hp engine, is light enough to be carried by two men and will pump water at rates of 1,500 to 3,000 liters/minute at lifts of 1 to 4 m.

The simple, self-priming pump can be fabricated in small shops with standard metal forming tools. Its bearings are made of oil-soaked hardwood and all components are readily available in developing countries.

Manual 5-row transplanter

A shortage of transplanting labor is a main reason for a long turnaround period between two rice crops. Direct seeding is sometimes used to reduce the turnaround time, but it is not always practical because of poor land preparation and inadequate water control. We continued development of a low-cost, simple, manually operated transplanter that should reduce transplanting time by 30–50%.

In tests at Los Baños, 30-day-old mat-type (soil bearing) seedlings were transplanted in water as deep as 10 cm. The transplanter was advanced to tests in farmers' fields in the Philippines, Thailand, Burma, Indonesia, and Pakistan by IRRI Farm Machinery Development Program Network engineers.

Rotary tiller attachment for IRRI tiller

Several manufacturers cooperating with IRRI have found that customers prefer rotary tillers to the plow for the tillage of wetland rice fields. They also observed that a lightweight 2-wheel tractor does not always develop sufficient pull for draft implements in dry soils.

In response to those needs, we developed a 60-cm-wide rotary tiller attachment for the IRRI tiller. After 1,400 hours of field tests we released a rotary tiller design to cooperating manufacturers in December 1979.

In wetland fields an IRRI power tiller with a 6-hp diesel engine and the rotary tiller attachment prepared a hectare in

about 10 hours – using about 0.6 liter of fuel/hour. Normally two passes are required for complete land preparation.

As part of the rotary tiller attachment project, we developed a 4-speed belt and chain drive to replace the tiller's existing 2-speed belt design. The new drive system provides speeds of 2.5 km/hour for rotary tillage, 4.5 km/hour for harrowing, 8 km/hour (60 rpm) for use with axle-mounted spiral plows, and 13 km/hour for overland transport.

International activities

The mid-1970s marked the start of a concerted move toward cooperation with national rice improvement programs. The period that started in 1974, in the second decade of IRRI, could well be called the decade of international cooperation for rice improvement. Our international activities increased markedly in 1979.

Cooperative country projects

We had cooperative country projects in Bangladesh, Burma, Indonesia, Pakistan, Philippines, and Sri Lanka.

- *Bangladesh.* A team of six IRRI scientists worked with scientists of the Bangladesh Rice Research Institute on development of improved varieties for deepwater areas, removal of soil-related constraints to rice yields, a field trials program for varietal testing, fertilizer trials and crop management, manufacture of IRRI-designed small-scale machines, implementation of an irrigation research program, cropping systems research, and establishment of a national cropping systems research network.
- *Burma.* One IRRI scientist worked with observational nurseries to identify new introductions and with selections from previous introductions, breeding lines from new and previous crosses, and promising wetland rice selections under irrigation. He also organized training in varietal improvement.
- *Indonesia.* Eleven IRRI scientists worked in Indonesia with the Central Research Institute for Agriculture (CRIA) at Bogor, Maros, Sukamandi, and Pasar Minggu. We established a cooperative GEU program with CRIA in 1979, to facilitate the selection of elite crosses for evaluation in Indonesia and at IRRI. The Government of Indonesia supported collaboration in the development, testing, and extension of small farm machines.
- *Pakistan.* Two IRRI scientists in Pakistan worked in applied research for rice production and the development and

evaluation of farm machinery. An applied research program (*Sarian Jo* 77) was designed to determine whether high yields could be demonstrated on whole farms with a new package of technology. An agricultural machinery program, started in 1976, found that relatively large and powerful machinery is in demand in Pakistan.

- *Philippines.* One IRRI scientist was assigned to work with Philippine researchers and extension specialists in rice pest management.
- *Sri Lanka.* Four IRRI scientists worked in a Government of Sri Lanka-IRRI rice research project, which included rice breeding, cropping systems field trials and adaptive research, and a resource capability survey.

People's Republic of China

We continued to expand collaborative work with scientists of the People's Republic of China.

- The IRRI Board of Trustees held their annual meeting in Beijing in early October. After the meeting Board members made an official 10-day tour to see rice research in China.
- A rice research workshop jointly sponsored by the Chinese Academy of Agricultural Sciences and IRRI was held in October 1979 in Guangzhou. A significant outcome of the workshop was the identification of areas for cooperation in research and other activities.
- Participation of Chinese scientists in training and in workshops, conferences, and monitoring tours increased.
- IRRI and the Chinese Academy of Agricultural Sciences agreed to collaborate in developing a plan for a National Rice Research Institute for China.

Liaison operations

IRRI liaison scientists assisted in developing collaborative projects and helped coordinate the International Rice Testing Program (IRTP) activities in Southeast Asia, Africa, Latin America, and India.

- *Africa.* An IRRI liaison scientist assigned to the International Institute of Tropical Agriculture, Ibadan, worked with national research centers in testing IRTP materials.
- *Latin America.* An IRRI liaison scientist assigned to the Centro Internacional de Agricultura Tropical supervised the IRTP Program for Latin America and helped national improvement programs by providing improved germplasm.
- *India.* A Ford Foundation scientist at New Delhi provides a link with Indian rice research. The National Bureau of Plant Genetic Resources made funds available for coordinated

Table 1. The 1979 international meetings at IRRI attracted more than 600 participants.

Title	Date	Attendance
IRRI-Office of Rural Development, Korea, annual planning workshop on collaborative projects	21–23 Feb	15
Center for Southeast Asian Studies-IRRI workshop on land evaluation for rice-based cropping systems	12–23 Mar	13
Irrigation water management workshop	26–30 Mar	48
International rice research conference	12–14 Apr	144
IRAEN constraints workshop	1–3 May	34
Conference on the communication responsibilities of the international agricultural research centers	14–19 May	60
IRRI-International Food Policy Research Institute-International Fertilizer Development Center workshop on rice policies in Southeast Asia	22–25 May	39
Eighth cropping systems working group meeting	28–31 May	37
IRRI/Cornell University conference on priorities for alleviating soil-related constraints to food production in the tropics	4–8 Jun	74
Workshop on consequences of small farm mechanization	1–4 Oct	43
IRRI/Chinese Academy of Agricultural Sciences international rice research workshop	22–30 Oct	32
IRRI-World Meteorological Organization symposium on the agrometeorology of the rice crop	3–7 Dec	68

collection of rice varieties in parts of India. Collaborative research on resistance to gall midge, brown planthopper, and viruses and on tolerance for drought, high and low temperatures, and adverse soil conditions is under way at Indian research stations.

- *Thailand.* A Rockefeller Foundation scientist provides leadership for deepwater rice research coordination and for liaison concerning farm machinery, water management, and agricultural economics research.

International meetings

More than 600 scientists participated in 12 conferences, workshops, and symposia sponsored or cosponsored by IRRI in 1979 (Table 1, above).

Associated formal training

The broad objective of our training activities is to serve national rice improvement programs by improving the capability of their rice scientists and extension workers. In 1979, 426 rice scientists from 33 countries were in training programs at IRRI (Table 1). Among the training participants were 219 postdoctoral fellows, research fellows, and research scholars, and 207 research and

Table 1. Distribution, by country, of IRRI research fellows, scholars, and trainees, 1979.

Country	Research oriented				Production oriented	International-network oriented				
	Post-doctoral	Research fellows, scholars								
		Ph D	MS	ND[a]	RPTR[b]	CSTP[c]	GEU[d]	INSFFER[e]	IWMT[f]	AET[g]
Australia	–	1	–	–	–	–	–	–	–	–
Bangladesh	2	3	24	1	4	10	10	2	5	2
Brazil	–	1	–	–	–	–	–	–	–	–
Burma	–	–	2	1	–	3	–	–	–	1
Canada	–	1	–	–	–	–	–	–	–	–
China	–	–	3	4	–	–	8	–	–	2
Colombia	–	–	1	–	–	–	–	–	–	–
Costa Rica	–	–	–	1	–	–	–	–	–	–
Cuba	–	–	–	3	–	–	2	–	–	–
Dominican Republic	–	1	–	–	–	–	–	–	–	–
Egypt	–	–	–	–	–	–	–	1	–	–
England	–	1	–	3	–	–	–	–	–	–
India	13	4	–	1	19	–	6	6	–	6
Indonesia	1	5	8	9	4	12	8	4	6	3
Japan	4	1	–	5	–	–	–	–	–	–
Kenya	–	–	1	1	–	–	–	–	–	–
Korea	1	1	3	8	–	1	–	1	–	1
Malaysia	–	–	–	4	4	3	3	–	2	1
Mexico	–	1	1	–	–	–	–	–	–	–
Nepal	–	1	1	–	–	3	2	1	–	–
Netherlands	–	1	1	1	–	–	–	–	–	–
Nigeria	–	–	–	–	1	–	–	–	–	–
Pakistan	1	3	1	2	–	–	2	–	–	2
Papua New Guinea	–	–	–	–	1	–	–	–	–	–
Philippines	1	6	18	4	1	5	2	2	6	1
Sri Lanka	5	1	5	2	3	2	5	1	2	–
Taiwan	–	–	1	–	–	–	–	–	–	–
Tanzania	–	–	–	–	–	–	1	–	–	–
Thailand	–	5	12	8	–	8	5	4	3	2
Turkey	–	–	–	–	1	–	1	–	–	–
United States	1	6	–	–	–	–	–	–	–	–
Vietnam	–	2	–	–	–	–	–	–	–	–
West Germany	3	2	–	–	–	–	–	–	–	–
Total	32	47	82	58	38	47	55	22	24	21

[a]Nondegree. [b]Rice Production Training Program – 6 mo. [c]Cropping Systems Training Program – 6 mo. [d]Genetic Evaluation and Utilization – 4 mo. [e]International Network on Soil Fertility and Fertilizer Evaluation in Rice – 4 mo. [f]Irrigation Water Management Training – 6 wk. [g]Agricultural Engineering Training – 2 wk.

extension workers in 4–6 month courses. In addition about 100 rice production specialists and others attended 3 special 2-week rice production courses. At the end of 1979 a grand total of nearly 3,000 people had participated in IRRI training (Table 2).

Almost all of our 1979 training participants were from developing countries. They returned to key positions in national rice research or production programs in their respective countries after completion of their IRRI training.

Of the 129 Master of Science and Doctor of Philosophy

Table 2. Nearly 3,000 rice scientists and extension workers have participated in IRRI training programs since 1962.

Year	Countries (no.) represented	Participants (no.)
1962	3	29
1963	8	58
1964	15	101
1965	14	85
1966	19	107
1967	19	129
1968	19	126
1969	25	133
1970	24	148
1971	29	172
1972	26	103
1973	24	126
1974	24	157
1975	28	208
1976	27	244
1977	29	253
1978	29	380
1979	33	426

The use of azolla as a biological source of nitrogen for rice was a main topic for the first INSFFER trainees at IRRI.

scholars at IRRI in 1979, 122 were enrolled in courses at the University of the Philippines at Los Baños and did their research under the guidance of IRRI scientists. Seven of the graduate students were enrolled for course work in other countries, but also did their thesis research at IRRI.

Our nondegree scholars come to IRRI for periods of 4–6 months to learn special techniques such as methodology for grain quality evaluation, screening techniques for resistance to pests, diseases, problem soils, etc.

Five 1979 training sessions of 2-week to 6-month duration were designed to support collaborative international network activities (Table 1). A first among the 1979 training courses was the 4-month course for the International Network on Soil Fertility and Fertilizer Evaluation in Rice (INSFFER). That course, offered for the first time, dealt with all aspects of soil fertility management, including biological nitrogen fixation. All the 22 scientists in the INSFFER course became network collaborators in their respective countries.

Finances

The Institute received cash grants amounting to $16,044,132 during 1979. The Ford Foundation gave $247,500: $100,000 was for core operations and capital expenditure, and the remainder was in support of the rice research and development programs of India ($122,500) and the Philippines ($25,000).

The Rockefeller Foundation contributed $226,604 which included $200,000 for core operations and capital needs. The

Foundation also gave $17,604 toward the stipend and miscellaneous expenses of a postdoctoral appointee at the Institute, and $9,000 toward the costs of a visit of top administrators and senior scientists from the People's Republic of China to IRRI and the University of the Philippines at Los Baños to acquaint them with rice research and production programs.

The U.S. Agency for International Development (USAID) released a total of $5,235,954. The Institute received $3,600,000 for its core operations; $84,679 for expanding, strengthening, and further institutionalizing the National Applied Research and Extension Program for Transplanted Rice; and $159,256 for industrial extension of small-scale agricultural equipment developed at IRRI.

In 1979 USAID released $1,392,019 to the Institute for six continuing contracts:

- $839,949 for a 5-year contract, signed in 1977, between IRRI and the Government of Sri Lanka for assistance in implementing rice and cropping systems research projects with funds provided by a loan from the USAID.
- $335,140 for a contract, signed in 1977, between IRRI and USAID, supporting a 2½ year project for accelerated development and utilization of improved rice technology in Indonesia.
- $86,442 for a contract, signed in 1977, for a 2-year project on collaborative rice research in Pakistan.
- $71,428 for a contract, signed in 1977, for a project on the consequences of mechanization on small farms.
- $49,605 for a contract, signed in 1978, for the services of an industrial extension engineer for the small-scale agricultural equipment extension project of the Government of Indonesia.
- $9,455 for a contract, signed in 1977, between IRRI-FNRI and USAID for supporting a project entitled *Protein quality of milled rice in preschool children.*

The Japanese Government gave $2,600,000 in 1979 for purchase of equipment for research and training, for partial support of cropping systems research, for the direct and indirect expenses of the Institute's plant physiology and soil microbiology departments, and for partial support of genetic evaluation and utilization.

The Ministry of Overseas Development, United Kingdom, released $1,134,450 toward the support of IRRI's core program.

The Canadian International Development Agency gave $1,121,900 toward the Institute's core operations; $421,250 toward a cooperative program for research and development between the Bangladesh Rice Research Institute and IRRI; and

$125,775 toward cooperative research programs on rice, rice-based cropping systems, and development of machines for small-scale farming between the Government of Burma and IRRI.

The International Development Research Centre (IDRC), Canada, granted IRRI $337,444. Of that $173,524 was part of a 2-year grant to the Institute for cropping systems research in the Philippines. The IDRC grant included $67,367 as part of a 2-year support of Indonesian research in cooperation with the Central Research Institute for Agriculture, to develop cropping systems for rainfed and partially irrigated rice areas and to adapt them through cooperative trials in farmers' fields; $22,235 as part of a 4-year grant to enable the University of the Philippines at Los Baños to conduct, in support of IRRI's multiple program, varietal screening for maize, sorghum, mung bean, eggplant, tomato, and sweet potato; $72,640 as part of a 4-year grant to support a multiple cropping research project at the Bangladesh Rice Research Institute; and $1,678 toward the publication of the second volume of *Changes in Rice Farming in Selected Areas of Asia.*

The European Economic Community released $818,334 toward the direct and indirect costs of water management, scholarships for candidates from developing countries, and partial support of the Genetic Evaluation and Utilization program of the Institute.

The Australian Government gave $786,833 in 1979. Of that, $596,313 was for core operations including travel of Australian scientists; $157,220 supported expansion of technical assistance and collaborative relationships with the Bangladesh Rice Research Institute; and $33,300 covered fellowship grants.

The West German Government gave $754,508 toward core operations and $62,729 for the workshop on program priorities for alleviating soil-related restraints to food production.

The International Development Association gave $595,000 toward core operations and capital expenditures of the Institute.

The United Nations Development Programme released $644,516 of which $260,598 was part of a 5-year contract for the International Rice Testing Program; $291,407 as part of a 5-year contract to investigate nitrogen fixation in association with wetland rice; $77,052 toward the cost of a symposium on rice culture and biological nitrogen fixation; and $15,459 toward the cost of a meeting of the Nitrogen Fixation Advisory Committee.

The Netherlands Government gave $243,361 as part of a 5.5-year grant for a project for regional rice research station development in Indonesia.

The Government of Indonesia, using a World Bank loan, released $217,802 to IRRI as part of a 7-year contract for development of research facilities at the Sukamandi Branch of the Central Research Institute for Agriculture and for scientific and technical assistance to rice research at Sukamandi.

The Government of Denmark gave $141,254 to support the core program.

The Government of Sweden gave $68,454 toward the core program.

Since July 1976, a contract between IRRI and the International Centre of Insect Physiology and Ecology has supported a joint program for ecological research on rice planthoppers using funds from the Australian Government. In 1979, $35,185 was released to the Institute.

Since February 1978, a contract between IRRI and the International Fertilizer Development Center supported a joint project entitled *Fate and efficiency of nitrogen fertilizers in lowland rice.* In 1979, IFDC reimbursed IRRI $34,362.

In 1976, IRRI entered into a cost-reimbursement contract with the U.S. National Institutes of Health to study ways of increasing protein and essential amino acids in the rice grain through plant breeding. In 1979, $8,167 was reimbursed.

The other donors were:

- Philippine Council for Agriculture and Resources Research:
  - (a) cooperative applied research on rainfed rice.... 36,555
  - (b) cooperative project toward improved organization of small farmers for intensified rice production..... 40,816
  - (c) cooperative applied research trials for wetland rice areas in Cagayan Province 2,545
- Swiss Development Corporation, cost of conference on communication responsibilities..... 30,000
- National Food and Agriculture Council, training government extension technicians 29,796
- International Board for Plant Genetic Resources, field collection of indigenous rice germplasm in South and Southeast Asia 18,000
- Potash Institute of North America and International Potash Institute, soil fertility 9,038
- Imperial Chemical Industries, research grant..... 5,000
- UNESCO, partial support of participants in the INSFFER 4,000
- Stauffer Chemical Company, weed control..... 3,000
- Ciba-Geigy, agrochemical research 2,000
- Monsanto, herbicide research 2,000

Board of trustees

DR. CLARENCE C. GRAY III
Chairman of the Board
c/o The Rockefeller Foundation
New York, USA

HON. ARTURO R. TANCO, JR.
Vice Chairman of the Board
Minister of Agriculture
Philippines

DR. NYLE C. BRADY
Director General
International Rice Research Institute
Philippines

DR. BHAKDI LUSANANDANA
Regional Plant Production Officer
Food and Agriculture Organization
Regional Office for Asia and the Far East
Bangkok, Thailand

DR. NORMAN R. COLLINS
The Ford Foundation
New Delhi, India

DR. ONOFRE D. CORPUZ
President
University of the Philippines
Philippines

DR. TOMOJI EGAWA
Professor of Soil Science
Meiji University
Kanagawa Prefecture 214
Japan

DR. MUSTAFA M. ELGABALY
No. 6 Nabatat Street
Garden City
Cairo, Egypt

DR. M. AMIRUL ISLAM
69 Tejkunipara
Tejgaon, Dacca
Bangladesh

MR. LIN SHIH-CHENG
Plant Breeder
Chinese Academy of Agricultural Sciences
Beijing, People's Republic of China

DR. H. K. PANDE
Director
Central Rice Research Institute
Cuttack, Orissa
India

ING. SADIKIN, S. W.
Badan Penelitian Dan Pengembangan Pertanian
Jalan Ragunan 29, Pasar Minggu
Jakarta, Indonesia

DR. HANS W. SCHARPENSEEL
Universitat Hamburg
Ordinariat fur Bodenkunde
Von Melle Park 10, D-2000 Hamburg 13
Federal Republic of Germany

MR. ALBAN GURNETT-SMITH
Officer in Charge
Centre for International Research Cooperation
CSIRO, P.O. Box 260
Canberra City, Australia

DR. FRANCISCO DE SOLA
H. de Sola e Hijos
Sucesores
San Salvador, El Salvador
Central America

Personnel

OFFICE OF THE DIRECTOR GENERAL

NYLE C. BRADY, Ph D, director general

MARCOS R. VEGA, Ph D, deputy director general

DENNIS J. GREENLAND, Ph D, deputy director general

MANO D. PATHAK, Ph D, director, research and training coordination

HUGH T. MURPHY, BA, director, administration

FAUSTINO M. SALACUP, BS, CPA, controller

ADMINISTRATIVE AND PROFESSIONAL STAFF

REBECCA C. PASCUAL, MS, manager, food and dormitory services

ZOSIMO Q. PIZARRO, LLB, senior administrative associate

PEDRO G. BANZON, LLB, administrative associate

PURITA M. LEGASPI, BBA, CPA, assistant treasurer

RENE D. LATOSA, BS, CPA, assistant controller

AUGUSTO P. CORPUS, BSME, manager, buildings and properties

ILDEFONSO L. GUINOO, BS, assistant to the director general*

GEMELO S. ALVEZ, MBA, assistant to the director general

OUTREACH STAFF

Bangladesh

C. THOMAS BRACKNEY, MS, rice production specialist

PETER R. HOBBS, Ph D, associate agronomist (cropping systems)

DWIGHT G. KANTER, Ph D, associate plant breeder

GLENN M. PETERSON, MS, agricultural engineer

HIROSHI SAKAI, D Agr, agronomist**

FRANK W. SHEPPARD, JR., D Ed, research systems analyst/IRRI representative

Burma

PEDRO B. ESCURO, Ph D, plant breeder

JAMES E. TOWNSEND, Ph D, agricultural engineer

India

MATTHEW DAGG, Ph D, Ford Foundation, serving as IRRI liaison scientist+

P. S. SRINIVASAN, BA, administrative associate

Indonesia

HENRY M. BEACHELL, MS, plant breeder

RICHARD BERNSTEN, Ph D, agricultural economist

J. RITCHIE COWAN, Ph D, IRRI liaison scientist

CARLOS GARCES, MS, farm development engineer*

JAMES R. HOOPPER, Ph D, associate agronomist

CEZAR P. MAMARIL, Ph D, agronomist/team leader

JERRY L. MCINTOSH, Ph D, agronomist

OSAMU MOCHIDA, Ph D, entomologist

LOUIS T. PALMER, Ph D, plant pathologist*

PAIDIPELLY S. RAO, Ph D, associate plant pathologist*

VENKAT R. REDDY, MS, agricultural engineer

Latin America

MANUEL ROSERO, Ph D, IRRI liaison scientist

Pakistan

INOCENCIO I. BOLO, BS, consultant

AMIR U. KHAN, Ph D, IRRI representative/ agricultural engineer

VERNON E. ROSS, MS, rice production specialist

Philippines

REESHON FEUER, Ph D, crop production specialist

Sri Lanka

RUSSELL D. FREED, Ph D, associate plant breeder

WALTER L. GRIFFETH, Ph D, crop production specialist/team leader

RICHARD L. TINSLEY, Ph D, associate agronomist*

JAMES E. WIMBERLEY, MS, acting team leader*

Thailand

RAYMOND C. FISCHER, MBA/BS Agric. Engineering, associate agricultural engineer

DERK HILLERISLAMBERS, Ph D, associate plant breeder

BEN R. JACKSON, Ph D, Rockefeller Foundation, serving as IRRI representative+

West Africa

KAUNG ZAN, Ph D, IRRI liaison scientist

CORE STAFF

JOHN F. ANGUS, Ph D, visiting agronomist*

ALVA A. APP, Ph D, visiting scientist

SADIQUL I. BHUIYAN, Ph D, associate agricultural engineer

ROBERT BRINKMAN, Ph D, visiting soil scientist

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

TE TZU CHANG, Ph D, geneticist
W. RONNIE COFFMAN, Ph D, plant breeder
ANTHEA G. COOK, Ph D, visiting scientist
J. T. COPE, JR., Ph D, visiting scientist*
ROBERT W. COWELL, MS, visiting associate editor
ERIC T. CRASWELL, Ph D, visiting scientist
JERRY PAT CRILL, Ph D, plant pathologist
SURAJIT K. DE DATTA, Ph D, agronomist
J. BART DUFF, MS, associate agricultural economist
V. SESHU DURVASULA, Ph D, plant breeder
V. ARNOLD DYCK, Ph D, entomologist
ALAN C. EARLY, Ph D, associate agricultural engineer
ALAN M. FLETCHER, BS, visiting editor*
JOHN C. FLINN, Ph D, agricultural economist
KWANCHAI A. GOMEZ, Ph D, statistician
GRACE E. GOODELL, Ph D, visiting scientist
THOMAS R. HARGROVE, Ph D, editor
L. DALE HAWS, Ph D, crop production specialist
YUJIRO HAYAMI, Ph D. visiting scientist*
KENETH PAUL HAYDOCK, MS, visiting statistician*
ELVIS A. HEINRICHS, Ph D, entomologist
ROBERT W. HERDT, Ph D, agricultural economist**
DERK HILLERISLAMBERS, Ph D, associate plant breeder
OSAMU HORINO, Ph D, visiting plant pathologist
THEODORE C. HSIAO, Ph D, visiting scientist*
ROBERT E. HUKE, Ph D, visiting scientist
ROBERT N. HURST, Ph D, visiting communications scientist*
HIROSHI IKEHASHI, Ph D, plant breeder*
SISIRA JAYASURIYA, Ph D, associate agricultural economist
ULYSSES S. JONES, Ph D, visiting agronomist
BIENVENIDO O. JULIANO, Ph D, chemist
HAROLD E. KAUFFMAN, Ph D, plant pathologist
GURDEV S. KHUSH, Ph D, plant breeder
DONALD W. KUETHER, MS, associate agricultural engineer
JOHN LEECE, Ph D, visiting associate statistician*
KEH-CHI LING, Ph D, plant pathologist**
JAMES A. LITSINGER, Ph D, associate entomologist
JOHN A. MCMENNAMY, MS, agricultural engineer
TWNG-WAH MEW, Ph D, associate plant pathologist
KEITH MOODY, Ph D, agronomist
RICHARD A. MORRIS, Ph D, agronomist
CHARLES J. MOSS, BS, agricultural engineer
JATA S. NANDA, Ph D, plant breeder
LYLE E. NELSON, Ph D, visiting scientist*
IWAO NISHIYAMA, Ph D, visiting plant pathologist*
JOHN C. O'TOOLE, Ph D, associate agronomist
CHON SUH PARK, Ph D, visiting scientist
MANO D. PATHAK, Ph D, entomologist+
JOHN PERFECT, MS, visiting scientist
FELIX N. PONNAMPERUMA, Ph D, principal soil chemist
EDWIN C. PRICE, Ph D, agricultural economist
DONALD W. PUCKRIDGE, Ph D, visiting scientist*
FEDERICO V. RAMOS, MS, farm superintendent
W. HARVEY REISSIG, Ph D, visiting scientist
WALTER G. ROCKWOOD, MS, editor
PIERRE A. ROGER, D Pedologie, visiting scientist
MILTON C. RUSH, Ph D, visiting plant pathologist
ORLANDO G. SANTOS, MPS, associate farm superintendent
RAMESH C. SAXENA, Ph D, associate entomologist
LESLIE E. SMALL, Ph D, visiting agricultural economist
WILLIAM H. SMITH, BS, editor
KAZUSHIGE SOGAWA, Ph D, visiting scientist*
BRUCE A. STONE, Ph D, visiting scientist*
BENITO S. VERGARA. Ph D, plant physiologist
LINA M. VERGARA, MS, librarian
S. S. VIRMANI, Ph D, visiting scientist
SATOSHI WAKIMOTO, Ph D, visiting scientist*
GILBERT P. WALDBAUER, Ph D, visiting scientist*
IWAO WATANABE, D Agr, soil microbiologist
JOHN ARTHUR WICKS, Ph D, associate agricultural engineer
SHOUICHI YOSHIDA, D Agr, plant physiologist
HUBERT G. ZANDSTRA, Ph D, agronomist and cropping systems program leader
S. Y. ZEE, Ph D, visiting scientist*

*Left during the year.
**On study leave.
+On part time.