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Wilfredo C. Barraquio, *MS, research assistant*
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**Transferred during the year.
***On study leave.
†On project appointment.
††On part-time basis.

About this report

This 18th annual report includes research reported during 1979. The department or departments that performed the research are identified in italics below the topic heading. For example:

EVALUATING DISEASE RESISTANCE OF BREEDING MATERIALS
Plant Pathology Department

In collaborative work, the department that did one phase of the research is identified in italics in parentheses following the subtopic. For example, the Agronomy and Plant Breeding Departments cooperate in the project VARIETAL SCREENING. Because the Agronomy Department bears responsibility for one phase of that work, its name follows the heading:

Dryland field screening *(Agronomy).*

This report makes reference to three fundamental types of rice culture. Dryland (upland) culture means rice grown without irrigation in unbunded fields. Rainfed paddy culture means rice grown without irrigation but in fields that are bunded to impound water. Irrigated culture means rice grown with irrigation in bunded fields. The adjectives *dryland* (instead of upland) and *wetland* (instead of lowland) describe rice and rice-growing soils.

Pedigrees are indicated by a slant bar (/) rather than by the multiplication sign (×). For example, IR32 × IR34 is written IR32/IR34. The sequence of crosses is indicated by the number of slant bars. (IR32 × IR34) × TKM6 is written IR32/IR34//TKM6. The fourth and further crosses are designated /4/, /5/, and so on. Backcrosses are indicated by a superscript numeral.

Scoring of morphological characters and of damage due to rice pests and physio-chemical stresses is based on scales in *Standard Evaluation System for Rice* (SES), 2d ed., 1980. Copies are available from the International Rice Testing Program, IRRI.

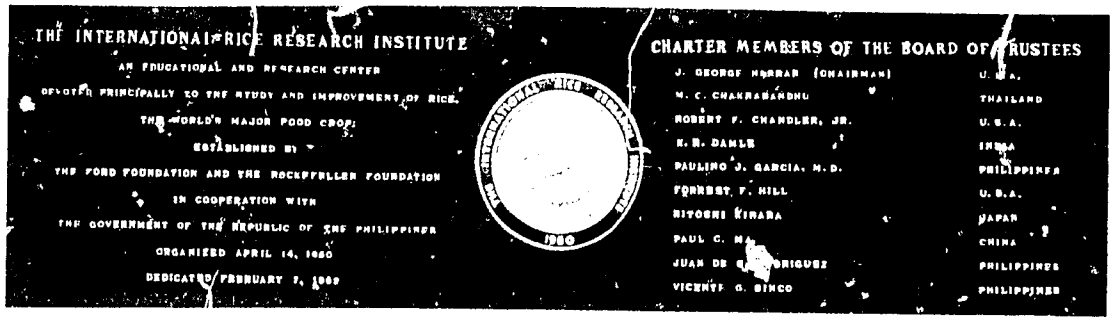
This report is on a metric basis. The International System of Units (SI) is not, however, completely adopted for abbreviations. All monetary units are as U. S. dollars ($). Unless otherwise stated, *control* or *check* means an untreated control, grain yield is calculated as rough rice at 14% moisture, and protein content is calculated as a percentage of brown rice at 14% moisture.

A single asterisk (*) means different at the 5% level of significance, and a double asterisk (**) means significantly different at the 1% level.

Names and terms often repeated within sections are abbreviated, e.g. BPH (brown planthopper), GLH (green leafhopper), DT (days after transplanting), DAT (days after treatment), etc. Such abbreviations are spelled out when first used.

The report uses generic names instead of brand names for chemicals. Use of a commercial or brand name when the generic name is unobtainable does not constitute an endorsement of the product.

A thumb index on the back cover provides quick access to each section. To use it, bend the book slightly and follow the margin index to the page with the black-edge marker.


THE INTERNATIONAL RICE RESEARCH INSTITUTE
AN EDUCATIONAL AND RESEARCH CENTER
DEVOTED PRINCIPALLY TO THE STUDY AND IMPROVEMENT OF RICE,
THE WORLD'S MAJOR FOOD CROP;
ESTABLISHED BY
THE FORD FOUNDATION AND THE ROCKEFELLER FOUNDATION
IN COOPERATION WITH
THE GOVERNMENT OF THE REPUBLIC OF THE PHILIPPINES
ORGANIZED APRIL 14, 1960
DEDICATED FEBRUARY 5, 1962
1960
CHARTER MEMBERS OF THE BOARD OF TRUSTEES
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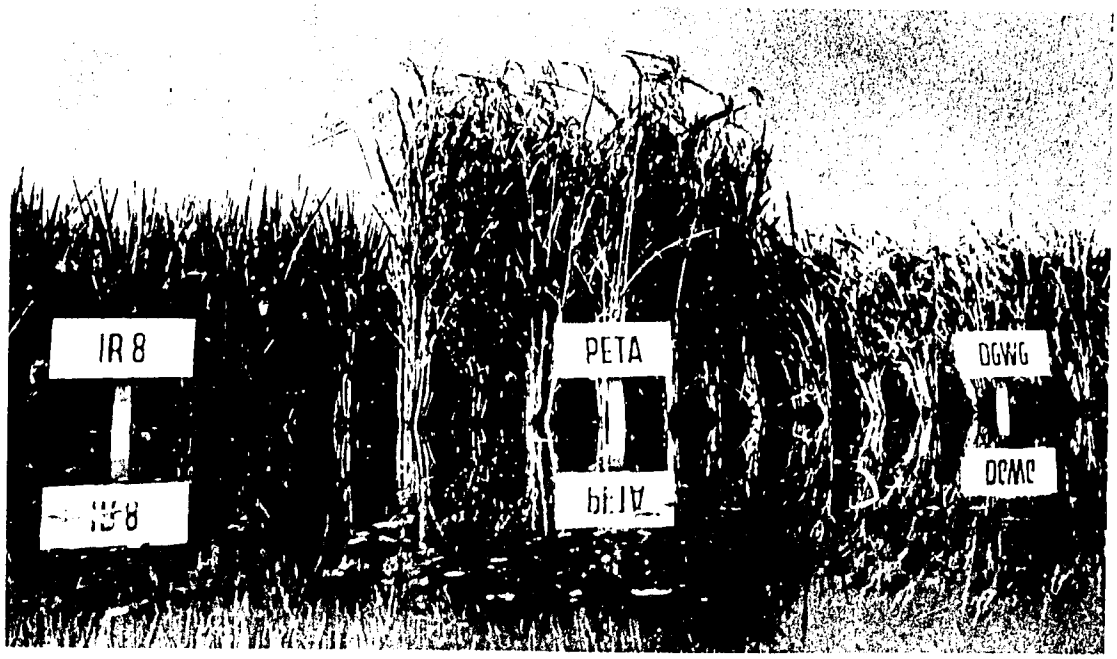
IR 8
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Research highlights

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 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 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.

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)
- 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.

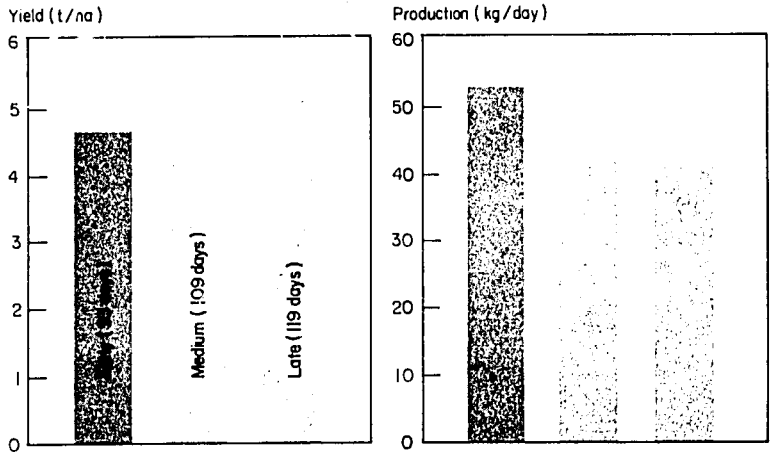
We received data from 431 individual trials of 17 types of 1978 IRTP nurseries. These data were compiled, analyzed, and published in 1979.

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



1. The top entries in the international rice yield nurseries were the late-maturing rice. 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.

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:

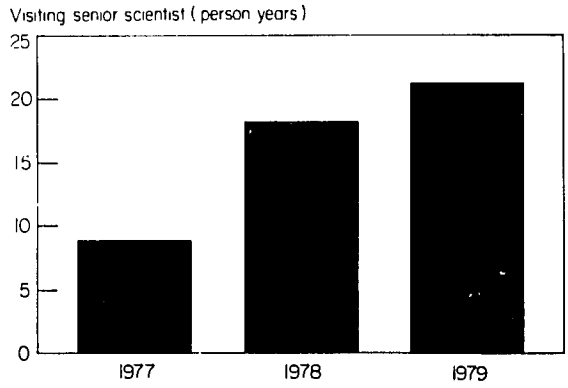
- Burma
- China
- Cuba
- France
- India
- Indonesia
- Philippines
- Thailand
- Vietnam
- Russia

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.

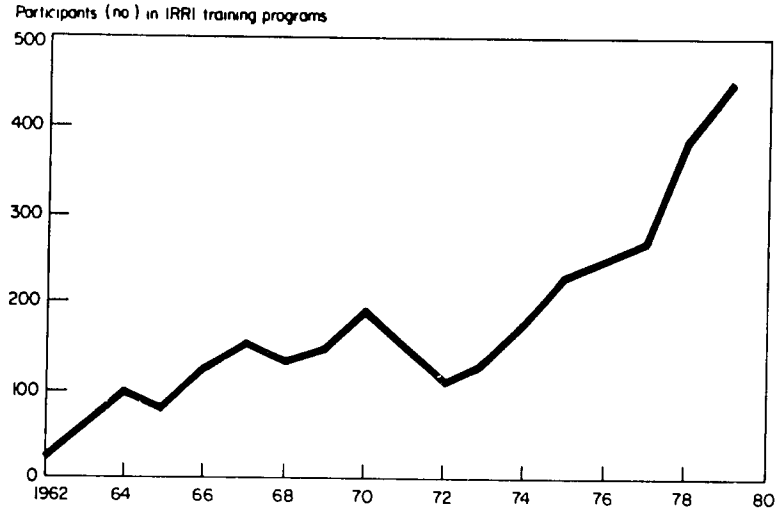
- Centro Internacional de Agricultura Tropical (CIAT)
- International Centre for Insect Physiology and Ecology (ICIPE)
- International Fertilizer Development Center (IFDC)
- International Food Policy Research Institute (IFPRI)
- International Institute of Tropical Agriculture (IITA)
- West Africa Rice 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



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.

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



scientist-years of service at IRRI headquarters. Coming from 11 countries they helped us develop new research methodologies 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.

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 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 F_1 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 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.

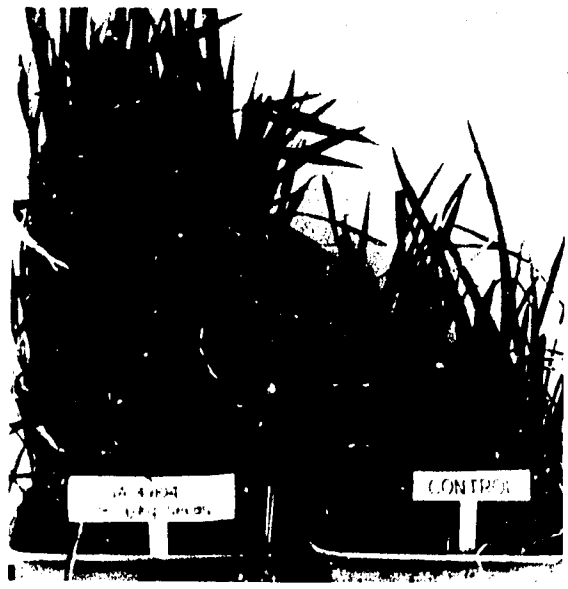
Rapid generation advance. Using a newly constructed greenhouse-darkroom, we speeded the reproduction of day length-sensitive progeny of crosses made by, or for, our cooperators in national research programs. The new facility grows too or three generations a year of lines that normally produce only one 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 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.

We evaluated insecticides in the greenhouse and in the field for control of the brown planthopper and found some to be highly effective. 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.

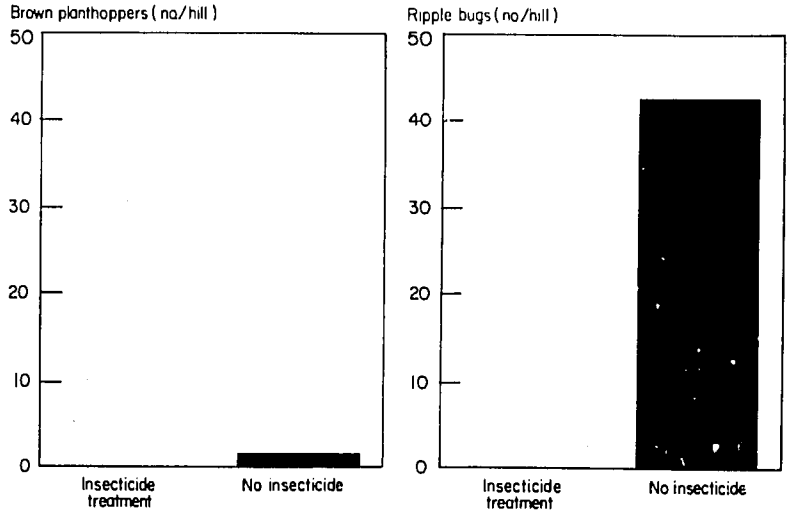


4. Treatment of rice seeds with 8 g of a systemic fungicide/kg seed gave good control of leaf blast in 1979 tests.

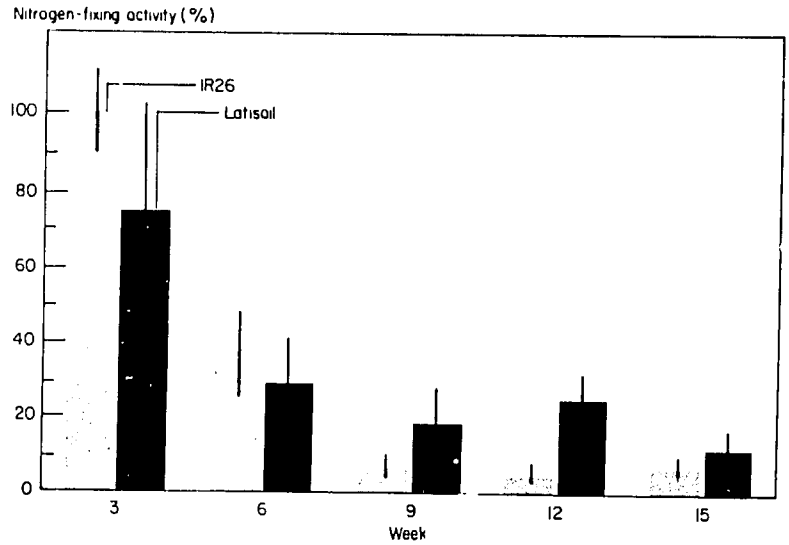
Natural plant products

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 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 chemi-



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.



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.

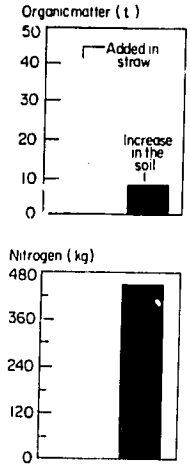
cals that had adverse effects on the embryo and larvae of the brown planthopper and decreased survival and oviposition of this pest. The same extract also inhibited the growth of pathogens causing several rice diseases.

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.



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.

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.

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.

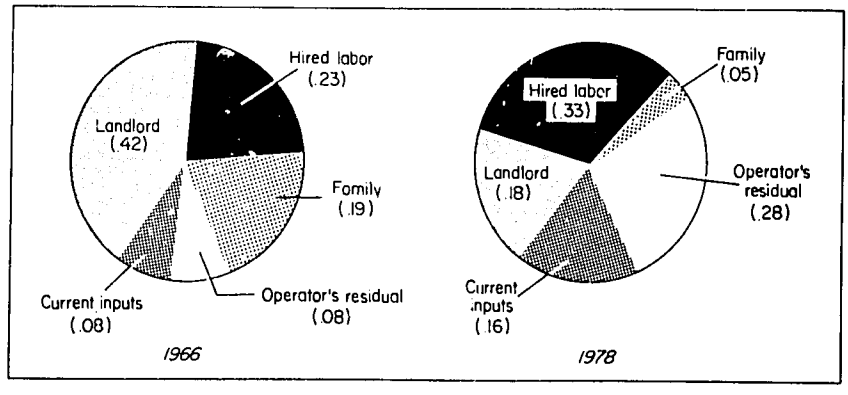
Improved irrigation water management

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.

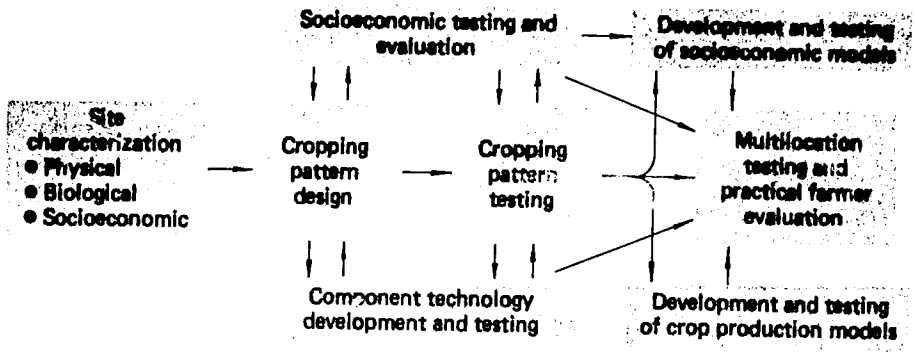
Consequences of new technology

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.



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

Cropping systems

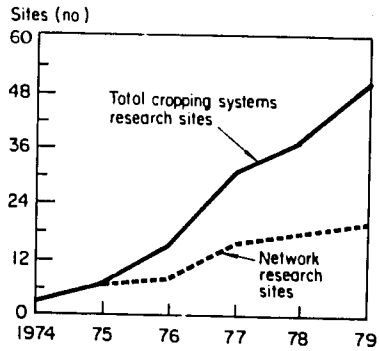
By far the most significant contribution we have made in cropping systems research during the past 5 years is the development and testing of a farm-based research methodology (Fig. 9). We select sites with probable potential for improved cropping systems and identify their environmental characteristics. 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 being implemented. At 22 of these sites, the research is a component of the research network that we helped establish.

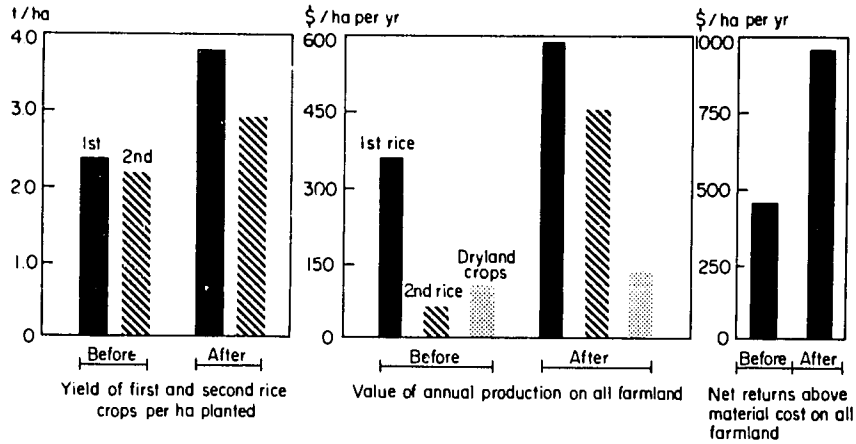
International agencies and donor organizations have studied the research methodology and are increasingly using it in integrated rural development projects or agricultural research programs they sponsor.

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

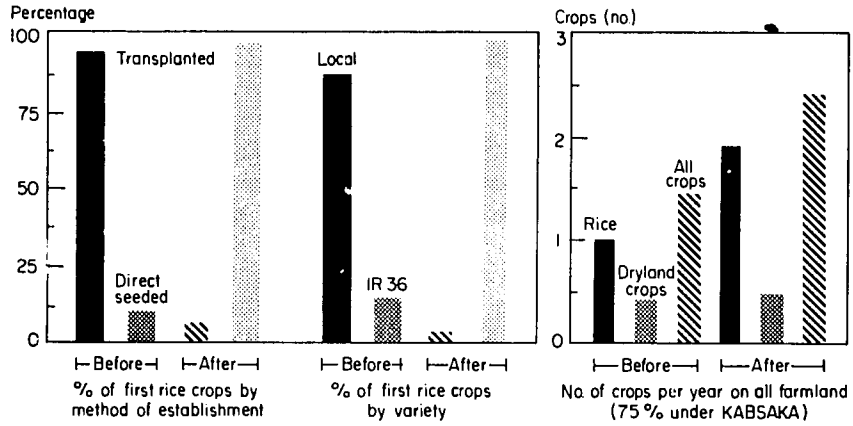
10. The number of cropping systems research sites in 8 cooperating Asian countries has increased dramatically over the past 5 years. About 40% of these sites in 1979 were in the IRRI-established cropping systems network.



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.

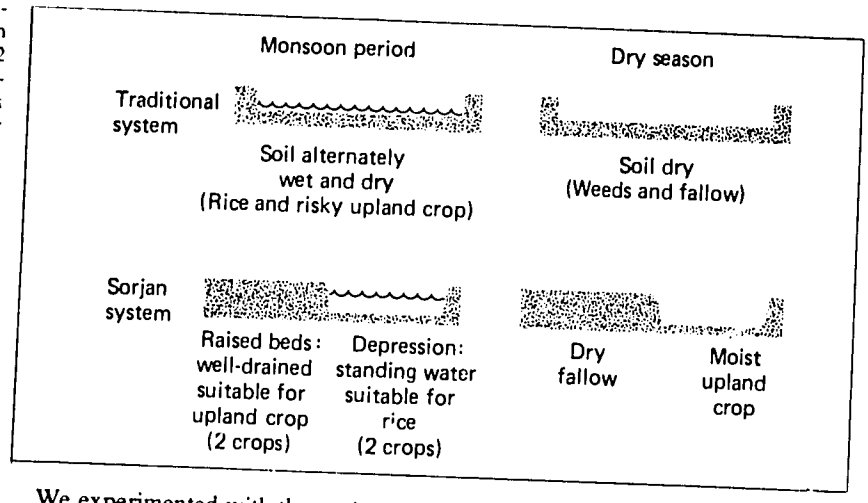


improved cropping patterns and increased their cropping intensities but also benefited financially from the adoption (Fig. 11 and 12). They were financially better off. They had paid debts, initiated home repairs, and purchased both household and field equipment. The farmers had responded quickly to 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 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.

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.



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.

Genetic evaluation and utilization (GEU) program

Germplasm collection and maintenance

Plant Breeding Department

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FIELD COLLECTION

Development of systematic field collection operations in major rice-producing countries in South and Southeast Asia continued. A grant by the International Board for Plant Genetic Resources (IBPGR) to assist collaborative efforts was used to help the national collection centers in Bangladesh, Indonesia, Sri Lanka, and Thailand collect local rices and ship samples to IRRI.

An IRRI staff member joined field collectors in Sri Lanka during the main rice cropping season and the canvassing of all major production areas in the country was virtually completed; 231 cultivars and 16 populations of wild rices were obtained.

The IRRI representative also visited eastern Kalimantan and central Sulawesi in Indonesia. A first-ever canvass along the Mahakaman River of eastern Kalimantan netted 238 local cultivars. A canvass in central Sulawesi netted 106 cultivars. Extension workers on 7 Indonesian islands sent in 1,223 seed samples, of which 695 were found viable.

During the monsoon season, a joint venture in Bangladesh was implemented in low-lying districts of Pabna and Faridpur and in the northeastern district of the country. In those canvasses, 187 deepwater cultivars and 20 wild rices of diverse composition were obtained. An additional 212 samples were collected by local extension workers. Collaborative efforts resulted in the collection of about 4,500 cultivars and 44 wild rices from various parts of Bangladesh.

Direct participation by IRRI personnel in collection activities ensured the gathering of fresh rice seeds in previously unexplored areas and also led to:

- the training of local extension and research staff on methods of collection;
- the recording of characteristics of varieties in the field and their specific uses; and
- recording of the types of rice culture used in the remote areas and the building of a picture of the varietal diversity.

Local workers' extensive collection efforts in the Central Plain, and in North and Northeast Thailand brought in a total of 777 samples, including floating, wetland, and dryland types.

The collection efforts in India under the auspices of the Indian Council for Agricultural Research continued, but were less than those during 1978.

Workers in the Philippine Bureau of Agricultural Extension and the Bureau of Plant Industry collected 422 samples in Aklan province and the Ilocos region.

Field collectors in Malaysia provided 113 seed samples. Table 1 summarizes collection activities.

INSTITUTIONAL EXCHANGES

Institutions in India continued to deposit a duplicate set of their collections at IRRI. During 1979, IRRI received a total of 1,545 samples. The major donors were the N. Dev University of Agriculture and Technology at Faizabad, Udaipur University of Rajasthan, the Paddy Breeding Station of Mandya, the ICAR-Research Complex at Margoa (Goa), the Rice Research Station at Moncompu, and the Central Rice Research Institute. Hundreds of Indian donor-parents and improved lines entered earlier in the international nurseries were received from the International Rice Testing Program (IRTP) at IRRI.

Table 1. Indigenous rice varieties collected with IRRI's direct or indirect participation in 14 collaborating Asian countries, 1971–79.

Country	Years	Indigenous varieties collected with IRRI's	
		Direct participation	Indirect participation
Bangladesh	1973–79	2,317	2,659
Bhutan	1975–76	–	121
Burma	1973–74, 1976	225	406
India	1978–79	–	3,940
Indonesia	1972–76, 1978–79	4,799	4,633
Kampuchea	1973	280	–
Laos	1972–73	–	898
Malaysia	1973–79	–	972
Nepal	1971–72, 1979	–	968
Pakistan	1972–73, 1976, 1979	–	772
Philippines	1973–76, 1977–79	510	1,922
Sri Lanka	1972, 1975–76, 1978–79	1,675	405
Thailand	1973, 1975–76, 1978–79	–	2,420
Vietnam	1972–75	108	650
Total		9,914	20,766

A visiting delegation from the People's Republic of China brought 250 cultivars, 50 breeding lines, and 4 cytosterile stocks to IRRI during May 1979. Other donations included 4 progenies of rice/sorghum hybrids, 4 varieties developed by anther culture, and 3 outstanding hybrid rices. During the International Rice Research Workshop held in China in October, 3 provincial academies under the Chinese Academy of Agricultural Sciences presented IRRI 159 cultivars, 70 breeding lines, 4 cytosterile stocks, and 17 wild taxa.

Samples sent by field collectors in Colombia, Malaysia, Mexico, Nepal, and Brazil totaled 467. The International Institute of Tropical Agriculture (IITA) in Nigeria sent IRRI 382 samples of *O. glaberrima* and the Institut de Recherches Agronomiques Tropicales et des Cultures Vivrières (IRAT) supplied 290 samples of *O. sativa* and 5 samples of *O. glaberrima* collected from West Africa.

In 1979 IRRI requested and subsequently received 554 samples to replace those accessions that were no longer available because of either expired variability or destruction by pests in the fields.

IRRI continued to systematically exchange computer-printed accession lists and characterized data with major national genetic resources centers and other international agricultural research centers.

SEED INCREASE, REJUVENATION, AND DISTRIBUTION

Field space used for seed increase, characterization, and rejuvenation during different plantings was expanded to 12 ha. During the year 11,155 plots were planted for seed multiplication, 8,176 for systematic characterization, and 1,200 for rejuvenation.

In November, 3,479 plots were planted for initial seed increase of strongly photoperiod-sensitive accessions. About 1,800 short rows were also grown for seed increase of exotic varieties, mutants, genetic testers, *O. glaberrima* strains, and wild species.

Seed distribution continued to be a principal service of the germplasm bank: 3,260 Asian rice samples and 1,086 samples of African rices, wild taxa, and genetic testers were furnished to 173 researchers in foreign countries. Within IRRI 26,700 samples of Asian rices and 401 samples of other species were provided to GEU scientists (Table 2). Many of such requests specified certain desired characteristics and increased use was made of the computerized data retrieval system in identifying the appropriate accessions in the bank for specific requirements.

By late 1979, about 7,970 samples with reputed tolerance for 1 or more specialized problems had been assembled. An extra cycle of seed increase was often needed to produce sufficient seed for evaluation. The following special types were offered to various IRRI GEU scientists for evaluation: 41 for flood tolerance, 44 for tolerance to adverse soils, and 54 for drought testing.

INVENTORY, CHARACTERIZATION, AND DATA PROCESSING

At the end of 1979, the IRRI germplasm bank had 47,743 registered accessions of *O sativa*, 2,278 accessions of *O. glaberrima*, 961 populations of wild species or taxa, and 772 genetic testers and mutants (Table 2). Of the *O. sativa* accessions, 40,768 have been characterized for all morphoagronomic characters; another 4,400 accessions have been completely characterized in the field, but laboratory measurements on 8 remaining items have not been recorded. Among the *O. glaberrima* populations, 785 have been completely characterized.

Table 2. Progress of the IRRI Genetic Resources Program in field collection, preservation, and distribution of seed of *Oryza sativa* cultivars, 1973–79.

Year	Samples collected in Asia (no.)	Distinct accessions in germplasm bank (no.)	Samples distributed (no.)	
			Inside IRRI	In national programs
1973	1,405	24,162	8,275	9,777
1974	2,982	26,818	19,236	2,603
1975	566	30,332	22,155	4,043
1976	1,466	34,229	40,200	4,819
1977	696	36,956	49,778	4,089
1978	1,134	40,768	31,941	7,316
1979	762	47,743[a]	26,694	3,260

[a]About 9,483 recently received seed samples are yet to be registered; 5,362 duplicate accessions and 3,644 nonviable seed samples were removed from the registry during 1973–79.

SEED STORAGE

Monitoring of seed viability in the medium- and short-term storage were continued. A large number of 3.5-year-old seeds in short-term storage were tested and found to have striking differences in longevity. The least durable varieties came from countries of the temperate zone and were nondormant while the highly viable samples came from high-rainfall areas in the tropics.

TRAINING OF GENETIC STOCK OFFICERS

IRRI staff members participated in a training course on genetic resources documentation jointly sponsored by IBPGR, the University of the Philippines at Los Baños, and the Philippine Council for Agriculture and Resources Research held at Los Baños. The genetic resources program leader participated in two training programs organized by India's National Bureau of Plant Genetic Resources in New Delhi: the South Asian Training Course on Plant Exploration and Collection, and the National Rice Exploration and Collection Training Course.

Several GEU trainees received training on various aspects of genetic conservation.

INTERNATIONAL AND INTERINSTITUTIONAL COLLABORATION

IRRI continued to serve as the principal depository for the base collection of the world's rice. Institutions in Brazil, China, Colombia, Cuba, India, Malaysia, and Thailand, as well as the IITA, IRAT, and IBPGR, sent thousands of samples from their collections for preservation at IRRI. IRRI staff members advised national centers of Bangladesh, China, and India, plus the Centro Internacional de Mejoramiento de Maíz y Trigo, International Crops Research Institute for the Semiarid Tropics, International Institute of Tropical Agriculture, and West African Rice Development Association on the construction or improvement of seed storage facilities.

Systematic exchange of accession lists and characterized data with major national genetic resources centers, the IITA, and IRAT continued for the *O. sativa* and *O. glaberrima* accessions. Such exchanges reduce redundancy in conserved stocks and minimize the possibility of overlooking accessions that carry identical names but have different ecogenetic origin.

Genetic evaluation and utilization (GEU) program

Agronomic characteristics

Agronomy and Plant Breeding Departments

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YIELD PERFORMANCE AND NITROGEN RESPONSE OF RICE VARIETIES AND SELECTIONS

Agronomy Department

Promising breeding lines and varieties were evaluated at IRRI, at the Philippine Bureau of Plant Industry (BPI) stations, and on farms.

IRRI irrigated trials. Twelve IR varieties and 21 new IR lines were evaluated in irrigated plots at IRRI (Table 1).

In the dry season, IR48 yielded highest, 7.0 t/ha, at 90 kg N/ha and almost 7.0 t/ha at 120 kg N/ha. Yields of most of the new early-maturing lines were much better at 60 kg N/ha and 90 kg N/ha than at 120 kg N/ha. In plots with no nitrogen added, IR4568-86-1-3-2 had the highest yield.

During the wet season, IR9860-26-2-2-2, which yielded 3.2 t/ha with no nitrogen added, had a marked yield response to increased nitrogen. IR42 and IR26 had the highest yield at 60 kg N/ha. In most varieties, responses to nitrogen rates higher than 60 kg N/ha were minimal because of lodging.

The generally low yield of most varieties and lines in both seasons was due to lodging caused by strong winds.

IRRI rainfed trials. In rainfed trials, IR48 had the highest yield at 30 kg N/ha and IR9217-58-2-2

Table 1. Yields of rice varieties and promising lines at 5 nitrogen levels[a] in irrigated plots, IRRI, 1979 dry and wet seasons.

Variety or line	Maturity (days)	Dry season yield[b] (t/ha)					Maturity (days)	Wet season yield[b] (t/ha)				
		0 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha		0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha
IR8	126	3.8	4.3	4.7	4.3	4.0	130	2.2	3.3	4.1	4.2	4.4
IR20	119	2.3	4.3	4.0	3.7	4.1	120	2.3	3.2	3.6	3.3	3.7
IR26	123	3.7	5.0	4.8	5.5	4.9	138	2.2	4.0	4.9	4.8	4.8
IR32	139	1.7	3.8	4.6	2.9	2.6	–	–	–	–	–	–
IR36	108	2.8	4.2	5.3	5.0	5.7	103	2.0	3.0	3.3	3.3	2.7
IR38	123	3.0	5.0	4.9	4.4	4.6	–	–	–	–	–	–
IR40	133	2.6	4.1	3.7	3.6	3.4	–	–	–	–	–	–
IR42	139	2.9	4.4	4.6	5.0	3.9	138	2.2	4.4	4.9	4.8	5.0
IR44 (IR2863-38-1)	126	2.6	3.4	3.5	3.7	3.8	130	2.3	3.2	3.6	3.7	4.1
IR46 (IR2058-78-1-3-2)	124	4.1	4.7	4.3	4.8	4.6	130	2.3	3.3	3.9	4.0	3.5
IR48 (IR4570-83-3-3-2)	139	3.5	4.8	7.2	6.9	4.7	138	2.2	3.5	3.5	4.4	4.4
IR50 (IR9224-117-2-3)	102	2.2	3.6	5.2	4.0	3.6	103	1.5	2.6	3.1	3.2	2.7
IR4432-52-6-4	126	2.9	4.6	4.5	2.8	3.7	–	–	–	–	–	–
IR4568-86-1-3-2	126	4.6	5.2	5.8	5.2	4.7	119	2.1	3.5	4.0	3.4	4.0
IR5853-118-5	116	3.2	4.0	4.7	4.4	4.8	112	2.1	2.7	3.3	3.6	3.6
IR5853-162-1-2-3	118	2.5	3.6	4.9	4.3	4.5	116	2.3	3.0	3.3	3.4	3.7
IR8192-31-2-1-2	–	–	–	–	–	–	124	2.3	3.7	3.8	3.9	3.9
IR8608-167-1-2	–	–	–	–	–	–	97	1.4	2.1	2.6	2.6	2.3
IR8608-189-2-2-1-3	134	2.7	3.7	4.1	3.9	3.1	99	1.8	1.9	2.1	2.6	2.6
IR8608-288-3-1-1-2	105	3.4	4.8	5.8	5.4	3.3	102	1.7	2.8	2.2	2.8	2.4
IR9129-209-2-2-2-3	102	3.5	5.4	5.8	4.1	3.2	105	1.7	2.9	3.2	3.2	3.0
IR9129-457-2-2-1-2	102	3.0	3.8	4.0	5.0	3.4	102	1.6	2.7	2.8	2.8	2.8
IR9224-140-3-2-2-3	–	–	–	–	–	–	100	1.9	2.8	3.1	3.3	3.1
IR9224-162-3-1-3-2	–	–	–	–	–	–	105	1.9	3.0	3.2	3.2	3.1
IR9761-19-1	106	3.4	5.1	4.4	4.0	4.0	105	2.0	2.7	3.1	3.2	2.8
IR9761-75-3	106	2.8	3.9	4.3	[illegible]	3.9	124	2.7	3.0	3.5	3.1	3.4
IR9802-10-3	126	3.6	4.1	5.0	3.5	3.4	–	–	–	–	–	–
IR9846-215-3	124	3.7	4.4	5.0	5.1	4.4	–	–	–	–	–	–
IR9860-26-2-2-2	–	–	–	–	–	–	102	3.2	4.0	4.1	4.6	4.8
IR11297-158-3	105	3.0	4.7	5.9	5.2	3.6	–	–	–	–	–	–
IR13168-143-1	103	2.4	3.6	4.0	4.1	3.8	100	2.2	2.7	3.0	2.8	2.5
IR13240-10-1	103	3.3	4.2	5.5	4.5	3.8	–	–	–	–	–	–
IR13429-196-1	–	–	–	–	–	–	107	2.3	3.1	3.2	2.6	2.6
Peta	152	2.3	3.3	4.3	3.9	3.0	138	2.0	2.2	2.9	2.6	2.7

[a]Includes 30 kg N/ha topdressed at panicle initiation in the dry season and 10 kg N/ha topdressed at panicle initiation in the wet season. [b]Av, 3 replications. To compare means within the same row or column, LSD (5%) = 0.60 t/ha for dry season, 0.73 t/ha for wet season.

Table 2. Yield of rice varieties and promising lines at 5 nitrogen levels[a] in rainfed wetland plots, IRRI, 1979 wet season.

Variety or line	Maturity (days)	Yield[b] (t/ha)				
		0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha
IR8	129	2.3	3.6	4.0	4.0	4.2
IR36	108	1.6	2.4	2.5	2.3	2.8
IR42	135	2.2	4.0	4.4	4.4	4.3
IR48	135	2.2	4.5	4.3	3.8	4.6
IR5853-118-5	112	2.0	3.4	2.9	3.2	3.6
IR8073-65-6-1	121	2.2	3.9	3.3	3.6	3.5
IR9217-58-2-2	129	3.2	4.0	4.4	4.5	4.8
IR9852-22-3	121	2.1	3.4	4.0	2.9	3.8
IR13146-41-3	130	2.4	3.7	3.5	3.6	4.7
IR13149-19-1	119	2.3	3.6	3.7	3.6	3.9
IR13419-113-1	129	2.2	3.5	3.0	3.3	3.9
IR13426-19-2	119	2.1	2.8	3.0	3.3	3.0

[a]Each treatment, except 0 kg N/ha, included 20 kg N/ha topdressed at panicle initiation. [b]Av, 3 replications. To compare means within the same row or column, LSD (5%) = 0.98 t/ha.

Table 3. Yield of rice varieties and promising lines at 4 nitrogen levels[a] in an irrigated farmer field, Laguna province, Philippines, 1979.

Variety or line	Maturity (days)	Dry season yield[b] (t/ha)				Maturity (days)	Wet season yield[b] (t/ha)			
		0 kg N/ha	50 kg N/ha	100 kg N/ha	150 kg N/ha		0 kg N/ha	40 kg N/ha	80 kg N/ha	120 kg N/ha
IR8	124	2.3	3.4	4.0	5.3	124	4.0	4.6	5.3	4.6
IR32	135	2.4	2.5	3.1	3.9	–	–	–	–	–
IR36	105	2.4	4.0	4.9	5.0	105	1.5	2.3	2.8	2.4
IR42	139	2.6	3.4	3.8	4.3	132	4.1	5.6	5.8	5.8
IR44	122	2.3	3.6	4.8	4.7	123	3.8	5.0	4.6	4.6
IR46	122	3.5	5.2	6.2	5.2	123	4.2	4.7	4.8	4.8
IR48	140	3.0	4.3	4.1	4.5	132	4.4	5.3	5.4	5.4
IR4432-52-6-4	125	2.7	2.8	3.5	4.9	–	–	–	–	–
IR5853-118-5	–	–	–	–	–	111	1.8	1.9	3.7	3.6
IR5853-162-1-2-3	–	–	–	–	–	123	3.0	4.9	5.2	4.6

[a]Each treatment, except 0 kg N/ha, included 20 kg N/ha topdressed at panicle initiation for both seasons. [b]Av, 3 replications. To compare means within the same row or column, LSD (5%) = 0.64 t/ha for dry season, 0.81 t/ha for wet season.

had the highest yield in plots without added nitrogen (Table 2).

Farmer field trials. Seven IR varieties and three new IR selections were tested in farmers' fields (Table 3).

In the dry season, IR46 yielded the highest at all nitrogen levels but it lodged and its yield dropped at 150 kg N/ha. In the wet season, nitrogen rates higher than 40 kg N/ha did not increase grain yield. High wet season yields of IR8, IR42, IR44, and IR48, with no nitrogen added, were due to high natural fertility in farmers' fields.

In rainfed wetland farmers' fields (Table 4), early-maturing varieties and lines (IR36, IR5853-118-5, and IR9852-22-3) suffered from limited rainfall from flowering to maturity. At 80 kg N/ha

Table 4. Yield of rice varieties and promising lines at 4 nitrogen levels[a] in rainfed wetland, farmer field, Laguna province, Philippines, 1979 wet season.

Variety or line	Maturity (days)	Yield[b] (t/ha)			
		0 kg N/ha	40 kg N/ha	80 kg N/ha	120 kg N/ha
IR8	117	2.0	2.4	2.5	3.0
IR36	102	1.5	2.1	2.1	2.4
IR42	128	2.3	3.0	3.9	4.8
IR48	128	2.3	3.3	3.8	3.1
IR5853-118-5	102	2.1	2.3	2.6	3.6
IR9852-22-3	106	2.1	2.8	3.1	2.7
IR13419-113-1	117	2.4	3.9	3.6	3.2
IR13426-19-2	117	2.1	3.8	4.6	4.0

[a]Each treatment, except 0 kg N/ha, included 20 kg N/ha topdressed at panicle initiation. [b]Av, 3 replications. To compare means within the same row or column, LSD (5%) = 0.53 t/ha.

IR13426-19-2 outyielded the other varieties and lines. IR42 outyielded all the other entries at 120 kg N/ha.

BPI, Maligaya. In the dry season, most new selections showed favorable responses to high nitrogen applications (Table 5). IR42, IR50, IR13240-10-1, IR4568-86-1-3-2, and IR8608-189-2-2-1-3 had nearly similar high yields at 150 kg N/ha but IR5853-118-5, IR8608-189-2-2-1-3, and IR4568-86-1-3-2 yielded just as well at 120 kg N/ha. Most IR varieties and new lines yielded more than 4.0 t/ha in plots with no added nitrogen.

During the wet season, IR4568-86-1-3-2 showed a good response to 30 kg N/ha but not to higher levels. IR5853-118-5, IR5853-162-1-2-3, and IR9129-209-2-2-2-1 gave similar good yields at 60 kg N/ha.

BPI, Camarines Sur. In the dry season the new lines and IR8, IR42, IR44, and IR48 responded to 90 kg N/ha with nearly similar yields of more than 6.0 t/ha (Table 6). With no nitrogen added, IR5853-118-5, IR8608-189-2-2-13, IR9129-209-2-2-2-1, and IR13240-10-1 yielded nearly 4.0 t/ha.

During the wet season, yields of the new lines were affected by frequent rains and a heavy incidence of bacterial blight and tungro virus diseases. However, IR42, IR4568-86-1-3-2, IR5853-118-5, and IR5853-162-1-2-3 exhibited good tolerance for the diseases and yielded more than 4.0 t/ha in nitrogen-treated plots.

BPI, Iloilo. Because of dry season irrigation problems only wet season data are presented. IR36, IR50, IR13168-143-1, IR9224-140-3-2-2-3, IR9129-209-2-2-2-1, IR4568-86-1-3-2, IR5853-118-5, and IR9224-162-3-1-3-2 had yields higher than 5.0 t/ha at 90 kg N/ha (Table 7).

GROWTH DURATION

Plant Breeding Department

A large number of breeding lines with a growth duration of less than 100 days were evaluated in replicated yield trials in the wet season. In the trials 12.7% (47 of 368) entries matured in less than 100 days. In the 1978 wet season trials, only 3.2% matured in less than 100 days. Many of the 1979 entries yielded as well as IR36 (Table 8).

A large number of the entries had multiple resistance to major diseases and insects. Numerous crosses were made with the selections and other early-maturing varieties from national programs.

SCREENING BREEDING LINES FOR RATOONABILITY

Plant Breeding Department

Nearly 2,000 varieties and breeding lines were evaluated for the ability to ratoon after the harvest of the main crop lots in replicated yield trials and observational yield trials of the 1979 wet season. The main crop was harvested at maturity and stems were cut to 15-cm stubble height. Plots were top-dressed with 40 kg N/ha 10 days after entries were cut and plots were flooded. Entries were scored for overall ratoon growth, ratoon stand count, tiller number, plant height, uniformity in flowering, ratoon crop duration, and grain yield. Sheath blight infestation of the main crop, which killed many of the nodal primordia, and a virus infection that caused stunted ratoon growth in some entries introduced an unexpected variability.

Among the plots, 303 entries had excellent regrowth and 130 of those exhibited synchronous flowering. The ratoon crop yield ranged from none to 1.8 t/ha and maturity ranged from 48 to 68 days. The advanced lines IR9761-40-3-2, IR9852-19-2, IR13413-54-2, IR13423-71-2, and IR13429-305-3 and the varieties Gulfrose, Milbuen, Mingolo, and Intan were outstanding.

SOURCES OF SEMIDWARFISM

Plant Breeding Department

A search for new dwarfs and semidwarfs among accessions of the germplasm bank continued. Those identified are crossed with one of the IR semidwarf varieties carrying the Dee-geo-woo-gen recessive gene to determine if there is an identical gene for semidwarfism.

Progeny of the 10 dwarf/semidwarf crosses made showed distinct segregation for plant height in the F_2 generation, indicating that different height genes were involved. Four of the dwarfs were induced mutants from Tellakathera, a tall Indian variety. Four other dwarfs were mutants derived from Tainan 5, and two were from Tainan 6. Both Tainan 5 and Tainan 6 were principal pon-

Table 5. Yields of rice varieties and promising lines at 6 nitrogen levels[a] in irrigated plots, Maligaya Rice Research and Training Center, Nueva Ecija, Philippines, 1979.

Variety or line	Maturity (days)	Dry season yield[b] (t/ha)						Maturity (days)	Wet season yield[b] (t/ha)					
		0 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha	180 kg N/ha		0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha
IR8	132	4.5	6.8	7.0	5.4	6.3	4.9	128	3.2	4.9	5.3	6.0	5.4	5.8
IR20	121	4.2	5.8	7.0	5.7	5.3	5.4	127	3.4	4.6	4.8	5.2	4.8	4.2
IR32	139	4.1	5.2	5.8	5.8	5.0	4.2	–	–	–	–	–	–	–
IR36	107	3.8	5.9	6.0	6.0	6.3	6.8	115	4.2	5.5	5.3	5.8	6.1	5.2
IR38	126	4.2	5.7	6.4	6.6	5.9	5.7	–	–	–	–	–	–	–
IR42	139	4.0	6.1	7.0	6.6	7.8	6.7	129	4.0	4.9	5.6	5.3	5.7	5.3
IR44 (IR2863-38-1)	135	3.4	5.5	5.7	5.1	5.3	6.0	121	2.5	4.7	5.6	5.4	5.5	5.0
IR46 (IR2058-78-1-3-2)	121	4.8	5.6	7.1	6.4	5.6	6.1	120	3.7	4.7	6.2	5.2	5.4	4.6
IR48 (IR4570-83-3-3-2)	133	4.4	6.6	7.0	6.9	6.0	7.1	133	4.1	5.0	5.0	6.1	5.9	5.3
IR50 (IR9224-117-2-3-3-2)	105	4.3	6.3	6.7	7.1	7.3	6.7	107	3.5	4.3	4.5	4.7	4.5	4.2
IR4432-52-6-4	126	3.9	6.6	5.6	5.7	5.3	4.2	–	–	–	–	–	–	–
IR4568-86-1-3-2	121	4.8	6.7	7.0	7.7	7.5	7.5	119	4.1	5.5	5.4	5.5	5.0	5.0
IR5853-118-5	113	4.5	6.4	6.9	7.5	6.3	6.5	116	3.7	4.6	4.9	5.5	5.3	4.9
IR5853-162-1-2-3	117	4.2	6.8	6.0	6.5	6.5	4.8	120	4.0	4.7	4.7	5.5	5.3	4.4
IR8608-167-1-2	–	–	–	–	–	–	–	105	2.8	3.4	3.6	4.0	3.9	4.1
IR8608-189-2-2-1-3	103	3.9	5.3	6.6	7.8	7.5	6.7	–	–	–	–	–	–	–
IR9129-209-2-2-2-1	105	3.6	5.4	6.4	6.6	6.6	6.5	107	3.3	3.7	4.6	4.2	3.9	4.2
IR9224-140-3-2-2-3	–	–	–	–	–	–	–	107	3.6	4.6	5.6	5.2	5.2	5.1
IR9224-162-3-1-3-2	–	–	–	–	–	–	–	107	3.9	5.2	5.3	5.4	5.3	5.1
IR13168-143-1	–	–	–	–	–	–	–	105	3.8	4.3	4.5	4.2	4.8	3.8
IR13240-10-1	103	4.0	5.7	6.6	6.8	7.3	7.5	–	–	–	–	–	–	–
IR13429-196-1	–	–	–	–	–	–	–	105	4.2	5.2	5.0	5.3	5.2	4.4
Peta	142	2.3	4.4	3.9	2.9	2.7	2.3	133	2.5	3.0	2.3	2.8	3.5	2.4

[a]Each treatment, except 0 kg N/ha, included 30 kg N/ha topdressed at panicle initiation in dry season and 20 kg N/ha in wet season. [b]Av, 3 replications. To compare means within the same row or column, LSD (5%) = 1.06 t/ha for dry season, 0.87 t/ha for wet season.

Table 6. Yields of rice varieties and promising lines at 6 nitrogen levels[a] in irrigated plots, Bicol Rice and Corn Experiment Station, Camarines Sur, Bicol Region, Philippines, 1979.

Variety or line	Maturity (days)	Dry season yield[b] (t/ha)						Maturity (days)	Wet season yield[b] (t/ha)					
		0 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha	180 kg N/ha		0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha
IR8	134	4.1	5.8	6.4	6.3	5.6	4.8	116	2.4	2.6	2.8	3.0	2.5	2.1
IR20	118	3.0	5.0	5.7	5.3	5.3	4.9	116	3.0	4.2	3.8	3.8	3.7	2.7
IR32	140	3.4	4.4	4.2	4.1	4.4	2.9	–	–	–	–	–	–	–
IR36	108	3.6	4.7	5.7	5.4	5.6	5.3	105	3.2	3.6	3.9	3.7	4.0	2.8
IR38	126	4.7	5.8	6.1	5.3	5.9	5.3	–	–	–	–	–	–	–
IR42	135	3.8	5.4	6.4	6.4	5.9	6.6	131	3.4	4.1	4.3	3.8	3.7	4.0
IR44 (IR2863-38-1)	131	3.8	6.6	6.5	5.5	5.6	5.4	116	4.1	3.8	3.5	3.7	3.9	3.3
IR46 (IR2058-78-1-3-2)	125	3.8	5.6	6.2	5.4	5.6	5.8	116	3.1	3.2	3.4	3.5	3.5	3.8
IR48 (IR4570-83-3-3-2)	137	3.6	6.5	6.3	5.7	5.2	5.7	132	3.9	4.1	3.8	3.7	4.1	3.5
IR50 (IR9224-117-2-3-3-2)	110	3.8	5.3	6.8	5.9	6.1	5.2	98	2.6	3.9	3.7	3.8	3.8	3.0
IR4432-52-6-4	132	3.7	5.4	6.4	5.4	5.8	4.5	–	–	–	–	–	–	–
IR4568-86-1-3-2	122	3.8	5.3	6.1	5.6	6.1	4.9	116	3.8	4.4	4.3	4.4	4.4	4.0
IR5853-118-5	115	3.4	5.1	6.2	5.2	6.0	4.3	109	3.5	4.1	3.9	4.4	3.8	3.2
IR5853-162-1-2-3	119	3.2	5.1	5.6	6.5	5.6	4.6	116	3.8	4.5	4.3	4.6	4.2	4.0
IR8608-167-1-2	–	–	–	–	–	–	–	97	2.8	2.9	2.9	3.2	2.7	3.1
IR8608-189-2-2-1-3	108	3.5	5.0	6.2	6.7	5.8	5.5	–	–	–	–	–	–	–
IR9129-209-2-2-2-1	110	3.7	5.3	6.1	6.3	5.5	4.8	102	2.8	3.8	4.0	3.6	3.2	2.7
IR9224-140-3-2-2-3	–	–	–	–	–	–	–	98	3.2	3.6	3.9	3.8	3.4	3.2
IR9224-162-3-1-3-2	–	–	–	–	–	–	–	98	3.0	3.6	3.9	3.5	3.4	2.8
IR13168-143-1	–	–	–	–	–	–	–	98	3.2	3.0	3.4	3.2	3.1	3.4
IR13240-10-1	103	3.8	4.9	5.4	5.9	6.1	5.5	–	–	–	–	–	–	–
IR13429-196-1	–	–	–	–	–	–	–	102	3.1	3.4	4.0	4.0	3.5	3.2
Peta	141	3.8	4.4	2.8	1.8	1.7	1.8	137	2.8	2.9	2.6	2.5	2.6	1.6

[a]Each treatment, except 0 kg N/ha, included 30 kg N/ha topdressed at panicle initiation in dry season and 20 kg N/ha in wet season. [b]Av, 3 replications. To compare means within the same row or column, LSD (5%) = 1.01 t/ha for dry season, 0.81 t/ha for wet season.

Table 7. Yields of rice varieties and promising lines at 6 nitrogen levels[a] in irrigated plots, Visayas Rice Experiment Station, Iloilo province, Philippines, 1979 wet season.

Variety or line	Maturity (days)	Yield[b] (t/ha)					
		0 kg N/ha	30 kg N/ha	60 kg N/ha	90 kg N/ha	120 kg N/ha	150 kg N/ha
IR8	122	2.5	3.8	5.0	5.0	3.9	3.9
IR20	117	3.5	3.7	4.1	4.1	4.0	3.9
IR36	109	3.4	4.6	5.0	5.4	4.8	4.3
IR42	129	3.3	3.8	4.5	4.9	4.8	4.8
IR44 (IR2863-38-1)	115	2.7	3.2	3.9	4.0	3.9	3.1
IR46 (IR2058-78-1-3-2)	122	4.0	4.2	4.9	4.7	4.5	3.6
IR48 (IR4570-83-3-3-2)	129	3.1	3.5	4.4	4.6	3.8	4.3
IR50 (IR9224-117-2-3)	109	4.2	5.7	5.8	5.8	5.3	5.4
IR4568-86-1-3-2	119	3.7	4.4	4.8	5.1	4.9	4.8
IR5853-118-5	109	3.5	3.9	4.5	5.0	5.0	4.4
IR5853-162-1-2-3	121	3.7	4.3	4.2	4.2	4.0	3.8
IR8608-167-1-2	101	3.8	4.4	4.8	4.5	4.2	4.1
IR9129-209-2-2-2-1	109	4.0	4.1	4.8	5.4	4.9	4.9
IR9224-140-3-2-2-3	109	3.7	4.5	5.2	5.3	5.1	5.0
IR9224-162-3-1-3-2	105	4.6	4.7	5.2	5.5	4.7	4.6
IR13168-143-1	105	4.2	4.4	4.6	5.2	5.4	4.8
IR13429-196-1	107	4.3	4.6	4.6	4.8	4..7	4.1
Peta	130	2 9	4.0	3.5	3.3	1.5	1.9

[a]Each treatment, except 0 kg N/ha, included 20 kg N/ha topdressed at panicle initiation. [b]Av, 3 replications. To compare means within the same row or column, LSD (5%) = 0.90 t/ha.

Table 8. Yield of early-maturing entries in the replicated yield trials at IRRI, 1979 wet season.

Selection	Cross	Growth duration (days)	Yield (t/ha)	Yield[a] (kg/ field day)
IR9752-71-3-2	IR28/Kwang-chang-ai//IR36	99	5.08	66.8
IR9729-67-3	BG 34/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	"	98	3.99	53.2
IR19746-28-2-2	IR9129-192-2/IR10183-7	98	4.02	56.0
IR13204-3-3-3	IR28/CO 39//IR36	98	4.52	60.2
IR19795-17-3-2	IR9703-41-3/IR10185-68	98	4.34	58.0
IR19819-31-2-3	IR9715-4-2/IR10176-79	98	4.30	57.2
IR9708-51-1-2	ADT 26/IR1561-228-3//IR28	98	3.55	53.2
IR10179-2-3-1	IR74782-6-3-2/Ai-nan-tsao 1	93	3.66	52.3
IR36	IR1561-228-1//IR24[4]/*O. nivara*///CR94-13	109	3.80	44.3

[a]Excludes 23 days in the seedbed.

lai varieties of Taiwan. Mutant Tainan 5-73-111 appeared agronomically more desirable than the other nine dwarfs.

Among the progeny of 26 semidwarf/semidwarf crosses, 5 dwarfing sources distinct from Dee-geo-woo-gen sources were obtained. Those were Mutant 65 (spontaneous mutation of Honya 349 from Pakistan), G.S. 1649A (a selection obtained in Thailand from a Chinese variety Sze-mu), Nadula Dwarf (spontaneous mutation of Nadula from Fiji), 2243-85F (an accession from Ivory Coast), and Short Straw Starbonnet (a US selection from CP231/Bluebonnet). The allelic relationship among the above five sources will be studied.

Seven semidwarf/semidwarf crosses produced a high proportion of semidwarf F_2 plants and a few intermediate-to-tall plants. The sources probably share a compound locus with the Dee-geo-woo-gen gene, or the two loci are closely linked. Sources belonging to this category are Gora NCS

16 (from India), Sekarmandi (from Indonesia), Synthetic Sativa (a high-protein selection from India), Shiranui/Goinchu 61-54 (from the Central Rice Research Institute, India), TR-17 (an induced mutant from India), Kochihibiki (Kanto 77//Akibare *2 from Japan), and Hoyoku (Jikkoku/Zensho 26 from Japan).

Fourteen other semidwarf/semidwarf crosses produced F_2 plants that fell largely within the range of the two parents. Sources of this group included spontaneous mutations of tall indica varieties, hybrids of unknown parentage but probably derived from Dee-geo-woo-gen or its progenies, and progenies of distant crosses.

Genetic evaluation and utilization (GEU) program

Grain quality

Chemistry, Plant Breeding, and Soil Chemistry Departments

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BREEDING PROGRAM

Plant Breeding and Chemistry Departments

A large number of crosses involving breeding lines with intermediate amylose content were made during 1979. The proportion of lines with intermediate amylose grown in the various nurseries was much higher than in previous years. Several elite lines with intermediate amylose were evaluated in replicated yield trials. IR9129-209-2-2-2 was found to be an outstanding intermediate-amylose line; it also has intermediate gelatinization temperature (GT).

The Philippine Seed Board named IR4570-83-3-3-2 as IR48, the first intermediate-amylose IRRI line to be named a variety. Several crosses between aromatic varieties and improved breeding lines and varieties were made.

Six intermediate-amylose lines were evaluated through a preliminary consumer panel test in Batangas Province, Philippines, by the Institute of Human Ecology, University of the Philippines at Los Baños (UPLB) with C4-63G and BPI-121-407 as check varieties. C4-63G is Peta/BPI-76 and both BPI-76 and BPI-121-407 were derived from Fortuna/Seraup Besar 15. Both Fortuna and Seraup Besar 15 are intermediate-amylose varieties.

Because of sample limitation, total milled rice was used and raw-rice preference and acceptability scores were grossly influenced by percentage of brokens (25-73% of milled rice) and whiteness of rice. Samples with Kett whiteness readings below 40 were not rated well (Table 1). IR9129-209-2 and IR9129-457-2 (10% protein rices) had low whiteness readings. The two IR4570 lines, with the longest grains in the set, and IR4215-27-3 had preference scores comparable to that of the C4-63G check in both raw and cooked forms. IR9129-209-2 was comparable to C4-63G in preference scores of cooked rice only. C4-63G, particularly in cooked form, was preferred to BPI-121-407. C4-63G is the intermediate-amylose source for IR4215 and IR9129, and BPI-121-407 for IR4570 and IR8192. The relative qualities of C4-63G and BPI-121-407 were not consistently inherited by the lines derived from them, but the alkali spreading value of the intermediate-amylose parent was inherited.

The study underlined the importance of reducing differences in dimensions, whiteness, and head rice of samples for consumer panel tests because samples not preferred in raw form also tended to rank poorly as cooked rice.

INTERNATIONAL COOPERATIVE TESTS ON METHODS

Chemistry Department

As a followup of the 1978 workshop on chemical

Table 1. Preference scores for raw and cooked rice (in decreasing order for cooked rice) by a consumer panel, and properties of 8 total milled rices. Institute of Human Ecology, University of the Philippines at Los Baños, and IRRI, 1979.

Variety or line name	Mean preference score[a]		Alkali spreading value	Amylose content (%)	Kett whiteness reading	Cooked-rice Instron hardness (kg)
	Raw	Cooked				
			Set 1			
IR4570-74-2	0.022 ab	0.247 a	7.0	24.7	40.8	6.4
C4-63G (check)	0.178 a	0.094 ab	3.8	23.7	43.1	4.8
IR9129-209-2	-0.264 b	0.089 ab	4.7	21.6	37.4	5.6
C4-63G	0.081 ab	-0.136 bc	4.0	24.6	40.8	5.7
BPI-121-407	-0.017 ab	-0.294 c	7.0	23.9	38.0	6.6
			Set 2			
IR4570-83-3 (IR48)	0.204 a	0.306 a	7.0	23.8	41.7	5.9
IR4215-27-3	0.404 a	0.276 a	3.5	23.5	41.8	4.7
C4-63G (check)	0.217 a	0.213 a	3.8	23.7	43.1	4.8
IR8192-155-2	-0.459 b	-0.122 b	7.0	26.0	41.0	5.9
IR9129-457-2	-0.366 b	-0.672 c	4.8	23.2	36.6	5.4

[a]By average of 39 panelists who rated each of the 5 samples in 2 sets, with a common C4-63G check sample, at Bukal, Lemery, Batangas. 1st = 1.16; 2nd = 0.50; 3rd = 0; 4th = -0.50; and 5th = -1.16. In a column, under each set, means followed by a common letter are not significantly different at 5% level. All samples were considered acceptable; raw 85–100%; and cooked 77–92%.

aspects of rice grain quality, four cooperative tests — gel consistency, alkali digestibility, amylose content, and instrument methods for cooked-rice texture — were organized. These four methods were tested in 1979.

The gel consistency test on 6 high-amylose rices was completed by 10 scientists or analysts from 8 countries (Table 2). The greatest variation among cooperator ratings was that for the medium-gel samples IR20 and IR26. Medium-gel samples tend to harden during storage, as discussed later in the section on aging. The gel consistency test samples were stored as flour while the aging study samples were whole-grain milled rice. Various mixers and heated baths were used in the different laboratories. Because the flours were prepared at IRRI, the major source of variation was probably the efficiency of dispersion of the gel in a boiling water bath.

The cooperative alkali test used 3 nonwaxy and 2 waxy milled rices differing in GT and compared the scoring system of Little and coworkers with that of Bhattacharya using 1.1, 1.4, and 1.7% KOH. Alkali solution was increased to have an area of at least 5 cm^2/grain and a minimum depth of 4.5 mm. Results from 10 participants showed better correspondence of scores with the method of Little. Many participants had difficulty in further classifying the degradation pattern into A, B, B_1, C, and D types proposed by Bhattacharya.

The cooperative amylose test used iodine colorimetry at 620 nm on 6 whole milled-rice samples, their starches, and their defatted milled-rice flours. Correction for amylopectin-iodine interference at pH 4.5–4.8 was minimized by the use of amylose-amylopectin mixtures instead of amylose alone for the standard curve. More stable color was still attainable with acetate buffer than with pH 7 phosphate buffer (which gave a deep blue starch-iodine color) particularly since the amylose standard was obtained by magnesium sulfate precipitation from potato starch dispersion. Variable improvement in amylose data resulted from defatting the starch dispersion with petroleum ether and carbon tetrachloride in contrast to defatting the flour with refluxing 95% ethanol before weighing and dispersion.

Table 2. Range and overall mean gel consistency rating of 6 IRRI milled rices by 10 analysts from 8 countries. IRRI, 1979.

Sample	Mean gel consistency (mm)	
	Range	Overall mean
IR5	91–100 soft	97.7 soft
IR8	26– 35 hard	31.0 hard
IR20	29– 53 hard/medium	39.2 hard
IR26	35– 79 hard/medium/soft	53.1 medium
IR32	70–104 soft	97.3 soft
IR42	27– 32 hard	29.7 hard

FACTORS THAT AFFECT GRAIN QUALITY

Chemistry Department

Correlation of properties of world rices. Correlation analysis was undertaken on properties of 1,075 milled rices grown in about 40 countries and analyzed at IRRI during the last 17 years (Table 3). Amylose content and gel consistency were better correlated with Amylograph viscosity and cooked-rice texture than were alkali spreading value and protein content. Gel consistency and amylose content were negatively correlated in the samples ($r = -0.43^{**}$, $n = 746$).

Amylograph peak viscosity was significantly correlated with Amylograph consistency and cooked-rice texture but not with Amylograph setback, although Amylograph setback and consistency values were significantly positively correlated (Table 3). Amylograph consistency also correlated negatively with gel consistency and with hardness of cooked rice. The relationship between gel consistency and gel viscosity, however, is not simple because amylopectin has a higher gel viscosity than amylose at the 5% gel concentration used for the method.

In 1979, samples from Cuba, Egypt, Mexico, Nigeria, Peru, and Surinam were analyzed as part of the continuing survey of world rice. The samples showed wide range in protein, amylose content, and other grain properties (Table 4).

Rice/sorghum hybrids. Milled-rice samples of 4 rice/sorghum hybrids analyzed for endosperm properties showed typical rice properties. Amylose content ranged from 14.9 to 23.9% dry basis; gel consistency, 84–100 mm; alkali value, 3.9–7.0; and protein content, 9.0–10.7%. Lysine content was closer to rice at 3.1–3.6 g/16.8 g N than to sorghum (1–2% lysine).

Table 3. Mean and range of values and linear correlation coefficients of physicochemical properties of milled rice from various countries. IRRI, 1963–79.

Property	Amylograph viscosity (B.U.)			Cooked-rice Instron	
	Peak	Setback	Consistency	Hardness (kg)	Stickiness (g · cm)
Observations (no.)	542	541	542	254	256
Range	200–1290	-405–1175	25–1090	3.0–10.1	31–895
Mean	767	73	311	6.12	117
Correlation coefficients					
Amylose	0.29**	0.62**	0.71**	0.59**	-0.82**
Alkali spreading	-0.23**	0.01	-0.14**	-0.18**	0.06
Gel consistency	-0.17**	-0.57**	-0.60**	-0.63**	0.44**
Protein	-0.15**	0.12**	0.06	0.16*	0.04
Amylograph peak		0.02	0.40**	0.35**	-0.42**
Amylograph setback			0.89**	0.74**	-0.37**
Amylograph consistency				0.75**	-0.48**
Cooked-rice hardness					-0.55**

Table 4. Ranges of amylose and protein contents, gel consistency, and gelatinization temperature (GT) types of milled rices obtained from rice-producing countries. IRRI, 1979.

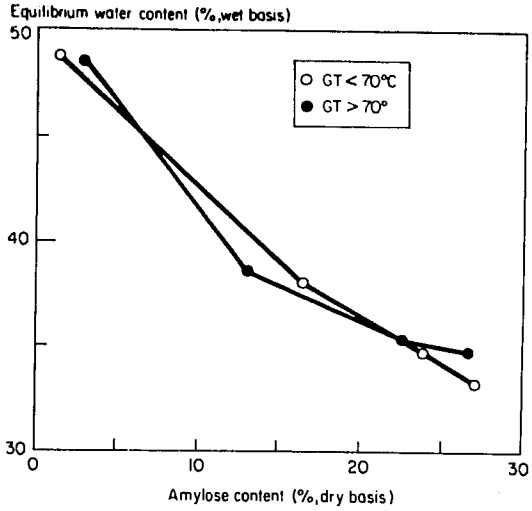
Country	Milled rices (no.)	Protein (% at 14% H_2O)	Amylose types[a]	Gel consistency types[b]	GT types[c]
Cuba	10	5.8– 7.7	H>L,I	M>S>H	L>I
Egypt	10	4.8– 6.4	L>H	S>H	L>I
Mexico	18	5.1– 9.6	H>I>L	S>M>H	I,HI>L
Nigeria[d]	28	5.9–10.7	H>I	S	I>L
Peru	12	6.7–10.4	H>L>I	H>M,S	L>I
Surinam	10	6.8– 9.4	H>I>L	S>M	I,HI>H

[a]Amylose types: 0–2% = waxy; 10–20% = low (L); 20–24% = intermediate (I); >25% = high (H). [b]Gel consistency types: 26–40 mm = hard (H); 41–60 mm = medium (M); 61–100 mm = soft (S). [c]GT types: 1–2 = high (H); 3 = high-intermediate (HI); 4–5 = intermediate (I); and 6–7 = low (L). [d]Parboiled samples.

Equilibrium water content of steeped grain. Earlier studies had shown that amylose content correlates inversely with equilibrium water content of steeped grain and that the presence of opaque portions (air spaces) also contributes to the higher water content of the grain (1972 annual report). Recent studies in India indicated that other factors besides opacity may be involved in differences among high-amylose rices.

A restudy using 4 pairs of samples differing in GT — 1 pair of each amylose type — showed that the major difference was due to amylose content (Fig. 1). Greater variation was noted among the high-amylose samples. This was confirmed from the study of 4 translucent-grained high-amylose (25.2–26.6%) rices with 11.0–12.1% protein and with an alkali spreading value of either 5.0 (intermediate GT) or 7.0 (low GT). Equilibrium water content for the intermediate-GT samples was 31.3% wet basis for IR36 and 31.0% for IR38, compared with that for the low-GT samples: 33.5% for IR26 and 33.1% for IR42. Because all the samples had translucent grains, GT probably inversely affected the equilibrium water content of high-amylose rice. Thus, the reported differences among high-amylose Indian rice samples can be explained on the basis of GT differences.

Varietal resistance to storage deterioration. A cooperative study with entomologists and pathologists at UPLB was undertaken to explore the existence of varietal resistance to insects and fungal infection in 15 brown-rice samples differing



1. Relationship between amylose content and equilibrium water content of steeped milled rices differing in gelatinization temperature (GT). IRRI, 1979.

in GT, amylose content, and protein content. Three insects and two fungi were used.

Triplicate brown-rice samples (50 g) were inoculated with 20 adults for 1 week, and the F_1 adults from the eggs laid by the rice weevil *Sitophilus oryzae* (L)/*S. zeamais* Motsch., the red flour beetle *Tribolium castaneum* (Herbst), and the lesser grain borer *Rhizopertha dominica* (F.) were observed. The data on mean developmental period (M), length, weight, and number (F) of F_1 adults, and percentage weight loss were collected. Index of susceptibility was calculated as:

$$\text{Index of susceptibility} = 10^2 (\ln F)/M.$$

All 3 insects showed significant differences in F, M, index of susceptibility, and percentage weight loss among the 15 brown-rice samples but only the rice weevil differed in the length and weight of emerging adults. The rice weevil and the lesser grain borer preferentially ate the endosperm, but the red flour beetle ate the embryo and bran layers first. The correlation of index of susceptibility to rice weevil with grain properties showed the insects' preference for larger and softer grain based on the hardness index (Table 5). Grain hardness was also negatively correlated with insect weight ($r = -0.79^{**}$). Amylose content of rice and insect length were negatively correlated ($r = -0.56^{*}$), although the negative relationship between amylose and index of susceptibility was not significant. Protein content and gel consistency were not correlated significantly with varietal differences in susceptibility to the three insects.

Waxy rices tended to be more resistant to the red flour beetle than nonwaxy rices on the basis of index of susceptibility (Table 5) but that trend may not be important as the beetle did not readily consume the endosperm in which starch is located. Brown-rice weight and insect length were also significantly correlated ($r = 0.80^{**}$). Studies at the University of California, reported in a later section, indicated a better correlation of susceptibility with starch properties among rices presented as flours, and as milled rather than brown rice.

Malagkit, a waxy variety, was the most susceptible to the rice weevil and the lesser grain borer

Table 5. Range of indexes of susceptibility to 3 insects and aflatoxin B_1 content after inoculation with 2 fungi and correlations with physicochemical properties of 15 samples of brown rice differing in amylose content and gelatinization temperature. University of the Philippines at Los Baños and IRRI, 1979.

Property and range of values	Correlation coefficient with				
	Index of susceptibility to			Aflatoxin B_1 (μg/g)	
	Sitophilus spp.	*Tribolium castaneum*	*Rhizopertha dominica*	*Aspergillus oryzae*	*Aspergillus parasiticus*
Brown-rice width (2.0–2.8 mm)	0.59*	-0.19	0.43	-0.28	0.34
Brown-rice grain wt (14.4–25.0 mg)	0.59*	-0.33	-0.15	-0.10	0.31
Brown-rice hardness (32.0–47.5%)	-0.62*	0.34	-0.14	0.29	-0.37
Milled-rice amylose (1.6–29.1%)	-0.38	0.65**	0.30	0.37	-0.24
Milled-rice alkali spreading (2.0–7.0)	-0.37	-0.12	0.18	0.38	0.21
Milled-rice gel consistency (46–100 mm)	-0.15	-0.29	-0.24	0.40	-0.24
Milled-rice gel viscosity (217–1248 cps)	0.47	-0.39	-0.05	-0.43	0.11
Milled-rice protein (6.0–13.4%)	-0.28	0	-0.03	-0.39	-0.12
Range of values	10.4–15.0	7.3–12.5	3.2–10.7	0.457–7.86	0.011–9.90

but another waxy variety, IR29, was the most resistant to the lesser grain borer. Amylose content and insect weight were significantly correlated (r = 0.58*). Percentage weight loss and alkali spreading value were also positively correlated (r = 0.66**).

Actual milling tests gave the worst grain deterioration from the rice weevil. IR3880-13-5, which had 5.9% damaged grain from rice weevil infestation, showed a 26% drop in head-rice yield relative to uninfested control. The actual head-rice losses due to red flour beetle and lesser grain borer infestation were less than 10% for the samples with maximum weight loss (number or percentage of damaged grains).

UPLB pathologists noted that the molds that occurred on the 15 brown rices were *Penicillium* sp. (10–80%), *Aspergillus niger* (0–30%), and *Aspergillus flavus* (0–30%). *A. niger* was present in only five samples, which were of intermediate- to high-amylose content. The only sample with *A. flavus* was IR2071-137-5, with 13.4% amylose.

Duplicate 50-g brown-rice samples were inoculated with a 10-ml spore suspension from 5- to 7-day-old cultures of *A. flavus* and *A. parasiticus* and incubated for up to 7 days. The growth of both fungi was slowest in C441-4, a waxy sample. Spores ranged from 0.66 to 4.10 × 10^7 for *A. flavus* cultures and from 6.62 to 26.44 × 10^7 for *A. parasiticus* cultures. Aflatoxin B_1 analysis of the pooled samples by thin-layer chromatography at the Aflatoxin Laboratory, UPLB, showed that the waxy group had the lowest mean value with *A. flavus*. The high-protein sample IR9761-19-1 had the lowest aflatoxin B_1 content, 0.457 μg/g with *A. flavus* but another high-amylose sister line, IR9761-75-3, had the highest content of 7.860 μg/g. In contrast, IR9761-75-3 had the least aflatoxin B_1 content, 0.011 μg/g, with *A. parasiticus*, followed by the waxy line C441-4, with 0.114 μg/g. Another waxy rice, IR29, had the highest aflatoxin content with *A. parasiticus*, 1.10 μg/g. Aflatoxin B_1 levels on grain incubated on the two fungi were negatively correlated (r = −0.63*). Sporulation and aflatoxin B_1 level were not significantly correlated for both fungi.

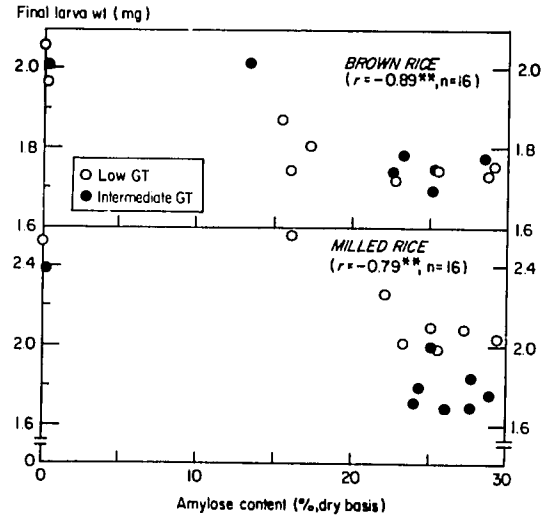
The conflicting relationship to starch properties for the two *Aspergillus* species may be explained on the basis of growth of these fungi mainly on the nonstarch layers — seed coat-aleurone layer. Milling of parboiled infested brown rice of three rices differing in spore content showed that the aflatoxin was mainly in the bran fraction after 7 days' incubation (Table 6). The sample with the highest aflatoxin content had a trace of aflatoxin in the milled rice, the fraction consumed by man.

Table 6. Distribution of aflatoxin B_1 in milling fractions of 3 brown rices incubated 7 days with *Aspergillus flavus* and parboiled before milling. University of the Philippines at Los Baños and IRRI, 1979.

Line name	Aflatoxin B_1[a] (μg/g)	
	Bran polish	Head rice
IR9761-19-1	0.737	Negative
IR3880-13-5	0.773	Negative
IR9129-457-1	1.891	Trace

[a]10% weight removal of bran polish from parboiled brown rice.

Growth of red flour beetle on rice flours. Recent studies by scientists at the University of California, Davis, suggested that the larvae of the red flour beetle grew well on diets based on rice flour and on starches rich in amylopectin. Flours of 16 brown rices and 16 milled rices from IRRI differing in protein content and starch properties were tested at Davis to verify those results (Fig. 2).



2. Red flour beetle (*Tribolium castaneum*) larvae fed rice-based diets were heavier when starch had low-amylose content for both brown and milled rices. Growth was also faster on low-gelatinization-temperature (GT) milled rices, and among high-amylose samples. University of California (Davis) and IRRI, 1979.

Among the brown-rice samples (15 from the UPLB study), the 3 waxy rices produced the heaviest larva. The only red rice, H4 (high amylose), had the lightest (1.69 mg) larva. Larval growth was also better in waxy and low-amylose milled rice. Larval weights in milled rice were generally higher than in the corresponding brown rice. Amylose content was significantly negatively correlated with larval weight for both brown-rice and milled-rice diets. Among the intermediate- and high-amylose milled samples, those with low GT produced heavier larvae than those with intermediate GT. Partial correlation coefficient of larval weight with milled-rice alkali digestibility value, independent of amylose content, was 0.69**. Protein content and gel consistency were less important factors. Brown and milled H4 rice produced the same final larval weight of 1.69 mg, but a second red milled rice, Newudu Samba, gave 1.83 mg.

These results indicate that milled rice would be a preferable material to screen for varietal resistance to insects on the basis of endosperm properties. The relationships between growth of the beetle larva and starch amylose content and GT were similar to those of in vitro α-amylolysis of starch granules using pancreatic α-amylase at 40°C (1975 annual report).

COOKING AND EATING QUALITY FACTORS

Chemistry Department

Emphasis in 1979 was on the properties of cooked rice because of reported varietal differences in grain disintegration during cooking.

Varietal differences in splitting during cooking. Cuban chemists have observed that IR8 splits more during cooking and its cooked rice is more sticky than that of other varieties, particularly the low-amylose rice IR1529. Pakistani chemists also observed IR8 to be more sticky and to burst more on cooking than Mehram 69 (IRR16). To verify those observations, milled Cuban high-amylose, low-GT rice samples of IR8, IR880-C9, Naylamp, and IR1529 were boiled for 18 minutes in 8 times their weight of water. Cooked grains were soaked overnight in water and then judged for disintegration. IR8 disintegrated more than the other samples.

Comparison of five samples from Pakistan and elsewhere differing in amylose content and grain size and shape showed a decrease in the cottony appearance of cooked rice soaked overnight with increasing amylose content. Microscopic examination of thin cross sections of the nonelongating rice, Palman, showed along the lateral axis, an elongated core of small isodiametric cells surrounded by indistinct cells. In the elongating variety Basmati 6129, the cells were still intact and of similar size throughout the cross section. The cells of longitudinal sections of cooked Palman grain were mainly small and isodiametric but those of Basmati had a core of small isodiametric cells surrounded by elongated rectangular cells. Basmati had large internal fissures perpendicular to the longitudinal axis at regular intervals; such fissures were absent in Palman.

Aging and rice texture. Earlier studies with IR8 (1967 annual report) showed that Amylograph peak and setback viscosities progressively increased during the first 2– 3 months of storage at 30°C and levelled off by the 4th month. Because sufficiently aged samples are required for Amylography and cooked-rice texture tests of various rices, the progressive change in these properties was followed for 6 months in 7 milled rices differing in amylose content from the 1978 wet season crop.

Amylograph peak viscosity, setback, and consistency values, in general, stopped increasing after 3 months of storage. IR42, a high-amylose hard-gel rice, showed the highest viscosity values and the highest viscosity increase. The waxy sample Malagkit Sungsong showed the lowest peak viscosity and no change in setback and consistency values.

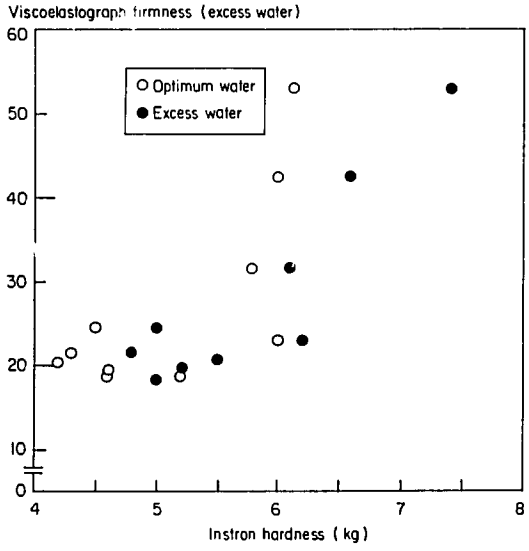
Cooked-rice hardness measured by the Instron OTMS (Ottawa Texture Measuring System) cell also increased during the first 3 months of storage of all milled rices, except the waxy rice. Hardness of cooked rice of the 6 nonwaxy samples increased by 0.6–2.0 kg; that of waxy rice only by 0.2 kg. There was little change in the stickiness of cooked rice during storage. The waxy-rice sample had the softest but stickiest cooked rice of the set; it was followed by the low-amylose sample. The two intermediate-amylose and two high-amylose rices had overlapping values for cooked-rice texture.

The gel of milled rice progressively hardened during storage, but the samples usually stayed within the same gel consistency group, except

IR32, whose gel consistency was 92 mm (soft) before storage but decreased to 45 mm (medium) after 3 months of storage.

The results indicate that 3 months is the minimum storage period at 30°C to obtain reproducible texture measurements.

Instrument methods for cooked-rice texture. A comparison was made between cooked-rice hardness, measured by the IRRI Instron OTMS method, and firmness, measured by the Viscoelastograph technique, of 10 French cooked-rice samples in a joint study with the Laboratory of Durum Wheat and Rice Technology, Institut National de la Recherche Agronomique, Montpellier, France. At Montpellier, viscoelastograms were done on single grains of rice cooked in excess water up to optimum grain cooking. At IRRI the same rices were cooked in optimum water in a rice cooker and in excess water at 100°C for Instron measurement. The Instron data showed a wider range of and higher hardness values for the rice cooked in excess water (4.6–7.4 kg) than for the rice cooked in the cooker (4.2– 6.1 kg) (Fig. 3). Viscoelastograph firmness correlated better with Instron hardness of the rice cooked in excess water than with Instron hardness of rice cooked in the rice cooker. Arlésienne was the hardest sample in all tests. It



3. Relationship between Instron hardness of 10 French rices cooked in optimum and excess water and Viscoelastograph firmness of the rice cooked in excess water. IRRI and Institut National de la Recherche Agronomique, 1979.

was the only sample with medium gel consistency; the rest had soft gel consistency. All 10 had low GT (alkali spreading value of 7.0).

A comparison of cooked-rice textures, using various instruments, was undertaken as a followup of the 1978 workshop on chemical aspects of rice grain quality. Ten samples — two waxy rices from Thailand and eight nonwaxy samples (2 from U.S., 2 from Australia, and 4 from IRRI) — were used to represent the full spectrum of cooking quality of rice. They were cooked in excess water for 2 minutes more than the time required for the grain to completely gelatinize or become translucent. Results to date include data from 4 Instron testers, 2 Texturometers, 1 Viscoelastograph, 1 Tensipresser, 1 Pabst texture tester, and a taste panel. Mean cooking time ranged from 18.5 to 21.3 minutes, representing a spread of 7 or 8 minutes cooking time for the 10 samples at any laboratory. Mean water contents ranged from 71.1 to 74.1% wet basis. The cooked sample of waxy rice RD6 was rated the softest and that of IR42, the hardest. Another sample, however, was rated the hardest by the Texturometer and by the Instron with compression and back extrusion cells. All methods rated RD6 as the most sticky and IR42 the least sticky among the 10 cooked rices.

Intermediate-amylose rices. An earlier survey indicated a higher preference in the Southeast Asian region for low-amylose rices than for high-amylose rices (>25%). C4-63G has been considered a good-quality intermediate-amylose (22–24%) Philippine variety. In the Philippines, however, dryland varieties with 18–22% amylose are also popular. Previous consumer panel tests by UPLB showed a preference for low-amylose entries over C4-63G.

A followup consumer panel test was made to verify actual preference for nonwaxy rice. Aside from C4-63G and BPI-121-407, two dryland rices, IR43 (IR1529-430-2-3) and C171-136 (Sigadis/BPI-76-1), and a high-amylose, soft gel consistency rice, IR46 (IR2058-78-1), made up the set of five rices. IR43 is a CP-SLO derivative. The samples had 69–100 mm gel consistency, 445–650 cps gel viscosity, and 6.4–8.5% protein.

The Filipino panel preferred C4-63G as raw rice (Table 7). IR46 and BPI-121-407 were finer grained than the three others and were darker colored. IR43 grains showed some degree of white

Table 7. Relative preference and acceptability scores in consumer panel tests, and properties of 5 raw and cooked head milled rice differing in starch properties. Institute of Human Ecology, University of the Philippines at Los Baños, and IRRI, 1979.

Property	IR43	C171-136	C4-63G	BPI-121-407	IR46
Mean preference score[a]					
Raw	-0.161 bc	0.081 b	0.622 a	-0.502 c	-0.039 b
Cooked	0.730 a	0.266 b	-0.216 c	-0.382 c	-0.398 c
Acceptability[b]					
Raw	83	88	93	63	88
Cooked	100	85	80	70	58
Grain length (mm)	7.0	6.6	6.9	6.5	6.2
Length-width ratio	2.8	2.8	2.8	3.0	3.0
1000-grain wt (g)	20.1	16.9	17.3	14.9	15.0
Kett whiteness reading	42.0	47.0	43.5	40.4	38.2
Amylose (% dry basis)	15.8	22.9	23.3	23.7	28.6
Alkali spreading value	7.0	4.2	4.7	7.0	5.1
Cooked-rice Instron					
Hardness (kg)	5.5	5.6	7.9	7.8	9.7
Stickiness (g·cm)[c]	195	137	143	121	97

[a]Mean of 40 panelists who rated the samples: 1st = 1.16; 2nd = 0.50; 3rd = 0; 4th = -0.50; and 5th = -1.16. In the same row, means followed by a common letter are not significantly different at the 5% level. [b]Expressed in % of acceptable or "Yes" responses (<60% acceptability is considered unacceptable). [c]Stickiness is expressed as a product of weight and distance (g·cm).

belly. Among the cooked rices, IR43 and C171-136, both dryland rices, were rated better than C4-63G. They had lower Instron hardness values but only IR43 was more sticky than C4-63G. BPI-121-407 cooked rice was again less preferred than C4-63G. The lowest preference for IR46, the hardest cooked rice, suggests the Filipinos' preference for a softer cooked rice. Freshly harvested IR24 with 15% amylose was not acceptable as it was too sticky. The results suggest that Filipinos prefer rices with 18–22% amylose, which is typical of local dryland varieties, to rices with 22–25% amylose. The low-amylose variety Khao Dawk Mali is also popular in Thailand.

A detailed study of intermediate-amylose IRRI and Philippine rices was also made. Of seven Philippine intermediate-amylose rices tested, five had intermediate GT, and two (BPI-121-407 and IR4570-83-3) had low GT. All except UPL-Ri-2 (Intan/B5580-A_1-15) were derived from Fortuna/Seraup Besar 15. Results from 2 crops showed BPI-76 to have 25% amylose, the highest protein content, and the hardest cooked rice. C4-63G had softer cooked rice than BPI-121-407 and IR4570-83-3 (IR48). Low-GT rices tended to have lower Amylograph peak viscosity (<750 B.U.) than intermediate-GT rices.

Starches from five of these milled rices purified by sodium dodecyl benzene sulfonate (DoBS) extraction of protein from rice flour showed similar contents of total (29.7–30.8%) and hot water-soluble (15.4–15.7%) amylose. Alkali viscogram peak viscosity corresponded to viscosity of gels in the gel consistency test, with BPI-76 having the highest viscosity, followed by IR4570-83-3. The two rices had the same relative rankings for milled-rice gel viscosity. Amylogram peak and setback viscosities were higher and consistency values lower for the low-GT rice and for BPI-76 than for the three other intermediate-GT (71–73°C) starch samples. Mean granule sizes ranged from 5.9 to 6.9 μm.

Waxy rices. Limited sources of the waxy gene are used in the IRRI and Philippine breeding programs. IRRI uses Gam Pai 15 in IR29 through IR833 (IR262-43-8-11/Gam Pai 15). The waxy Philippine lines are derived from Pangasinan through Panpet 63 (Pangasinan/Peta).

The same consumer panel tested both the raw and cooked samples of five waxy and five non-waxy rices of low GT. The rice cakes, cooked in coconut milk and wrapped in wilted banana leaves the day before, were served cold.

The consumer panel scores for raw rice showed a preference, among Filipinos, for coarse waxy grain, influenced by the size and shape of Malagkit Sungsong, which also has a characteristic starchy aroma (Table 8). IR29 and IR4445-53-2 had the finest grains and the lowest grain weights.

As rice cakes, Malagkit Sungsong was again

Table 8. Preference and acceptability scores in consumer panel tests and properties of 5 raw and cooked waxy head milled rice. Institute of Human Ecology, University of the Philippines at Los Baños, and IRRI, 1979.

Property	Malagkit Sungsong	IR29	IR4445-63-1	MRC-1502-751	UPL-Ri-1
Mean preference score[a]					
Raw	0.514 a	-0.415 c	-0.340 c	-0.104 c	0.344 b
Cooked	0.464 a	-0.072 bc	-0.080 bc	-0.382 c	0.070 b
Acceptability[b]					
Raw	95	55	65	78	93
Cooked	90	83	88	83	90
Grain length (mm)	5.2	6.5	6.8	6.6	6.7
Length-width ratio	1.7	2.8	2.8	2.4	2.3
1000-grain wt (g)	18.7	15.8	17.0	19.1	21.7
Kett whiteness reading	50.5	51.2	49.8	55.0	52.8
Alkali spreading value	7.0	7.0	7.0	7.0	6.9
Neutral gel consistency (mm)	48	40.5	39.5	39.5	43
Cooked-rice Instron					
Hardness (kg)	3.0	1.6	2.3	2.3	2.1
Stickiness (g·cm)	278	240	227	252	253

[a]Mean of 40 panelists who rated the samples: 1st = 1.16; 2nd = 0.50; 3rd = 0; 4th = -0.50; and 5th = -1.16. Means in the same row followed by a common letter are not significantly different at the 5% level. [b]Expressed in % of acceptable or "Yes" response (<60% acceptability is considered unacceptable).

Table 9. Physicochemical properties of milled rice and starch of 5 Thai waxy rices. IRRI and Rice Division, Thailand, 1979.

Property	RD2	RD4	RD6	Muey Nawng 62M	Niaw San Pahtawng
Milled rice					
Relative quality in Thailand	Fair	Poor	Good	Good	Good
Alkali spreading value	6.0	3.7	6.2	6.0	6.3
Gel consistency (mm)	78	80	96	76	98
Gel viscosity (cps)	1513	1408	1088	1437	1126
Neutral gel consistency (mm)	50	36	83	78	82
Amylograph peak viscosity (B.U.)	450	695	485	495	460
Cooked-rice hardness (kg)	3.7	4.6	3.0	3.6	3.4
Starch					
Final GT (°C)	65.5	74.5	64.5	66	64.5
Amylograph peak viscosity (B.U.)	690	680	610	710	635
Alkali viscogram peak viscosity (cps)	431	466	320	356	398
Gel consistency (mm)	94	100	100	100	100
Gel viscosity (cps)	1520	1970	974	1050	1180

rated the best; UPL-Ri-1 was rated second best (Table 8). Malagkit Sungsong cake was probably preferred because of its greater hardness, which results in tackiness. The differences in amylose content (1.6–1.8%), protein content (6.0–7.9%), alkali gel consistency (89–100 mm), and viscosity (1069–1434 cps) among the five varieties were slight but Malagkit Sungsong had the softest neutral gel in the set. UPL-Ri-1 had a higher gel viscosity than the others.

Five low-GT and two high-GT waxy rices from IRRI and Philippine programs were also studied in detail for grain properties. Neutral gel consistency were harder for the two high-GT samples (C441-4 and RD4) than for the others. Only C441-4 showed a higher Amylograph peak viscosity than low-GT rices, but this difference was not present in the starch preparations.

Starch prepared from the seven waxy milled rices showed no consistent differences in Amylogram and alkali viscogram peak viscosities between high-GT and low-GT samples. C441-4 had the hardest gel. Among the five low-GT samples, IR29 and IR833-6-2 had higher gel viscosity than

Malagkit Sungsong, whereas IR4427-57-5 and UPL-Ri-1 had lower viscosity. In terms of freeze-thaw stability, all the five low-GT starches were stable for 5–6 cycles whereas the 2 high-GT samples were stable only for 1 cycle. The two high-GT samples had larger starch granules (mean size 7.3 and 7.4 μm) than the other samples (mean size 5.5–5.8 μm). That was confirmed by the use of an automatic image analyzer at Carlsberg Research Laboratories.

Five Thai waxy milled rices were also studied in cooperation with the Rice Division, Thailand. All except RD4 had low GT, but RD2 was inferior to the three others with low GT (Table 9). Neutral gel consistency values, but not alkali gel consistency, of RD2 and RD4 also were lower. RD6 had softer cooked rice than RD2 and RD4. The four low-GT samples also had similar Amylograph peak viscosities, which were lower than that of RD4. The starches prepared by DoBS extraction of protein showed less differences in Amylograph peak viscosity than the milled rices (Table 9). The three varieties with good eating quality also had lower alkali viscogram peak viscosity than RD2 and RD4 — a result supported by starch gel viscosity data.

The peak viscosity of 9% starch pastes was higher than that of 10% milled-rice pastes in all the samples, but only that in waxy samples increased by more than 100%. The reason suggested by Japanese workers was the higher α-amylase activity in waxy milled rice than in nonwaxy rice.

Because α-amylase activity of rice endosperm is low and boiling of the aqueous extract to inactivate any α-amylase does not appreciably increase the peak viscosity of waxy milled rice, possible causes for the difference were investigated. Earlier studies had shown that the waxy rice endosperm has more free sugars and nonstarch lipids than the nonwaxy endosperm. These minor constituents of milled rice affected the Amylograph peak viscosity of waxy rice flour.

Raw and parboiled Sri Lankan rices. Many Sri Lankan rices are red-pericarped and most are high amylose. But the small-grained, round samba varieties (brown rice wt, 10–12 mg) are preferred to the long-grained coarse varieties. About 75% of Sri Lankan rice is parboiled. A study of 22 samples was made to determine other attributes contributing to preference for samba rice, besides dimensions and resultant resistance to splitting during cooking. Raw milled rice had a narrow range of total (25 8–28.1%) and hot water-soluble amylose (12.2–14.4%) but differed widely in other properties (Table 10). Traditional varieties were of intermediate GT (alkali spreading value 4–5) and soft gel consistency. Cooked-rice hardness of samba rices was below 7 kg for raw rice and below 8 kg for parboiled rice. The three low-GT (alkali spreading value of 6–7) rices were confined to the

Table 10. Comparison of grain properties of raw and parboiled Sri Lankan samba and long-grained traditional and new varieties.[a] IRRI, 1979.

Property	Traditional		New varieties	
	Samba (3)	Others (6)	Samba (2)	Others (11)
Brown-rice wt (mg)	10.2–12.1	15.9–25.2	12.2–15.6	17.2–25.8
Milled rice (raw)				
Alkali spreading value	3.8–5.5	4.0–5.0	5.0–5.3	4.8–7.0
Gel consistency (mm)	61–78	66–95	44–61	29–44
Cooked-rice Instron				
Hardness (kg)	6.0–6.6	6.0–7.8	6.2–6.3	6.7–7.5
Stickiness (g·cm)	–	38–58	57–57	41–59
Milled rice (parboiled)				
Gel consistency (mm)	100	94–100	72–93	48–95
Cooked-rice[b] Instron				
Hardness (kg)	6.5–7.7	7.4–8.8	6.7–7.3	7.5–8.8
Stickiness (g·cm)	44–56	46–61	62–65	37–61

[a]Numbers in parentheses indicate number of samples. [b]Presoaked for 40 minutes before heating.

Table 11. Gel consistency of raw and parboiled milled Sri Lankan rices. IRRI, 1979.

Sample, treatment	Gel consistency (mm)			
	Bg 34-6		Bw 265	
	Raw	Parboiled	Raw	Parboiled
Unsieved, 8 min boiling	40	95	27	90
100-mesh flour, 8 min boiling	36	47	28	54
100-mesh flour, 15 min boiling	28	33	28	35

new varieties. Both the raw and parboiled samples of the improved varieties have hard to medium gel and generally harder cooked rice.

Amylograms of selected samples confirmed that soft-gel samples tended to have lower peak viscosity and consistency than the other samples. Parboiling further reduced the Amylograph viscosity curve in conformity with previous results.

The softer gel of parboiled rice compared with that of raw rice (Table 11) was investigated further. Parboiled rice of Bg 34-6 and Bw 265, which showed the biggest drop in gel consistency values, had 0.26% less nonstarch lipids, by cold chloroform:methanol (2:1) extraction, than raw rices. The addition of 0.26% lipids to parboiled rice did not restore its gel consistency to equal that of raw rice. Parboiled rice was more difficult to disperse in N NaOH without shaking, as indicated by the lower amylose solubilization than in raw rice (19.1% vs 26.9%). Grinding the two pairs of samples in a Wig-L-Bug amalgamator resulted in 39% of raw rice but only 16% of parboiled rice finer than 100 mesh (150 μm). When 100-mesh flours were used, harder gels were obtained with parboiled samples than with unsieved parboiled rice, but reproducibility was poorer (Table 11). Prolonging the dispersion time to 15 minutes further hardened the gel, indicating that the softer gels obtained for parboiled flour by the standard procedure for raw rice flour was due to incomplete dispersion — a result of grain hardening from gelatinization of starch during parboiling. Parboiled rices need a dispersion period of at least 15 minutes.

MINOR CONSTITUENTS AND GRAIN QUALITY

Chemistry and Soil Chemistry Departments

Cell-wall polysaccharides (*Chemistry*). Cell walls are important for grain integrity during cooking of milled rice. American and Japanese rice chemists recently reported that cell-wall polysaccharides contribute to Amylograph viscosity of milled-rice flour. New methods of isolation and characterization have been developed since an IRRI study of hemicelluloses of rice in 1968.

Methods for isolating intact endosperm cell walls, developed for wheat and barley, were applied on well-milled IR36 rice. The attempts were unsuccessful because the tightly compacted and strongly bound protein bodies and compound starch granules showed more resistance to breakage than the walls. Rice cell walls were more fragile and thinner (2 μm) than those of wheat and barley.

Preparation of both water-soluble and water-insoluble cell wall materials from IR36 milled rice was attempted for chemical studies. A cold-water-soluble fraction was obtained by homogenizing milled rice in twice the weight of water and the residue was homogenized two more times with fresh water. Then the extracts were combined. The residue of cold water extraction was heated to 100°C with 10 volumes of water and continuous stirring. The hot-water extract and the cold-water extract were concentrated under reduced pressure below 60°C until incipient cloudiness and incubated with human salivary α-amylase at pH 6.9 in 0.01 M maleate buffer with 1 mM calcium at 40°C for 8 days. The α-amylase was inactivated by heating and the solution was centrifuged, dialyzed, and freeze-dried. Percent recovery by weight was 0.4% for cold-water-soluble material and 0.8% for hot-water-soluble material. Both materials were hygroscopic and contained at least 50% carbohydrate. Protein content was higher for the cold-water-soluble preparation, probably because of albumin contamination. The presence of arabinogalactan-protein type polymers in the water-soluble extracts was indicated by gel diffusion experiments with Yariv antigen (β-glucosyl phenylazo dye).

Several methods for preparing the water-insoluble cell wall fraction from IR36 milled rice were tried avoiding the use of alkali to allow isolation of glycoproteins containing serine and threonine linkages with carbohydrates. The first scheme combined homogenization, sonication, and sieving and gelatinization to solubilize the starch granules. The method was laborious, and

gelatinized starch, together with protein bodies, adhered to the cell wall. A second scheme consisted of starch gelatinization at <80°C, hydrolysis with heat-stable *Bacillus licheniformis* α-amylase (previously heated at 80°C to inactivate β-glucanase) at 60–70°C, and removal of protein with 2.5% sodium dodecyl sulfate (SDS)–2% β-mercaptoethanol (β-ME) at 100°C and then washing. The method was not satisfactory, since α-amylolysis took 30 hours and the high SDS-β-ME concentration did not fully remove protein contamination.

The method selected consisted of wet milling and sieving IR36 milled rice before three extractions with 0.5% SDS-0.6% β-ME at room temperature. Because cooking reduced protein solubility, protein extraction before starch gelatinization reduced residual protein. After washing, the flour was gelatinized at <80°C and incubated at 60–70°C for 2–3 hours in sodium phosphate buffer containing calcium chloride with the β-glucanase-free, heat-resistant *Bacillus licheniformis* α-amylase. The residue was cleaned by sedimentation until the supernatant liquid was clear. The lyophilized preparation had 51% carbohydrate and 4% protein. Residual protein bodies seen on microscopic examination were removed by overnight incubation with pronase.

Lipids (*Chemistry*). Studies in 1978 indicated that waxy rice grain has the same total lipid content as, but more nonstarch lipids than, nonwaxy grain because it has low content of amylose capable of binding lipids. Waxy rice also contained more free fatty acids in an earlier study. The fat acidity of stored milled rice 6 months after harvest was determined for a waxy rice and three nonwaxy rices. The waxy sample had the highest nonstarch lipid content of 1.2%, in contrast with 0.8–1.0% for nonwaxy rice. Corresponding fat acidity was 140 mg KOH/100 g for the waxy rice and 66–77 mg KOH/100 g for the 3 nonwaxy rices stored for a similar period. Thus the higher nonstarch lipid fraction of waxy rice contributed to faster lipid deterioration of the grain during storage. It also contributed to the flour's lower Amylograph peak viscosity.

Although cold extraction of lipids from starch with water-saturated butanol (BuOH) was used in studies on granular starch (1978 annual report), hot extraction is usually used for lipid studies with resultant starch gelatinization. Lipids were more effectively extracted from two intermediate-amylose and two high-amylose starch samples prepared by DoBS extraction with hot BuOH than with the cold BuOH (Table 12). Again intermediate-amylose rices gave higher lipids than did high-amylose rices. Cold BuOH extracted more lipids from the two samples with low GT (IR480-5-9 and IR8) than from those with intermediate GT. The starch prepared by alkaline protease (pronase) treatment had higher lipid content than the DoBS-prepared starch but the intermediate-amylose C4-63G again had more lipids than the high-amylose IR32. Earlier reports were that DoBS partially extracted starch lipids.

Defatting did not affect residual nitrogen content but reduced residual phosphorus of DoBS-prepared starch. Defatting reduced both nitrogen and phosphorus contents of pronase-prepared starch. Residual nitrogen and phosphorus, after defatting, may involve bound protein-N, choline-N, and phosphate esters of starch.

Table 12. Effect of method of preparation and starch properties on bound lipids of rice starch granules extracted by cold and hot water-saturated butanol (BuOH).[a] IRRI, 1979.

Starch sample	Preparation method	Amylose content (%)	Final GT[b] (°C)	Lipids (%) extracted with		Residual phosphorus (ppm dry basis)		
				Cold BuOH	Hot BuOH	Native	Extracted with Cold BuOH	Extracted with Hot BuOH
C4-63G	DoBS[c]	27.7	74	0.39	0.82	268	157	41
IR480-5-9	DoBS	28.4	63	0.44	0.78	318	193	72
IR5	DoBS	30.3	73	0.34	0.75	259	157	45
IR8	DoBS	30.2	65	0.40	0.70	282	200	66
C4-63G	Pronase	27.6	74	0.72	0.96	444	–	134
IR32	Pronase	30	73.5	0.75	0.86	334	–	107

[a]Thrice, for a total of 24 h cold extraction; once at 100°C for 8 h hot extraction. [b]GT = gelatinization temperature. [c]Sodium dodecyl benzene sulfonate.

Based on fatty acid recoveries of the lipid fractions of DoBS-prepared starch, the mean apparent neutral lipids-glycolipids-phospholipids ratio of 1:1:1 was 5:1:4 after correction.

Problem soils and mineral content (*Chemistry and Soil Chemistry*). Grain samples of varieties tolerant of adverse soil conditions were obtained from the Soil Chemistry Department for analysis. The samples were from rices grown in Maahas clay and in the problem soils (simulated) during the 1978 wet season.

Crude ash content was reduced by 0.5% and phosphorus content by 0.1% in two pairs of samples of rice grown on phosphorus-deficient soils. Zinc-deficiency caused a greater reduction of potassium content of grain (by 0.1–0.2%) than of zinc content (3 ppm). Acid sulfate soils increased by 5 ppm the iron in the grain. Soil salinity resulted in a large increase in potassium content of grain (0.2–0.4%) and no change in ash or sodium content.

In the 1979 dry season, IR42 grown on alkaline and saline soils had higher grain protein. In three pairs of rices, phosphorus deficiency reduced ash and phosphorus content of the grain.

Two samples of IR42 brown rice with 0.96% and 1.32% ash were milled and assessed for cooked-rice texture. The cooked samples gave similar hardness (8.4 vs 8.4 kg) and stickiness values (72 vs 75 g·cm). The raw milled samples contained 9.6% and 9.3% protein and 0.35% and 0.48% ash. Thus, adverse soils may not adversely affect the eating quality of cooked rice.

Genetic evaluation and utilization (GEU) program

Disease resistance

Plant Pathology and Plant Breeding Departments and International Rice Testing Program

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SCREENING FOR MULTIPLE DISEASE RESISTANCE

Plant Pathology Department

One hundred and thirty GEU breeding lines and IR varieties were evaluated for resistance to 12 rice diseases (Table 1). Some lines were highly resistant to only one disease, most to two or three diseases, and some to four or five. Three lines were resistant to six diseases.

SCREENING FOR BLAST RESISTANCE

Plant Pathology Department

A total of 98,878 entries from different sources were tested in the International Rice Blast Nursery (IRBN) (Table 2). Some lines with a consistently high level of resistance to blast are IR5533-13-1-1, IR1905-81-3-1, IR1416-128-5-8, IR4547-6-2-5, IR3273-289-2-1473, IR4563-52-1-3-6, IR5929-12-3, IR9559-4-1-1, Carreon, and Tadukan.

Blast tests of selected breeding lines and resistance donors. Selected breeding lines and their resistance donors were tested in the IRBN from 1975 to 1978. The susceptibility indices (SI) of the various varietal reactions were computed using the formula,

$$SI = \frac{1N_R + 3N_M + 5N_S}{N_R + N_M + N_S}$$

where N_R is the number of reactions with a rating of 0–2 on the scale, N_M is those with 3–4, and N_S is those with 5–9. The lower the value of the susceptibility indices, the higher the resistance of the lines. The results indicated that most of the breeding lines outranked their donor parents in resistance to blast in many countries where they were tested (Table 3).

Tests of Japanese varieties with field resistance to blast. Eighty-six varieties with field resistance to blast in Japan were tested twice in the IRRI blast nursery. Many of the varieties that had field resistance in Japan were moderately resistant to very susceptible at IRRI (Table 4). Some varieties within the group exhibited type 3–4 reac-

Table 1. Disease reaction of elite breeding lines and IR varieties. IRRI, 1979.

Variety or line	Disease[a] reaction[b]											
	Blast	LS	CLS	HLS	Shb	ShR[c]	Bke	8B	BLS	RTV	GSV	RSV
IRB	S-S	S	MR-S	MR	M-M	M	R-R	S-S	R	S-S	R-R	S-S
IR20	S	R	S	–	M	–	R	R	–	S	R	S
IR26	S	MS	M	–	M	–	R	R	–	M	R	S
IR32	MS-S	S	MS-S	S	MR-M	MR	R-R	R-R	R	S-S	R-R	S-S
IR36	MS-S	MR	M	S	M	M	S-S	R-R-S	R	S-S	R-R	S-S
IR38	S	MR	MR	–	M	–	R	R	–	S	R	S
IR42	MS-S	MR	M-M	MS	MR-M	MR	MS-MS	R	R	S-S	R-R	S-S
IR43	S	MS	M	MR	M	M	MS	R	R	S	R	S
IR44	S	MR	M	MS	M	M	R	R	R	S	R	S
IR45	MS	S	M	R	M	M	R	R	R	S	R	S
IR46	S	S	MS	MR	M	MR	R	MR	R	S	R	S
IR48	S	MS	R	MR	MR	R	R	R	R	S	R	M-S
IR50	S	MS	R	R	MR	R	R	R	MR	M-S	R	M-S
IR2058-78-1-3-2-3	S	S	R	–	M	–	R	R	–	S	R	S
IR2061-522-6-9	S	S	MR	MS	M	MS	R	R	R	M	R	S
IR2071-685-3-5-4-3	S	MS	M	MR	MR	M	R	R	MR	S	M	S
IR2307-247-2-2-3	S	–	M	–	M	–	MR	R	–	S	M	S
IR2797-105-2-2-3	S	S	M	–	M	–	R	R	–	M	R	S
IR2863-3B-1-2	S	S	S	–	M	–	MR	R	–	S	–	S
IR3351-3B-3-1	S	–	M	–	M	–	S	R	–	S	–	M
IR3680-65-6-1	S	MS	M	MS	M	MR	R	R	R	S	R	S
IR3839-1	MS-S	S	M-S	MR	M-M	M	R-MR	R	R	S-S	R	S-S
IR3880-10	S-S	MS	R-S	MR	M-M	MS	R-MR	S-R	R	S-S	R	S-S
IR3880-13	S	S	MR	MR	M	M	S	MR	R	S	R	M

Continued on opposite page

Table 1 continued

Variety or line	Disease[a] reaction[b]											
	Blast	LS	CLS	HLS	ShB	ShR[c]	BLB	BB	BLS	RTV	GSV	RSV
IR8192-31-2-1-2	S-S	S	R-S	MR	M-M	M	R-R	R-R	R-R	S-M	R-R	M-S
IR8192-166-2-2-3	S-S	MS	R-M	MR	M-M	MR	R-R	R-R	MR	M-S	R-R	S-S
IR8192-200-3-3-1-1	S-S	MR	M-S	MS	M-M	MR	MS-S	R-R	R	M-M	R-R	M-M
IR8608-79-3-2	S	–	M	–	M	–	MS	R	–	M	R	S
IR8608-167-1-2	S-S	S	MR-M	MS	M-MS	MR	MS-S	R-R	MR	S	R-R	S-S
IR8608-189-2-2-1-3	S-S	MR	MR-M	MS	M-M	MR	R-S	R-R	R	M-M	R-R	S-M
IR8608-298-3-1-1-2	S-S	S	R-M	MR	M-MS	MR	R-S	R-R	R	M-M	R-R	M-S
IR9129-136-2-2-1-2	S-S	MS	MR-MR	MR	M-M	M	R-R	R-R	R	MS	R-R	MS
IR9129-136-2-2-2-1-2	S	MS	MR	MR	M	M	R	R	MR	S	R	S
IR9129-169-3-2-3-3	S	S	R	MR	M	M	R	R	R	R	R	S
IR9129-209-2-2-2-1	S-S	S	R-MR	MR	M-M	MR	R-R	R-R	R	M-S	R-R	S-S
IR9129-456-2-2-1-2	S	MS	R	R	M	M	R	MR	MR	M	R	S
IR9129-457-2-2-1-2	S	–	R	–	M	–	R	R	–	S	R	S
IR9209-26-2-2-2-3	S	–	M	–	MS	–	S	R	–	S	R	S
IR9209-181-2-2	S	MS	R	MR	M	MS	R	R	MS	S	R	S
IR9209-262-1-3-1	S	MR	R	S	MS	M	R	R	R	S	R	M
IR9217-58-2-2	S	MS	R	MS	M	R	R	R	R	S	R	M
IR9224-22-2-2-2-3	S	–	M	–	M	–	S	R	–	S	R	S
IR9224-162-3-1-3-2	S	R	R	R	M	MR	R	R	MR	S	–	S
IR9264-321-3	S	MR	MR	R	M	R	R	R	R	M	–	S
IR9411-5-3-3	S	MS	R	MR	M	R	MR	R	MS	S	–	S
IR9703-41-3-3-1	S	–	M	–	M	–	S	R	–	S	R	S
IR9729-287-3-3-2	S	–	MR	–	M	M	R	R	–	S	R	S
IR9732-118-3	S	MR	R	MR	M	MR	R	R	MS	S	–	S
IR9761-8-2	S	–	S	–	M		S	R	–	S	R	S
IR9761-19-1	S	MS	MR	MS	M	MR	R	R	R	S	–	S
IR9761-47-3	MS	MS	M	R	M	M	MS	R	R	S	–	S
IR9761-75-3	S	MR	MR	R	M	MR	R	MR	MR	S	–	S
IR9763-11-2-2	S	MR	R	R	M	MR	R	R	R	M	–	M
IR9764-45-2-2	S	MS	R	R	M	R	R	R	S	M	–	S
IR9784-42-3-1	MS	MS	R	R	M	R	S	R	MR	S	–	S
IR9788-19-2-3	S	–	M	–	M	–	MS	R	–	S	R	S
IR9788-19-2-3-3	MS	MR	R	R	M	MR	R	MR	MS	S	–	M
IR9802-10-3	S	–	M	–	M	–	MS	R	–	S	R	S
IR9802-10-3-3-1	MS	S	MR	R	M	MR	MS	R	MS	S	–	S
IR9802-30-2	MS	MS	M	R	M	M	R	R	MS	S	–	S
IR9805-78-2	MS	S	R	R	M	MR	R	S	R	M	–	S
IR9805-97-1	S	MR	R	R	M	MR	S	R	R	M	–	S
IR9809-9-2	MS	S	M	R	M	MR	MR	R	R	M	–	S
IR9814-6-3	S	MR	MS	R	M	MR	S	R	–	S	R	M
IR9814-6-3-3-2	MS	MS	MS	R	M	MR	R	R	MR	S	–	S
IR9846-215-3	MS-S	MS	R-S	R	M-M	M	MS-S	R-R	MS	S-S	R	S-M
IR9846-261-3	S	R	S	–	M	–	R	R	–	S	R	M
IR9852-22-3	MS	S	R	R	M	MR	MR	R	MR	S	–	S
IR9859-45-2	S	–	S	–	M	–	S	R	–	S	R	S
IR9860-26-2-2-2	MS	MR	MR	MR	M	MR	MR	R	MR	M	–	S
IR9884-54-3	S	–	M	–	M	–	S	R	–	S	R	M
IR9975-5-1	S	–	M	–	M	–	R	R	–	S	R	M
IR10167-17-5-2	S	–	S	–	M	–	R	R	S	S	R	S
IR10198-66-2	S	–	M	–	M	–	S	R	–	S	R	M
IR10199-128-2	R	–	M	–	M	–	S	R	–	S	R	M
IR10206-29-2	S	–	MR	–	M	–	S	R	–	S	R	M
IR10781-143-2-3	S	–	–	–	M	–	R	R	–	S	R	M
IR11248-13-2-3	S	–	–	–	M	–	MS	R	–	S	R	M
IR11248-83-3-2-1	MS	MS	R	R	M	M	MS	R	R	S	–	S
IR11248-242-3-2	S	–	–	–	M	M	MS	R	–	S	R	M

Continued on next page

Table 1 continued

Variety or line	Disease[a] reaction[b]											
	Blast	LS	CLS	HLS	Shb	ShR[c]	Bke	BB	BLS	RTV	GSV	RSV
IR9729 287 3 3 2	S		MR		M	M	R	R		S	R	S
IR9732 118 3	S	MR	R	MR	M	MR	R	R	MS	S		S
IR9761 8 2	S		S		M		S	R		S	R	S
IR9761 19 1	S	MS	MR	MS	M	MR	R	R	R	S		S
IR9761 47 3	MS	MS	M	R	M	M	MS	R	R	S		S
IR9761 75 3	S	MR	MR	R	M	MR	R	MR	MR	S		S
IR9763 11 2 2	S	MR	R	R	M	MR	R	R	R	M		M
IR9764 45 2 2	S	MS	R	R	M	R	R	R	S	M		S
IR9784 42 3 1	MS	MS	R	R	M	R	S	R	MR	S		S
IR9788 19 2 3	S		M		M		MS	R		S	R	S
IR9788 19 2 3 3	MS	MR	R	R	M	MR	R	MR	MS	S		M
IR9802 10 3	S		M		M		MS	R		S	R	S
IR9802 10 3 3 1	MS	S	MR	R	M	MR	MS	R	MS	S		S
IR9802 30 2	MS	MS	M	R	M	M	R	R	MS	S		S
IR9805 78 2	MS	S	R	R	M	MR	R	S	R	M		S
IR9805 97 1	S	MR	R	R	M	MR	S	R	R	M		S
IR9809 9 2	MS	S	M	R	M	MR	MR	R	R	M		S
IR9814 6 3	S	MR	MS	R	M	MR	S	R		S	R	M
IR9814 6 3 3 2	MS	MS	MS	R	M	MR	R	R	MR	S		S
IR9846 215 3	MS S	MS	R S	R	M M	M	MS S	R R	MS	S S	R	S M
IR9846 261 3	S	R	S		M		R	R		S	R	M
IR9852 22 3	MS	S	R	R	M	MR	MR	R	MR	S		S
IR9859 45 2	S		S		M	-	S	R		S	R	S
IR9860 26 2 2 2	MS	MR	MR	MR	M	MR	MR	R	MR	M		S
IR9884 54 3	S		M		M		S	R	-	S	R	M
IR9975 5 1	S		M		M		R	R		S	R	M
IR10167 17 5 2	S		S		M		R	R	S	S	R	S
IR10198 66 2	S		M		M		S	R		S	R	M
IR10199 128 2	R		M		M		S	R		S	R	M
IR10206 29 2	S		MR		M		S	R		S	R	M
IR10781 143 2 3	S				M		R	R		S	R	M
IR11248 13 2 3	S				M		MS	R		S	R	M
IR11248 83 3 2 1	MS	MS	R	R	M	M	MS	R	R	S		S
IR11248 242 3 2	S				M		MS	R		S	R	M
IR11297 158 3	S				M		R	R		S	R	S
IR11418 19 2 3	S				M		R	R		S	R	M
IR13146 41 3	S	S	MR	MS	M	MR	MS	MR	R	S		M
IR13142 19 1	S	MS	MR	MR	M	M	S	MR	MR	M		S
IR13149 43 2	S	M	R	MR	MR	R	S	R	MR	M		S
IR13168 143 1	S	S	MS	MR	MR	M	R	R	R	S		S
IR13240 10 1	R	S	MR	S	M	MR	R	MR	R	S		S
IR13240 83 1	S	R	M	S	M	MR	R	MR	MR	S		S
IR13299 96 2 2	MS	S	M	S	M	M	R	MR	R	S		M
IR13415 9 3	MS	MS			M		R	R		S	R	S
IR13419 113 1	S	MS	MR	S	M	M	R	R	R	S		S
IR13426 19 2	S	S	MR	MS	MS	MR	R	R	R	S		M
IR13426 26 2	S				M		MS	R		S	R	S
IR13429 47 3	S	MS	R	S	MS	M	S	MR	R	M		S
IR13429 105 3	R	MS	M	MR	M	MR	R	-	R	S		M
IR14632 22 3	MS	MS	R	S	M	R	MS	MR	R	S		S
IR14753 120 3	S	MR	R	S	M	M	MS	R	MR			
IR15629 256 1		MR	M	R	M	MR	MS	R	MR	S		
IR 11444	S		MS	MR	M	MS	S	S	MS	S		S

[a]LS = leaf scald, CLS = Cercospora leaf spot, HLS = Helminthosporium leaf spot, ShR = sheath blight, Shb = sheath rot, Bke = bakanae disease, BB = bacterial blight, BLS = bacterial leaf streak, RTV = rice tungro virus, GSV = grassy stunt virus, RSV = ragged stunt virus. [b]R = resistant, MR = moderately resistant, M = intermediate, MS = moderately susceptible, S = susceptible. Dashes indicate no information due to either no seed germination, rat damage, or no inoculation. A dash between reactions indicate reaction difference as a result of 2 or more tests. [c]Field reaction to natural infection, all others are to artificial inoculation.

Table 2. Summary of screening for blast resistance at IRRI, 1979.

Source	Varieties (no.)			
	Resistant (1–2)	Intermediate (3–4)	Susceptible (5–9)	Total
Elite breeding lines[a]	7	34	129	170
Germplasm bank	53	67	60	180
Pedigree nursery lines	8,785	26,382	57,166	92,333
Hybridization block[a]	126	101	226	453
Observational yield trial[a]	372	704	1,492	2,568
Replicated yield trial[a]	111	252	382	745
Varietal yield testing	23	13	293	329
Indonesian breedling lines	134	85	71	290
CIAT[b] breeding lines	12	9	3	24
Japanese varieties[a]	11	38	37	86
Korean lines	24	0	33	57
International nurseries				
IRBN[a]	320	189	177	686
IRON	38	95	209	342
IRLRON	29	69	151	249
IURON	39	38	64	141
IRCTN	75	42	108	225
Total	10,159	28,118	60,601	98,878
Percent	10.27	28.44	61.29	100

[a]Tested 2–3 times. [b]Centro Internacional de Agricultura Tropical, Colombia.

Table 3. Blast resistance of selected breeding lines, resistance donors, and other varieties in the International Rice Blast Nursery tests, 1975–78.

Line	Donor	Tests (no.)	Percentage with given reaction[a]			Susceptibility index
			R(0–2)	M(3–4)	S(5–9)	
IR5533-PP854-1	IR8^3/Carreon//Tetep	79	88.6	10.1	1.3	1.253
IR3259-PP5-160-1	IR8^3/Tetep	53	88.7	9.4	1.9	1.264
IR5533-P855-1	IR8^3/Carreon//Tetep	87	89.7	6.9	3.4	1.275
IR1905-PP11-29-4-61	IR8/Tetep	82	86.7	12.1	1.2	1.289
IR9660-50-3-1-1	IR8^6/IR3260	60	85.0	15.0	0.0	1.300
Tetep		104	86.5	11.5	2.0	1.307
IR1905-81-3-1	IR8/Tetep	85	82.4	17.6	0.0	1.352
IR9660-00951-1	IR8^6/IR3260	55	85.5	10.9	3.6	1.363
IR5533-PP856-1	IR8^3/Carreon//Tetep	87	83.9	13.8	2.3	1.368
IR4547-14-3-1	IR8^6/PK203//IR4477///IR3265	92	83.7	14.1	2.2	1.369
IR9569-PP830-1	IR8^3/Carreon	59	81.4	18.6	0.0	1.372
IR5533-15-1-1	IR8^3/Carreon//Tetep	59	83.0	15.3	1.7	1.372
IR3259-PP18-821-2	IR8^3/Tetep	80	81.3	18.7	0.0	1.375
IR9559-4-1-1	IR8^3//IR1904/IR1905	61	82.0	16.4	1.6	1.393
IR4547-16-3-4	IR8^6/PK203//IR4477///IR3265	60	81.7	16.7	1.6	1.400
IR9669-PP846-1	IR8^3/Carreon	60	83.4	13.3	3.3	1.400
IR5533-56-1-12	IR8^3/Carreon//Tetep	60	83.4	13.3	3.3	1.400
IR3273-342-1-6	IR8^6/PK203	61	80.4	18.0	1.6	1.426
IR3271-760-1482	IR8^4/PK203//Dawn	59	78.0	22.0	0.0	1.440
IR9559-PP870-1	IR8^3//IR1904/IR1905	86	80.2	17.5	2.3	1.441
IR1905-PP19-73-2	IR8/Tetep	86	80.2	17.4	2.4	1.441
IR4547-16-3-7	IR8^6/PK203//IR4477///IR3265	61	80.3	16.4	3.3	1.459
Carreon		109	78.0	19.3	2.7	1.477
IR3259-PP11-182-4	IR8^3/Tetep	79	78.5	19.0	2.5	1.481
IR5533-13-1-1	IR8^3/Carreon//Tetep	91	80.2	15.4	4.4	1.483
IR4547-6-1-3		59	76.3	22.0	1.7	1.508
IR4547-6-2-4		59	78.0	18.6	3.4	1.508

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Table 3 continued

IR4547-6-3-2		61	77.0	19.7	3.3	1.524
IR4547-16-3-2		61	78.7	16.4	4.9	1.524
IR4547-6-2-6		60	78.3	16.7	5.0	1.533
IR5533-55-1-11	IR8^3/Carreon//Tetep	60	76.7	20.0	3.3	1.533
IR4547-6-2-5		60	78.3	15.0	6.7	1.566
IR4472-53-10-8-1-2	IR8^8/Dawn	58	74.1	22.4	3.5	1.586
IR3273-289-2-1473	IR8^6/PK203	60	73.4	23.3	3.3	1.600
IR9669-PP836-1	IR8^3/Carreon	71	74.7	19.9	5.6	1.619
IR1909-1-3-3	IR8^4/Dawn	60	75.0	16.7	8.3	1.666
IR4547-10180-20-7	IR8^6/PK203//IR4477///IR3265	61	72.1	18.0	9.9	1.754
IR9559-3-1-1	IR8^3//IR1904/IR1905	61	63.9	29.5	6.6	1.852
Dawn		105	56.2	26.7	17.1	2.219
Kataktara DA-2		106	42.5	33.0	24.5	2.641
KTH-17		108	23.2	17.5	59.3	3.722
Kung-Shan-Wu-Shen-Ken		43	16.3	7.0	76.7	4.209
Fanny		93	6.5	7.5	86.0	4.591
B40		109	1.8	13.8	84.4	4.697
Taichung T.C.W.C.		63	0.0	12.7	87.3	4.746

[a]R(0–2) = resistant, with a rating of 0–2; M(3–4) = moderate, with a rating of 3–4; S(5–9) = susceptible, with a rating of 5–9.

Table 4. Reaction[a] in 2 tests at IRRI of 86 varieties with field resistance to blast in Japan. April–May 1979.

Variety	Genotype for true resistance	Field resistance (Japan)	IRRI nursery blast reaction	
			Nursery 1	Nursery 2
Sensho	+	rr	m	s
Shingu	+	–	ss	ss
Norin 22	+	r	m	m
Kogane Nishiki	+	r	ss	–
Ukon Nishiki	+	r	ss	ss
Ginga	+	r	s	s
Suzuhara-mochi	+	–	s	s
Rikuu 132	+	–	m	m
Harima	+	rr	m	m
Honen Wase	+	r	m	s
Norin 29	+	–	ss	s
Norin 6	+	–	ss	ss
Rikuto Norin 12	+	r	m	ss
Rikuto Norin 4	+	–	m	m
Coshi-riku 1	+	–	s	m
Coshi-riku 2	+	–	s	m
Nu-shu	+	–	ss	ss
Chubu 22	+	–	m	m
Kansai 6	+	r	m	m
Hokoriku 52	+	–	s	m
Chubu 32	+	–	m	m
Chugoku 40	+	–	m	s
Chugoku 68-hen	+	–	ss	ss
Norin 8	+ (K^S)	–	ss	ss
Koshihikari	+ (K^S)	–	s	s
Kameji	–	–	ss	ss
Koshiji Wase	+	r	m	m
Ishioka-mochi 14	–	–	rr	m
Ishioka-mochi 10	–	–	m	m
Ishioka-mochi 7	–	–	s	m

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Table 4 continued

Variety	Genotype for true resistance	Field resistance (Japan)	IRRI nursery blast reaction	
			Nursery 1	Nursery 2
Mizuhata-mochi	–	–	rr	rr
70 GR	–	–	m	m
Hokkai 188	–	–	ss	ss
Inakei 154	–	–	m	m
Hokushi Tami	–	–	m	s
Ou 301	–	–	rr	rr
Chubu-mochi 37	–	–	s	rr
Chubu 33	–	–	rr	rr
K 59	–	–	ss	ss
Futaba	*Pi-a*	–	s	ss
Shuiho	*Pi-a*	–	ss	ss
Homare-Nishiki	*Pi-a*	r	m	m
Toyonishiki	*Pi-a*	r	s	ss
Yamabiko	*Pi-a*	r	ss	s
Fujiminori	*Pi-a*	r	ss	ss
Yamaji Wase	*Pi-a*	r	s	m
Akibare	*Pi-a*	–	m	m
Nippon base	*Pi-a* +	–	m	m
BL 1	*Pi-b*	–	s	rr
Inoba Wase	*Pi-i*	–	rr	rr
Fujisaka 5	*Pi-i*	r	m	rr
Todoroki Wase	*Pi-i*	r	m	m
Chubu 17	*Pi-a, Pi-i*	–	m	rr
Chubu 34	*Pi-a, Pi-i*	–	m	m
Chubu 35	*Pi-a, Pi-i*	–	rr	rr
Akishima-mochi	*Pi-a, Pi-i*	r	m	rr
Chubu 38	*Pi-a, Pi-i*	–	ss	m
K 2	*Pi-a, Pi-K*^{p}	–	m	ss
Nu-aki	*Pi-K*	–	m	rr
Inakei 173	*Pi-K*	–	rr	rr
Kusabue	*Pi-K*	–	m	rr
K 3	*Pi-K*^{h}	–	m	s
Fuji 120	*Pi-K*^{h}	–	ss	s
Pi No 1	*Pi-a, Pi-ta*	–	s	ss
Chubu 24	*Pi-ta*^{z}	–	m	m
Chubu 29	*Pi-ta*^{z}	–	s	ss
Yamahikon	*Pi-ta*^{z}	–	m	ss
Pi No. 4	*Pi-ta*^{z}	–	m	m
Pi No. 5	*Pi-ta*^{z}	–	m	m
Reiho	*Pi-ta*^{z}	–	s	ss
Chugoku 68	*Pi-ta*^{z}	–	s	ss
Chugoku 65	*Pi-ta*^{z}	–	m	m
Yashiro-mochi	*Pi-ta*	–	s	ss
Choguku 31	*Pi-t, Pi-K*^{c}	–	m	rr
Hukunishiki	*Pi-z*	–	rr	rr
Hukuhikari	*Pi-z*	–	rr	rr
Ou 24	*Pi-z*	rr	rr	rr
Toride 1	*Pi-z*^{t}	–	m	rr
TY. B	*Pi-z*^{t}	–	s	m
TY. C	*Pi-z*^{t}	–	ss	ss
Yamatobare	*Pi-a, Pi-K, Pi-m*	–	m	rr
Minehikare	*Pi-a, Pi-K, Pi-m*	–	m	s
BR No. 1	*Pi-a, Pi-k, Pi-m*	rr	m	ss
Minishike	*Pi-a, Pi-K, Pi-m*	–	ss	ss
Tsuyuake	*Pi-K, Pi-m*	–	ss	ss
Fukei 111	*Pi-a, Pi-b, Pi-i*	–	rr	rr

[a]rr = highly resistant (1), r = resistant (2), m = moderately resistant (3–4), s = susceptible (5–6), ss = very susceptible (7–8). Dashes indicate no rating.

tions; others, type 5–6 reactions; and still others, type 7–9 reactions. Reactions within a group of varieties with a specific resistance gene (*Pi-a*, *Pi-K*, *Pi-M*) differed, indicating that the resistance genes involved were not detected by races in Japan.

Reaction to races of Pyricularia oryzae *in the Philippines*. Fifty-one Japanese varieties with field resistance and resistance genes were inoculated with 20 isolates from 8 Philippine blast races. The varieties' reactions ranged from resistant to susceptible (Table 5). T28, T54, T55, and T61 — isolates of race 102 — induced different reactions in Suzuhara-mochi, Rikuto Norin 24, Ishioka 3, Sensho, and Fukoton, suggesting that the isolates differ in virulence. The specific susceptibility and resistance of one group of varieties among the entries tested suggest that their field resistance is due to an unknown gene (or genes) not detected by races in Japan.

Races of Pyricularia oryzae. Nine new Japanese differential varieties with corresponding specific resistance gene and code number were inoculated with 110 isolates of *Pyricularia oryzae*. Forty-one races were identified; five of them (R-003, R-103, R-107, R-137, and R-303) were the same as races identified in Japan (Table 6). The most prevalent race was R-102, with 12 isolates, followed by R-100 and R-103. Four isolates did not cause any infection on the new Japanese differentials, but produced lesions on other differential varieties. The set of new differential varieties may be defective because it could not classify all isolates into races.

Table 5. Reaction of 51 Japanese field-resistant varieties to races of *Pyricularia oryzae* in the Philippines, IRRI, 1979.[a]

Variety	Genotype for true resistance	Field resistance (Japan)	Reaction to Philippine races and isolates of *P. oryzae*																									Susceptibility index
			002[b]	100	100	100	102	102	102	102	102	102	103	103	104	104	106	106	106	106	107	107	107	107		
			T34	T69	T63	T67	T28	T54	T56	T55	T61	T02	T59	T21	T60	T65	T36	T37	T66	T64	T23	T57		
Chiyokihari	+	rr-r	R	R	R	R	R	R	R	R	R	R	Rm	R	R	R	R	R	R	R	R	R	R	R		1.3
Ou 247	+	rr	R	R	S	R	R	R	S	R	R	R	R	R	R	R	R	R	R	R	Rm	S	S			2.0
Tokai 26	+	rr	R	R	R	R	R	R	S	R	S	R	Rm	R	R	R	R	R	R	R	R	R	Rm			1.6
San'in 63	+	rr	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	Rm			1.1
Harima	+	rr	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	Rm	S	Rm			1.4
Murasaki-ine	+	rr	R	Rm	S	R	S	R	S	S	S	R	R	R	R	R	S	S	R	S	S	S	R			2.9
Suzuhara-mochi	+	rr	R	Rm	S	R	S	R	S	S	S	S	S	R	S	S	S	R	R	S	S	S	S			1.1
Rikuto Norin 24	+	rr	R	Rm	R	R	S	S	R	R	Rm	R	R	R	R	R	R	R	R	Rm	S	Rm				2.0
Ishioka 3	+	rr	S	Rm	S	R	S	R	R	S	S	S	S	R	S	S	S	S	R	S	S	S				3.9
Sensho	+	rr	R	R	R	R	R	R	Rm	S	S	R	Rm	R	R	R	R	S	R	Rm	Rm	Rm				2.1
Fukoton	+	rr	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	Rm	R	R	R	R	R			1.1
Rikuto Norin Mochi 4	+	rr	R	R	R	R	Rm	R	R	R	R	R	R	R	R	R	R	Rm	R	R	R	R	R			1.2
Rikuto Norin Mochi 26	+	rr	R	R	R	R	Rm	Rm	Rm	R	R	S	R	R	R	R	R	S	R	Rm	Rm	R				1.9
Rikuto Norin 12	+	r	R	Rm	R	R	S	S	S	S	S	R	R	R	R	R	R	S	R	S	R	R				2.4
Honen Wase	+	r	R	R	R	R	R	Rm	R	R	R	R	Rm	R	R	S	R	R	R	R	Rm	Rm				1.6
Saikai 90	+	r	S	Rm	R	R	S	R	S	S	S	S	S	R	S	Rm	S	R	R	S	S	S				3.6
Tangin Bozu	+	r	R	R	R	R	R	R	R	R	R	S	S	R	R	R	R	R	R	R	S	S				1.8

Ukon Nishiki	+	r	R	Rm	S	R	S	S	S	R	S	R	Rm	R	R	R	S	Rm	R	S	S	Rm	1.2
Kogane-masari	+	r	R	R	R	R	R	R	R	R	R	R	R	R	R	R	Rm	R	R	S	R	R	1.3
Koshiji-Wase	+	r	R	R	R	R	R	R	R	R	R	R	R	R	R	R	Rm	R	R	R	R	R	1.1
Miyama-Wase	+	r	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	Rm	R	R	1.3
Yamaji Wase	+	r	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	Rm	R	R	1.1
65A-8	*Pi-a*	rr	R	S	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	Rm	R	R	1.1
Rikuto Norin 11	*Pi-a*	rr	R	R	R	R	R	R	R	R	R	R	Rm	R	R	Rm	R	R	R	S	Rm	R	1.5
Shin Hakaburi	*Pi-a*	rr	R	R	S	R	R	R	R	R	R	R	R	R	R	Rm	R	R	R	Rm	S	R	1.6
Kuroka	*Pi-a*	rr	R	R	R	R	Rm	R	R	S	R	S	S	S	R	S	R	S	R	Rm	S	Rm	2.7
Kirishima	*Pi-a*	rr	R	R	R	R	Rm	R	R	R	R	R	Rm	R	R	R	S	Rm	R	R	S	R	1.7
Kahei	*Pi-a*	rr	R	R	R	R	S	R	R	S	R	R	Rm	Rm	R	R	R	Rm	Rm	Rm	S	R	2.1
Hirayama	*Pi-a*	rr	S	R	R	R	S	R	S	R	S	S	Rm	R	R	S	S	S	S	S	S	Rm	3.4
Yamabiko	*Pi-a*	r	S	R	R	R	R	R	R	R	S	S	S	S	R	S	R	S	R	S	S	Rm	2.9
Fujiminori	*Pi-a*	r	R	R	R	R	R	R	S	S	R	R	R	Rm	R	S	Rm	R	R	Rm	Rm	Rm	2.1
Reimei	*Pi-a*	r	R	R	R	R	R	R	S	S	R	R	R	R	R	S	S	R	R	Rm	S	Rm	2.2
Homare Nishiki	*Pi-a*	r	R	R	R	S	R	R	S	S	R	R	S	R	S	S	S	R	S	S	S	S	3.2
Toyonishiki	*Pi-a*	r	R	R	R	R	R	R	S	Rm	R	R	R	R	R	S	R	R	S	R	R	S	1.9
Himehonami	*Pi-a*	r	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	Rm	S	1.3
Swanishiki	*Pi-a*	r	R	R	R	R	R	R	S	R	R	R	R	R	R	Rm	S	R	S	Rm	S	Rm	2.1
Asagiri	*Pi-a*	r	R	Rm	S	R	S	S	S	S	R	S	R	R	R	S	R	S	R	Rm	R	S	3.0
Yoneshiro	*Pi-i*	rr	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	Rm	Rm	R	R	1.2
Kuiku 9	*Pi-i*	rr	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	Rm	R	R	1.1
Kukei 22	*Pi-i*	rr	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	1.0
Toyama Wase	*Pi-i*	rr	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	S	S	S	1.5
Isao Mochi	*Pi-i*	rr	R	Rm	S	S	S	S	R	S	R	S	S	R	S	S	S	S	S	S	S	R	3.9
Sorachi	*Pi-i*	rr	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	1.0
Todoro Wase	*Pi-i*	r	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	1.0
Akishino-mochi	*Pi-a, Pi-i*	r	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	S	R	R	1.4
Shinsetsu	*Pi-a, Pi-i*	r	R	R	R	R	R	Rm	R	R	R	R	R	R	R	R	S	R	R	R	R	R	1.3
Tatsumi-mochi	*Pi-K*	r	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	1.0
Matsumae	*Pi-K*	r	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	1.0
Ishikari	*Pi-a, Pi-K*	r	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	1.0
Ou 244	*Pi-z*	rr	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	1.0
54 BC-68	*Pi-z*	rr	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	1.0
	Virulence index		1.3	1.4	1.6	1.2	2.0	1.6	2.2	2.1	1.8	1.8	2.0	1.3	1.3	2.1	2.3	2.0	1.5	2.8	2.8	2.4	

[a]rr = highly resistant, r = resistant, R = resistant, Rm = moderately resistant, S = susceptible. [b]Race number based on the reaction of the new Japanese differential varieties.

Table 6. Races of *Pyricularia oryzae* identified by new Japanese differentials. IRRI, 1979.

Isolate no.	Reaction[a] of isolates to each differential variety									Race no.
	Shin 2 (*Pi-K*^{s}, 1)	Aichi Asahi (*Pi-a*, 2)	Ishikare shiroke (*Pi-i*, 4)	Kanto 51 (*Pi-K*, 10)	Tsuyu-ake (*Pi-m*, 20)	Fukuni-shiki (*Pi-Z*, 40)	Yashiro mochi (*Pi-ta*, 100)	Pi No. 4 (*Pi-ta*^{2}, 200)	Toride 1 (*Pi-Z*^{t}, 400)	
4	R	R	R	R	R	R	R	R	R	000
6	R	S	R	R	R	R	R	R	R	002
5	S	S	R	R	R	R	R	R	R	003
2	R	R	R	S	R	R	R	R	R	010
1	R	R	S	S	R	R	R	R	R	014
1	R	S	S	S	R	R	R	R	R	016
1	R	S	R	R	S	R	R	R	R	022
1	S	S	R	R	S	R	R	R	R	023
1	R	S	R	S	S	R	R	R	R	032
8	R	R	R	R	R	R	S	R	R	100
12	R	S	R	R	R	R	S	R	R	102
7	S	S	R	R	R	R	S	R	R	103
3	R	R	S	R	R	R	S	R	R	104
5	R	S	S	R	R	R	S	R	R	106
2	S	S	S	R	R	R	S	R	R	107
2	R	R	R	S	R	R	S	R	R	110
1	R	S	R	S	R	R	S	R	R	112
2	R	S	R	R	S	R	S	R	R	122
1	S	S	S	R	S	R	S	R	R	127
2	R	S	R	S	S	R	S	R	R	132
2	R	S	S	S	S	R	S	R	R	136
2	S	S	S	S	S	R	S	R	R	137
1	R	R	R	R	R	R	R	S	R	200
1	R	S	R	S	R	R	R	S	R	212
1	R	S	R	S	S	R	R	S	R	232
1	R	S	S	S	S	R	R	S	R	236
4	S	S	R	R	R	R	S	S	R	303
1	R	R	R	R	R	R	R	R	S	400
3	S	S	R	R	R	R	R	R	S	403
1	S	S	S	R	R	R	R	R	S	407
1	S	S	R	R	S	R	R	R	S	423
2	S	S	R	S	S	R	R	R	S	433
3	R	S	R	R	R	R	S	R	S	502
4	S	S	R	R	R	R	S	R	S	503
1	S	S	S	R	R	R	S	R	S	507
3	S	S	R	R	R	R	R	S	S	603
1	S	S	R	S	S	R	R	S	S	633
2	R	S	R	R	R	R	S	S	S	702
4	S	S	R	R	R	R	S	S	S	703
2	S	S	S	R	R	R	S	S	S	707
3	S	S	S	R	R	R	S	S	S	743

[a]R = resistant, S = susceptible. The specific resistance gene and code number are given in parentheses after the variety's name.

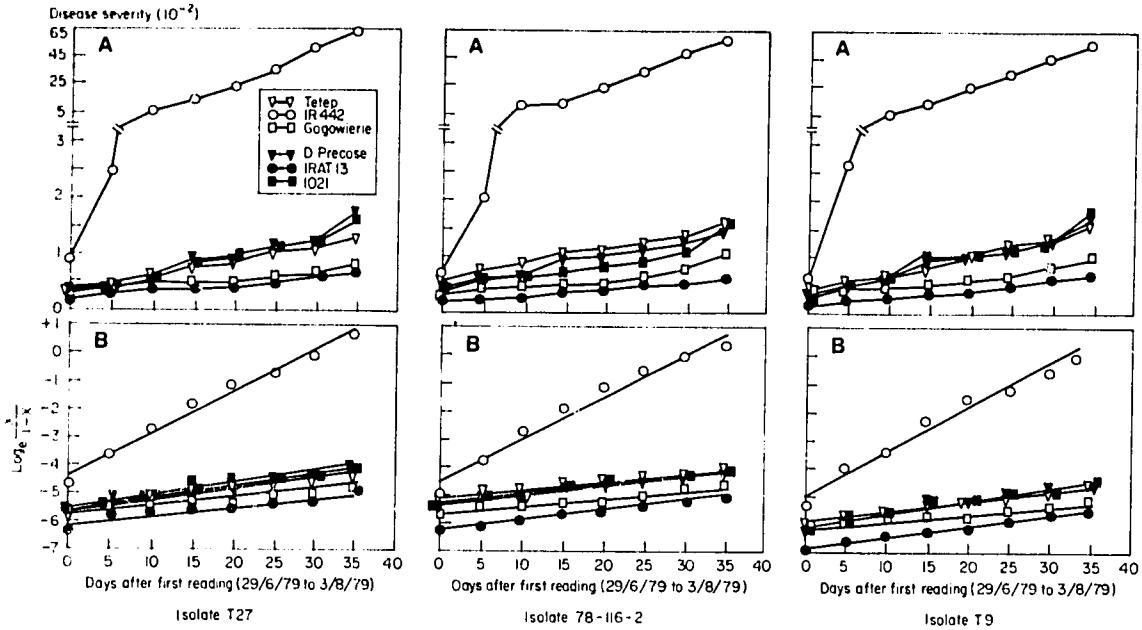
time (t), corrected for decreasing amounts of healthy tissue ($1 - x$), is given in the equation:

$$r = \frac{1}{t_2 - t_1} \left(\log_e \frac{x_2}{1-x_2} - \log_e \frac{x_1}{1-x_1}\right.$$

where the subscripts denote the beginning and end points of the time interval for which r is calculated.

The rates of increase in leaf blast severity varied among experiments and among varieties within the three experiments (Fig. 1). Differences in disease severity among varieties became marked as the experiments progressed. Cultivars showed variations in leaf blast severity, indicating resistance of the rate-limiting type.

The experiments demonstrated that leaf blast infection developed more slowly on IRAT 13,



1. Disease progress curves (A) for 3 isolates of *Pyricularia oryzae* Cav. on 6 rice cultivars and their logit plots (B) (Jun 1979 experiment).

Gogowierie, Tetep, Dourado Precose, and 1021 than on the susceptible IR442-2-58. Gogowierie and IRAT 13 consistently had the slowest rate of leaf blast increase, IR442-2-58 always had the most rapid increase, manifested by rapid development of the disease on the lower and upper leaves and rapid spread of the infection to the adjacent plants.

The experiments confirmed the ability of some rice cultivars to retard rice blast development. The consistent differences in this character among cultivars suggest that it could be used for cultivar improvement.

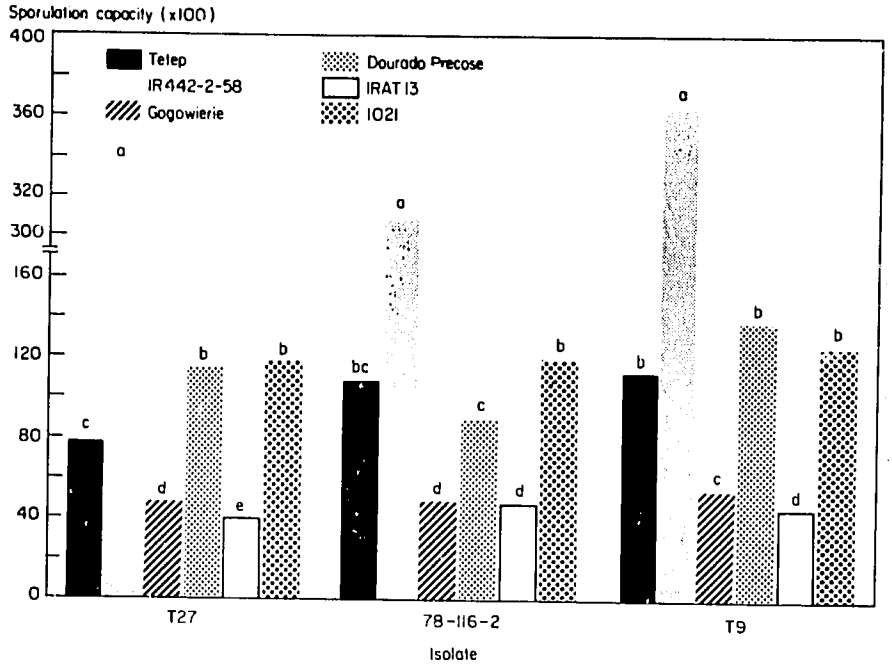
Components of horizontal resistance (*Plant Breeding*). Disease efficiency (DE), latent period (LP), lesion size (LS), and sporulation capacity (SC) of three isolates of *P. oryzae* Cav. (T9, T27, and 78-116-2) were measured on Tetep, IR442-2-58, Gogowierie, Dourado Precose, IRAT 13, and 1021. DE was determined as the percentage of inoculated spores that produced visible lesions, and LP was based on the number of lesions that appeared on the leaf surface each day. SC was measured as the cumulative number of spores sampled from individual lesions at 24-hour intervals. LS was determined by measuring the length and width (widest portion) of a lesion and expressing lesion area in square millimeters.

Analysis of the data showed that the cultivars possessed different levels of horizontal resistance. IRAT 13 and Gogowierie had high levels (Fig. 2). It was also shown that the major factor that slowed the rate of infection in the six cultivars was the capacity to reduce DE, LP, and SC. The exception was 1021, which had the ability to reduce DE and SC but had an LP similar to that of the susceptible check. The results suggested that lesion size was not a major factor in determining resistance because, in most cases, the spore yield per lesion and lesion size exhibited a negative relationship.

The study also revealed interactions between horizontal resistance and epidemiological fitness, indicating that horizontal resistance could decrease over time.

Results of the study support the concept that slow leaf-blast infection is a form of horizontal resistance. The methodology used represents the application of the epidemiological theory to breeding of crops that possess resistance to a disease by virtue of their ability to restrict the rate of epidemic development.

Mechanisms of horizontal resistance (*Plant*



2. Sporulation capacity of 3 isolates of *Pyricularia oryzae* Cav. on 6 rice cultivars; variety means for 3 isolates followed by a common letter are not significantly different at the 5% level. IRRI, 1979.

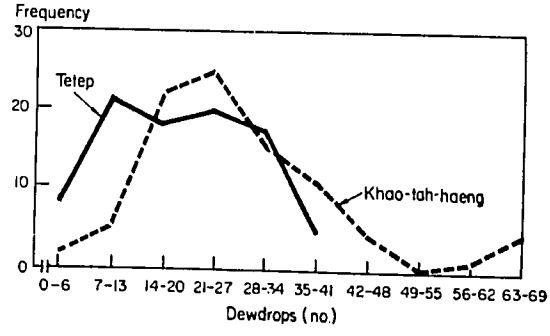
Pathology). A study of the distribution of *P. oryzae* on the leaf surface of blast-resistant and susceptible rice cultivars in the laboratory and in samples collected from the blast nursery indicated that a smaller number of conidia were deposited on the leaf surface of the resistant cultivars (Table 7).

Estimates of the relative wettability of leaves of blast-resistant or susceptible cultivars indicated that leaves of the former were wetted to a lesser extent. A study of the frequency distribution of the number of water drops per unit area of the leaf surface indicated that retention of a large number of drops was lower on Tetep than on susceptible Khao-tah-Haeng (KTH) (Fig. 3). Bigger droplets had lower retention on rice leaf surfaces and also appeared to be retained less frequently on the resistant IR36 than on the susceptible IR442. F_1 plants of a Tetep × KTH cross behaved like the resistant parent, indicating that the wettability component of blast resistance is heritable.

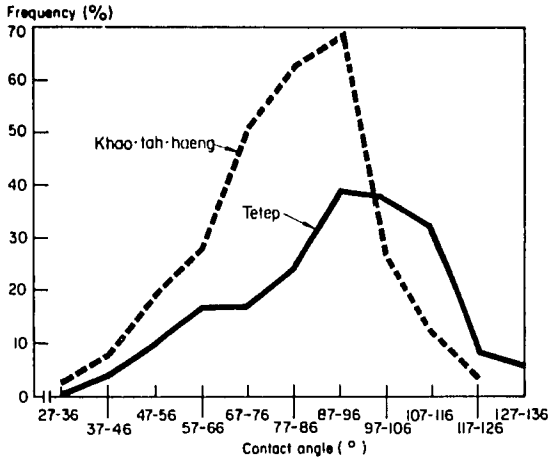
Table 7. Deposit of *Pyricularia oryzae* conidia on adaxial leaf surfaces of blast-resistant or susceptible rice cultivars. IRRI, 1979.

Exp. no.	Nature of infestation	Conidia[a] (no./microscope field [12.5 x 20])			
		Carreon (R)	Tetep (R)	IR36 (R)	IR442 (S)
1	Artificial	1.9	0.9	1.6	3.9
2	Artificial	1.4	4.1	2.5	3.5
3	Artificial	1.1	1.5	1.5	2.3
4[b]	Natural	5.6	3.6	–	10.8
5[b]	Natural	1.2	–	3.9	11.6

[a]Figures are means of about 200 observations on segments from 3 leaves. A dash means not investigated. R = resistant, S = susceptible.
[b]Number of conidia/mm² leaf surface.



3. Frequency of retention of different numbers of water drops by blast-resistant Tetep and susceptible Khao-tah-haeng. IRRI, 1979.



4. Contact angle for dewdrops on the leaves of blast-resistant Tetep and susceptible KTH. IRRI greenhouse, 1979.

Experiments in a dew chamber indicated that although there was no marked difference in the amount of dew condensed per unit area of detached horizontally laid leaves of Tetep and KTH, less dew was retained on intact leaf surfaces of resistant Tetep than on susceptible KTH. Shaking the plants after dew had condensed left less residual dew on the leaf surface of Tetep than on KTH.

Dewdrops on Tetep leaves registered a larger mean contact angle than those on KTH leaves. This difference was more evident with plants grown at day/night temperatures of 29°/21°C than with those at 32°/24°C. Frequency distribution plots of the contact angles of dewdrops on the two varieties showed that drops with lower contact angles were less frequent on Tetep (Fig. 4). The ability of Tetep leaves to shed dew to a greater extent is associated with the lower distribution of conidia on the leaf surface and consequent development of fewer lesions in that variety.

Table 8. Distribution of appressoria per unit area of leaf surface on detached leaves of blast-resistant Tetep and susceptible KTH. IRRI, 1979.

Variety[a]	Appressoria (no./microscopic field [12.5 x 20])				
	Leaf 1	Leaf 2	Leaf 3	Leaf 4	Mean
Tetep (R)	4.3	6.4	7.9	5.0	5.9
KTH (S)	7.8	9.0	11.7	9.7	9.6

[a]R = resistant, S = susceptible.

The infection structure formed by the germinating conidia also appears to be affected by the physicochemical properties of rice leaves. The number of appressoria per unit area of the leaf surface was lower in detached resistant leaves of Tetep than in leaves of the susceptible KTH when the varieties were inoculated with the same conidial suspension (Table 8). Similarly, less appressoria were formed in vitro on epicuticular waxes extracted from Tetep. However, the presence of dew on epicuticular waxes promoted early differentiation of appressoria. Appressorial formation was virtually complete by 6 hours in the presence of wax and dew, but was slow in the presence of dew or wax alone.

PATHOGEN VARIATION IN *P. ORYZAE*

Plant Pathology Department

The inheritance of blast resistance was studied using four blast isolates (750778, T72, T63, and 2017, belonging to three race groups) and five parents (Tetep, Carreon, IR36, Sensho, and KTH-17). Isolate T63 exhibited a consistent (resistant or

Table 9. Stable and unstable reaction[a] of 4 isolates of the blast fungus. IRRI, 1979.

750778 (ID13)	T63 (ID14)	T72 (IH_1)	2017 (IA65)
	Stable reaction		
Tetep (19, 0) (R)	Sensho (0, 5) (S)	Tetep (14, 0) (R)	KTH (170, 5) (S)
Carreon (5, 0) (R)	Tetep (24, 0) (R)	Carreon (15, 0)	
	IR36 (39, 0) (R)		
	Unstable reaction		
IR36 (22, 17) (M)		IR36 (5, 15) (M)	Tetep (1, 3) (M)
Sensho (4, 4) (M)		Sensho (5, 10) (M)	IR36 (3, 2) (M)
			Carreon (4, 3) (M)
			Sensho (1, 4) (M)

[a]R = resistant, S = susceptible, M = mixed reaction. Figures in parentheses represent the number of plants showing resistant and susceptible reactions, respectively.

susceptible) reaction on the parents and was considered a stable isolate. Isolate 2017 exhibited a mixed reaction on the parents and was considered an unstable isolate (Table 9).

The process of reproduction in the rice blast fungus *P. oryzae* is by atypical mitosis. The number of chromosomes in the hyphal, conidiophore, and conidium cells varied from 2 to 12; the most frequent variation was 3 followed by 6 chromosomes. The difference in number of chromosomes may result in duplication or deletion of genes for pathogenicity or virulence.

LEAF SCALD RESISTANCE

Plant Pathology Department

Screening for resistance. Screening of varieties and lines in the hybridization block and of GEU elite entries for leaf scald resistance continued during the 1979 wet season. Entries were artificially inoculated at maximum tillering stage by the clipping method.

Of 292 entries inoculated, 31.9% were resistant, 14.7% were moderately resistant, 21.2% were moderately susceptible, and 32.2% were susceptible (Table 10).

Production of the perfect stage of *Rhynchosporium oryzae*. Attempts were made to produce the perfect stage of the leaf scald fungus by mating single ascospore cultures and growing them singly in petri dishes containing Sach's medium in 1.7% agar into which pieces of IR42 leaf sheaths were embedded. In an experiment with 39 single ascospore cultures, 22 produced perithecia in cultures with leaf sheath tissue, but none produced perithecia in plates without leaf sheath pieces. The results indicated that the organism was homothallic and the rice tissue in the medium was necessary for the production of the perfect stage.

SCREENING FOR RESISTANCE TO BAKANAE DISEASE

Plant Pathology Department

A total of 170 GEU elite lines were screened for resistance to bakanae disease of rice. An arbitrary scale of 0 to 9, with 0 as resistant and 9 as susceptible, was used in classifying varietal resistance to the disease (Table 11). About 48% of the entries were resistant, 28% had moderate reaction, and 24% were susceptible.

Table 10. Summary of field screening for leaf scald resistance. IRRI, 1979 wet season.

Source	Entries (no.) showing the given reaction[a]			
	1–2	3	4	5–9
Elite breeding lines	2	22	31	29
Hybridization block	91	21	31	65

[a]Disease reaction was based on the following scale unit: 1 = Lesions 0–1 cm long; 2 = Lesions 1.01–2 cm long; 3 = Lesions 2.01–3 cm long; 4 = Lesions 3.01–4 cm long; 5 = Lesions 4.01–5 cm long; 9 = Lesions >8 cm long

The results indicated that there are many resistant varieties and lines that could be used directly by farmers or as sources of resistance in breeding for bakanae disease resistance. Among the entries screened, varieties IR20, IR26, IR32, IR38, IR44, and IR45 were resistant; IR36, IR42, and IR43 were moderately susceptible; and lines IR3351-38-3-1, IR6140-22-2, IR6228-2-1, IR9703-41-3-3-1, and IR9846-215-3 were very susceptible.

SCREENING FOR RESISTANCE TO SHEATH BLIGHT, SHEATH ROT, AND CERCOSPORA LEAF SPOT

Plant Pathology Department

A total of 6,574 entries were screened for sheath blight resistance. As in previous years, no entry was rated resistant, but about 6% were classified moderately resistant. Most of the test materials had a moderate reaction. In a confirmation test, only 28 entries remained moderately resistant (Table 12).

One hundred and thirty-one elite breeding lines and varieties were screened for resistance to sheath

Table 11. Results of screening seedlings of GEU elite lines for bakanae disease resistance. IRRI, 1979.

Scale		Actual incidence (%)	Entries tested	
			No.	%
0 Immune	R	0	27	15.9
1 Highly resistant	R	1–10	20	11.8
2 Resistant	R	11–20	34	20.0
3 Moderately resistant	M	21–30	16	9.4
4 Moderately susceptible	M	31–40	20	11.8
5 Moderately susceptible	M	41–50	12	7.0
6 Susceptible	S	51–60	9	5.3
7 Susceptible	S	61–70	8	4.7
8 Very susceptible	S	71–80	7	4.1
9 Very susceptible	S	81–100	17	10.0
Total			170	100.0

Table 12. Summary of sheath blight screening. IRRI, 1979 wet and dry seasons.

Source	Entries (no.)	Entries (no.) with given disease reaction[a]					
		R	MR	M	MS	S	VS
Elite breeding lines	170	0	8	154	7	1	0
Lowland:							
Replicated yield trial	1,200	0	6	1,179	15	0	0
Observational yield trial	719	0	28	676	13	2	0
Upland:							
Replicated yield trial	80	0	3	65	6	6	0
Observational yield trial	1,254	0	208	759	167	79	41
Hybridization block	558	0	6	537	15	0	0
Germplasm bank	2,438	0	77	2,339	18	4	0
Resistant entries (Crowley Disease Nursery)	14	0	3	9	1	1	0
Sheath blight entries (12) in hybridization block	12	0	1	9	1	1	0
Confirmation test							
Elite breeding lines	16	0	0	16	0	0	0
Replicated yield trial	1	0	0	1	0	0	0
Observational yield trial	5	0	0	5	0	0	0
Hybridization block	4	0	3	1	0	0	0
Germplasm bank	66	0	25	40	1	0	0
International Rice Blast Nursery	2	0	0	2	0	0	0
International Rice Yield Nursery	1	0	0	1	0	0	0
International Rice Observational Nursery	1	0	0	1	0	0	0
Stress-resistant donor	4	0	0	4	0	0	0
Collaborative sheath blight screening	15	0	0	14	0	1	0
5th International Rice Sheath Blight Nursery	7	0	0	7	0	0	0
Plant pathology lines	5	0	0	5	0	0	0
Korean breeding lines	2	0	0	2	0	0	0

[a]R = resistant, MR = moderately resistant, M = intermediate, MS = moderately susceptible, S = susceptible, and VS = very susceptible.

blight, Cercospora leaf spot, and sheath rot diseases (Table 13).

Most entries exhibited a consistently moderate reaction to sheath blight at several sites; some had reactions ranging from moderately resistant to moderate, and a few were moderate to moderately susceptible. Only IR5982-7-6-1 was susceptible.

The Cercospora leaf spot screening results indicated that the disease was generally less severe during the wet season than in the dry, with lines susceptible in the dry season becoming resistant in the wet season.

Eleven of 85 lines screened in the wet season had a resistant reaction to sheath rot.

Physiologic race study of *Cercospora oryzae*. From a few hundred varieties and breeding lines previously inoculated with isolates of *Cercospora oryzae* in the field, 49 were repeatedly inoculated in the greenhouse. Different sets of the 49 varieties were planted in trays and inoculated with an isolate 3 weeks after seeding. Based on their reactions to the different isolates and their individual plant type at the seedling stage, 8 entries were selected to compose the tentative set of differential varieties: IR8 (IRRI), Zenith (US differential), IR20 (IRRI), Delitus (US differential), IR26 (IRRI), Southern Red Rice (US differential), IR9129-159-3-2-3-3 (IRRI), and MI 273 (Ivory Coast). Preliminary inoculation tests suggested the occurrence of about 6 race groups comprising 13 races.

Screening methods for sheath rot resistance. Sheath rot caused by *Acrocylindrium oryzae* has become increasingly prevalent on varieties and breeding lines at IRRI. To develop an efficient technique for reproducing the disease for resistance screening, three methods of inoculation were tested: inserting single-grain culture between the leaf sheath and culm, injecting spore suspension behind the sheath, and spraying spore suspension on plants at different growth stages.

Inoculation with a single grain at the tillering-to-panicle-initiation stage consistently produced severe infection. A relatively higher incidence was obtained with the injection method among plants at

Table 13. General screening of elite lines for resistance to sheath blight, Cercospora leaf spot, and sheath rot. IRRI, 1979 wet and dry seasons.

Elite line	Reaction[a]		
	Sheath blight	Cercospora leaf spot	Sheath rot
IR8	M/M/M/M/M	MS/MR	M
IR20	M/M/M/MR	VS	
IR26	M/M/M/M/M	M	
IR32	M/MR/M/MR/M	MS/MS	MR
IR36	M/M/M/M/M	M/M	M
IR38	M/M	MR	
IR42	M/MR/M/M/MR	M/M	MR
IR43	M	M	M
IR44	M	M	M
IR45	M	M	M
IR46	M	MS	MR
IR2058-78-1-3-2-3	M/M/M/M	R	
IR2061-522-6-9	M	MR	MS
IR2071-685-3-5-4-3	M/M	M	R
IR2307-247-2-2-3	M/M	M	
IR2797-105-2-23	M/M	M	
IR2863-38-1-2	M	MS	
IR3351-38-3-1	M/M/M	M	
IR3680-65-6-1	M	M	MR
IR3839-1	M/M	MS/M	M
IR3880-10	M/M	MS/R	MS
IR3880-13	M/M	MR	M
IR3880-13-10	M	R	MS
IR3880-29	M	M	
IR4219-35-3-3	M/M	MS	
IR4422-480-2-3-3	M/M	M	
IR4432-28-5	M/MR/M/M	M/R	M
IR4432-52-6-4	M/M/M	M/MR	R
IR4563-52-1-3-6	M/M	M	
IR4568-86-1-3-2	M/M/M	M/R	M
IR4568-225-3-2	M/M	M	
IR4570-83-3-3-2	M/M/M/M	M/R	R
IR4570-117-2-1-2	M/M	MR	
IR4683-19-3-3	M/M	M	
IR5178-1-1-3	M	R	M
IR5178-1-1-4	M/M	M	
IR5179-2	M	MR/MS	MS
IR5260-1	M	M/M	MS
IR5716-18-1	M	R	MS
IR5853-118-5	M/M/M	MS/MS	M
IR5853-162-1-2	M	M/MR	M
IR5853-162-1-2-3	M/M/M	MR	M
IR5853-165-1-1-2	M	MS	
IR5853-213-6-1	MR/M/M	MS	MR
IR5929-12-3	M/MR	M/R	MS
IR5931-81-1-1	M	R	

Continued on opposite page

Elite line	Reaction[a]		
	Sheath blight	Cercospora leaf spot	Sheath rot
IR5931-110-1	M/M	M/M	MS
IR5982-7-6-1	S	R	M
IR5983-13-1-2	M	MR	MS
IR6115-1-1-1	M/M	M/MR	M
IR6140-22-2	M/M	MR	
IR6228-2-1	M	R	
IR6256-8-2	M	M	
IR7760-4-8-2	M/M	MR/MR	MS
IR7790-18-1-2	M/M	MR/R	M
IR8192-31-2-1-2	M/M/M	MS/R	M
IR8192-166-2-2-3	M/M/M	M/R	MR
IR8192-200-3-3-1-1	M/M/M	MS/M	MR
IR8608-79-3-2	M/M/M	M	
IR8608-167-1-2	MS/M/M	M/MR	MR
IR8608-189-2-2-1-3	M/M/MS	M/MR	MR
IR8608-298-3-1-1-2	MS/M/M	M/R	MR
IR9129-136-2-2-2-1-2	M/M	MR	M
IR9129-136-2-2-2-1-2	M	MR	
IR9129-169-3-2-3-3	M/M	R	M
IR9129-209-2-2-2-1	M/M/M	MR/R	MR
IR9129-456-2-2-1-2	M	R	M
IR9129-457-2-2-1-2	M/M	R	
IR9209-26-2-2-2-1	MS	M	
IR9209-181-2-2	M/M	MR/R	MS
IR9209-262-1-3-1	M/MS/M	M/R	M
IR9217-58-2-2	M/M/MR	MR/R	R
IR9224-22-2-2-2-3	M/M	M	
IR9224-117-2-3-3-2	M/MR/M	M/R	R
IR9224-162-3-1-3-2	M/M/M	R	MR
IR9264-321-3	M/M	MR	R
IR9411-5-3-3	M/M	R	R
IR9703-41-3-3-1	M/M/M	M	
IR9729-287-3-3-2	MS	MR	
IR9732-119-3	M/M/M	M/R	MR
IR9761-8-2	M/M	MS	
IR9761-19-1	M/M/M	MS/MR	MR

Table 13 continued

Elite line	Reaction[a]		
	Sheath blight	Cercospora leaf spot	Sheath rot
IR9761-47-3	M/M	MR	M
IR9761-75-3	M/M/M	M/MR	MR
IR9763-11-2-2	M/M	R	MR
IR9764-45-2-2	M/M/M	R	R
IR9784-42-3-1	M/M	R	R
IR9788-19-2-3	M	M	MR
IR9788-19-2-3-3	M	R	
IR9802-10-3	M	M	
IR9802-10-3-3-1	M	MR	MR
IR9802-31-2	M/M	M	M
IR9805-78-2	M	R	MR
IR9805-97-1	M/M	M/R	MR
IR9809-9-2	M	M	MR
IR9814-6-3	M	M	
IR9814-6-3-3-2	M/M	MS	MR
IR9846-215-3	M/M/M	VS/R	M
IR9846-261-3	M/M	MS	
IR9852-22-3	M/M	R	MR
IR9859-45-2	M/M	VS	
IR9860-26-2-2-2	M/M	MR	MR
IR9884-54-3	M/M	M	
IR9975-5-1	M/M	M	
IR10167-17-5-2	M/M	MS	
IR10198-66-2	M/M	M	
IR10199-128-2	M/M	M	
IR10206-29-2	M/MS	MR	
IR10781-143-2-3	M/M		
IR11248-13-2-3	M/M		
IR11248-83-3-2-1	M	R	M
IR11248-242-3-2	M/M/M	R	M
IR11297-158-3	M		
IR11418-19-2-3	M/M		
IR13168-143-1	M/MR/M	MS	M
IR13149-13-1	M/M	MR	M
IR13146-41-3	M	MR	MR
IR13149-43-2	MR/M	R	R
IR13240-10-1	M/M/M	MR	MR
IR13240-83-1	M/M/M	M	MR
IR13299-96-2-2	M/M	M	M
IR13415-9-3	M/M/M		
IR13419-113-1	M/M	MR	M
IR13426-19-2	M/MS/M	MR	MR
IR13426-26-2	M	M	
IR13429-47-3	MS/M	R	M
IR13429-105-3	M/M	M	MR
IR14632-22-3	M/M/M	R	R
IR14753-120-3	M/M	R	M
IR15529-256-1	M/M	M	MR
IET1444	M	MS	MS

[a]R = resistant, MR = moderately resistant, M = intermediate, MS = moderately susceptible, S = susceptible, and VS = very susceptible. Reactions separated by a slash (/) indicate tests at different sites or times.

an earlier growth stage, but the symptoms produced were atypical. Injection at the boot stage produced 84.4% infection and reduced grain yield about 75%. Sheaths sprayed with spore suspension did not develop sheath rot symptoms.

BACTERIAL BLIGHT RESISTANCE

Plant Pathology and Plant Breeding Departments and International Rice Testing Program

More than 82,000 entries were screened for bacterial blight resistance (Table 14). More than 99% of the resistant entries from pedigree nurseries had the *Xa 4* gene for resistance. A few might have *xa 5 + Xa 7* from DV85, DV86, and ARC5756.

Specific and differing resistance to *X. oryzae* *(Plant Pathology)*. Rices from the germplasm col-

Table 14. The proportion of diverse genetic background in breeding materials screened for bacterial blight resistance. IRRI, 1979.

Nursery	Total entries (no.)	Entries (no.) with given gene for resistance		
		Xa 4	*xa 5*	*xa 5 + Xa 7*
Pedigree[a]	61,556	61,109	435	12
Replicated yield trial	1,198	1,198	0	0
Observational yield trial	3,108	3,102	4	2
Hybridization block	505	501	4	0
Elite	171	169	2	0
Germplasm bank	15,763	–[b]	–	–
Total	82,301	66,079	445	14

[a]October, November, and December pedigree nurseries are excluded.
[b]No information.

Table 15. Rice accessions from the IRRI germplasm collection evaluated at 2 Philippine sites and against 2 virulence group strains showing distinct blight reaction. 1979.

Resistance group	Reaction[a]		Entries (no.)			
			Dry season		Wet season	
	MT	FL	IRRI[b]	MRRTC[c]	IRRI	MRRTC
Overall resistance	1	1	430	44	169	82
Intermediate resistance	3–5	3–5	87	6	635	74
Adult plant resistance	7–9	1–3	2	52	0	0
No resistance	7–9	7–9	7	18	45	106
Others[d]	Unstable		124	255	421	255
Total			650	375	1270	517

[a]Based on the Standard Evaluation System for Rice scale: 1 = less than 1% (of leaf blade area showing necrotic symptoms); 9 = more than 50%. MT = maximum tillering stage, FL = flowering stage. [b]Strain PXO61 of virulence group 1 (pathotype 1). [c]Maligaya Rice Research and Training Center; strain PXO83 of virulence group 2 (pathotype 2). [d]Reaction was not consistent during the two seasons.

lection identified to have some resistance to *X. oryzae*, the causal agent of bacterial blight, were used at two sites in the Philippines. At each site, a specific pathotype strain was used to evaluate for specific or general resistance.

Of 1,270 entries tested at IRRI, more than 400 had specific resistance to PXO 61, a strain of pathotype 1. Among 892 entries tested at the Maligaya Rice Research and Training Center, more than 200 entries showed specific resistance to PX083, a strain of pathotype 2. The number of entries with specific or general reaction to the two strains are in Table 15.

Many of the entries were later tested in an IRRI greenhouse, and an effort was made to specifically select varieties with differential reactions to the four bacterial blight pathotypes. The results are summarized in Table 16. Table 17 includes a few varieties that revealed differential reactions to strains of specific virulence.

The disease score was simplified on the basis of lesion length: a variety had either a long lesion or a short lesion after inoculation. The scale is simple and especially applies to mass-testing in the greenhouse with different strains in the same experimental treatment.

By that scale, the Indonesian variety Cempo selak, whose resistance to all strains of the four virulence groups was incomplete, showed a much shorter lesion with some strains. Evaluation of this variety through collaborative research elsewhere in

Table 16. Summary of reactions of 156 rice varieties from germplasm collections to strains of *Xanthomonas oryzae* of the 4 virulence groups (VG) in the Philippines. IRRI, 1979.

Reaction[a]	Entries (no.)			
	PXO61 (VG 1)	PXO71 (VG 4)	PXO79 (VG 3)	PXO86 (VG 2)
R (1)	55	35	45	42
MR (3)	43	39	19	30
MS (5)	51	68	64	80
S (7–9)	7	14	28	3

[a]R = resistant, MR = moderately resistant, MS = moderately susceptible, S = susceptible. Numbers in parentheses stand for the Standard Evaluation System for Rice scale: 1 = less than 1% (of leaf blade area showing necrotic symptoms), 9 = more than 50%.

Table 17. Some rice varieties from the bacterial blight general screening nursery with distinct differential reaction to the 4 virulence groups (VG) of *Xanthomonas oryzae*. IRRI, 1979.

Designation	Acc. no.	Origin	Reaction[a]			
			VG 1	VG 2	VG 3	VG 4
Chacacero	3280	Argentina	L	S	S	S
Monchi Gomi	5061	Japan	L	S	S	S
Gendjah Ploso	17635	Indonesia	L	S	S	S
CO-9 (PI 193176)	3690	India	L	S	L	L
Gelendoran	17615	Indonesia	L	S	S	L
Gewal	14603	Indonesia	L	L	L	S
INTIP	14608	Indonesia	L	L	L	S
Ikogan	19412	Philippines	L	S	L	L

[a]Long lesion (L) and short lesion (S) of the initial and confirmation evaluation.

Asia indicated that it was very resistant at Sukamandi (Indonesia) and Parwanipur (Nepal), and to some strains at the Bangladesh Rice Research Institute (Bangladesh) and the Central Rice Research Institute (India).

Differential for *X. oryzae* **pathotypes** (*Plant Pathology*). Cas 209 (Acc. No. 15793) from Senegal was identified as a variety suitable for differentiating the virulence-pathogenicity of *X. oryzae*. In the general disease reaction, Cas 209 was susceptible to strains in virulence groups 1 and 3, but varied in reaction to strains in group 2. At IRRI, Cas 209 evaluated against PXO 79 of group 2 was susceptible, but became resistant to PXO 83 of the same group at the Maligaya Rice Research and Training Center in the field.

A test was designed to confirm Cas 209's reaction to strains of group 2. The results demonstrated that 6 of 16 group 2 strains evaluated were virulent to Cas 209 and 10 were avirulent (Table 18). It was obvious that group 2 strains of *X. oryzae* in the Philippines are heterogeneous, and Cas 209 is a distinct variety that differentiates them. Although Cas 209 is susceptible to PXO 61 of group 1 and PXO 71 of group 3, it is resistant to some and susceptible to others in group 2. Thus, *Xanthomonas oryzae* in the Philippines presently has four distinct virulence groups or pathotypes, besides group 0.

Earlier, it was found that PXO 61 was virulent to a selection from a cross of TN1 and DZ78. The line, tentatively designated as LI 1160-8-5-1, may be conditioned by *Xa 7* for resistance to *X. oryzae*. It was found, however, that the line may be susceptible to PXO 79 but resistant to PXO 86 of group 2. Based on this reaction, Cas 209 may be also conditioned by a gene at a locus similar to that of *Xa 7*.

International collaboration on bacterial blight (*Plant Pathology and Plant Breeding and International Rice Testing Program*). Rice differentials composed of varieties from IRRI, Japan, Korea, and some local varieties were distributed in South Asia, including Bangladesh, India, and Nepal, for evaluation against local bacterial strains. The virulence of the bacterial pathogens varied on the set of rice differentials. Tests at Parwanipur, Nepal, indicated that IR20 with *Xa 4* from TKM6 for resistance, and IR1545-339 with *xa 5* from DZ192 for resistance were susceptible to local strains. Strains from Faizabad, Chinsurah, Cuttack, Bhubaneswar, and Patna (India) were also virulent to IR20 and IR1545-339. DV85, a rice from Bangladesh that is resistant to all strains in the Philippines, was susceptible to several strains on the Indian subcontinent (Table 19).

Table 18. Differentiation of virulence group 2 strains of *Xanthomonas oryzae* by Cas 209, a new rice differential from Senegal. IRRI, 1979.

Strain	Visual score[a]		Lesion length (cm) on Cas 209
	IR8	IR20	
PXO 18 (IIa)	S	S	30.2
PXO 79 (IIa)	S	S	23.9
PXO 81-L (IIa)	S	S	27.8
PXO 87 (IIa)	S	S	27.6
PXO 88 (IIa)	S	S	29.8
PXO 22 (IIa)	S	S	24.1
PXO 47 (IIb)	S	S	1.4
PXO 63 (IIb)	S	S	2.2
PXO 63-6 (IIb)	S	S	1.5
PXO 64 (IIb)	S	S	1.9
PXO 65B (IIb)	S	S	1.5
PXO 73 (IIb)	S	S	2.1
PXO 78 (IIb)	S	S	1.9
PXO 82 (IIb)	S	S	1.8
PXO 83 (IIb)	S	S	1.4
PXO 86 (IIb)	S	S	2.1
PXO 61 (I)	S	R	19.7
PXO 71 (III)	S	M	27.3

[a]S = susceptible, R = resistant, M = moderate.

Development of isogenic lines (*Plant Breeding*). Efforts continued to incorporate the genes for bacterial blight resistance identified at IRRI into rice plants of a nearly isogenic background. IR9101-45, an improved rice line with resistance to most of the insects and diseases but not to bacterial blight, is a recurrent susceptible parent. In the screening of the BC3 F_2 populations, some lines that had been selected indicated that resistance to the bacterial strains had been incorporated.

Variability of *Xanthomonas oryzae* (*Plant Pathology*). *Virulence of natural population*. The population of *X. oryzae* in the Philippines has been gradually changing in virulence. Based on a continuous survey of rice with natural bacterial blight infection at IRRI, the field population has gradually shifted to virulence matching the *Xa 4* for resistance (Table 20). In 1976 and 1977, no isolates virulent to IR1545-339, which conveys an *xa 5* gene for resistance, were identified. In 1978 and 1979, about 5%

Table 19. Summary of the initial study on pathogenic variability of *Xanthomonas oryzae* in the Indian subcontinent on rice differentials from IRRI, Japan, and Korea. 1979.

Variety	Reaction[a]													
	Indian strains							Nepal strains		Bangladesh strains				
	a	b	c	d	e	f	g	a	b	a	b	c	d	e
IRRI														
IR8	S	S	S	S	S	S	S	S	S	S	S	S	S	S
IR20	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Cempo selak	R	S	S	S	S	S	S	R	S	–	–	–	–	–
IR1545-339	S	S	S	S	S	S	S	S	S	S	S	S	S	S
DV85	S	R	R	R	R	S	R	S	R	S	R	S	S	S
Japan														
Kinmaze	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Kogyoku	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Rantai-emas	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Chugoku 45	R	S	S	S	S	S	S	R	S	R	S	R	S	–
Java 14	–	–	S	–	–	–	S	R	R	–	–	–	–	–
Korea														
Milyang 23	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Yushin	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Suweon 281	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Tongil	S	S	S	S	S	S	S	S	S	S	S	S	S	S
TN1	S	S	S	S	S	S	S	S	S	S	S	S	S	S

[a]R = resistant, S = susceptible, – = not tested. The data were collected during the IRTP-79 monitoring tour on bacterial blight. The tests were conducted at the Bangladesh Rice Research Institute by S. A. Miah and associates; at the Central Rice Research Institute, India, by P. R. Reddy; and at the National Rice Improvement Program, Parwanipur, Nepal, by B. B. Shahi and S. P. Singh. Part of the data from India was provided and the test conducted by A.P.K. Reddy of All India Coordinated Rice Improvement Project.

and 15% of the isolates were virulent to IR1545-339.

Variation in induced mutation. Two parent strains of *X. oryzae* — PXO 61 S^+V^{+Y} and PXO 63 S^+V^{+Y} — marked with streptomycin resistance and derived from original PXO61 S^-V^+ and PXO 63 S^-V^+ streptomycin-susceptible ones, were used in an induced mutation study together with strains of the different virulence groups. The mutants developed were classified into three types on the basis of virulence to rice and colony morphology on peptone sucrose agar (PSA) medium (Table 21).

Table 20. Frequency distribution of the *Xanthomonas oryzae* population at IRRI with specific virulence to differential varieties. IRRI, 1978 and 1979.

Differential	Distribution (%)					
	1978[a]			1979[b]		
	R	I	S	R	I	S
IR8	0.0	0.0	100.0	0.0	0.0	96.4
IR20	32.0	7.7	58.3	23.8	10.7	61.3
IR1545-339	92.2	2.9	4.8	79.7	1.2	15.5
Cempo selak	1.0	50.4	48.6	0.0	13.1	83.3
DV85	95.1	4.9	0.0	86.5	9.7	0.0

[a]Percent of 103 isolates from naturally infected rice plants. R = resistant, I = intermediate, S = susceptible. [b]Percent of 84 isolates collected from naturally infected rice plants. Three (3.6%) of the isolates had no virulence.

The weak virulent mutants derived from PXO 63 S^-V^{+Y} showed shorter lesions than the parent strain regardless of rice variety. Mutants derived from PXO 63 S^+V^{+Y} of pathotype 2 were relatively stable in colony color and identical to the parent strain in virulence. But mutant PXO 61 S^+V^{-W} derived from PXO 61 S^+V^{+Y} was nonvirulent to all rice tested and also unstable in colony color, i.e. a spontaneous reversion in colony color from white to yellow was observed on PSA plates. Both the mutant and the revertant were nonvirulent.

Two virulent revertants were induced from PXO 61 S^+V^{-W} One of them was virulent to IR8 and IR20, but nonvirulent to IR1545-339. The reaction suggested that the shift of virulence from IR8 to IR8 and IR20 might have occurred (Table 22).

A bacteriological study indicated that all the

Table 21. Markers of parents and induced mutants of *Xanthomonas oryzae*. IRRI, 1979.

Strain[a]	Virulence	Streptomycin resistance	Colony color on peptone sucrose agar
PXO 61 $S^{-}V^{+Y}$	+	–	Yellow
PXO 61 $S^{+}V^{+Y}$	+	+	Yellow
PXO 61 $S^{+}V^{-W}$	–	+	White
PXO 61 $S^{+}V^{-Y}R{\cdot}1$	–	+	Yellow
PXO 61 $S^{+}V^{+Y}R{\cdot}2$	+	+	Yellow
PXO 61 $S^{+}V^{+Y}R{\cdot}3$	+	+	Yellow
PXO 63-6 $S^{-}V^{+Y}$	+	–	Yellow
PXO 63-6 $S^{+}V^{+Y}$-1	+	+	Yellow
PXO 63-6 $S^{+}V^{+Y}$-2	+	+	Yellow
PXO 63-6 $S^{+}V^{+W}$-2	+	+	White
PXO 63-6 $S^{+}V^{+Y}$-3	+	+	Yellow
PXO 63-6 $S^{+}V^{\pm Y}$-5	±	+	Yellow
PXO 63-6 $S^{+}V^{+W}$-8	+	+	White
PXO 63-6 $S^{+}V^{+W}I{\cdot}1$	+	+	White
PXO 63-6 $S^{+}V^{+W}I{\cdot}2$	+	+	White
PXO 63-6 $S^{+}V^{+W}$-11	+	+	White
PXO 63-6 $S^{+}V^{+W}$-12	+	+	White
PXO 63-6 $S^{+}V^{\pm Y}$-15	±	+	Yellow
PXO 63-6 $S^{+}V^{\pm Y}$-17	±	+	Yellow

[a]S^{+} and S^{-} = streptomycin resistance and susceptibility; V^{+}, $V^{\pm}$, and V^{-} = virulent, weakly virulent, and nonvirulent; R = revertant; I = reisolation; Y = yellow colony; W = white colony.

mutants had similar physiological reactions to parents and to each other, but some differences were noted on a few characters. The weak virulent mutants showed negative or weak reaction for acid production from carbohydrates. Growth of white mutants was inhibited in a liquid medium containing galactose, but not in medium containing glucose or sucrose. Phage sensitivity was different from that of parent strains in some mutants. There was no change in colony color of white mutants by mixed culture with yellow mutants. Virulence as indicated by lesion length was suppressed as the concentration of cells of the nonvirulent mutant increased in the inoculum (Table 23). Similarly, after inoculation of rice leaves with a nonvirulent mutant following the challenge of a virulent mutant, lesion development was inhibited. No inhibition effect was observed when the inoculation order was reversed (Table 24).

With a heterologous system, parent strains of *X. oryzae* and all mutants, except nonvirulent ones, induced a hypersensitive reaction on cowpea, an indicator plant. With nonvirulent mutants, the appearance of necrosis from infiltration sites was normally delayed or did not occur. No hypersensitive reaction was induced by the polysaccharide fraction of the bacterial culture.

Inheritance of resistance to bacterial blight (*Plant Breeding*). Forty-three bacterial blight-resistant varieties were analyzed to find new genes for resistance. They were crossed with the susceptible variety TN1, and the F_1 and F_2 were analyzed to determine the mode of inheritance

Table 22. Virulence of mutant and revertant strains derived from PXO 61 on different rice varieties. IRRI, 1979.

Strain	Lesion length (cm)[a]		
	IR8	IR20	IR1545
PXO 61 $S^{+}V^{+Y}$	20.3 a	7.4 b	2.5 a
PXO 61 $S^{+}V^{-W}$	0.0 d	0.0 c	0.0 b
PXO 61 $S^{+}V^{-Y}R{\cdot}1$	0.0 d	0.0 c	0.0 b
PXO 61 $S^{+}V^{+Y}R{\cdot}2$	15.2 b	15.3 a	3.5 a
PXO 61 $S^{+}V^{+Y}R{\cdot}3$	7.9 c	9.1 b	2.5 a

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

Table 23. Effect of a mixture of virulent (V) with nonvirulent (NV) strains, and of V with weakly virulent (WV) strains on lesion development.[a] IRRI, 1979.

Inoculum: Strains mixed	Ratio	Lesion length[b] (cm)
PXO 61 $S^{+}V^{+Y}$ (V) + PXO 61 $S^{+}V^{-W}$ (NV)	1:9	17.2 bcd
	1:1	18.0 abcd
	9:1	21.2 ab
PXO 61 $S^{+}V^{+Y}$ (V) + PXO 63-6 $S^{+}V^{\pm Y}$-5 (WV)	1:9	15.4 d
	1:1	19.8 abc
	9:1	20.5 abc
PXO 63-6 $S^{+}V^{+Y}$ (V) + PXO 61 $S^{+}V^{-W}$ (NV)	1:9	14.6 d
	1:1	15.4 d
	9:1	18.0 abcd
PXO 63-6 $S^{+}V^{+Y}$ (V) + PXO 63-6 $S^{+}V^{\pm Y}$-5 (WB)	1:9	14.6 d
	1:1	15.5 d
	9:1	16.6 cd
PXO 61 $S^{+}V^{+Y}$ (V)		21.3 a
PXO 61 $S^{+}V^{-W}$ (NV)		0.0 e
PXO 63-6 $S^{+}V^{+Y}$ (V)		16.9 cd
PXO 63-6 $S^{+}V^{\pm Y}$-5 (WV)		2.6 e

[a]IR8 was used. [b]Means followed by a common letter are not significantly different at the 5% level.

Table 24. Inhibitory effects of pre-inoculation strains on lesion development. IRRI, 1979.

Inoculum[a]		Lesion length[b] (cm)	% of control
Strain of pre-inoculation	Challenge inoculation		
PXO 61 S^tV^W (NV)	PXO 61 S^tV^{tY} (V)	4.9 d	43
Needle-prick (H)	PXO 61 S^tV^{tY} (V)	11.5 bc	00
PXO 61 S^tV^{tY} (V)	PXO 61 S^tV^W (NV)	11.9 bc	90
PXO 61 S^tV^{tY} (V)	Needle-prick (H)	13.2 b	00
PXO 61 S^tV^W (NV)	Needle-prick (H)	0.0 e	
PXO 61 S^tV^W (NV)	PXO 63-6 S^tV^{tY}-2 (V)	9.7 c	53
PXO 63-6 S^tV^{tY}-5 (WV)	PXO 63-6 S^tV^{tY}-2 (V)	12.6 b	69
Needle-prick (H)	PXO 63-6 S^tV^{tY}-2 (V)	19.2 a	100
PXO 63-6 S^tV^{tY}-2 (V)	PXO 61 S^tV^W (AV)	19.5 a	99
PXO 63-6 S^tV^{tY}-2 (V)	PXO 63-6 S^tV^{tY}-5 (WV)	20.1 a	102
PXO 63-6 S^tV^{tY}-2 (V)	Needle-prick (H)	19.6 a	100
PXO 63-6 S^tV^{tY}-5 (WV)	Needle-prick (H)	2.8 d	

[a]Symbols in parentheses are the reaction type on rice. NV = nonvirulent, V = virulent, WV = weakly virulent, H = healthy (wounding only). [b]Means followed by a common letter are not significantly different at the 5% level.

(Table 25). The F_1 of 38 crosses were resistant or moderately resistant, indicating that dominant or partially dominant genes govern their resistance. The F_1 progenies of the remaining five varieties were susceptible, showing that resistance is controlled by recessive genes. The F_2 of the crosses of TN1 with 38 varieties segregated in a ratio of 3 resistant to 1 susceptible, indicating that single dominant genes govern resistance in these varieties. The F_2 from the crosses of the remaining 5 varieties with TN1 segregated in a ratio of 1 resistant to 3 susceptible, showing that their resistance is governed by single recessive genes.

The 38 varieties with dominant genes for resistance were crossed with IR22, which is homozygous for the dominant gene *Xa 4* for resistance. The F_1 progenies of all crosses, as expected, were resistant. The F_2 populations of the crosses were also resistant and no susceptible seedlings were observed. These results indicated that all of the 38 varieties have *Xa 4* for resistance (Table 25).

The 5 varieties with recessive genes for resistance were crossed with IR1545-339, which is homozygous for the recessive gene *xa 5* for resistance. The F_1 progenies from the crosses of IR1545-339 with Koalarata, Dharial (Acc. 34034), and Dharial (Acc. 3396) were resistant; the F_2 populations from these three crosses did not segregate for susceptibility (Table 26). These data indicate that Koalarata, Dharial (Acc. 34034), and Dharial (Acc. 3396) have *xa 5* for resistance. The F_1 progeny of IR1545-339/Khao Lay Nhay was susceptible and the F_2 segregated in a ratio of 7 resistant to 9 susceptible. These data indicate segregation for two recessive genes in this cross. It appears that the recessive gene of Khao Lay Nhay segregates independently of *xa 5*. Investigation of the allelic relationships of the recessive gene of Khao Lay Nhay with *xa 8* started. If found to be nonallelic to *xa 8*, it would be a new gene for resistance to bacterial blight.

RICE VIRUS DISEASES

Plant Pathology and Plant Breeding Departments

Tungro (*Plant Pathology and Plant Breeding*). A total of 9,688 entries were tested for their tungro resistance in the greenhouse. The varieties that consistently showed low percentage of tungro infection were Basmati and ARC11554.

The IR variety and lines that were resistant in a replicated test in the rice tungro virus nursery in Zamboanga del Sur, Philippines, where a tungro outbreak was reported in 1979, were IR34, IR8192-200-3-3-1-1, IR15314-43-2-3-3, IR17525-146-2, and IR19670-264-3.

Tungro propagation. A method for propagating tungro-infected rice seedlings and tungro vectors was developed. The method (Fig. 5) consisted of:

- rearing tungro vector *Nephotettix virescens* on Taichung Native 1 (TN1) plants as feeding material and source for a constant supply

Table 25. Reactions[a] to bacterial blight of F_1 and F_2 progenies from the crosses of TN1 with resistant varieties. IRRI, 1979.

Cross	F_1 reaction	F_2 (reaction no.)			Chi-square	
		R	S	Total	3:1	1:3
TN1/ADT2	R	223	94	317	3.66	
/ADT4	MR	159	49	208	0.23	
/ADT9	R	168	64	232	0.83	
/ADT10	R	191	68	259	0.22	
/ADT12	R	154	65	219	2.56	
ADT13	MR	245	94	339	1.35	
/ADT14	R	84	29	113	0.03	
/ADT15	R	100	46	146	3.30	
/ADT17	R	90	26	116	0.41	
/ADT18	R	167	63	230	0.70	
/ADT19	R	86	26	112	0.19	
/ADT22	R	310	112	422	0.53	
/ASD5	MR	196	67	263	0.03	
/ASD8	MR	96	35	131	0.21	
/CO 2	MR	201	75	276	0.70	
/CO 3	MR	207	85	292	2.63	
/CO 5	MR	224	83	307	0.68	
/CO 7	MR	278	96	374	0.09	
/CO 9	R	177	61	238	0.05	
/CO 10	MR	254	79	333	0.29	
/CO 11	R	257	87	344	0.02	
/CO 17	R	269	82	351	0.50	
/CO 18	MR	175	66	241	0.73	
/CO 21	MR	134	56	190	2.03	
/CO 22	R	256	100	356	1.81	
/CO 23	MR	90	36	126	0.86	
/CO 27	MR	203	69	272	0.02	
/CO 29	MR	191	56	247	0.71	
/CO 30	MR	94	34	128	0.17	
/Burerata	R	177	69	246	1.22	
/Panaimara Samba	R	213	72	285	0.01	
/Polan Samba	R	174	42	216	3.56	
/Poon jar	MR	79	32	111	0.87	
/Sandikar	R	109	43	152	0.88	
/TKM 3	R	128	36	164	0.81	
/TKM 5	R	189	79	268	2.87	
/TKM 6	MR	176	68	244	1.07	
/Atema	R	302	122	424	3.22	
/Koalarata	S	66	156	222		2.65
/Dharial (Acc. 34034)	S	84	276	360	-	0.53
/Dharial (Acc. 3396)	S	94	258	352		0.55
/Khao Lay Nhay	S	85	262	347		0.05
/Sateng	S	53	179	232	-	0.57

[a]R = resistant, MR moderately resistant, S susceptible.

Table 26. Reactions[a] to bacterial blight of F1 and F2 populations from the crosses of IR1545-339 with cultivars having recessive genes for resistance. IRRI, 1979.

Cross	Reaction of F1 progenies	F2 populations (no.)			Chi-square
		R	S	Total	7:9
IR1545-339/Koalarata	R	407	0	407	
IR1545-339/Dharial (Acc. 34034)	R	356	0	356	
IR1545-339/Dharial (Acc. 3396)	R	353	0	353	
IR1545-339/Khao Lay Nhay	S	149	207	356	0.52

[a]R = resistant, S susceptible.

of viruliferous insects.

- raising TN1 seedlings in seedbeds covered with improvised wooden cages with metal screen,
- inoculating the seedlings by releasing viruliferous insects into the cages, and
- transplanting the seedlings after they were exposed to the viruliferous insects.

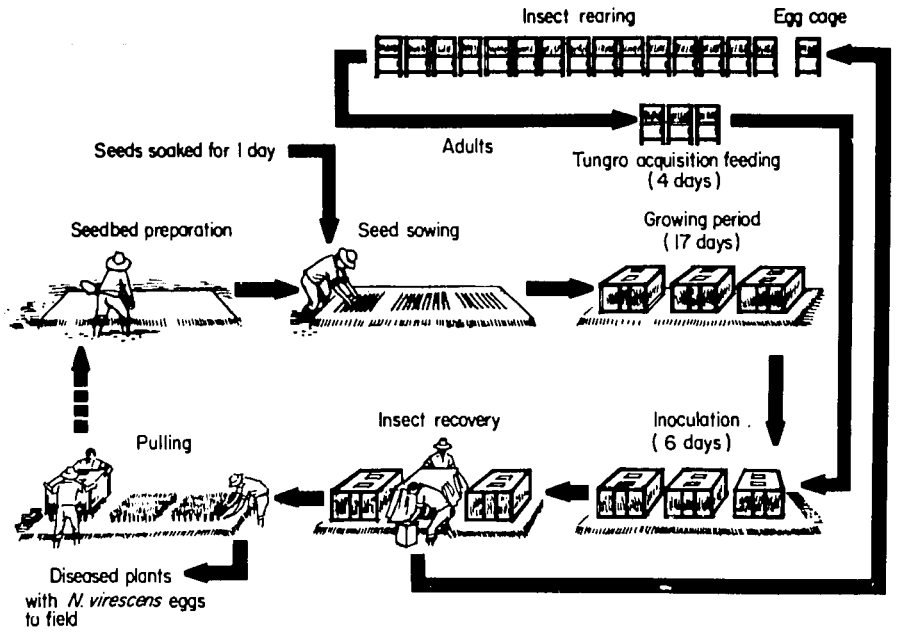
The steps from seed soaking to transplanting were accomplished in 3 weeks. The method produced 30,000 seedlings deposited with eggs of *N. virescens* weekly, 90% of which were infected with tungro. An average of 2 nymphs/seedling developed. About 64% of the nymphs were capable of causing tungro infection.

From April to November 1979, 697,000 inoculated seedlings were transplanted to the pedigree and rice tungro virus nurseries.

Resistance of 10 varieties to tungro vector and virus. Tests for resistance of 10 rice varieties to the tungro vector and to the tungro virus were made at IRRI, as part of a Rice Tungro Virus Collaborative Project.

When life span was used to indicate the effect of rice variety on the insect, IR34, Ptb 18, Gam Pai 30-12-15, and Pankhari 203 were more resistant to the insects than Kataribhog, Habiganj DW8, and TN1. The percentage of infected seedlings showed that the insects were less efficient in transmitting the tungro virus to Pankhari 203 and Habiganj DW8 than to the other varieties. Hence, these varieties were more resistant to tungro than the other varieties in the test.

Breeding for tungro resistance. During 1972–75 the incidence of tungro virus at IRRI was high and breeding materials were screened for tungro resistance in the field. The screening was so rigorous that only the tungro-resistant selections entered replicated yield trials. Several tungro-resistant varieties were selected from this material. For example, IR28, IR29, and IR34 were selected from the



5. A method for propagation of tungro-infected seedlings and tungro vectors developed at IRRI, 1979.

cross involving Gam Pai as the source of tungro resistance and IR32, IR36, IR38, IR40, IR42, IR44, and IR48 from the cross involving Ptb18 as the source.

No natural infection of tungro occurred at IRRI during 1976–78 and no incidence of tungro was reported anywhere in the Philippines. In the 1979 dry season, there were reports of tungro in farmers' fields in Mindanao. IR36 and IR42 were severely infected. In the 1979 wet season, all entries in IRRI replicated yield trials were tested in farmers' fields in Zamboanga del Sur Province (Barrio Rizal, 45 km from Pagadian City).

The incidence of tungro in farmers' fields in some provinces in Mindanao was so high that many fields were abandoned. The infection in the test materials was excellent, and clear-cut differences were noted in the resistant and susceptible materials. The susceptible materials were characterized by severe stunting, leaf yellowing and bronzing, and poorly formed panicles.

Among 400 entries, 123 were resistant, 10 were moderately resistant, 13 were segregating, and 254 were susceptible. All the varieties (including IR36 and IR42) and breeding lines originating from the crosses involving Ptb18 as the source of resistance were susceptible. However, many lines and varieties (including IR29 and IR34) originating from the crosses involving Gam Pai 15 and Pankhari 203 were resistant.

The results clearly showed that Ptb 18 as source of resistance was no longer effective against tungro in Mindanao in 1979. Gam Pai and Pankhari sources remained highly resistant in the field, and many elite lines from those parents were resistant.

One of the resistant lines, IR9224-117-2-3-3-2, was recommended as IR50 in the Philippines and was distributed to seed growers in Mindanao.

Ragged stunt (*Plant Pathology*). The search for possible sources of resistance to ragged stunt continued. In greenhouse inoculation of 7,960 entries, Ptb 33, Ptb 21, and several lines of Ptb 21 showed low percentage of infection.

Genetic evaluation and utilization (GEU) program

Insect resistance

Entomology, Plant Breeding, and Chemistry Departments

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SCREENING FOR RESISTANCE SOURCES

Entomology Department

In screening of the world collection to identify sources of resistance to 8 insects, 58 accessions with resistance to the whitebacked planthopper (WBPH) and 19 with resistance to biotypes 1, 2, and 3 of the brown planthopper (BPH) were identified.

W1263 (Acc. No. 11057), Muthumanikam (Acc. No. 15327), and IR4707-106-3-2 (Acc. No. 47549) had moderate resistance to the leaf folder in screening initiated in 1979. Further studies were conducted to determine the nature of resistance. Studies on oviposition preference indicated that the moths oviposited equally on both the susceptible and resistant varieties. However, the percentage of damaged leaves and larval survival was significantly lower on the resistant varieties than on the susceptible check (Table 1), indicating an antibiosis effect of the plants on the larvae.

In cooperative screening at the Philippines' Maligaya Rice Research and Training Center, a *hot spot* for yellow stem borer, CO18 (Acc. No. 6331), CO21 (Acc. No. 6396), and IB56-8 (Acc. No. 33136) were selected for resistance to that pest.

In 1979 a systematic evaluation of the world wild rice collection for insect resistance began. Of about 100 accessions tested, 4 had resistance to the 3 BPH biotypes, the WBPH, and the green leafhopper (GLH). None were resistant to the yellow or striped stem borer, leaf folder, or the whorl maggot.

Table 1. Survival and damage caused by leaf folder larvae feeding on resistant cultivars.[a] IRRI, 1979.

Variety or line	IRRI acc. no.	Damaged leaves (%)		Larval survival[d] (%)
		Field[b]	Greenhouse[c]	
W1263	11057	3.73 a	32.62 a	26.0 a
IR4707-106-3-2	47459	8.43 a	35.51 a	25.0 a
Muthumanikam	15327	8.28 a	36.35 a	27.0 a
TN1 (susceptible check)			83.36 b	53.0 b
IR36 (susceptible check)		45.38 b		

[a]Means followed by a common letter are not significantly different at the 5% level. [b]Av of 10 plants. [c]Av of 10 pots with 5 plants/pot. [d]Greenhouse test.

EVALUATION OF BREEDING LINES FOR STEM BORER RESISTANCE

Entomology and Plant Breeding Departments

Because the level of resistance to stem borers is only moderate the multiple crossing program continued the attempt to develop breeding lines with higher levels of resistance. In screening against the striped stem borer, IR13635-45 (IR1628-632-1/IR1917-3-19-2//IR1539-823-1/IR2071-625-1-252), four lines from the IR13641 cross (IR1721-11-6-8-3/IR2307-64-2/IR1628-632-1/IR1514A-E666 IR13641-20, IR13641-22, IR13641-23, and IR13641-26 and IR19362-62 (IR4227-28-3-2/IR1917-3-19-2 IR2071-625-1-252) were selected. In yellow stem borer screening, the most resistant breeding lines were IR19362-182 (IR4227-28-3-2 IR1917-3-19-2 IR2071-625-1-252), IR19391-167, and IR19391-239 (IR4427-51-6-3/IR1820-52-2-4/ IR2071-625-1-252). These lines had resistance equal to that of IR1820-52-2-4-1 and resistance to several diseases and other insects. The resistance of IR1820-52-2-4-1 was verified (Table 2).

Table 2. Survival of first-instar yellow stem borer larvae on cut stems of rice cultivars with 3 levels of resistance. IRRI, 1979.

Cultivar	Survival (%)[a]
IR1820-52-2-4-1-1 (resistant)	11 a
IR29 (moderately resistant)	37 b
Rexoro (susceptible)	88 c

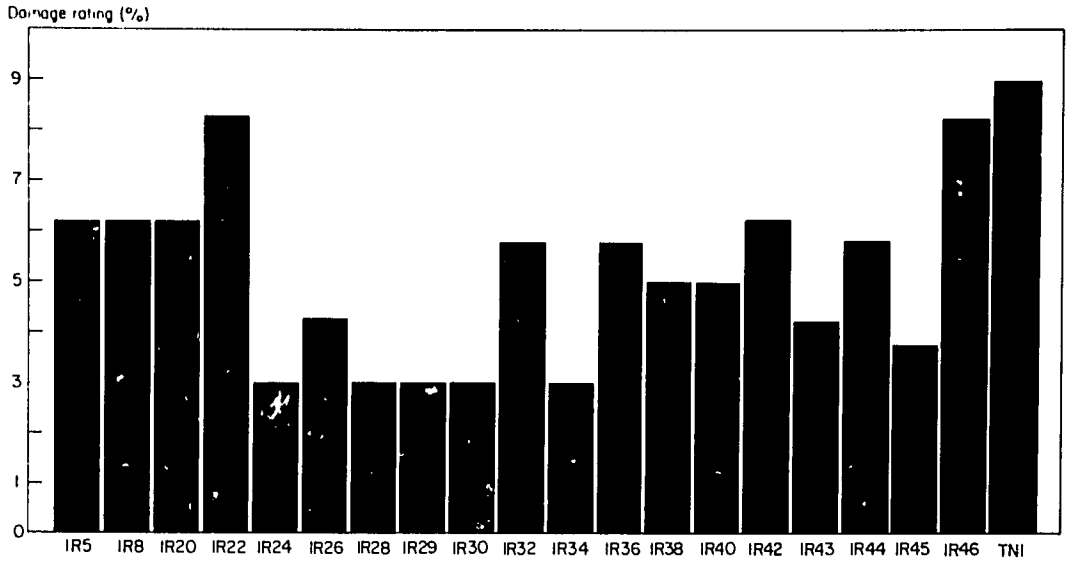
[a]Mean of 10 replications of 10 larvae each. Observation was at 10 days after infestation. Means followed by a common letter are not significantly different at the 5% level.

LEVEL OF RESISTANCE OF RICE VARIETIES TO THE GREEN LEAFHOPPER

Entomology Department

The level of resistance to GLH of IR varieties IR5 to IR46 and selected varieties having identified genes for resistance was studied. Criteria were damage in the seedling bulk test, insect survival, and population buildup. Plants of four ages (15, 30, 45, and 60 days after seeding [DS]) were used in the survival and population buildup studies to determine the effect of plant age on the insect.

Seedling bulk test for plant damage. At 7 DS seedlings were infested with first- and second-



1. Damage ratings of IR varieties exposed to feeding by a greenhouse colony of green leafhoppers reared on TN1. Mean of 3 replications. Damage rating: 0 = no damage, 9 = all plants dead. IRRI, 1979.

instar nymphs reared on the susceptible variety Taichung Native 1 (TN1). The entries were rated for damage at 7 days after infestation (DI), when all TN1 seedlings were killed. IR22 and IR46 were highly susceptible and IR24, IR28, IR29, IR30, IR34, and IR45 were highly resistant (Fig. 1).

Plant age and green leafhopper survival. Ten first-instar GLH were placed on plants of four ages, in a mylar film cage. Surviving insects were counted 15 DI. Survival on plants of the same age

Table 3. Survival[a] of green leafhoppers (GLH) on IR varieties at different stages of growth. IRRI, 1979.

Variety	GLH survival[b] (%) on plants			
	15 DS	30 DS	45 DS	60 DS
IR5	78 abc	42 cdef	2 fg	10 efg
IR8	70 abcd	38 efgh	38 bcd	0 g
IR20	70 abcd	68 bc	38 bcd	12 efg
IR22	80 abcd	88 a	54 ab	82 a
IR24	34 ef	36 defg	6 fg	24 cde
IR26	38 ef	48 cdef	14 def	18 cdef
IR28	2 gh	4 j	0 g	0 g
IR29	0 h	10 ij	0 g	12 defg
IR30	6[illegible] abcd	58 bcde	46 bc	36 c
IR32	66 abcd	52 cde	58 ab	34 cd
IR34	16 fg	30 efgh	10 efg	2 fg
IR36	70 abcd	52 cde	48 bc	34 cd
IR38	68 abcd	78 ab	66 ab	42 bc
IR40	40 e	12 hij	24 cde	10 efg
IR42	64 bcd	64 bcd	68 ab	38 c
IR43	52 de	26 fghi	40 bc	14 efg
IR44	54 cde	56 bcde	54 ab	28 cde
IR45	64 abcd	18 ghi	14 efg	4 fg
IR46	86 ab	72 abc	64 ab	68 ab
TN1	90 a	90 a	82 a	86 a

[a]Survival was recorded 15 days after infestation with first-instar nymphs. [b]In a column means followed by a common letter are not significantly different at the 5% level. DS = days after seeding.

Table 4. Survival[a] of green leafhoppers (GLH) reared on varieties with various genes for resistance. IRRI, 1979.

Variety	Resistance gene	GLH survival[b] (%) on plants			
		15 DS	30 DS	45 DS	60 DS
Pankhari 203	*Glh 1*	50 bc (a)	2 c (b)	6 bc (b)	0 d (b)
ASD7	*Glh 2*	30 c (a)	3 bc (b)	0 c (b)	0 d (b)
IR8	*Glh 3*	84 a (a)	24 b (b)	14 bc (bc)	0 d (c)
Ptb 8	*glh 4*	70 ab (a)	76 a (a)	58 a (a)	12 cd (b)
ASD8	*Glh 5*	56 b (a)	14 bc (b)	16 bc (b)	4 d (b)
TAPL #796	*Glh 6*	88 a (a)	28 b (b)	22 b (b)	36 b (b)
Moddai Karuppan	*Glh 7*	84 a (a)	74 a (a)	64 a (a)	28 bc (b)
IR29	Unidentified	74 ab (a)	0 c (b)	0 c (b)	0 d (b)
TN1 (susceptible)		90 a (a)	80 a (a)	84 a (a)	86 a (a)

[a]A greenhouse colony reared for several years on TN1 was used as test insect. Survival was recorded 15 days after infestation with first-instar nymphs.
[b]Mean of 5 replications. Means followed by a common letter (outside parentheses for columns, within parentheses for rows) are not significantly different at the 5% level. DS = days after seeding.

differed significantly among the IR varieties (Table 3) and various resistance gene sources (Table 4).

In general, GLH survival decreased with increase in plant age, with the 60-day-old plants as most resistant. On IR8, insect survival was high for 15 DS plants, but zero on 60 DS. IR28 and IR29 were highly resistant at all plant ages.

Population buildup of green leafhopper. Measurements of the levels of resistance of the IR varieties to GLH, as based on the population buildup studies, indicated significant differences among varieties (Table 5). No progeny were produced on IR34 at 30 and 60 DS. Change in population buildup with plant age varied depending on the variety.

Reaction of Philippine green leafhopper colonies to varieties with known genes for resistance. To determine the possible existence of GLH biotypes in the Philippines, seven varieties with genes for resistance — Pankhari 203 (*Glh 1*),

Table 5. Population buildup of green leafhopper on IR varieties at different stages of growth. IRRI, 1979.

Variety	Population buildup[a] (no.) at		
	30 DS	45 DS	60 DS
IR5	40.0 bcd	1.4 gh	0.0 g
IR8	3.8 ij	0.8 gh	1.8 fg
IR20	20.0 def	23.8 bc	65.2 b
IR22	70.4 b	31.6 b	112.4 ab
IR24	9.4 gh	6.6 ef	11.6 cd
IR26	12.4 fgh	5.6 fg	12.8 cd
IR28	1.6 jk	0.0 h	0.0 g
IR29	2.2 jk	0.0 h	0.0 g
IR30	6.0 hi	3.0 gh	19.2 cd
IR32	15.8 defg	9.2 de	67.8 b
IR34	0.0 k	1.0 h	0.0 gh
IR36	32.4 bcde	1.2 gh	28.0 c
IR38	14.8 efg	29.4 b	18.0 cd
IR40	1.4 jk	3.4 gh	26.0 c
IR42	61.2 bc	7.8 def	64.4 b
IR43	6.2 ghi	2.4 gh	9.4 de
IR44	11.0 fgh	10.0 cde	26.0 c
IR45	7.6 fgh	0.0 h	10.4 ef
IR46	36.4 bcde	18.6 bcd	149.8 ab
TN1	236.6 a	166.0 a	212.7 a

[a]Av for 5 replications. Progeny of 5 pairs of 3-day-old adults. Means in a column followed by the same letter are not significantly different at the 5% level. DS = days after seeding.

Table 6. Seedbox damage rating of varieties with different genes for green leafhopper (GLH) resistance when exposed to leafhopper colonies collected throughout the Philippines. IRRI greenhouse, 1979.

Variety	Gene	Damage rating[a] of varieties exposed to GLH colonies												
		Green-house	Ilocos Norte	Ilocos Sur	La Union	New Corella	Mata-lam	Malaw-	Tagum	Pagadian City	Tala-vera	Santa Maria	Laur	Rosales	Tarlac
Pankhari 203	*Glh 1*	2	1	1	1	1	1	1	2	1	1	1	4	2	5
ASD7	*Glh 2*	2	1	1	1	1	1	1	2	1	1	1	2	1	3
IR8	*Glh 3*	6	6	8	6	6	6	6	7	6	9	8	9	8	8
Ptb 8	*glh 4*	9	7	7	6	6	5	8	8	7	8	9	8	6	9
ASD8	*Glh 5*	2	1	1	1	1	1	1	1	1	2	1	3	5	1
TAPL #796	*Glh 6*	6	5	6	4	4	4	4	6	5	4	4	6	3	7
Moddai Karuppan	*Glh 7*	9	8	8	9	9	7	9	9	9	8	8	7	8	7
IR29 (resistant)		4	1	1	3	3	1	1	3	1	2	3	3	3	4
TN1 (susceptible)		9	9	9	9	9	9	9	9	9	9	9	9	9	9

[a]Damage rating: 0 = no damage, 9 = all plants dead. Figures are average for 3 replications rated 11 days after infestation.

ASD 7 (*Glh 2*), IR8 (*Glh 3*), Ptb 8 (*glh 4*), ASD8 (*Glh 5*), TAPL # 796 (*Glh 6*), and Moddai Karuppan (*Glh 7*) — were tested for their reaction to GLH colonies collected throughout the Philippines and to the IRRI greenhouse colony. IR29 and TN1 were used as resistant and susceptible checks. The reaction of the various colonies on the various gene sources was measured by the seedling bulk test for plant damage. Colonies were reared on TN1 in the greenhouse for 2 generations before use in the seedling bulk test.

The reactions of the various varieties showed distinct differences (Table 6). Genes *Glh 3*, *glh 4*, *Glh 6*, and *Glh 7* were the weakest genes; *Glh 1*, *Glh 2*, and *Glh 5* had the strongest level of resistance.

However, there were no distinct differences among colonies for a given variety. The greenhouse colony reared on TN1 for several years was as virulent as the field-collected colonies. Assuming no change in the virulence of the greenhouse colony over the years, the various colonies tested indicated little or no selection for a virulent GLH biotype in the Philippines.

LEVEL OF RESISTANCE TO WHITEBACKED PLANTHOPPER OF CULTIVARS WITH RESISTANCE GENES

Entomology Department

The level of resistance reported in five cultivars with known genes for WBPH resistance was determined by using the seedling bulk test for plant damage and the survival test.

Seedling bulk test. Cultivars (and their resistance genes) were N22 (*Wbph 1*), ARC10239 (*Wbph 2*), IR2035-117-3 (*Wbph 1* + *Wbph2*), WC1240 (*Wbph 1* + 1 recessive), and Colombo (*Wbph 2* + 1 recessive). By the seedling bulk test N22, ARC10239, and Colombo were moderately resistant, and IR2035-117-3 and WC1240 were highly resistant to the greenhouse WBPH colony (Table 7).

Survival test. Insect survival on the various cultivars, determined 15, 30, 45, and 60 days after seeding, was similar. It decreased with increase in plant age (Table 8). Survival on all cultivars was significantly lower at 45 DS than at 15 DS. Thus, the resistance factors affecting survival appear to be most effective in older plants.

Table 7. Damage rating of cultivars with different genes for whitebacked planthopper (WBPH) resistance. IRRI, 1979.

Cultivar	Resistance gene	Damage rating[a]
N22	*Wbph 1*	5
ARC10239	*Wbph 2*	5
IR2035-117-3	*Wbph 1 + Wbph 2*	1
WC1240	*Wbph 1* + 1 recessive	1
Colombo	*Wbph 2* + 1 recessive	5
TN1 (susceptible)		9

[a] Based on the seedling bulk test of a greenhouse WBPH reared on TN1. Ratings 11 days after infestation: 0 = no damage, 9 = all plants dead.

CHANGE IN VIRULENCE OF A GREENHOUSE WHITEBACKED PLANTHOPPER COLONY FEEDING ON RESISTANT CULTIVARS

Entomology Department

Biotype development is believed to be due to natural selection of individuals, from within a population, that can survive on a resistant variety. To determine if virulent WBPH could be selected, a greenhouse colony reared on susceptible TN1 was reared alternately on TN1 and the resistant cultivars for four generations. After the fourth generation, the insect colonies were tested for virulence against the resistant cultivars.

All the colonies reared on a resistant cultivar for only two generations increased in virulence compared to those reared only on TN1 (TN1 colony) (Table 9). The colonies on IR2035-117-3 and WC1240 were the most virulent, killing all the varieties except WC1240. This indicates that the unidentified recessive gene in WC1240 imparts a high level of resistance, which is not readily overcome by biotype selection.

INHERITANCE OF WHITEBACKED PLANTHOPPER RESISTANCE

Plant Breeding Department

Twenty-one WBPH-resistant varieties were analyzed to find new genes for resistance (Table 10). They were crossed with susceptible variety TN1,

Table 8. Survival[a] of a colony of whitebacked planthopper (WBPH) reared on susceptible TN1 when placed on varieties with genes for resistance. IRRI, 1979.

Variety	WBPH survival[b] (%) on plants			
	15 DS	30 DS	45 DS	60 DS
N22	78 b (a)	64 ab (ab)	44 b (b)	56 b (b)
ARC10239	60 b (a)	28 c (b)	24 b (b)	18 c (b)
IR2035-117-3	80 ab (a)	48 bc (b)	40 b (b)	16 c (c)
WC1240	74 b (a)	46 bc (b)	38 b (b)	34 bc (b)
Colombo	76 b (a)	48 bc (b)	48 b (b)	30 c (b)
TN1	94 a (a)	78 a (ab)	76 a (b)	78 a (ab)

[a]Determined at 15 days after infestation with first-instar nymphs. [b]Mean of 5 replications. Means followed by a common letter (outside parentheses for columns, and in parentheses for rows) are not significantly different at the 5% level. DS = days after seeding.

Table 9. Damage rating on varieties with known whitebacked planthopper (WBPH) genes for resistance to different colonies of WBPH. IRRI, 1979.

Variety	Resistance gene	Damage[a] due to WBPH colonies reared on					
		N22	ARC10239	IR2035-117-3	WC1240	Colombo	TN1
N22	*Wbph 1*	9	7	9	9	7	5
ARC10239	*Wbph 2*	9	9	9	9	9	5
IR2035-117-3	*Wbph 1 + Wbph 2*	3	3	9	9	3	1
WC1240	*Wbph 1 + 1 recessive*	1	3	3	3	3	1
Colombo	*Wbph 2 + 1 recessive*	5	7	9	9	7	5
TN1 (susceptible)		9	9	9	9	9	9

[a]Damage rating based on seedling bulk test: 0 = no damage, and 9 = severely damaged. Ratings were taken at 11 days after infestation. [b]All colonies originated from greenhouse TN1 culture.

Table 10. Whitebacked planthopper-resistant rice varieties used in a genetics study. IRRI, 1979.

Variety	IRRI acc. no.	Country of origin
Mushkan 41	6828	Pakistan
Santhi	28222	Pakistan
Siahnakidar 195	28265	Pakistan
SM2-34	28266	Pakistan
Tirisurkh 251	28310	Pakistan
Zirijowaian 245	28325	Pakistan
18	28348	Pakistan
24A	28358	Pakistan
39	28377	Pakistan
65	28390	Pakistan
76S	28399	Pakistan
78	28401	Pakistan
180	28424	Pakistan
213B	28428	Pakistan
267	28434	Pakistan
274A	28440	Pakistan
293	28442	Pakistan
CI 6037-4	3667	India
NP97	3700	India
S39JKW	6836	India
Bansphul	28313	Nepal

and the F_1, F_2, and F_3 progenies were analyzed to determine the mode of inheritance. The data are presented in Table 11. All the F_1 progenies were resistant, indicating resistance under dominant gene control. The F_2 populations from crosses of those varieties, except those of TN1/65 and TN1/274A, segregated in a ratio of 3 resistant to 1 susceptible, indicating that a single dominant gene confers resistance. The F_2 populations of the crosses TN1/65 and TN1/274A segregated in a ratio of 13:3, indicating that resistance in the two varieties is governed by one dominant and one recessive gene.

The results from the F_3 progenies confirmed the conclusions drawn from the F_2 data. In all crosses except TN1/65 and TN 274A, the observed data agreed with the 1:2:1 (resistant:segregating:susceptible) ratio expected for monogenic control of resistance. The F_3 data from the crosses of TN1/65 and TN1/274A agreed with the 7:8:1 ratio expected for digenic control of resistance.

All the varieties were also crossed with N22 which is homozygous for *Wphh 1*, the dominant gene for resistance to whitebacked planthopper, and F_1, F_2, and F_3 progenies were analyzed (Table 12). As expected the F_1 progenies of all crosses were resistant. Similarly none of the F_2 populations segregated for susceptibility. A few

Table 11. Reactions[a] to whitebacked planthopper of F_1, F_2, and F_3 progenies from the crosses of TN1 with resistant varieties. IRRI, 1979.

Cross	F_1 reaction	F_2 seedlings				F_3 families			
		R (no.)	S (no.)	$X^2$3:1	$X^2$13:3	R (no.)	Seg. (no.)	S (no.)	$X^2$1:2:1
TN1/Mushkan 41	R	247	92	0.83		46	75	33	2.30
/Santhi	R	185	73	1.49		49	75	32	3.94
/Siahnakidar 195	R	306	91	0.91		41	81	32	1.47
/SM2-34	R	297	107	0.48		29	79	43	2.92
/Tirisurkh 251	R	417	128	0.67		30	82	35	2.31
/Zirijowaian 245	R	243	88	0.44		38	68	26	2.30
/18	R	268	76	1.55		47	71	36	2.51
/24A	R	249	96	1.47		36	88	30	3.61
/39	R	279	74	3.07		42	82	29	3.00
/65	R	222	45	9.45	0.63	95	95	18	2.88[b]
/76S	R	344	109	0.21		39	87	28	4.17
/78	R	228	69	0.49		31	70	29	0.83
/180	R	165	53	0.06		43	79	32	1.68
/213B	R	268	81	0.60		46	76	32	2.57
/267	R	234	91	1.56		36	66	25	2.10
/274A	R	352	69	16.65	1.54	57	84	13	3.42[b]
/293	R	242	78	0.07		39	82	33	1.12
/CI6037-4	R	313	99	0.21		48	76	30	4.23
/NP97	R	355	109	0.56		38	61	32	1.17
/S39JKW	R	213	62	0.88		43	79	32	1.68
/Bansphul	R	185	71	1.02		48	71	35	3.13

[a]R = resistant, S = susceptible, Seg = segregating. [b]X^2 for 7:8:1 ratio.

Table 12. Data on the reaction[a] to whitebacked planthopper of the F_1, F_2, and F_3 populations from the crosses of N22 with resistant varieties. IRRI, 1979.

Cross	F_1 reaction	F_2 seedlings (no.)		F_3 lines (no.)		
		R	S	R	Seg	S
N22/Mushkan 41	R	221	0	141	0	0
/Santhi	R	269	5	154	0	0
/Siahnakidar 195	R	283	0	154	0	0
/SM2-34	R	476	2	154	0	0
/Tirisurkh 251	R	367	8	154	0	0
/Zirijowaian 245	R	412	5	154	0	0
/18	R	384	7	154	0	0
/24A	R	387	0	144	0	0
/39	R	351	6	152	0	0
/65	R	282	4	154	0	0
/76S	R	492	6	154	0	0
/78	R	358	3	154	0	0
/180	R	384	0	145	0	0
/213B	R	362	7	154	0	0
/267	R	297	0	154	0	0
/274A	R	284	2	154	0	0
/293	R	378	9	154	0	0
/CI603704	R	379	0	147	0	0
/NP97	R	328	4	154	0	0
/S39JKW	R	302	5	154	0	0
/Bansphul	R	528	0	154	0	0

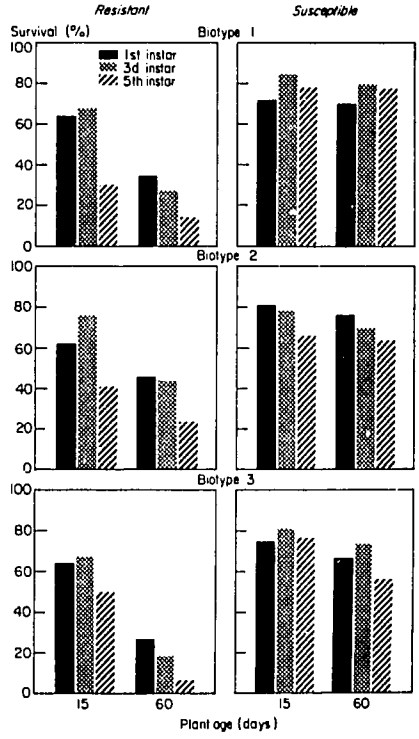
[a]R = resistant, S = susceptible, Seg = segregating.

seedlings that died had been classified as susceptible in some F_2 populations. However, this does not indicate genetic segregation for susceptibility because a few seedlings of the resistant parents also died. All the F_3 families of the crosses were resistant. The data indicate that all the resistant varieties had *Wbph 1* for resistance. Varieties 65 and 274A had an additional recessive gene for resistance.

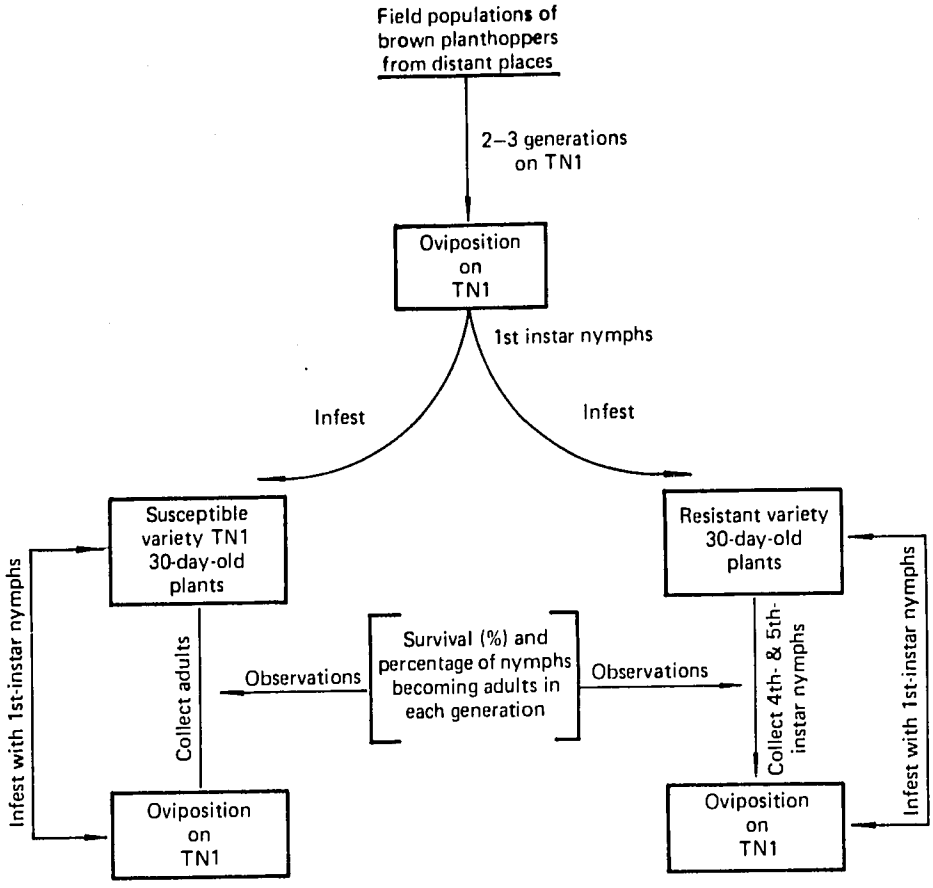
BROWN PLANTHOPPER RESISTANCE STUDIES

Entomology Department

Plant age and level of resistance. In past survival studies, first-instar nymphs were used to assess varietal levels of resistance to the BPH. In 1979, the survival of the first-, third-, and fifth-instar BPH nymphs on 15- and 60-day-old plants was studied to determine the effect of insect age and plant age on BPH survival. Based on insect survival, the level of resistance was distinctly higher in the 60-day-old plants (Fig. 2). Survival of the older (fifth-instar) nymphs was significantly lower than that of the younger nymphs on the 15-day-old plants. The fifth-instar nymphs provided maximum differences in survival between the susceptible and



2. Reaction of BPH nymph instars on resistant and susceptible rice varieties. Resistant varieties for biotype 1 were IR26 and Mudgo (*Bph 1* gene), IR42 and ASD7 (*bph 2*), and Rathu Heenati (*Bph 3*); those for biotype 2 were ASD7, IR42, and Rathu Heenati; and those for biotype 3 were IR26, Mudgo, and Rathu Heenati. IRRI, 1979.



3. Rearing technique used to select for brown planthopper biotypes virulent to a resistant rice variety. IRRI, 1979.

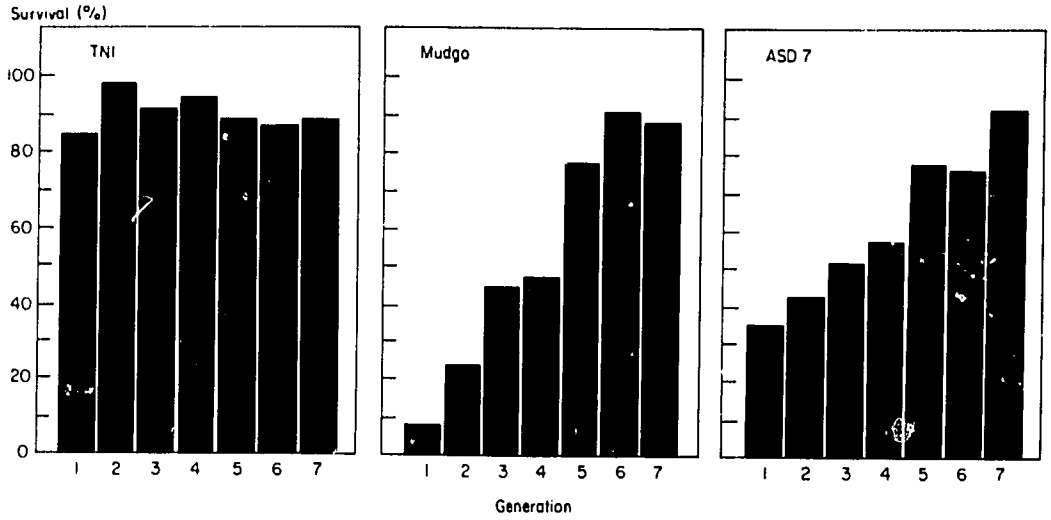
resistant varieties, indicating that the older insects are more suitable for survival studies.

Brown planthopper biotype selection. Studies were conducted to determine the rate at which BPH biotype selection occurs. A special rearing scheme (Fig. 3) was used to provide selection pressure. Biotype 1, a wild population reared on the susceptible variety TN1 for several years, was reared on two resistant varieties — Mudgo with the *Bph 1* gene, and ASD 7 with the *bph 2* gene for resistance. Plant damage, insect survival and nymphal period, feeding activity, and fecundity were studied to determine the rate of selection.

Plant damage. After the fifth generation on the resistant varieties, the selection colonies were not sufficiently virulent to kill the resistant variety in the seedling bulk test. However, by the ninth generation both the Mudgo and ASD7 colonies could kill Mudgo and ASD7. That indicated that by the 9th generation the insect is highly adapted to feeding on the resistant variety. In farmers' fields only three successive crops provide time necessary for nine BPH generations.

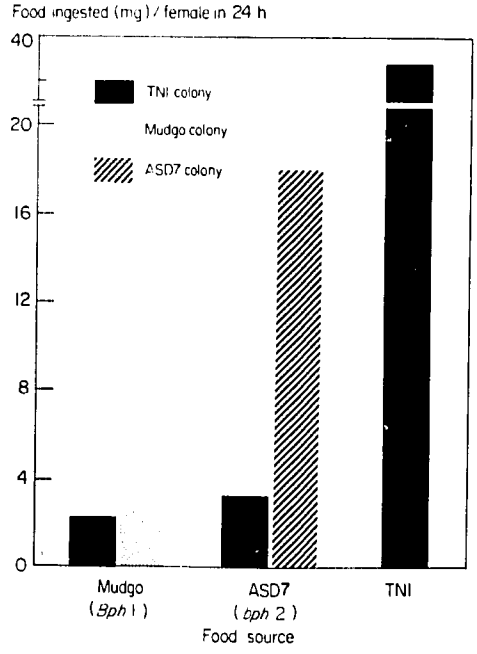
Survival and nymphal period. Survival on the resistant varieties increased with each generation and was equal to that on the susceptible TN1 at the seventh generation (Fig. 4). The growth index, based on survival and the length of the nymphal period, increased sharply in the fifth generation. By the sixth generation the growth index on Mudgo and ASD7 was almost equal to that of the susceptible TN1.

Feeding activity. As indicated by feeding activity, the ASD7 colony had a high level of adaptation



4. Survival of brown planthopper biotype 1 nymphs on TN1, Mudgo, and ASD7 from the first to the seventh generation. Each colony originated from a culture reared for about 12 years on TN1. IRRI, 1979.

in the eighth generation, although the amount of food ingested was only about half that by the TN1 colony on TN1 (Fig. 5). The Mudgo colony, however, had not yet adapted to feeding on Mudgo as the food ingested was only slightly more than that ingested by the TN1 colony on Mudgo.

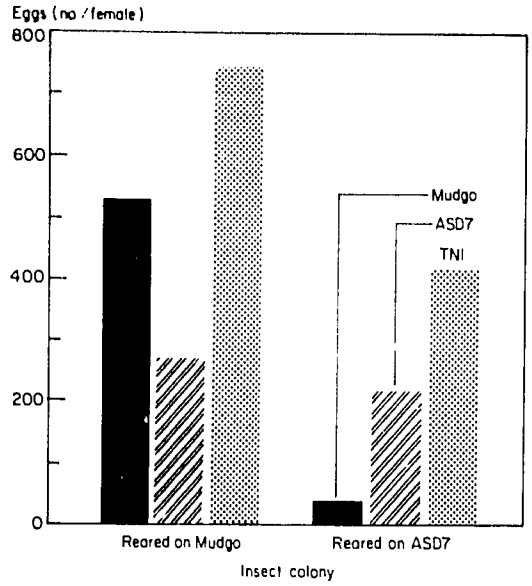


5. Feeding activity of three brown planthopper colonies on 30-day-old plants of a susceptible (TN1) and two resistant (Mudgo and ASD7) varieties. The Mudgo and ASD7 colonies originated from the TN1 colony and were reared on Mudgo and ASD7 for 8 generations. IRRI, 1979.

Fecundity. Although the ASD7 colony had a high level of feeding activity on ASD7, its fecundity on ASD7 and Mudgo was lower than that of the Mudgo colony (Fig. 6). The Mudgo colony's high level of adaptation on Mudgo was not yet equal to its adaptation on TN1. Fecundity rate was higher for the Mudgo colony on ASD7 than for the ASD7 colony on ASD7.

It was evident that BPH adaptation to resistant varieties depended on the character measured. Although the survival rate in both the Mudgo and ASD7 colonies was similar, the feeding activity and fecundity varied.

Identification of moderately resistant varieties. Because the rapid adaptation of the BPH to resistant varieties with major genes for resistance results in biotype selection, studies were conducted to determine if a more stable type of resistance can be found. Moderately resistant varieties may provide a more stable type of resistance to biotype selection. Moderate resistance was difficult to detect in the common seedbox screening technique, where 7- to 10-day-old seedlings were usually rated as susceptible. However, in

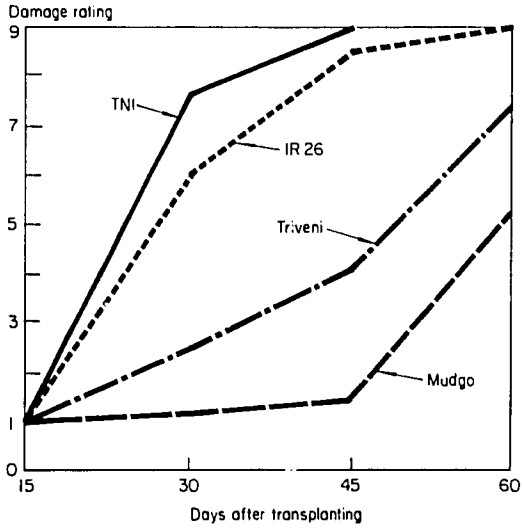


6. Number of eggs laid on Mudgo and ASD7 (both resistant), and TN1 (susceptible) by a TN1 colony of brown planthoppers that had been reared on Mudgo and ASD7 for 9 generations. IRRI, 1979.

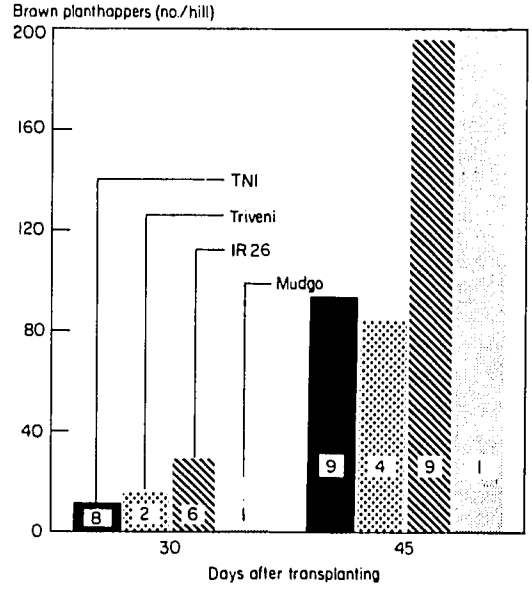
field studies when BPH attacked older plants, moderate resistance was more easily detected. Several varieties from the International Rice Brown Planthopper Nursery were killed in seedbox screening for biotype 2 but had a moderate level of BPH resistance as older plants in field screening. These varieties include Triveni and Mudgo from India, Utri Rajapan from Bangladesh, and IRRI's IR46. Further evaluation of the moderately resistant varieties Triveni and Mudgo against biotype 1 and 2 hoppers in a screenhouse verified the field results (Fig. 7). Under intense insect pressure the moderately resistant varieties were damaged but still survived, but IR26 and TN1 were killed.

Nature of moderate brown planthopper resistance. Moderately resistant varieties maintain insect populations equal to those on the susceptible TN1 but suffer less damage. As shown in Figure 8, the damage ratings of Triveni were lower than those of TN1 despite similar BPH populations. The same was true of Mudgo, a moderately resistant variety, when compared to IR26, both of which are susceptible to biotype 2. Although both varieties have the same major gene (*Bph 1*), Mudgo had a rating of 1 (= slight injury) at 45 DT while IR26 had 9 (= all plants dead). Two aspects of the difference were investigated — feeding activity and plant tolerance.

Feeding activity, based on honeydew excreted



7. Damage ratings of varieties exposed to brown planthopper biotypes 1 and 2 in a screenhouse. 1 = slight damage, 9 = all plants dead. These varieties are all susceptible to biotype 2 when evaluated as 7- or 10-day-old seedlings in the seedling bulk technique. IRRI, 1979.



8. Population of brown planthoppers and damage ratings (in bar) on varieties exposed to a mixture of biotype 1 and 2 hoppers in the screenhouse. Damage rating: 1 = slight damage, 9 = all plants dead. All varieties were equally susceptible in the seedbox screening of 7-to 10-day-old seedlings. IRRI, 1979.

Table 13. Change in body weight and quantity of honeydew excreted in 24 hours by brown planthopper biotypes feeding on highly resistant, moderately resistant, and susceptible varieties.[a] IRRI, 1979.

Variety[b]	Biotype 1		Biotype 2		Biotype 3	
	Wt gain (%)	Honeydew excreted (mg)	Wt gain (%)	Honeydew excreted (mg)	Wt gain (%)	Honeydew excreted (mg)
Rathu Heenati (R)	8 b	1.3 b	7 b	4.6 b	0 c	2.0 c
Triveni (MR)	31 b	8.1 b	28 b	6.3 b	52 b	16.1 bc
TN1 (S)	81 a	49.6 a	69 a	47.5 a	87 a	36.1 ab

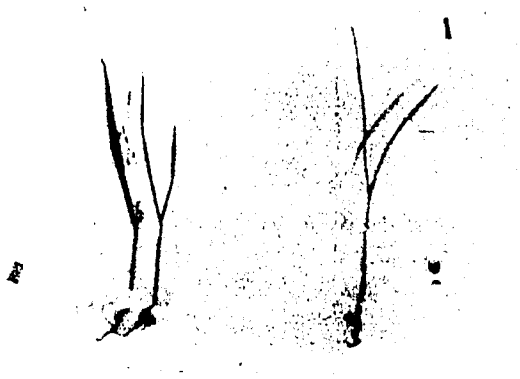
[a]Mean of three replications consisting of one insect each. Twelve-hour-old female adults that had been starved for 4 hours were used. Means followed by a common letter are not significantly different at the 5% level. [b]R = resistant, MR = moderately resistant, S = susceptible.

and gain in weight of the three IRRI BPH biotypes feeding on a resistant, moderately resistant, and susceptible variety (as based on greenhouse tests), is indicated in Table 13. Feeding on Triveni was about half of that on TN1. This may be one reason Triveni suffers less damage than TN1 at similar populations.

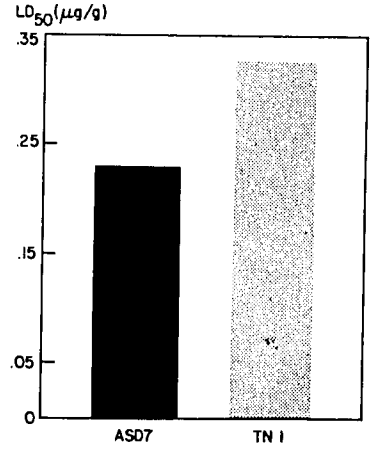
Tolerance is the ability of a plant to survive and grow despite insect feeding. To measure the level of tolerance in a moderately resistant and a susceptible variety, plants were exposed to feeding by hoppers until they were almost killed. The level of photosynthetic activity of plants under this stress condition was determined by growing them in a solution containing ^{14}C and measuring by X-ray film the amount of radioactivity in the seedlings. The color intensity of the autoradiograph was related to the amount of ^{14}C uptake. The autoradiograph of Triveni, a moderately resistant variety, was dark, indicating continued photosynthetic activity; that of TN1, a susceptible variety, was light (Fig. 9). It was apparent that photosynthetic activity in Triveni continued despite severe plant damage. In TN1 photosynthetic activity practically ceased at the same level of damage. The Triveni plant could recover and grow when the insects were removed from it.

Integrating moderate resistance with chemical and biological control. Initial studies indicated that carbofuran is more toxic to biotype 2 hoppers feeding on ASD7 than to those feeding on the susceptible variety TN1 (Fig. 10).

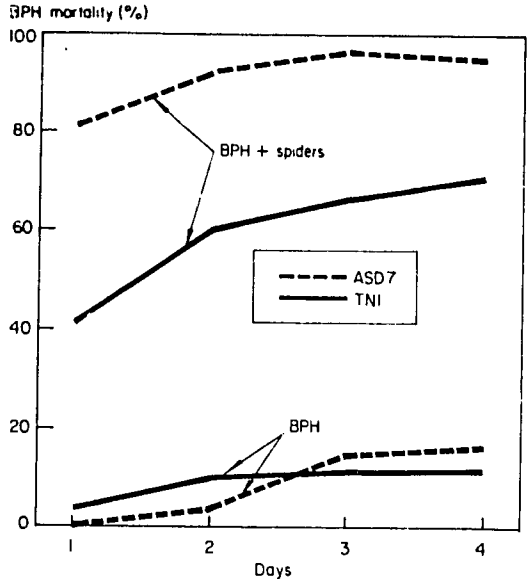
Moderately resistant varieties can increase the effectiveness of biological control agents. The spider *Lycosa pseudoannulata* was a more effective predator when feeding on hoppers growing on a moderately resistant variety (Fig. 11).



9. Photosynthetic activity based on ^{14}C uptake in the brown planthopper-tolerant variety Triveni (left) and susceptible TN1 (right). The photo shows the actual plants (right) and autoradiographs (left). Color intensity of the autoradiograph indicates the amount of photosynthetic activity occurring after the 10-day-old seedlings were almost killed by feeding of 20 adults BPH in 3 days. The plants were put in a chamber with 5 BPH adults and exposed to an atmosphere of ^{14}C for 24 hours. Triveni showed high photosynthetic activity; there was little activity in TN1. IRRI, 1979.



10. Susceptibility to carbofuran as indicated by LD_{50} (mean lethal dose) values when biotype 2 brown planthoppers were reared on a moderately resistant (ASD7) and a susceptible (TN1) variety. IRRI, 1979.



11. Efficiency of the spider *Lycosa pseudoannulata* when feeding on brown planthopper (BPH) on a resistant (ASD7) and a susceptible (TN1) variety. Ratio of BPH to spiders was 20:1. IRRI, 1979.

BIOCHEMICAL BASES OF BPH RESISTANCE

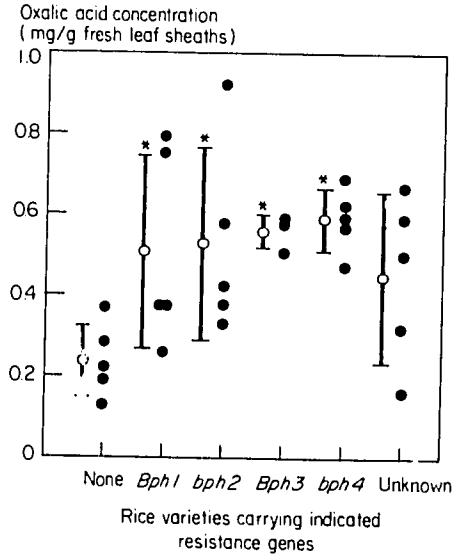
Chemistry and Entomology Departments

Oxalic acid. In 1978, oxalic acid was isolated from the resistant variety Mudgo. In 1979 the oxalic acid concentration in 28 varieties with various resistance genes was determined. Organic acids were separated from 70% ethanol extracts of fresh leaf sheaths from 40-day-old plants using ion exchange chromatography through Amberlite CG-120 and Amberlite CG-4G. Quantitative measurement of oxalic acid was facilitated by gas liquid chromatography of methyl esters of the organic acids. Levels of total organic acids were almost identical for the varieties (4.1–4.7 mg/g fresh leaf sheath). However, the oxalic acid concentrations of susceptible and resistant variety groups differed significantly (Fig. 12). The average concentration of oxalic acid was 0.24 mg/g fresh leaf sheath tissue in susceptible varieties and 0.45 to 0.59 in the 5 groups of resistant varieties. Likewise, the average percentage of oxalic acid in total organic acids was lower in susceptible (5–8%) than in resistant varieties (10.0–14.4%). The data indicate that oxalic acid is one of the chemical factors governing resistance to the BPH, but further experiments are required to determine the differential oxalic acid concentrations in the phloem sap, which is the dietary source of the BPH.

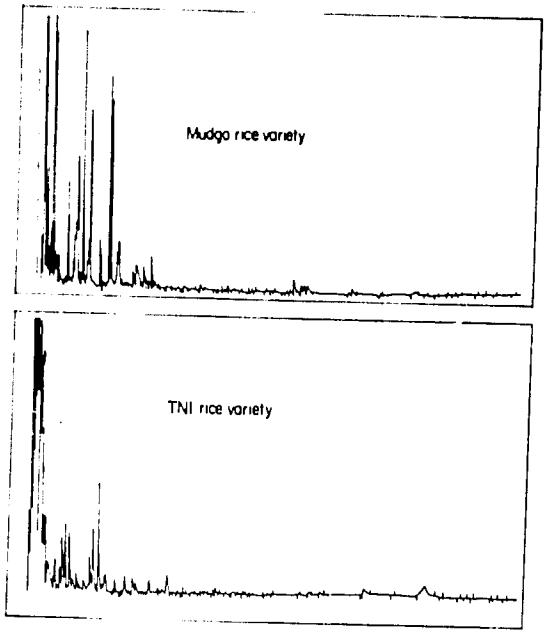
High molecular weight fractions. Earlier studies indicated that homogenates of whole plants contain high molecular weight fractions that were inhibitory to brown planthopper feeding. All other studies have used 70% ethanol as an extracting solvent, which automatically excludes the high molecular fraction. A 1979 study was undertaken to determine if active fractions also exist in the water-soluble high molecular weight fractions of rice leaf sheaths.

Leaf sheath segments of 7- to 9-week-old IR24 and IR26 seedlings were soaked in water at 0–4°C for 4 days to collect diffusates representing phloem and xylem sap. The total extract showed antifeeding activity in the bioassay. The diffusates were further fractionated in Sephadex G-25 and the fractions bioassayed. There was little high molecular weight fraction (mainly protein), and it had no inhibitory effect on insect feeding.

In contrast, the low molecular fractions were inhibitory and showed the presence of colloidal silica. A yellowish constituent (lowest molecular weight fraction) with very high ultraviolet absorption was not inhibitory but was toxic to the insects. Thin layer chromatography separated it into six



12. Oxalic acid concentration in rice varieties carrying different BPH resistance genes. o = values for individual varieties; I—•—I, mean and its standard error for each group of varieties; means with * are significantly higher than the mean for susceptible varieties.



13. Gas chromatograms of essential oils in steam distillates of leaf sheaths of biotype 1-resistant Mudgo and susceptible TN1 rice varieties. IRRI, 1979.

components, which were probably flavonoids.

The antifeeding activity of the diffusates tended to decrease upon storage even at 0–4°C. The diffusates had high carbohydrate content but varying reducing sugar levels. Soluble protein was less than 5% of the carbohydrates and was also less than the level of free amino acids.

High molecular fractions of bleeding sap collected from the base of panicles at flowering and of honeydew from brown planthoppers feeding on resistant and susceptible varieties did not show any antifeeding activity.

Essential oils. The essential oils are considered important factors in determining susceptibility or resistance of rice varieties to insect pests. These biochemicals, isolated as steam distillates from susceptible and resistant varieties, affect the insect both behaviorally and physiologically. In 1979, the steam distillates of leaf sheaths of BPH-susceptible TN1 and Mudgo, which is resistant to BPH biotype 1 and 3, were analyzed by gas chromatography and compared for any inherent differences. The gas chromatograms (Fig. 13) showed distinct qualitative and quantitative differences among the volatiles of Mudgo and TN1 rice varieties. The *fingerprints* of the steam distillate volatiles obtained by gas chromatography illustrated basic chemotaxonomic differences between the susceptible and resistant rice varieties. Work to identify the volatiles was started.

Genetic evaluation and utilization (GEU) program

Protein content

Chemistry, Plant Breeding, and Statistics Departments

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EVALUATION TRIALS

Plant Breeding, Statistics, and Chemistry Departments

Yield trials *(Plant Breeding, Statistics, and Chemistry).* In the dry season replicated yield trials, rough-rice yield and brown-rice protein were highly correlated in the irrigated trial ($r = -0.50^{**}$, n = 370) but were not correlated in the rainfed trial ($r = 0.10^{ns}$, n = 185). For the irrigated trial, brown-rice protein ranged from 6.7 to 11.2% with a mean value of 8.3%. Grain yield ranged from 5.2 to 8.2 t/ha. For the rainfed trial, brown-rice protein ranged from 6.5 to 9.6% with a mean of 7.8%; grain yield ranged from 4.5 to 8.2 t/ha.

High-protein parents *(Plant Breeding and Chemistry).* High-protein accessions (1,364) from the IRRI germplasm bank were successfully grown in the 1979 wet season for verification of their protein content and agronomic characteristics. The best entries will be used as possible high-protein parents in the breeding program.

PROPERTIES OF RICE PROTEIN

Chemistry Department

Protein and silicon distribution in rice grain. In a cooperative study with biochemists at the Australian National University, Canberra, the protein distribution obtained from milling fractions of high-protein and average-protein brown rice (1978 annual report) was verified. Techniques to separate embryo, grain coat, grain coat plus aleurone cells, and starchy endosperm for amino acid analysis were developed. Of the fractions, the starchy endosperm had the greatest increase in protein and the embryo had the least with a 45% increase in brown-rice protein (Table 1).

The increase in lysine, the first limiting essential amino acid of rice protein, was less than proportionate to the increase in protein of brown-rice, except in the embryo. By contrast, the increase in threonine, the second limiting essential amino acid, was proportional to that of protein. The results, however, are misleading since brown and milled rices actually have similar utilizable protein contents, the digestibility of brown-rice protein being poorer. Antinutrition factors, including phytate and dietary fiber, are concentrated in the bran layers.

Colorimetric assay of silica showed decreasing silica contents, except the close values for subaleurone layer and middle endosperm, for a high-protein (11%) brown rice (IR480-5-9,260 ppm Si): bran (0–6% fraction of brown rice), 1,930 ppm Si; polish (6–12%), 620 ppm; subaleurone layer (12–20%), 170 ppm; middle endosperm (20–30%), 260 ppm; and inner endosperm (30–100%), 50 ppm. The corresponding values for an average-protein rice (IR32, 7% protein) were subaleurone layer, 350 ppm Si; middle endosperm, 140 ppm; and inner endosperm, 90 ppm. Dietary and crude-fiber values followed closely the silicon distribution, except that the relative differences in fiber content were higher than those in silicon content of the milling fractions.

Growth of children on high-protein rice diets. Cooperative nitrogen balance studies on Peruvian and Filipino children earlier showed that high-protein rice was not significantly less retained than average-protein rice. Growth studies were undertaken to determine the long-range effect of replacing average-protein rice with high-protein rice in typical rice-based diets of preschool children.

Table 1. Ratio of the amount of protein and amino acid in the various components of the high-protein (11%) grain (IR480-5-9) compared with that in the average-protein (7%) grain (IR32). Australian National University, Canberra, and IRRI, 1979.

Protein or amino acid	Ratio in				
	Brown rice	Starchy endosperm	Embryo	Aleurone cells + grain coat	Grain coat
Protein	1.45	1.49	1.09	1.22	1.31
Lysine[a]	1.18	1.26	1.14	0.97	1.25
Threonine[b]	1.52	1.44	1.04	1.22	1.53
Mean for all 17 amino acids	1.43	1.43	1.09	1.20	1.36

[a]First limiting essential amino acid in rice protein. [b]Second limiting essential amino acid.

The effect of a high-protein rice (IR2153-338-3, 10% protein) on the growth of preschool Indian children was assessed in 1-year cooperative feeding trials in a residential home by the Christian Medical College and Hospital, Vellore, South India. The children were offered ad libitum a typical South Indian rice-based diet at 4 meals a day. The children in the experimental group were given the high-protein rice and those in the control group were given a local rice (Ponni, 7% protein). Energy intakes were similar (Table 2) but 85% of the dietary protein was from rice (235 g/1,000 kcal) in the experimental group and 79% in the control group. The rest of the dietary protein was from black gram and pigeon pea.

Although the nitrogen balance data on the children in the two groups were similar (1978 annual report), the increased nitrogen retention in the experimental group did not result in taller and heavier children (Table 2). However, although the two groups were not significantly different in the pattern and severity of illnesses, the control group had more cases of upper respiratory infection than the experimental group (32 vs 21). The lack of response to high-protein rice may be attributed to the high contribution of protein to energy (8.0% in control and 10.8% in experimental diet) in the South Indian diet and the effective consumption of the bulky diet even by the younger children. The control diet also was adequate in all essential amino acids (Table 2).

A second study — to determine the effect of zinc supplementation on the growth of preschool Filipino children at an orphanage in Metro Manila — was undertaken in cooperation with the Food and Nutrition Research Institute. Zinc, an essential element for appetite and normal growth and an essential constituent of many enzyme proteins, is needed for protein synthesis. The study included a third diet, which involved zinc supplementation plus high-protein rice (IR480-5-9, 10.4% protein) in place of the average-protein commercial rice (~7.4% protein). Each group consisted of at least 30 children 1 – 6 years old, 27 of whom completed the 6-month trial. Preliminary analysis indicated the zinc intake in the orphanage to be 4 – 6 mg daily compared with the recommended daily allowance of 10 mg for this age group.

The control group received the usual diet consisting of three meals and two snacks, with vitamins and minerals, except zinc, added to the morning snack. A second group had 5 mg zinc as $ZnSO_4 \cdot 7 H_2O$ added to the mineral mixture. A third group had, in addition to zinc supplementation, high-protein rice in place of the orphanage rice. Other protein sources were eggs, pork, milk, and bread. The three groups had similar rice intake, 154 – 157 g/day; rice contributed about 40% of the dietary protein in the control group.

Table 2. Comparison of parameters of preschool children in high-protein and control groups fed South Indian rice-based diets for 1 year. Christian Medical College and Hospital, Vellore, India, and IRRI, 1978–79.

	Experimental (high-protein rice)	Control (low-protein rice)
Initial ht (mm)	915.8 ± 65.5	918.1 ± 55.1
Final ht (mm)	985.6 ± 64.0	969.4 ± 68.3
Increase in ht (mm)	69.8 ± 15.0	71.3 ± 20.4
Initial wt (kg)	11.96 ± 1.68	11.88 ± 2.94
Final wt (kg)	13.09 ± 1.90	13.20 ± 2.64
Increase in wt (kg)	1.13 ± 0.75	1.32 ± 1.07
Energy intake (kcal/kg body wt)	81.0 ± 6.4	81.0 ± 7.2
Nitrogen intake (g/day)	5.31 ± 0.79	4.09 ± 0.36
Amino acid intake (mg/kg body wt)		
Lysine	90	70
Methionine + cysteine	103	78
Threonine	80	59
Trytophan	24	18

Zinc supplementation alone for 6 months had no significant effect on the growth of preschool children (Table 3). But the diet combining zinc supplementation with high-protein rice resulted in faster growth than the control diet. Although the children fed those diets had similar serum properties, including serum zinc, the children in the group that received zinc and high-protein rice had higher final hemoglobin levels.

The seeming disparity in results of the two studies is not easy to explain as there was no common treatment of high-protein rice diet without zinc supplementation. Energy intakes were slightly lower with the Filipino children, particularly the older ones (72–77 kcal/kg body wt). Protein intakes were more than adequate in both studies, but on the basis of amino acid analysis, protein quality was better in the nonvegetarian Filipino diet (Table 4). The Filipino children also grew faster. Since the

Table 3. Effect of 6-month zinc supplementation with and without high-protein rice on growth of preschool children in White Cross orphanage, Metro Manila, Philippines.[a]

Diet	Zn intake (mg/day)	Lysine content of diet (g/16 g N)	Mean increase in Ht (cm)	Mean increase in Wt (kg)	Mean final serum Zn (µg/ml)
Control	5	5.6	4.21 b	0.81 b	1.40 a
Control + 5 mg Zn	10	5.6	4.38 ab	0.99 b	1.42 a
High-protein rice diet + 5 mg Zn	10	4.9	4.83 a	1.38 a	1.29 a

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

Table 4. Essential amino acids in the protein of defatted composite rice diets in feeding studies on Indian and Filipino children, compared with the World Health Organization (WHO) pattern. IRRI, 1979.

Amino acid	Amino acid content (g/16 g N) of diet fed to: Indian children, Low-protein	Indian children, High-protein	Filipino children, Low-protein	Filipino children, High-protein	WHO pattern (g/16 g N)
Isoleucine	4.2	4.2	4.3	4.2	4.0
Leucine	8.6	8.6	8.3	8.4	7.0
Lysine	4.3	4.1	5.3	4.7	5.5
Methionine + cystine	4.8	4.7	6.3	6.3	3.5
Phenylalanine + tyrosine	10.8	10.8	9.0	9.4	6.0
Threonine	3.7	3.7	3.5	3.5	4.0
Valine	5.7	5.7	5.3	5.4	5.0
Tryptophan	1.4	1.3	0.8	1.0	1.0

diets were more than adequate in protein, the impact of replacing average-protein rice with high-protein rice will probably be more apparent in diets deficient in energy and protein.

Total and undigested protein of rice. Studies to explain why 10–15% of the milled-rice protein becomes poorly digestible on cooking were continued. The undigested protein has lower molecular weight (MW) and lysine content than whole milled-rice protein bodies, and represents its core proteins (1978 annual report). Protein bodies were prepared from raw and cooked IR480-5-9 milled rice by treatment with crystalline hog pancreatic α-amylase. Cooking decreased protein extraction with 0.5% sodium dodecyl sulfate (SDS)–0.6% β-mercaptoethanol (ME) from 98% to 73% but lipid extraction with petroleum ether remained low (26–27%). Only the results on protein extractability were similar to those in 1978 when protein bodies were prepared from rice destarched with pancreatic and *Aspergillus oryzae* α-amylases. With the pepsin-treated protein bodies, the efficiency of lipid extraction with petroleum ether was 74% for raw rice and 89% for cooked rice.

Protein bodies prepared from raw IR480-5-9 milled rice by pancreatic α-amylase action had lower lipid content (5.8%) than those prepared from cooked rice (7.8%). Overnight treatment of C4-63G starch with *Aspergillus* α-amylase resulted in the recovery of only 3% of its lipids in the residual dextrin. In contrast, waxy IR29 milled rice, which had trace starch lipids, gave a cooked-rice protein-body preparation with 69.2% protein and a high lipid content of 10.0%. Starch lipids, in contrasts to nonstarch lipids, were presumably readily lost during α-amylolysis of raw granules.

The ratio of the lipid fractions (neutral lipids:glycolipids:phospholipids) associated with protein-body preparations was affected by the amylase used for destarching although these

enzyme preparations had negligible lipase activity. *Aspergillus* α-amylase treatment of cooked rice resulted in a lipid ratio of 92:5:3. Pancreatic α-amylase treatment resulted in raw-rice protein bodies with a lipid ratio of 52:7:41 and in cooked-rice protein bodies with a lipid ratio of 54:7:39.

Thin-layer chromatography on silica gel of the lipid fractions of raw and cooked IR480-5-9 protein bodies prepared by treatment with pancreatic and *Aspergillus* α-amylase showed that the major lipid classes were free fatty acids in the neutral fraction together with triglycerides, diglycerides, and monoglycerides, and lysophosphatidyl choline and lysophosphatidyl ethanolamine in the phospholipid fraction, with trace amounts of phosphatidyl choline and phosphatidyl ethanolamine.

Comparison of milled rice and pepsin-treated (core) raw-rice protein bodies showed milled-rice protein to have 9% albumin-globulin and 2% prolamin. Core protein bodies had 8% albumin-globulin and 2% prolamin. Thus, the core protein that resisted digestion after cooking was about 90% glutelin.

Scale preparation of the two major polypeptides of undigested protein bodies was undertaken, with sodium chloride-extracted milled rice as starting material. The MW 16000 and MW <5000 polypeptide were also present in raw milled rice and glutelin, free from degradation products of protein hydrolysis in fecal samples. Protein extracted by 0.1 N NaOH-0.6% β-ME was fractionated on Sephadex G-75 to obtain the MW <5000 subunit. Characterization of the low-MW polypeptide, which resolved on Bio-Gel P-2 gel filtration into 1 major and 5 minor peptides, was started. The crude preparation, however, had a high lysine content of 4%.

Emphasis was shifted to the MW 16000 subunit, which probably was the low-lysine protein of interest in undigested rice protein. Among glutelin subunits, the MW 16000 subunit tended to have the lowest lysine content (1976 annual report). Attempts were made to prepare this subunit from milled rice to isolate a polypeptide subunit with lysine content of <2% without the use of SDS. The solvent 0.1 N NaOH-0.6% β-ME readily dissolved the protein from 0.7 M NaCl-washed IR480-5-9 milled-rice flour. Fractional precipitation by pH adjustment to 10 and to 7 did not enrich the MW 16000 subunit.

Albumin-globulin-free milled rice was extracted with 0.1 N NaOH-1.8% β-ME and the extract was alkylated with acrylonitrile in the presence of urea. Although the alkylated protein was soluble in 0.05 N NaOH and 4 M guanidine·HCl, it did not resolve into subunits on gel filtration in these solvents on Sephadex G-50 and G-100 and gave only a peak at the void volume. The results suggest that sodium hydroxide and guanidine are less efficient solvents of alkylated rice protein than SDS. Alkylation was complete, as evident from the identical subunit pattern on SDS-polyacrylamide disc gel electrophoresis, with or without β-ME. The protein, however, showed less intense bands with MW >38000 than the SDS extract. Aggregation of the polypeptide chains in these solvents was probably due mainly to hydrophobic bonding. A scale preparation of the MW 16000 subunit of milled-rice protein extracted by SDS-β-ME had been made using fractionation through Sephadex G-150 (1975 annual report).

Albumins and globulins. Albumins and globulins constitute 15% of milled-rice protein. Albumin is water soluble and globulin is salt soluble. They are difficult to separate because water extracts may also dissolve globulin because of the soluble mineral (salt) content of the grain. Dialysis of salt extracts to precipitate globulin also results in precipitation of some albumin due to denaturation.

Albumins. Albumins were prepared by extraction of IR480-5-9 milled-rice flour with distilled water, overnight dialysis to remove globulins, and saturation of the soluble fraction to 80% with ammonium sulfate to precipitate the albumins. The residue from water extraction was then extracted with 0.25 M $(NH_4)_2SO_4$ and precipitated with the addition of ammonium sulfate to 80% saturation (4 M). This preparation was found to be contaminated with α-globulin; subsequently 0.1 to 0.15 M $(NH_4)_2SO_4$ was used for albumin extraction to minimize α-globulin contamination. The major albumins in these extracts were readily precipitated at 40% $(NH_4)_2SO_4$ saturation (1.8 M).

Brown rice stored at room temperature was milled and defatted with petroleum ether. Serial extraction of the defatted IR36 milled rice with water and increasing concentrations of sodium chloride showed reduction during storage in protein extractable by all solvents except 0.5 M NaCl (Table 5). The addition of 1 mM dithiothreitol (DTT) as sulfhydryl preservative reduced the pro-

teins extracted by water and 0.25 M NaCl but increased those extracted by 0.5 M and 0.8 M NaCl in the control sample only. Basic disc gel electrophoregrams of the extracts indicated that only albumins were extracted by water and 0.25 M NaCl. They consisted of two major protein bands. The pattern was identical to that of the 0.15 M $(NH_4)_2SO_4$ extract. The 0.5 and 0.8 M NaCl extracts gave only 1 major band intermediate in mobility to the 2 major albumin bands. It was probably the α-globulin.

The dilute-salt extracts had detectable activities of protease (hemoglobin and benzoyl-L-arginine *para*-nitroanilide substrates), α-amylase, and ribonuclease. They had no α-amylase inhibitor activity, in contrast to wheat albumins. An inhibitor of trypsin-like activity was also found for both the low- and high-MW fractions of dilute salt extracts obtained by Sephadex G-25 gel filtration.

The major protein peak obtained from Sephadex G-100 gel filtration of the 0.15 M $(NH_4)_2SO_4$ extract of IR36 milled rice was fractionated on DEAE-Sephacel using a 0–0.4 M NaCl gradient. The major fraction (44%) was unadsorbed protein, followed by 3 other partially resolved peaks, representing 21%, 16%, and 15% of total protein. Analytical disc gel electrophoresis suggested that the main unadsorbed fraction, which migrated in acid gel only, was basic protein. The second peak showed mainly the slower major albumin electrophoretic band at pH 8.3; the fourth peak showed mainly the faster albumin band, and the middle (third) peak gave both bands. The major unadsorbed fraction was termed basic albumin, and peaks 2 and 4, albumin 1 and 2, respectively. Albumin 1 was the fraction that denatured on standing of albumin solution at 0–4°C.

The major albumins of IR36 milled rice from Triton X-100-polyacrylamide disc gel electrophoresis showed MW 86000 for the water extract, MW 242000, 126000, and 62000 daltons for the 0.25 M NaCl and 0.15 M $(NH_4)_2SO_4$ extracts, and MW 248000 for the 0.5 M NaCl extract. Gel filtration of Sephadex G-100 gave a major peak for the 0.15 M $(NH_4)_2SO_4$ extract with MW 20000, together with an aggregated high-MW fraction at the void volume. This major peak comprised 61–82% of the crude albumin extract. SDS-gel electrophoresis showed that the water and 0.25 M NaCl extract had only 1 major subunit with MW 16800. In addition, the 0.5 M and 0.8 M NaCl had MW 22000 and 17200 major subunits besides the MW 16600. Basic albumin and albumin 2 had two major subunits with MW 16600 and 17200. Albumin 1 had only one major subunit with MW 16800.

Amino acid analysis of the albumin preparations showed the water extract to have 5.9% lysine compared with 3.6% lysine for the IR36 milled rice. In contrast, use of 0.1 M $(NH_4)_2SO_4$ as albumin extractant improved protein extraction from 1.3% to 7.3%, but caused lysine content to drop to 3.7%. In the 0.1 M $(NH_4)_2SO_4$ extract, the fraction precipitated at 0–40% $(NH_4)_2SO_4$ saturation, representing 82% of the total extracted proteins, had 2.2% lysine and 2.6% cystine, and the remainder or the 40–80% saturation fraction had 5.8% lysine and 3.1% cystine. For the DEAE-

Table 5. Comparison of progressive extraction of soluble proteins of defatted IR36 milled rice from brown rice stored at different temperatures.[a] IRRI, 1979.

Solvent	Extractable protein (% of total protein) from brown rice					
	Control[b]		Stored 1 mo at 35°C[b]		Stored 4 mo at 28°C[b]	
	No DTT	1 mM DTT	No DTT	1 mM DTT	No DTT	1 mM DTT
H_2O	2.2	1.4	1.9	2.2	1.3	1.4
0.25 M NaCl	7.8	6.0	7.3	7.9	4.6	4.8
0.5 M NaCl	2.8	5.1	3.0	3.2	3.0	3.2
0.8 M NaCl	1.5	2.4	1.1	1.4	1.1	1.3
Total	14.3	14.9	13.3	14.7	10.0	10.7
Protein content (%)	7.5		7.4		7.9	

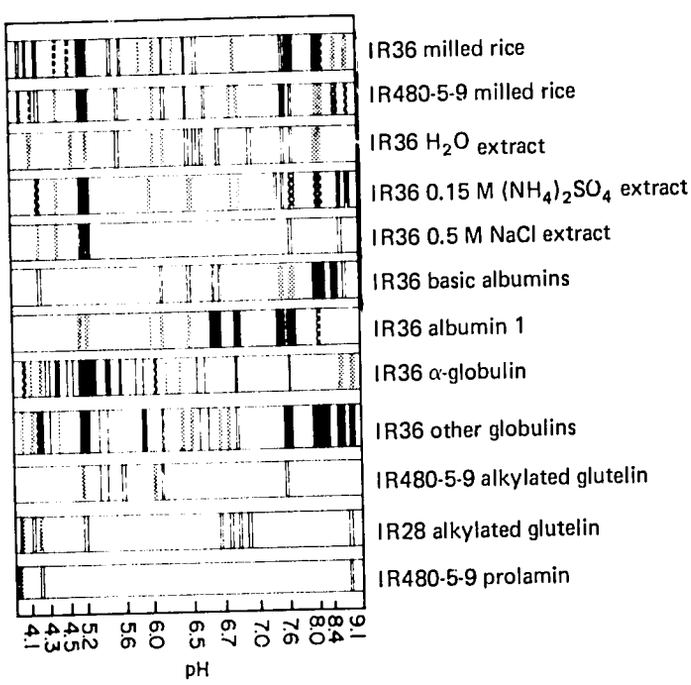
[a]DTT = dithiothreitol. [b]Previously stored as brown rice for 2.5 months at 0–4°C.

Sephacel fractions, basic albumin had 2.0% lysine and 6.4% cystine, albumin 1 had 3.2% lysine and 6.0% cystine, and albumin 2 had 2.6% lysine.

Isoelectric focusing in cooperation with the Wheat Research Unit, CSIRO, North Ryde, Australia, confirmed the results of analytical gel electrophoresis at pH 4.5 and 8.3. Water extracts showed 10–11 bands of medium intensity at pH 6.0–7.5 (Fig. 1). The 0.15 M $(NH_4)_2SO_4$ extract showed a distinct major protein band with isoelectric point at pH 5.3 and about 4 medium-intensity bands between pH 7.6 and 9.0. Basic albumin had 2 major bands with isoelectric points about 8.3 and 8.7. Albumin 1 had 4 major polypeptides at pH 6.8, 7.0, 7.6 and 7.7. The globulins extracted by 0.5 M and 0.8 M NaCl had 1 major component with isoelectric point at 5.3, which was higher than the pH 4.5 previously reported for α-globulin.

Globulins. Globulins other than α-globulin, which were reported elsewhere to also be high in cystine and methionine, were studied further. Crude globulin was prepared by 0.7 M NaCl extraction from IR480-5-9 milled rice, precipitated by 30% saturation with $(NH_4)_2SO_4$ (1.3 M), redissolved in 0.7 M NaCl, and precipitated by dialysis against water. Precipitated globulins were dissolved in acetic acid to pH 2.5 and α-globulin was precipitated by adjusting pH to 4.5 with sodium hydroxide. The fraction soluble at pH 4.5 and even at pH 7.0, however, still showed the presence of α-globulin.

Isoelectric focusing at CSIRO showed α-globulin prepared by isoelectric precipitation at pH 4.5 to still be heterogeneous with a major band at pH 5.3 (Fig. 1). Below pH 5.3, it had a prominent band at pH 4.5 and less intense bands down to pH 4.1. Above pH 5.3 it also had prominent bands at pH 5.4, 5.6, 6.2, 6.5, and 6.9 and minor bands up to pH 9.1. In contrast the nonprecipitated globulin also contained the pH 5.3 protein but the major bands had isoelectric points between pH 8.0 and 9.1. It also had the bands below pH 5.3 but lacked the prominent bands at pH 5.4–5.6, 6.2, and 6.5, but instead had bands at pH 6.0, 6.3, 6.6., and 7.7. The results indicated that isoelectric precipitation at pH 4.5 did not remove all the protein with low isoelectric points. A higher pH of 6.0 may be more appropriate. The albumins left in



1. Isoelectric focusing patterns of 3 M urea-1% β-mercaptoethanol soluble proteins of milled rices and their protein fractions. Wheat Research Unit, Commonwealth Scientific and Industrial Research Organization, North Ryde, Australia, 1979.

solution by $(NH_4)_2SO_4$ precipitation of globulin from 0.7 M NaCl had an isoelectric focusing pattern identical to that of water-extracted albumins of milled rice.

Analytical disc gel electrophoresis showed that pH 4.5 isoelectric precipitation resulted in pure α-globulin (2 bands) but the subsequent precipitation at pH 7.0 gave fractions of similar electrophoregram. Interestingly the soluble protein from the dialysis of the ammonium sulfate precipitate against water had a similar electrophoregram to that of the globulin fraction soluble at pH 4.5. Since distilled water has a pH of 5.5–6.0, dialysis probably preferentially precipitated α-globulin, while the more basic protein (isoelectric points >6) remained in water solution. The soluble protein during dialysis was a richer source of non- α-globulins than the pH-4.5 soluble protein fraction during isoelectric precipitation of α-globulin. The major water-soluble globulins corresponded in isoelectric points to the basic albumins discussed above. The water-soluble globulin contained 2.6% lysine; α-globulin, 0.6%.

To minimize aggregation of α-globulin subunits during purification, gel filtration on Sephadex G-100 of crude globulin was undertaken at pH 3.6, instead of pH 6.5. Globulin from IR480-5-9 bran, milled rice, and overmilled rice, and IR36 milled rice all gave only one major peak with V_e/V_o of 2.0–2.2. DEAE-Sephacel ion-exchange chromatography could not be used as the globulin was only 10% soluble in 0.1 M Tris-HCl pH 7.8.

DEAE-Sephacel chromatography of water-soluble globulin at pH 8.5 showed the presence of at least 6 protein peaks and unadsorbed protein. Alkylation of the proteins with acrylonitrile to remove disulfide linkages improved the resolution of water-soluble globulin on DEAE-Sephacel.

Globulin particles. Extraction of IR480-5-9 milled rice and milling fractions with 0.5 M NaCl at 50°C and cooling of the extract at 4°C resulted in the formation and settling of spherical particles, 1–3 μm in diameter, with a distinct core. The particulate protein accounted for 23% of the extracted protein in the subaleurone layer and for 15% of the extracted protein in the inner endosperm. The particles from the subaleurone layer (12–20%) had 63% protein and represented 1.3% of total protein. Those from the inner endosperm (30–100%) had 54% protein and represented 1.1% of total protein. Similar crystalline globulin had been reported by Japanese chemists in 1930.

Recrystallized particles were characterized by analytical and SDS-polyacrylamide disc gel electrophoresis to be mainly a mixture of three globulin proteins, while proteins remaining in solution at 4°C were a mixture of albumins and globulins. The globulin particles had lower lysine but higher cystine and methionine contents than the soluble proteins. They were rich in α-globulin.

Urea-mercaptoethanol-soluble proteins. Cooperative studies of isoelectric focusing of milled rice protein fractions were undertaken at CSIRO, to identify the nature of the 3 M urea-1% β-ME extract of milled rice by isoelectric focusing. Australian chemists found varietal differences in electrophoretic pattern among brown rice samples of rice varieties. In wheat and barley, the protein fraction involved is prolamin. The urea-ME extract of IR480-5-9 and IR36 milled rice had major bands with isoelectric points at 5.3 and 7.8 and other proteins with isoelectric points between pH 4 and 9.1 (Fig. 1). The electrophoregram indicated that the extracted proteins were mainly albumins and globulins. Glutelin and prolamin were poorly soluble in the solvent. Prolamin showed faint bands through pH 4 to 9 with no major band. Glutelins had also 2 medium-intensity bands corresponding to pH 5.3 and 6.2 and faint bands from pH 4.5 to 9.

Nutritional Evaluation Laboratory. A regional Nutritional Evaluation Laboratory for the evaluation of high-protein and rice-based weaning foods through balance studies in preschool children was established at the Food and Nutrition Research Institute, National Science Development Board, Manila, in cooperation with IRRI, and with funding from the US Agency for International Development. The unit is expected to be operational in 1980.

Genetic evaluation and utilization (GEU) program

Drought resistance

Agronomy, Plant Breeding, Plant Physiology, and Irrigation Water Management Departments

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HYBRIDIZATION AND SELECTION

Plant Breeding Department

The drought resistance program crosses for both dryland and rainfed-wetland cultures included 301 single crosses, 165 topcrosses, 29 backcrosses, and 33 double crosses. As much as possible a drought-resistant upland parent was involved in the topcrosses, backcrosses, and double crosses to recover the traits related to drought avoidance such as a deep-root system.

Bulk populations of 105 F_2s were grown in upland fields at IRRI and in a farmer's field, and 1,776 F_2 plants from the 2 sites were selected during the wet season. The F_3-F_5 were planted in the upland pedigree nurseries during late July. The crop underwent two short stress periods that affected the vegetative and the reproductive stages and most of the lines had high panicle sterility. Only 565 rows were selected out of 5,872 pedigree lines.

For crosses intended for rainfed-wetland cultures, 17 F_2 bulk populations were grown along with many crosses intended for other types of rainfed-wetland culture. Most of the populations were susceptible to sheath blight and bacterial blight and only 84 plants were selected.

VARIETAL SCREENING

Agronomy and Plant Breeding Departments

Field-screening rices for drought resistance (*Agronomy*). A total of 3,897 lines and varieties were tested at IRRI for drought resistance during the vegetative stage. Entries were GEU materials from pedigree nurseries, observational yield trials (OYT), replicated yield trials (RYT), and hybridization blocks (HB) for the 1978 wet and 1979 dry seasons, and selected accessions from the germplasm bank.

Table 1 lists 29 entries that received a score of 1 at 2 and 5 bars soil moisture tension (SMT). The drought scores of the resistant checks IR442-2-58 and Salumpikit were 1 at 2 bars and 3 at 5 bars SMT, which indicated that at 5 bars SMT the listed lines and accessions had better resistance than the resistant checks.

Another 764 entries had a drought score of 3 at 5 bars SMT – similar to that of the resistant checks IR442-2-58 and Salumpikit. Of those, 116 appeared better than the rest in degree of leaf-tip drying. They included IR5853-118-5, which performed consistently well in 3 years of drought testing at IRRI (Table 2). IR5853-118-5 had Nam Sagui 19 (a deepwater variety moderately resistant to drought) as a parent.

Another line that showed consistently good drought resistance was IR8103-120-3 (IR2031-238-5-2-6/AUS 197//IR2061-213-2-16). In 1978 it was the only entry among 4,757 that scored 1 at 10 bars SMT. In 1979 it was among the 116 that performed better than the resistant checks at 5 bars SMT.

Table 1. Rices outstanding in field drought screening during the vegetative stage. IRRI, 1979 dry season.

Entries with drought reaction[a] of 1 at 2 and 5 bars SMT

Line or accession	*Origin*
IR6115-1-1-1	Philippines
IR6172-6-3	Philippines
IR9669 Sel	Philippines
ARC 11430C	India
ARC 11432	India
ARC 12059	India
B995c-Bc-1-10	Indonesia
Bhawalia Diga	Bangladesh
BKN 6986-167	Thailand
Chung Ta 312/Binastian	China
DNJ 155	Bangladesh
IAC 5544	Brazil
Intan	Philippines
Jampah 133	Thailand
Kaika	Bangladesh
Ketan Beledeng	Indonesia
Ketan Cere	Indonesia
Khao Dawk Mali	Thailand
Kinandang Patong	Philippines
KLG 6987-143-2-P	Thailand
Kulawalai	Sri Lanka
KU 86	Thailand
Manik Digha	Bangladesh
Moroberekan	Guinea
Nam Sagui 19	Thailand
Paedai Kulibungga	Indonesia
Pate Blanc	Ivory Coast
PN677-2	Nigeria
PN678-4	Nigeria

Check

Checks	Drought reaction		
	2 bars SMT	5 bars SMT	Recovery[b]
IR442-2-58 (resistant)	1	3	1
Salumpikit (resistant)	1	3	1
IR20 (susceptible)	3	5	3
IRAT 9 (susceptible)	3	7	5

[a]SES 1–9 scale: 1 = no to negligible effect of soil moisture stress (SMT), 9 = all plants apparently dead. [b]SES 1–9 scale: 1 = 90% of plants fully recovered, 9 = no plant recovered.

Table 2. Three-year summary of drought resistance ratings[a] of promising lines and varieties at different soil moisture tension (SMT) values at IRRI.

Line or variety	1977		1978		1979
	4 bars SMT	10 bars SMT	5 bars SMT	10 bars SMT	5 bars SMT
IR5853-118-5	3	3	1	3	3
IR8103-120-3	3	3	1	1	3
IR36	5	8	3	6	5
IR43	–	–	3	7	3
IR45	–	–	3	6	3
Kulawalai	–	–	1	3	1
Checks					
IR442-2-58 (resistant)	4	5	2	5	3
Salumpikit (resistant)	4	5	2	4	3
IR20 (susceptible)	7	8	6	9	5
IRAT 9 (susceptible)	7	8	7	9	7

[a]SES 1–9 scale: 1 = no to negligible effect of soil moisture stress, 9 = all plants apparently dead.

Rices outstanding for drought resistance (*Agronomy*). Among lines identified for drought resistance IR5853-118-5, IR8103-120-3, and IR9669 Selection from IRRI and BKN 6986-108-2 and KU86 from Thailand showed consistent resistance for 3 consecutive years (Table 3). Another 4 IRRI-bred lines had good drought ratings in 1978 and 1979. Table 3 also gives the reactions to drought of 5 parents of the selected lines. These parents showed consistent resistance only to relatively moderate stresses (5 bars SMT and below), while the progenies rated excellent even at 10 bars SMT. Nam Sagui 19, Leb Mue Nahng 111, and Khao Dawk Mali 105 were earlier reported resistant to prolonged (10 days) moisture stress (1975 and 1976 annual reports).

Table 3. Rices outstanding for drought resistance, IRRI, 1977–79 dry seasons.

Designation[a]	Possible source of resistance	Drought score[b] 1977		1978		1979
		4 bars SMT	10 bars SMT	5 bars SMT	10 bars SMT	5 bars SMT
IR5853-118-5	NS 19	3	3	1	3	3
IR8103-120-3	Aus 197	3	3	1	1	3
IR9669 Selection	Carreon	4	4	1	3	1
IR5624-110-2	KDM 105	–	–	1	3	3
IR8154-95-1	KU70-1	–	–	1	3	3
IR8234-174-3	NS 19	–	–	2	3	3
IR9995-96-2	NS 19	–	–	1	3	3
BKN 6986-108-2		3	3	2	3	3
KU 86		2	2	1	3	1
Nam Sagui 19		7	7	3	7	3
Carreon		3	3	3	5	3
Leb Mue Nahng 111		3	3	2	4	3
Khao Dawk Mali 105		3	6	3	6	3
KU70-1		4	5	–	–	–
IR442-2-58 (R ck)	LMN 111	4	5	1	5	3
Salumpikit (R ck)		4	5	1	4	3
IR20 (S ck)		7	8	5	8	5
IRAT 9 (S ck)		7	8	6	9	7

[a]R ck = resistant check, S ck = susceptible check. [b]SES 1–9 scale: 1 = no to negligible effect of soil moisture stress, 9 = all plants apparently dead. SMT = soil moisture tension. A dash (–) means not tested during year.

Table 4. Summary of field scores on drought resistance of 3,763 accessions and lines at the vegetative and reproductive phases. IRRI, 1979 dry season.

Growth stage	Entries scored[a] (no.)	Entries (no.) that scored[b]								
		1	2	3	4	5	6	7	8	9
Germplasm bank accessions										
Vegetative	2449		10	99	311	1007	866	152	4	
Reproductive	783	2	7	61	113	236	101	147	42	74
Dryland breeding lines from IITA[c] and IRAT[d]										
Vegetative	273		1	29	116	112	15			
Reproductive	89			9	10	33	12	14	5	6
Entries from IRRI dryland replicated yield trial										
Vegetative	35				3	22	10			
Reproductive										
Entries from IRRI dryland observational trial										
Vegetative	835			41	192	413	178	11		
Reproductive	89			8	7	20	4	27	1	22
1978 IURON entries										
Vegetative	171			2	22	83	58	6		
Reproductive	22			2	3	6	2	3	1	5
Total	3763		11	171	644	1637	1127	169	4	
	983	2	7	80	133	295	119	191	49	107

[a] – means dry season ended before the stressed plants produced panicles. [b] 1 = highly resistant, 9 = highly susceptible. [c] International Institute of Tropical Agriculture. [d] Institute for Tropical Crops Research.

Field screening of germplasm bank and breeding lines (*Plant Breeding*). During the dry season, 2,449 accessions from the germplasm bank and 1,314 breeding lines from IRRI and the International Institute of Tropical Agriculture (IITA) were screened for field resistance to drought (Table 4). Because of differences in maturity range, only 783 accessions and 200 breeding lines were scored at the reproductive phase before the dry season ended during mid-April.

As in previous screening, a large number of accessions from Africa, India, Laos, and Pakistan showed moderate to high levels of drought resistance at the vegetative phase. A large number of accessions also had high levels of drought resistance at the reproductive phase of growth. They included the traditional varieties from Laos, a number of Assam varieties from India, TOX lines from IITA, and breeding lines from IRAT. Among the 1978 IURON entries, ARC 10372 and IRAT 108 scored 3. Three accessions, Khao Khao Kendu, Khao Teng, ang Khao Nho, and IRRI breeding lines from dryland nurseries were later used as parents in crosses with high-yielding and pest-

Table 5. Summary of field scores on drought resistance in simulated rainfed-wetland test of 16 accessions and 269 breeding lines at the reproductive phase. IRRI, 1979 dry season.

	Entries (no.)	Entries (no.) that scored[a]								
		1	2	3	4	5	6	7	8	9
Traditional rainfed-wetland varieties from the Philippines	16			1	2	10	2	1		
Breeding lines from wetland nurseries	22				3	17	2			
Breeding lines from rainfed-wetland replicated yield trial	70			7	19	38	6			
Breeding lines from dryland nurseries	104		1	19	45	29	10			
Wetland breeding lines from Indonesia	26			5	11	10				
Entries from IRRI-Thailand rainfed-wetland collaborative experiment	25			3	3	8	9	2		
Total	285		1	35	86	129	31	3		

[a] 1 = highly resistant, 9 = highly susceptible.

resistant lines from the wetland breeding nurseries.

Dryland breeding lines of IRRI — IR5440-1-1-3, IR5987-25-1, IR6231-3-5, and IR6254-27-1 — also showed moderate to high levels of drought resistance at the reproductive phase. One of the parents of these IR lines belonged to traditional varieties such as 63-83 and Khao Lo, known to have high levels of drought resistance.

Screening for drought resistance in rainfed-wetland culture (*Plant Breeding*). In the 1979 dry season, 52 accessions from the germplasm bank and 277 breeding lines from the wetland and dryland breeding nurseries, rainfed-wetland replicated yield trials, and wetland breeding lines from Indonesia were screened for drought resistance as a rainfed-wetland crop. The crop was transplanted 7 February and allowed to grow for 30 days, after which the fields were drained and left to dry. The plants showed no marked symptoms of drought stress at the vegetative phase after a 3-week stress period, and occasional rainshowers in early April enabled most entries to recover. In the reproductive phase, however, symptoms of stress were visible in the medium late- and late-maturing entries.

Table 5 summarizes field scores on drought resistance taken at the reproductive stage of 16 accessions and 269 breeding lines in the medium late- and late-maturing groups. Scores of the traditional rainfed-wetland varieties from the Philippines ranged from 3 to 7. Of the 35 accessions, only 16 headed and were scored; the other 19 were photoperiod sensitive. Varieties such as Pangasinan, Melandres, and Inapostol produced well-filled grains and scored 3-4. A number of entries from both wetland and dryland breeding nurseries scored 3-4 at the reproductive stage. The scores obtained in the simulated rainfed-lowland test may not, however, be as reliable as those obtained in the upland field screening test, because occasional showers fell at the reproductive stage.

In the wet season, the same set of varieties and lines were planted in a rainfed-wetland observational trial on an IRRI upland area. The crop was transplanted 19 July, and drought spells during 20-26 August and 3-9 September did not severely affect the test plants. Because of severe lodging before and at maturity, no reliable yield data were obtained. However, a number of promising entries were visually observed as promising: IR40, IR43 IR3304-23, IR6254-33-3 IR8073-3-3, IR8192-242-3-2-1, IR9217-58-2-2, and IR9264-321-3.

Drought screening in the greenhouse (*Agronomy*). Screening for drought resistance was continued in the greenhouse with major emphasis on the GEU elite lines and the dryland and rainfed wetland breeding materials from IRTP nurseries. Among 810 entries screened, some traditional var-

Table 6. Drought tolerance ratings at vegetative stage of promising GEU elite lines and some selected entries and their drought recovery scores after relief from stress. IRRI, drought screening greenhouse, 1979 dry season.

Variety or line	Drought tolerance rating[a]			Av
ARC 10362	2	3	2	2.3
ARC 11430C	3	3	3	3.0
ARC 11432	3	2	3	2.7
Bluebonnet 50	2	3	3	2.7
BK 88-BR6	2	3	2	2.3
Dacca 14	4	3	2	3.0
DD 118	3	3	3	3.0
DNJ 155	3	2	2	2.3
Dova H	3	3	3	3.0
Iguape Cateto	3	3	3	3.0
IAC 25	3	3	2	2.7
IAC 5544	4	3	2	3.0
IR8103-120-3	4	4	3	3.7
Maleba L	3	2	2	2.3
MRC 85	2	2	2	2.0
Munot variety	3	3	2	2.7
Paedi Kalibungga	3	3	3	3.0
PN677-1	3	3	3	3.0
PN678-4	3	3	3	3.0
Ram Kajara	2	2	2	2.0
Sikodok	3	2	2	2.3
Tri	2	3	2	2.3
1021 (Guatemala)	3	3	3	3.0
CR141-3128-2-234	3	3	3	3.0
CR143-2-10 (IET 3331)	3	2	3	2.7
B1014B-PN-18-1-4	3	3	3	3.0
Surjamukhi	3	1	1	1.7
Naung Tu	1	4		2.5
PTB 14	3	3		3.0
Sanpyasein	3	3		3.0
T-2018	3	3		3.0
B541B-Kn-47-1-1	2	5		3.5
C166-135	4	3		3.5
IR5853-118-5	3	2	2	2.3
IR5825-41-2-P2	3	3		3.0
IR8608-79-3-2	3	3	3	3.0
IR5260-1	3	4	3	3.3
IR5931-81-1-1	4	3	3	3.3
IR6140-22-2	4	3	3	3.3
IR9209-262-1-3-1	4	3	3	3.3
IR9761-75-3	4	3	3	3.3
IR10198-66-2	4	3	3	3.3
IR13240-10-1	4	3	3	3.3
IR9129-209-2-2-2-1	3	5	3	3.7

[a]Standard Evaluation System for Rice 1–9 scale: 1 = no to negligible effect of soil moisture stress, 9 = all plants apparently dead.

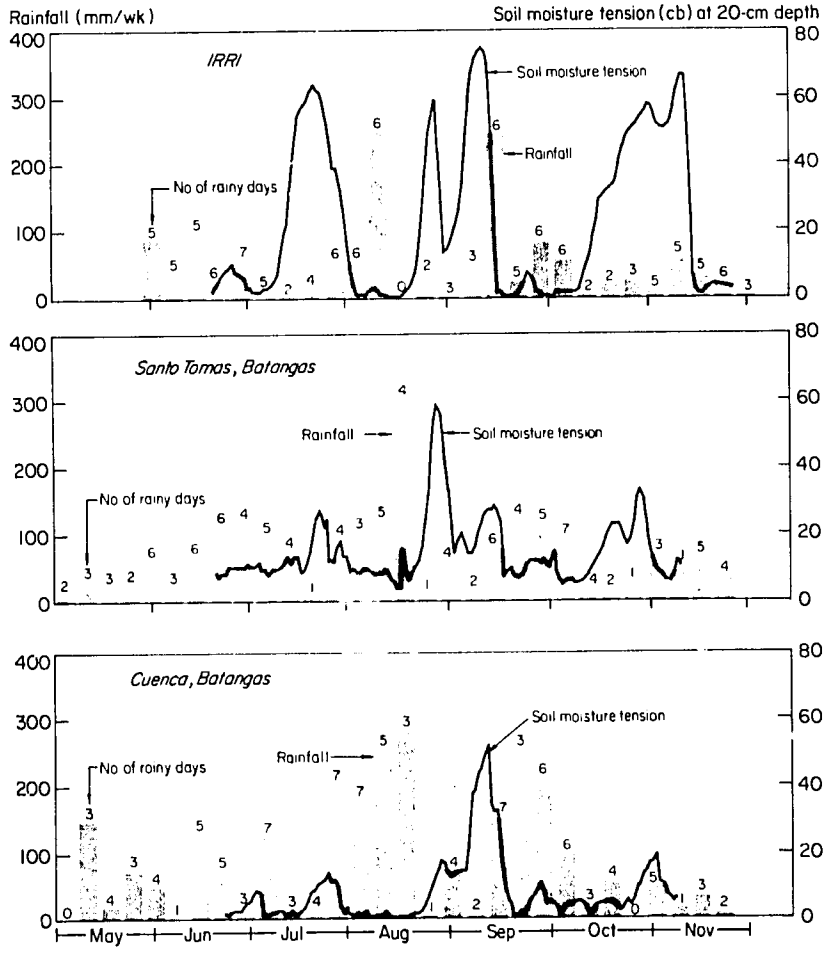
ieties and breeding lines of varied geographic origins scored about 3.0 or better (Table 6).

Dryland rice yield tests (*Agronomy*). Dryland-rice yield tests of 81 entries were at IRRI, and in farmers' fields at 2 sites (Cuenca and Santo Tomas) in Batangas Province, and at the Philippine Bureau of Plant Industry (BPI) experiment stations in Ilagan, Isabela Province, and La Granja, Negros Occidental Province.

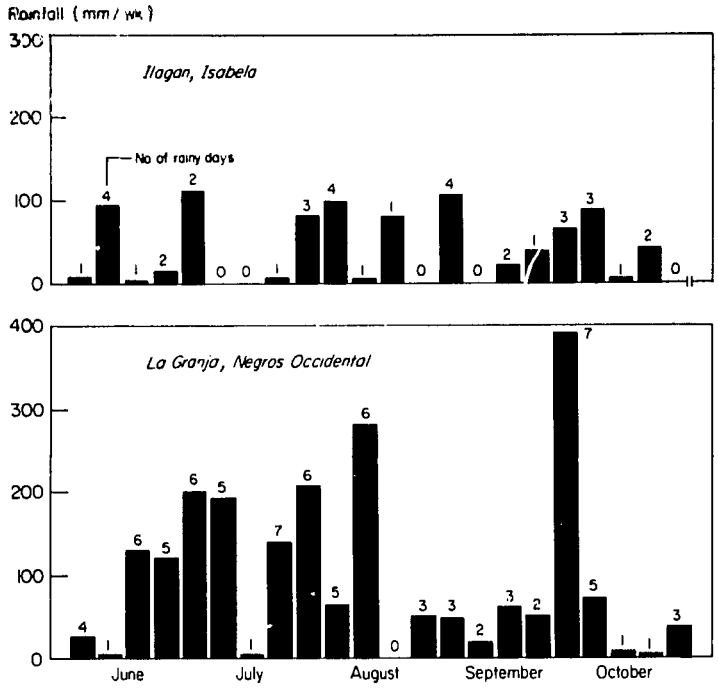
Soil moisture and rainfall. Soil moisture stress occurred during various stages of crop growth at the different sites. SMT reached 60 centibars (cb) at Santo Tomas in late August, and 51 cb at Cuenca and 75 cb at IRRI in early September (Fig. 1). A severe drought occurred in Ilagan (Fig. 2).

Grain yield. The highest yield of 5.7 t/ha was from C166-135 at La Granja (Table 7), where weather was most favorable for dryland rice. In the other four sites, the effect of drought was reflected by the generally low yields. Yields of the earlier maturing entries planted at the start of the wet season suffered more from the soil moisture stress than yields of the later -maturing entries (Table 7, 8). Despite the low rainfall in Ilagan, IR9560-2-6-3-1 and IR9669 Selection had yields of 3.5 and 3.1 t/ha, indicating good yield ability in drought conditions.

B733C-167-3-2 had the highest mean yield of 2.5t/ha (Table 8) among the 12 selected early-maturing entries. Among the late-maturing entries,



1. Weekly rainfall and soil moisture tension during dryland rice yield tests at IRRI and in Batangas province, Philippines, 1979 wet season.



2. Weekly rainfall during dryland rice yield tests at Ilagan, Isabela province, and La Granja, Negros Occidental province, Philippines, 1979 wet season.

IR9669 Selection and IR9560-2-6-3-1 (UP'76 # 69) showed consistently outstanding grain yield for all test sites and dates.

In 1978, B733C-167-3-2, IET 4094, IR9669 Selection, Gama 318, and IR43 were also among those better than the check entries.

Agronomic characteristics. The low rainfall in Ilagan delayed flowering of the entries. The shortest delay — 7 days — was on MW10 (Table 9). All the listed entries were shorter in stature than the checks M1-48 and C22 and had more panicles than M1-48. The agronomic characteristics of the

Table 7. Grain yield of selected late-maturing rices in a dryland rice yield test at 5 sites in the Philippines. 1979 wet season.

Designation	Grain yield (t/ha)								
	IRRI		Santo Tomas		Cuenca		Ilagan	La Granja	Mean
	6 Jun[a]	10 Jul	26 May	3 Jul	29 May	28 Jun	7 Jun	1 Jun	
IR9669 Selection	2.4*	2.4*	3.6*	3.5*	3.2*	3.1*	3.1*	4.4	3.2
IR9560-2-6-3-1	2.8*	2.2	3.4*	3.3*	3.1*	3.0*	3.5*	4.7	3.2
Gama 318	2.8*	1.9	1.9	2.6	2.6	3.1*	2.9*	5.0*	2.8
IR43	2.4*	3.1*	2.4	3.0*	2.4	2.5	2.4	3.4	2.7
KN 96	2.0	2.3*	2.5	2.8	2.2	2.4	2.3	4.6	2.6
IET 1785	1.8	2.5*	2.3	3.3*	2.1	2.4	1.8	4.8	2.6
C166-135	2.5*	2.0	1.8	2.2	2.5	1.9	2.2	5.7*	2.6
IR45	1.9	2.4*	2.8	3.2*	1.3	2.0	2.8*	4.0	2.6
IR9995-96-2	1.9	2.0	2.4	3.5*	2.1	2.8	1.9	3.6	2.5
B541B-PN-58-5-3-1	1.6	2.4*	2.0	2.7	2.2	3.0*	1.9	4.1	2.5
IR5853-118-5	1.4	2.4*	2.8	2.3	2.6	3.3*	1.8	3.2	2.5
IR2823-399-5-6	1.9	2.2	2.8	3.2*	1.2	1.8	1.8	4.5	2.4
C171-136	1.9	1.8	2.1	2.2	2.6	2.1	2.5	3.7	2.4
IR9266-124	1.6	1.6	2.2	2.8	2.7*	2.3	2.2	3.3	2.4
C22 (late check)	1.5	1.6	2.4	2.1	1.8	2.5	2.2	3.7	2.2

[a]Seeding date. *Significantly higher than the check, C22, at P = 0.05.

Table 8. Grain yield of selected early-maturing rices in a dryland rice yield test at 5 sites in the Philippines. 1979 wet season.

Designation	Grain yield (t/ha)								
	IRRI		Santo Tomas		Cuenca		Ilagan	La Granja	Mean
	6 Jun[a]	10 Jul	26 May	3 Jul	29 May	28 Jun	7 Jun	1 Jun	
8733C-167-3-2	1.7*	2.1*	2.1	2.9*	2.2	2.6*	1.9*	4.4	2.5
IR5716-18-1	1.2	2.4*	2.4	2.9*	1.8	1.9	2.4*	3.6	2.3
IET 4094	1.1	2.3*	2.0	2.8*	2.7	2.3*	0.5	5.0*	2.3
IR2061-522-6-9	1.1	2.4*	2.0	2.8*	2.3	2.4*	1.2	4.1	2.3
IR3839-1	0.7	2.2*	1.9	2.7*	2.1	2.4*	2.0*	3.9	2.2
BG35-2	0.8	1.6	2.4	2.0	2.9*	2.0	2.0*	3.2	2.1
IR9410-80	0.8	2.0*	1.4	2.0	2.5	2.1	2.3*	3.8	2.1
IR2061-628-1-6-4-3	0.5	1.6	1.6	2.7*	2.4	2.5*	1.3	3.8	2.0
IR7473-118-2-2-3	0.8	2.0*	1.2	2.1	1.8	2.4*	1.4	4.0	2.0
IR9828-36-3	0.7	1.8*	1.8	2.4*	1.6	2.3*	1.6	3.6	2.0
IR9101-37-1	0.6	1.8*	1.8	2.5*	1.8	2.4*	1.5	3.2	2.0
IR36	1.0	1.8*	2.2	2.2	1.7	2.0	1.5	3.2	1.9
MW10	[b]	1.9*	2.8	2.6*	3.1*	1.6	0.8	3.2	2.3
M1-48 (early check)	0.6	1.0	2.0	1.4	1.9	1.6	1.5	3.3	1.7

[a]Seeding date. [b]Rat damage. *Significantly higher than the check, M1-48, at P = 0.05.

late-maturing entries are in Table 10.

Sheath blight was prevalent and leaf scald was serious at both Batangas sites. Bacterial blight was the most common disease at Ilagan and at IRRI. The least infected entry was IR5853-118-5, which had only bacterial blight at Ilagan and sheath blight at Cuenca. IR9560-2-6-3-1 had bacterial blight and leaf blight in Ilagan, and leaf scald and sheath blight in Cuenca. On the basis of this year's and previous years' observation, sheath blight could become a serious threat to upland rice production.

IR9560-2-6-3-1 (IR8///IR8*2//IR1905/IR1904) was recommended for inclusion in the International Upland Rice Yield Nursery (IURYN) and the Philippine national trials.

Field evaluation of dryland breeding lines (*Plant Breeding*). Eighty entries from the upland and lowland breeding nurseries were evaluated at two IRRI sites and in a farmer's field in Batangas Province.

A rainfall of 1,730 mm was evenly distributed from seeding to the last harvest at Batangas. The highest yields, 4.2 – 4.7 t/ha, were from the late-maturing lines (IR43, IR9669 Selection, and

Table 9. Agronomic characteristics of selected early-maturing rices in dryland rice yield test at 5 sites in the Philippines. 1979 wet season.

Designation	Grain yield (t/ha)	Days to heading	Plant ht (cm)	Panicles (no /m^2)	Drought score[a]		Diseases[b]
					IRRI	Ilagan	
B733C-167-3-2	2.5	76–102	93	258	4.7	5.0	LB, LSC, BB, BLS, SHB
IR5716-18-1	2.3	70–126	85	238	4.3	3.0	LB, BS, BB, SHB
IET 4094	2.3	77–99	75	291	3.7	3.0	LB, LSC, BB, BLS, SB
IR2061-522-6-9	2.3	75–123	85	256	4.7	5.0	LB, NBLB, LS, BB, SHB
IR3839-1	2.2	75–96	79	292	3.7	4.3	BS, BB, SHB
BG35-2	2.1	75–103	77	252	3.3	5.0	LB, LSC, BB, SHB
IR9410-80	2.1	77–114	76	302	3.7	3.0	LB, NBLS, LSC, BB, SHB
IR2061-628-1-6-4-3	2.0	75–121	75	259	4.7	7.7	LB, BB, SHB
IR7473-118-2-2-3	2.0	80–101	84	254	4.0	3.0	LB, BS, LSC, BB, SHB
IR9828-36-3	2.0	77–100	68	289	4.0	5.0	LSC, BB, SHB
IR9101-37-1	2.0	72–96	78	277	3.7	5.0	LB, NBLS, LSC, BB, SHB
IR36	1.9	75–121	65	286	3.7	5.0	LB, LSC, SHB
MW10	2.3	74–81	71	259	3.3	5.0	NBLS, BB, SHB
M1-48 (early check)	1.7	77–116	107	145	3.3	5.0	LB, BB, SHB

[a]SES 1–9 scale: 1 = no to negligible effect of soil moisture stress, 9 = all plants apparently dead. Done 29 Aug at IRRI and 25 Aug at Ilagan. [b]LB = leaf blast, BS = brown spot, NBLS = narrow brown leaf spot, LSC = leaf scald, LSM = leaf smut, BB = bacterial blight, BLS = bacterial leaf streak, SHB = sheath blight.

Table 10. Agronomic characteristics of selected late-maturing rice in dryland rice yield test at 5 sites in the Philippines, 1979 wet season.

Designation	Grain yield (t/ha)	Days to heading	Plant ht (cm)	Panicles (no./m²)	Drought score[a]		Diseases[b]
					IRRI	Ilagan	
IR9669 Selection	3.2	93–130	77	255	3.7	5.0	LB, BB, SB
IR9560-2-6-3-1	3.2	94–104	78	259	3.0	5.0	LSC, BB, SHB
Gama 318	2.8	91–117	87	237	3.7	3.0	BS, LSC, BB, SHB
IR43	2.7	88–121	77	251	4.3	3.7	LSC, BB, SHB
KN91	2.6	90–109	100	238	4.0	3.0	LB, BB, SHB
IET 1785	2.6	86–130	74	253	4.0	7.0	LB, LSC, BB, SHB
C166-135	2.6	88–115	106	211	3.3	4.3	LSC, BB, SHB
IR45	2.6	91–122	75	318	3.7	3.7	LB, LSC, BB, SHB
IR9995-96-2	2.5	86–116	84	253	4.0	7.0	LB, BS, LSC, BB, SHB
B5418-PN-58-5-3-1	2.5	82–102	92	251	4.0	3.0	BS, LSC, BB, SHB
IR5853-118-5	2.5	82–120	81	260	4.0	3.0	BB, SHB
IR2823-399-5-6	2.4	87–126	80	274	4.7	3.0	LB, LSC, BB, SHB
C171-136	2.4	88–121	102	186	4.0	5.0	LSC, BB, SHB
IR9266-124	2.4	84–102	83	235	3.7	3.0	BS, BB, SHB
C22 (late check)	2.2	85–111	[illegible]	187	4.0	3.0	LSC, BB, SHB

[a]SES 1–9 scale: 1 = no to negligible effect of soil moisture stress; 9 = all plants apparently dead. Done 29 Aug at IRRI and 25 Aug at Ilagan. [b]LB = leaf blast, BS = brown spot, NBLS = narrow brown leaf spot, LSC = leaf scald, LSM = leaf smut, BB = bacterial blight, BLS = bacterial leaf streak, SHB = sheath blight.

IR6115-1-1-1), which benefited from late rains. IR6115-1-1-1 (IR1529-680-3/Moroberckan) has consistently produced 4.2 t/ha at Batangas since 1977.

Among the early-maturing (110-day) group, IR2061-522-6-9 and IET 1444 produced 3.6 and 3.5 t/ha at Batangas. Promising lines with moderate to high levels of drought resistance were IR5982-7-6-1, IR6023-10-1-1, IR5440-1-1-3, and IR5716-18-1 (Table 11).

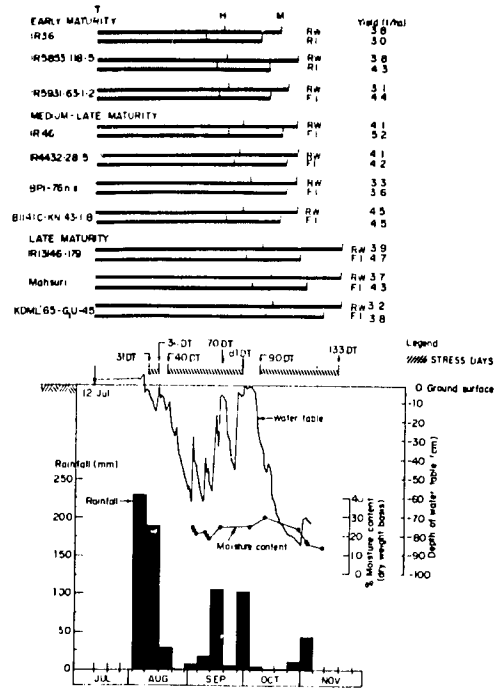
On the IRRI new farm the crop went through two short stress periods that coincided with the reproductive stage of growth of the early- and medium-maturing lines. The crop showed visible symptoms of drought stress around flowering time. The highest yields were from IR43, IR6115-1-1-1, and IR9669 Selection.

At a low-fertility, well-drained site at IRRI, the crop went through severe stress periods that coincided with the booting and flowering stages of

Table 11. Comparison of yields and number of days to heading of 17 selected lines and varieties grown at 3 sites as a dryland crop. IRRI, 1979 wet season.[a]

Variety or line	Santo Tomas		IRRI new farm		IRRI railroad site	
	DTH	Yield (t/ha)	DTH	Yield (t/ha)	DTH	Yield (t/ha)
IR43	102	4.7	104	3.6	126	0.3
IR45	107	3.3	104	2.8	130	0.3
IR3646-8-1-2	104	2.3	103	2.0	129	0.5
IR3646-9-1-1	99	3.1	100	2.2	128	0.5
IR4895-1-2-1	92	1.7	92	1.3	106	0.4
IR5178-1-1-3	74	1.3	74	0.6[b]	76	0.5
IR5440-1-1-3	90	3.3	94	2.2	114	0.1
IR5716-18-1	90	3.2	95	2.4	115	0.1
IR5853-118-5	101	3.0	99	2.8	128	0.2
IR5982-7-6-1	100	3.5	100	2.8	130	0.1
IR6023-10-1-1	100	3.4	100	2.6	128	0.6
IR6115-1-1-1	99	4.2	102	3.6	128	0.2
IR9669 selection	104	4.5	104	3.7	108	0.4
MRC 438	105	2.9	104	2.8	132	0.6
C 171-136	107	2.9	103	2.6	135	0.6
IR36 (check)	82	2.1	90	1.6	106	0.0
Kinandang Patong (check)	97	2.6	97	1.4	106	0.2

[a]DTH = number of days to heading. [b]Lodged plots.



3. Rainfall distribution, soil moisture content, depth of water table, stress days, growth duration, yields and drought reactions of 10 rices tested at Gapan, Nueva Ecija province, Philippines, 1979 wet season. A stress day is any day after 5 consecutive days without standing water in a paddy. T = transplanting, H = heading, M = maturity, RW = rainfed-wetland, FI = fully irrigated, DT = days after transplanting.

most entries. Grain yields were extremely low; IR36, IR2061-522-6-9, and IR3816-2-5-3 produced no grain at all. The highest yields were from IR6023-10-1-1, MRC 438, and C171-136, all of which have good recovery ability. IR6023-10 also had a high level of drought resistance at the vegetative phase.

Comparisons of yield performance and the number of days to heading of selected lines and varieties among the three test sites are shown in Table 11. The performance of the crop at the railroad site indicated that lines and varieties with high levels of drought resistance, good recovery ability, or elastic growth duration could still produce some grains even under severe stress. Several such lines performed better than the traditional check variety Kinandang Patong. IR5853-118-5, reported to be drought resistant in the greenhouse test and a top yielder in the national rainfed-wetland yield trials of the Philippines, produced only 0.2 t/ha — the same as Kinandang Patong. Moreover, it produced only 3.0 t/ha in a farmer's field in Batangas and 2.8 t/ha at the IRRI new farm.

DROUGHT RESISTANCE IN RAINFED WETLAND CULTURE

Plant Breeding, Irrigation Water Management, and Agronomy Departments

Yield performance of 24 rices under 2 water regimes (*Plant Breeding and Irrigation Water Management*). Tests of promising lines in a farmer's field continued in Central Luzon in fully irrigated and rainfed plots. The rainfed plots underwent a prolonged stress period (Fig. 3).

The early-maturing lines markedly suffered

Table 12. Number of days to full heading and yield of 24 varieties and lines grown in fully irrigated (FI) and rainfed-wetland (RW) plots at Gapan, Nueva Ecija, Philippines, 1979 wet season.

Variety or line	Days to heading		Yield (t/ha)	
	FI	RW	FI	RW
IR34	92	105	4.1	3.3
IR36	78	88	3.0	3.8
IR44	89	97	4.3	3.6
IR46	90	97	5.2	4.1
IR3464-126-1-3	100	112	4.2	3.6
IR3646-9-2-1	90	95	4.2	3.4
IR3880-17-3	89	97	4.0	3.3
IR4219-35-3-3	110	120	3.9	3.0
IR4432-28-5	93	96	4.2	4.1
IR5420-1-1-2	79	79	4.2	3.0
IR5853-118-5	[illegible]	89	4.3	3.8
IR5873-9-1	86	92	4.6	3.4
IR5931-63-1-2	85	90	4.4	3.1
IR9264-321-3	108	119	4.1	2.1
IR10168-52-4-2	87	90	5.1	3.8
IR10781-75-3-2	98	106	4.4	3.6
IR13146-179	100	109	4.7	3.9
IR14753-70-2	91	97	3.7	3.5
8PI-76 n.s.	92	101	3.6	3.3
C166-133	90	98	4.2	3.4
Mahsuri	103	114	4.3	3.7
KDML'65-G_1U-45	111	115	3.8	3.2
B865C-Mr-144-3-1-2	90	97	4.7	3.8
B1141C-Kn-43-1-8	89	97	4.5	4.5

from the drought before heading — the yield differences between fully irrigated and rainfed plots amounted to about 1 t/ha. The medium-maturing lines showed a smaller difference between the two treatments. The late-maturing entries were visibly affected by drought during October. However, the reduction in yield of the 3 late-maturing lines in the rainfed plots — from 0.6 to 0.8 t/ha — was rather small compared with that in the fully irrigated plots.

IR46, IR4432-28-5, and B1141C-Kn-43-1-8 — from the medium-late maturing group — were the best performers with yields ranging from 4.1 to 4.5 t/ha (Table 12). IR46 showed the greatest difference in yield between the rainfed and the irrigated treatments. Similar to IR46, IR10168-52-4-2 produced 5.1 t/ha in the irrigated treatment, but the yield dropped to 3.8 t/ha in the rainfed regime.

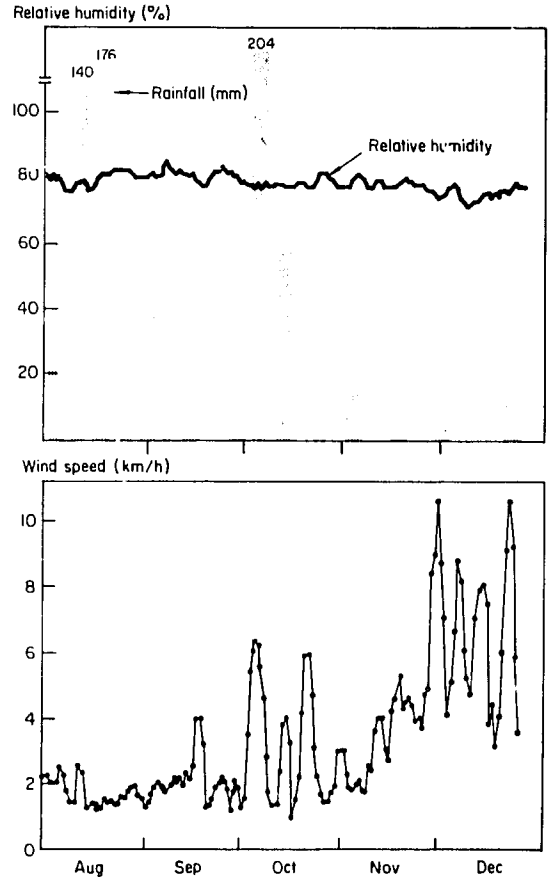
At the Talavera site, the crop underwent a prolonged stress period starting 18 days after transplanting. The crop stand was uneven and several entries had a large number of dead plants. The total precipitation from transplanting to harvest was only 276.3 mm. Because of uneven stand in many plots, yields were not reliable and could not be compared with those obtained from the fully irrigated and the rainfed plots of Gapan. The yields from those plots with a full stand ranged from 1.3 to 2.4 t/ha only.

Rainfed wetland yield nursery for drought-prone areas (*Agronomy*). A rainfed wetland yield nursery for drought-prone areas was grown at Guimba, Nueva Ecija, at the end of the 1979 wet season. The entries (selected varieties and lines from the 1978 International Rainfed Lowland Rice Observational Nursery and from the IRRI breeding program) consisted of 10 each of 4 maturity classes — very early (<105 days), early (105-115 days), medium (115-130 days), and late (>130 days). Fertilizer was applied at 100-30-0 with nitrogen as urea in split application. The nursery was transplanted 13 August and 1 September.

All entries in the first transplanting, except IR9995-65, had higher yield than those in the second (Table 13). A high amount of rainfall from August to mid-October kept all the plots in the first transplanting well watered until harvest time. Wind speed was slow from August to September (Fig. 4).

The second transplanting had a generally low yield because of low rainfall from mid-October to December, which subjected the plants to moisture stress at the reproductive stage. Wind speed generally increased during November-December, causing higher evapotranspiration.

A comparison of the yields of the well-watered and stressed plots (Table 13), identified IR9129-161-2, IR5853-198-1-2, and IR7149-35-2-3-2 as promising drought-resistant lines among the 40 entries. IR9209-26-2, IR3941-25-2, Salumpikit, IR2823-103-5-1, and IR4707-14-3-1 also had small yield differences between the well-watered and stressed plots.



4. Weekly rainfall, 3-day moving average of mean daily wind speed and relative humidity for evaluation of a rainfed yield nursery for drought-prone areas at Guimba, Nueva Ecija province, Philippines, 1979.

Table 13. Grain yield[a] and maturity of 40 entries in the rainfed lowland yield nursery for drought-prone areas. Guimba, Nueva Ecija, Philippines, 1979 wet season.

Entry	13 Aug first transplanting		1 Sep second transplanting	
	Yield (t/ha)	Maturity	Yield (t/ha)	Maturity
IR14753-72-3	5.0 a	132	2.0 abcdefgh	110
IR5853-198-1-2	4.9 ab	132	2.3 abcde	118
IR4570-83-3-3-2	4.8 abc	140	2.1 abcdefgh	117
IR32	4.6 abcd	129	2.2 abcdef	110
IET 1444	4.6 abcd	112	2.5 abc	110
IR4707-140-1-3	4.5 abcd	126	1.9 bcdefgh	111
IR5623-189-3	4.5 abcd	132	2.1 abcdefgh	116
IR26	4.4 abcde	132	1.5 cdefghi	112
IR9129-161-2	4.1 abcdef	112	2.9 ab	110
IR2307-437-3-1-2	4.1 abcdef	117	2.1 abcdefg	111
IR1529-430-3	4.1 abcdef	129	2.1 abcdefgh	111
IR2823-103-5-1	4.0 bcdefg	126	2.2 abcdef	114
IR4707-14-3-1	4.0 bcdefg	128	2.4 abcde	116
Gama 318	3.9 cdefgh	129	1.7 cdefghi	110
IR20	3.8 cdefgh	129	1.3 defghi	110
IR5629-64-3	3.8 cdefgh	117	1.5 cdefghi	110
IR9209-26-2	3.8 cdefgh	108	2.5 abc	103
IR3941-25-2	3.8 cdefgh	105	2.4 abcd	105
IR13426-19-2	3.7 cdefghi	132	1.1 ghi	115
MR 7	3.7 cdefghi	127	1.7 cdefgh	114
8G 35-2	3.7 defghi	117	1.8 cdefgh	110
IR7149-35-2-3-2	3.7 defghi	107	3.0 a	108
B462B-PN	3.5 defghij	126	1.3 defghi	110
IR3464-96-3-3-1-3	3.5 defghij	133	1.1 ghi	120
IR3464-96-3-3-1-1	3.5 defghij	133	1.0 hi	120
IR9129-192-2	3.5 defghij	108	2.1 abcdefgh	103
B441B-126-3-2-1	3.4 efghij	132	1.3 efghi	115
IR9764-45-2-2	3.3 fghij	137	1.2 fghi	110
IR5817-45-3	3.1 fghijk	140	1.5 cdefghi	122
Palawan	3.1 fghijk	129	1.6 cdefghi	115
C22	3.1 fghijk	132	1.4 cdefghi	111
IR5931-110-1	3.0 fghijk	117	1.2 efghi	110
B2039C-KN-7-2-5-3-1	3.0 ghijk	123	1.8 bcdefgh	110
IR5716-45-1	2.8 hijkl	117	1.6 cdefghi	110
B1050C-MR-26-2	2.8 hijkl	132	1.8 cdefgh	113
IR6217-3-2	2.7 ijkl	129	0.6 i	110
IR7790-18-1-2	2.5 jkl	120	1.3 efghi	110
Salumpikit	2.5 jkl	110	2.1 abcdefgh	110
IR3304-23	2.2 kl	117	1.6 cdefghi	110
IR9995-65	1.9 l	123	2.2 abcdef	110

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

In the well-watered plots (1st transplanting), high yields were distributed among all the maturity groups and maturity was delayed for almost all the varieties. In the stressed plots, however, the five highest yielding entries were in the very early-maturing group. Because maturity was hastened (or senescence was accelerated) for almost all entries, no entry could be classified as late maturing.

INTERNATIONAL COLLABORATION

Plant Breeding and Agronomy Departments

Regional evaluation of rice germplasm for drought resistance was continued in India, Indonesia, and Thailand, and the collaborative efforts on breeding for drought resistance were expanded in India and Thailand.

Evaluation of and breeding for drought resis-

tance (*Plant Breeding and Agronomy*). *India-IRRI*. A collaborative screening nursery for drought resistance in dryland culture was tested at eight sites within the drought-prone zone of India and at IRRI. The test materials consisted of the reputedly resistant varieties in the areas concerned and promising lines from Indian agencies and IRRI.

Ranchi (Bihar) received only 505 mm rainfall, which was about 50% of the average annual precipitation, and it was necessary to irrigate 2 replications of the nursery to compare reproductive growth among entries. The traditional varieties such as Black Gora, Brown Gora, and Kalakari survived the drought better than the breeding lines and produced some seed after irrigation.

Among the breeding lines, IR5178-1-1-4, D6-2-2, IAC 25, and OR165-5-12 were relatively better than the others. Early maturity and good recovery ability appeared to be essential components of drought resistance.

At Faizabad (Uttar Pradesh), only 25% of the normal 1,100-mm precipitation was received and 50% of the collaborative nursery was irrigated. The entries in the experiment and those observed at Ranchi had similar rankings.

An identical set of 22 varieties and lines were planted at IRRI in late August. There were dry spells in the early vegetative and early reproductive phases and results were the same as those in India.

Breeders of the Central Rice Research Institute, the Ranchi, Faizabad, and Mandya (Karnataka State) Rice Experiment Stations, and IRRI met and developed a plan to generate early-maturing genotypes with other improved features to serve the endemically droughty regions of India. The Indian collaborators will supply seed of donor parents for crosses at IRRI and the F_2 seed will be sent to the stations involved for selection under local conditions.

Indonesia-IRRI. A collaborative rainfed wetland nursery was planted at Ngale, in East Java, in February. Much of the experiment was damaged by brown planthopper and no yield data were obtained.

Thailand-IRRI. Varieties were tested in both dryland and rainfed-wetland conditions at three sites in Northeast Thailand. In the collaborative rainfed-wetland experiment, IR3880-13-10 and B98ld-Si-46 appeared promising at the heading stage. Among the entries with later maturity, RD15 and several IRRI lines looked vegetatively vigorous.

In the dryland screening, the most drought-resistant entries were Thai hill rices, IAC lines of Brazil, the traditional varieties of the Philippines, and several aus varieties of Bangladesh. Four IR dryland breeding lines also showed high levels of drought resistance: IR5179-2, IR3880-10, IR3880-13-10, and IR5178-1-1-4.

Deepwater rice drought screening (*Agronomy*). Seventeen rices were listed at IRRI as common entries to the international collaborative deepwater rice drought screening for 1979. Two sets of seeds of each variety or line were sent to Thailand and a set each to West Africa and West Bengal, India. A set was also included in the IRRI 1979 dry-season field screening for drought resistance. Two successive typhoons prevented the soil from reaching 10 bars SMT before the onset of the wet season.

Most of the rices were tolerant of 2 bars SMT. However, only KU 86, an accession from Thailand, was tolerant of 5 bars SMT (Table 14). A few entries, most of them deepwater varieties, were moderately resistant to 5 bars SMT. All rices tested had better drought ratings than the susceptible checks IR20 and IRAT 9.

ROOT STUDIES

Plant Physiology Department

Screening for deep-root system. The deep root-shoot ratio and some agronomic characteristics of 1,081 lines or varieties were tested by the root box technique.

Deep root-shoot ratio approximately represents the amount of roots that have deeply penetrated the soil (1974 annual report).

Two check varieties, OS4 and IR20, were included in every set of trials. The deep-root scores of entries were adjusted relative to those of check varieties whose deep root-shoot ratios varied from one set to another. Many entries had root systems as deep as, or deeper than, that of OS4 (Table 15) because more dryland rices than wetland rices were included in the screening trials. The deep-root scores and field ratings for drought resistance of some lines and varieties are listed in Table 16.

Table 14. Drought tolerance and recovery ratings of common entries in the international collaborative deepwater drought experiment. IRRI, 1979 dry season.

Designation[a]	Accession no.	Origin	Drought rating[b] 1st scoring (1–2 bars SMT) 26–27 Mar	2d scoring (4–5 bars SMT) 7 Apr	Recovery score[c] 21 Apr
BKN6986-147-2	39174	Thailand	3	5	1
FR 13A	6144	India	3	5	1
Khao Dawk Mali 105	27748	Thailand	1	3	1
KLG6986-165-P		Thailand	1	3	1
KU 86	15027	Thailand	1	1	1
Leb Mue Nahng 111	7819	Thailand	1	3	1
Nam Sagui 19	11462	Thailand	1	3	1
63-83	14725	Ivory Coast	1	3	1
IR442-2-58 (R ck)		IRRI	1	3	1
IR5853-118-5		IRRI	1	5	1
IR8098-152-1		IRRI	1	5	1
IR8103-120-3		IRRI	1	3	1
IR8151-23-2		IRRI	3	5	1
IR8234-174-3		IRRI	3	5	1
Salumpikit (R ck)	5423	Philippines	1	3	1
IRAT 9 (S ck)	28503	Ivory Coast	3	7	3
IR20 (S ck)		IRRI	3	7	1

[a]R = resistant, S = susceptible, ck = check. [b]SMT = soil moisture tension. SES 1–9 scale: 1 = no to negligible effect of soil moisture stress, 9 = all plants apparently dead. [c]SES 1–9 scale: 1 = all plants fully recovered, 9 = no plant recovered.

Simple correlation coefficients between deep-root score and agronomic characteristics are summarized in Table 17. Growth duration was not correlated with deep-root score. Deep-root score was negatively correlated with plant height. Deep-root score was positively correlated with tiller number, implying that low-tillering varieties tend to have deep root systems. However, there was good negative correlation between plant height and tiller number. The results simply summarized a common observation that dryland rice varieties are usually tall, low tillering, and deep rooted. The correlation between plant height and root system is not genetically linked.

Aluminum toxicity in rice. Aluminum toxicity is suspected to be a major factor limiting the production of dryland rice on acid soils and of wetland rice on acid sulfate soils. A wide range of varietal differences in tolerance for aluminum toxicity has been reported (1977 annual report). A series of experiments in 1979 studied the nature of aluminum toxicity.

Effect of aluminum on germination. Aluminum at concentrations from 0 to 60 ppm in solution had no influence on germination.

Effect of aluminum on the maximum and total

Table 15. Summary of screening for deep roots by the root box technique. IRRI, 1979.

	Deep-root score[a] 1	2	3	4	5	Total
Number	294	180	233	241	133	1081
Frequency	27.2	16.7	21.5	22.3	12.3	100.0

[a]Scoring system for deep root system.

Score	*Root characteristic*	*Check variety*
1	Very deep	–
2	Deep	OS4
3	Intermediate	–
4	Shallow	–
5	Very shallow	IR20

Table 16. Examples of deep-root score of lines and varieties and their field rating of drought resistance. IRRI, 1979.

Deep-root score	Variety	Drought resistance[a]
1	Moroberekan	R
1	Seratus Malam	R
1	20 A	R
1	Rikuto Norin 21	R
1	OS6	MR
2	E425	MR
2	M1-48	R
2	OS4	R
2	Azucena	MR
2	Magsanoya	MR
3	Miltex	MR
3	IR442-2-58	I
3	Dular	R
3	Kandingog	MR
3	RP79-16	MR
4	IR5	I
4	IR8	I
4	C22-51	I
4	Pelita I/1	I
4	IR127-80-1	I/MS
5	IR20	MS
5	TN1	S
5	MRC 172-9	MS
5	IR1416-131-5	MS
5	IR2035-117-3	I

[a]Rated by Plant Breeding Department: R = resistant, MR = moderately resistant, I = intermediate, MS = moderately susceptible.

root length. Aluminum impaired both maximum and total root length (Table 18). At 3 ppm, it affected only susceptible varieties; at 10 ppm, however, it damaged severely all the varieties tested. Modern wetland varieties such as IR5, IR8, and CICA 4 have large values of total root length relative to the maximum root length (Fig. 5). These data imply that aluminum impairs both elongation and branching of roots.

Effect of aluminum on water uptake. Aluminum may affect water uptake by rice roots through

Table 17. Correlation coefficients for 1,081 entries screened for deep-root system. IRRI, 1979.

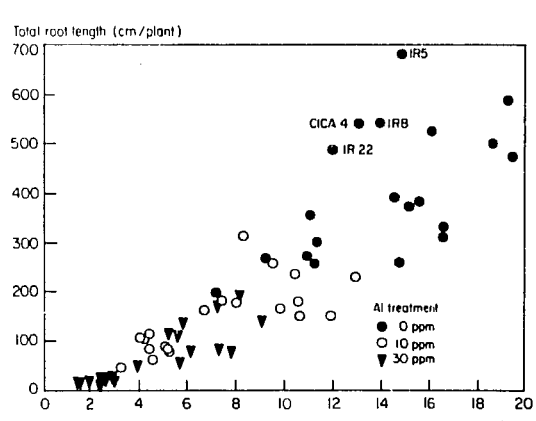
	Plant ht	Tillers (no.)	Deep-root score
Days to flowering	0.13**	0.16**	0.11*
Plant height		−0.46**	−0.45**
Tiller number			0.39**

Table 18. Effect of aluminum on the maximum and total root length of 6 varieties grown in culture solution.[a] IRRI, 1979.

Variety	0 ppm Al	3 ppm Al	10 ppm Al	30 ppm Al
	Maximum root length (cm)			
IR20	7.2	5.9	3.2	1.5
CICA 4	13.0	9.8	4.2	2.4
IR5	14.8	12.6	6.7	4.0
Bluebonnet	15.5	15.9	7.3	5.3
Monolaya	19.3	19.3	9.5	8.1
E425	19.5	16.7	12.9	9.1
	Total root length (cm/plant)			
IR20	194	112	46	19
CICA 4	539	282	98	13
IR5	686	385	163	56
Bluebonnet	380	370	176	119
Monolaya	587	464	258	194
E425	474	456	232	142

[a]Measurements were done 2 weeks after sowing of pregerminated seeds.

reduction in total root length or reduction in water uptake per unit length of root, or both. To study such effect, plants were grown with and without aluminum for 12 days; they were then divided into two groups and transferred to culture solutions with and without aluminum. Water uptake was measured by gravimetric method (Table 19). The total amount of water absorbed was larger for larger plants with longer total root length. Consequently, water uptake rate per unit length was almost constant (about 1.9×10^{-2} g/cm per 12 h) regardless of the pretreatment and the absence or



5. Relationship between maximum root length and total root length for 20 rice varieties grown in culture solution at 3 levels of aluminum content. IRRI, 1979.

Table 19. Effect of aluminum on water absorption by healthy and aluminum-pretreated plants of variety Palawan.[a] IRRI, 1979.

	Pretreatment 0 ppm Al			Pretreatment 30 ppm Al		
	0 ppm Al	10 ppm Al	30 ppm Al	0 ppm Al	10 ppm Al	30 ppm Al
Shoot						
Dry wt (g/6 plants)	0.80	0.89	0.89	0.35	0.37	0.35
Ht (cm)	33.8	34.2	34.8	22.8	24.4	22.4
Leaf area (cm^2/6 plants)	130	121	128	61	61	60
Root						
Dry wt (g/6 plants)	0.24	0.26	0.23	0.10	0.10	0.11
Longest root length (cm)	9.5	10.0	10.2	5.2	5.4	5.1
Total root length (cm/6 plants)	1500	1570	1640	675	655	700
Amt of water absorbed (g/6 plants per 12 h)	29.1	31.2	32.0	11.5	12.9	11.6
Water uptake rate per unit root length ($\times 10^{-2}$ g/cm per 12 h)	1.9	2.0	2.0	1.7	2.0	1.7

[a]Experimental conditions 12-day-old seedlings; 6 plants/1-liter pot; temp, 27°C; light intensity, 30 klx; humidity, 70%.

presence of aluminum at the time of water-uptake measurement. That indicated that aluminum impairs total root length but does not affect water uptake rate per unit length.

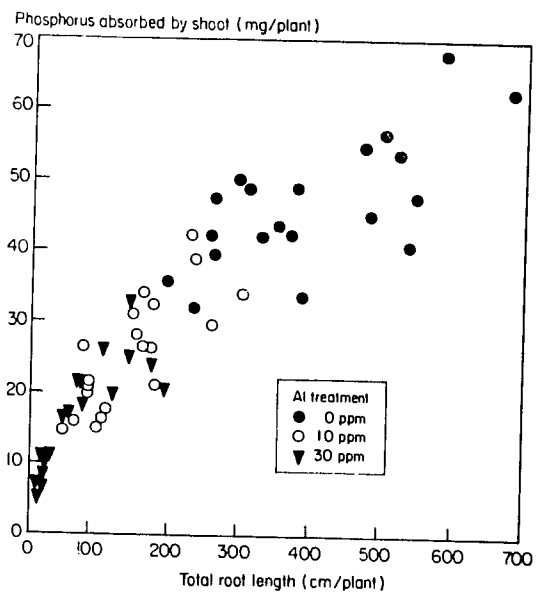
Effect of aluminum on phosphorus and aluminum content. The percentage of phosphorus in the plant is affected only by very high aluminum concentration (30 ppm) in culture solution (Table 20). The total amount of phosphorus absorbed by the plant, however, was closely related to total root length, which in turn was affected by aluminum (Fig. 6). Aluminum in the plant exceeded about 200 ppm when root growth was impaired by aluminum. However, the relationship between a plant's aluminum content and its tolerance for aluminum toxicity was not consistent.

Mode of aluminum toxicity in rice growth. The results of the aluminum toxicity experiments suggest that high concentrations of aluminum in the

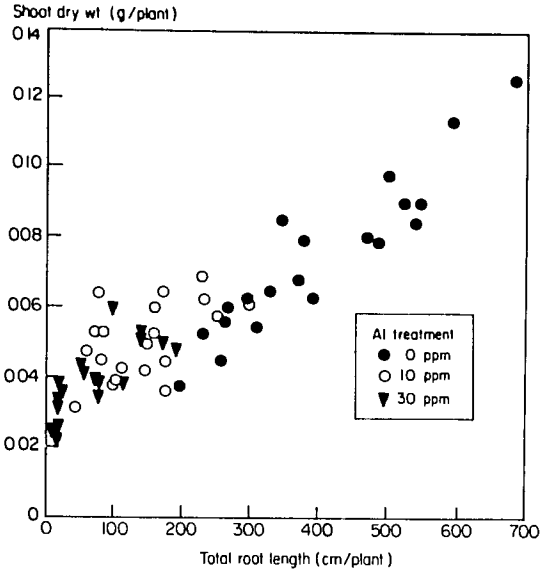
Table 20. Effect of aluminum on phosphorus and aluminum content of shoots of 6 varieties grown in culture solution.[a] IRRI, 1979.

Variety	0 ppm Al	3 ppm Al	10 ppm Al	30 ppm Al
	P (%) in shoot			
IR20	0.54	0.55	0.47	0.25
CICA 4	0.48	0.41	0.41	0.29
IR5	0.50	0.47	0.50	0.31
Bluebonnet	0.62	0.55	0.59	0.50
Monolaya	0.60	0.49	0.51	0.43
E425	0.69	0.70	0.61	0.63
	Al (ppm) in shoot			
IR20	103	332	369	421
CICA 4	65	99	203	1550
IR5	47	88	175	990
Bluebonnet	57	77	150	858
Monolaya	47	77	184	680
E425	85	145	283	366

[a]Measurements were done 2 weeks after sowing of pregerminated seeds.



6. Relationship between total root length and amount of phosphorus absorbed by shoots of 20 varieties grown in culture solution of 3 levels of aluminum content. IRRI, 1979.



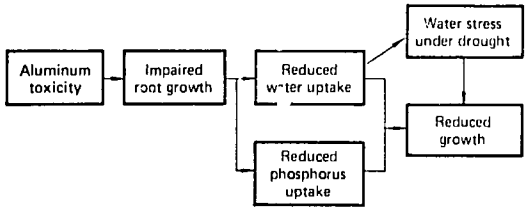
7. Relationship between total root length and shoot dry weight of 20 varieties grown in culture solution with 3 levels of aluminum. IRRI, 1979.

soil affect rice growth and yield by affecting root growth (reduction in total root length) in moist conditions. Shoot dry weight is closely correlated with total root length (Fig. 7). That may imply that total root length controls uptake of water and nutrients, which in turn controls the amount of growth. Under drought, aluminum-affected plants would suffer more water stress because the maximum root depth is shallower. Thus, aluminum toxicity is considered an important soil factor affecting drought resistance of rice (Fig. 8).

SOIL-PLANT-WATER RELATIONSHIPS

Agronomy Department

Drought tolerance under limited rooting



8. Mode of aluminum toxicity in rice growth. IRRI, 1979.

depth. Screening of rices for drought tolerance and the ability to recover from drought stress under limited rooting depth (about 45 cm) was continued.

Eighty-five elite breeding lines and 19 varieties and lines were seeded into dry soil to evaluate their drought tolerance at the vegetative stage. The entries were scored as soon as Leb Mue Nahng (grown with two other entries in a drum) was apparently dead. Immediately thereafter, soil moisture content was determined and the plants were watered.

Table 21 lists the entries that performed better than Leb Mue Nahng, and their drought tolerance and recovery scores. Recovery from drought 20 days after the relief from moisture stress was outstanding with IR5623-50-3-1, IR4432-28-5, and Kulawalai. Leb Mue Nahng did not recover. Table 22 lists selected entries from the 1979 wet season test. Differences in drought recovery visually observed 20 days after relief from stress were distinct. However, the entries' reaction to the relief from stress 40 days after rewatering was marked.

Reproductive stage water stress. In 1979, emphasis shifted from vegetative stage water stress to water deficits at the reproductive stages. In a

Table 21. Drought tolerance ratings at vegetative stage of promising GEU elite lines and some selected entries and their drought recovery scores 20 days after relief from water stress. IRRI greenhouse, 1979 dry season.

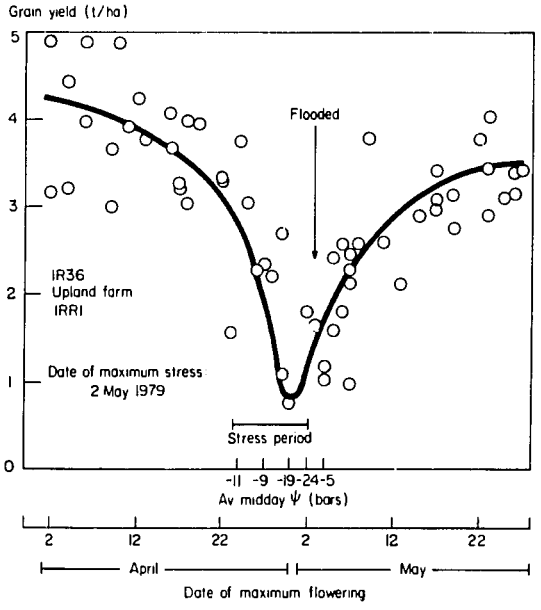
Variety or line	Drought tolerance rating[a]	Drought recovery[b]
IR5623-50-3-1	7	2
IR4432-28-5	7	3
Kulawalai	7	3
IR9846-215-3	7	4
IR3880-10	7	5
IR10781-143-2-3	7	5
IR5623-97-3	7	5
IR9805-97-1	7	5
IR9129-457-2-2-1-2	7	6
B44b-50-2-2-5-1	8	6
IR9814-6-3	8	7
IR5677-138-1-3	7	7
UCP 41	7	8
Leb Mue Nahng (tolerant check)	9	9

[a]Standard Evaluation System for Rice (SES) 1–9 scale: 1 = no to negligible effect of soil moisture stress, 9 = all plan apparently dead. [b]SES 1–9 scale: 1 = 90% of plants fully recovered, 9 = no plant recovered.

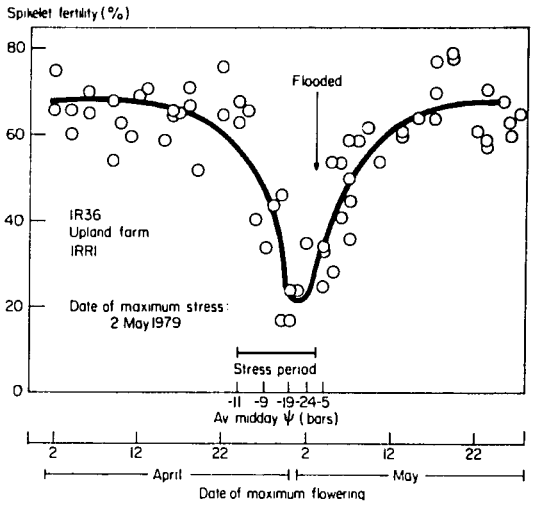
Table 22. Drought tolerance ratings at vegetative stage of promising GEU elite lines and some selected entries and their drought recovery scores 20 and 40 days after relief from water stress. IRRI greenhouse, 1979 wet season.

Variety or line	Drought tolerance rating[a]	Recovery from drought[b] 20 days	40 days
IR9209-262-3-6	7.0	8.0	4.0
IR9209-262-1-3-1	7.0	8.0	4.0
IR3646-9-3-1	8.0	8.0	5.0
IR2058-78-1-3-2-3	8.0	8.0	6.0
IR4683-19-3-3	7.0	8.0	7.0
IR5178-1-1-3	8.0	8.0	7.0
Cauvery	8.0	8.0	8.0
IR9788-19-2-3-3	8.0	8.0	8.0
IR8192-31-2-1-2	8.0	8.0	8.0
IR4570-117-2-1-2	7.0	6.0	3.0
IR9264-321-3	7.0	7.0	3.0
IR9860-26-2-2-2	7.0	6.0	4.0
IR7790-18-1-2	7.0	7.0	4.0
IR3680-65-6-1	7.0	7.0	5.0
IR43	7.0	8.0	5.0
IR2035-242	7.0	8.0	5.0
IR5179-2	7.0	8.0	5.0
IR2061-522-6-9	7.0	7.0	6.0
IR3839-1	7.0	8.0	6.0
IR6115-1-1-1	7.0	8.0	6.0
Leb Mue Nahng (tolerant check)	9.0	9.0	9.0

[a]Standard Evaluation System for Rice (SES) 1–9 scale: 1 = no to negligible effect of soil moisture stress, 9 = all plants apparently dead. [b]SES 1–9 scale: 1 = 90% of plants fully recovered, 9 = no plant recovered.



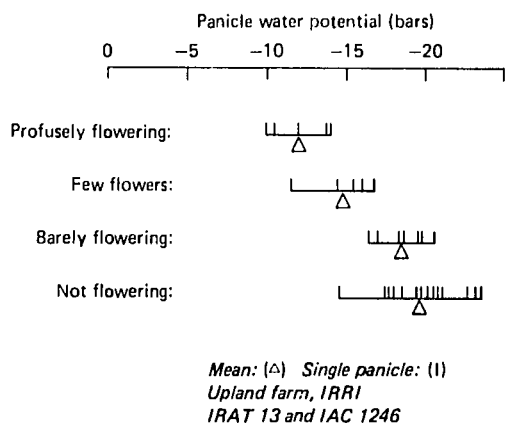
9. Effect of soil moisture stress on spikelet fertility. IRRI, 1979.



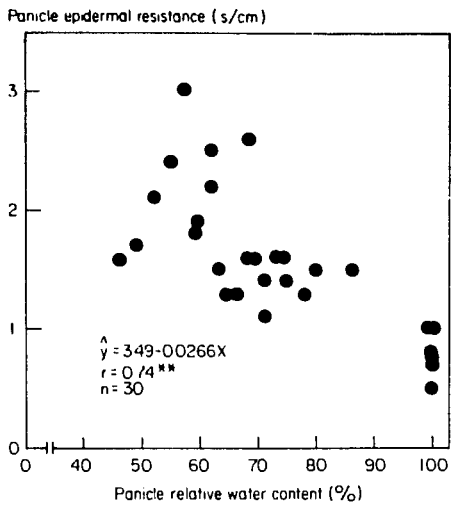
10. Effect of soil moisture stress on spikelet fertility. IRRI, 1979.

1979 dry-season experiment in dryland field plots, IR36 was planted on 16 different dates. The plants were subjected to stress simultaneously at 16 different growth stages.

During the stress period, the midday plant water potential dropped from −11 to −24 bars (Fig. 9). The field was irrigated on 3 May, resulting in midday plant water potential of −5 bars the following day, indicating that plants regained turgor. Yield was markedly affected by stress. When maximum flowering coincided with maximum stress, the yield dropped to about 1t/ha. Plots due to flower within 10



11. Flowering response of 2 upland rice varieties to different levels of stress.



12. Epidermal resistances of IR36 panicles at flowering. IRRI, 1979.

days after stress were also badly affected.

The yield reduction was mainly due to reduced spikelet fertility. Figure 10 shows that the fertility level dropped to about 20% in plots severely stressed at maximum flowering. Spikelet fertility, however, gradually increased after water stress was relieved.

The results indicate that low spikelet fertility is a primary factor determining grain yield during stress but the actual cause of high sterility in a stressed field was not determined.

Flowering and panicle water relations. A preliminary study suggested that there is a threshold panicle water potential for flowering (Fig. 11).

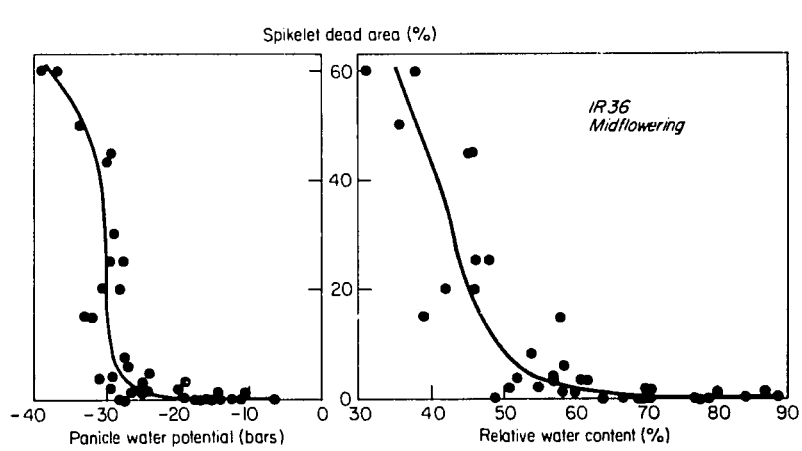
The panicle water potentials of IRAT 13 and IAC 1246, both dryland varieties from a stressed field, were measured with a pressure chamber during the normal flowering time of rice (0930-1100). Panicles suffering from severe stress (−14 to −24 bars) did not flower but those that experienced only a mild stress (−10 to −13 bars) flowered profusely.

The occurrence of *white areas* in the spikelets, observed in severely stressed plants, suggested that there was very little control of water loss in the inflorescence.

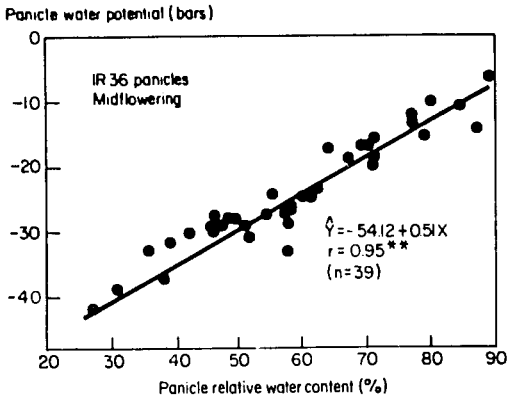
Epidermal resistance of IR36 panicles to water loss at flowering were measured at full turgidity and at different water contents. The panicle resistance of IR36 ranged from 0.5 to 1.0 s/cm at fully turgid condition (Fig. 12). Panicle resistance was negatively correlated with panicle relative water content. Epidermal resistance increased only slightly with decreasing panicle relative water content.

In a separate study, the occurrence of *white area* increased with decreasing panicle relative water content and water potential (Fig. 13). In IR36 spikelet desiccation rarely occurred at water potential above −20 bars or relative water content above 65%.

A significantly positive relationship (r = 0.95) of panicle water potential and panicle relative water content (Fig. 14) suggested that either of the two expressions can be used to relate the water status of the whole rice panicle to the dying of the spikelet.



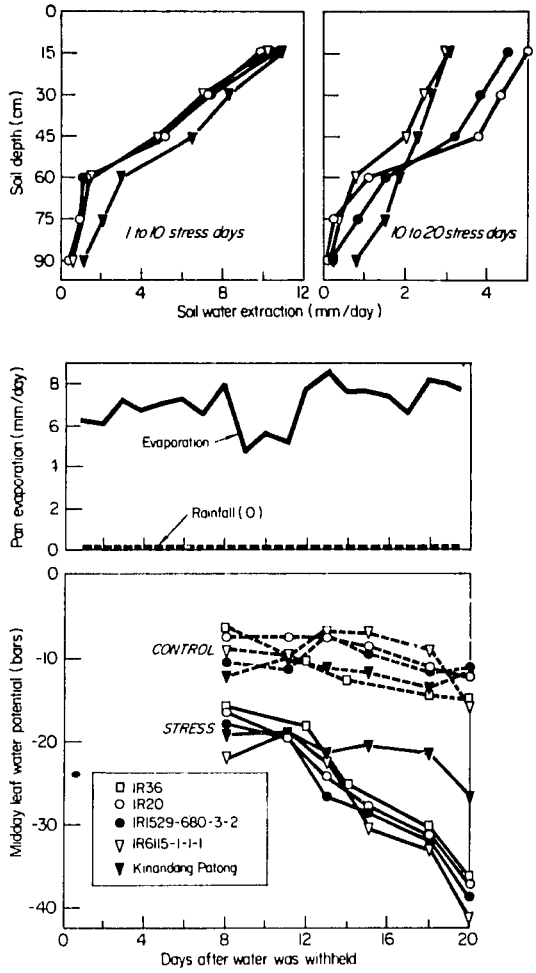
13. Effect of water stress on the occurrence of spikelet dead area. IRRI, 1979.



14. The relationship of panicle water potential and panicle relative water content. IRRI, 1979.

Effects of water stress at flowering on yield quantity and quality. Water was withheld from five rices for 20 days at the reproductive stage (Fig. 15). The Philippine traditional dryland cultivar Kinandang Patong depleted most of the stored soil moisture at all profile depths in the first 10 days and that below 60 cm in the last 10 days. This capability to extract water is reflected in the higher midday leaf water potentials exhibited. Figure 16 illustrates the developmental stage of each cultivar at the end of the stress period, when all cultivars, except IR1529-680-3-2, were at the flowering-heading stage. IR1529-680-3-2, which was at panicle initiation stage, *escaped* the effect of moisture stress at flowering seen in the other rices. The occurrence of the moisture stress increased the days to maturity of some entries by about 3 weeks. Table 23 illustrates the components of yield reduction shown in Figure 16. Quality of grain also decreased as a result of reproductive stage water stress. Figure 17 illustrates the degree of grain discoloration by portion of panicle. The better score of Kinandang Patong may be associated with its relatively higher water potential during the stress period, which caused less desiccation of glumes or occurrence of whiteheads. Grain discoloration was associated with the incidence of sheath rot disease caused by *Acrocylindrium oryzae* on the panicles.

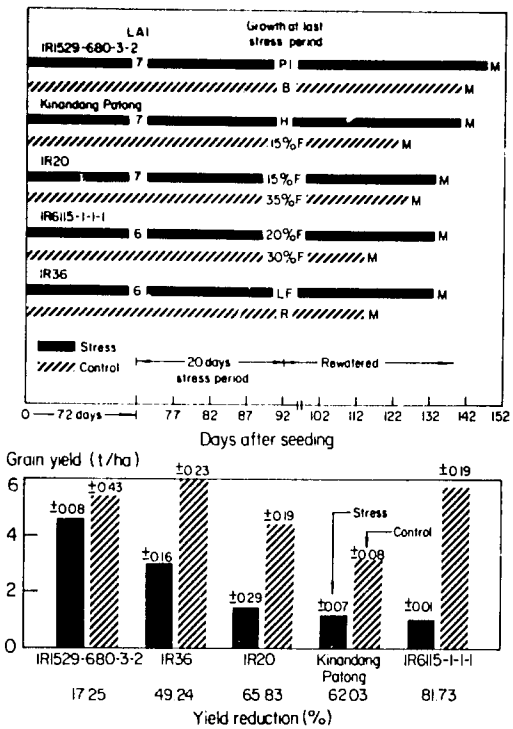
Osmotic adjustment in rice. Lowering of the osmotic potential by osmotic adjustment, which enables the plant to maintain turgor at low water potential, is an important drought tolerance mechanism.



15. Pan evaporation, midday leaf water potential, and soil water extraction rate during drought stress in the rice field. IRRI, 1979. (Note the difference in scale in bottom figure and the absence of water extraction data for IR36).

The osmotic potential of several rice cultivars grown in irrigated conditions was evaluated. Seasonal changes in the osmotic potentials ranged from −9.3 to −11.3 bars for crops grown in the wet season and from −12.4 to −14 bars for those grown in the dry season (Table 24). Seasonal radiation levels appeared to influence the magnitude of solute potential.

In a greenhouse experiment to evaluate osmotic adjustment in rice leaves in response to water deficit, IR36 and Dular were grown under flooding in 100-liter (shallow) and 200-liter (deep) containers for 45 days, after which water was withheld.



16. Phasic development, leaf area index (LAI), grain yield, and percentage of yield reduction of 5 rice cultivars grown under control and stress treatments. PI = panicle initiation, B = booting, H = heading, F = flowering, LF = late flowering, R = ripening, M = maturity. IRRI, 1979. S.E. values above bars.

Dawn water potential measurements were made on the second youngest fully expanded leaf, and tiller samples at dawn were brought to full turgidity before osmotic potentials of similar leaves were determined by psychrometric technique. Figure 18 presents the relationship between turgid osmotic potential and dawn water potential.

The varietal difference between osmotic potentials of stressed leaves was attributed to rate of stress development. Dular suffered stress earlier than IR36, which possibly limited further net increase in solute content or further lowered osmotic potential. Most plants (IR36) grown in deep containers maintained high dawn water potential (> −5 bars) for a longer period of stress and had low solute potentials.

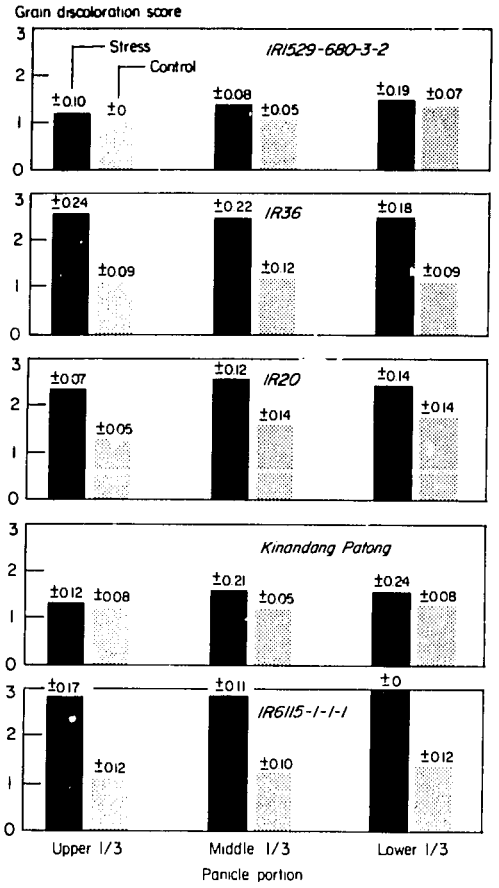
In shallow containers dawn water potential of less than −5 bars was reached in 12-16 days in Dular and in 19-22 days in IR36 (Fig. 19). Both cultivars adjusted osmotically (Fig. 20).

Lower limit of available water for rice during drought. In the greenhouse, IR36 and Dular were grown in clay, loam, and sand in shallow (35-cm-deep soil, 100-liter capacity) and deep (75-cm-deep soil, 200-liter capacity) containers. Soils of varying water retention and transmission characteristics were artificially produced by amending

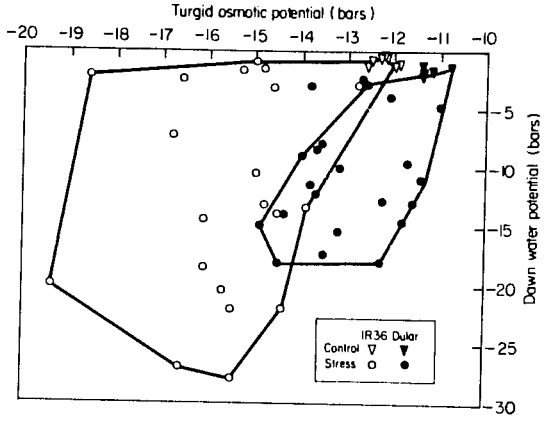
Table 23. Effects of stress on tagged panicles that were flowering[a] during peak stress period. The data are of subsamples tagged at peak stress, not of yield components of the large plots. IRRI, 1979.

	Filled grains (% panicle)	Grain wt per panicle (g)	Grains (no./panicle)	Panicle length (cm)
		IR1529-680-3-2		
Stress	74.26 ± 3.87	1.79 ± 0.03	106 ± 5	21.17 ± 0.44
Control	92.93 ± 1.01	2.89 ± 0.28	102 ± 13	22.12 ± 0.87
		IR36		
Stress	57.80 ± 4.80	1.63 ± 0.14	137 ± 7	20.24 ± 0.31
Control	95.70 ± 1.31	2.31 ± 0.41	121 ± 5	19.94 ± 0.06
		IR20		
Stress	0.78 ± 0.55	0.16 ± 0.04	127 ± 12	20.53 ± 0.62
Control	86.17 ± 1.03	1.92 ± 0.17	102 ± 7	20.93 ± 0.67
		Kinandang Patong		
Stress	45.11 ± 18.88	1.34 ± 0.59	123 ± 16	20.80 ± 0.52
Control	91.57 ± 2.27	4.05 ± 0.44	195 ± 26.31	24.23 ± 1.26
		IR6115-1-1-1		
Stress	0	0.16 ± 0.01	110 ± 8	19.32 ± 0.50
Control	94.69 ± 1.06	1.83 ± 0.18	101 ± 5	20.14 ± 0.38

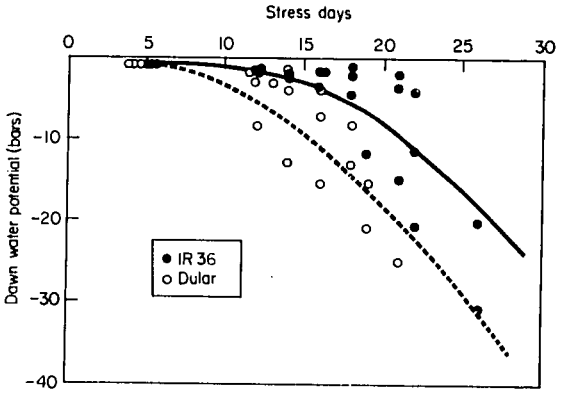
[a]With the exception of IR1529-680-3-2 which was at the panicle initiation stage.



17. Grain discoloration (1 = normal grain color, 3 = whole grain discoloration) associated with moisture stress at flowering (except for IR1529-680-3-2, which flowered after stress period). IRRI, 1979. S.E. values above bars.



18. Relation between dawn water potential and turgid osmotic potential of rice leaves. IRRI, 1979.

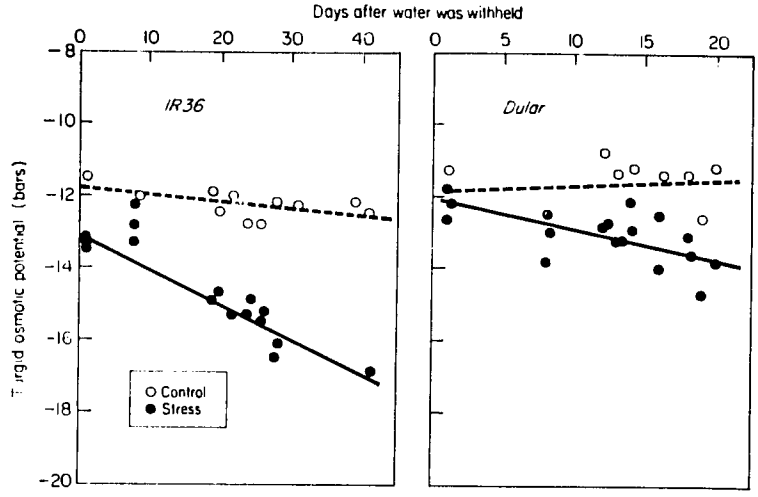


19. Changes in dawn leaf water potential in IR36 and Dular grown in 100-liter containers during stress period. IRRI, 1979.

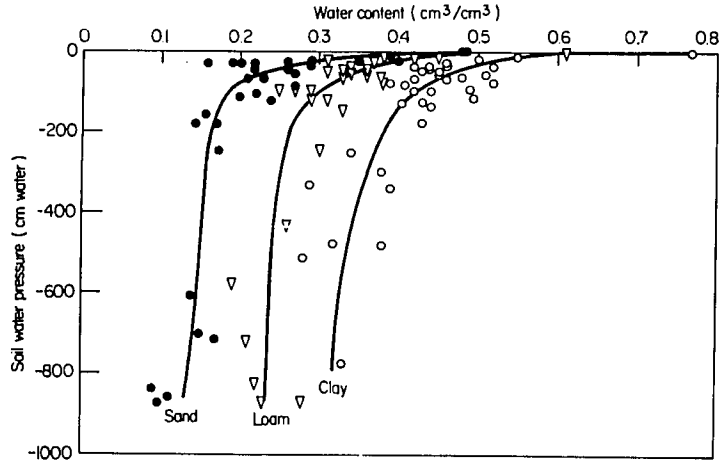
Table 24. Osmotic potentials of rice leaves grown in different seasons. IRRI, 1979.

Condition[a]	Osmotic potential (bars)	Date of sampling	Solar radiation[b] (cal/cm² per day)	Temp[c] (°C) Max	Temp[c] (°C) Min
1. Wetland-irrigated DS (4 varieties)	−14 ± 0.3	9 Jan 1979 16 Jan 1979	393.7	29.8	20.5
2. Dryland-irrigated DS (6 varieties)	−13.7 ± 0.3	1 Mar 1979 9 Mar 1979	533.1	33.5	20.9
3. Wetland-irrigated DS (8 varieties)	−12.4 ± 0.3	22 Mar 1979	550.8	33.5	20.9
4. Dryland-irrigated WS (6 varieties)	−11.3 ± 0.3	28 Sep 1979	451.1	31.5	22.7
5. Dryland field WS (5 varieties)	−9.7 ± 0.4	22 Nov 1978	392.6	29.8	22.7
6. Greenhouse-well watered (flooded) WS (2 varieties)	−9.3 ± 0.1	23 Nov 1977– 21 Dec 1977	365.8	25.7	19.8

[a]DS = dry season, WS = wet season. [b]Mean of 20 days. [c]Monthly mean for date of sampling.



20. Changes in turgid osmotic potential in IR36 and Dular grown in 100-liter containers during stress period. IRRI, 1979.

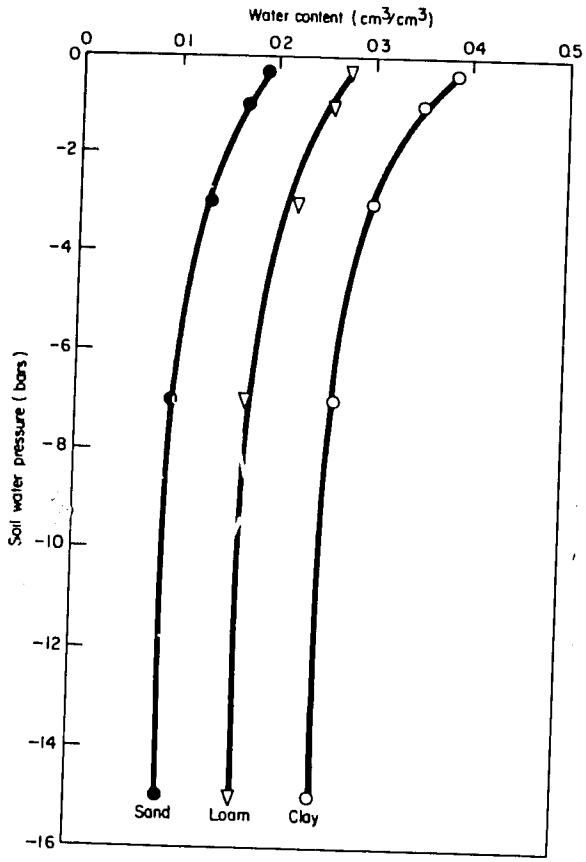


21. Pressure-water content relationship in the tensiometer range of 3 greenhouse soils. IRRI, 1979.

clay with sand (Fig. 21, 22; Table 25). Twelve hills were transplanted in each container and grown in flooded soil for 45 days. At that time control plants were left in flooded soil and water was withheld to stress the test plants. Results for shallow and deep soils were similar except in the time taken to extract the profile water. Therefore, only results for the deep soils are presented.

Soil water depletion. Successive water-content profiles for the three soils in which IR36 and Dular were grown are shown in Figure 23. Water content profiles for clay and loam soils differed little at the end of the experiment (25 Dec-12 Jan). Water content profiles differed appreciably in sand under IR36 and Dular.

Soil water content and water use at different times during stress are shown in Table 26. Even though the time taken to reach the lower critical limit of water content differed in different soils, the profile water content, irrespective of cultivar, was virtually the same in a given soil. This threshold water content for clay, loam, and sand in the active root zone was 0.27, 0.19, and 0.11 cm^3/cm^3, which corresponded to −7.0, −5.0, and −5.0



22. Pressure-water content relationship to -15 bars of 3 greenhouse soils. IRRI, 1979.

bars soil water potential, respectively.

Leaf water potential. Changes in predawn and midday leaf water potentials are illustrated in Figure 24. Predawn values of leaf water potential remained constant over a long period of stress. When soil water content decreased to a critical value, predawn values of leaf water potential decreased to less than −15 bars within a few days, with little subsequent change in soil water content. The trend was similar for both the cultivars in all the soils. During day hours, plants experienced low midday water potential much before the critical soil water content was reached.

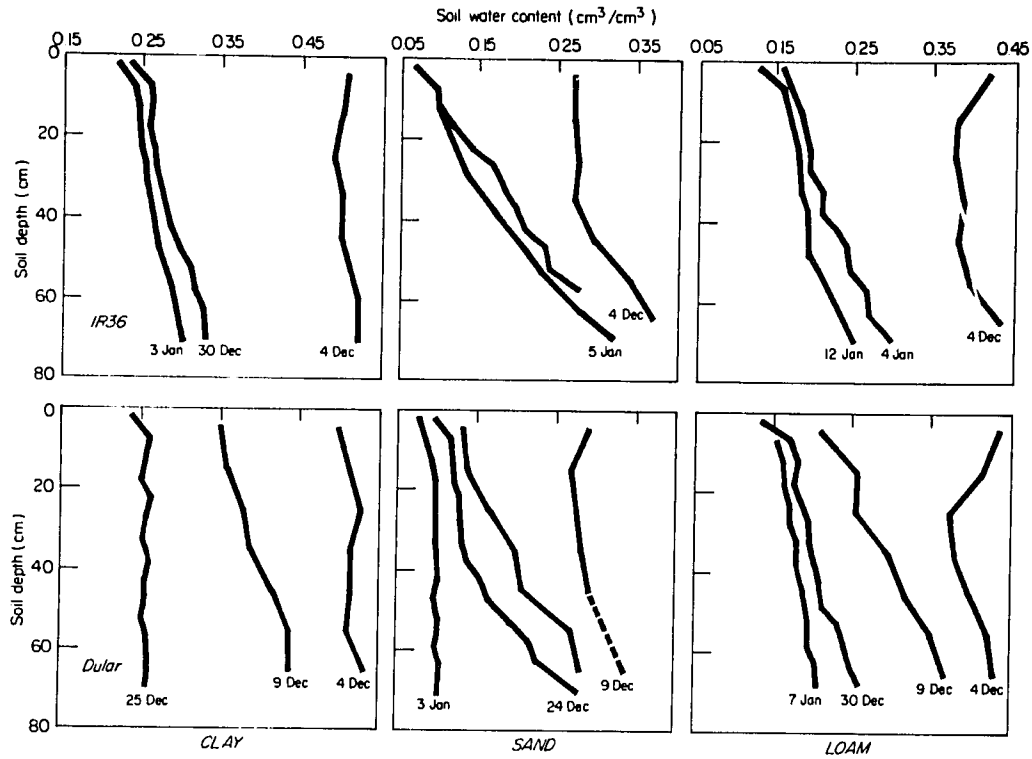
Root length density. Root length density of the cultivars decreased with depth in all the three soils (Fig. 25). At greater depths, however, Dular had relatively higher density than IR36, although IR36 also had as high density as Dular at all depths in clay.

Evaluation of the line source sprinkler system as a drought screening method. Numerous screening techniques to evaluate rice plant response to drought have been used at IRRI. During the 1979 dry season, a new irrigation technique, the line source sprinkler system, was tested for possible use in drought screening of elite germplasm. The sprinkler maintained variable water application rates across plots, and allowed an assessment of the effect of different levels of water supply on growth and development of contiguous plots. The sprinkler layout, water distribution pattern, and resultant crop growth are illustrated in Figure 26. IRRI's IR20 and IR36, selected for wetland culture, and Kinandang Patong, a traditional Philippine upland variety, were sown and the area was uniformly watered from sowing (day 0) to day 23 with 3 sets of sprinklers. The 2 outer sets were then removed and the number of sprinklers on the line source was increased to give a spacing of 6.1 m between sprinklers (Fig. 26). The irrigation schedule aimed at a highest application rate — measured 0.75 m from the line — of 20% more than pan evaporation.

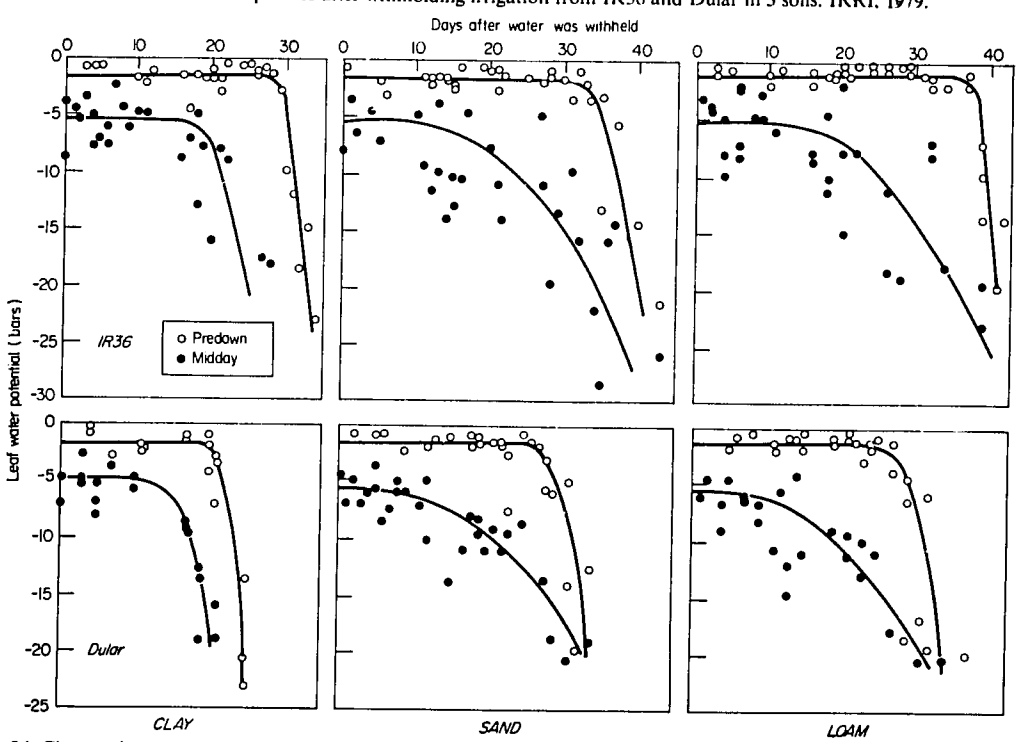
Figure 27 illustrates the linearity of water application across the plots on day 47, 61, 96, and 114. Figure 28 shows the irrigation, pan evaporation, and rainfall during the experiment. A typhoon occurred before the experiment was completed and thus grain yield was not obtained. However, sampling of dry weight of shoots and monitoring of

Table 25. Physicochemical properties of soils used in greenhouse experiments. IRRI, 1979.

Soil	Place	Bulk density (g/cm³)	%				pH (1:1)	Ec, mmho (1:1)
			Sand	Silt	Clay	Org. C		
Clay	Greenhouse	1.19	33.3	36.5	30.2	0.88	6.77	0.653
Loam	Greenhouse	1.37	68.3	17.1	14.6	0.52	7.57	0.896
Sand	Greenhouse	1.45	86.2	7.6	6.2	0.26	7.70	0.757



23. Succesive water content profiles after withholding irrigation from IR36 and Dular in 3 soils. IRRI, 1979.



24. Changes in predawn and midday leaf water potential of IR36 and Dular in 3 soils. IRRI, 1979.

Table 26. Soil water content and water use during stress period in 3 soils.[a] IRRI, 1979.

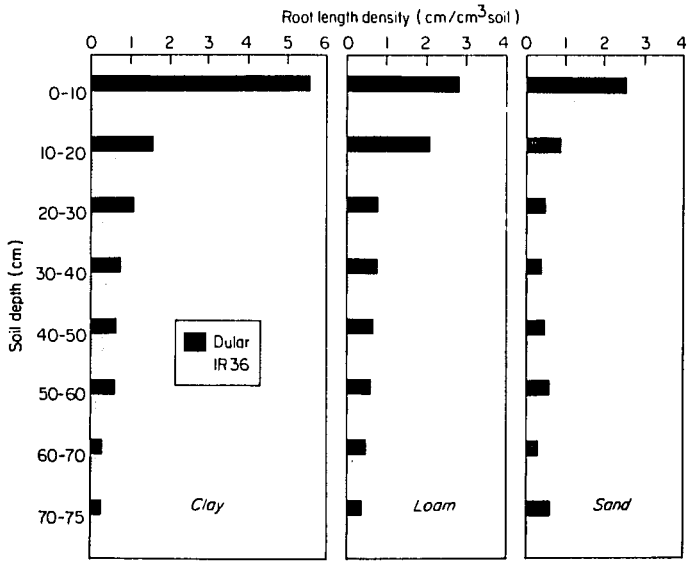
Period	Soil depth (cm)	Clay		Loam		Sand	
		Water content (cm^3/cm^3)	Cumulative[a] water use (cm)	Water content (cm^3/cm^3)	Cumulative water use (cm)	Water content (cm^3/cm^3)	Cumulative water use (cm)
			IR36				
Three days of withholding water	0–75	0.501		0.398		0.298	
At lower limit	0–45	0.264		0.183		0.121	
At lower limit	45–75	0.316	14.93 (25)[b]	0.242	14.60 (35)	0.248	9.66 (31)
			Dular				
Three days of withholding water	0–75	0.522		0.408		0.311	
At lower limit	0–45	0.271		0.193		0.111	
At lower limit	45–75	0.280	18.54 (20)	0.222	15.29 (27)	0.160	13.61 (27)

[a]Numbers in parentheses refer to stress days required to reach the lower limit. [b]Water use was for 0–75 cm soil depth.

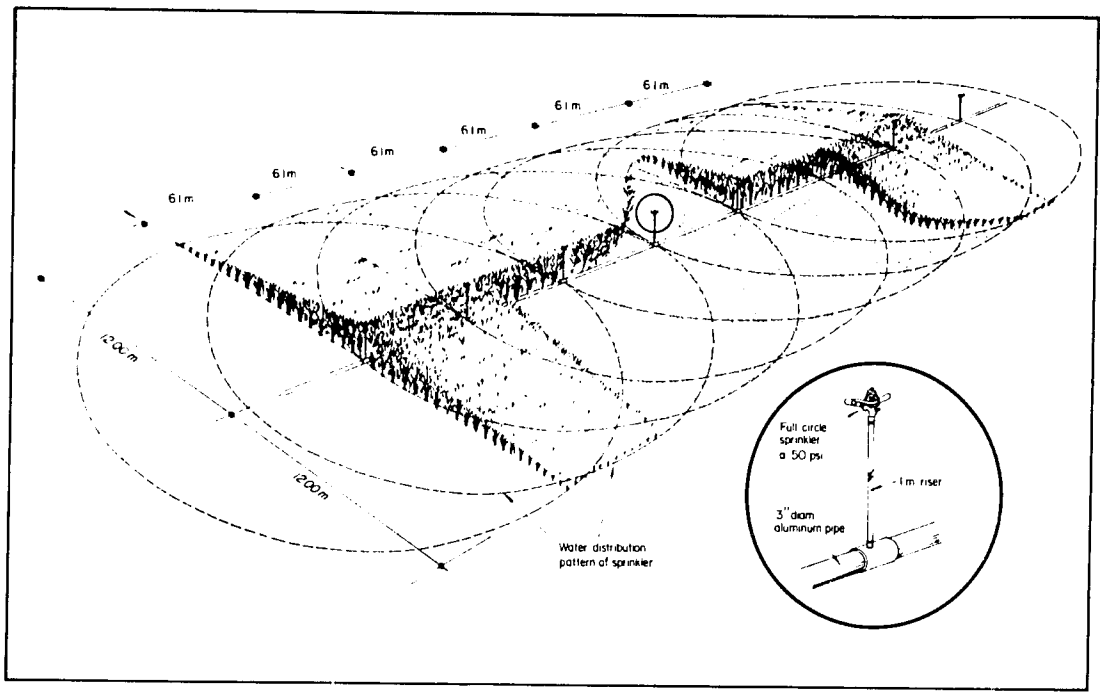
soil-water depletion provided information that illustrates the potential of this technique for screening and for many types of dry season research where a gradient of water application is desired.

Figure 29 shows the dry weight of tops of the three rices in relation to the water applied. Initially, the relationship for Kinandang Patong appeared different from that for the two IR varieties. However, the soil water used by the varieties was also measured by a neutron probe, which showed little difference among the rices (Fig. 29). Thus, Kinandang Patong's apparent higher water-use efficiency is really a more effective absorption or root system, as illustrated in Figure 30.

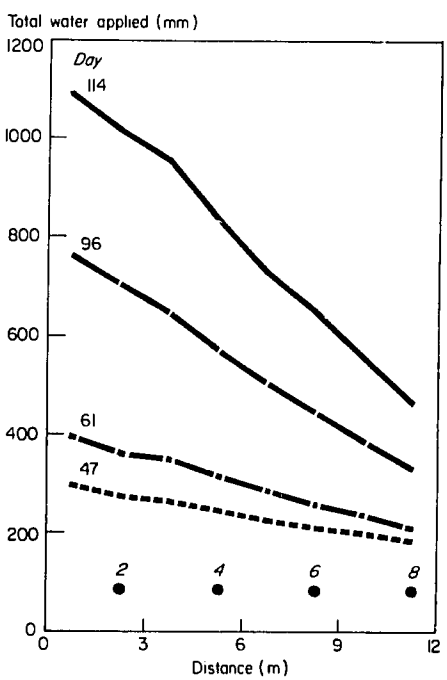
Effect of water stress on nitrogen uptake and yield. Reduced crop growth rate and enhanced nutrient-deficiency symptoms during drought indicate that low utilization of applied fertilizer may indirectly influence crop yield. A dry season field trial with IR36 measured the nitrogen uptake and rice yield under different water regimes and nitrogen fertilization. Treatments and the effect of



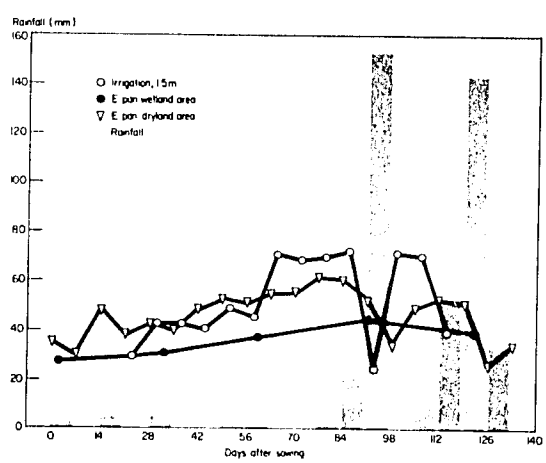
25. Root length density patterns of IR36 and Dular different layers of 3 soils. IRRI, 1979.



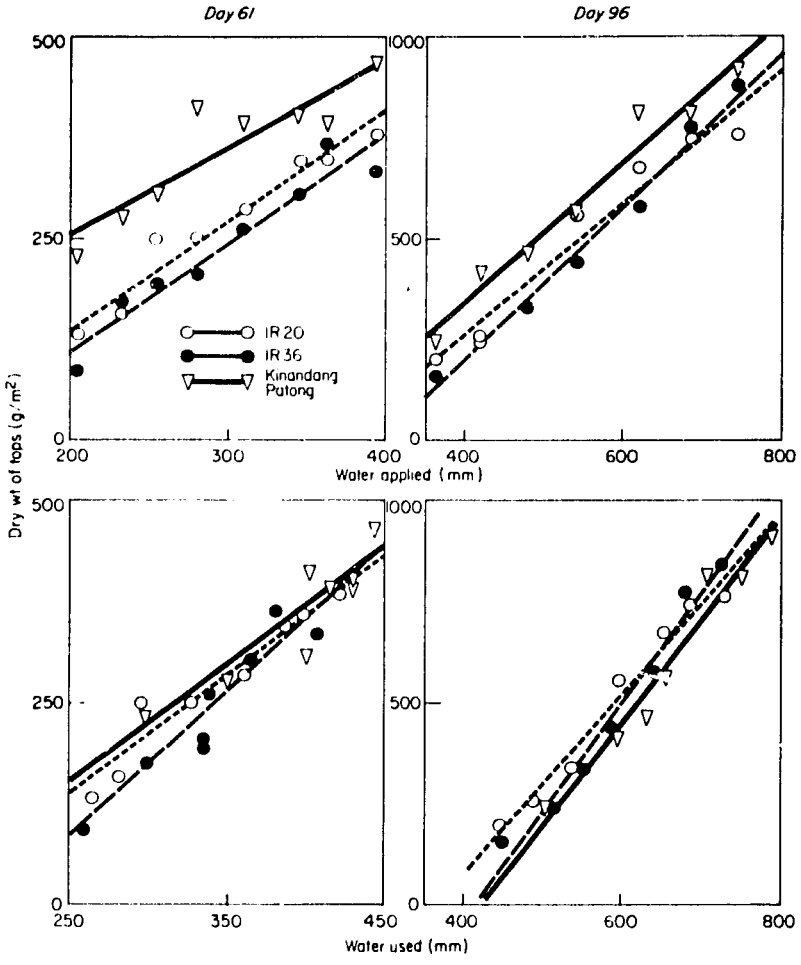
26. Schematic representation of the line source sprinkler and crop response to the variable water supply. IRRI, 1979.



27. Irrigation measured at 8 positions from line source plus rainfall gives water applied. Location of neutron access tubes in even-numbered positions is shown by black dots. IRRI, 1979.



28. Rainfall, weekly maximum irrigation measured 1.5 m from sprinkler line, and pan evaporation with weekly values for the dryland site during the experiment and monthly values for the 10-year mean of the wetland site. IRRI, 1979.

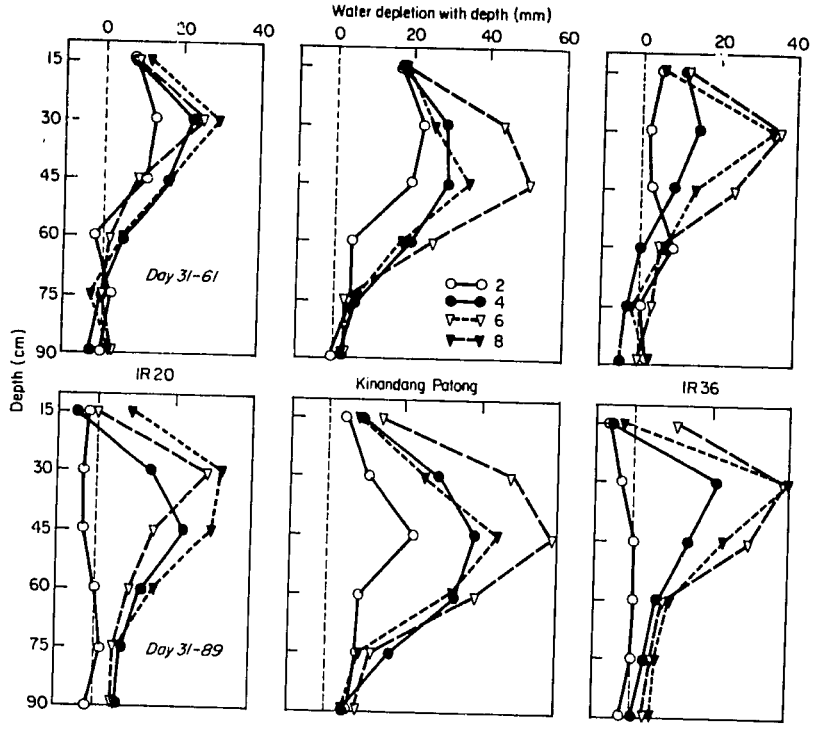


29. Effect of correcting for soil water changes when comparing dry-matter production of cultivars. IRRI, 1979.

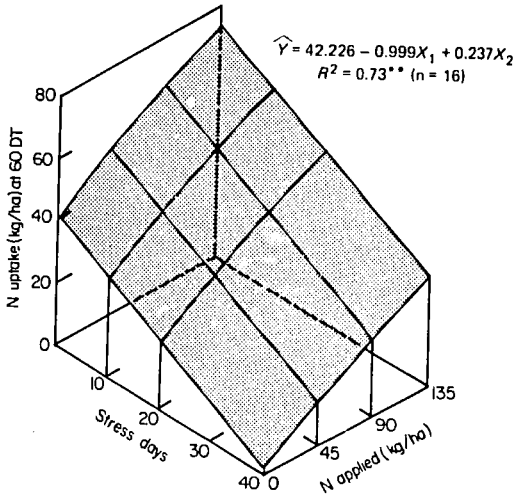
water stress on nitrogen uptake are presented in Figure 31. Differences in nitrogen uptake noted among the water treatments were significant. Nitrogen uptake was significantly lower in the 20- and 40-day stress treatments than in the control or continuously flooded treatment.

Yield analysis (Fig. 32) revealed a significant reduction from flooding to 40 stress day treatments. Application of 135 kg N/ha did not ameliorate the effect of water stress on rice yield. Severe stress delayed the maturity of IR36 by 2-3 weeks.

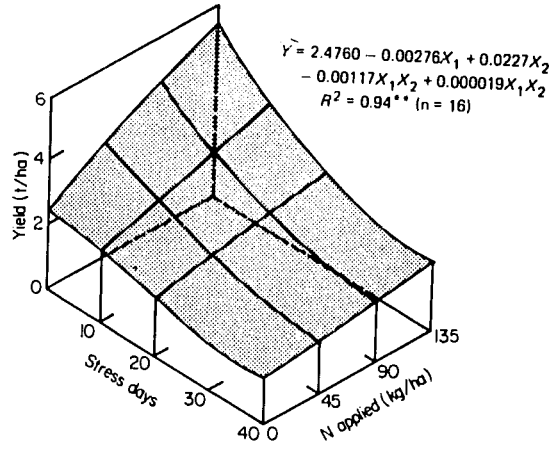
Microclimatic modification and plant response in a rice-maize intercrop. In a previous study (1977 annual report), the effect of intercropping maize and rice on the microclimate and plant water status of rice was illustrated. During the 1979 dry season, more detailed studies on the modification of the microclimate in the intercrop and its influences on crop growth characteristics were made. Three double rows of maize spaced 6 m apart (plots were 5 × 8 m) and oriented perpendicularly to the prevailing wind direction were grown as an intercrop with IR30, IR36, and Salumpikit. All the plots within (protected) and outside (unprotected) the intercrop were well watered from the start to the end of the study. Water vapor pressure deficit (VPD) of the air was monitored above the plots.



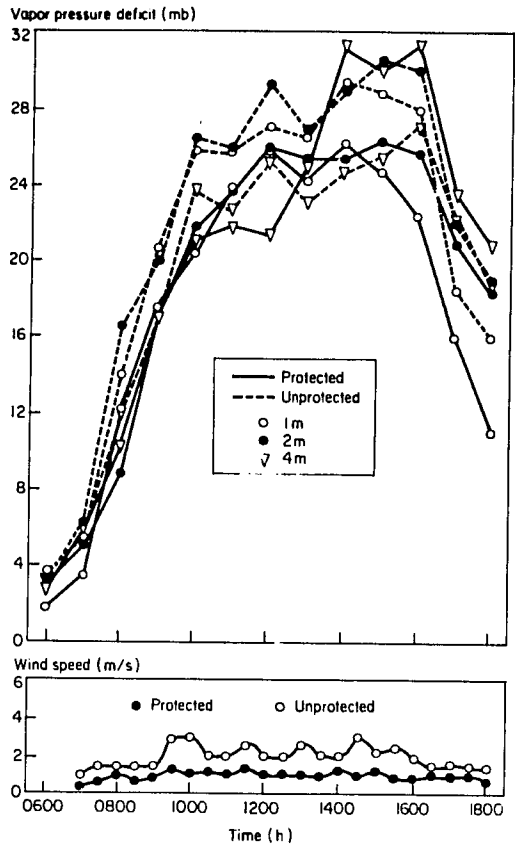
30. Water depletion of soil layers calculated from consecutive neutron readings at depths indicated. Numbers 2-8 indicate position and water application as shown in Figure 26.



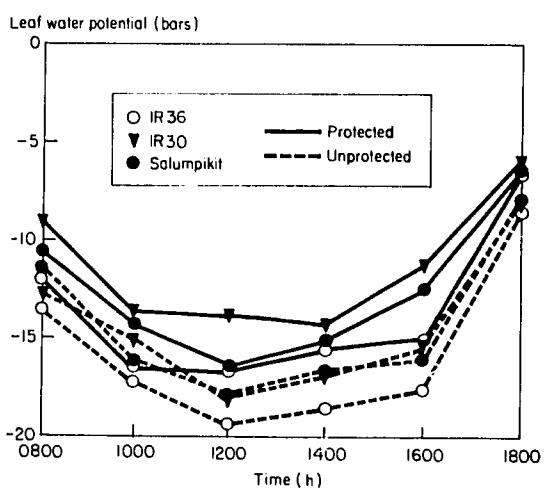
31. Response surface showing the nitrogen uptake as influenced by water stress, nitrogen application, and their interaction. IRRI field trial, Santa Rosa, Laguna province, Philippines, 1979.



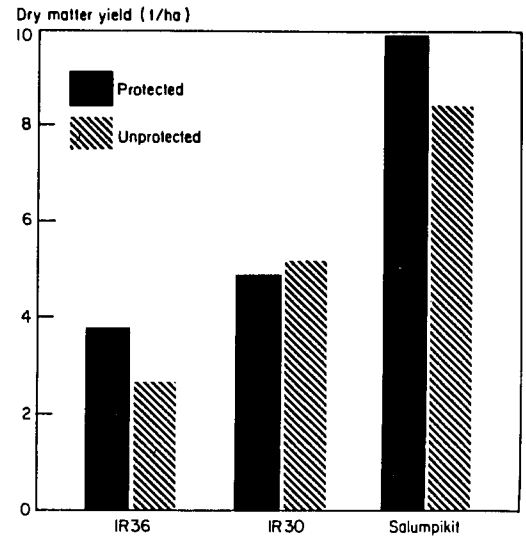
32. Response surface showing the yield of IR36 as influenced by water stress, nitrogen application, and their interaction. IRRI field trial, Santa Rosa, Laguna province, Philippines, 1979.



33. Diurnal change of water vapor pressure deficit (VPD) and wind speed in protected (intercropped with maize) and unprotected rice plots. IRRI, 1979.



34. Diurnal change in leaf water potential of 3 rice varieties grown in protected (intercropped with maize) and unprotected plots. IRRI, 1979.



35. Dry matter production of 3 rice varieties grown in protected (intercropped with maize) and unprotected plots. IRRI, 1979.

Figure 33 illustrates the diurnal pattern of VPD at the flowering stage and is representative of the other observation periods. Protected plots usually showed 2-6 mb lower VPD at the rice canopy level during midday than the unprotected plots. However, a slight change in wind direction disturbed this relationship because of plot size limitations. At 4-m height, the diurnal trend of VPD was about the same for both treatments. Wind speed was about 2 m/s less in the protected plots (Fig. 33). Figure 34 illustrates the diurnal trend of leaf water potential. The protected plots show a higher leaf water potential in response to the lower wind speed and VPD noted before.

The intercropped rice also showed interesting trends in dry matter production at maturity (Fig. 35). Because neck blast was severe yields were not comparable.

Genetic evaluation and utilization (GEU) program

Adverse soils tolerance

Soil Chemistry and Plant Breeding Departments

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The adverse soils tolerance component of GEU screened 25,086 rices in 1979 and found 4,532 tolerant of adverse soil conditions (Table 1). Of those 3,227 were rices from the general breeding program, where no planned effort was made to breed or select for adverse soils tolerance.

SALINITY

Soil Chemistry Department

In South and Southeast Asia, about 58 million ha lie uncultivated largely because of salinity (Table 2).

In 1979, 16,276 rices were tested for salinity tolerance in the greenhouse and in the field (Table 1). The field performance of 12 promising salt-tolerant rices was tested at 10 sites in the Philippines; 16 other rices were tested at an 11th site. The tests revealed consistent salt tolerance in 14 traditional varieties, 9 IR varieties, and 22 IR lines. Tolerant rices that performed well in replicated yield trials on coastal saline soils in the Philippines were IR36, IR42, IR46, IR4395-4-1-13, IR4630-22-2-5-1-3, IR9884-3-3, and IR9884-54-3.

Table 1. Summary of 1979 screening tests for adverse soils tolerance. IRRI, 1979.

Soil condition	No. screened	Tolerant (no.)	
		Total	General breeding program
Salinity	16,276	3,542	2,405
Alkalinity	1,733	260	236
Iron toxicity-acid sulfate soil	932	125	112
Peat soil	165	12	11
Boron toxicity	24	7	7
Phosphorus deficiency	1,605	153	105
Zinc deficiency	3,703	388	309
Aerobic neutral soil	317	22	22
Aerobic acid soil	331	23	20
Total	25,086	4,532	3,227

Screening. The 16,276 rices tested in the greenhouse included 13,135 from the salt tolerance breeding program. Outstanding among the 3,542 that had tolerant scores were:

- the varieties BG11-11, Bhurarata 4-10, Cheriviruppu, CSR 1, Kalarata 1-24, Kuatik Putih, Nonasail, Nona Bokra, Pokkali, and three C23 lines;
- the IR lines 2307-247-2-2-3, 4462-22A-101, 4595-4-1-13, 9129-136-2-2-1-2, 9732-119-3, 9761-47-3, 9852-19-2, 9884-54-3, 10198-142-3, and 10206-29-2; and
- 15 IR pedigrees.

Field screening at IRRI confirmed the salt tolerance of IR42, IR44, IR46, IR2307-27-2, IR5657-33-2, Patnai 23, IR1561-228-2, IR13646-2, IET3103, IR4432-28-5, IR5853-162-1, IR8192-200-3, IR9224-162-3, IR9846-215-3, IR9852-22-3, IR13149-43-2, and IR13426-19-2.

In mass screening of 1,437 pedigrees at IRRI, 77 entries in the hybridization block and 376 in the observational yield trial, 44 pedigree materials, and 7 IR lines — 5853-198-1, 6503-24-3, 8440-138-1, 9828-43-2, 13385-48-1, 13420-15-2, 13429-290-2

Table 2. Estimated distribution and extent of problem rice lands in South and Southeast Asia. IRRI, 1979.

Country	Problem rice lands (million ha)				
	Saline soils	Alkali soils	Acid sulfate soils	Peat soils	Total
Bangladesh	2.5	0.5	0.7	0.8	4.5
Burma	0.6		0.2		0.8
India	23.2	2.5	0.4		26.1
Indonesia	13.2		2.0	16.0	31.2
Kampuchea	1.3		0.2		1.5
Malaysia	4.6		0.2	2.4	7.2
Pakistan	10.5	4.0			14.5
Philippines	0.4				0.4
Thailand	1.5		0.6	0.2	2.3
Vietnam	1.0		1.0	1.5	3.5
Total	58.8	7.0	5.3	20.9	92.0

— showed more tolerance than the tolerant check.

The International Rice Salinity and Alkalinity Tolerance Observational Nursery (IRSATON) at IRRI had mean scores of 3 or less, indicating tolerance, for Getu, CSR1, CSR2, CSR3, MR359, IR4595-4-1, IR4630-22-2, M117, M242, and M432.

Yield trials in farmers' fields. Tables 3 and 4 summarize the observations on 11 tests of 12 varieties in farmers fields in coastal saline areas.

The 1979 field experiments confirmed an earlier observation that coastal saline soils vary widely in chemical characteristics, salt dynamics, and hydrology. Overall performance was best at the two slightly saline sites not subject to deep flooding. Among the rices that performed well under both salt and flood stress were IR4630-22-2-5-1-3, IR4595-4-1-13, and IR9884-54-3. Salt and submergence tolerance gave these lines a yield advantage, under stress, of 1.2 t/ha over IR26.

ALKALINITY

Soil Chemistry Department

Sodic or alkali soils cover about 6.5 million ha in Pakistan and India (Table 2) on the Indo-Gangetic plains.

Screening. Of the 1,733 rices screened in the IRRI greenhouses in 1979, 260 showed alkali tolerance (Table 1). Besides nine traditional varieties, the following showed high tolerance: IR36, IR4-11, IR1561-228-2-2, IR2035-290-2-1-1, IR2058-78-1-3-2-3, IR2070-522-6-9, IR2070-414-3-9, IR2307-84-2-1-2, IR2307-217-2-3, IR4227-28-3-2, IR4417-179-1-5-2, IR5853-118-5, and six IR4630-22 lines.

In 1979, a total of 178 rices were field tested in an artificial sodic soil at IRRI. Those found to be tolerant were IR5853-118-5, IR9846-261-3, BR4-10, IR4432-52-6-4, IR8192-200-3, IR9805-78-2, IR9805-97-1, IR3941-25-1, IR9846-256-3, and IET 1444.

In the IRSATON at IRRI a mean alkalinity score of 3 or less was noted for IR46, CSR1, CSR3, IR4227-109-1, IR4870-15-1, IR4595-4-1, M114, and M242.

Yield test in a farmer's field. On an alkali soil in Barrio Lagao, General Santos City, South Cotabato (silt loam with a pH of 8.5 and sodium adsorption ratio of 21.5), 10 varieties were grown with nitrogen and phosphorus fertilizers and seedling dip in 4% suspension of zinc oxide in water. The results are in Table 5.

Table 3. Summary of tests of 12 varieties and lines on 5 Philippine coastal saline soils, 1979 dry season.

Site	Salt source	EC_e[a] trend (mmho/cm)	Soil pH	Soil organic matter content (%)	Other soil problems	Yield range (t/ha)	Best yielders	Remarks
Agdangan, Quezon	Creek	15 → ?	5.9	5.9	Zn deficiency	none		Excess salt was lethal
Aparri, Cagayan	Seepage	9 → ?	6.0	14.0	none	none		Water supply failed
Mexico, Pampanga	Saline irrigation water from creek	3 → B	7.0	1.2	Zn deficiency	0.0–0.6	IR4595-4-1 IR4432-28	Sterility due to late salinity
Minalin, Pampanga	Saline irrigation water from creek	9 → 1	5.8	2.7	none	1.4–6.5	IR42	Rains depressed salinity drastically
Taal, Batangas	River	3 → 8	7.1	2.3	Zn deficiency B toxicity	1.4–3.6	IR4595-4-1 IR4432-2B	Moderate average salinity

[a]Electrical conductivity in the saturation extract.

Table 4. Summary of tests of 12 varieties and lines on 6 Philippine coastal saline soils, 1979 wet season.

Site	Salt source	EC_e[a] trend (mmho/cm)	Soil pH	Soil organic matter content (%)	Other soil problems	Yield range (t/ha)	Best yielders	Remarks
Aguilar, Pangasinan	Seepage	9 → 12	7.2	1.5	Zn deficiency	0.3–1.4	IR4630-22-2 IR4595-4-1	Flood damage, prolonged high salinity
Bani, Pangasinan	Creek	8 → 10	6.1	1.3	none	0.4–1.6	IR4432-20 IR4630-22-2	Frequent tidal intrusions
Butuan,[b] Agusan del Norte	Creek	3 → 4	4.9	9.5	Zn deficiency	2.4–6.5	IR42	Salt injury was slight
Cebu, Cebu	Creek		7.4	6.8	Zn deficiency B toxicity	2.3–3.9	IR42	Late salt injury
Samal, Bataan	Creek	1 → 4	6.5	2.6	–	1.9–3.3	IR4432-20 IR9884-54-3	Rains depressed salinity
Taal, Batangas	River	3 → 4	1	2.3	Zn deficiency B toxicity	0.0–1.1	IR4595-4-1	Severe flood damage

[a]Electrical conductivity in the saturation extract. [b]1978 tests.

Table 5. Grain yield of 10 rices on an alkali soil, Barrio Lagao, General Santos City, Philippines, 1979 wet season.

Variety	Mean grain yield[a] (t/ha)
IR42	5.2 a
IR36	5.0 ab
IR2863-38-1	5.0 ab
IR26	4.1 ab
IR46	4.1 ab
IR4227-28-3-2	4.0 ab
IR2307-217-3	3.8 abc
IR3518-1-6-2-2-2	3.6 bc
IR2153-26-3-5	2.5 cd
IR9129-393-2-6-2-2	1.2 d

[a]Means followed by a common letter are not significantly different at the 5% level. Average of 4 replications.

IRON TOXICITY

Soil Chemistry Department

Iron toxicity is a widespread nutritional disorder of wetland rice on strongly acid soils. It occurs on acid Oxisols, Ultisols, Histosols, and acid sulfate soils.

Screening. Greenhouse screening in 1979 for iron toxicity tested 585 rices on a strongly acid soil that, on flooding, built up to 300-400 ppm water-soluble iron and maintained that concentration for several weeks. Eighty-nine entries had tolerant scores. The best among them were IR20, IR36, IR42, IR43, IR44, IR1552, IR9788-19-2, Mat Candu, and Nachin 39.

In the Philippines field screening for iron toxicity tolerance included 347 promising lines from the general breeding program. Screening was on an acid sulfate soil (pH: 3.5, organic C: 1.3%, active Fe: 2.5%, active Mn: 0.001%, SO_4^{2-}:2,700 ppm) fertilized with 50 kg N and 10 kg P/ha. Three-week-old seedlings raised on a normal wetbed were transplanted in single 3-m rows and were scored at 4 and 8 weeks after transplanting. Those that showed tolerance were B2149-PN-26-1, IR1552, IR4442-165-1-3-2, IR4625-269-4-2, IR36, BPI R1-2, IR3839-1, IR8192-200-3-3-1-1, IR4568-225-3-2, IR5853-118-5, IR9129-136-2, IR13168-143-1, IR13149-43-2, and IET 1444.

Of 100 rices field-screened in Sri Lanka, IR32, IR42, Mahsuri, and 7 IR lines showed tolerance for iron toxicity on a strongly acid Tropaquult at Padukka in the wet zone (Table 6).

Yield trials. To test the performance of rices considered iron toxicity tolerant in greenhouse

Table 6. Varieties and lines tolerant of soil stresses in field screening tests in Sri Lanka, 1979.

Varieties with tolerance for	
Iron toxicity	Phosphorus deficiency
IR32	Pelita I/1
IR42	IR36
Mahsuri	IR2071-176-1-1
IR5741-73-2-3	IR2797-105-2-2-3
IR2070-747-4-4	BR51-91-5
IR2061-214-2-7-63	IR2071-745-7-5-3
IR2031-724-2-3-2	IR2070-178-2-3-4
IR2070-434-3-5	IR5853-118-5
IR2832-173-6-2	IR1632-93-2-2
IR3518-96-2-2-2	IR2071-105-9-1

Table 7. Performance of 8 rices on an iron-toxic, acid sulfate soil. Malinao, Albay, Philippines, 1979 dry season.

Variety or line	Yield (t/ha)[a]
IR4683-54-2 (resistant check)	4.5 a
IR2863-38-1	3.7 b
IR5863-163-1	3.6 b
IR4432-52-6	3.4 b
BHR 134-33	3.4 b
BHR 145-47	3.3 b
IR46	3.2 b
IR26 (susceptible check)	1.7 c

[a]Means followed by a common letter are not significantly different at the 5% level. Average of 4 replications.

tests, 15 rices (including IR26, a susceptible check) were grown at Malinao, Albay, Philippines, with nitrogen and phosphorus fertilizers in a replicated dry-season trial. The yields of the seven best are in Table 7. In the wet season, despite severe iron toxicity, IR46, IR4422-480-2-3-3, IR4625-269-4-2, and B2149-PN-26-1 yielded 2.5-2.7 t/ha.

BORON TOXICITY

Soil Chemistry Department

The discovery of boron toxicity in IRRI soils prompted a 1979 study of varietal reactions to excess boron. Table 8 shows the reactions of 4 varieties to excess boron (10 to >20 ppm) in solution culture. Excess boron produced elliptical necrotic lesions in all varieties except IR20. It depressed growth markedly in all varieties except IR46.

A study of 24 varieties in culture solution containing 10 ppm boron showed severely retarded growth but only 13 entries showed the elliptical necrotic spots characteristic of boron toxicity.

Table 9 shows varietal differences in yield depression caused by excess boron. Seventeen ppm B in the soil solution caused a yield reduction of almost 50% in IR46, but less than half that amount in Peta, H4, and IR42.

Yield trial on a boron-toxic soil at IRRI. Ten IR varieties were grown in a replicated yield trial on a boron-toxic soil (pH:6.4, EC_e:3.4 mmho/cm, available B: 10.8 ppm) in the 1979 wet season. Table 10 shows that IR34, IR40, IR42, and IR44 had a yield advantage of about 1 t/ha over the pre-1975 varieties.

PEAT SOILS

Soil Chemistry Department

Peat lands cover about 21 million ha of flatland in the humid tropics of South and Southeast Asia. Large peat soil areas in Indonesia, Malaysia, and Thailand are being cleared for crop production. In 1979 rices were screened on peat soils in the greenhouse, in the presence of nitrogen, phosphorus, potassium, copper, and zinc. Of 165

Table 8. Influence of excess boron in the culture solution on toxicity symptoms, dry weight, and boron content of 4 rice varieties, 11 weeks after sowing. IRRI, 1979.

Variety	Symptom[a]	Dry wt of shoot (g) with addition of		Decrease (%)	Shoot boron content (ppm) with addition of	
		0 ppm boron	20 ppm boron		0 ppm boron	20 ppm boron
IR8	6	175	97	44.6	23	386
IR20	7	156	90	42.3	23	509
IR42	7	184	112	39.1	16	398
IR46	5	110	106	3.6	35	375

[a]1 = almost normal plants; 9 = almost dead plants.

Table 9. Straw yield and boron content of 5 rice varieties at 2 boron levels in a neutral clay soil. IRRI, 1979.

Variety	Boron (ppm) in soil solution	Straw yield (g/pot)	Yield reduction (%)	Boron (ppm) in straw
Peta	0.6	80	–	16.1
	17.3	56	20.0	168
H4	0.6	69	–	14.5
	17.3	57	17.4	150
IR20	0.6	79	–	24.5
	17.3	46	42.8	135
IR42	0.6	67	–	22.7
	17.3	52	22.4	183
IR46		76	–	23.0
		39	48.7	165

Table 10. Grain yields of 10 IR varieties on a boron-toxic soil. IRRI, 1979 wet season.

Variety	Year named	Grain yield[a] (t/ha)
IR8	1966	3.6 cd
IR20	1969	3.3 de
IR26	1973	3.5 de
IR28	1974	2.8 e
IR32	1975	3.7 bcd
IR34	1975	4.4 ab
IR38	1976	3.5 de
IR40	1977	4.4 ab
IR42	1977	4.6 a
IR44	1979	4.2 abc

[a]Means followed by a common letter are not significantly different at the 5% level. Average of 4 replications.

entries, IR36, IR38, IR2797-105-2-2-3, IR4568-225-3-2, IR5853-162-1-2, IR8192-166-2-2-3, IR9129-136-2-2-2-1-2, IR9217-58-2-2, IR9814-6-3, IR2071-685-3-5-4-3, and IR3880-10 had tolerant scores.

PHOSPHORUS DEFICIENCY

Soil Chemistry Department

Phosphorus deficiency limits rice yields on millions of hectares of Andosols, Oxisols, Ultisols, acid sulfate soils, and peat soils.

Screening. Of 836 varieties and breeding lines tested in culture solution in the greenhouse, 48 were highly tolerant of phosphorus deficiency. Among those were IR44 and 35 IR lines.

Mass field screening of 769 lines from the general breeding program on a phosphorus-deficient soil (Luisiana clay — pH:4.8, O.M.: 4.2%, Olsen P: 4 ppm) at Pangil, Laguna, Philippines, revealed phosphorus deficiency tolerance in 105.

Of 100 rices screened for phosphorus deficiency in Sri Lanka, IR36, Pelita I/1, one BR line, three IR2071 lines, and four other IR lines were tolerant of phosphorus deficiency (Table 6).

Yield trials. Despite water stress at Pangil, Laguna, IR20, IR38, IR1514A-E666, and BR51-91-6 gave yields of 2.6 to 2.9 t/ha without phosphate fertilizer. With 25 kg P/ha, yields increased more than 20%.

ZINC DEFICIENCY

Soil Chemistry Department

Zinc deficiency, a widespread nutritional disorder of rice, occurs on alkali, calcareous, and peat soils, and on soils that are poorly drained or irrigated with high-silica water. About 2 million ha of current and potential rice lands in the Philippines are zinc deficient.

Screening. Of 1,831 entries tested in a zinc-deficient soil in concrete beds at IRRI, 204 showed tolerance. Of the latter, 142 were elite lines from IRRI's general breeding program. IR36 had tolerant scores six times in the 1979 tests.

Mass screening for zinc deficiency was conducted in 1979 in a farmer's field at Bay, Laguna, Philippines (Lipa clay loam with pH: 7.3, O.M.: 12.3%, available Zn: 0.1 ppm). Of 1,872 entries screened, 184 had tolerant scores. IR36 was among them.

Yield trials. Sixteen rices were grown on Lipa clay loam without applied zinc at Bay, Laguna, in the 1979 dry and wet seasons. Extensive rat damage spoiled the dry-season experiment, but despite severe zinc deficiency (the susceptible check perished) IR20, IR34, IR2070-423-5-5-2, IR8067-41, IR9109-71-2-1, IR11418-15-2, and MR346 scored as tolerant.

In the wet-season trial, severe zinc deficiency was once again observed 4 weeks after transplanting, but the plants recovered. IR44 and IR8192-166-2 recovered earlier than other entries. The three top yielders were IR9129-209-2-2-2-1 (3.6

t/ha), IR46 (3.2 t/ha), and IR36 (2.8 t/ha). IR26 yielded 1 t/ha.

Because zinc deficiency is widespread in South Cotabato, Philippines, a replicated yield trial with 9 tolerant varieties and a susceptible check (IR26) was installed on zinc-deficient silty clay (pH: 7.8, O.M.: 6.8%, available Zn: 0.1 ppm), at Baluan, General Santos, South Cotabato. Two weeks after planting, all varieties in the treatment without zinc died. Yields for the zinc-treated rices ranged from 1.3 t/ha for IR26 to 3.7 t/ha for IR9109-71-2-1 (Table 11).

Varietal reactions of IR36 and IR42 to the residual effects of zinc were studied on a zinc-deficient soil (pH: 7.3, O.M.: 4.2%, available Zn: 0.01 ppm) at Bugallon and on another soil (pH: 7.4, O.M.: 2.1%, available Zn: 0.02 ppm) at Natividad, Pangasinan, Philippines (Table 12).

GROWTH-LIMITING FACTORS IN AEROBIC SOILS

Soil Chemistry Department

Factors limiting rice growth in aerobic soils, in the absence of water stress, include manganese and aluminum toxicities in strongly acid soils and iron deficiency in slightly acid, neutral, and alkaline soils. Greenhouse tests had earlier revealed marked varietal differences in reactions to all four kinds of soil.

Screening. A total of 331 rices were tested on Maahas clay (pH: 6.0, O.M.: 1.9%) at IRRI and Luisiana clay (pH: 4.9, O.M.: 4.8%) at Pangil, Laguna, in the presence of adequate nitrogen, phosphorus, potassium, and with no water stress. Included were 171 entries from the 4th International Upland Rice Observational Nursery (IURON) and 160 GEU elite lines.

The rices were scored for iron deficiency on Maahas clay and for manganese toxicity on Luisiana clay 6, 8, and 10 weeks after sowing. The 8th week scores showed the smallest coefficient of variation and the highest discriminating quality, and were used for classifying the rices.

Forty rices indicated tolerance for the soil conditions at the two sites. IR43, IR46, IR48, IR2797-105-2, IR4432-52-6, and IR5853-162-1-2 had scores of 3.3 or less at both sites.

Yield trial. Twenty-four selected rices from 1978 drought screening at IRRI were tested in a replicated experiment on Maahas clay in the presence of adequate nitrogen, phosphorus, potassium, and without water stress.

Eight weeks after sowing, varietal differences in iron deficiency symptoms appeared. Mean scores and yield for 12 entries are in Table 13.

Three of the 5 rices that yielded more than 4 t/ha scored 3.3 or less. The lowest yielders scored 5.3 or 5.7, indicating that tolerance for iron deficiency is important in dryland rice.

ALUMINUM AND MANGANESE TOXICITIES

Soil Chemistry Department

Solution culture studies showed striking varietal differences in tolerance for excess aluminum or manganese as measured by relative dry matter weight of 4-week-old plants. But there was no clear-cut association between tolerance for acid soils and tolerance for excess manganese or aluminum. Nor was there a correlation between manganese tolerance and aluminum tolerance.

Table 11. Grain yields of 10 rices (dipped in zinc oxide) on a strongly zinc-deficient soil in Barrio Baluan, General Santos City, Philippines, 1979 wet season.

Variety	Grain yield[a] (t/ha)
IR9109-71-2-1	3.7 a
IR11418-15-2	3.1 ab
IR11418-19-2-3	3.1 ab
IR34	2.6 bc
IR5677-17-3-1-2	1.8 cd
IR20	1.8 cd
IR42	1.7 cd
MR346	1.6 cd
IR4630-22-2-5-1-2	1.5 cd
IR26	1.3 d

[a]Means followed by a common letter are not significantly different at the 5% level. Average of 4 replications.

Table 12. Performance of 2 varieties on zinc-deficient soils at 2 sites in Pangasinan, Philippines, 1979 wet season.

Initial zinc (kg/ha)	Yield (t/ha)			
	Bugallon		Natividad	
	IR36	IR42	IR36	IR42
0	2.6	2.7	0.0	0.0
4[a]	4.4	5.5	4.2	6.2
8	3.3	4.3	4.8	5.8
16	3.7	4.2	4.5	6.1

[a]Current application.

Table 13. Performance of 12 rices on a slightly acid aerobic soil, in the absence of water stress. IRRI, 1979 dry season.[a]

Variety or line	Yield (t/ha)	Score at 8 weeks[b] (1–9)
IR46	4.8 a	4.7 efgh
IR8608-189-2-2	4.3 ab	2.7 ab
IET1444	4.3 ab	3.3 abcd
IR8192-200-3-3-1	4.1 abc	4.3 defg
IR36 (resistant check)	4.1 abc	2.7 ab
IR3648-1-1-1	3.8 abcd	4.0 cdef
IAC 1246	3.7 abcd	3.7 bcde
IR11297-158-3	3.6 bcde	2.3 a
IR5853-162-1-2-3	3.2 bcdef	4.7 efgh
Salumpikit	2.8 def	3.0 abc
IR28 (susceptible check)	2.7 def	5.7 h
IR3464-96-3-3-1-3-1	1.3 gh	5.3 gh

[a]Means followed by a common letter are not significantly different at the 5% level. Av of 3 replications. [b]1 = almost normal plants, 9 = dead plants.

Table 14, however, suggests some association between tolerance for acid soil conditions and aluminum tolerance.

NITROGEN EFFICIENCY

Soil Chemistry Department

A greenhouse study of the nitrogen response of two traditional varieties (Peta and H4) and two modern rices (IR42 and IR48) at six nitrogen levels on Maahas clay confirmed the earlier finding that Peta and H4 use nitrogen for grain and total dry matter production more efficiently than the two modern rices (Fig. 1, 2).

Table 14. Tolerance scores for acid soil conditions of 9 rices with tolerance for aluminum or manganese as measured by relative yield in the presence and absence of an excess of the element in the culture solution.

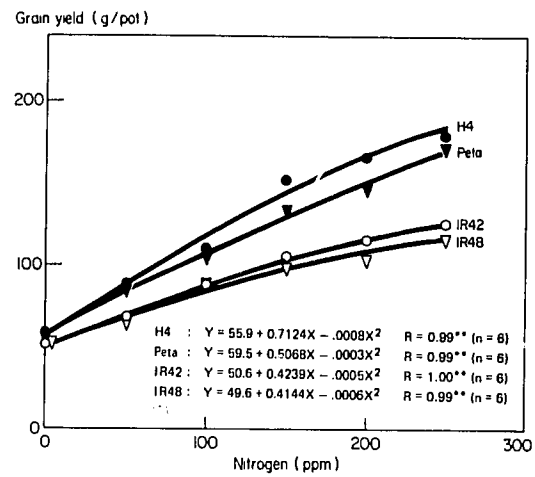
Variety or line	Acid soil tolerance score[a]	Relative yield (%)	
		Aluminum (30 ppm)	Manganese (80 ppm)
IR20	6	20	51
IR22	5	19	59
IR24	5	17	74
IR127-80-1	3	26	65
IR712-23-2	5	21	88
E425	5	38	44
M1-48	2	31	68
Monolaya	3	–[b]	29
Peta	7	21	84

[a]On the 1–9 scale: 1 = almost normal plants, 9 = dead plants. [b]No test.

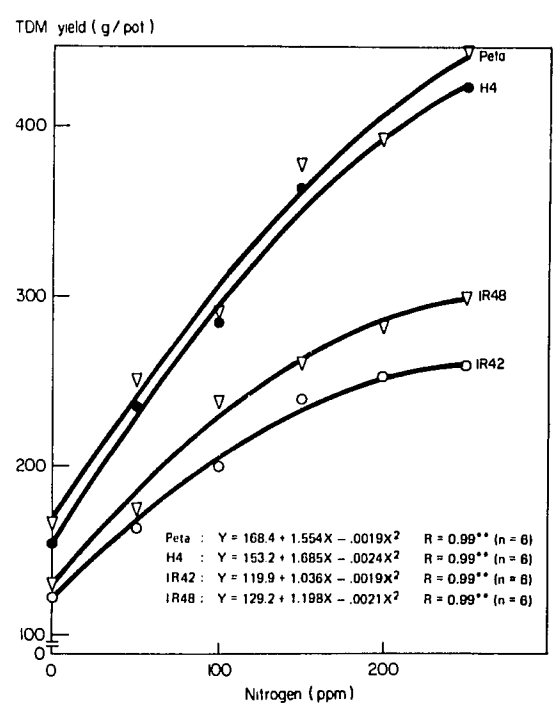
MULTIPLE STRESSES

Soil Chemistry Department

Multiple tolerance for stresses, especially for those that often occur simultaneously in problem soils, is



1. Grain yield of 4 varieties at 6 nitrogen levels. IRRI greenhouse, 1979 dry season.



2. Total dry matter (TDM) yield of 4 varieties at 6 nitrogen levels IRRI greenhouse, 1979 dry season.

an advantage. Table 15 shows the reactions of 21 IR varieties to various soil stresses.

IR36 had tolerance for salinity, alkalinity, and zinc and iron deficiencies and is suggested for salt-affected soils of arid regions. IR42 and IR44 had tolerance for salt, iron toxicity, and phosphorus deficiency and did well on an acid sulfate soil. Because of its tolerance for deficiencies of phosphorus and iron as well as toxicities of aluminum and manganese, IR43 did better than the other entries as a dryland rice. IR50, with tolerance for salt, zinc deficiency, phosphorus deficiency, and organic soil problems, is suggested for coastal organic soils. Of all IR varieties IR36 had the highest multiple stress tolerance.

It appears that tolerance for adverse soils can be combined with good agronomic characteristics and resistance to insects and diseases, and that many IR varieties showed multiple soil stress tolerance even without a planned effort to achieve such tolerance (Table 16).

Table 15. Reactions of IR varieties to adverse soil conditions. IRRI, 1979.

Variety	Reaction[a]							
	Wetland soils						Dryland soils	
	Toxicity				Deficiency		Iron deficiency	Aluminum and manganese toxicity
	Salt	Alkali	Peat	Iron	Phosphorus	Zinc		
IR5	4	7	0	6	5	5	4	5
IR8	3	6	5	3	4	4	4	4
IR20	5	7	4	2	1	3	4	4
IR22	5	7	0	3	3	3	5	5
IR24	3	5	0	3	1	4	3	4
IR26	5	6	6	6	1	5	4	3
IR28	7	5	6	4	3	5	6	5
IR29	6	7	5	4	5	3	0	0
IR30	5	6	3	3	3	3	0	0
IR32	5	7	5	3	3	5	5	5
IR34	5	5	3	3	3	3	0	0
IR36	3	3	3	3	7	2	2	4
IR38	5	5	3	5	1	3	5	4
IR40	5	6	5	3	1	2	0	0
IR42	3	4	5	3	3	4	6	5
IR43	3	7	7	4	3	3	5	3
IR44	3	5	3	3	3	4	4	4
IR45	4	7	6	5	3	4	4	4
IR46	4	3	5	6	5	3	4	3
IR48	4	7	5	6	5	5	[illegible]	3
IR50	4	5	3	4	3	3	4	4

[a]On a scale of 0–9: 0 = no information, 1 = almost normal plants, 9 = almost dead or dead plants.

GENETIC ASPECTS

Plant Breeding Department

A preliminary study on inheritance of tolerance for zinc deficiency and the interrelationships among zinc deficiency, iron deficiency, and alkalinity was undertaken. Three generations of two crosses involving parents tolerant (IR20 and IR30) of and sensitive (E425) to zinc deficiency stress were screened in concrete beds at IRRI. One hundred genotypes (varieties and breeding lines) were screened for injury caused by alkalinity and zinc deficiency. The results of this experiment and of earlier mass-screening experiments were subjected to association analyses (Table 17). The results, in general, indicated that tolerance for different min-

Table 16. Grain yields of stress-tolerant varieties in the absence of the stress. IRRI, 1979 dry season.

Variety or line	Grain yield[a] (t/ha)	Stress
IR9884-54-3	6.0 a	Salinity
IR46	5.8 a	Salinity, zinc deficiency
IR4227-28-3-2	5.7 ab	Phosphorus deficiency
IR4422-480-2-3-3	5.6 ab	Phosphorus and zinc deficiencies
IR2058-85-3-3	5.5 abc	Alkalinity
IR38	5.5 abc	Zinc deficiency and organic soil problems
IR20	5.5 abc	Zinc deficiency, iron toxicity, and phosphorus deficiency
IR42	5.4 abc	Salinity, alkalinity, iron toxicity
IR2823-103-5-1	5.4 abc	Phosphorus deficiency
IR4432-103-6	5.3 abcd	Organic soil problems
IR4763-141-2-16	5.3 abcd	Salinity and alkalinity
IR32	5 0 abcd	Iron toxicity, phosphorus deficiency
IR2307-247-2-2-3	5.0 abcd	Salinity, alkalinity
IR36	4.8 bcde	Salinity, alkalinity, iron toxicity, zinc deficiency
IR40	4.7 bcdef	Zinc deficiency and organic soil problems
IR4816-70-1	4.7 bcdef	Organic soil problems
IR1529-430-3-1	4.6 cdef	Iron deficiency
IR24	4.3 defg	Iron toxicity and iron deficiency
IR4763-73-1	4.3 defg	Salinity
IR4630-22-2	3.0 h	Salinity

[a]Means followed by a common letter are not significantly different at the 5% level. Av of 3 replications.

eral stresses behaves nearly independently. The frequency distribution of ratings for three generations (Table 18) indicated that tolerance for zinc deficiency is under polygenic influence, showing continuous variation and transgression in F_2. Tolerance seemed to be dominant. Heritability varied between crosses.

ROLE OF MINERAL STRESS TOLERANCE IN YIELD STABILIZATION

Plant Breeding Department

The work on the role of varietal tolerance for mineral stresses in stabilizing yield was continued on four problem soils at five sites in the Philippines. The results of the performance tests confirmed the

Table 17. Correlation coefficients based on ratings of 44 genotypes' reactions to various adverse soils. IRRI, 1979.

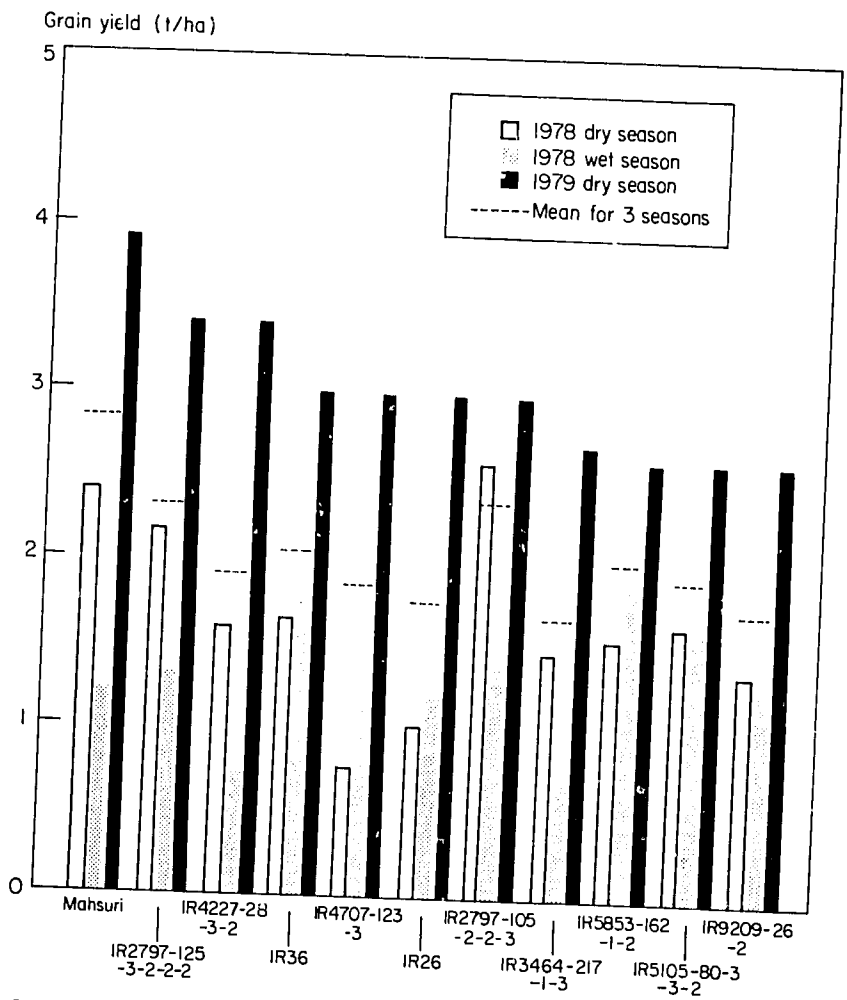
Character	Correlation coefficient[a]				
	Salinity	Alkalinity	Iron toxicity	Peat soil	Phosphorus deficiency
Zinc deficiency	0.224	0.074	0.075	0.002	0.054
Salinity		0.154	0.146	−0.009	−0.014
Alkalinity			0.245	−0.005	0.114
Iron toxicity				−0.171	−0.015
Peat soil					0.055

[a]None is significant at 5% level.

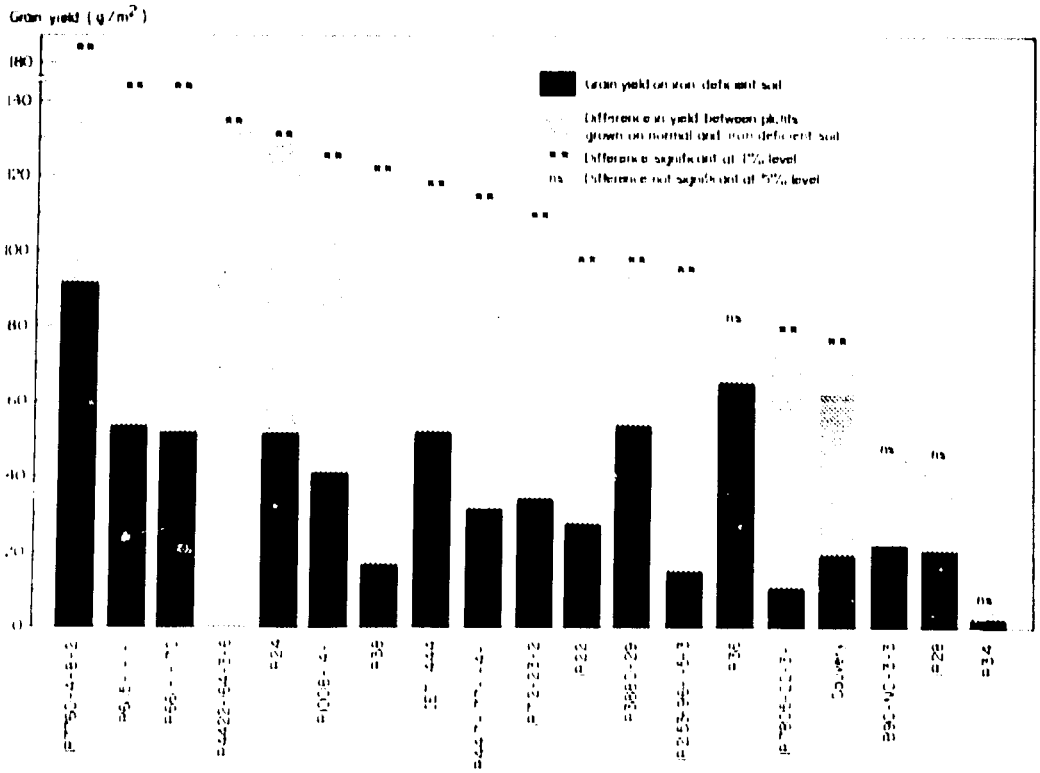
Table 18. Frequency distribution of ratings for zinc deficiency tolerance of parents and progeny of crosses involving tolerant (T) and susceptible (S) cultivars, 1978 wet season.

Generation	Frequency distribution of tolerance rating[a]											Total
	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	
P_1 IR20 (tolerant)			1	8	2							11
P_2 E425 (susceptible)						1	3	5	1		1	11
F_1 (IR20/E425)					1	1						2
F_1 (E425/IR20)					1	1						2
F_3 progeny	2	5	21	20	32	19	3	5	2			109
P_1 IR30 (tolerant)			1	3	6	1						11
P_2 E425 (susceptible)						1	6	1	2	1		11
F_1 (IR30/E425)			1		1							2
F_1 (E425/IR30)		1	1									2
F_3 progeny	1	20	37	27	19	5	6				1	116

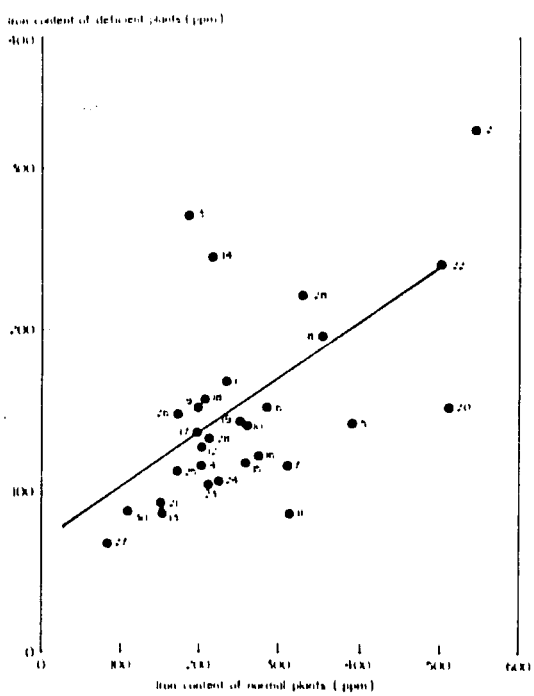
[a]Ratings assigned on a scale from 1 to 9, with 1 = most tolerant and 9 = most sensitive. Mean of 2 replications.



3. Performance of 11 genotypes on iron toxic soil at Malinao, Albay, Philippines (3 seasons).



4. Performance of 19 genotypes on iron deficient soil. Upland IRRI farm, 1979 dry season



5. Iron content of 30 genotypes at maximum growth stage. IRRI, 1979 wet season

range of varietal tolerance that was measured in the previous year.

A field test conducted for the third time on an iron-toxic soil at Malinao, Albay, during the 1979 dry season revealed significant varietal differences in ratings and grain yield. During three seasons, Mahsuri, IR2797-105-2-2-3, IR2797-125-3-2-2-2, and IR36 consistently produced yields of 2.1 to 2.8 t/ha (Fig. 3). The lines IR4422-143-2 and IR26 gave consistently low yields. Iron content in grain tended to be greater in tolerant lines (185-290 ppm) than in sensitive lines (144-218 ppm).

The performance test conducted on an iron-deficient dryland soil at IRRI confirmed the earlier results that iron deficiency depressed the grain yield over 40% in sensitive rices (Fig. 4), compared with tolerant rices. The plant analysis showed that the genotypes differed significantly in their ability to absorb iron under both normal and iron-deficient conditions (Fig. 5). Furthermore, absorption of iron from the iron-deficient soil was lower than that from normal soil. But in some of the tolerant lines, iron absorption from deficient and normal soils did not differ significantly.

Genetic evaluation and utilization (GEU) program

Deepwater and flood tolerance

Plant Breeding, Plant Physiology, and Agronomy Departments and Thailand-IRRI Cooperative Deepwater Project

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BREEDING PROGRAM AT IRRI

Plant Breeding and Plant Physiology Departments

A total of 7,593 breeding lines and varieties were screened for submergence tolerance.

Three hundred single and 816 multiple crosses to generate improved germplasm for the medium water depth were made with emphasis on intermediate stature, submergence tolerance or internode elongation ability or both, and resistance to major insects and diseases. FR13A, BKN 6986-147-2, Goda Heenati, Kurkaruppan, Thavalu, FRG, and CNL lines from India; Beguamon 202, Ashini, Chaplash, Kumargoir, and Joli Aman from Bangladesh were used extensively in programs to incorporate submergence tolerance and elongation ability. Indonesian lines were used for intermediate stature and sturdy culm. Most of the crosses with FR13A, Thavalu, and Kurkaruppan were highly sterile.

The inheritance of tolerance for submergence appears to be complex. To find out the feasibility of increasing selection efficiency, F_2 seedbeds with 10-day-old seedlings were submerged for 10 days at 25–30 cm depths. Survival was scored 5 days after the standing water was drained. The survival score varied from low to high in crosses where only one of the parents had submergence tolerance, but was high in crosses where two of the parents had submergence tolerance (Table 1). The results indicated that F_2 populations may be screened for submergence tolerance at the seedling stage.

Table 1. Survival score of F_2 seedlings submerged for 10 days in the seedbed. IRRI, 1979.

Source of submergence tolerance	Crosses (no.) with given survival score		
	Low (<50%)	Moderate (50–70%)	High (>70%)
Chakia 59	2	3	1
Goda Heenati	5	3	1
FR13A	–	3	4
Tara Bao	–	1	–
Chaplash + Beguamon	–	–	2
Chaplash + BKN6986-147-2		–	1
Chaplash + Pukhi	–	–	1
Chaplash + Badal	–	–	1
BKN6986-147-2 + Hijlidigh	1	–	–

The elongation ability of lines involving 64 crosses in the F_3, F_4, F_5, and F_6 was tested. Of the 1,584 lines screened, only 10% had a score of 5 and less than 1% had a score of 3. Most of the lines had a poor score (7). In crosses where the elongating parent contributed only one-fourth to the cross, no scores better than 7 were obtained. In crosses involving an elongating variety, such as Leb Mue Nahng 111 as a primary parent, lines with a score of 5 were obtained

A score of 3 was obtained only in crosses involving BGD7-6-1PE/T442-57 as a parent. BGD7-6-1PE has Habiganj Aman 4 as an elongating parent, and T442-57 has Leb Mue Nahng 111 for this trait.

BREEDING PROGRAM IN THAILAND

Thailand-IRRI Cooperative Deepwater Project

Submergence tolerance. A total of 2,700 lines were screened for submergence tolerance by a new procedure in deepwater ponds:

- Pregerminated seeds were planted in a wet seedbed in rows 125 cm long, with 25 cm between rows.
- Check varieties were planted in every tenth row, alternating between FR13A as a resistant check, and a susceptible check, which can be a prevalent variety. Khao Dawk Mali 105 was used.
- After 25–30 days, seedling height for each row was measured, and water added to a level of 120 cm.
- The water was drained 10 days after flooding. One week later, the final score for survival was made on the basis of the appearance of green leaves.

The new method represents an increase in severity over previous tests. In the first test of 1,600 entries, only 115 entries survived. Fifty-six of those that survived represented lines having FR13A as one of the parents, 13 were derived from FR43B, and the remainder came from various parents, among them Nam Sagui 19. Survival scores of 1 and 3 were prevalent with entries derived from FR13A and FR43B, but in no case could they be given to the other lines showing some survival.

Some considerations for parental choice and breeding strategy for submergence tolerance

Table 2. Survival percentage in a submergence test, and proportion of plants with acceptable grain fertility in pooled data from 3 types of composite crosses. IRRI, 1979.

Submergence tolerance source	Survival (%)	Acceptably fertile plants (%)
1/8 FR13A + 1/8 FR13A	40	8
1/8 FR13A + 1/8 Goda Heenati	29	21
1/8 Goda Heenati + 1/8 Goda Heenati	21	93

emerged from work with composite crosses involving the varieties FR13A and Goda Heenati. The surviving plants were transplanted, and at harvest the proportion of sterile plants rejected from each cross was noted. The data indicated that in order to increase the proportion of agronomically acceptable plants in crosses aiming at submergence tolerance, including FR13A or Goda Heenati in only 25% of the parentage of composite crosses would give acceptably high survival percentages (Table 2). Increased usage of Goda Heenati as a parent also drastically increased panicle fertility.

Screening for elongation ability. About 10,000 advanced and early generation lines were screened for elongation ability at the seedling stage. Elongation ability for survival at the 1-m water depth was stressed. The rices tested for elongation ability were also tested simultaneously or in alternating generations in shallow water at the Klong Luang Rice Experiment Station.

Hybridization. A total of 337 crosses were made at the Huntra and Bangkhen stations, or at IRRI upon request. F_2 populations were grown at Huntra, Prajinburi, and Bangkhen stations. About 3,000 entries of F_3 and more advanced pedigree were grown at the three stations. Selections were made on the basis of observations in the field and in parallel tests for plant type, elongating ability, submergence tolerance, growth duration, resistance to bacterial blight, grain shape, appearance of the dehulled grain, and resistance to brown planthoppers. About 50% of the lines were photoperiod sensitive and submergence tolerance was present in 15%.

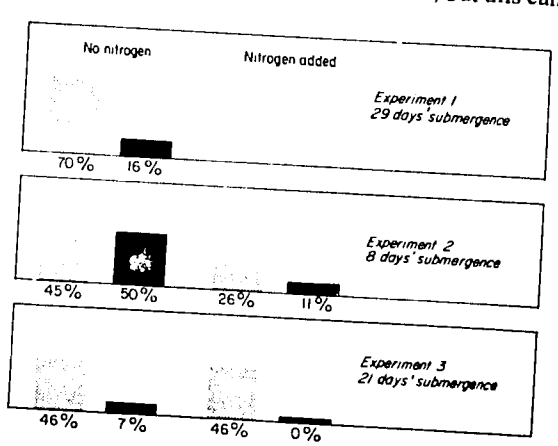
Observation nurseries. Four observation nurseries comprising about 400 lines were planted at 10 sites in Thailand. Ten percent of the lines were kept for further observation or for yield trials.

Rapid generation advance. A rapid generation advance (RGA) program in Thailand handled two populations. F_5 populations from three generations of RGA at IRRI, and one population from the Huntra RGA effort were tested in deep water. Lines that had an elongation ability score of 6 or better in 90-cm water were from BKNFR76033 (18%); BKNFR76932 (44%); and BKNFR76910 (21%).

Selection for submergence tolerance during rapid generation advance. To test the available methods of recognizing superior submergence tolerance in seedlings grown in RGA, a simulated selection experiment used 12 entries in the Cooperative International Submergence Test. Among them, FR13A, Kurkaruppan, Thavalu 15314, and Thavalu 15325 had previously been identified as superior varieties for submergence tolerance. Three experiments were done with 21-day-old seedlings planted in film capsules and submerged in 72-cm-deep water. The duration of submergence was kept flexible depending on the progress made in destroying plants by submergence.

The results of these preliminary tests (Fig. 1) show that it should be possible to make mass selection for submergence tolerance in hybrid populations of appropriate parentage during a cycle of RGA. The following qualifications need to be made:

- On the average about 50% of the tolerant plants will be destroyed.
- There is risk of heavy destruction, but this can



1. Comparison of the survival of 4 submergence-tolerant varieties (dotted bar) and 8 nontolerant varieties (black bar) in simulated rapid generation advance-type submergence screening. IRRI, 1979.

be minimized by using check varieties to help decide on the duration of submergence for each run.

Release of RD17 and RD19. The Thai Ministry of Agriculture and Cooperatives approved the release of RD17 and RD19, 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 RD19 possess dwarfing genes, conferring shallow-water plant heights ranging from 110 to 150 cm, depending on the environment. During the vegetative phase, they can withstand gradual flooding to 1 m. Both varieties form longer than usual internodes up to a maximum plant length of about 180 cm. Both are moderately susceptible to bacterial blight, and have long grains and acceptable cooking quality. They differ from each other in flowering behavior:

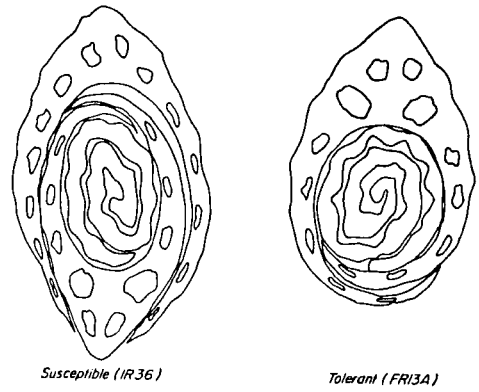
- RD17 (BKN6986-66-2) matures in 140 to 150 days regardless of the photoperiod prevailing in Thailand. It can be grown in both the dry and wet seasons.
- RD19 (BKN6986-147-2) is Thailand's first photoperiod-sensitive semidwarf rice variety. If planted early, it flowers by mid-November in Thailand, and harvest is in mid-December. This variety is meant for the vast areas immediately east and north of Bangkok, where traditional tall, photoperiod-sensitive varieties are grown in the wet season.

MORPHOLOGICAL STUDIES OF VARIETAL TOLERANCE FOR COMPLETE SUBMERGENCE

Plant Physiology Department

A series of studies was started to help find the physiological and morphological basis of submergence tolerance. Twelve varieties with varying degrees of submergence tolerance were grown in trays for 10 days and then submerged completely in 30 cm water for 6 days.

Culm thickness. Tolerant varieties generally had narrow culms compared to the susceptible varieties. There was, however, no clear varietal trend in culm thickness; the tolerant varieties generally had round culms and the susceptible varieties had slender or flat. The data also showed that the tolerant varieties had greater overlapping of leaf sheaths than the susceptible varieties. The overlapping leaf sheaths and the rounder culm provide strength to the culm (Fig. 2).



2. Diagram showing the overlapping of the first leaf sheath of the tolerant and susceptible rice varieties of 10-day-old seedlings. IRRI, 1979.

Number of vascular bundles. The total number of vascular bundles in the first and second leaf sheaths of the different rice seedlings tested did not show differences between tolerant and susceptible varieties (Table 3). However, the two tolerant varieties Kurkaruppan and Thavalu 15325 had the highest number.

The number of vascular bundles per millimeter of culm width showed high ratios for the tolerant varieties except FR13A. The average ratio was 28.1 for the tolerant varieties and 23.3 for the susceptible entries. Breakage or collapse of the culm usually occurs across the longitudinal axis, and the number of vascular bundles along that axis might be useful in strengthening the culm.

SCREENING METHOD FOR INTERNODE ELONGATION AND NODAL ROOTING ABILITY

Plant Physiology Department

An experiment was conducted to develop a method for screening nodal rooting ability, to study the effect of nitrogen application on nodal rooting ability, and to evaluate the relation between nodal rooting ability and elongation ability.

Twenty-two varieties or lines and two levels of nitrogen fertilizer were used. At 42 days after sowing (DS), the plants planted in pots were trans-

Table 3. Plant height and number of vascular bundles in submergence-tolerant and susceptible rice varieties. IRRI, 1979.

Variety	Plant ht (cm)		Vascular bundles[a] (no.)	
	Initial	6 days after treatment	Per culm	Per mm width
Tolerant				
FR13A	21	26	33	24
Kurkaruppan	18	24	42	35
Thavalu 15325	20	24	36	28
Thavalu 15314	26	29	32	28
SML Temerin	23	30	33	27
Nam Sagui 19	21	29	32	26
Av	22	27	35	28
Susceptible				
Leb Mue Nahng 111	24	28	33	24
T442-57	20	21	35	23
IR36	20	24	33	24
IR8	20	21	32	23
RD7	21	22	34	22
IR42	21	23	33	24
Av	21	23	33	23

[a]Based on the 1st and 2d leaf sheaths.

Table 4. Average length of internodes of 22 rice varieties at 35, 52, and 60 days after sowing (DS). Plants were grown in dryland condition with 2 levels of nitrogen and submerged at 42 DS. IRRI, 1979.

Type	Entries (no.)	Av internode length (cm)					
		2 g N/pot			6 g N/pot		
		35 DS	52 DS	60 DS	35 DS	52 DS	60 DS
Floating rice varieties	12	9	49	61	10	51	64
Semidwarf deepwater rice lines	7	0	23	36	0	25	37
Traditional nonfloating varieties	3	0	16	24	0	16	29

ferred to a tank and subjected to increasing water level at the rate of 35 cm/day until the maximum depth (85 cm) was reached. The water level was maintained at 85 cm until the last sampling. Elongated internodes were measured.

Internode elongation ability. Among the 22 entries, 9 showed internode elongation even before submergence (Table 4). All varieties that had such early elongation were floating rices. The high nitrogen level tended to promote internode elongation and the first internode was the longest in every entry. In this group, Laki 491, Kalimekri 77-5, Gowai 476, Habiganj Aman 1, Gowai 84, and Khama 380 showed early internode elongation. In the test, the Thai deepwater rice varieties (except Khao Med Lek), semidwarf deepwater rice lines, and nondeepwater rice varieties did not show internode elongation at 35 DS.

After 10 days in deepwater (52 DS), all rice varieties showed internode elongation ranging from 13 cm in FR13A to 65 cm in Gowai 476. The higher nitrogen level tended to increase internode elongation, but the increase was small.

The traditional deepwater rice varieties had a higher number of internodes (about 4–5) than the semidwarf deepwater rice lines and nondeepwater rice varieties (only 2–3). The first internode was the longest in the first observation, but at 10 days after treatment (52 DS), the second and third internodes were longest. The first internode, which was

already mature, did not elongate much after it was subjected to deepwater.

At 18 days after treatment (60 DS), Gowai 476 showed the longest internode (79 cm), followed by Laki 491 and Gowai 84. Among the semidwarf rice lines, BKN6986-147-2 and T442-57 had the shortest internode (29 cm), which, was however, longer than that of FR13A (22 cm). The higher nitrogen level tended to promote internode elongation.

Plant length increased with increased N level at every stage of observation. The data indicated a high correlation between plant length and length of internodes (r = 0.17**).

Nodal rooting ability. Nodal roots usually develop after internode elongation. Three days after treatment (DAT) or 45 DS, nodal roots were observed in many varieties such as Gowai 476 and Habiganj Aman I (Table 5). Most of the nodal roots were on the first node above the soil surface. Out of nine rice varieties that showed early internode elongation seven had nodal roots. In succeeding observations, nodal roots occurred in many rice varieties. However, the varieties that showed earlier elongation had better rooting ability.

Because the elongation needed for tall deepwater rices to be above the water surface is minimal, roots were formed earlier. Semidwarf deepwater rice lines had to elongate first and then form roots. Except for BKN6986-147-2, they had no roots even at 18 DAT. Nonfloating wetland varieties such as Khao Dawk Mali 105 and Nam Sagui 19

Table 5. Nodal rooting of 22 rice varieties grown under 2 nitrogen levels and subjected to 85-cm water depth. IRRI, 1979.

Entry	Nodal roots[a]					
	2 g N/pot			6 g N/pot		
	3 DAT	10 DAT	18 DAT	3 DAT	10 DAT	18 DAT
Floating rice varieties						
Birain 392	x	7	5	x	7	2
Gowai 84	x	7	5	xx	5	3
Gowai 476	xx	5	4	xx	4	1
Habiganj Aman 1	xx	7	3	xx	4	1
Kalimekri 77-5	x	5	4	xx	1	1
Kalimekri 391	–	7	5	–	6	3
Khao Med Lek	–	7	7	–	6	6
Khama 380	x	6	6	xx	4	2
Laki 491	x	4	4	xx	2	1
Leb Mue Nahng 111	–	8	7	–	8	7
Po Ngern	–	9	9	–	9	8
Tapow Gaew 161	–	9	8	–	9	7
Av	–	6.8	5.6	–	5.4	3.5
Semidwarf deepwater rice						
BKN6986-108-2	–	9	9	–	9	8
BKN6986-108-3	–	9	9	–	9	8
BKN6986-147-2	–	9	8	–	9	8
BKN6986-167	–	9	9	–	9	9
BKN6987-127-2	–	9	9	–	9	8
BKN6986-161-1-3	–	9	9	–	9	9
T442-57	–	9	9	–	9	9
Av	–	9.0	8.9	–	9.0	8.4
Traditional nonfloating rice						
FR13A	–	9	9	–	9	9
Khao Dawk Mali 105	–	9	9	–	9	9
Nam Sagui	–	9	9	–	9	9
Av	–	9.0	9.0	–	9.0	9.0

[a]DAT = days after treatment (submergence), x = nodal roots visible, xx = nodal roots starting to elongate. 1 = excellent nodal rooting, 9 = no nodal roots formed.

also had no roots at 18 DAT (Table 5). Thai traditional floating rice varieties (Leb Mue Nahng 111, Khao Med Lek, and Tapow Gaew 161) had good nodal rooting ability.

As early as 3 DAT the varieties with good rooting ability could be differentiated. But to differentiate rooting ability in semidwarf lines, scoring should be at 20 DAT. Nitrogen fertilizer promoted the production of nodal roots.

The results of the experiments suggest that screening for internode elongation and nodal rooting ability should follow these steps:

1. Apply a high level of nitrogen fertilizer (1.5 g ammonium sulfate/kg soil).
2. Subject the plant to 85-cm-deep water at 6 weeks after sowing.
3. Score elongation ability 10 DAT.
4. Score nodal rooting ability 20 DAT.

Rooting ability was scored on a scale of 1 to 9:

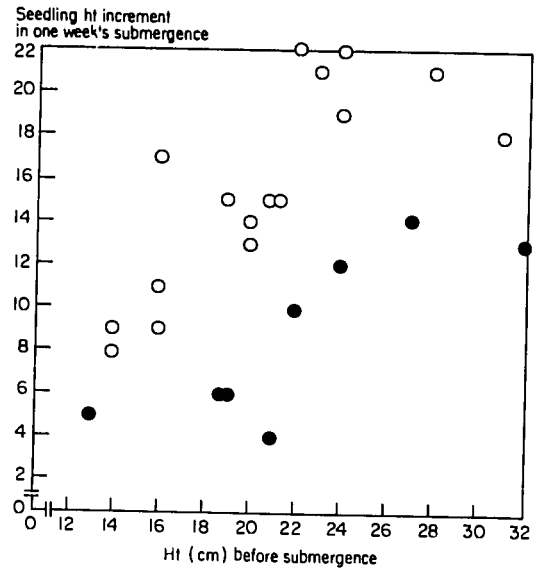
1 = excellent rooting ability, plenty of roots produced, roots longer than 5 cm and healthy;
3 = good rooting ability, many roots produced, roots about 5 cm long, some are thin but most are healthy;
5 = fair rooting ability, many roots produced, roots shorter than 5 cm, some are healthy but most are thin;
7 = poor rooting ability, few roots produced, short and thin; and
9 = no rooting ability, complete absence of nodal roots.

SUBMERGENCE TOLERANCE AND ELONGATION ABILITY

Thailand-IRRI Cooperative Deepwater Project

Characterization of submergence tolerance. A simulation experiment on effects of selection for submergence tolerance during rapid generation advance yielded information on the relation of submergence tolerance with seedling growth. In two of three experiments, seedling heights were measured at first submergence when the seedlings were 21 days old and in 72-cm water at 28 days. In the third experiment, parallel seedling measurements were made on a control, which was not submerged.

Figure 3 gives the relationship between seedling height just before submergence, and seedling height increase during 1 week's submergence for 12 entries in 2 experiments.



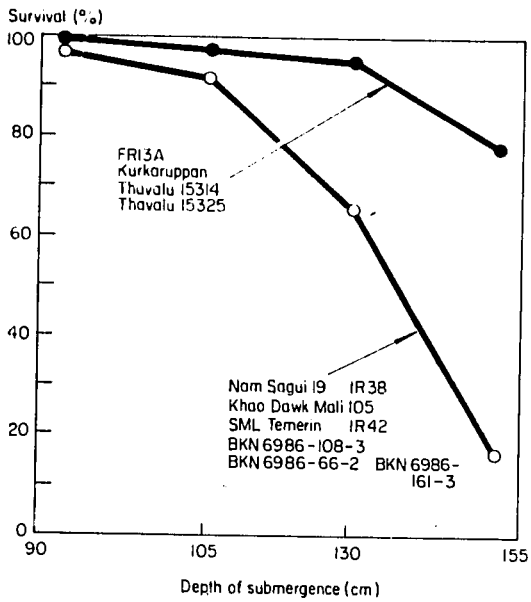
3. Height increment of 21-day-old seedlings during submergence, and initial seedling height of submergence-tolerant (black dots) and nontolerant (open circles) entries.

Water level and submergence tolerance. The 12 entries in the international cooperative test for submergence tolerance were planted in a four-water-level pond. The pond was flooded for 9 days at 44 DS (20 days after transplanting). Water levels were 90, 105, 130, and 155 cm, but they fluctuated about 30 cm because of seepage and subsequent refilling.

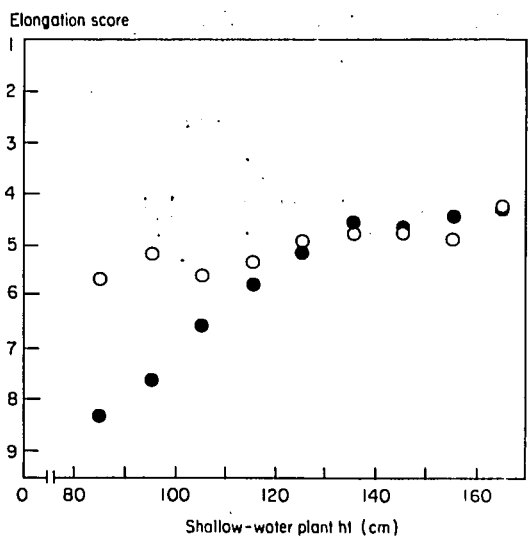
The results conformed with those of other tests featuring the same varieties and clearly demonstrated that, to distinguish excellent submergence tolerance from poor and mediocre tolerance, deep water levels are needed.

Figure 4 shows the mean survival of highly tolerant varieties compared with that of the poor and average entries. As water levels increase, all varieties show reduced survival, but the spread between varieties increases.

Elongation ability, plant height, and maturation. The elongation scores of 397 mostly photoperiod-insensitive lines were plotted against their corresponding shallow-water plant heights. One hundred and forty lines that mature in 130 days or less were compared with 256 lines that



4. Survival after emergence of a group of 4 submergence-tolerant varieties and of a group of 8 varieties without such distinction, at 4 water depths. IRRI, 1979.



5. Elongation in 90-cm water depth of lines that mature in 130 days (O) and lines that mature in more than 130 days (●). Elongation score: 1 = best elongation response, 9 = poorest elongation, or none

mature later. The resulting graph (Fig. 5) shows the relation between elongation ability and plant height for lines of later maturity. Early-maturing lines demonstrate better elongation performance than would be expected on the basis of their plant heights in shallow water. Presumably, the preflowering stem elongation common to all rices acts in concert with the water-level-induced elongation in seedlings between the ages of 30 and 50 days.

This finding has implications for genetic work on elongation ability if flowering time also segregates in populations; it also implies that early maturity in areas where expected water levels are not higher than 1 m could be favorable.

Table 6. Effects of fertilizer and spacing on tiller density, plant height, and yield of RD17. Seedlings were transplanted at 25 days of age and water was added 45 days after transplanting at 5 cm/day to a maximum level of 85 cm. Huntra Station, Thailand, 1979.

Spacing (cm)	0 N and 0 P	25 kg N and 25 kg P/ha	60 kg N and 25 kg P/ha
	Tiller density (no./m²) at 121 days		
25 x 12.5	160	160	179
25 x 25	140	137	135
25 x 40	103	95	126
	Plant ht (cm) at maturity		
25 x 12.5	162	159	166
25 x 25	157	161	160
25 x 40	153	155	155
	Grain yield (t/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
Av	3.2	3.2	3.7

FERTILIZER TRIALS

Thailand-IRRI Cooperative Deepwater Project, Agronomy and Plant Physiology Departments

Effect of fertilizer and spacing on yield of RD17 *(Thailand-IRRI Cooperative Deepwater Project)*. RD17, a newly released variety combining dwarfing genes with elongating ability, was assessed for performance under three levels of fertilizer and three spacings. Harvest was 140 DS for the denser spacing and 147 for the 25- × 40-cm spacing.

The results demonstrated the possibility of yields of 3 t/ha with no fertilizer or a basal fertilizer application under conditions of flooding when moderate varieties would fail (Table 6). The spacing of 25 × 40 cm/hill limited grain yield and delayed maturity.

Table 7. Effects of different forms and mode of fertilizer applied basally on the yield of IR42 under medium deepwater culture (max water depth 40 cm). IRRI, 1979 dry season.

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

[a]Any 2 means followed by the same letter are not significantly different from each other at the 5% level. [b]PU = prilled urea, SCU = sulfur-coated urea, FG = forestry grade.

Table 8. Effect of basal nitrogen application on grain yield of 15 rice lines grown in medium deep water. IRRI, 1979 dry season.

Entry	Grain yield (t/ha)		
	0 N	80 kg N/ha	Mean
BKN6986-147-2	3.59	4.66	4.13
CICA 8	4.06	5.26	4.66
IR3880-13-4	3.33	4.56	3.95
IR4432-52-6-4	3.83	5.52	4.68
IR5629-64-3	3.88	4.59	4.24
IR5825-44-3-P2	3.74	5.35	4.55
IR5857-3-2E-1-1	2.29	3.48	2.89
IR5857-3-2E-1-2	2.82	4.16	3.49
IR5857-3-2E-1-27	2.84	3.75	3.30
IR5857-3-2E-1-33	2.57	4.16	3.37
IR5857-4-1E-1-8	2.84	4.41	3.63
MRC505	4.38	5.01	4.70
N22	3.31	4.75	4.03
RD7	3.90	4.67	4.29
T442-57	4.26	5.25	4.76
Mean	3.44	4.64	1.20*

The higher tiller densities obtained at the closest spacing appeared to have been offset by smaller panicles that brought about the similar grain yields of the 25 × 12.5 and 25 × 24 cm spacings. Experiments at lower basic soil fertilities than those at Huntra station are needed to better evaluate the potential of closer spacings in deepwater situations.

In shallow water, RD17 was around 120 cm in height. At the 80-cm water depth, plant height ranged from 153 to 166 cm.

Slow-release fertilizer nitrogen for medium deepwater rice *(Agronomy)*. Experiments at IRRI during the 1979 dry season evaluated slow-release nitrogen fertilizers (54 kg/ha) for IR42. There was a significant response to the slow-release fertilizer nitrogen (Table 7).

Response of medium-deepwater rice to nitrogen fertilizer application *(Plant Physiology)*. An experiment was conducted to better understand the increase in grain yield of the new medium-deepwater rice lines with fertilizer application. Two levels of nitrogen were applied before transplanting and water level was increased 30 DAT at the rate of 5 cm/day until a 50-cm water depth was reached. That level was maintained until all entries had flowered. The water was slowly drained before harvest.

Grain yield. Basal nitrogen application resulted in a significant increase (35%) in grain yield of all entries (Table 8). Higher grain yields with nitrogen application were due principally to the greater number of panicles per square meter (Table 9). The positive responses to nitrogen application ranged from 14% for MRC505 to 62% for IR5857-3-2E-1-33.

Yield components. Basal nitrogen application increased the number of panicles per square meter for all entries — an average of 47% increase of panicles per unit area — but did not affect the number of spikelets per panicle, fertility percentage, and 1,000-grain weight (Table 9). The results clearly showed that the role of basal nitrogen in achieving higher grain yields is to increase the panicle number per unit area — basal application increased the tiller number per unit area for all entries as early as 30 DAT or before the water level was increased. Use of slow-release nitrogen compounds may subsequently increase the number of spikelets per panicle.

Except T442-57, all the rice lines that produced high grain yields had high tillering ability. The high grain yield of T442-57 was attributed to the big panicle size or more spikelets per panicle and heavier 1,000-grain weight, which are the dominant characters of Thai floating rice. These results

Table 9. Yield components[a] (av of 15 entries) as affected by basal nitrogen application under medium deep water condition. IRRI, 1979 dry season.

Yield components	0 N	80 kg N/ha
Panicles per square meter	163 b	240 a
Spikelets per panicle	112 a	115 a
Fertility (%)	86 a	83 a
1000-grain wt (g)	23.38 a	23.46 a

[a]For each component, values followed by the same letter are not significantly different at the 5% level.

Table 10. Agronomic characters (av for 15 rice entries) as affected by basal nitrogen application under medium deep water condition.[a] IRRI, 1979 dry season.

Character	0 N	80 kg N/ha
Leaf area index at flowering	1.8 b	3.5 a
Tillers per square meter[b]	164 b	244 a
Productive tillers (%)	100 a	95 a
Dry matter production (t/ha)[b]	7.33 b	10.46 a
Maturity (days)	107	107

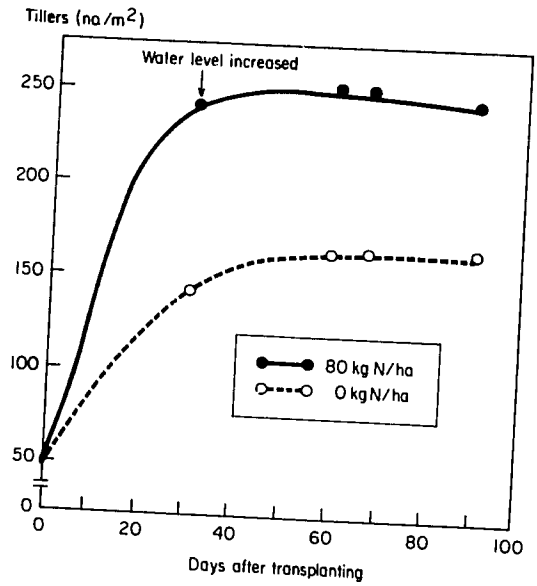
[a]For each character, values followed by the same letter are not significantly different at the 5% level. [b]At maturity.

indicate that if selection for intermediate stature is needed in deepwater areas, not only good tillering ability at early stage but also panicle weight should be considered.

Leaf area index. Increase in leaf area index (LAI) at flowering was due to nitrogen application (Table 10). The increase was attributed mainly to an increase in tiller number and plant length above the water surface. In both the nitrogen and no nitrogen plots, the LAI was relatively low (av of 3.5 in the plot with 80 kg N) compared with previous results obtained with Peta (about 7) under irrigated conditions. Because the lower leaves that were submerged died, the LAI in medium deep water would be lower than in shallow water.

Plant length and tiller number. Basal nitrogen application significantly increased plant length by promoting internode elongation, and significantly increased tiller number before the water level was increased.

Previous research had shown that grain yields decreased as water level increased; increase in water level resulted in the cessation of tiller production. However, this might have been a useful way of preventing the production of unproductive tillers as shown in Figure 6. Normally productive tillers range from 50% in Peta to 81% in Tainan 3. In medium deep water, the productive tillers ranged from 95% to 100% in plots with and without nitrogen application (Table 6). This points to the importance of early tiller production by basal fertilization and closer plant spacing to achieve higher grain yields of deepwater rice.



6. Effect of basal nitrogen application on tiller number of 15 lines grown in medium deep water. IRRI, 1979 dry season.

Nitrogen application in medium deepwater rice increased grain yields primarily by increasing tiller number per unit area, percentage of effective tillers, and plant height, which increases plant survival and LAI.

COLLABORATIVE FIELD SCREENING FOR DROUGHT RESISTANCE AT SEEDLING STAGE

Agronomy Department

Drought is a problem during the early stages of growth in the deepwater rice areas where seed are broadcast. Collaborative screening involving Thailand, West Africa, West Bengal (India), and IRRI was started with 17 common entries. Tests at IRRI (see Drought resistance section of this report) showed that only KU86 was tolerant of 4–5 bars of soil moisture tension. A few other rices (mostly deepwater) had moderate resistance to drought of 4–5 bars. Similar tests at Huntra and Klong Luang stations, Thailand, failed to yield reliable data because of soil heterogeneity.

Genetic evaluation and utilization (GEU) program

Temperature tolerance

Plant Physiology and Plant Breeding Departments

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LOW TEMPERATURE

Plant Physiology and Plant Breeding Departments

Genetic studies on cold tolerance at seedling stage. Genetic analysis was made for 14 crosses involving a cold-tolerant cultivar and a susceptible line. Ten days after sowing of parental lines and the F_1 and F_2 of each cross, seedlings were put in a cold water (12°C) tank. When the susceptible parent showed symptoms of cold injury (severe yellowing of leaves), the F_1 and F_2 seedlings were scored for cold tolerance. In all the crosses the F_1 seedlings showed tolerance for cold water, indicating that cold tolerance is a dominant trait. In 11 of 14 crosses, the F_2 populations segregated in the ratio of 3 resistant to 1 susceptible to low water temperature at the seedling stage, indicating simple monogenic inheritance (Table 1). Crosses between Jodo and JC24 indicated that the two lines have the same gene for cold tolerance.

Breeding. To develop improved germplasm for low-temperature areas, 121 single and 404 multiple crosses were made during the year and F_2 seeds of 72 crosses were distributed to breeders in 6 countries.

Field evaluation of cold-tolerant breeding materials was continued at Banaue, Philippines, in collaboration with the Bureau of Plant Industry. Five F_2 populations were grown and 822 single-plant selections were made. A total of 1,178 pedigree lines derived from 50 crosses were evaluated in a pedigree nursery. All entries in the pedigree nursery were screened for resistance to blast, bacterial blight, green leafhopper, zinc deficiency, cold tolerance at seedling stage, and grain quality characteristics. The promising breeding lines are listed in Table 2.

At Banaue 1,860 lines and varieties were screened for cold tolerance at the seedling stage; entries in the International Rice Cold Tolerance Nursery were screened for tolerance at the seedling stage, at panicle initiation, and at anthesis.

Rapid generation advance for cold-tolerant rices. The use of rapid generation advance (RGA) to accelerate the breeding program on cold tolerance started in late 1978. In 1978, 48 crosses specifically for low-temperature areas such as India, Nepal, Korea, and the high-altitude areas of Indonesia and the Philippines were grown through RGA.

KOREA-IRRI COLLABORATIVE PROJECT

Plant Physiology and Plant Breeding Departments

In 1979, additional temperature-controlled facilities were built by the Korean Government and new land was added to the Chuncheon station.

Rice Cold Tolerance Screening Nursery. A total of 1,620 entries were screened at Chuncheon for tolerance for low water temperature from the

Table 1. Reaction[a] of parental lines (P_1, P_2), and F_1 and F_2 seedlings of 14 crosses to cold temperature. IRRI, 1979.

Cross combination	Reaction to cold temperature						X^2 value (3:1)
	P_1	P_2	F_1	F_2 seedlings (no.)			
				R	S	Total	
Calrose/IR8866	R	S	R	380	111	491	1.4997
Calrose/IR30	R	S	R	656	198	854	1.5004
Calrose/IR5853	R	S	R	655	234	889	0.8283
JC24/IR30	R	S	R	533	114	647	18.7950**
JC24/IR5853	R	S	R	742	229	971	1.0384
Jodo/IR8866	R	S	R	597	199	796	0.0000
Jodo/IR30	R	S	R	605	172	777	3.3981
Jodo/IR5853	R	S	R	519	178	697	0.1076
KT31-1/IR8866	R	S	R	531	159	690	1.4087
KT31-1/IR30	R	S	R	695	256	951	1.8679
KT31-1/IR5853	R	S	R	640	242	882	2.7952
Eiko/IR8866	R	S	R	647	250	897	3.9424*
Eiko/IR30	R	S	R	694	168	862	13.9598**
Jodo/JC24	R	R	R	1087	–	1087	

[a]R = resistant, S = susceptible.

Table 2. Characteristics of selected cold-tolerant breeding lines grown at Banaue, Philippines. 1979 dry season.

Designation	Cross	Maturity (days)	Ht (cm)	Amylose (%)	Reaction[a] to		
					BB	B	GLH
IR5867-45-2-3-2	IR747B2-6/Kn-1b-361-1-8//IR747B2-6/ Kn-1b-213-1-4	136	102	9	1	1	3
IR5896-10-2-1-1	IR747B2-6/Bagsan daykat//IR2061-213-2-16	136	103	7	1	1	3
IR7167-33-2-3	China 1039/Kn-1b-361-1-8-6-10	136	96	9	1	8	3
IR7167-33-2-5-1-3	"	136	93	9	1	8	5
IR8845-10-3-3	K17-Bk-4-1/IR2053-521-1-1	138	102	7	1	1	7
IR9105-42-1-3	China 1039/IR1561-228-3-3//IR2053-521-1-1	136	113	9	1	4	7
IR9107-93-3-3	China 1039/IR2061-213-2//IR2053-521-1-1	134	114	7	1	4	7
IR9202-5-2-2-2	IR2053-521-1-1/K116//Kn-1b-361-1-8-6-9-1	132	99	9	1	1	5
IR9202-6-1-1-2	"	132	99	9	1	1	5
IR9202-6-1-2	"	132	101	9	1	1	6
IR9202-21-3-2	"	136	97	9	1	3	3
IR9202-23-2-1-3	"	132	95	9	1	1	3
IR15889-112-3	IR3941-37-2/Kn-1b-361-B1k-27-1//IR3941-25-1	132	94	9	1	–	S
IR15889-113-3	"	134	94	7	1	–	3
IR15889-130-3	"	132	91	9	1	–	3
RPKN 2	IR8/Jerak	162	99	7	1	1	–
Local		–	125	7	7	–	–

[a]Standard Evaluation System for Rice: Bacterial blight (BB) – 1 = less than 1%, 7 = 26–50% incidence; blast (B) – 1 = small brown specks of pinhead size, 8 = 51–75% of leaf area infected with typical blast lesions and many leaves dead; green leafhopper (GLH) – 3 = first and second leaves yellowing, 7 = more than half of plants dead and remaining plants severely stunted; S = segregating.

vegetative stage to maturity. On the basis of phenotypic acceptability at maturity, growth duration of 110 days or less, a score of 1 for leaf yellowing at 42 days after transplanting, panicle exsertion score of 1, and spikelet fertility of at least 73%, the following entries were selected: Fuji 269, Wase Toramochi, Somewake, Tatsumi-mochi, Hwanghaedo, Von Ja 2, SR3049-58-1-5-1, SR3049-58-1-5-2, SR3054-55-1-2-3, SR3055-129-3-2-2, CI 11041, and CI 11043. The reactions of the rest of the entries are available in the IRRI data bank.

Nitrogen response at different water temperatures. An experiment with six varieties examined varietal response to various levels of nitrogen and temperature. The plants were transplanted in plots that received 50, 150, and 200 kg N/ha and subjected to water temperature of either 17 or 21°C from tillering to maturity.

With water temperature at 17°C, grain yields were highest in all cases at 150 kg N/ha (Table 3). At 21°C, the grain yields were generally higher at 200 kg N/ha, mainly the result of higher panicle number per hill.

The importance of nitrogen fertilizer at low water temperature is shown in the number of tillers per hill and percentage of increase in tiller number with increase in nitrogen level (Table 4).

Fertilizer level and low-temperature damage. An experiment examined reduction of low-

Table 3. Effect of 3 nitrogen levels (50, 150, 200 kg N/ha) on the grain yield of 6 varieties or lines irrigated with water at 17 or 21°C from tillering to maturity. Korea-IRRI Collaborative Cold Tolerance Project, Chuncheon, Korea, 1979.

Variety or line	Grain yield (t/ha)					
	17°C			21°C		
	50	150	200	50	150	200
Josaengtongil	1.70	2.22	1.83	3.75	4.99	5.36
Suweon 264	0.40	2.19	1.87	3.52	4.47	4.43
Nongbaek	2.17	3.51	3.42	4.35	5.06	6.18
Suweon 235	1.94	3.60	3.58	4.00	5.26	6.23
Kn-1b-361	2.09	4.07	3.56	3.59	4.76	4.97
IR7167-33-2-3	2.76	4.08	3.93	4.08	5.94	4.76

Table 4. Tiller number per hill of 6 varieties or lines irrigated with water at 17 or 21°C and fertilized with 50 or 150 kg N/ha. Korea-IRRI Collaborative Cold Tolerance Project, Chuncheon, Korea, 1979.

Variety or line	17°C			21°C		
	Tillers (no.)		Tiller increase (%)	Tillers (no.)		Tiller increase (%)
	50	150		50	150	
			45 DT[a]			
Josaengtongil	9.2	13.4	46	11.8	15.2	29
Suweon 264	11.2	17.7	58	10.8	13.3	23
Nongbaek	8.6	13.2	53	9.6	11.3	18
Suweon 235	12.0	17.6	47	11.1	18.2	64
Kn-1b-361	9.1	13.2	45	8.6	12.1	41
IR7167-33-2-3	10.1	13.2	31	8.5	12.2	44
			At maturity			
Josaengtongil	7.7	11.0	43	9.4	12.2	30
Suweon 264	5.6	13.7	145	9.2	11.6	26
Nongbaek	7.5	11.7	56	7.9	9.4	19
Suweon 235	8.6	13.5	57	8.8	12.0	36
Kn-1b-361	4.8	8.4	75	6.6	8.9	35
IR7167-33-2-3	8.1	9.8	21	7.0	10.0	43

[a]Days after transplanting.

Table 5. Discoloration score of Suweon 264 planted with 2 levels of nitrogen, phosphorus, silicon, and compost and irrigated with cold water (17°C) at tillering or meiotic stage. Korea-IRRI Collaborative Cold Tolerance Project, Chuncheon, Korea, 1979.

Compost (t/ha)	Discoloration score[a]							
	100 kg N/ha				200 kg N/ha			
	0 P		120 kg P/ha		0 P		120 kg P/ha	
	0 Si	3000 kg Si/ha	0 Si	3000 kg Si/ha	0 Si	3000 kg Si/ha	0 Si	3000 kg Si/ha
				Tillering stage				
0	3	3	3	3	2	2	1	2
15	3	3	4	3	2	2	2	2
				Meiotic stage				
0	5	5	5	6	3	4	4	4
15	6	5	6	4	2	4	4	5

[a]Standard Evaluation System for Rice score: 1 = green, 9 = dead leaves.

temperature damage by application of fertilizer. The levels used are shown in Table 5. A low temperature (17°C) treatment was given for 10 days at tillering (30 days after transplanting) or at the meiotic stage.

Discoloration scores were obtained after the low-temperature treatment at the meiotic stage, after the plants treated at tillering stage had recovered to a certain degree. Nevertheless, the higher nitrogen level resulted in greener leaves. Phosphorus, silicon, and compost had little effect on protecting the plant from low water temperature at tillering or at the meiotic stage.

Low water temperature reduced grain yields more at the meiotic stage than at tillering (Table 6). Higher nitrogen and compost levels resulted in higher grain yield in all cases, regardless of the time of low-temperature treatment.

Generally, increased phosphorus and silicon gave a slight increase in yield regardless of nitrogen and compost level. However, the increase was not statistically significant.

Table 6. Effect of varying levels of nitrogen, phosphorus, silicon, and compost on yield of Suweon 264 irrigated with cold water (17°C) at tillering or meiotic stage. Korea-IRRI Collaborative Cold Tolerance Project, Chuncheon, Korea, 1979.

Compost (t/ha)	Grain yield (t/ha)							
	100 kg N/ha				200 kg N/ha			
	0 P		120 kg P/ha		0 P		120 kg P/ha	
	0 Si	3000 kg Si/ha	0 Si	3000 kg Si/ha	0 Si	3000 kg Si/ha	0 Si	3000 kg Si/ha
				Tillering stage				
0	5.47	5.28	5.56	5.75	5.84	6.04	6.30	6.41
15	6.03	6.03	5.90	6.15	6.24	6.34	6.45	6.74
				Meiotic stage				
0	3.78	3.82	3.85	4.10	3.99	4.07	4.17	4.17
15	4.04	4.15	3.93	4.34	4.62	4.52	4.39	4.67

Treatment at the meiotic stage showed that although addition of compost did not increase panicle number, there was a definite increase in fertility of the spikelets. The effect is more of a *protective treatment* rather than the effect obtained from higher nitrogen level.

Effect of low water temperature at different growth stages. Seven differential varieties were subjected to water at 17°C at the tillering, meiotic, heading, and ripening stages. This is the second year of the experiment. Except at the meiotic stage, which had 20-cm water depth, the water level was maintained at 5 cm. The duration of treatment was 10 days, except at the ripening stage, which was 20 days.

As in the 1978 study, the plants were most sensitive to low water temperature during the active tillering and meiotic stages (Table 7). There was no significant reduction in grain yields for low-temperature treatments at the heading and ripening stages. At the meiotic stage, decrease in grain yields was due to reduction in fertility of the spikelets. In both years, Leng Kwang had the most stable yields or was least affected by low temperature.

One of the reasons for the high fertility of Leng Kwang and Kn-1b-361, even with low water temperature at the meiotic stage, is the position of the developing panicle in terms of the water level. The panicle primordium of Leng Kwang and Kn-1b-361, which are tall varieties, is above the cold water level. Suweon 235, with its panicle primordia below the water level, had high spikelet fertility indicating a true tolerance rather than avoidance.

Cold water injury at the reproduction stage. Previous experiments indicated that some varieties tolerate low temperature by virtue of plant height. Those varieties had their growing points above the water level. A 1979 experiment checked

Table 7. Effect on grain yield of low water temperature treatments at different growth stages. Korea-IRRI Collaborative Cold Tolerance Project, Chuncheon, Korea, 1979.

Variety	Grain yield (t/ha)				
	Tillering	Meiotic	Heading	Ripening	Control
Josaengtongil	4.67	3.93	4.91	5.13	4.92
Nongbaek	4.80	3.71	5.52	5.43	5.17
Towada	4.45	4.23	5.26	5.57	5.53
Suweon 235	5.64	4.91	5.06	6.32	5.57
Suweon 264	4.80	1.55	4.98	5.64	5.39
Leng Kwang	5.05	4.43	5.12	5.19	5.06
Kn-1b-361	4.69	3.92	4.50	5.04	3.86

the effect of low water temperature at the reproductive stage on varieties differing in tolerance and plant height. Determination of the stage of development of the panicle was based on the distance of the auricle of the flag leaf from the auricle of the next leaf below. The 17°C water treatment was for 10 days (Fig. 1).

In Gumi and Suweon 235, the effect of low temperature in increasing sterility percentage at the reproductive stage was greater in deeper water. Towada and Leng Kwang had low sterility percentage at all water depths, and Suweon 235 had a high percentage in almost all treatments. The stages most sensitive to low water temperature were those with negative values for auricle distance. The more developed the panicle, the more tolerant it was of low water temperature.

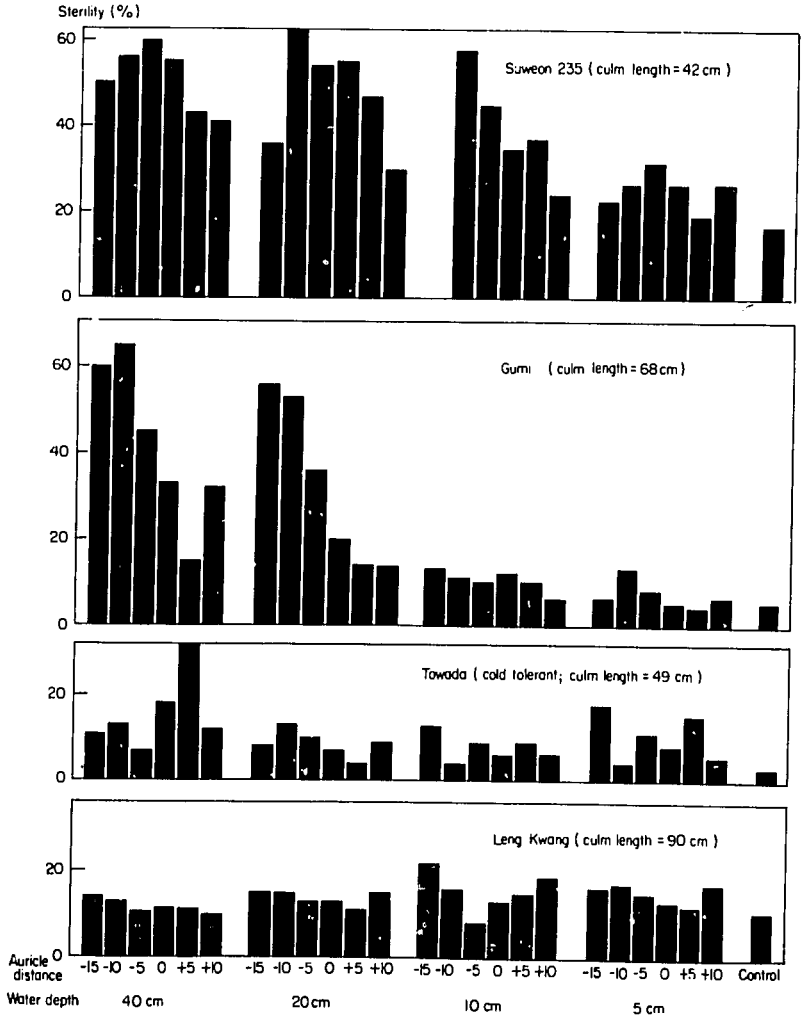
Both Towada and Suweon 235 are short, but Towada has cold tolerance. Although Gumi shows that taller plants have the advantage of escaping the effect of low water temperature and thus have lower spikelet sterility (Fig. 1), tolerance as exhibited by Towada is a better mechanism.

HIGH TEMPERATURE

Plant Physiology Department

Heat-tolerant early-maturing lines. Continued screening for heat-tolerant early-maturing lines identified 11 promising lines (Table 8). It appears that a combination of heat tolerance and early maturity can easily be found in available breeding materials.

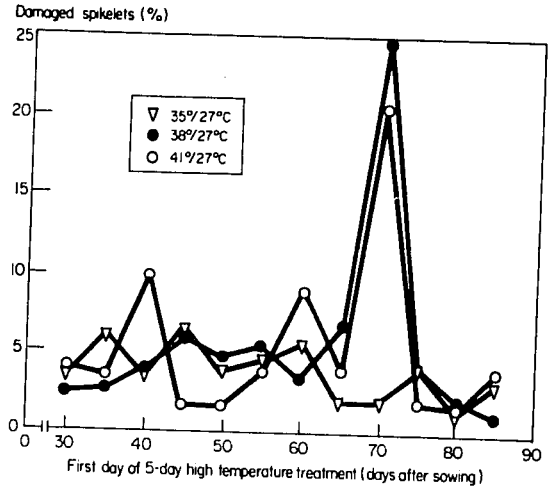
High temperature injury at panicle



1. Percent sterility of four selected varieties as affected by water (17°C) depth and stage of panicle development. IRRI, 1979.

Table 8. Heat-tolerant early-maturing lines. IRRI, 1979.

Line	Days to flowering at IRRI
IR9129-136-2	66
IR9209-26-2	67
IR9209-263-3	70
IR9224-117-2	72
IET 5714	70
IET 5688	60
IET 6187	57
IET 6238	60
IET 4700	71
IET 4701	71
IET 5734	70



2. Effect of high (day/night) temperature on spikelets. IRRI,1979.

initiation. White-tipped panicles were widespread in Palawan in 1977. Both spikelets and rachises were white. The symptoms, conspicuous on improved varieties such as C4-63G and IR26, were suspected to be caused by high temperature.

In a 1979 study of the effect of high temperature on growing panicles, IR26 plants were exposed for 5 days to the day-night temperature regimes 35°/27°C, 38°/27°C, and 41°/27°C at different growth stages. When the plants were subjected to 38°/27°C and 41°/27°C at 70 days after sowing (when panicle length was about 2 mm), about 20 and 25% of white spikelets were observed. The symptom induced by high temperatures was identical with what was observed in Palawan. At 35°/27°C, only a few spikelets were white (Fig. 2). Thus, occurrence of white-tipped panicles was attributed to high temperature injury at panicle initiation. But in Palawan the daily maximum air temperature is unlikely to exceed 38-41°C. Hence, high soil temperature near the soil surface is suspected to be the cause of white-tipped panicles.

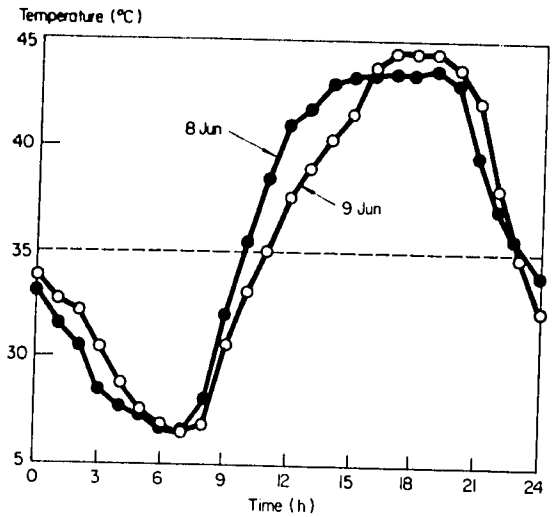
In a separate experiment, IR26 had 38% spikelet sterility when the plants were subjected to 35°/27°C at heading. Thus, the critical temperature for white-tipped panicles is higher than that for sterility at heading.

Early morning anthesis. Early morning anthesis, a characteristic of *Oryza glaberrima* (1977 annual report), is one way of avoiding high-temperature-induced sterility. In interspecific crosses between *O. glaberrima* and *O. sativa*, 6 of 25 hybrid lines had anthesis about 1 hour earlier than IR36 (Table 9). The peak time (about 40-60% of flowers opening) for anthesis was 0700-0800 for *O. glaberrima* lines, 0900-1000 for the 6 hybrids, and 1000-1100 for the rest of the hybrids and IR36. In the Punjab, India, temperature in the morning rises about 3°C/hour or faster, and goes above 35°C at around 1000 (Fig. 3). With anthesis before 1000, high-temperature-induced sterility can be avoided.

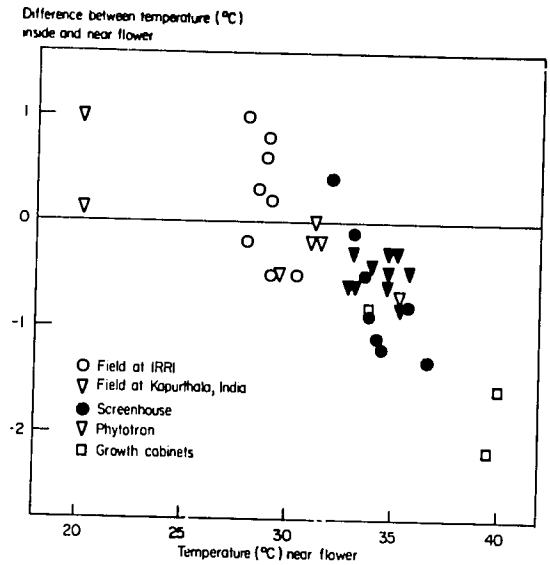
Temperature inside the flower. High air temperature (above 35°C) just before and during anthesis induces sterility (1976 annual report). Temperatures inside and outside the flower were measured with a thermocouple thermometer in glasshouse rooms of the phytotron, in artificially lighted

Table 9. Origin of 6 hybrid lines with early flowering characteristic. IRRI, 1979.

Designation	Parents
IR20959-43	*Oryza glaberrima* Acc. No. 102485/3*IR1561-228-3-3
IR20965-11	*Oryza glaberrima* Acc. No. 102550/3*IR1561-228-3-3
" -17	"
" -23	"
" -26	"
IR20971-12	"



3. Diurnal change of air temperature on 2 consecutive days in June in the Punjab, India. 1979.



4. Effect of air temperature on rice flower temperature. Field measurements were on clear windless days in flooded plots. 1979.

growth cabinets, in the screenhouse, and in fields at IRRI and at the Regional Rice Research Station, Punjab Agricultural University, Kapurthala, India.

The temperature inside the flower was 0-1°C higher than that outside when ambient temperature was about 30°C and below. When ambient temperature was above 30°C, however, the temperature inside the flower was lower than that outside (Fig. 4). At an ambient temperature of 40°C, temperature inside the flower was lower by about 2°C. Temperature drops inside the flower were attributed to increased transpiration. The magnitude of the temperature decrease observed for the flower was about the same order as that for leaves. Thus, environmental conditions such as air humidity may affect temperature inside the flower through transpiration.

Measurements in the artificially lighted cabinet indicated that temperature drops inside the flower were greater when ambient air was drier (Table 10). If the cooling effect of transpiration lowers temperature inside the flower, high-temperature-induced sterility would be lower under conditions that favored increased transpiration, provided ambient air temperature remained the same. A shading experiment showed that fertility percentage was higher under higher light intensity when ambient air temperature was the same (Table 11).

Table 10. Effect of air humidity on the temperature difference between ambient air and air inside the flower in an artificially lit growth cabinet (KG106 SHLD). 1979.[a]

	VPD 12 mb, RH 79%		VPD 24 mb, RH 57%		VPD 36 mb, RH 36%	
	Repl. 1	Repl. 2	Repl. 1	Repl. 2	Repl. 1	Repl. 2
Temperature inside flower (°C)	32.8	33.4	33.4	32.7	32.7	32.4
Temperature near flower (°C)	33.8	34.0	34.2	33.6	34.6	34.3
Difference (°C)	−1.0	−0.6	−0.8	−0.9	-1.9	−1.9

[a]VPD = vapor pressure deficit, RH = relative humidity, repl. = replication.

Table 11. Effect of shading on fertility of variety BKN6624-46-2 at high temperature (35°C). IRRI, 1979.

Shading (%)	Fertility[a] (%)
0	86 a
25	71 b
50	66 b
75	60 b

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

Genetic evaluation and utilization (GEU) program

International rice testing program

International Rice Testing Program

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INTERNATIONAL NURSERIES

Data from about 500 individual 1978 trials (17 types of nurseries) were analyzed, and reports printed and sent to cooperators. The most promising entries are shown in Table 1.

During 1979 nearly 1,200 sets of 1979 nurseries were dispatched from 2 central points: 923 nurseries went from IRRI to 55 countries and 254 sets of the Latin America nurseries went from Centro Internacional de Agricultura Tropical (CIAT) to 21 Latin American countries.

Table 1. Promising entries in the IRTP yield and screening nurseries tested in 1978–79.

Nursery	Promising entries
	Yield
Irrigated – Early (IRYN-E)	IET4094 (CR156-5021), IR5853-118-5, IR9093-216-3, IR36, B541b-Pn-58-5-3-1, MRC603-303
Irrigated – Medium (IRYN-M)	BR51-46-5, IET6073 (RP825), IR2058-78 (IR46), IR4570-83 (IR48), IR42, IR5853-162-1-2-3, BR51-282-8
Irrigated – Late (IRYN-L)	CR1002, CR1009, IET5656 (RP975), RP1064-14-2-2, IR4625-132-1-2
Upland (IURYN)	IR1529-430-3 (IR43), IR9669 Sel., IET1444, IR36, IR2035-242-1 (IR45), IR3839-1, B541b-Kn-19-3-4
	Biological Stress
Blast (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 (Special Set)	IET4699 (RP967-11), IR4422-98-3-6, Suduwee, Tadukan
Tungro (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
Brown Planthopper (IRBPHN)	PTB33, Sinna Sivappu, Hondarawala, Mudu Kiriyal, Suduru Samba
Gall Midge (IRGMN)	BG404-1, W1263, RPW6-17
Stem Borer (Special Set)	IR1820-52-2 (vegetative), IR4227-28-3-2 (heading)

MONITORING TOURS

Planning of the International Rice Testing Program (IRTP) and other international GEU activities continued through IRTP monitoring tours and workshops.

The first of four monitoring tours was held in the northern region of South America in conjunction with the third Latin American IRTP workshop at CIAT. The workshop had 73 participants representing 21 Latin American countries and 6 international agricultural research institutes. The monitoring tour participants — from five Latin American countries, International Institute of Tropical Agriculture, West African Rice Development Association, and IRRI — visited Ecuador, Colombia, Venezuela, Guyana, and Surinam to observe rice research activities and on-farm rice-growing practices.

Two problem-area monitoring tours were held in Asia. One covered rice diseases with a focus on bacterial blight and the other covered insects with a focus on brown planthopper and gall midge.

The fourth tour of 1979 was associated with an International Rice Research Workshop in the People's Republic of China. That workshop, sponsored by IRRI and the Chinese Academy of Agricultural Sciences, was the first international meeting on rice held in China. Thirty workshop participants from eight Asian countries discussed integrated pest control measures with a focus on the use of resistant varieties. Monitoring tour participants visited research institutes and rice production communes in Guandong and Hunan Provinces.

COMMUNICATION AND DATA DISSEMINATION

Reports of the 1978 nurseries and special screening trials were published to provide cooperating and other interested scientists information on the performance of all entries. The master fieldbook of the 1979 nurseries provided cooperators with information about all entries in the various trials. Reports of monitoring tours and workshops summarized the observations and recommendations made by the groups. IRTP publications for 1979 (Table 2) are available at IRRI.

Scientists from various international centers responsible for organization of international testing programs met at the Centro Internacional de

Table 2. 1979 International Rice Testing Program publications.

GENERAL REPORT
- 1978 Report of IRTP Activities

FIELDBOOKS
- 1979 Master Fieldbook

NURSERY REPORTS
- Preliminary Reports of 1978 IRTP Nurseries
- 1978 Final Reports

Yield

Irrigated
- IRYN-E (Early)
- IRYN-M (Medium)
- IRYN-L (Late)

Dryland
- IURYN

Observational

Irrigated
- IRON
- IRARON (Arid regions)

Rainfed stress
- IURON (Upland)
- IRLRON (Rainfed lowland)
- IRDWON (Deepwater)

Stress screening
- IRSATON (Salinity/Alkalinity)
- IRCTN (Cold tolerance)

Diseases
- IRBN (Blast)
- IRTN (Tungro)

Insects
- IRBPHN (Brown planthopper)
- IRGMN (Gall midge)

WORKSHOP AND MONITORING TOUR REPORTS
- Report of the 3d IRTP Conference for Latin America
- Northern Region of South America (Ecuador, Colombia, Venezuela, Guyana, and Surinam)
- Rice Diseases in Northern and Eastern India, Nepal, and Bangladesh (with focus on bacterial blight)
- Status of Rice Varietal Resistance to Brown Planthoppers and Gall Midge in India and Thailand
- International Rice Research Workshop and Monitoring Tour in the People's Republic of China (IRTP and China Collaboration)

Mejoramiento de Maíz y Trigo in August 1979 to discuss approaches and problems for effective implementation of multilocation testing. Topics included types and sizes of nurseries, seed dispatch mechanics, data collection methodologies, data reporting, data utilization in plant breeding programs, and plant quarantine.

RESEARCH LEADS

The information from IRTP nurseries, workshops, and monitoring tours continued to provide research leads for scientists in various countries and at IRRI.

- The performance of entries in yield trials at various test sites helped classify the genetic response of rice to different agroclimatic conditions.
- The excellent performance and acceptance of early-maturing entries in the IRYN-E stimulated the development, by several breeding programs, of varieties maturing in less than 100 days. A new, very early yield nursery (IRYN-VE) was planned for 1980.
- Dwarf breeding materials performed well under favorable dryland conditions. But in some cases of severe drought and problem soils stresses, the intermediate-height plant types tended to perform better; however, plant type cannot be considered in isolation from other relevant factors. There were indications of need for intensified cooperative work on dryland rice.
- International Rice Blast Nursery test sites with a representative spectrum of blast races were identified. Those races can classify the genetic response of varieties into specific groups. Intensive testing at the sites may help national breeding programs broaden the base of their blast-resistance breeding.
- Several varieties resistant to the BPH biotype of South Asia were identified. They can be used more widely by breeding programs in the region. Already available are several varieties and breeding lines with resistance to the biotypes in East and Southeast Asia. These biotypes seem to be distinct from those in South Asia.
- Gall midge resistance appeared to be stable in India, Sri Lanka, Indonesia, and Thailand during 5 years of testing. Additional efforts by the rice improvement programs are indicated to incorporate such resistance into more diverse high-yielding varieties for the region and thus provide a range in maturity, grain quality, and plant height.

J

Genetic evaluation and utilization (GEU) program

Integrated GEU program

Plant Breeding and Plant Physiology Departments and Office of Information Services

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EXCHANGE OF GERMPLASM

Plant Breeding Department

In 1979 special requests for 16,817 packets of improved breeding lines and varieties were filled. The International Rice Testing Program (IRTP) provided another 75,677 packets of the best GEU lines and varieties to participating national programs. Collaborative research projects with several national programs continued and varieties, breeding lines, and early generation materials were exchanged.

IRRI LINES NAMED IN NATIONAL PROGRAMS

Plant Breeding Department

Nine IRRI lines were named as varieties in national programs in 1979 (Table 1). Sinshwethwe and IR34 recommended in Burma and India, respectively, are identical to IR34, named in the Philippines in 1975. IR36, which is identical to its Philippine counterpart, was recommended for both the dry and wet seasons in Orissa State of India. Rajinder Dhan 201 is a high-yielding variety with excellent grain quality and resistance to bacterial blight. It was recommended for areas of good water control in Bihar State, India.

Laxmi and Sabitri have multiple disease and insect resistance, short growth duration, and excellent grain quality. They were recommended for the terai region of Nepal. IR1529 is a medium-duration variety with very high yield potential released in both the Niger and 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 (105 days) with multiple disease and insect resistance. It is resistant to the tungro virus in the southern Philippines, where IR36 and other widely grown varieties are showing some susceptibility. IR2053 has intermediate stature and long slender grains. It is the first rice variety to be named in the Sudan.

BREEDING OPERATIONS

Plant Breeding Department

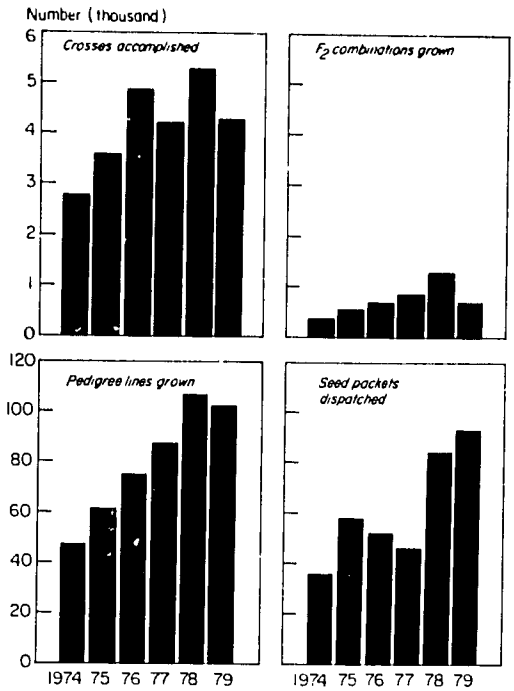
The volume of the IRRI crossing program stabilized at about 5,000 combinations in 1979 (Fig. 1). The number of F_2 combinations grown decreased sharply because a fire late in 1978 destroyed most of the F_2 seed scheduled for planting in the 1979 dry season. The number of pedigree lines grown decreased slightly during 1979. The increase in number of seed packets dispatched was largely due to an increase in the number of sets of nurseries dispatched through IRTP.

An operations manual was compiled by the GEU Operations Committee to provide detailed information on the operational procedures within the GEU program. The manual is used for training and assists GEU scientists in coordination of activities.

Irrigated rice. Emphasis in the irrigated rice improvement program continued to be on incorporation of diverse genes for disease and insect resistance, shorter growth duration, and improved grain quality. Two new genes for brown planthopper resistance (*Bph 3* and *bph 4*) were incorporated

Table 1. IRRI lines named in national programs in 1979.

Variety name given	IR line	Parents	Country where named
Sinshwethwe	IR2061-213-2-17	IR833-6//IR1561-149/IR1737	Burma
IR34	IR2061-213-2-17	IR833-6//IR1561-149/IR1737	India (Tamil Nadu)
IR36	IR2071-625-1-252	IR1561-228//IR24*4/*O. nivara*///CR94-13	India (Orissa)
Rajinder Dhan 201	IR579-97-2-2-1	IR8/Tadukan	India (Bihar)
Laxmi	IR2061-628-1-6-4-3	IR833-6//IR1561-149/IR1737	Nepal
Sabitri	IR2071-124-6-4	IR1561-228//IR24*4/*O. nivara*///CR94-13	Nepal
IR1529	IR1529-680-3-2	IR305-3-17/IR24	Niger
IR48	IR4570-83-3-3	IR1702-74/IR1721-11//IR2055-481	Philippines
IR50	IR9224-117-2-3-3-2	IR2153-14/IR28//IR2071-625	Philippines
IR2053	IR2053-206-1-3	IR1416-131/IR22//C4-63	Sudan
IR1529	IR1529-680-3-2	IR305-3-17/IR24	Upper Volta



1. Growth of the IRRI Genetic Evaluation and Utilization Program, 1974-79.

into numerous breeding lines of varying growth duration. The two genes convey resistance to all the three IRRI biotypes as well as to biotypes present in South Asia (Bangladesh, India, and Sri Lanka).

Two recently identified genes for resistance to whitebacked planthopper (*Wbph 1* and *Wbph 2*) were also incorporated into an improved plant type.

Genes for green leafhopper resistance from three accessions of *Oryza glaberrima* were transferred to an *O. sativa* background by backcrossing.

Several new sources of resistance to blast, bacterial blight, and tungro virus were used in the hybridization program. Crosses were made with Ptb 21 as source of resistance to ragged stunt.

A large number of lines that mature in 90-100 days and have multiple resistance to major diseases and insects have been generated. Several of those lines yielded as well as IR36 in replicated yield trials.

Numerous breeding lines with intermediate amylose content and other desirable traits are available, and many crosses were made to incorporate aroma into the best materials of improved plant type and with multiple disease and insect resistance. Some of the promising lines with multiple attributes are listed in Table 2.

A total of 821 crosses for irrigated rice were made in 1979 — 316 crosses (157 single and 159 multiple) in the dry season and 505 (315 single and 190 multiple) in the wet season. F_2 populations were grown from 39 multiple crosses in the dry season and from 53 single crosses and 68 multiple crosses in the wet season.

The number of pedigree nursery rows grown during the year totaled 52,359. Pedigree nurseries in January and July were limited to materials of less than 110 days growth duration; the March and September pedigree nurseries had materials with growth duration as long as 125 days, and pedigree nurseries grown in May and November consisted of materials with growth duration of more than 125 days.

In the dry season, 368 entries were evaluated in replicated yield trials and 205 in unreplicated observational yield trials. In the wet season the entries evaluated in replicated and observational yield trials were 368 and 226, respectively. Small seed-increase plots of 348 and 308 entries were grown during the dry and wet seasons and breeder seed of 5 and 14 entries was produced.

Rainfed wetland rice. More than half of the wetland rice grown in South and Southeast Asia is rainfed. For several years we have been working to incorporate the components of yield stability such as flood tolerance, drought tolerance, tolerance for mineral stresses, and intermediate stature into our improved germplasm. Most of the lines listed in Table 3 have intermediate stature and combine multiple disease and insect resistance with tolerance for several physical or chemical stresses.

Collaborative work on rainfed wetland rice is through a network of scientists in six countries throughout the rice areas of South and Southeast Asia (Fig. 2). Through this network early-generation breeding material is shuttled through several sites in sequential years. The parents for the crosses that are selected through the system are chosen by the collaborating scientists; the crosses are made at IRRI and distributed to the collaborators in the F_2. Outstanding lines eventually selected from this system will be distributed throughout the world in the International Rainfed Lowland Rice Observational Nursery (IRLRON).

Table 2. Main characteristics of selected promising lines developed for irrigated rice culture. IRRI, 1979.

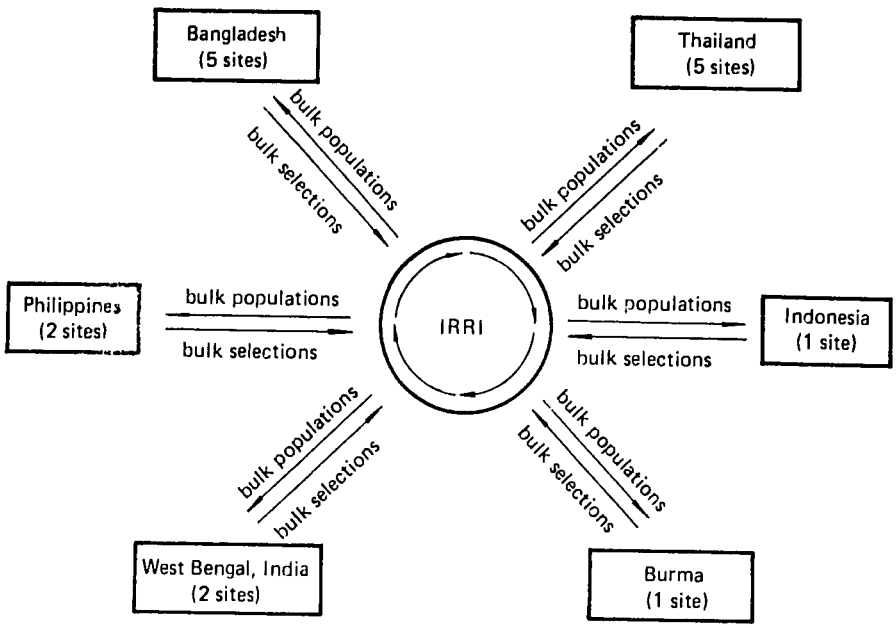
Designation	Cross	Ht (cm)	Growth duration (days)	Amylose content (%)	Gelatinization temp	Reaction[a] to diseases				Reaction[a] to insects				
						Blast	Bacterial blight	Tungro	Grassy stunt	BPH[b] biotype 1	BPH[b] biotype 2	BPH[b] biotype 3	GLH[c]	WBPH[d]
IR4568-86-1-3-2	IR1702-74-3/IR2061-464//IR2055-475-2	112	118	26	L	4	1	3	3	3	9	3	5	7
IR5853-162-1-2-3	Nam Sagui/IR2071-88//IR2061-214	112	118	25	I	1	1	1	1	3	3	9	3	7
IR8608-298	IR2061-465-1-5-5/IR36	98	103	26	L	7	1	1	1	3	3	7	3	7
IR8608-167-2	IR2061-465-1-5-5/IR36	102	100	26	L	4	1	3	1	3	3	7	5	7
IR9129-209-2-2-2-1	IR28/IR2053-521-1-1//IR36	100	105	22	I	4	1	1	1	3	3	3	3	5
IR9224-117-2-3-3-2	IR2153-14-1-6/IR28//IR36	97	105	25	I/L	6	1	1	1	3	3	5	3	5
IR13423-17-1-2-1	IR44/IR2588-132-1-2//IR4417-177-1-4	111	119	26	L	4	1	1	3	3	3	9	3	7
IR9752-71-3-2	IR28/Kwang Chang Ai/IR36	91	99	25	L	3	1	1	1	3	3	7	3	7
IR13249-109-2-2-1	IR4432-53-3/Ptb 33//IR36	94	107	26	L	1	1	1	3	1	1	1	3	7
IR13429-196-1-2-2	IR4432-53-3/Ptb 33//IR36	112	107	25	I/L	4	1	1	3	3	3	3	3	5
IR13525-43-2-3-1	Ptb 33/IR2153-196-1//IR36	104	119	26	I/L	4	1	1	3	3	3	3	5	3
IR13540-56-3-2-1	Ramu Heenati/IR2153-196//IR2823-399-5-6	123	119	27	L	3	1	1	1	3	3	3	5	5
IR15314-30-3-1-3	Babawee/IR4432-53-3//IR2061-628-1-6-4	106	119	26	I	3	1	1	3	3	3	3	3	5
IR15318-2-2-2-2	Ptb 33/IR3403-267//IR36	113	125	26	I/L	1	1	1	1	3	3	5	5	9
IR19661-131-1-2	Ptb 33*4/IR3403-267-1	105	121	25	L	4	1	1	1	1	1	1	3	7
IR19743-25-2-2	IR9129-192-2/IR10176-79	104	98	26	L	3	1	1	1	3	3	9	3	7
IR19743-46-2-3	IR9129-192-2/IR10176-79	107	98	25	L	5	1	1	1	3	3	9	3	7
IR19746-28-2-2	IR9129-192-2/IR10183-7	100	98	25	L	5	1	1	1	3	3	9	3	7

[a]1980 Standard Evaluation System for Rice scale. [b]Brown planthopper. [c]Green leafhopper. [d]Whitebacked planthopper.

Table 3. Selected rainfed wetland breeding lines that combine multiple disease and insect resistance with tolerance for drought, submergence, and salinity. IRRI, 1979.

Designation	Cross	Ht (cm)	Growth duration (days)	SES[a] rating									
				Drought tolerance	Submergence tolerance	Salinity tolerance	Blast	Bacterial blight	Brown planthopper biotype 1	Brown planthopper biotype 2	Brown planthopper biotype 3	Green leafhopper	Amylose content (%)
IR4570-83-3-3-2	IR1702-74-/IR1721-11//IR2055-481	115	130	5	5	3	4	1	3	3	3	3	22
IR5853-118-5	Nam Sagui/IR2071-88//IR2061-214	107	118	3	7	4	4	1	3	3	3	3	27
IR9217-58-2-2	IR2071-588-6/IR2061-213//IR2058-78	126	130	3	9	4	3	3	3	3	7	3	26
IR9264-321-3	Mahsuri/2•IR2061-213	133	135	5	5	4	5	1	3	5	7	3	26
IR9800-74-1-2	IR2058-78/IR2071-176//IR34	129	130	–	9	–	5	3	3	3	7	1	26
IR9852-22-3	IR2562-68/IR2588-48//IR2071-625	118	120	5	7	3	1	1	3	3	3	5	26
IR9861-25-1-1	IR5492-3-147/IR5534//IR2070-414	113	120	–	7	–	4	3	1	5	3	3	25
IR10168-52-4-2	IR30/Nona Bokra//IR2035-290	108	115	–	5	–	8	3	3	9	3	9	26
IR10781-143-2	BG90-2/IR2863-38	127	125	–	9	–	6	1	3	3	3	5	28
IR11418-15-2	IR2863-38/IR2058-78	108	113	–	5	–	5	3	1	3	3	5	25
IR13146-41-3	BG90-2/IR34//IR2058-78	132	127	5	5	5	5	3	3	7	3	9	25
IR13146-158-1	BG90-2/IR34//IR2058-78	125	125	–	7	–	5	3	3	5	3	9	25
IR13419-22-1	IR2863-38/IR2071-586//IR2071-625	95	111	–	7	–	4	3	3	3	3	5	27
IR13426-19-2	IR2863-38/Mahsuri//IR2863-38	113	126	3	7	3	4	1	3	3	3	3	27
IR14632-2-3	IR2863-38/IR2058-78	122	125	–	7	–	4	3	3	3	3	3	26
IR10206-29-2	IR2071-179/SR26B//IR2153-26	116	110	–	7	–	5	1	3	9	3	5	27

[a]1980 Standard evaluation system for rice.



2. Schematic representation of international movement of materials in IRRI's rainfed wetland collaborative project. 1979.

Dryland rice. Among dryland breeding lines tested, IR5260-1 and IR5931-110-1 performed well under relatively wet conditions. Both had good drought recovery ability. IR5716-18-1 responded early to water stress by rolling its leaves, but it had a drought resistance score of 3 at the reproductive stage. At an IRRI site, where severe stress occurred at the reproductive stage, this line was one of the few entries that produced grains, although the yield was only 0.1 t/ha. IR6115-1-1-1 has consistently yielded more than 4 t/ha for 3 consecutive years in the trials planted in a farmer's field in Batangas Province. This line has an elastic growth duration, which enables it to tolerate the effect of drought stress. It also has good recovery ability, and thus benefited from late rains. IR6115-1-1-1 has moderate resistance to blast and BPH biotypes 1, 2, and 3, and is highly resistant to bacterial blight.

BREEDING METHODS

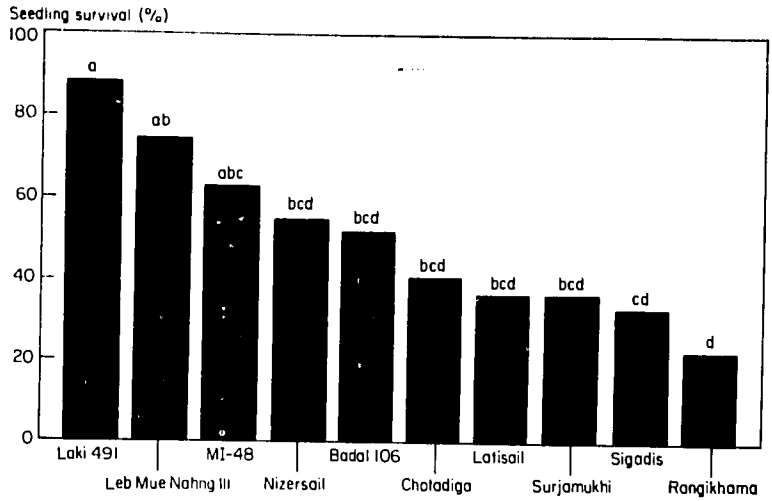
Plant Physiology Department

Rapid generation advance. In rapid generation advance (RGA), the growth duration of the rice plant is shortened by high temperature and short days. A RGA facility at IRRI, completed late in 1979, accommodates 205,200 plants/cycle, or a total of 616,000 plants/year. In 1979, 292,954 plants involving 189 crosses from F_2 to F_5 were sown in the RGA facilities. The crosses included deepwater and cold-tolerant materials, and were made at IRRI, Thailand, India, Sri Lanka, and Bangladesh. Certain crosses were made by IRRI at the request of plant breeders from Burma, Indonesia, Thailand, and Bangladesh.

Screening seedlings for drought resistance. Some varieties with known reactions to drought were tested at the seedling stage under different levels of water stress in RGA to study the feasibility of screening rices for resistance to drought.

The seedlings were well watered until 18 days after sowing when water was withheld for 0, 5, and 7 days. The plants were rewatered after each treatment and scored for survival 7 days later.

Drought stress for 7 days killed the seedlings of the 10 varieties studied. The varieties showed marked differences in seedling survival at the 5-day-stress treatment (Fig. 3). Those from the rainfed rice-growing areas of Bangladesh and Thailand showed high seedling survival. These are areas chronically drought prone during the onset of monsoon rains. The results indicate that RGA



3. Effect of drought stress for 5 days on seedling survival in 10 rices grown in rapid generation advance. Means of seedling survival percentages followed by a common letter are not significantly different at the 5% level. IRRI, 1979.

screening can detect superior rice genotypes that have resulted from realistic selection pressures in situ.

Drought treatment at seedling stage in RGA did not delay flowering. The plants subjected to drought stress were shorter than the control plants by an average 24 cm, the panicles were shorter by 3 cm, grain yield was reduced by 3.5 g/pot, and sterility increased by 7.8%.

Screening for resistance to bacterial blight. Some varieties with known reactions to bacterial blight (BB) were tested at three levels of nitrogen during RGA to study the feasibility of screening rices for BB resistance. Table 4 shows the varieties used and their reaction to two BB strains.

Lesion development on the varieties at the different levels of inoculum differed. As expected, IR1545-339-2-2 was resistant to PXO 61 and PXO 86 irrespective of nitrogen level and inoculum dose. Ch 1039 was susceptible. IR28 showed resistance to all concentrations of the PXO 61 strain,

Table 4. Length of lesions caused by 2 strains of *Xanthomonas oryzae* (PXO 61 and PXO 86), each at 3 concentrations of inoculum on seedlings of 3 rices grown in RGA. IRRI, 1979.

Nitrogen level[a]	Entry	Av length (cm) of lesions due to PXO 61				Expected reaction[b]	Av length (cm) of lesions due to PXO 86				Expected reaction[b]
		10^0	10^{-1}	10^{-2}	Mean		10^0	10^{-1}	10^{-2}	Mean	
	IR28	1.3	1.3	1.2	1.3	R	2.8	2.9	2.8	2.8	S
0	IR1545-339-2-2	1.3	1.3	1.2	1.3	R	1.5	1.2	1.3	1.3	R
	CH 1039	14.8	11.6	9.1	11.8	S	13.4	9.6	8.7	10.6	S
	Mean	5.6	4.7	3.8	4.8		5.9	4.6	4.3	4.9	
	IR28	1.5	1.4	1.2	1.4	R	4.7	4.6	3.5	4.3	S
2	IR1545-339-2-2	1.5	1.3	1.3	1.4	R	1.7	1.7	1.4	1.6	R
	CH 1039	15.5	16.7	10.3	14.2	S	17.8	18.7	13.8	16.8	S
	Mean	6.2	6.5	4.3	5.7		8.1	8.3	6.2	7.6	
	IR28	1.7	1.4	1.2	1.4	R	6.0	5.5	4.9	5.5	S
4	IR1545-339-2-2	1.4	1.3	1.2	1.3	R	2.3	1.7	1.5	1.8	R
	CH 1039	17.5	16.3	16.0	16.6	S	19.2	18.3	17.5	18.3	S
	Mean	6.9	6.3	6.1	6.4		9.2	8.5	8.0	8.5	

[a]Grams of ammonium sulfate/box per week. [b]R = resistant, S = susceptible.

but failed to show the expected susceptible lesion development when inoculated with PXO 86 strain.

Days to flowering was not greatly affected by either BB or nitrogen level. The zero nitrogen treatment, in general, delayed flowering by about 5 and 6 days, but it differed only slightly from the two other nitrogen treatments. The results indicated that neither days to flowering nor disease development patterns were adversely affected by BB inoculation in the RGA facilities.

Mutation breeding. The chemical mutagen ethyleneimine was used to improve traditional cultivars well adapted to adverse soils and medium elevations. Mutations intermediate in plant height or with reduced maturity period were identified. Some mutations combining both intermediate plant height and earliness were also recovered.

Viable dry seeds of 8 Indonesian tidal swamp varieties and a variety adapted to medium elevations were treated with 0.2 and 0.4% solutions of ethyleneimine for an hour and 3 hours. The germination of M_1 seeds differed because of both treatments and treatment x variety interaction; most of the varieties showed a germination between 43 and 87%. The M_1 seeds with germination higher than 40% were planted, with respective controls, in populations ranging from 500 to 1,500. The spikelet fertility of the M_1 plants showed a positive correlation (0.313 significant at 5% level at 43 d.f.) with the germination of M_1 seeds.

The M_1 populations of treatments showing nearly normal spikelet fertility in M_1 panicles were selected for advance to M_2. Single panicles harvested from M_1 plants from 2 effective treatments (0.2% for an hour and 0.4% for 3 hours) produced 1,879 M_2 progenies.

In the M_2, the seedling mutants segregated in a simple Mendelian ratio of 3:1. Screening of the M_2 families under natural conditions in the 1979 dry season facilitated selection of photoperiod-insensitive types (IR29386) from Siyam Halus mutations, and photoperiod-insensitive as well as intermediate-plant-stature types (IR29385) from Intan mutations. Mutants intermediate in plant height but sensitive to photoperiod were also selected and maintained until they matured under natural short-day conditions in the following wet season.

The early mutants, simultaneously raised in the wet season as M_3 plant progenies, bred true for earliness — they matured about a month earlier than the parents even with short days. They showed no change in other characteristics like plant height, and panicle and grain characteristics (Table 5). The early and intermediate-plant-stature mutants also matured earlier by about a month, were shorter by about 35 cm, but were unaltered in agronomic as well as grain characteristics (Table 6). The mutants intermediate in plant height and with photoperiod sensitivity also maintained all the original characteristics of the parents except that tillering and spikelet number per panicle exhibited a range of variation offering scope for further selection in M_3 for these traits (Table 7).

Population breeding. Population breeding is a method used mostly in cross-pollinated crops. It involves random mating of selected individuals to increase the frequency of favorable alleles in the population. Genetic male sterility can be used in self-pollinated crops to facilitate crossing. A monogenic male-sterile mutant was developed by treating IR36 with ethyleneimine. The extent of natural crossing was 52% when 2 rows of normal IR36 were planted for every row of IR36 male-

Table 5. Characteristics (mean of 10 observations) of Siyam Halus and its M_2 progenies. IRRI, 1979 wet season.

Designation	Plant ht (cm)	Panicle length (cm)	Spikelets		Days to maturity
			No. per panicle	Fertility (%)	
IR29386-2	151	24.5	177	75.8	128
IR29386-3	145	25.0	170	78.8	128
IR29386-4	141	23.0	157	74.4	128
IR29386-5	146	27.5	188	77.1	128
IR29386-6	144	23.5	216	73.9	128
IR29386-7	147	27.0	190	75.2	128
Siyam Halus	147	26.5	196	76.2	158

Table 6. Characteristics (mean of 10 observations) of Intan and its M_3. IRRI, 1979 wet season.

Designation	Plant ht (cm)	Panicle length (cm)	Spikelets (no.) per panicle	Spikelet fertility (%)	Days to maturity[a]
IR29385-1	105	25.5	183	78	129
IR29385-2	103	24.5	186	75	133
Intan	133	26.0	194	79	149

[a]Maturity period as observed in M_3 seeded on 2 July 1979. The M_2 flowered about 100 days from seeding when seeded on 9 February 1979; thus the maturity period of M_2 was about 135 days.

Table 7. Characteristics (av of all plants) of Siyam Kuning and its mutants as observed in M_2 progenies. IRRI, 1979.

Designation	Plant ht (cm)	Tillers (no.)	Panicle length (cm)	Spikelets per panicle (no.)	Spikelet fertility (%)	Days to maturity	Plants (no.) in each M_2 progeny
IR30446-3-61	134	31	24.8	203	91	30–315	16
IR30446-4-2	126	30	24.3	193	83	300–312	9
IR30446-4-4	128	30	25.2	178	89	298–310	9
IR30446-4-11	129	29	24.3	195	79	295–305	8
IR30446-4-414	130	25	24.9	212	85	300–310	5
Siyam Kuning	163	25	24.3	220	92	304	–

sterile mutant at a spacing of 10 × 10 cm (Table 8). The male-sterile mutant was used extensively in the hybridization program to build up a composite population for the rainfed wetland breeding program. To stabilize the composite population the F_1 of each rainfed wetland cross involving an IR36 male-sterile mutant was backcrossed to an IR36 male-sterile mutant. The harvest of male-sterile plants from the backcross population was bulked to build up the stable composite population. Seeds of this composite population are shared by the collaborators in the rainfed wetland breeding program.

Hybrid rice. Research on hybrid rice was initiated at IRRI in 1970 and a cytoplasmic-genetic male-sterile line was developed in indica rice. The line possessed cytoplasmic factors from Taichung Native 1 and genetic factors from Pankhari 203 (1970, 1971 annual reports).

About the same time, rice researchers in the People's Republic of China also started exploring the possibilities of hybrid rice.

During 1979, the IRRI program on hybrid rice was revived to investigate:

- the presence of true F_1 superiority, not only over the better parent but also over the best commercial variety;
- the availability of efficient cytoplasmic-genetic male-sterile and fertility restorer lines; and
- the ability of the male-sterile lines to show satisfactory seed set through cross pollination.

Nine cytoplasmic-genetic male-sterile lines developed at IRRI (2), China (4), Korea (2), and USA (1) were evaluated for agronomic potential, adaptability, and stability of their pollen sterility mechanism. Three of those lines were crossed with several elite breeding lines to transfer their cytosterility system to agronomically superior genotypes. Crosses were made to identify agronomically superior and better adapted maintainer and restorer lines, and to determine cytogenic relationships among some cytosterile lines. The outcrossing potential of some male-

Table 8. Effect of 2 row arrangements and 3 spacings on the seed set of IR36 male sterile mutants. IRRI, 1979.

Spacing	Seed setting (%)	
	1 normal, 1 male sterile	2 normal, 1 male sterile
10 x 10 cm	31.8	52.0
20 x 10 cm	20.8	35.0
30 x 10 cm	15.4	18.6

sterile lines was tested. To improve outcrossing in selected male-sterile lines and economize on the cost of hybrid seed production, selection and breeding for floral characters influencing outcrossing (e.g. stigma exsertion, duration of opening of florets, and anther size) were planned.

Tissue culture. In 1979 a series of experiments was started to evaluate the application of rice tissue culture to varietal improvement. Initial experiments identified germplasm with high inherent capability to produce callus and homozygous plants from pollen through anther culture. For anther or pollen culture, rice breeders make conventional crosses and produce F_1 hybrid plants. By plating anthers from the F_1 plants, they can establish genetically homozygous lines, which can immediately be screened for resistance to pests, nutrient deficiencies or toxicities, salinity, drought, or other constraints. Plants within lines will also be homozygous for maturation, height, grain quality, cold tolerance, photoperiod response, and other agronomic and physiological characteristics.

Eighty-two varieties and breeding lines from the

Table 9. R-2 medium developed for rice anther culture by R. S. Chaleff, Department of Plant Breeding and Biometry, Cornell University.

	Constituent	Amount
Stock solution:		
A	NH_4NO_3	4.0 g/liter
	KNO_3	25.3 g
	$CaCl_2 \cdot 2H_2O$	4.4 g
	$MgSO_4 \cdot 7H_2O$	3.7 g
	KH_2PO_4	1.7 g
B	H_3BO_3	620 mg/liter
	$MnSO_4 \cdot H_2O$	1680 mg
	$ZnSO_4 \cdot 7H_2O$	662 mg
	KI	83 mg
	$NaMoO_4 \cdot 2H_2O$	25 mg
	$CuSO_4 \cdot 5H_2O$	2.5 mg
C	Thiamine HCl (make fresh stock each week)	1 mg/ml
D	NAA (adjust pH to 6.0 with KOH, filter sterilize with millipore system)	1 mg/ml
E	Kinetin (filter sterilize with millipore system)	0.3 mg/ml (dissolved in 0.1 N KOH)
F	Na_2EDTA	0.746 g/200 ml H_2O
G	$FeSO_4 \cdot 7H_2O$	0.556 g/200 ml H_2O
To make R-2 medium add:		
Stock A		100 ml
Stock B		10 ml
Stock C		1 ml
Stock F		10 ml
Stock G		10 ml
Inositol		100 mg
Sucrose		30 g
Agar		8 g

Adjust pH to 6.0 with KOH and bring volume to 1 liter with deionized water. Autoclave for 15 minutes. Allow to cool to 40°C and add filter-sterilized stock D (2 ml/liter) and stock E (1 ml/liter).

Pour into plates or dispense into sterile tubes or flasks.

Table 10. Performance of varieties and lines with anthers plated on Chaleff's R-2 medium as of 31 December 1979. IRRI.

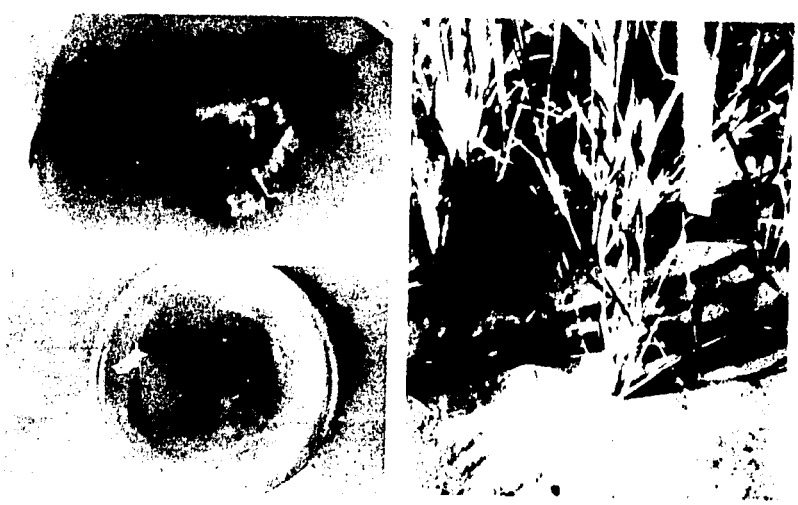
Cultivar	Anthers plated (no.)	Anthers (%) producing callus	Callus produced[a] (total no.)	Plants produced[b] (no.)	
				Green	Albino
IR5	730	0	0	0	0
IR6	557	0	0	0	0
IR20	1179	0.17	2	0	0
IR24	813	0.49	4	0	0
IR26	799	1.00	17	0	0
IR28	98	0	0	0	0
IR30	153	0	0	0	0
IR32	476	0	0	0	0
IR34	647	1.08	11	0	5
IR36	269	0	0	0	0
IR38	899	0.11	1	0	0
IR40	1078	1.21	12+	0	0
IR42	780	0.13	1	0	0
IR46	872	2.52	36	0	7
IR2797-125-3-2-2-2	808	0.87	18	0	2
IR44	741	1.35	17	0	0
IR4215-27-3-2-2	526	0	0	0	0
IR4422-98-3-6-1	1011	1.17	16	0	0
IR4432-52-6-4	1041	1.73	30	0	1
IR4683-54-2	334	3.30	23	0	1
IR5657-33-2	974	1.03	15	0	0
IR5853-118-5	434	0.69	3	0	0
IR8073-65-6-1	753	0.13	3	0	0
IR9129-209-2-2-2-1	671	0.30	2	0	0
IR9264-324-1	345	2.32	13	1	6
IR9764-45-2-2	831	0.60	7	0	0
IR10781-75-3-2	1129	2.04	61	4	0
IR11248-131-3-2-2	788	0	0	0	0
IR13146-41-3	558	1.79	17	0	0
IR13419-113-1	811	1.48	18	0	0
IR13240-39-3	504	0	0	0	0
IR13292-5-3	1093	0.46	10	0	0
IR13426-19-2	660	3.03	43	0	0
2123	1225	0.33	5	0	1
2188	1311	0	0	0	0
Anlong Phnom	481	0.42	2	0	0
Beak Ganges	325	0	0	0	0
BKN BR1031-7-5-4	350	1.14	7	0	1
BRRI Sail	989	0	0	0	0
IET 5656	546	1.10	11	0	0
Mahsuri	985	0.10	1	0	0
Mingdlo	674	3.86	47	4	9
MR10	449	0	0	0	0
RP1064-2-2	617	0.49	3	0	0
Sukamandi	655	0	0	0	0
TN1	847	0.59	7	0	0
Cul. 854	346	0.29	1	0	0
Cul. 956	804	0.62	7	0	0
D66	392	2.55	25	0	7
Double Dwarf 1	271	0	0	0	0
Double Dwarf 3	488	0	0	0	0
IR520-1-26	1458	3.22	102	0	3
M7	139	13.67	47	0	5
Nongbaek	392	0	0	0	0
Pai-kan-tao	138	10.87	62+	0	2
Peta	310	0	0	0	0

Continued on next page

Table 10 (continued)

Cultivar	Anthers plated (no.)	Anthers (%) producing callus	Callus produced[a] (total no.)	Plants produced[b] (no.)	
				Green	Albino
Suduwee	539	0	0	0	0
Tetep	345	1.16	7	0	3
Zenith	463	0.65	11+	0	1
Kuatik Putih	648	0.46	3	0	0
Cula	270	6.30	21	0	0
Dudmona Barisail	426	7.04	65	0	0
Goda Heenati	464	0	0	0	0
Gowa 38-13	286	4.20	82+	0	21
Kurkaruppan	371	0.27	1	0	0
Leb Mue Nahng 111	1362	1.62	37	0	0
Patnai 23	1019	0	0	0	0
SML Temerin	502	0.60	14	0	0
Sungail	1224	0.16	2	0	0
B2266B-CW-16-2-1	464	1.08	5	0	0
Dumsiah 81	563	1.60	9	0	1
ESD 7-1	134	0	0	0	0
Leng Kwang	611	0.49	3	0	0
Moosa Tarum	295	0	0	0	0
Sathra 278	44	0	0	0	0
Silewah	217	4.60	26	0	2
Taichung No. 65	374	1.87	25	0	3
Tainan No. 5	577	5.55	146 +	0	2
Taipei No. 309	222	14.41	120 +	11	57
Pelita 1-1	801	3.50	125 +	0	0

[a]Some cultivars had anthers that produced multiple calluses, i.e., 2 to 40 distinct calluses/anther. The entries marked with a plus sign frequently produced multiple calluses. [b]Many of these calluses had not had sufficient time to form plants by 31 December 1979.



4. Production of homozygous rice plants by anther culture. Callus is produced by pollen growing on an anther (left). Haploid plant grows from callus (middle). Haploid and diploid plants from pollen growing in nursery bed (right). IRRI. 1979.

1979 wet-season hybridization block were evaluated for their ability to produce callus and homozygous plants through anther culture. Anthers were collected at the late boot stage of growth and plated on Chaleff's R-2 medium (Table 9). Fifty-six of the cultivars produced callus from pollen at rates from 0.10 to 14.4% (Table 10). Several cultivars produced from 2 to 40 calluses from different pollen grains in each anther that produced callus. Sixteen plants produced from callus of several of the cultivars tested were successfully transferred from the tissue culture media

Table 11. Data on rice varieties and hybridizations compiled through the international rice genetic survey. IRRI, 1979.

Data	No.
Data file cards	
Older varieties	1086
Widely grown varieties	158
Post-IR8 varieties	385
Elite breeding lines	219
Crosses in punched cards	
Bangladesh	2515
Brazil	175
Dominican Republic	276
India	7815
Indonesia	4769
Korea	4204
Pakistan	495
Sri Lanka	559
Thailand	252
Progenitor cards (for all of above)	1949

to soil. Callus and plants at various stages of development are shown in Figure 4.

INTERNATIONAL RICE GENETIC SURVEY

Office of Information Services and Plant Breeding Department

In the international rice genetic survey, the origin of pre- and post-IR8 varieties released by national rice improvement programs was traced to the original progenitors. Hybridization records from national programs were compiled and entered into the computer system from which scientists can request printouts of the complete ancestry of both IRRI and national varieties and lines. Table 11 summarizes the data compiled in 1979.

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Genetic evaluation and utilization (GEU) program

Computerized data management

Statistics Department

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GERMPLASM BANK

In 1979, 2,233 registered accessions of *Oryza sativa* were added to the IRRI germplasm computer data bank. In addition, the data bank was updated with all the information on the 38 basic morphoagronomic characters of 2,384 accessions and with the 33,633 records involving 10 GEU traits of 12,322 accessions. At the end of 1979, the bank contained 1,448,027 records representing all existing information on the basic morphoagronomic characters and the 37 GEU traits of 40,768 accessions.

Activities related to the germplasm data bank were undertaken in 1979:

- A standard set of rules for writing the names of varieties in the germplasm computer data bank (Table 1) was set up; all variety names in the bank were revised to comply with the rules. The rules will facilitate retrieval of information based on variety name.
- A computer program for sorting the germplasm data bank on the basis of alphabetical or numerical arrangement of the variety names was developed. It provides an alternative to accession numbers for visual searching for desired accessions.
- The format of the germplasm data file on the part of the morphoagronomic characters was revised to comply with the new set of uniform descriptors and descriptor states set up by the Rice Advisory Committee of the International Board for Plant Genetic Resources. Nine new descriptors were

Table 1. Standardized system for writing variety names in the germplasm computer data bank, IRRI, 1979.

Rules	Example	
	Wrong	Correct
• No special character or blank space should appear as the 1st digit of the name.	"FORTUNA" (J 214) A A H U	FORTUNA J 214 A A H U
• No hyphen (-) should appear between coded name and the serial number.	CHINA-22 SLO-17	CHINA 22 SLO 17
• For pedigree names, place a hyphen (-) between the numbers.	IR9 60 2 A 28/8 ARIMODAN 0.68.3	IR9-60-2 A 28-8 ARIMODAN 0-68-3
• Use a hyphen (-) to separate different syllables in a Chinese, Korean, or Japanese cultivar.	TONGIL AI NAN TSAO 1	TONG-IL AI-NAN-TSAO 1
• Use asterisk (*), instead of exponentials, to indicate backcross.	IR24²/O. NIVARA	IR24*2/O. NIVARA
• Use slash (/) or slashes to indicate crosses instead of the multiplication sign (x).	(P6x8LUE ROSE) xP6	P6/BLUE ROSE//P6
• Leave no space before, after, nor between the slash signs.	P6 / BLUE ROSE / / P6	P6/BLUE ROSE//P6
• If the prefix is a breeding code, leave no space between the breeding code and the number, except when the breeding code ends with any of the following 3 letters: I, L, O.	BKN 6987 BPI 76	BKN6987 BPI 76
• If the prefix is a name, leave a space between the name and the number.	AUS17	AUS 17
• Leave one space after the period (.), except when a slash sign follows it or is used between two consecutive initials.	SEL.6 ANDI FROM N. POKHARA HILL SEL. /B8T U. V. S-UNBLATUZI	SEL. 6 ANDI FROM N. POKHARA HILL SEL./BBT U. V. S.- UNBLATUZI
• Use Roman numeral only if it is a part of the official name; otherwise, use arabic figures.	PELITA I-2 APARE I-48	PELITA I-2 APARE I-48

defined, two old descriptors were dropped, and the descriptor states of 26 descriptors were revised.

BREEDING AND TESTING

History-of-cross files. The history-of-cross (HC) data file for IR crosses was updated with information on the immediate parentage of 7,334 crosses made during 1979. The HC file included 29,277 IR crosses by the end of 1979.

A 1978 search for all IRRI crosses (i.e., descendants) of a prescribed parent revealed some inconsistencies in the designation of parent names over time. A computer program was developed in 1979 to handle the changes in the parentage names that are required to maintain uniformity throughout the whole HC files and consistency with the germplasm data bank.

Work was initiated to apply computer systems for the support of the HC file to the creation and maintenance of similar data files for parentage records of crosses made in national breeding programs. The data for the parentage records come from the International Rice Genetic Survey of the Office of Information Services.

Testing. Programming continued for the improvement of the computer-based system for the inventory of all selected lines from IRRI crosses tested in various generations at IRRI. The compatibility in data format from one nursery to another and the linkage among nurseries (i.e., the F_1 hybrids, the F_2 nursery, the pedigree nursery, the observational yield trial, the hybridization block, the replicated yield trial, and the elite lines) were strengthened. The computer system generates periodic reports on all traits collected by GEU scientists from each trial for circulation among all GEU scientists. In addition, the system provides computer-generated tags for field trials and computer-generated composition cards for breeders' use in selection processes.

International Rice Testing Program (IRTP). The main frame of the computer system for the processing of data from the IRTP nurseries was completed in 1978. Minor improvement of the system, primarily in the incorporation of additional analyses and summary tables, was made in 1979. The format of the IRTP computer-generated master fieldbook was revised to simplify and facilitate its use in the field.

The development of Phase I of the IRTP information retrieval system was completed. The system searches for a specific set of IRTP nurseries that contain data on the test entries identified by any combination of variables — entry name, characters or traits, test locations, year and season, and type of nurseries. The system required a *cleanup* of the master file of the IRTP entries to remove inconsistencies in the names of test entries.

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Control and management of rice pests

Diseases

Plant Pathology Department

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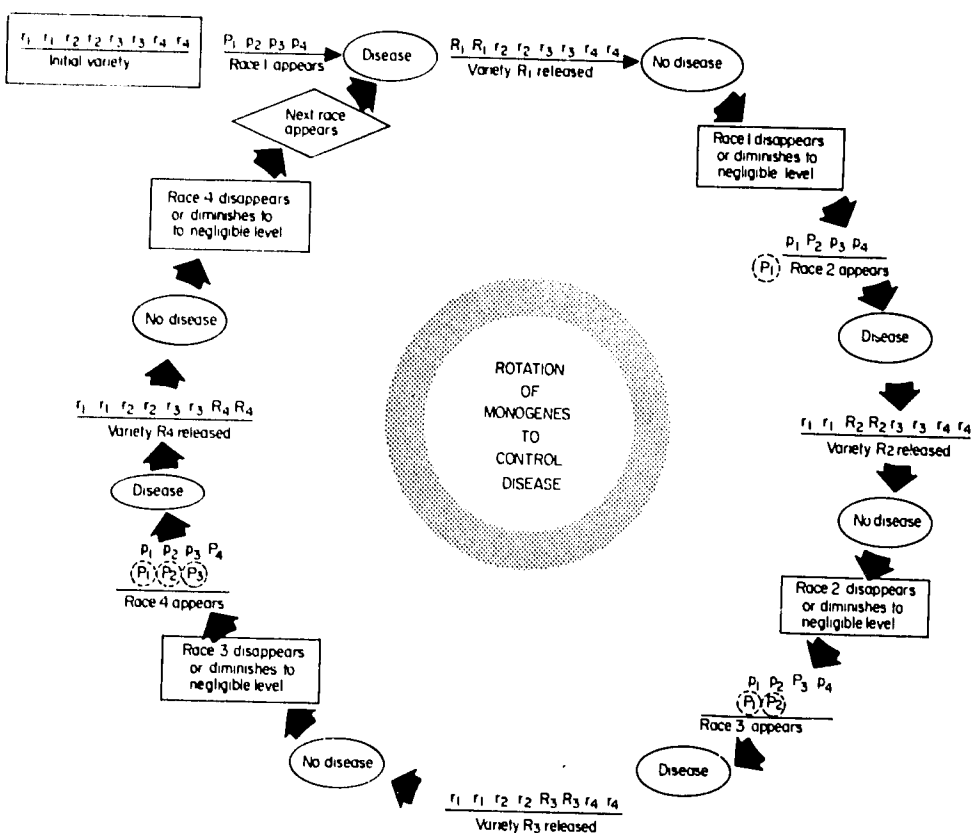
Integrated control. Rice blast has never been effectively controlled with host resistance. Horizontal resistance is not effective or stable when environmental factors are conducive to epidemics. Varieties with monogenic resistance initially are completely protected against blast; they become susceptible when a new fungus race capable of attacking them evolves. To capitalize on the initial freedom from disease conferred by monogenic resistance, a program of *race prediction and gene rotation* was proposed (Fig. 1). Korean rice scientists put such a program in operation for rice blast and bacterial blight control.

Race prediction and gene rotation cannot be used in disease management programs that rely on horizontal resistance. Horizontal resistance to blast and sheath blight were evaluated for 1978-79 at IRRI and found ineffective in intensive cropping systems without supplemental chemical protection.

The studies indicated that horizontal resistance components that result in reduced leaf blast favored increased neck blast in the high-yielding varieties.

Fungicide tests. Spores from pure cultures of fungus pathogens of rice were used to test the effect of various fungicide suspensions at different concentrations on the spore germination of each



P = specific gene for pathogenecity in the pathogen population
p = allele of *P* incapable of being pathogenic.
R = specific gene for resistance in a rice variety
r = allele of *R* resulting in susceptibility
(*P*) = broken circle designates presumed fate of *P* gene in the pathogen population as disappearing or becoming much reduced in frequency.

1. A proposed rotation of monogenes to control disease. IRRI, 1979.

pathogen. The number of effective fungicides and the fungus disease they controlled by suppressing spore germination were: 13, blast; 24, leaf scald; 16, Cercospora leaf spot; 6, brown spot; 20, sheath rot; and 6, bakanae (Table 1).

Based on measurement of growth-inhibition zones formed around the fungicide suspension-soaked filter paper discs in PDA spore-seeded or sclerotial body-seeded plates, six fungicides showed activities against the blast fungus; two against the sheath blight, none against *Sclerotium rolfsii*, the seedling blight pathogen; two against bakanae; eight against Cercospora leaf spot; six against leaf scald; five against sheath rot; and three against the brown spot fungus (Table 2).

Chemical control. *Blast.* Seed treatments with CGA 49104 (50% W.P.) at 4 and 8 g/kg seed and PP389 JF5816 (50% W.P.) at 20 and 40 g/kg seed confirmed 1978 test results which indicated the effectiveness of both fungicides in protecting seedlings against leaf blast infection (Table 3, 4).

The test chemicals were sometimes phytotoxic at close (10 cm) row spacing. PP389 JF5816 at 40 g/kg had a slight phytotoxic effect, which appeared as leaf tip blighting in the blast nursery 2 weeks after seeding but the effect disappeared within a week. Benlate at 20- and 40-g rates in slurry and dry form sometimes caused seedling stunting and leaf tip blighting 2 weeks after seeding in the blast nursery but those symptoms also disappeared within a week.

Storage of CGA-treated seeds (with 13.5% moisture content) for as long as 12 weeks at ordinary room temperature neither reduced the effectiveness of the fungicide for leaf blast control nor appreciably decreased the percentage of germination of the treated seeds (Table 5, 6).

In direct seeding on a simulated muddy paddy soil, leaf blast control was effective until 6 weeks after seeding when IR442 seeds were treated with

Table 1. Fungicidal activities of chemical suspensions at various concentrations against the germination of spores of different rice fungus pathogens in the laboratory. IRRI, 1979.

Chemical[a]	Effective rate(s) (% suspension range)	Activity against the pathogen[b]					
		Leaf scald	Sheath rot	Cercospora leaf spot	Blast	Bakanae	Brown spot
Homai (80% W.P.)	0.05–0.1	+	+	+	+	+	+
Vitavax 200 (75% W.P.)	0.025–0.05	+	+	+	+	+	+
Benlate-T (40% W.P.)	0.05–0.1	+	+	+	+	+	NT
Chevron 26745 (50% W.P.)	0.025–0.05	+	+	+	+	+	NT
Vitavax 300 (75% W.P.)	0.025–0.05	+	+	+	+	+	NT
BAS 3302F (82% W.P.)	0.05–0.1	+	+	+	+	NT	NT
CGA 49104 (50% W.P.)	0.06–0.24	+	+[c]	+[d]	NT	NT	+
Chevron 20615 (50% W.P.)	0.025–0.05	+	+	NT	+	+	NE
Daconil 2787 (75% W.P.)	0.05–0.1	+	+	+	+	NT	NT
Delsene MX (78% W.P.)	0.05–0.1	+	+	+	+	NT	NT
Dithane M-45 (80% W.P.)	0.05–0.1	+	+	+	+	NT	NT
Brestan (60% W.P.)	0.05–0.1	+	+	+	NT	NT	NT
Difolatan (50% W.P.)	0.05–0.1	+	+	+	NE	NT	NT
Hinosan (50% E.C.)	0.05–0.1	+	+[e]	(?)	+	NT	NT
Hoe 25986 (75% W.P.)	0.03–0.04	+	+	+	NT	NT	NT
RH 2161 (2% E.C.)	0.15–0.3	+	NT	+[f]	NT	NT	+[g]
Top Cop (54.4% F)	0.15–0.3	+	+	+	NE	NT	NT
Zinc Omadine (48% dispersion)	0.05–0.1	+	+	+	NT	NT	NT
Benlate OD (50% OD)	0.05–0.1	+	NT	NT	+		NE
Fuji-One (40% E.C.)	0.05–0.1	+	NT	NT	+	NT	NT
Hinosan TCP (35% W.P.)	0.03–0.29	+	NT	(?)	NT	NT	+[h]
Kocide 101 (83% W.P.)	0.05–0.1	+	+	NE	NE	NT	NT
M7007 PB20 (20% W.P.)	0.0625–0.125	+	+	NE	NE	NT	NT
PP389 JF5816 (50% W.P.)	0.32–0.64	(?)	+	NE	NE	NT	+
Iprodione (50% W.P.)	0.05–0.1	+	NT	NT	NT	NE	NE

[a]W.P. = wettable powder, E.C. = emulsifiable concentrate, OD = oil dispersible, F = flowable. [b]+ = Very effective in suppressing germination of spores; NE = not effective; NT = not tested; (?) = inconsistent results. [c]At 0.05 to 0.1%. [d]At 0.1 to 0.24%. [e]At 0.1% only. [f]At 0.3% only. [g]At 0.05 to 0.2%. [h]At 0.06 to 0.24%.

Table 2. Fungicidal activities[a] of chemical suspensions at various concentrations against growth of the different rice fungus pathogens in agar medium in the laboratory. IRRI, 1979.

Chemical [b]	Rates (range in % suspension)	Rice pathogen							
		Cercospora leaf spot	Blast	Leaf scald	Sheath rot	Brown spot	Sheath blight	Bakanae	*Sclerotium rolfsii*
Difolatan (50% W.P.)	0.025–0.1	+	+	+	+	+	NT	+	NT
Hoe 25986 (75% W.P.)	0.015–0.04	+	+	+	+	NT	+	+	NT
Brestan (60% W.P.)	0.015–0.05	+	+	+	NT	+	+	NT	NT
Benlate (50% W.P.)	0.025–0.1	+	+	+	+	NT	NT	NT	NT
RH 2161 (2% E.C.)	0.025–0.1	+	NT	+	+	+	NT	NT	NT
Daconil 2787 (75% W.P.)	0.025–0.1	+	+	NT	+	NT	NT	NT	NT
Delsene MX (78% W.P.)	0.025–0.1	+	NT	+	NT	NT	NT	NT	NT
Cercobin M (70% W.P.)	0.025–0.1	+	NT	NT	NT	NT	NT	NT	NT
Hinosan E.C. (50% E.C.)	0.05–0.1	NT	+	NT	NT	NT	NT	NT	NT

[a] + = with fungicidal activity against the pathogen; NT = not tested. [b] W.P = wettable powder, E.C. = emulsifiable concentrate.

Table 3. Effect, at 3-6 weeks after seeding (WS), of seed treatment with systemic fungicides for leaf blast control in IR442-2-58 grown in the blast nursery. IRRI, 1979.

Chemical [a]	Rate (g formulation/kg seed)	Lesions[b] (no./seedling)			
		3 WS	4 WS	5 WS	6 WS
CGA 49104 (50% W.P.)	8	0.0 a	4.3 a	10.5 ab	16.1 a
	4	0.0 a	15.1 ab	26.8 bc	44.8 b
PP389 JF5816 (50% W.P.)	40	0.1 a	4.0 a	10.5 ab	12.7 a
	20	2.2 b	30.2 b	45.4 c	67.8 b
Cercobin M (70% W.P.)	40	36.8 c	140.1 c	166.3 d	194.2 c
	20	55.1 cd	180.6 c	218.5 d	249.6 c
Benlate (50% W.P.)	40	47.1 cd	164.7 c	222.3 d	240.9 c
	20	68.1 d	195.7 c	232.3 d	246.3 c
Benlate (50% W.P.)					
Slurry	40	54.9 cd	116.9 c	142.9 d	148.5 c
Slurry	20	78.2 d	147.3 c	190.5 d	201.8 c
Control (untreated)	0	83.9 d	235.8 c	264.0 d	299.7 c

[a] W.P. = wettable powder. Mean of 3 replications; 25 seedlings from each replication were used for disease reading. Means followed by a common letter are not significantly different at the 5% level.

Table 4. Effect, at 3–8 weeks after seeding (WS), of seed treatment with systemic fungicides for leaf blast control in IR442-2-58 grown directly in the blast nursery beds. IRRI, 1979.

Chemical[a]	Rate (g formulation/kg seed)	Lesions[b] (no./seedling)					
		3 WS	4 WS	5 WS	6 WS	7 WS	8 WS
PP389 JF5816 (50% W.P.)	40	0.1 a	4.1 ab	14.5 a	19.6 a	23.8 a	27.4 a
PP389 JF5816 (50% W.P.)	20	0.6 a	11.5 b	38.0 bc	49.9 ab	69.1 bc	81.8 bc
CGA 49104 (50% W.P.)	8	0.0 a	2.6 a	14.8 ab	28.3 a	44.0 ab	47.7 ab
CGA 49104 (50% W.P.)	4	0.2 a	2.3 a	27.1 ab	40.7 a	49.5 ab	65.7 b
Cercobin M (70% W.P.)	40	15.2 c	53.9 c	80.9 cd	102.1 bc	115.6 cd	135.5 cd
Cercobin M (70% W.P.)	20	14.1 bc	76.4 c	130.4 d	163.0 c	176.8 de	216.6 de
Benlate (50% W.P.)	40	5.9 b	58.5 c	117.8 d	149.5 c	155.1 de	206.1 de
Benlate (50% W.P.)	20	10.4 bc	63.4 c	115.4 d	154.1 c	176.0 de	208.2 de
Control (untreated)	0	19.6 c	110.7 c	207.2 d	241.7 c	269.7 e	291.3 e

[a] W.P. = wettable powder. [b] Mean of 3 replications; 25 seedlings from each replication were used for disease reading. Means followed by a common letter are not significantly different at the 5% level.

Table 5. Effect of storing at ordinary room temperature of IR442-2-58 seeds treated with the systemic fungicide CGA 49104 on leaf blast control on the seedlings. IRRI, 1979.

Chemical[a]	Rate (g formulation/kg seed)	Lesions[b] (no./seedling) (8 wk after each seeding)						
		0 WTS	1 WTS	2 WTS	3 WTS	4 WTS	5 WTS	6 WTS
CGA 49104 (50% W.P.)	8	42.0	33.3	6.1	10.5	7.3	19.7	18.4
CGA 49104 (50% W.P.)	4	57.9	41.0	24.4	32.5	30.8	41.0	42.2
Control (untreated)	0	159.1	122.5	104.0	99.6	101.2	100.1	128.8

[a]W.P. = wettable powder. [b]Mean of 3 replications; 25 seedlings from each replication were used for disease reading. WTS = weeks after treatment and storage.

CGA 49104 at 4 and 8 g and with PP389 at 40 g of formulation/kg seed (Table 7). Benlate and Cercobin M at 40 g/kg seed gave moderate leaf blast control.

A rate study on CGA 49104 as seed treatment on IR442 confirmed information from a previous test that the rates of 16 and 32 g formulation/kg seed, although the most effective against leaf blast control, caused reduction in seed germination. The lowest moderately effective rate for leaf blast control was 2 g formulation/kg seed (Table 8).

Hoe 00550 (75% W.P.), as a seed dressing, exhibited systemic action on IR442 against leaf blast infection. When applied at 20 and 40 g formulation/kg seed, the blast-susceptible IR442 had low blast incidence for as long as 8 weeks after seeding (Table 9).

In a preliminary test of fungicides as foliar sprays, Benlate OD, a 50% oil dispersible formulation, Benlate-T (40% W.P.), and Homai (80% W.P.), all applied as 0.05% formulation sprays, effectively controlled leaf blast on IR442 seedlings. In another preliminary test, Bla-SM (3.7% W.P.), Bla-S (2% E.C.), and Kitazin (48% E.C.), all used at 0.1% formulation spray, appeared effective for leaf blast control.

In preliminary trials with seedlings grown in plastic trays and subjected to moderate leaf blast infection, Benlate (50% W.P.), Hinosan TCP (35% W.P.), PP389 JF5816 (50% W.P.), and Cercobin M (70% W.P.), each used as a 0.05% spray, effectively controlled leaf blast even 3 weeks after the last spray. Hinosan (50% E.C.), Delsene MX (78% W.P.), Dithane M-45 (80% W.P.), Daconil 2787 (75% W.P.), each applied as 0.05% sprays, and Top Cop (54.4% a.i.) as 0.3%, effected only slight to moderate leaf blast control.

However, under heavy disease pressure or highly infective blast disease conditions, such as those prevailing in the blast nursery most of the time, Hinosan TCP, Hinosan, and CGA 49104 (50% W.P.), each applied as a 0.05% formulation spray, showed the most effective leaf blast control among the chemicals tested. PP389 JF5816, Cercobin M, Daconil 2787, Benlate, and PH51-01 as 0.25%; Top Cop, EL-291 as 0.035%; Hoe 25986 as 0.04%; and Hoe 00550 as 0.013% formulation sprays, gave only moderate leaf blast control.

Sheath blight. In a preliminary test of systemic fungicides as seed treatment (seed dressing), Benlate (50%W.P.) and Cercobin M (70%W.P.), at 20 and 40 g formulation/kg seed, effectively controlled sheath blight on IR1317-392-1-2 seedlings until 8 weeks after seeding (Table 10).

Iprodione (50% W.P.), when applied to seedlings in 3 weekly sprays as a 0.05% suspension, appeared most effective for sheath blight control in the greenhouse trials. Three other fungicides — Validacin (3% solution) used as a 0.1% formulation spray and Daconil 2787 (75% W.P.) and Brestan (60% W.P.) as a 0.05% formulation suspension — although not as effective as Iprodione, effectively controlled sheath blight.

Bakanae. A preliminary test of a 4-hour dipping of IR9703 seedlings in fungicide suspensions showed Benlate (50% W.P.) and Homai (80% W.P.), both at 1 g formulation/liter of suspension, to be moderately effective for bakanae disease control in 6 weeks after planting.

In a series of preliminary tests on seed treatment for bakanae disease control, the same chemicals, applied at 10, 20, and 40 g formulation/kg seed, gave encouraging disease control on both IR9703 and IR9846, two bakanae-susceptible breeding lines.

Cercospora leaf spot. In a preliminary seed treatment test, Benlate OD (50% oil dispersible), Benlate (50% W.P.), Benlate-T (40% W.P.), and

Table 6. Effect of CGA 49104 systemic fungicide on germination of stored CGA 49104-treated IR442-2-58 seeds sampled immediately after treatment and at weekly intervals thereafter. IRRI, 1979.

Chemical[a]	Rate (g formulation/kg seed)	Seed germination[b] (%)												
		0 WTS	1 WTS	2 WTS	3 WTS	4 WTS	5 WTS	6 WTS	7 WTS	8 WTS	9 WTS	10 WTS	11 WTS	12 WTS
CGA 49104 (50% W.P.)	8	95.7	96.7	94.0[b]	93.0	90.8	90.8	90.0	88.3	93.7	93.0	94.5	91.2	88.9
CGA 49104 (50% W.P.)	4	93.7	98.3	97.0	89.0	90.3	92.3	89.2	87.5	92.3	92.5	93.3	90.4	88.8
Control (untreated)	0	95.3	97.0	95.3	93.3	91.7	92.3	90.0	91.3	95.7	95.6	96.0	93.7	92.3

[a]W.P. = wettable powder. [b]Counted 1 wk after each seeding, mean of 3 replications, each with 100 seeds planted, WTS = weeks after treatment and storage. Few seedlings from the 8-g rate treatment exhibited mild leaf tip-drying and stunting 1 wk after seeding but the seedlings recovered and the tip-drying disappeared later.

Cercobin M (70% W.P.), each applied at 20 g formulation/kg seed, effectively controlled Cercospora leaf spot on IR20 seedlings 3 weeks after artificial inoculation.

Sclerotium seedling blight. Predominant commercial rice varieties are not resistant to seedling blight caused by *Sclerotium rolfsii*. Tests in 1979 screened seed-protectant fungicides for their ability to control the disease. Vitavax, alone or combined with other fungicides, was highly effective (Table 11). Vitavax 75% W.P. controlled the disease at the low concentration of 19 g active ingredient/100 kg seed (Table 12). Presprouting the seeds did not affect the fungicide's efficacy. Combining Vitavax with Benlate did not affect the efficacy of control of *S. rolfsii by* Vitavax or the control of leaf blast by Benlate.

Survey of seedbeds for seedling diseases. Thirty-five seedbeds, mostly of the dapog type in Laguna Province, were spot checked for seedling diseases before the dry-season rice crop.

Bakanae was observed in all seedbeds except two, both of IR36. The disease varied from a few scattered plants in some beds to about 50% infected seedlings in a bed of IR42. Infected varieties included IR36, IR42, C-4, C-12, and IR833. Bakanae occurred in all types of dapog seedbeds — dapog, regular wetbed, Taka-tak beds, and upland nursery beds.

In one set of dapog seedbeds *Sclerotium* seedling blight was observed. In one bed a brown spot similar to that caused by *S. rolfsii* was observed. The seeds and bases of the seedlings were covered with bacterial slime. The rotting plants had an odor typical of a bacterial soft rot.

In many dapog and wet beds, seeds had a white mycelial growth that covered the area of the germinating radical and plumule. They rotted and no seedlings developed from them. The incidence of this disease varied from about 1-2% of the seed to about 30% in spots within a bed.

In a Taká-tak seedbed, a few seeds had symptoms typical of the water-mold disease common in water-seeded rice in the United States. The dead seeds on the soil surface had coarse mycelium radiating from the seed surface in a circular pattern.

Specimens of diseased seedlings or rotted seeds were collected from each bed where disease was observed for isolation and identification of the pathogen. However, because bakanae was so com-

Table 7. Effect at 3–6 weeks after seeding (WS) of seed treatment with systemic fungicides on leaf blast control on IR442-2-58 grown directly in big clay pots with muddy soil simulating rice paddy conditions in the screenhouse. IRRI, 1979.

Chemical[a]	Rate (g formulation/kg seed)	Lesions[b] (no./seedling)			
		3 WS	4 WS	5 WS	6 WS
CGA 49104 (50% W.P.)	8	0	0	0	0
CGA 49104 (50% W.P.)	4	0	0	0	0
PP389 JF5816 (50% W.P.)	40	0	0	0	0.2
Benlate (50% W.P.)	40	1.7	3.5	7.6	13.8
Cercobin M (70% W.P.)	40	1.4	5.2	12.7	21.3
Control (untreated)	0	6.6	16.8	24.3	33.6

[a]W.P. = wettable powder. [b]Mean of 3 replications; 25 seedlings from each replication were used for disease reading.

Table 8. Effect at 3–8 weeks after seeding (WS) of seed treatment with CGA 49104 (50% W.P.) at various rates of application on leaf blast control in IR442-2-58 seedlings grown in the blast nursery. IRRI, 1979.

Rate of application (g formulation/kg seed)	Lesions[a] (no./seedling)						Phytotoxic effect
	3 WS	4 WS	5 WS	6 WS	7 WS	8 WS	
32	0	0	0	4.2	7.1	9.2	+[b]
16	0	0.2	0.5	12.2	20.5	24.1	+[b]
8	0	0	0.1	17.0	23.5	28.7	None
4	0	0.1	3.5	27.6	41.3	46.5	None
2	0.1	0.1	5.7	30.3	43.4	50.8	None
1	4.5	10.0	25.9	63.4	91.8	99.6	None
0 (untreated control)	21.5	37.8	44.5	71.4	90.9	99.7	None

[a]Mean of 3 replications; 25 seedlings from each replication were used for disease reading. [b]Reduced percentage germination of treated seeds.

Table 9. Effect at 3–8 weeks after seeding (WS) of seed treatment with systemic fungicides on leaf blast control on IR442-2-58 grown directly in the blast nursery. IRRI, 1979.

Chemical[a]	Rate (g formulation/kg seed)	Lesions[b] (no./seedling)					
		3 WS	4 WS	5 WS	6 WS	7 WS	8 WS
Hoe 00550 (75% W.P.)	40	0.2	4.8	12.3	15.9	18.5	19.1
Hoe 00550 (75% W.P.)	20	0.8	19.2	42.1	55.9	58.8	60.2
Hoe 25986 (75% W.P.)	40	5.3	68.4	111.8	131.5	139.9	141.3
Hoe 25986 (75% W.P.)	20	7.9	91.1	144.4	159.9	168.8	170.9
Homai (80% W.P.)	40	10.7	88.7	138.9	154.9	161.6	164.2
Homai (80% W.P.)	20	10.3	91.9	148.4	161.5	165.8	167.8
LS 65-255 (50% W.P.)	40	9.2	106.5	165.3	179.0	183.8	186.3
LS 65-255 (50% W.P.)	20	9.9	102.5	153.1	169.7	175.8	178.1
Control (untreated)	0	13.3	111.8	176.3	193.6	198.8	200.4

[a]W.P. = wettable powder. [b]Mean of 3 replications; 25 seedlings from each replication were used for disease reading.

mon, samples were collected from selected beds in the different geographical areas visited.

Bakanae disease infection and yield loss. Thirty-two sites in Laguna Province were surveyed for bakanae infection. The infected tillers and the healthy tillers in IR42 were counted in plots ranging in area from 5 to 100 m². Twenty-five panicles from healthy plants were picked at random, threshed, dried at 14% moisture, and weighed; and the average yield was calculated. The number of infected tillers was multiplied by the average weight of 2 g/panicle from healthy IR42 seedlings to determine the loss and percentage of the yield loss per hectare. The percentages of tillers infected with the disease ranged from 0.63 to 12.8% and averaged 3.9% (Table 13).

Table 10. Effect at 3–8 weeks after seeding (WS) of seed treatment with systemic fungicides on sheath blight control on IR1317-392-1-2 grown in plastic trays in the greenhouse and artificially inoculated at 2 WS. IRRI, 1979.

Chemical[a]	Rate per kg seed	Leaf sheath infection[b] (%)						Leaf blade infection[b] (%)					
		3 WS	4 WS	5 WS	6 WS	7 WS	8 WS	3 WS	4 WS	5 WS	6 WS	7 WS	8 WS
Benlate (50% W.P.)	40 g	8.7	7.3	18.2	17.6	16.1	21.0	4.3	4.8	7.5	9.7	12.8	22.7
Benlate (50% W.P.)	20 g	25.5	37.5	33.8	36.3	37.0	40.3	12.6	28.8	22.9	20.2	28.0	37.8
Cercobin M (70% W.P.)	40 g	23.9	24.4	23.2	20.5	23.5	55.4	8.9	19.4	19.1	18.8	24.0	57.6
Cercobin M (70% W.P.)	20 g	56.7	48.3	42.1	48.8	48.9	60.7	36.5	55.9	48.2	52.7	52.0	64.6
PP389 JF5816 (50% W.P.)	40 g	53.1	50.0	45.5	42.4	42.9	41.9	25.6	57.9	50.9	47.3	45.7	48.3
PP389 JF5816 (50% W.P.)	20 g	66.7	56.3	47.5	46.2	43.3	43.3	33.6	59.7	51.8	47.5	42.9	43.3
BAS 3050F (75% W.P.)	4 g	60.7	56.6	51.4	46.7	45.0	57.1	55.7	67.4	59.2	55.3	52.7	61.2
EL-291 (75% W.P.)	2.6 g	65.2	63.9	53.1	52.4	49.5	53.8	38.5	72.1	62.2	58.2	55.6	56.9
RH2161 (24% E.C.)	1.2 ml	72.9	62.8	60.1	54.8	55.4	52.9	42.2	61.6	57.7	52.1	49.5	51.7
Control (untreated)	0	61.7	60.7	55.6	51.5	52.5	69.0	28.6	64.0	61.5	57.2	56.1	67.3

[a]W.P. = wettable powder, E.C. = emulsifiable concentrate. [b]Mean of 25 seedlings used for disease reading.

Inoculum potential and disease intensity. Three methods of bakanae inoculation — seed soaking, soil infestation, and spraying — were used to determine the minimum amount of inoculum in the seeds and in the vicinity of the plant system and also the relationship between various inoculum levels of the pathogen and the intensity of the disease in the seedlings.

The minimum amount of inoculum that caused bakanae disease infection by seed soak inoculation was 0.7×10^5 propagules (Table 14). However, the results tended to show that there was no direct relationship between inoculum levels and the intensity of bakanae infection in seedlings although disease infection appeared low at a lower amount of inoculum.

Four-day-old seedlings of IR9703-41-3-3-1 were transplanted in sterile and nonsterile soil infested with conidia of *Gibberella fujikuroi* Saw. at different inoculum levels (0.5:10, 1:10, 2:10, 3:10, 4:10, 5:10) and incubated 5 days. The minimum amount of inoculum required to cause bakanae infection was 0.5:10 (Table 14).

The inoculated seedlings in both sterile and nonsterile soil were considerably taller than the control plants. The increased height was attributed to the gibberellic acid secreted by the organism in the soil.

Data on the number of propagules in the infested and control soil were taken using Komada's medium to ascertain the length of time the fungus could survive in the soil and cause bakanae infection in seedlings. The preliminary finding was that after 45 days the number of propagules was much smaller than that before planting. Likewise, the number of infected seedlings in the second crop of IR9703-41-3-3-1 was reduced remarkably, with disease infection ranging from 4-14% in infested sterile and nonsterile soil. The results suggested that the propagules could not survive longer in the soil.

In a spray experiment, 19 dilutions of the conidial suspension of the organism, ranging from 1×10^4 to 30.81×10^6, were used to inoculate 15-day-old seedlings of IR9703-41-3-3-1. The minimum amount of inoculum needed to cause bakanae infection was 5×10^4, and infection varied from 1.3 to 5.6%. There was no direct relationship between amount of inoculum and the intensity of bakanae infection.

Effect of temperature on G. fujikuroi *Saw. and plant infection.* The breeding lines IR9703-41-

Table 11. Effect of seed-protectant fungicides on *Sclerotium* seedling blight. IRRI, 1979.

Treatment[a]	Rate (ml or g/100 kg seeds)	Mean stand[b] (%)		
		1st seeding	2d seeding	3d seeding
Untreated seed	0	5 cde	5 c	15 d
Vitavax 200	500	95 a	85 a	85 ab
Vitavax 200	1000	90 a	90 a	90 ab
Vitavax 300	500	95 a	85 a	85 ab
Vitavax 300	1000	90 a	80 a	100 a
TerraCoat L 205	500	15 cd	0 c	45 d
TerraCoat L 205	1000	20 c	5 c	55 d
Vitavax (75% W.P.) + Benlate (50% W.P.)	250 + 500	90 a	85 a	90 ab
Benlate (50% W.P.)	500	0 e	0 c	15 e
TCMTB (30 E.C.)	300	55 b	45 b	70 c

[a]Slurry treatment, 4 ml liquid/250 g seed. W.P. = wettable powder, E.C. = emulsifiable concentrate.
[b]Five replicates, drill seeded, means followed by a common letter are not significantly different at the 5% level.

Table 12. Effect of treatment rate on control of *Sclerotium* seedling blight by slurry treatment of seed with Vitavax 75% W.P. IRRI, 1979.

Vitavax 75% W.P.[a] rate of application (g formulation/100 kg seed)	Mean stand[b] (%)
2000	85 a
3000	80 a
1000	80 a
500	80 a
100	80 a
25	80 a
50	75 a
150	75 a
250	75 a
Untreated seed	30 b

[a]W.P. = wettable powder. [b]Drill seeded, mean of 10 replications.

3-3-1 and IR9846-215-3 were sprayed with a spore suspension of isolate F4 of the organism *Gibberella fujikuroi* 7 days after seeding. The inoculated potted plants were immediately placed in cabinets at constant temperatures of 20°, 25°, and 30°C and a constant 100% relative humidity.

Preliminary results based on daily collection of spores showed no definite trend of increase in spore number with days of incubation but there was an irregular pattern in all temperatures for both breeding lines. However, sporulation appeared to peak at the end of the experiment. Furthermore, the cumulative number of spores was maximum at a constant temperature of 30°C — almost double the number at temperature of 25° and 20°C (Fig. 2), indicating that 30°C is favorable for the sporulation of *G. fujikuroi* in plants.

The percentages of infection were 1.6, 7.3, and 18.7 for temperatures 20°, 25°, and 30°C for IR9703. For IR9846, the corresponding percentages of infection were 1.6, 19.8, and 20.2, again suggesting that 30°C is favorable for bakanae infection.

Temperature and growth and sporulation of G. fujikuroi *in potato dextrose agar.* Agar blocks containing active mycelial growth (4 mm in diameter) of isolate F4 were singly transferred to the center of potato dextrose agar in petri dishes and placed in incubators at temperatures of 5°, 10°, 15°, 20°, 25°, 30°, 35°, and 40°C. Temperature 10° was the minimum; 25°, optimum; and 30°C, maximum for the growth of the organism (Fig. 3). The organism grew faster at 25°C.

Constant temperatures and conidial release of G. fujikuroi. The same variety (IR42) and methods as those in the spore release study were used to determine the effects of constant temperatures on conidial release by *G. fujikuroi*. The results showed that the conidia of the organism are released at constant temperatures of 5°, 10°, 15°, 20°, 25°, 30°, and 35°C but not at 40°C(Fig. 4). The minimum, optimum, and maximum constant temperatures were 5°, 30°, and 35°C.

Constant temperatures and conidial germination of G. fujikuroi. Eight constant temperatures were used to determine the minimum, optimum, and maximum temperatures for germination of the

Table 13. Bakanae infection in relation to yield loss in rice at 32 sites surveyed in Laguna Province, Philippines, 1979.

Site	Infected tillers (%)	Yield loss	
		Kg/ha	%
Isla Pangil	0.6	88	0.6
Mabitac	1.0	92	1.0
Biñan	1.0	120.	1.0
Tipulan, Magdalena	1.2	133	1.2
San Francisco, Victoria	1.3	68	1.3
Masapang, Victoria	1.3	204	1.3
Tipulan, Magdalena	1.5	171	1.5
San Antonio, Pila	1.6	126	1.6
Kalayaan	1.7	156	1.7
Masapang, Victoria	1.7	102	1.7
Masapang, Victoria	1.8	152	1.8
Tipulan, Magdalena	2.0	136	1.9
Santa Clara, Pila	2.0	155	2.0
San Francisco, Victoria	2.2	102	2.2
Bucal, Calamba	2.7	147	2.7
Sampaloc, Pagsanjan	2.7	220	2.7
Maytalang, Lumban	2.9	204	2.9
Bangyas, Calauan	2.8	410	2.8
Pila	3.0	325	3.0
Santo Domingo, Bay	3.0	281	3.0
Lumban	3.0	302	3.0
Sampaloc, Pagsanjan	3.1	224	3.1
Real, Calamba	3.1	137	3.1
Balian, Pangil	4.1	280	4.1
Gamachile, Pila	4.3	312	4.3
Balite, San Francisco, Victoria	4.8	361	4.8
Lumban	6.0	722	6.0
Pagsanjan	6.9	496	6.9
Bay	9.4	820	9.4
Sala, Cabuyao	9.7	677	9.7
Masapang, Victoria	11.3	688	11.3
Sala, Cabuyao	12.8	983	12.8
Average	3.6	294	3.6

conidia in sterile distilled water. The spores of the organism started to germinate after 4 hours in sterile distilled water at 20°, 25°, 30°, and 35°C; after 6 hours at 10° and 15°C. Spore germination increased with time up to 24 hours but no spore germination was noted at either 5° or 40°C. The minimum, optimum, and maximum temperatures for spore germination were 10°, 25°, and 35°C (Fig. 5).

Relative humidity and G. fujikuroi *conidial formation.* Seven-day-old seedlings of the breeding lines IR9703-41-3-3-1 and IR9846-215-3 were sprayed with spore suspension and placed in cabinets at constant temperatures of 30°C and relative humidities of 55, 75, and 100%, respectively. Daily collection of spores started 3 days after inoculation.

Sporulation pattern was irregular in the different relative humidities but was maximum for both lines at the end of the experiment. The cumulative spore number was maximal at 75% relative humidity and minimal at 55% relative humidity.

The percentage of infection varied in the different relative humidities with infection of 9.6, 81.3, and 18.7% for 55, 75, and 100% relative humidities.

Relative humidity and conidial release of G. fujikuroi *Saw. at 30°C.* In a study of infected IR42 plants collected from artificially inoculated seedlings spores were released in 13, 49, 79, 86, 96, and 100% relative humidities (Fig. 6). Number of spores was minimal at 13 and 96%, more numerous at 86%, and maximal at 79%.

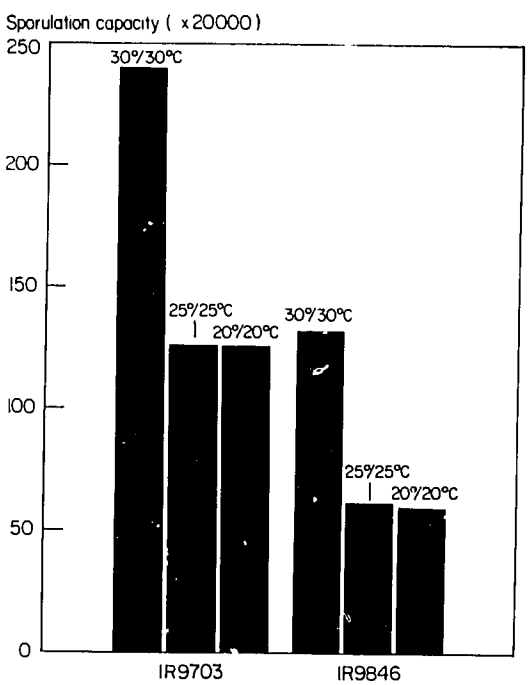
Effect of relative humidity and constant temperatures on G. fujikuroi *Saw. conidial germination.* Relative humidities ranging from 12.7 to 100% at 8 constant temperatures (5°, 10°, 15°, 20°, 25°, 30°, 35°, and 40°C) were used to determine the relative humidities at which the conidia will germinate. Conidia germinated in relative humidities ranging from 98.7 to 100% at constant temperatures of 20°, 25°, 30°, and 35°C. No germination occurred at relative humidities below 98.7% 48 hours after incubation and no spore germination was noted in all relative humidities at constant temperatures below 20°C or above 40°C.

Effect of light on growth and sporulation of G. fujikuroi *Saw.* Six light treatments — UV, fluorescent, intermittent UV-fluorescent, intermittent UV-dark, intermittent fluorescent light-dark, and dark — were used to determine which is favorable to the growth and sporulation of the fungus. The fungus grew fastest in the dark and in intermittent fluorescent light-dark combination, reaching maximum growth in 8 days in contrast to slow growth under UV light. However, spores were more numerous under UV light than under the other treatments (Table 15).

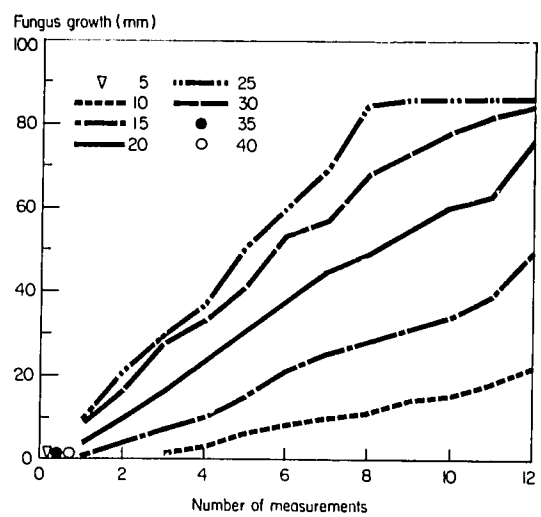
Survival of G. fujikuroi *Saw. conidia in rice seeds.* Seeds of IR38, IR5929-12-3, IR9859-45-2, and IR9703-41-3 were artificially infested by soaking them in spore suspension of *G. fujikuroi* for 2 days. Seeds of each entry were divided into 2 lots, separately air- and sun-dried for 3 days, and further subdivided and stored separately at temperatures of 20°, 25°, 30°, and 35°C to determine the temperatures at which the organism would survive the

Table 14. Results of tests of 3 methods of bakanae infection in relation to inoculum levels. IRRI, 1979.

Inoculum-soil ratios (V/V)	Soil infestation		Seed soaking		Spraying	
	Propagules (no./g soil)	Infection (%)	Propagules (no./ml)	Infection (%)	Propagules (no./ml)	Infection (%)
Sterile						
0.5:10	$.01 \times 10^5$	74.7	155.5×10^7	9.8	30.81×10^6	1.3
1:10	4×10^5	96.8	277.1×10^6	15.1	15.76×10^6	2.9
2:10	6×10^5	97.0	138.6×10^6	15.4	8.63×10^6	1.4
3:10	10×10^5	98.0	69.0×10^6	13.5	5.45×10^6	1.4
4:10	11×10^5	94.0	34.7×10^6	14.5	3.95×10^6	1.3
5:10	25×10^5	91.0	17.4×10^6	14.2	8.2×10^5	1.5
Control	0	0	170.5×10^5	3.1	3×10^5	1.5
	–	–	85.3×10^5	5.2	2.5×10^5	2.7
Unsterile			42.6×10^5	4.3	1.96×10^5	1.5
0.5:10	6×10^5	10.0	21.3×10^5	2.0	1.7×10^5	2.5
1:10	12×10^5	92.5	10.7×10^5	2.0	1.6×10^5	5.6
2:10	26×10^5	95.9	5.3×10^5	3.9	1.3×10^5	3.1
3:10	30×10^5	98.0	2.6×10^5	7.5	1×10^5	1.4
4:10	31×10^5	97.9	1.3×10^5	2.5	8×10^4	1.5
5:10	75×10^5	89.6	0.7×10^5	3.2	7×10^4	2.5
Control	0	0	0.3×10^5	0	5×10^4	1.4
	–		0.16×10^5	0	4×10^4	0
	–		0 (control)	0	3×10^4	0
	–		–	–	1×10^4	0
	–		–	–	0 (control)	0

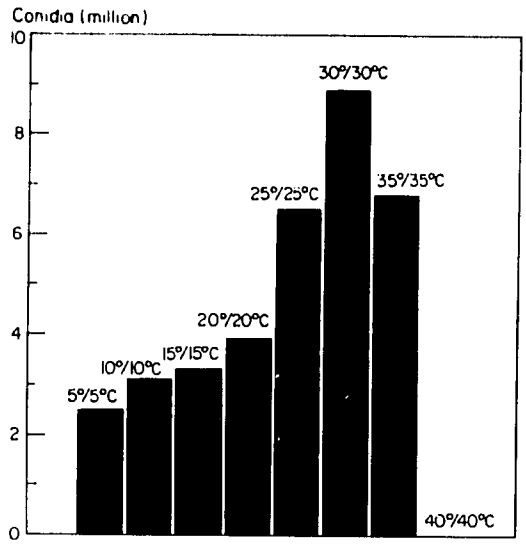


2. Cumulative number of *Gibberella fujikuroi* Sawada conidia in infected plants at different temperatures and at 75% relative humidity. IRRI, 1979.

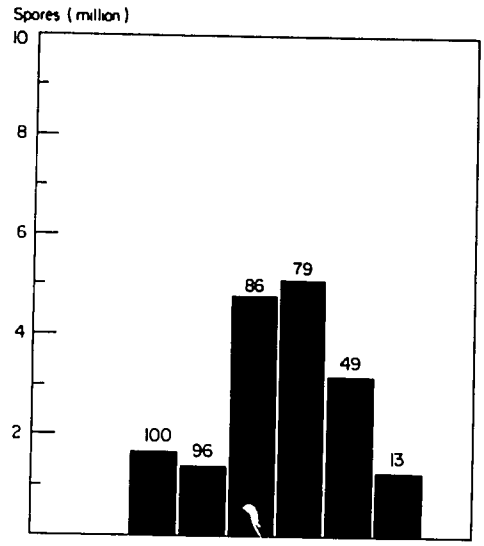


3. Growth rate of *Gibberella fujikuroi* under different temperature treatments. IRRI, 1979.

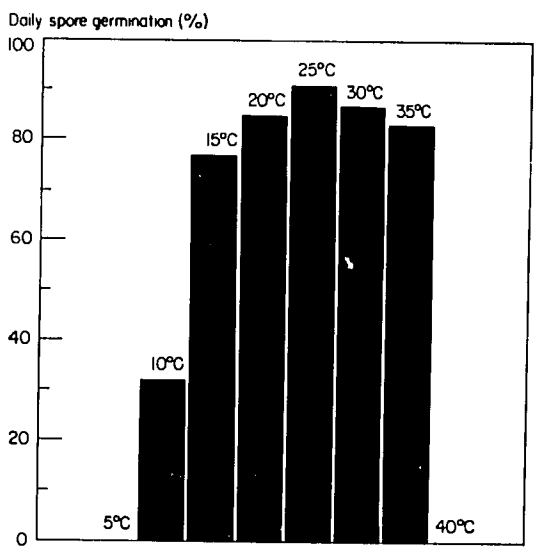
longest. The results generally showed that after 3 months, the organism's survival ranged from 0 to 10% in all varieties and lines at 30°-35°C in both air- and sun-drying treatments, indicating that those temperatures are not favorable for survival of the organism on the surface of the seed hull.



4. Cumulative conidia released by *Gibberella fujikuroi* Saw. at different constant temperatures at 100% relative humidity. IRRI, 1979.



6. Cumulative spores released by *Gibberella fujikuroi* Saw. at different relative humidities (numbers on bars) at constant temperature of 30° C. IRRI, 1979.



5. Effect of different temperatures on conidial germination of *Gibberella fujikuroi* Saw. IRRI, 1979.

Effect of nutritional disorders on blast and brown spot diseases of rice. The soil chemists and plant pathologists used 12 soils with different properties in a cooperative experiment to ascertain the influence of mineral stresses on the incidence and severity of *Pyricularia oryzae* and *Helminthosporium oryzae* (Table 16).

Three-kg portions each of crushed and air-dried soil (except the zinc-deficient soil and the peat soil) were placed in eight 4-liter-capacity porcelain pots. The zinc-deficient and the peat soils were obtained wet. Each soil was mixed with 50 ppm nitrogen as urea (except the nitrogen-deficient soil and the ammonium-toxic soil), and 25 ppm P as concentrated superphosphate (except the phosphorus-deficient soil) and 25 ppm K as muriate of potash (except the potassium-deficient soil). The nitrogen-deficient soil received no nitrogen fertilizer; the ammonium-toxic soil received 300 ppm N as urea: the phosphorus-deficient soil, 5 ppm P; and the potassium-deficient soil, no potassium fertilizer. The first 10 soils were flooded with demineralized water to a depth of 5 cm. The last 2 soils were moistened to field capacity.

For the *Pyricularia* study, 10 germinated seeds of IR442-2-58, a susceptible variety, were dibbled in each of 4 pots of each soil. Two pots were artificially inoculated with *P. oryzae* isolate from IR442, 18 days after seeding. The other 2 pots were kept free of the disease. For the *Helminthosporium* study, Sekiguchi-asahi, a susceptible variety, was used.

The incidence of *P. oryzae* (blast) on IR442-2-58

Table 15. Effect of light treatment on growth and sporulation of *Gibberella fujikuroi* in potato dextrose agar. IRRI, 1979.

Light treatment[a]	Daily growth rate (mm) at day								Spores (av no./ml)
	1[b]	2	3	4	5	6	7	8	
Dark	23	32	41	50	65	76	84	85	3.2×10^7
Intermittent fluorescent light-dark	21	31	41	51	61	70	83	85	4.3×10^7
Intermittent UV-dark	21	31	41	51	59	69	78	83	9.5×10^7
Intermittent UV-fluorescent	17	27	37	47	58	66	77	83	4.8×10^7
Fluorescent	18	27	36	44	60	68	77	82	5.0×10^7
UV	18	26	34	42	50	58	66	72	2.1×10^8

[a]Each treatment consisted of 4 replications. [b]First measurement taken after 2 days.

did not vary remarkably with the soil (range 85-100%). However, seedlings grown on the normal, potassium-deficient, nitrogen-deficient, and iron-deficient soils had considerably more blast lesions than seedlings grown on the alkali, ammonium-toxic, saline, and phosphorus-deficient soils (Table 17).

Sekiguchi-asahi seedlings inoculated with *Helminthosporium oryzae* had 100% disease incidence regardless of the type of soil in which they were grown (Table 18). However, number of lesions varied from 12.8 to 43.5/plant. Plants on soil with excessive nitrogen application had the least lesions and those on the iron-deficient (dryland) soil, the most.

BACTERIAL DISEASES

Bacterial foot rot. Bacterial foot rot was first found infecting a few IR36 plants at IRRI in 1977 but its incidence at IRRI has not increased since. However, the disease was recorded in Japan, Korea, and India in 1979.

In 1978, the causal pathogen was identified as bacteria. In 1979, further study indicated that the disease is similar to the bacterial cornstalk rot caused by *Erwinia chrysanthemi*. Isolates from rice and maize cause infection on either host (Table 19). The bacterium from rice also belongs to the same species. Whether the rice strain is distinctly different from the maize strain as well as other bacteriological characters must be determined.

Bacterial blight. *Effect on rice yield.* A project was designed to provide information to facilitate prediction of the loss caused by bacterial blight at different stages of infection and the severity of the disease. Initial experiments were done in the greenhouse and field experiments have been started.

IR8 and IR36 were infected at the seedling (35 days after seeding [DS]), maximum tillering (50 DS), booting (70 DS), and flowering (80 DS) stages. Lesion length was significant in plants infected at a younger age. IR8 and IR36 had the same disease reaction, however, both being susceptible to strain PXO 86 of *X. oryzae* at an inoculum dosage of about 10^9 cells/ml. Both panicle and tiller numbers were affected by the disease when infection started at early tillering, maximum tillering, and booting stages (Table 20). IR8's grain yield decrease was significant when the infection started at seedling, maximum tillering, and booting stages. A difference in IR36 grain yield was also observed.

When infection was initiated at seedling stage, kresek was observed on IR8 but not on IR36. In field experiments, 40-50% kresek infection resulted in more than 30% yield reduction. At least 10% yield reduction was noted when a field was affected with 20 — 30% kresek (Table 21).

Ecology of Xanthomonas oryzae. The bacteriophage method was applied in 1979 to study the survival of *X. oryzae* in rice plant tissues, leaves, and seed. Properties of *X. oryzae* phage P-2, the common phage strain in the Philippines, were studied collaboratively at Kyushu University, Japan, and at IRRI.

- Phage P-2 attacked most of the Philippine

Table 16. Properties of 12 soils used in a study of incidence and severity of blast and brown spot diseases. IRRI, 1979.

Soil	Problem	pH	EC[a] (1:1)	CEC[b]	Organic carbon (%)	Total nitrogen (%)	Olsen phosphorus (ppm)	Exchangeable potassium (meq/100 g)	Available zinc (ppm)
Lipa loam	None	6.5	0.93	39.1	1.36	0.127	18.4	0.62	0.66
Lipa loam	Nitrogen deficiency	6.5	0.93	39.1	1.36	0.127	18.4	0.62	0.66
Lipa loam (amended)	NH_4^+ toxicity	6.5	0.93	39.1	1.36	0.127	18.4	0.62	0.66
Lipa loam (amended)	Salinity	6.5	9.3	43.4	1.67	0.126	8.5	1.36	4.14
Lipa loam (amended)	Alkalinity	8.2	1.32	42.2	1.33	0.117	21.7	1.48	0.01
Buenavista sandy clay loam	Potassium deficiency	6.1	1.18	9.1	0.55	0.080	14.9	0.31	2.35
Lipa loam	Zinc deficiency	7.3	1.95	31.3	2.56	0.222	20.9	0.60	0.20
Pangil *peat*	Deficiencies in micro and macro elements	5.9	0.95	70.4	22.5	0.880	2.1	0.64	0.64
Paete clay loam	Phosphorus deficiency	5.7	1.48	24.2	1.71	0.202	4.1	0.31	3.45
Malinao fine sandy loam	Iron toxicity	4.8	1.03	12.0	0.96	0.093	8.9	0.29	1.03
Lipa loam	Iron deficiency (upland condition)	6.5	0.93	39.1	1.36	0.127	18.4	0.62	0.66
Luisiana clay loam	Mn and Al toxicity (upland condition)	5.2	0.64	25.0	1.3	0.171	4.3	0.46	3.67

[a]Electrical conductivity. [b]Cation exchange capacity.

isolates of the host bacterium.

- Phage P-2 was serologically identical with phage OP_1 from Japan. Therefore, anti-OP_1 phage serum was used for inactivating phage P-2 in some experiments.
- Among several kinds of the media hitherto reported, PSB and Wakimoto's media were superior to others for supporting the phage multiplication with the host bacterium. These two media were used for detecting *X. oryzae* in host tissue by phage method.
- One-step growth was carried out with a combination on phage P-2 and *X. oryzae* strain PXO 61. In this combination, the latent period was 35 minutes and the average burst size (average number of the progeny phage produced from a single cell) was around 20. The latent period seems too short to wash off the antiphage serum when it is used for detecting *X. oryzae*.

Survival of X. oryzae. Initial study indicated that the forms of the bacterial cells related closely to their ability to survive. In living intact leaf tissues, the bacteria actively multiplied at the expense of host nutrients.

- In pure culture no colony formed on the agar plate after 2 hours at 50°C, thus indicating that the bacterial cells were killed. On the other hand, bacterial cells from exponential growth stage were smeared onto the bottom of sterilized tubes, then incubated for 20 days at 10°C to initiate their resting phase. After that, the tubes were incubated at 50°C for the same time intervals as that for the *growing phase*. Once they became a *dry mass*, the bacteria were resistant to and stable in high temperature. There was reduction in colonies due to death of cells at 50°C but the death rate was slow.
- In diseased leaves, infected rice leaves (IR8 and PXO 61) were detached and dried at 10°, 20°, 30°, 40°, and 50°C for 20 days. As shown in Table 22, the bacterial cells (viable) were readily detected in leaves kept at 10° and 20°C. No bacteria, however, were detected in leaf tissues dried at temperatures higher than 40°C. Transformation to the dry form was induced. There was survival of the bacteria in the leaf tissues at 50°C once they had become transformed into a *dry mass* at

Table 17. Reactions of IR442-2-58 to nutritional disorders and *Pyricularia oryzae* infection, and soil injury rating at 0 and 11 days. IRRI, 1979.

Nutritional problem	*Pyricularia* inoculation	Soil injury rating		*Pyricularia* infection		
		0 day	11 days	Incidence (%)	Severity (no. of lesions/ plant)	Score
None	No	1	1.2	0	0	1
	Yes	1	2.2	100	435	9
Nitrogen deficiency	No	1	1	0	0	1
	Yes	1	2	100	456	9
Ammonium toxicity	No	5	2	0	0	1
	Yes	5	3.2	95	260	9
Salinity	No	5	3	0	0	1
	Yes	5	5	90	252	9
Alkalinity	No	3	2	0	0	1
	Yes	3	2	100	277	9
Potassium deficiency	No	1	1	0	0	1
	Yes	1	2	100	470	9
Zinc deficiency	No	1	2	0	0	1
	Yes	1	2.6	95	326	9
Peat soil problems	No	1	2	0	0	1
	Yes	1	3.1	100	362	9
Phosphorus deficiency	No	3	5	0	0	1
	Yes	3	5.9	100	210	9
Iron toxicity	No	7	8	0	–	–
	Yes	7	8	100	–	–
Iron deficiency	No	2	2	0	0	1
	Yes	2	2.3	85	410	9
Manganese/aluminum toxicity (dryland)	No	2	2	0	0	1
	Yes	2	2.5	100	349	9

low temperature (Table 23). To produce diseased husks, IR8 seeds were artificially infested at flowering. The rice grains were later harvested and dehusked and the husk was ground and treated similarly as for leaves. Comparable phage increase by plaque count indicated that the bacteria could survive in husk at low temperature but not at room temperature after harvest for 90 days. As the bacteria in the rice husk are most likely to form a dry mass at ripening, studies of temperature at ripening, harvest, and storage relative to bacterial survival in rice seed were started.

In fallow fields at IRRI several species of weeds were collected. Both *X. oryzae* and its bacteriophage were detected on roots of the grassy weeds and in their rhizosphere and on ratoon and volunteer rice, but not on the leaves of either plant.

Sheath blight. *Ecology of the pathogen.* Research on sheath blight concentrated on the parasitic and saprophytic survival of the pathogen and on the factors that may affect their survival in the tropics.

Parasitic survival. The rice sheath blight pathogen has a wide host range, which includes many weed species. In an initial experiment, inoculum was broadcasted in a direct-seeded unweeded rice field. Many weed species as susceptible as rice were found (Table 24). A following survey of IRRI indicated that many weeds of the Gramineae family in the rice fields were naturally infected with the sheath blight pathogen (Table

Table 18. Reaction of Sekiguchi-asahi to nutritional disorders and *Helminthosporium oryzae* infection, and soil injury ratings at 0 and 11 days. IRRI, 1979.

Nutritional problem	*Helminthosporium* inoculation	Soil injury rating[a]		*Helminthosporium* infection		
		0 day	11 days	Incidence (%)	Severity (no. of lesions/ plant)	Score
None	No	1	1	15	0.2	1
	Yes	1	1	100	24.8	3
Nitrogen deficiency	No	1	1	35	0.5	1
	Yes	1	1	100	24.0	3
Ammonium toxicity	No	5	3	30	0.6	1
	Yes	5	5	100	12.8	2
Salinity	No	5	5.7	20	0.3	1
	Yes	5	5.2	95	14.5	2
Alkalinity	No	3	3	45	0.9	1
	Yes	3	3	100	35.3	4
Potassium deficiency	No	1	1	65	1.1	1
	Yes	1	1	100	22.0	3
Zinc deficiency	No	1	2	45	0.9	1
	Yes	1	3	100	27.3	4
Peat soil problems	No	1	4	65	1.3	1
	Yes	1	4	100	34.0	5
Phosphorus deficiency	No	3	5	75	1.4	1
	Yes	3	5	100	22.8	3
Iron toxicity	No	7	7.3	85	1.9	1
	Yes	7	7.3	100	17.8	3
Iron deficiency	No	2	2	40	0.7	1
	Yes	2	2	100	43.5	6
Manganese/aluminum toxicity (dryland)	No	2	2	35	0.8	1
	Yes	2	2	100	30.3	4

25). The symptoms were similar to that of rice. A pathogenicity test of isolates obtained from the weeds suggested that they were highly virulent to rice, and many caused damping-off of the rice (Table 26). Obviously these weeds are hosts for the fungus and serve as sources of the inoculum that infects the rice crop.

Saprophytic survival. It is well established that sclerotial bodies are the primary inoculum of the rice sheath blight pathogen. In an initial study at IRRI, however, only a small number of sclerotia could be recovered in a field of more than 50% infection.

Previous results (1978 annual report) indicated that many of the sclerotia in the field either were colonized by bacteria or died. Survival of the pathogen was studied by burying rice straw in nonsterilized soil of dryland origin. The soil was mixed with different amounts of inoculum and incubated for 1 month in conditions of standing water and 100% and 50% soil saturation. There was a lower percentage of rice straw colonized by the fungus in conditions where the straw was buried in soil with standing water than in 50% saturation (Table 27).

In a similar experiment the infected rice straw was buried in sterilized and nonsterilized soil (dryland origin) with standing water and 50% saturation. Recovery of the sheath blight fungus was lower in nonsterilized than in sterilized soil (Table 28).

Table 19. Some characters of the foot rot bacteria of rice compared with other strains of *Erwinia chrysanthemi* from rice and maize. 1979.

Character	Strain[a]				
	Rice			Maize	
	IRRI	Japan	Korea	Philippines	USA[b]
Pathogenicity					
Rice	+	+	+	±	–
Maize	+	+	+	+	–
Rotting tissues at					
Cornstalk					
10°C	–			–[c]	
20°C	–			–[c]	
30°C	++			++	
35°C	+++			+++	
Rice stem					
10°C	–			–	
20°C	+			+	
30°C	++			++	
35°C	++			++	
Growth on PSA[d] at					
20°C	Mucoid/butyrous			Mucous	
25°C	Butyrous			Butyrous	
30°C	Butyrous			Butyrous	
35°C	Butyrous			Butyrous	
Flagellum	Peritrichous			Peritrichous	
Gram reaction	–			–	
Physiological/Biochemical test					
Nitrate reduction	+			+	
NaCl tolerance (growth)					
1%	+			+	
3%	+			+	
5%	–			–	
O/F					
Glucose	F			F	
Acid production					
Arabinose	+			+	
Fructose	+			+	
Mannitol	+			+	
Dextrin	–			–	
Galactose	+			+	
Lactose	+			+	
Maltose	–			–	
Raffinose	+			+	
Sorbitol	–			–	
Xylose	+			+	

[a] + = positive, – = negative. [b] Virulence apparently lost. [c] A blue pigment was produced on the cornstalk. At 20°C, it was very distinct. [d] Peptone sucrose agar.

VIRUS DISEASES

Tungro epidemiology. The field epidemiological study of rice tungro disease in Luzon was continued. Disease incidence was observed, the vector insects were collected, and the vectors' infectivity was tested at weekly intervals (Table 29).

Disease incidence. Tungro incidence in the study fields was low. The average tungro incidence

Table 20. Effect[a] on rice yield components of initial infection caused by a single inoculum dosage (about 10^9 cells/ml) of *Xanthomonas oryzae* (PXO 86) on potted plants at different growth stages. IRRI, 1979.

Growth stage	Lesion length[b] (cm)	Kresek (%)	Tillers (%)	Panicles (%)	Sterility (%)	Grain yield reduction (%)
			IR8			
Seedling	23 a	44	20	43	77	46
Max tillering	18 b	0	27	32	42	42
Booting	15 c	0	6	39	52	52
Flowering	10 d	0	0	6	10	1
			IR36[c]			
Seedling	25 a	0	57	12	33	26
Max tillering	21 b	0	43	21	23	14
Booting	17 c	0	5	0	72	43
Flowering	11 d	0	0	0	45	33

[a]Estimated on the basis of control, i.e. no artificial inoculation. [b]Lesion measured at 14 days after inoculation. Means followed by a common letter are not significantly different at the 5% level. [c]Natural infection was observed beginning at maximum tillering stage.

Table 21. Effect of kresek[a] caused by *Xanthomonas oryzae* on rice yield of IR8. IRRI, 1979 dry season.

Bacterial strain	Kresek (%)	Grain wt[b] (kg/plot)	Yield reduction (%) based on check
PXO 61	50.8	7.0	37.3
Kr 4	40.5	7.7	33.7
PXO 82	36.0	9.5	18.2
PXO 78	26.5	10.8	10.2
Check	0.0	11.6	0.0

[a]Inoculation by root-dip method at time of transplanting. [b]Based on 2.5- x 7-m plot.

Table 22. Survival of *X. oryzae* in diseased rice leaves under different temperatures.[a] 1979.

Temp (°C)	Plaques (no.) Check (0 h)	Test (5 h)	Survival of *X. oryzae*[b]
10	179	2.2×10^5	+
20	270	1.7×10^5	+
30	225	1051	+
40	433	335	–
50	441	355	–

[a]Leaves were preserved at each temperature in the petri dishes and 0.1 g of the sample was used for each experiment. [b]+ positive survival, – negative.

Table 23. Survival of *X. oryzae* in dry phase in diseased rice leaves at 50°C. 1979.

Days of treatment	Plaques (no.) Check (0 h)	Test (5 h)	Test (8 h)	Survival of *X. oryzae*[b]
0 (control)	55	N[a]	6.1×10^7	+
1	37	N	5.2×10^7	+
3	52	N	2.0×10^4	+
4	69	N	2.0×10^4	+
5	63	2920	3.1×10^5	+
6	64	2386	6.6×10^5	+
7	81	119	2.0×10^4	+
8	65	137	2.4×10^3	+

[a]Numerous [b]+ positive survival.

was 0.64% in 792 observations. However, about 11% of the study fields had tungro infection. Of the provinces covered by the study, Laguna and Tarlac had no tungro incidence throughout the study period. No disease was observed in all study sites in November, December, and January. The tungro incidence varied among varieties. No tungro incidence was recorded in IR38, IR40, and IR46 which accounted for about 16% of the varieties planted.

Number of vector insects and disease incidence. Of the 2,865 tungro vectors collected, 24% were nymphs and 76% were adults; 37% were *Nephotettix virescens*, 45% *N. nigropictus*, and 18% *Recilia dorsalis*. The number of tungro vectors collected averaged 4.9/10 sweeps.

It was reported in 1978 that the average number of vector insects and the percentage of infective insects from April to June determined the tungro incidence from June to October. This view was confirmed in 1979.

Percentage of infective insects slightly increased

Table 24. Incidence and severity of sheath blight on rice and various weeds on 2 observation dates. IRRI, 1979.

Host	29 October		6 November	
	Incidence (%)	Severity	Incidence (%)	Severity
Rice[a]	34.3	2.9	39.7	3.6
Weeds[b]				
Echinochloa colona	26.9	1.0	55.6	3.0
E. glabrescens	7.2	1.0	29.0	3.2
E. crus-galli ssp. *hispidula*	10.0	1.0	11.1	1.0
Monochoria vaginalis	0	0	2.2	1.0

[a]Data taken from cropping pattern field with 2 plots, weeded and unweeded, per cropping pattern. Field planted 4 September 1979. Previous crop was wet-seeded rice inoculated with the sheath blight pathogen at maximum tillering stage. [b]Based on 5 quadrats (0.5 x 0.5 m^2)/unweeded plot per cropping pattern. Incidence was based on the ratio of infected hills to the total population observed x 100 while severity was based on scale 1–9 (Standard Evaluation System for Rice by IRTP).

Table 25. Some weed hosts of sheath blight organism at IRRI, 1979.

Species name	Family	Plant part isolated	Area collected
Chloris sp.	Gramineae	Sheath	Dryland
Cleome rutidosperma	Capparidaceae	Leaf, pod, seed	Wetland
Digitaria sp.	Gramineae	Blade	Wetland
Echinochloa colona	Gramineae	Blade	Wetland
		Sheath	Dryland
E. crus-galli ssp. *hispidula*	Gramineae	Sheath	Wetland
Leptochloa chinensis	Gramineae	Sheath	Wetland
Monochoria vaginalis	Pontederiaceae	Leaf	Wetland
Paspalidium flavidum	Gramineae	Sheath	Wetland
Paspalum distichum	Gramineae	Blade	Wetland
		Sheath	
Rottboellia exaltata	Gramineae	Blade	Dryland
Cynodon dactylon	Gramineae	Blade	Dryland

from 0 in 1978 to 0.34 in 1979 from April to June. Similarly, disease incidence slightly increased from 0% in 1978 to 0.02% in 1979 from June to October. However, the percentage of infective insects from April to June was too low to cause a high disease incidence in the rainy months from June to November (Table 30).

Infective insects. During the study period, 7,127 insects were collected in the study fields and tested for infectivity. Of the tested insects, 28% were *N. virescens*, with 0.75% infective insects; 57% *N. nigropictus*, 0.09% infective; and 15% *R. dorsalis*, 0.29% infective. The percentage of infective insects was very low, averaging 0.31% throughout the study period.

Tungro in southern Philippines. In 1979, the Philippine Bureau of Plant Industry reported that 16 municipalities, mostly in Mindanao, were affected by tungro as of mid-August. Tungro vectors collected from the fields, mostly planted to IR36 and SN19, transmitted the disease to TN1 test seedlings.

Light-trapping of tungro vectors. The collection of tungro vectors (*Nephotettix virescens, N. nigropictus,* and *Recilia dorsalis*) and the grassy stunt vector (*Nilaparvata lugens*) by light trap at IRRI started in August 1972. In November 1977, ragged stunt disease, also transmitted by *N. lugens*, was added to the study.

In 1979, the highest proportion of tungro vectors collected was *N. nigropictus*. The average number of tungro vectors collected per trap per month from November 1978 to October 1979 was 73, 72, 15, 68, 1,055, 50, 4,337, 1,243, 675, 1,173, 3,850

Table 26. Pathogenicity in IR36 of *Rhizoctonia solani*, the rice sheath blight pathogen, from different weed species. IRRI, 1979.

Isolate no.	Weed	Pathogenicity[a]		Sclerotia (no./plant)
		Plants infected (%)	Damping-off (%)	
1	*Echinochloa colona*	100	4.2	65
2	*E. colona*	100	2.9	74
3	*L. chinensis*	100	2.4	120
4	*E. glabrescens*	100	4.6	64
5	*E. glabrescens*	88.1	0	19
6	*Paspalidium flavidum*	100	0	27
7	*P. flavidum*	88.3	0	2
8	*E. crus-galli* ssp. *hispidula*	100	7.3	28
9	*Cynodon dactylon*	–	–	–
10	*C. dactylon*	100	0	66
11	*Digitaria* sp.	100	4.8	112
12	*Digitaria* sp.	100	18.9	179
13	*E. colona*	100	2.4	6
14	*Rottboellia exaltata*	100	33.3	76
15	*Cleome rutidosperma*	92.3	0	15
16	*C. rutidosperma*	100	2.4	74
17	*C. rutidosperma*	–	–	–
18	*Chloms* sp.	100	0	6

[a]On 21-day-old IR36.

Table 27. Saprophytic colonization of *Rhizoctonia solani*, the causal fungus of rice sheath blight, on rice straw buried in nonsterilized soil of dryland origin in various moisture conditions. IRRI, 1979.

Inoculum level[a] (%, wt/wt)	Colonization[b] (%)			Infectivity[c] (%)		
	Standing water	100% saturation	50% saturation	Standing water	100% saturation	50% saturation
100	100.0	100.0	100.0	100.0	100.0	100.0
90	72.7	73.3	80.0	64.7	57.7	77.7
50	49.3	56.0	56.7	40.7	42.3	52.0
10	25.3	28.0	36.0	9.3	17.0	17.0
0	1.3	0	0	0	0	0

[a]100% inoculum, i.e. no soil added; 0% inoculum, i.e. no inoculum check. [b]Planting rice straw, 1 month after it was buried in soil, on water agar. [c]Infectivity of rice straw buried in soil and inoculated on IR36.

and 1,072. Of the 4,680 tungro vectors tested for infectivity, 0.26% were infective. The overall tungro incidence at the farm during the period was low (Table 31).

Effect of ages of diseased plants on infection. The infectivity of *N. virescens* was determined by the test-tube inoculation method after the insect fed on TN1 tungro-diseased plants of different ages. Diseased plants were inoculated 7 days after soaking and kept in the greenhouse for 15, 30, 60, and 90 days before they were used as virus sources for 1,920 adult insects.

The percentages of infective insects were not identical among diseased plants of different ages regardless of acquisition access time of 2, 24, or 96 hours. When the acquisition access time was 96 hours, the insects that fed on 30- and 60-day-old diseased plants had a higher percentage of infective insects, a longer retention period, and a greater percentage of infected seedlings than the insects that fed on 15- or 90-day-old diseased plants.

The variation in the insects' infectivity indicated that diseased plants of different ages were not identical in quality as virus source.

Different varieties as tungro source. The infectivity of *N. virescens* after feeding on tungro-

Table 28. Saprophytic survival[a] of *Rhizoctonia solani*, the rice sheath blight pathogen, in infected rice straws in soil of dryland origin. IRRI, 1979.

Treatment	Recovery of *Rhizoctonia solani* in rice straw (%)		Sclerotium bodies (no.)	
	2 wk	4 wk	2 wk	4 wk
Sterilized soil				
50% water saturation	100	100	49	0
Standing water	100	100	33	26
Nonsterilized soil				
50% water saturation[b]	54	50	0	0
Standing water	44	25	9	0
Check[c]				
50% water saturation	0	0	0	0
Standing water	0	0	0	0

[a]Plating on water agar 2 weeks after incubation. [b]Colonization of the infected straw buried in soil was exclusively *Trichoderma* sp. of this treatment. Although *R. solani* could be observed yet its growth was highly retarded compared with that of sterilized soil. [c]Nonsterilized soil to check for natural occurrence of the fungus.

diseased plants of IR8, IR34, and TN1 was determined by the test-tube inoculation method. Diseased plants were inoculated 7 days after soaking and kept in the greenhouse for 40 days before being used as virus sources for 1,440 adult insects.

Insects that fed on diseased TN1 plants consistently gave higher percentages of infective insects, longer retention period, and greater percentages of infected seedlings than insects that fed on IR8 and IR34 diseased plants as virus sources regardless of acquisition access periods of 2, 24, and 96 hours.

The infectivity of *N. virescens* was not identical for all combinations of IR8, IR34, and TN1 as recipient hosts and virus sources. The insects became more infective with the combination of TN1 as recipient host and virus source than combinations of IR8 and IR34. The percentages of infective insects in all combinations were greater for IR8 than for IR34 but less for both IR8 and IR34 than for TN1.

The factors determining infectivity of *N. virescens* among different combinations of recipient hosts and tungro source varieties remain unclear.

Acquisition of rice tungro virus through parafilm. The ability of 547 adult *N. virescens* to acquire the tungro virus from diseased leaves covered with parafilm was tested. After acquisition access periods of 1-4 days, 56-75% of the insects became infective when tested on TN1 seedlings. In general, the percentage of infective insects increased as the acquisition access time increased from 1 to 4 days. But it decreased on the third and fourth day in this test because the diseased leaves became necrotic because of continuous insect feeding.

Consequently, the parafilm membrane did not hinder the acquisition feeding by the insect. The parafilm membrane method may be used for developing a bioassay of the virus.

Ragged stunt. The collection of *N. lugens*, the vector insect of ragged stunt and grassy stunt, by light trap at IRRI was continued.

The average number of *N. lugens* collected per light trap per month was 6, 18, 1, 1, 1,480, 20, 417, 186, 56, 118, 482, and 2,185 from November 1978 to October 1979. Of the 1,059 *N. lugens* tested, not one transmitted grassy stunt and 2.2% transmitted ragged stunt. The overall disease incidence at the IRRI farm was trace for grassy stunt and low for ragged stunt (Table 32).

Possible vector insects of ragged stunt disease of rice, such as *N. nigropictus*, *N. virescens*, *R. dorsalis*, and *Sogatella furcifera*, were tested by using the daily serial transmission method with different acquisition access times.

The last-instar nymphs and adults of *N. nigropictus* used were collected from the field and the second-instar nymphs of the three other species were taken from greenhouse-reared cultures. The acquisition access periods used were 2 and 4 days for *N. nigropictus*, 4 days for *N. virescens*; 1, 2, 4, 8, and 16 days for *R. dorsalis*; and 2 and 4 days for *S. furcifera*. The insects were transferred serially in test tubes containing TN1 seedlings until their death. The average life span was 9 days for 98 *N. nigropictus* insects on 542 seedlings; 14 days for 120 *N. virescens* on 2,290 seedlings; 13 days for 785 *R. dorsalis* on 8,546 seedlings; and 17 days for 179 *S. furcifera* on 3,065 seedlings.

Rice plants were observed 3-4 weeks after inoculation. Out of 14,443 inoculated seedlings, not a single one showed symptoms of rice ragged stunt disease.

Capacity of N. lugens *to transmit ragged stunt.* Greenhouse-reared *N. lugens* were confined in screen cages with *Monochoria vaginalis* for egg laying. Nymphs that emerged were virus free and were provided with healthy TN1 seedlings.

Table 29. Tungro incidence and vector insects in the study fields in Luzon, Philippines, by month, province, field, and cultivar. IRRI, 1979.

	Observations (no.)	Tungro		Vector insects			
		Fields (%)	Incidence (%)	Collections (no.)	Av no. per 10 sweeps	Tested (no.)	Infective (%)
			Month				
November	78	0	0	42	1.7	376	0
December	75	0	0	51	7.1	860	0
January	94	0	0	68	4.1	702	0.28
February	74	13	0.08	35	5.7	494	0
March	74	13	0.08	41	5.1	739	0
April	74	16	0.09	56	5.4	861	0.23
May	92	18	0.08	61	2.0	369	0
June	76	13	0.03	45	2.4	552	0.72
July	92	7	0.02	59	1.6	553	0
August	78	12	0.08	50	1.1	273	0.37
September	74	19	1.20	29	3.4	305	1.97
October	92	24	4.59	53	18.2	1043	0.67
			Province				
Bulacan	264	23	0.65	181	4.6	2545	1.13
Laguna	212	0	0	127	4.1	1426	0.09
Nueva Ecija	131	11	0.13	85	9.1	1219	0.35
Pampanga	156	16	2.75	97	2.1	794	0.25
Tarlac	210	0	0	100	5.3	1143	0
			Type of field				
Seedbed	62	0	0	58	8.4	894	0.67
Paddy	488	12	0.99	226	1.7	1541	0.84
Stubble	242	11	0.10	239	8.1	4391	0.07
Idle	181	0	0	67	0.7	301	0
			Rice cultivar				
C1	50	8	6.30	37	3.9	366	2.19
C21	14	86	9.35	6	8.8	99	4.04
IR36	566	12	0.10	371	5.4	5225	0.19
IR38	31	0	0	24	1.8	193	0
IR40	14	0	0	7	0.6	30	0
IR42	60	0	0	41	7.0	538	0
IR44	33	21	0.13	21	13.1	293	0
IR46	24	0	0	16	0.9	82	0

Table 30. Tungro vectors from April to June and rice tungro disease incidence from June to October in study fields, Luzon, Philippines.

Year	Tungro vectors[a]				Tungro disease		
	Collections (no.)	No./10 sweeps	Tested (no.)	Infective (%)	Observations (no.)	Fields (%)	Incidence (%)
1973	68	5.8	1028	0	151	1[b]	0.60
1974	166	11.0	2425	1.77	244	45[c]	2.38[c]
1975	181	9.8	3319	0.69	234	72	3.32
1976	149	3.9	2244	0.18	267	25	0.33
1977	172	3.0	1578	0	235	15	0.03
1978	170	2.3	1844	0	241	0	0
1979	162	3.3	1782	0.34	234	18	0.02

[a]*Nephotettix virescens, N. nigropictus,* and *Recilia dorsalis.* [b]Rice fields with only a few tungro-infected plants were excluded. [c]The Philippine Government launched a green leafhopper control program in the area in July and August.

Table 31. Number of tungro vectors collected by light trap, and tungro incidence at the IRRI farm.

Period	Vector insects		Infective insects tested		Tungro incidence
	No./ collection	Ratio[a]	No.	%	
Aug–Oct 1972	2741	63:28: 9	1501	0.39	Low
Nov 1972–Oct 1973	458	56:36: 8	3618	1.54	Low
Nov 1973–Oct 1974	1881	50:40.10	4454	3.17	Low
Nov 1974–Oct 1975	849	61:29:10	6829	2.20	Low
Nov 1975–Oct 1976	895	69:21:10	4511	1.12	Low
Nov 1976–Oct 1977	253	45:33:22	4277	0.46	Low
Nov 1977–Oct 1978	339	32:25:42	4654	2.17	Low
Nov 1978–Oct 1979	1170	35:48:17	4680	0.26	Low

[a]*Nephotettix virescens* : *N. nigropictus* : *Recilia dorsalis*.

Table 32. Number of *Nilaparvata lugens* collected by light trap and the incidence of rice grassy stunt and ragged stunt at IRRI.

Period	Insects		Grassy stunt		Ragged stunt	
	No./ collection	Tested (no.)	Infective insects (%)	Incidence	Infective insects (%)	Incidence
Aug–Oct 1972	4213	678	2.30	High		
Nov '72–Oct '73	8279	2766	2.51	Very high		
Nov '73–Oct '74	1180	1907	1.47	Moderate		
Nov '74–Oct '75	276	2130	0.75	Low		
Nov '75–Oct '76	434	1679	0	Trace		
Nov '76–Oct '77	921	2145	0.07	Trace	10.50	Moderate
Nov '77–Oct '78	398	1655	0.91	Trace	8.94	Moderate
Nov '78–Oct '79	434	1059	0	Trace	2.17	Low

Second-instar nymphs were used in all the trials. TN1-infected plants were used as virus sources, and 5- to 7-day-old TN1 seedlings were used as indicators.

The nymphs were given acquisition access times of 15 and 30 minutes; 3, 6, 12, and 24 hours; and 2, 4, 8, and 16 days. They were allowed to inoculate only 1 TN1 seedling for 24 hours. The tests, which involved 2,801 viruliferous insects, were repeated. Likewise, different colonies of BPH nymphs were used to determine the effect of inoculation access time on percentage of infective insects. Individual insects were confined with 1 TN1 seedling in test tubes for 5, 10, 15, 30, and 60 minutes, and 4, 8, 16, 24, and 48 hours after 10 days' acquisition feeding on ragged stunt virus infected plants. The tests, involving 5,331 viruliferous insects, were repeated.

Inoculated plants were maintained in the greenhouse. Symptoms were observed 3-4 weeks after inoculation.

The minimum acquisition access time was 1 day. Out of 304 insects tested 0.68% were infective. The higest average percentage of infective insects was 28.50, recorded at 16 days acquisition access time involving 186 insects. The average percentage of infective insects increased as the acquisition access time was increased from 1 to 16 days (Table 33).

Similarly, the percentage of infective insects increased with length of inoculation access time (Table 34). The minimum inoculation access time recorded was 5 minutes with 1.24% infective insects with 538 test insects. The highest average percentage of infective insects was 18.64 obtained at 48 hours' inoculation access time with 534 viruliferous test insects. The average percentage of infective insects did not differ markedly among treatments 8, 16, and 24 hours.

Consequently, the percentage of infective insects is influenced by the length of acquisition and inoculation access time.

Antiserum to ragged stunt virus. Collaborators at the Laboratorio di Fitovirologia applicata del

Table 33. Effect of different acquisition access times on percentage of infective insects. IRRI, 1979.

Acquisition access time	Insects tested (no.)	Percentage av[a]
15 min	221	0.0 a
30 min	217	0.0 a
60 min	231	0.0 a
3 h	239	0.0 a
6 h	242	0.0 a
12 h	193	0.0 a
24 h	304	0.7 a
2 days	307	1.2 a
4 days	275	9.8 b
8 days	386	15.5 c
16 days	186	28.5 d
Total	2,801	

[a]Av of 4 trials except for the 16-day treatment, which had only 3 trials. Means followed by a common letter are not significantly different at the 5% level.

Table 34. Effect of different inoculation access times on percentage of infective insects. IRRI, 1979.

Inoculation access time	Insects tested (no.)	Percentage av[a]
5 min	538	1.2 a
10 min	501	1.5 a
15 min	598	2.2 a
30 min	526	2.4 a
60 min	650	5.1 b
4 h	519	6.3 b
8 h	428	12.7 c
16 h	477	11.5 c
24 h	560	13.0 c
48 h	534	18.6 d
Total	5,331	

[a]Av of 5 trials except for the 30-minute treatment, which had 6 trials and the 60-minute trial, which had 7 trials. Means followed by a common letter are not significantly different at the 5% level.

CNR at Turin, Italy, and IRRI studied the preparation and use of an antiserum to rice ragged stunt virus (RRSV) subviral particles. Crude or partially purified material containing the B-spiked subviral particles (SVPs) of the virus was used to produce an antiserum whose titer in gel diffusion tests was at least 1/64 against the SVPs, and was 1/16 against healthy material. The serum did not react with double-stranded viral ribonucleic acid or poly (I): poly (C). By using immunoelectron microscopy (the decoration method), the serum was shown to have a titer of 1/256 against the SVPs, but did not react with the SVPs of maize rough dwarf virus (MRDV), pangola stunt virus (PSV), or oat sterile dwarf virus (OSDV). Antisera to the SVPs of MRDV, PSV, OSDV, and fiji disease virus did not react with rice ragged stunt virus SVPs. The RRSV antiserum was used to show, by immunoelectron microscopy, that material with rice ragged stunt symptoms from Indonesia, Thailand, and India, as well as the Philippines, all contained RRSV.

Control and management of rice pests

Insects

Entomology Department

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INSECTICIDE EVALUATION

Coded and commercial insecticides were evaluated in the laboratory and greenhouse, and the promising compounds were further tested in the field.

LD_{50} values of coded insecticides. The relative toxicity of five coded insecticides was determined by LD_{50} studies (Table 1). Compared with the commonly used rice insecticides, FMC 27289 was as toxic as carbofuran, and M 8174 and M 8983 were similar to diazinon. Although R 677 was the most toxic to the leaf folder, it was only half as toxic as methyl parathion.

Greenhouse foliar spray studies. The effectiveness of insecticides as foliar spray was tested against the brown planthopper (BPH) (eggs and adults), green leafhopper (GLH), and leaf folder. Mass-rearing and insecticide evaluation techniques were developed for evaluating insecticides for rice bug control.

Brown planthopper and green leafhopper. Five tests were conducted to evaluate new and commercially available insecticides. The results are summarized in Tables 2—6. Fenitrothion and BPMC combined were no more effective than fenitrothion alone. New insecticides found to be effective (≥80% mortality) against the BPH were PH 66, Sulprofos, M 8174, UC 54229, and UC SF-1. Those with ≥80% mortality against GLH were PH 66, Sulprofos, R 28150, N 3727, M 8174, UC 54229, UC SF-1, UC 21865, UC 51762, UC/MP 19779, W 439, formothion, and thiometon.

Previous field studies had indicated that Perthane spray solution volumes from 200 to 1,000 liters/ha provided equally good BPH control. In a 1979 greenhouse study, 10 insecticides at spray volumes of 250, 500, and 1,000 liters/ha were evaluated for BPH and GLH control (Table 7). Most insecticides were distinctly more toxic to GLH than BPH at 14 days after treatment (DAT). All volumes were equally effective at 1 DAT, but at 7 and 15 DAT, the 250-liter treatment of most insecticides gave significantly lower mortality. The study indicated initial mortality is not greatly in-

Table 1. The toxicity of some coded insecticides applied topically to common insect pests of rice. IRRI laboratory, 1979.

Insecticide	LD_{50}[a] (μg/g)			
	Brown planthopper	Green leafhopper	Whitebacked planthopper	Leaf folder
M B174	9.73	18.18	1.67	82.13
M 8983	9.27	13.05	2.54	15.43
R 677	56.86	–[b]	62.65	13.57
W 439	–	–	35.94	177.12
FMC 27289	0.54	0.51	5.31	16.98

[a]Mean lethal dose. [b]No LD_{50} values up to 5,000 ppm; very low toxicity.

Table 2. Knockdown and residual toxicity of insecticides applied as foliar sprays for brown planthopper and green leafhopper control. IRRI greenhouse, 1979.

Insecticide[a]	Spray[b] concn (%)	Mortality[c] (%)					
		Brown planthopper			Green leafhopper		
		1 DAT	7 DAT	14 DAT	1 DAT	7 DAT	14 DAT
Methyl parathion 50 EC	0.100	100 a	23 a	10 ab	100 a	75 a	30 b
Methyl parathion 50 EC	0.05	67 bc	18 a	3 b	100 a	15 cd	3 d
Azinphos ethyl 40 EC	0.05	80 abc	25 a	13 a	100 a	62 a	58 a
Chlorpyrifos + BPMC 31.6 EC	0.05	65 c	35 a	13 a	100 a	23 bcd	3 d
Fenitrothion + BPMC 75 EC	0.100	100 a	25 a	5 ab	100 a	53 ab	10 cd
Fenitrothion 30 EC	0.100	95 ab	23 a	10 ab	100 a	28 bcd	25 bc
Fenitrothion 30 EC	0.05	87 abc	18 a	3 b	100 a	15 cd	0 d
Fenitrothion 30 EC	0.025	57 c	25 a	3 b	88 a	5 d	3 d

[a]EC = emulsifiable concentrate. [b]Applied in a spray solution of 1,000 liters/ha. Thus 0.1% = 1 kg a.i./ha. [c]Means followed by a common letter are not significantly different from each other at the 5% level. DAT = days after treatment when insects were placed on treated plants. Mortality was determined 48 hours after insects were caged.

Table 3. Knockdown and residual toxicity of insecticides applied as 0.04% (0.4 kg a.i. in 1,000 liters water/ha) foliar spray for the brown planthopper and the green leafhopper. IRRI greenhouse, 1979.

Insecticide[a]	Mortality[b] (%)					
	Brown planthopper			Green leafhopper		
	1 DAT	7 DAT	14 DAT	1 DAT	7 DAT	14 DAT
PH 66 16 WP	100 a	10 a	0 a	100 a	33 ab	5 bc
Sulprofos 72 EC	100 a	0 a	0 a	83 ab	33 ab	5 bc
M 8174 20 EC	100 a	8 a	3 a	60 b	3 c	3 bc
PH 66 14 WP	68 b	13 a	0 a	100 a	55 a	65 a
Methidathion 40 EC	65 b	5 a	0 a	100 a	20 b	0 c
Methomyl 90 WP	10 c	3 a	0 a	100 a	23 b	8 b
R 28150 48 EC	8 c	3 a	3 a	98 a	43 ab	5 bc
MK 501 50 WP	5 c	13 a	0 a	60 b	5 c	3 bc
N 3727 48 EC	3 c	3 a	3 a	90 c	0 c	0 c
R 677	3 c	5 a	0 a	0 c	5 c	0 c

[a]WP = wettable powder, EC = emulsifiable concentrate. [b]Av of 4 replications, each consisting of 10 adult hoppers caged on plants. Means followed by a common letter are not significantly different from each other at the 5% level. DAT = days after treatment.

Table 4. Knockdown and residual toxicity of insecticides applied as 0.04% (0.4 kg a.i. in 1,000 liters water/ha) foliar spray for the brown planthopper and the green leafhopper. IRRI greenhouse, 1979.

Insecticide[a]	Mortality[b] (%)					
	Brown planthopper			Green leafhopper		
	1 DAT	7 DAT	14 DAT	1 DAT	7 DAT	14 DAT
Perthane 45 EC	100 a	40 bc	18 ab	100 a	18 b	8 cd
Carbofuran 12 F	93 ab	88 a	25 ab	100 a	98 a	100 a
M 8174 20 EC	93 ab	18 cd	18 ab	98 ab	20 b	0 d
Ethion 48 EC	85 b	20 cd	38 a	100 a	93 a	85 b
Azinphos ethyl 40 EC	60 c	58 b	28 ab	100 a	98 a	93 ab
Chlorpyrifos + BPMC 31.6 EC	43 cd	13 d	10 b	88 bc	13 b	5 cd
BPMC 50 EC	30 cd	13 d	15 ab	88 bc	0 c	0 d
Pirimiphos-methyl 25 EC	25 d	8 d	15 ab	60 c	5 bc	3 cd
Methomyl 95 WP	25 d	18 cd	10 b	100 a	85 a	20 c

[a]EC = emulsifiable concentrate, F = flowable, WP = wettable powder. [b]Means followed by a common letter are not significantly different from each other at the 5% level. Av of 4 replications, each consisting of 10 insects caged on treated plants. DAT = days after treatment.

Table 5. Knockdown and residual effect of insecticides applied as 0.04% foliar spray (0.4 kg a.i. in 1,000 liters water/ha) against the brown planthopper and the green leafhopper. IRRI greenhouse, May 1979.

Insecticide[a]	Mortality[b] (%)					
	Brown planthopper			Green leafhopper		
	1 DAT	7 DAT	14 DAT	1 DAT	7 DAT	14 DAT
UC 54229 100 SP	100 a	100 a	100 a	100 a	100 a	100 a
Monocrotophos 16.8 EC	100 a	100 a	89 b	100 a	100 a	100 a
FMC 35001 45 EC	100 a	100 a	100 a	100 a	100 a	100 a
Carbofuran 12 F	100 a	100 a	100 a	100 a	100 a	100 a
Permethrin 10 EC	100 a	87 b	79 b	100 a	100 a	100 a
Fenitrothion 30 EC	100 a	70 b	16 c	100 a	100 a	46 bc
Carbaryl 85 WP	94 a	72 b	89 b	100 a	100 a	100 a
Fenitrothion + BPMC 75 EC	100 a	37 c	5 c	100 a	93 a	18 cd
Methomyl 90 WP	94 a	22 c	14 c	100 a	98 a	79 ab

[a]EC = emulsifiable concentrate, SP = soluble powder, WP = wettable powder, F = flowable. [b]Av of 4 replications. Adjusted using Abbott's formula. Mortality was assessed 48 hours after insects were caged on treated plants. In a column, means followed by a common letter are not significantly different from each other at the 5% level. DAT = days after treatment.

Table 6. Knockdown and residual toxicity of insecticides applied as 0.04% spray (0.4 kg in 1,000 liters water/ha) for the brown planthopper and the green leafhopper. IRRI greenhouse, 1979.

Insecticide[a]	Mortality[b] (%)									
	Brown planthopper					Green leafhopper				
	1 DAT	5 DAT	10 DAT	15 DAT	20 DAT	1 DAT	5 DAT	10 DAT	15 DAT	20 DAT
Carbofuran 12 F	100 a	95 a	80 a	55 a	30 ab	100 a	100 a	100 a	75 abc	75 ab
Methyl parathion[c] 24% EC	87 b	73 b	33 b	23 ab	23 ab	100 a	92 a	38 bcd	58 bcd	62 bc
UCS F-1 40% F	78 bc	87 ab	30 bc	13 b	13 abc	100 a	100 a	72 ab	100 a	100 a
Carbaryl + Phenthoate 40+20% WP	78 bc	28 cde	28 bcd	25 ab	5 bc	100 a	100 a	100 a	35 de	33 cde
UC 21865 75 WP	65 bc	38 c	13 bcd	30 ab	33 a	100 a	95 a	48 bc	43 cd	5 def
Phenthoate 50% EC	65 cd	10 e	3 d	18 ab	5 bc	100 a	55 b	10 cdef	5 e	5 def
UC 51762 75 WP	45 de	18 cde	13 bcd	15 b	25 abc	100 a	95 a	72 ab	100 a	85 ab
Chlorfenvinphos 25% EC	40 de	38 c	13 bcd	8 b	3 c	100 a	100 a	67 ab	48 bcd	35 cd
UC/MP 19779 50% WP	40 de	33 cd	13 bcd	15 ab	8 abc	95 a	100 a	52 b	85 ab	72 ab
W 439 100% Tech.	30 ef	28 cd	15 bcd	25 ab	20 abc	95 a	33 c	3 f	3 e	0 f
Formothion 33% EC	30 ef	13 de	3 d	8 b	18 abc	100 a	58 b	33 bcdef	28 de	5 def
Thiometon 25% EC	15 f	25 cde	8 d	10 b	3 c	98 a	28 c	10 def	3 e	5 def

[a]F = flowable, EC = emulsifiable concentrate, SP = soluble powder, WP = wettable powder, Tech. = technical material. [b]Av of 4 replications. Mortality was assessed 48 hours after insects were caged on treated plants. In a column, means followed by a common letter are not significantly different from each other at the 5% level. DAT = days after treatment when insects were placed on treated plants. [c]Penncap M, a microencapsulated formulation of methyl parathion.

Table 7. Effect of 3 spray volumes in the control of brown planthopper and green leafhopper.[a] IRRI greenhouse, 1979.

Insecticide and volume of spray solution (liters/ha)	Insecticide rate (kg a.i./ha)	Mortality[a]					
		Brown planthopper			Green leafhopper		
		1 DAT	7 DAT	14 DAT	1 DAT	7 DAT	14 DAT
BPMC 50%	0.75						
1000		100 a	53 fg	25 hij	100 a	60 b	40 c
500		85 bc	23 hi	10 ijk	100 a	35 c	23 d
250		60	20 hi	10 ijk	100 a	18 de	3 jk
Chlorpyrifos + BPMC 32%	1.5						
1000		100 a	100 a	88 abcd	100 a	100 a	90 a
500		100 a	100 a	65 defg	100 a	100 a	90 a
250		100 a	68 def	20 hijk	100 a	100 a	73 b
Carbofuran 12%	0.25						
1000		100 a	100 a	80 abcde	100 a	100 a	100 a
500		100 a	100 a	45 fgh	100 a	100 a	100 a
250		100 a	83 bcde	10 ijk	100 a	100 a	88 b

Carbophenothion 40%	0.75						
1000		100 a	100 a	100 a	100 a	100 a	100 a
500		100 a	100 a	95 ab	100 a	100 a	100 a
250		100 a	88 abc	15 ijk	100 a	100 a	98 a
MIPC 50%	0.75						
1000		100 a	100 a	75 bcde	100 a	100 a	100 a
500		100 a	100 a	38 ghi	100 a	100 a	100 a
250		100 a	85 abcd	20 hijk	100 a	100 a	100 a
Monocrotophos 16.8%	0.75						
1000		100 a	38 gh	13 ijk	100 a	100 a	18 d
500		100 a	15 hij	10 ijk	100 a	43 c	5 ef
250		75 c	8 ij	3 k	100 a	10 e	5 ef
MTMC 30%	0.75						
1000		98 ab	18 hij	13 ijk	100 a	28 d	10 de
500		70 c	18 hij	10 ijk	100 a	25 d	10 de
250		63 cd	5 j	10 ijk	100 a	23 d	5 ef
Perthane 45%	0.75						
1000		100 a	100 a	98 ab	100 a	100 a	90 a
500		100 a	100 a	70 cdef	100 a	100 a	73 b
250		100 a	75 cdef	20 hijk	100 a	50 b	8 ef
Fropoxur 50%	0.75						
1000		98 ab	55 efg	10 ijk	100 a	78 b	23 d
500		95 ab	13 hij	8 jk	100 a	30 cd	15 de
250		40 d	8 ij	5 jk	100 a	28 d	8 ef
FMC 35001 48%	0.75						
1000		100 a	100 a	100 a	100 a	100 a	100 a
500		100 a	100 a	90 abc	100 a	100 a	100 a
250		100 a	98 ab	63 efg	100 a	100 a	100 a
Control							
1000		8 e	0 l	8 jk	10 b	5 f	3 jk
500		8 e	5 jkl	3 k	5 b	5 f	0 k
250		8 e	5 jkl	15 jk	10 b	3 f	5 ef

[a] Mortality readings were taken 48 hours after insects were caged on treated plants. The insects were placed on plants at 1, 7, 14 days after treatment (DAT). In a column, means followed by a common letter are not significantly different from each other at the 5% level.

Table 8. Ovicidal effect of insecticides applied as foliar spray on 1- to 3-day-old brown planthopper (BPH) eggs. IRRI greenhouse, 1979.

Insecticide[a]	Rate[b] (kg a.i./ha)	Eggs hatched[c] (%)
Test 1		
Perthane 45 EC	0.75	97 c
Metalkamate	0.75	97 c
Fenitrothion 75 EC	0.75	89 c
Fenitrothion 30 EC	0.75	78 b
Azinphos ethyl 40 EC	0.75	7 a
Carbofuran 12 F	0.75	0 a
Control		100 c
Test 2		
Permethrin 10 EC	0.25	95 c
Isazophos 50 EC	0.75	93 c
Fenitrothion 30 EC	0.75	84 bc
Pirimiphos-methyl 25 EC	0.75	84 bc
Perthane 45 EC	0.75	60 b
Propoxur 20 EC	0.75	58 b
Azinphos ethyl 40 EC	0.75	21 a
Control		95 c

[a]BPH were allowed to lay eggs for 48 hours and then plants were sprayed with insecticides. [b]Applied on the basis of 1,000 liters solution/ha. [c]Means followed by a common letter within each test are not significantly different at the 5% level.

fluenced by volume, but that higher volumes provide longer residual activity.

BPH ovicidal activity. Testing insecticides for ovicidal activity against the BPH started in 1978. Two tests in 1979 evaluated the ovicidal activity of additional insecticides. Azinphos ethyl and carbofuran were highly ovicidal, but fenitrothion, Perthane, and propoxur only slightly depressed hatching (Table 8).

Leaf folder. Fourteen insecticides were tested as foliar spray against the leaf folder (Table 9).

Rice bug. Insecticides were tested as foliar spray for rice bug control. Those providing effective control (≥80% mortality) in the 2 tests are listed in Table 10.

Field evaluation of insecticides. Insecticides selected in greenhouse studies were further evaluated in the field against the whorl maggot and the BPH. Insecticides for whorl maggot control were evaluated as foliar spray, paddy water broadcast, and soil incorporated granules (Fig. 1). Soil incorporation of carbofuran granules provided most effective control. Of the foliar sprays, monocrotophos, fensulfothion, triazophos, and azinphos ethyl were most effective (rating of <4 at 24 days after transplanting [DT]).

Four insecticides at 0.5, 0.75, and 1.0 kg a.i./ha were soil incorporated before transplanting. Carbofuran provided good control of the whorl mag-

Table 9. Activity of insecticides applied as foliar spray on plants with leaf folder *Cnaphalocrocis medinalis* larvae. IRRI greenhouse, 1979.

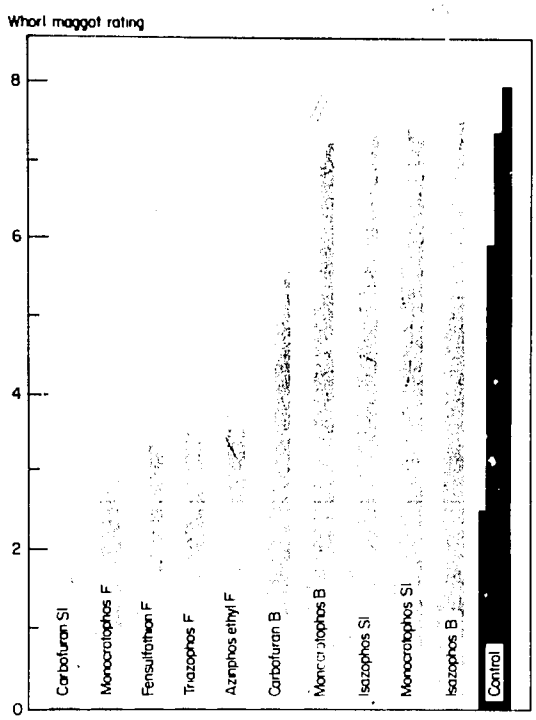
Insecticide	Rate (kg a.i./ha)	Larval mortality[a] (%)
UC 51762 75 WP	0.75	92 a
Acephate 40 EC	0.75	90 ab
Phenthoate 50 EC	0.75	90 ab
Chlorfenvinphos 25 EC	0.75	87 ab
UC 54229 100 SP	0.75	87 ab
Formothion 33 EC	0.75	80 ab
Methyl parathion[b] 24 EC	0.75	80 ab
Chlorpyrifos + BPMC 31.6 EC	1.5	78 abc
UCS F-1 40 F	0.75	75 abc
UC/MP 19779 50 WP	0.75	70 abc
Carbophenothion 40 EC	0.75	65 bcd
Carbaryl 85 SP	1.5	50 cd
MTMC 50 WP	0.75	38 de
Thiometon 25 EC	0.75	20 e

[a]Means followed by a common letter are not significantly different from each other at the 5% level. Av of 4 replications, each consisting of 10 larvae/potted plants. Insects were placed on the plants about 2 weeks before spraying and allowed to fold the leaves. Larvae were examined for mortality 48 hours after spraying. [b]Microencapsulated formulation (Penncap M).

Table 10. Activity of insecticides applied as foliar spray for control of the rice bug *Leptocorisa oratorius* (Fab.). IRRI greenhouse, 1979.

Insecticide	Concentration[a] (%)	Mortality[b] (%)
Effective (> 80% mortality)		
Monocrotophos 16.8 EC	0.05	100 a
Endosulfan 35 EC	0.06	100 a
Chlorpyrifos 40 EC	.016	100 a
Phosphamidon 50 EC	.07	100 a
Acephate 40 EC	.09	99 a
Triazophos 40 EC	.07	98 a
Carbaryl 85 WP	0.12	91 b
Monocrotophos + Mevinphos 20.2 EC	.06	100 a
Diazinon 20 EC	0.21	100 a
Fenitrothion 30 EC	.05	98 ab
Pirimiphos-methyl 25 EC	0.03	85 b
Intermediate (50–79% mortality)		
MIPC 50 WP	0.07	74 bc
Carbophenothion 40 EC	.09	73 bc
Methyl parathion 50 EC	.07	56 c
Chlorpyrifos + BPMC 31.6 EC	0.14	50 c

[a]Twelve ml of the indicated concentration was sprayed on 4 panicles. The concentration was based on manufacturers' recommendations in the Philippines. [b]Means followed by a common letter are not significantly different from each other at the 5% level. Av of 4 replications, each consisting of 20 rice bugs caged on a treated rice panicle, 1 day after treatment.



1. Field evaluation of insecticides for control of the whorl maggot *Hydrellia sasakii* on IR36 at 10, 17, 24, and 31 days after transplanting (DT). Insecticides were applied as foliar spray (F) and soil-incorporated (SI) granules at 0.75 kg a.i. ha; paddy water broadcast (B) at 1.0 kg a.i. ha, except for diazinon at 0.75 kg; and ultralow-volume (ULV) spray at 0.02 kg a.i. ha. Granules were soil incorporated before transplanting; foliar spraying was with knapsack sprayer and ULV each twice (3 and 15 DT); and broadcast was once at 3 DT. 1 = 0-1 leaf hill damaged; 9 = > 50% leaves damaged with some leaves broken. IRRI, 1979 dry season.

got at all rates; FMC 35001, bendiocarb, and isazophos provided poor control even at the highest rate. Carbofuran, FMC 35001, and isazophos stimulated plant growth as indicated by plant height.

Three coded insecticides — EXP 5469, MK 501, and R 677 — provided similar control of BPH as indicated by the reduction in the BPH population.

Field evaluation of application methods. To decrease the cost of chemical control of rice insect pests, the search for application methods that increase the effectiveness of insecticides was continued.

Seedbed and preplanting treatments. The effectiveness of carbofuran applied in the seedbed or as a preplanting treatment was tested in three experiments. Only preplanting soil incorporation showed decreased defoliation damage by caterpillars and low incidence of deadhearts caused by stem borers (mostly *Tryporyza incertulas*). The soil-incorporation treatment had significantly more whiteheads than the control.

None of the seedbed treatments subsequently controlled the whorl maggot in the field, but the soil-incorporation treatment provided control throughout the period of infestation. The seedling soak provided control at 12 DT, but damage increased thereafter, matching that of the control at 32 DT (Table 11).

Rotary weeder. Application with a rotary weeder and as paddy water broadcast were compared. Carbofuran was broadcast and incorporated with a rotary weeder at 32 DT in about 1 cm of standing water. Control of stem borers was the same for both treatments (Table 12). Mortality readings taken on caged BPH and GLH at 12 DT in the 0.75 kg a.i./ha treatment indicated that the rotary weeder provided longer residual activity against the BPH.

Slow-release formulation of carbofuran. In 1979 the search for formulations that would provide slow release of carbofuran and increased residual activity of the chemical continued. In cooperation with the University of Newscastle upon Tyne, UK, a formulation of carbofuran in kraft lignin was tested. Mortality studies on caged BPH and GLH indicated no difference in the residual activity of the slow-release and the commercial 3% granules (Fig. 2).

Neem cake (obtained after oil is pressed from the seed of the neem tree *Azadirachta indica*) when mixed with nitrogen fertilizer is known to cause slow release of nitrogen. Neem oil mixed with carbofuran treatments did not increase the residual activity of either the paddy water broadcast or soil-incorporation treatments, as indicated by whorl maggot and stem borer damage.

Broadcast, foliar spray, and root-zone application of isazophos. Isazophos has shown effectiveness as a root-zone application and as a paddy water broadcast or foliar spray application. The efficacy of the three methods with 0.5 kg a.i. isazophos/ha was compared for the control of whorl maggot, stem borers, BPH, and GLH. The root-zone application most effectively controlled the whorl maggot and stem borer (Table 13), and provided the longest residual activity against field-

Table 11. Effect of preplanting carbofuran treatments on the insect pests of IR22 rice.[a] IRRI, 1979 wet season.

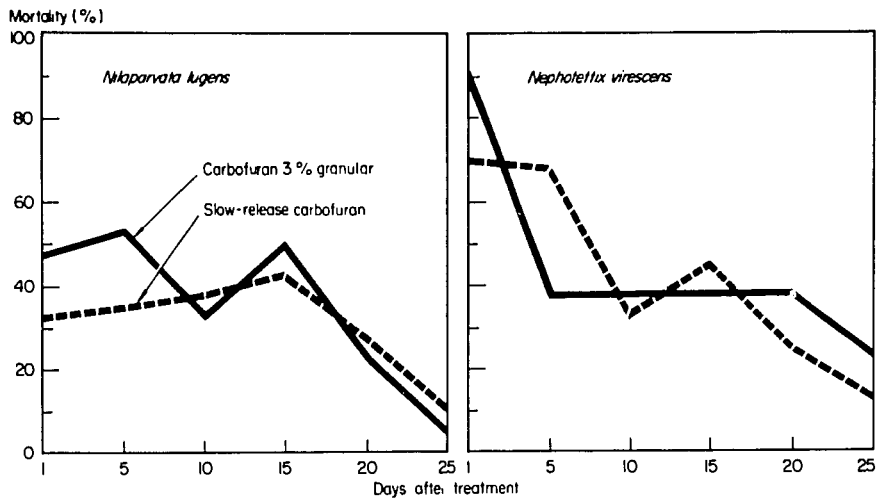
Treatment	Rate	Whorl maggot rating[b]				Plant ht (cm)	Caterpillar damage[c] (%)	Insects (no./10 sweeps) 32 DT					Dead-hearts (%)
		12 DT	18 DT	26 DT	32 DT	30 DT	32 DT	Green leaf-hopper	Brown plant-hopper	White-backed plant-hopper	*Cyrto-rhinus*	Whorl maggot adults	40 DT
Seedling soak	0.06%	1 a	3 b	5 b	6 b	45 b	13 b	32 c	5 a	7 b	28 bc	87 bc	7.5 c
Seedling soak + capsule 20 DT	0.06% + 1.0 kg a.i./ha	1 a	3 b	4 a	1 a	53 c	7 a	2 a	3 a	2 a	0 a	34 a	0.4 a
Soil incorporation	1.0 kg a.i./ha	1 a	2 a	3 a	1 a	54 c	9 a	8 b	5 a	7 b	19 b	60 b	4.1 b
Control		4 b	8 c	8 c	8 b	35 a	14 b	81 d	12 b	25	50 c	114 c	4.4 b

[a]In a column, means followed by a common letter are not significantly different from each other at the 5% level. DT = days after transplanting. [b]Based on scale of 1–9: 1 = 0–1 leaf damaged; 9 = > 50% leaves damaged with leaf breaking. [c]Percent of tillers damaged.

Table 12. Effect of rates and methods of carbofuran application on insect pests of IR22 rice. IRRI, 1979 wet season.[a]

Treatment[b]	Rate (kg a.i./ha)	Deadhearts (%)			Whiteheads (%)	Mortality[d] (%)							Yield (t/ha)
						Brown planthopper				Green leafhopper			
		6 DBT[c]	18 DT	30 DT	65 DT	1 DT	4 DT	8 DT	12 DT	1 DT	4 DT	8 DT	
Rotary weeder	1.5	2.1 a	0.8 a	1.8 a	1.3 ab	67 a	60 ab	61 a	27 a	52 a	50 a	82 a	3.9 a
Broadcast	1.5	1.7 a	0.9 a	1.8 a	1.0 a	46 b	66 a	60 a	27 a	52 a	56 a	82 a	4.0 a
Rotary weeder	0.75	2.3 a	1.0 a	2.5 ab	1.4 ab	35 b	47 ab	45 ab	27 a	39 a	46 a	69 ab	4.0 a
Broadcast	0.75	2.6 a	1.6 ab	3.5 ab	1.0 a	46 b	39 b	37 b	6 b	52 a	50 a	57 b	3.6 ab
Control		1.4 a	3.4 b	5.1 b	2.3 b	–	–	–	–	–	–	–	3.4 b

[a]In a column, means followed by a common letter are not significantly different from each other at the 5% level. [b]Insecticide was applied 32 days after transplanting (DT). [c]Days before treatment. [d]Insects were caged on treated plants and mortality readings taken 48 hours after caging. Means were adjusted using Abbott's formula.



2. Paddy water broadcast of commercially produced carbofuran granules and a slow-release formulation (in kraft lignin coded CL45) for brown planthopper *Nilaparvata lugens* and green leafhopper *Nephotettix virescens* control. Insects were caged on plants in the field at indicated days after treatment. IRRI, 1979.

caged BPH and GLH.

Optimum droplet size for ultralow-volume spraying. The spinning-disc ultralow-volume (ULV) sprayer gives a finer degree of control over droplet size than the knapsack sprayer. With the ULV sprayer (Micron mini ULVA), the relationship among droplet size, number of droplets deposited, and volume of spray material recovered after spraying was checked.

A decrease in volume mean diameter of droplet size from 127 to 84 μm gave a threefold increase in number of droplets deposited on the canopy (Table 14). There was, however, no corresponding increase in volume of spray deposited. Volume recovery was highest with 127 μm droplets — 20% higher than that recovered from the knapsack-sprayer treatment. At droplet sizes less than 80 μm there was a sharp decrease in number of droplets and volume of spray recovered. It is apparent that regulation of droplet size can be used to increase volume of deposit and thus decrease the amount of actual chemical required.

In a greenhouse bioassay varying dose rate, droplet deposit, and spray concentration of acephate, only dose rate affected BPH mortality. This indicated that fumigation was a principal mode of action. Based on that information another test was made with acephate at 0.75 kg a.i./ha to compare deposit level of ULV and knapsack spraying for BPH control. ULV gave a higher initial deposit (5 ppm) than

Table 13. Field evaluation[a] of three application methods using isazophos granules at the rate of 0.5 kg a.i./ha. IRRI, 1979.

Treatment	Whorl maggot damage[b]		Deadhearts (%)	Plant height (cm)	Yield (t/ha)
	9 DAT	22 DAT	42 DAT		
Broadcast	5.2 ab	6.7 b	2.9 b	47 ab	3.93 a
Foliar spray	5.5 ab	7.2 b	3.2 b	45 b	3.54 a
Root-zone (capsule)	4.4 a	1.0 a	1.0 a	50 a	4.16 a
Control	8.1 c	7.5 b	3.2 b	46 ab	3.77 a

[a]In a column, means followed by a common letter are not significantly different from each other at the 5% level. DAT = days after treatment, when insects were placed on caged IR22 rice plants. [b]Scoring of 20 hills/plot, on a scale of 0–9: 0 = no damage, 9 = severe feeding lesions causing curling and leaf breaking.

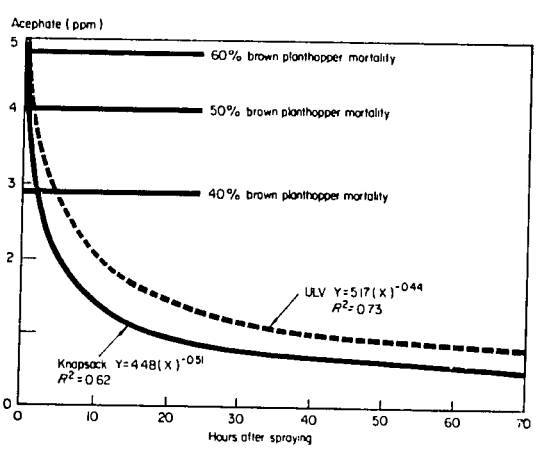
Table 14. Volume recovery rate and the equivalent number of droplets for a range of droplet sizes of a water-based ultralow-volume (ULV) spray and knapsack sprayer. IRRI, 1979.[a]

Droplet size[b] (μm, vmd)	Recovery rate[c]	
	Volume (ml deposited/ 100 ml emitted)	No. of droplets (1×10^5) deposited/ ml emitted
54	0.06 d	0.13 d
84	34.30 b	28.30 a
102	28.60 c	8.20 c
127	54.00 a	11.10 b
Knapsack[d]	37.50 ± 2.7	–

[a]In a column, means followed by a common letter are not significantly different from each other at the 5% level. [b]vmd = volume median diameter. [c]Estimated colorimetrically from the canopy of the rice crop at 45 days after transplanting (DT). The number of droplets was estimated from the volume by using the average diameter of the droplet spectrum. [d]Sprayed at the same growth stage as the ULV treatments, but at a different spray occasion. Droplet size was unknown.

the knapsack sprayer (4.5 ppm) and would be expected to provide slightly better BPH control (Fig. 3). Because of the short residual activity of the chemical, however, the difference did not appear to be of practical significance.

The ULV spinning-disc sprayer tested provided a deposit equal to, or better than, that of the common knapsack sprayer and gave similar insect control. The advantage of the ULV sprayer was in the savings in water and labor (Table 15).



3. Acephate recovered at indicated hours after spraying when applied in the field at the rate of 0.75 kg a.i./ha with an ultralow-volume spinning-disc sprayer and a high-volume knapsack sprayer. Deposit level is based on gas liquid chromatography. Brown planthopper mortality rates are based on mortality data taken from a previous study where the mortality percentage at various ppm deposit levels was determined. IRRI, 1979.

Table 15. Operational parameters for a high-volume knapsack and an ultralow-volume sprayer. IRRI, 1979.

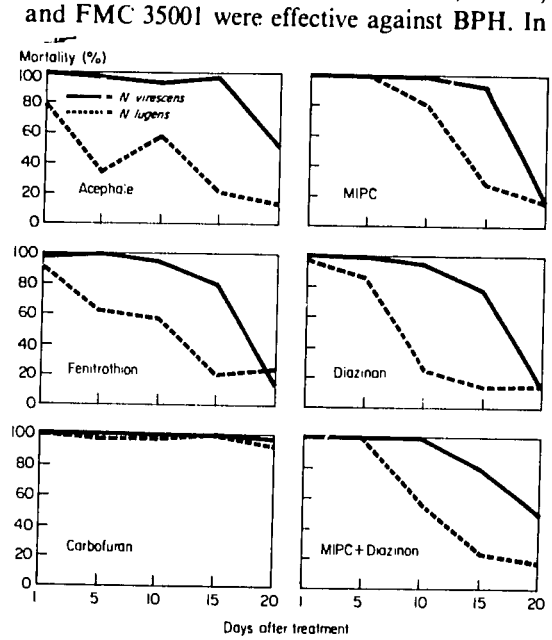
Sprayer type[a]	Cost ($) of sprayer	Solution used (liters/ha)	Operation time (h/ha)
ULV	17	6	2
Knapsack	45	450	20

[a]Locally produced.

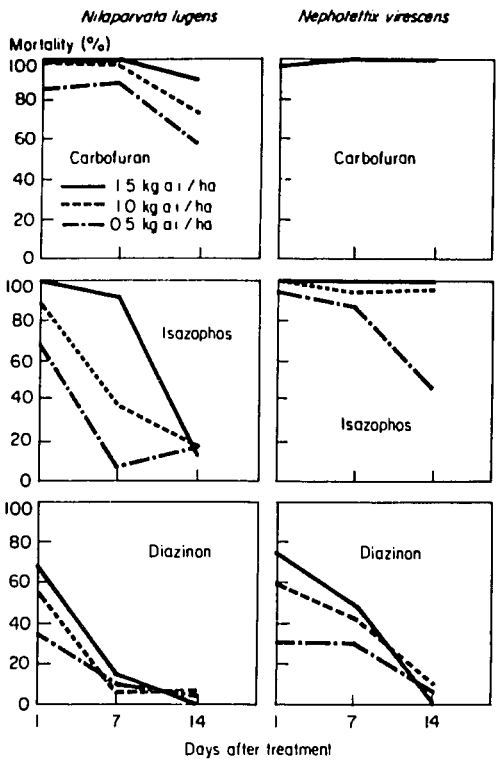
Paddy water broadcast of granules for BPH and GLH control. The relative effectiveness of granular formulations of insecticides against the GLH and BPH was determined in three tests. Most of the insecticides tested provided effective control. Mixing MIPC and diazinon produced no synergistic effect (Fig. 4).

Three rates of granular carbofuran, isazophos, and diazinon were evaluated as paddy water broadcast application against the GLH and BPH (Fig. 5).

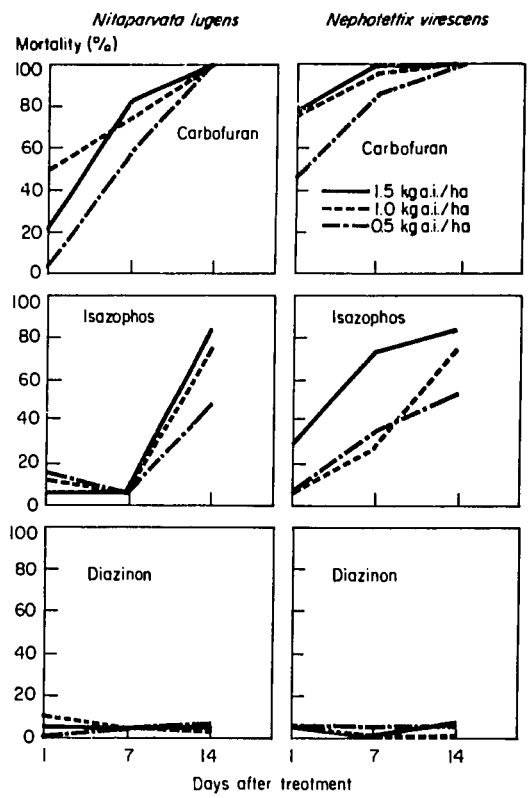
Root-zone application of granular insecticides. Eight insecticides were evaluated in the greenhouse as root-zone application at the rate of 1.5 kg a.i./ha. Carbofuran, MIPC, FMC 35001, and isazophos were effective against GLH; carbofuran, MIPC, and FMC 35001 were effective against BPH. In



4. Activity of granular formulations of insecticides applied at a rate of 0.75 kg a.i./ha as paddy water broadcast against the green leafhopper *Nephotettix virescens* and the brown planthopper *Nilaparvata lugens*. Mortality readings, taken 48 hours after insects were caged on treated plants, were adjusted using Abbott's formula. IRRI greenhouse, 1979.



5. Paddy water application of insecticides at three rates for control of the brown planthopper *Nilaparvata lugens* and the green leafhopper *Nephotettix virescens*. Each point is a mean of 4 replications. Mortality readings, taken 48 hours after insects were caged on treated plants, were adjusted using Abbott's formula. IRRI greenhouse, 1979.



6. Root-zone application of three rates of carbofuran, isazophos, and diazinon as granules placed in gelatin capsules for control of the brown planthopper *Nilaparvata lugens* and green leafhopper *Nephotettix virescens*. Mortality readings, taken 48 hours after insects were caged on treated plants, were adjusted using Abbott's formula. IRRI greenhouse, 1979.

comparisons of 1.5, 1.0, and 0.5 kg a.i. of carbofuran, isazophos, and diazinon per hectare for GLH and BPH control, carbofuran was most effective against both insects (Fig. 6). As indicated by insect mortality, uptake of both carbofuran and isazophos was delayed.

Figure 7 compares the activity of granular carbofuran, isazophos, and diazinon. All three had activity as paddy water broadcast, but only carbofuran and isazophos had sufficient systemic activity to provide control as a root-zone application.

Relative susceptibility of BPH biotypes. In tests of the susceptibility of the IRRI BPH biotypes 1, 2, and 3 to three carbamate insecticides, carbofuran was the most toxic (Table 16). Biotype 3 was most susceptible to carbofuran.

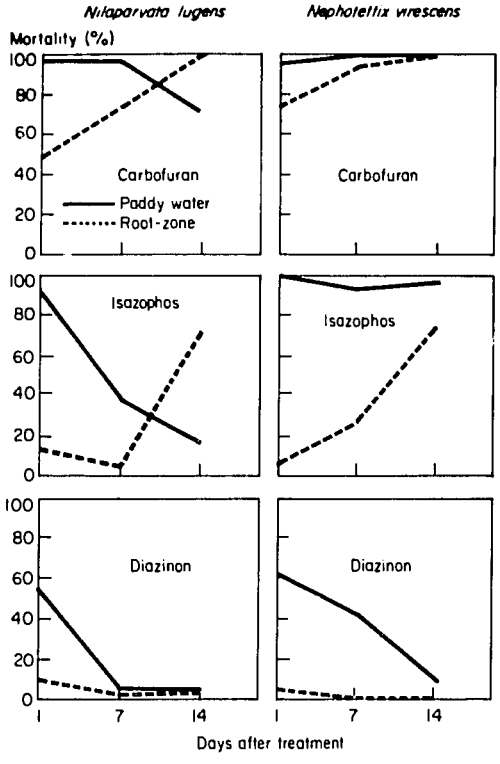
Contact toxicity. Insecticides were tested in Potter's spray tower for contact toxicity to BPH and GLH. At 0.75 kg a.i./ha, carbofuran had the most rapid knockdown for both BPH and GLH, and all insecticides were equal at 24 hous after treatment (Table 17). FMC 35001 and UC 54229 were effective new compounds.

At 0.4 kg a.i./ha, carbofuran was most effective against BPH, but methomyl had the most rapid knockdown for GLH (Table 18). In the contact

Table 16. Susceptibility of the 3 IRRI brown planthopper (BPH) biotypes to topically applied carbamate insecticides. IRRI, 1979.

Insecticide	LD_{50}[a] (µg/g)		
	Biotype 1	Biotype 2	Biotype 3
FMC 35001	3.62 a	3.77 a	2.92 a
Carbaryl	3.20 a	2.11 a	1.90 a
Carbofuran	0.45 a	0.39 a	0.16 b

[a]Median lethal dose. Within a row, means followed by the same letter are not significantly different from each other as based on fiducial limits at the 95% level.



7. Paddy water broadcast and root-zone application of 3 insecticides at 1.0 kg a.i./ha for control of brown planthopper *Nilaparvata lugens* and green leafhopper *Nephottetix virescens*. Each point is a mean of 4 replications. Mortality readings, taken at 48 hours after insects were caged on treated plants, were adjusted using Abbott's formula. IRRI greenhouse, 1979.

toxicity studies, the GLH was generally more susceptible to insecticides than BPH. Perthane was selectively most toxic to BPH and had a low toxicity for most other rice pests.

BROWN PLANTHOPPER AND WHITEBACKED PLANTHOPPER RESURGENCE

Studies of the relationship between insecticide application and BPH resurgence continued. The effect of insecticides on natural enemies of the BPH, BPH egg hatching, and the length of the BPH life cycle was studied; and the possibility of resurgence occurring on resistant and moderately resistant varieties was investigated.

Toxicity of insecticides for BPH and *Cyrtorhinus lividipennis*. Among four insecticides tested in 1979, decamethrin, diazinon, and methyl parathion

Table 17. Contact toxicity for the brown planthopper and the green leafhopper of insecticides applied at 0.075% (0.75 kg a.i. in 1,000 liters water/ha) by means of Potter's spray tower. IRRI greenhouse, 1979.

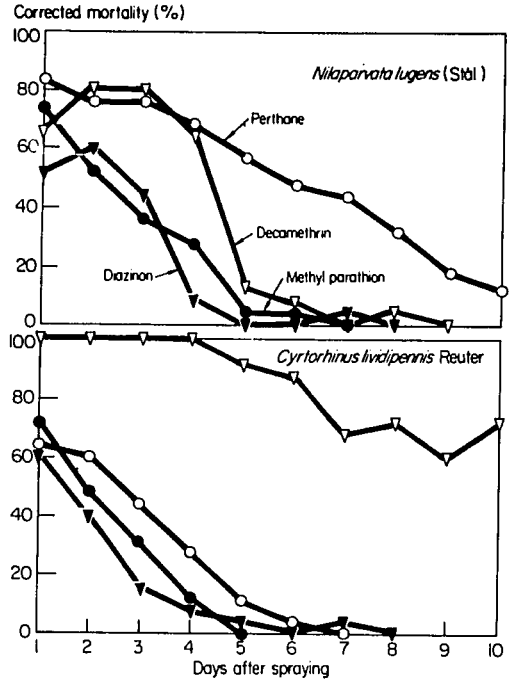
Insecticide[a]	Mortality[b] (%)							
	Brown planthopper				Green leafhopper			
	1 HT	4 HT	24 HT	48 HT	1 HT	4 HT	24 HT	48 HT
Permethrin 10 EC	10 f	49 bc	100 a	100 a	20 d	83 ab	100 a	100 a
UC 54229 100 SP	37 cd	52 bc	100 a	100 a	47 c	55 d	100 a	100 a
Carbaryl 85 WP	28 de	40 c	88 b	88 ab	17 d	44 d	100 a	100 a
Fenitrothion 30 EC	17 ef	45 c	100 a	100 a	26 d	44 d	100 a	100 a
Fenitrothion + BPMC 75 EC	46 bcd	63 bc	100 a	100 a	53 bc	67 bcd	100 a	100 a
Methomyl 90 WP	53 bc	57 bc	99 ab	98 ab	48 c	61 cd	100 a	100 a
Monocrotophos 16.8 EC	59 b	70 b	100 a	100 a	58 bc	62 cd	100 a	100 a
FMC 35001 45 EC	54 bc	60 bc	100 a	100 a	72 ab	80 bc	100 a	100 a
Carbofuran 12 F	80 a	98 a	99 ab	100 a	88 a	95 a	100 a	100 a

[a]EC = emulsifiable concentrate; SP = soluble powder; WP = wettable powder; F = flowable. [b]Av of 4 replications; adjusted using Abbott's formula. In a column, means followed by a common letter are not significantly different from each other at the 5% level. HT = hours after treatment, at which mortality reading was taken.

Table 18. Contact toxicity for the brown planthopper and the green leafhopper of insecticides applied at 0.04% (0.4 kg a.i. in 1,000 liters water/ha) by means of Potter's spray tower. IRRI greenhouse, 1979.

Insecticide[a]	Mortality[b] (%)							
	Brown planthopper				Green leafhopper			
	1 HT	4 HT	24 HT	48 HT	1 HT	4 HT	24 HT	48 HT
Carbofuran 12 F	24 a	47 a	76 a	76 a	34 b	100 a	100 a	100 a
Methomyl 95 WP	13 ab	23 b	26 b	26 bc	59 a	97 a	98 a	100 a
BPMC 50 EC	12 b	16 bc	22 b	32 bc	13 c	84 a	96 a	96 a
Pirimiphos-methyl 25 EC	2 c	4 de	14 b	17 c	4 d	4 c	26 cd	26 c
M 8174 20 EC	1 c	7 cde	19 b	24 bc	4 d	8 c	44 bc	55 b
Chlorpyrifos + BPMC	1 c	13 bcd	29 b	49 bc	2 d	38 b	63 b	65 b
Azinphos ethyl	1 c	5 de	8 b	31 bc	5 d	88 a	100 a	100 a
Perthane 45 EC	0 c	2 e	29 b	39 bc	0 d	9 c	15 d	21 c
Ethion 48 EC	0 c	8 bcde	17 b	24 bc	2 d	8 c	27 cd	36 bc

[a]WP = wettable powder, EC = emulsifiable concentrate. [b]In a column, means followed by a common letter are not significantly different from each other at the 5% level. Av of 4 replications, each consisting of 25 insects treated and caged on untreated plants. HT = hours after treatment.

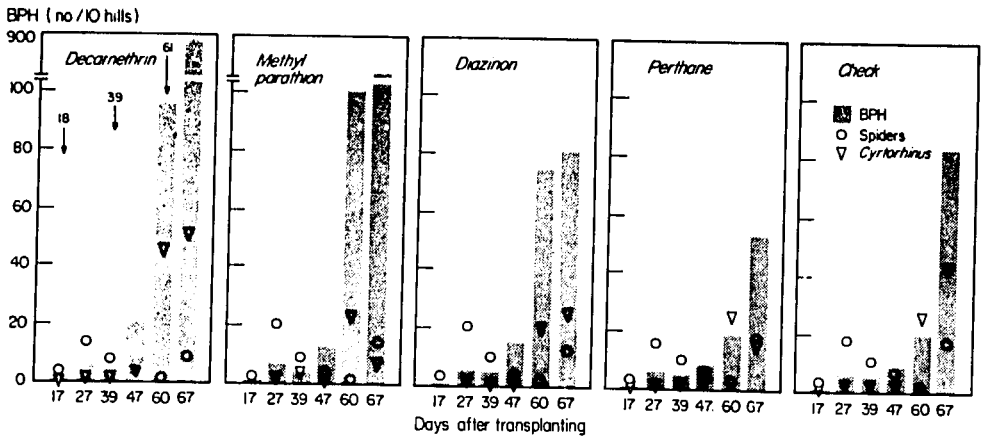


8. Toxicity for *Nilaparvata lugens* and the predator *Cyrtorhinus lividipennis* of insecticides foliar sprayed on rice. Thirty-day-old plants were sprayed once with insecticides. Ten insects were released daily, and mortality was assessed the following day. Corrected mortality was determined using Abbott's formula. IRRI greenhouse. 1979.

had previously caused BPH resurgence; Perthane had not. In a greenhouse study Perthane had the most persistent effect, killing as much as 30% of BPH 8 days after application (Fig. 8). With the 3 other insecticides, mortality was less than 14% within 5 days after spraying.

There was a distinct difference in the mortality of *C. lividipennis,* even among the resurgence-causing insecticides. Decamethrin was toxic to *C. lividipennis* for an extended period, but the residual toxicity of methyl parathion and diazinon was only for a short period. Comparison of the toxicity of the nonresurgence-inducing Perthane and of the three other resurgence-inducing insecticides did not indicate that increased toxicity of resurgence-inducing insecticides to *C. lividipennis* would contribute to BPH resurgence.

In field tests with the same four insecticides the BPH population was low up to 47 DT (Fig. 9). But

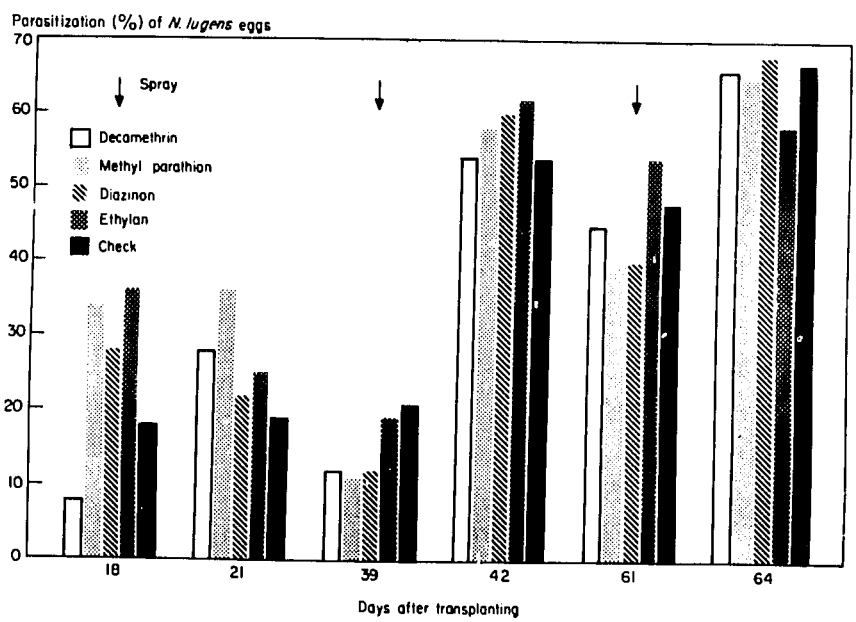


9. Interaction between field application of insecticide sprays and populations of brown planthopper (BPH), *Cyrtorhinus*, and spiders. All treatments except the check were sprayed thrice: at 18, 39, and 61 days after transplanting. IRRI, 1979.

at 67 DT, after the crop had received 3 sprayings, there was a marked increase in BPH especially in decamethrin- and methyl parathion-treated plots. The BPH population in Perthane-treated plots did not differ significantly from that in the untreated control.

The *Cyrtorhinus* populations in the treatments did not differ significantly up to 60 DT. At 67 DT, the population in plots treated with methyl parathion was significantly reduced. In the decamethrin treatment, which had a high resurgence ratio, the *Cyrtorhinus* population was equal to that of the check. The spider population was not affected by any of the insecticides.

Effect of foliar sprays of insecticides on BPH egg parasitization. In the field BPH eggs were predominantly parasitized by two species of parasites —*Anagrus* sp. and *Oligosita* sp. Parasitization by



10. Effect of insecticides on parasitization of brown planthopper eggs at various days after transplanting (DT). Sum of *Anagrus* sp. and *Oligosita* sp. parasitism. Decamethrin applied at 0.012 kg and all others at 0.75 kg a.i./ha at 18, 39, and 61 DT. IRRI, 1979.

Table 19. Nymphal survival and adult longevity of brown planthopper as influenced by insecticides applied as foliar spray.[a] IRRI greenhouse, 1979.

Treatment[b]	Nymphal survival		Adult longevity[e] (days)
	%[c]	No.[d]	
Methyl parathion	70.4 ab	108.2 ab	11.1 ab
Decamethrin	53.9 bc	96.4 b	12.7 a
Diazinon	74.6 a	126.6 a	9.9 b
Perthane	52.6 bc	11.6 c	10.3 b
Control	75.5 a	102.8 ab	10.2 b

[a]In a column, means followed by a common letter are not significantly different from each other at the 5% level. [b]All insecticides were applied at the concentration 0.04% for 500 liters water/ha, except decamethrin which was applied at 0.002%. [c]Percentage of surviving nymphs at 5th-instar stage, from 20 1st-instar nymphs released 15 days after the third spraying. Potted TN1 plants were sprayed at plant age of 30, 40, and 50 days. [d]Surviving nymphs at the 5th-instar stage. Insecticides were sprayed on 1-day-old BPH eggs in TN1 plants. [e]Newly formed female adults.

Anagrus, the more abundant species, was up to 65% at 64 DT; that by *Oligosita* sp. was about 23%. Throughout the crop period, BPH egg parasitization was similar for all treatments (Fig. 10), indicating no observable effect of insecticides on BPH egg parasites. The results of the 1979 predator and parasite study did not associate resurgence with selective destruction of natural enemies.

Effect of insecticide on rice plants on BPH egg, nymphal, and adult stages. Insecticides were evaluated to determine whether they would contribute to resurgence by increasing the hatchability of BPH eggs. No distinct difference occurred among the treatments. Egg mortality was higher in the methyl parathion treatment, perhaps because of the systemic ovicidal action of the insecticide.

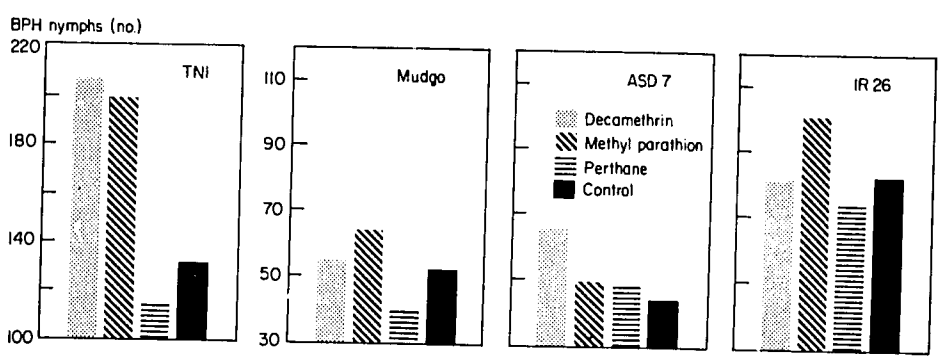
Nymphal survival varied among the insects cultured on plants that received different insecticide treatments (Table 19), but there were no indications that resurgence-causing insecticides, as a group, affected the survival rate of BPH nymphs.

When the insecticides were sprayed on plants infested with BPH eggs, the survival of the emerging nymphs varied significantly. Perthane recorded the lowest survival (52.6%), obviously due to persistent toxicity. The rate of survival in the other insecticide treatments did not differ from that in the untreated control.

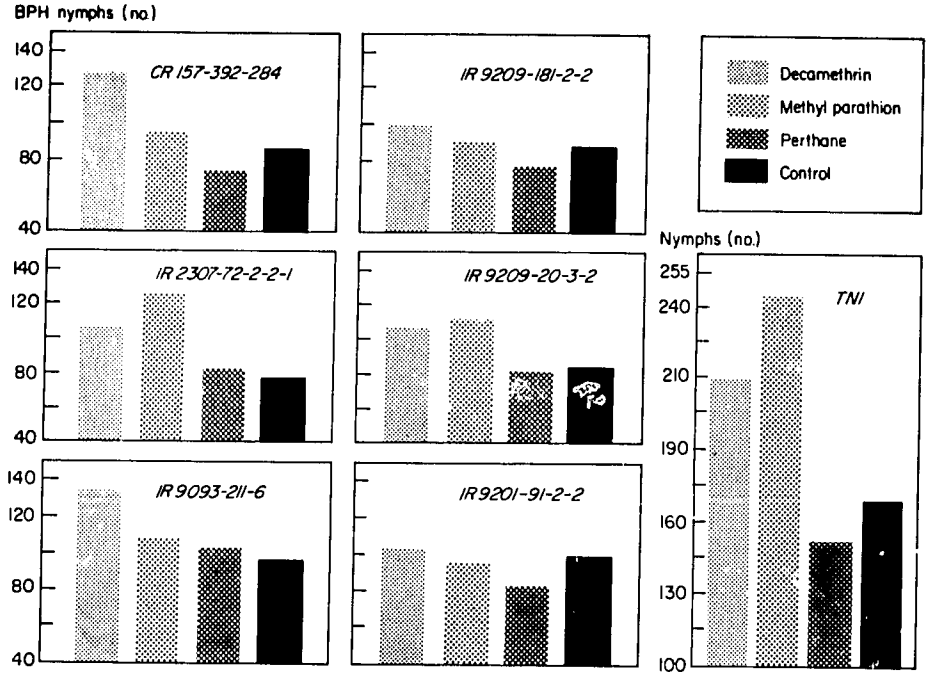
The BPH adults lived longer on plants sprayed with decamethrin and methyl parathion. An increase in adult longevity could contribute to an increase in the total number of eggs and, thus, to resurgence.

Effect on BPH resurgence of the interaction between rice varieties and insecticides. Decamethrin and methyl parathion consistently induced increased reproduction of BPH on susceptible TN1, but did not exert the same influence on resistant rice varieties (Fig. 11). An experiment with moderately resistant varieties indicated that decamethrin and methyl parathion increased BPH populations on some varieties (Fig. 12).

In an experiment with resistant and moderately resistant lines considered together for their interaction with insecticides to cause resurgence, the influence of decamethrin and methyl parathion was significant (Table 20). This indicates the possibility of an acceleration of biotype selection on resistant varieties because of the increased population



11. Nymphs produced by 2 gravid brown planthopper (BPH) biotype 1 females allowed to oviposit for 7 days on a plant of a susceptible variety (TN1) and 3 resistant varieties. Insecticides were foliar sprayed on plants aged 20, 30, and 40 days. Females were placed on the plants 15 days after the last spraying. IRRI greenhouse, 1979.



12. Nymphs produced by 2 gravid brown planthopper (BPH) biotype 1 females allowed to oviposit for 7 days on a plant of a susceptible variety (TN1) and 6 moderately resistant breeding lines. Insecticides were foliar sprayed on plants aged 20, 30, and 40 days. Females were placed on plants 15 days after the last spraying. IRRI greenhouse, 1979.

when an insecticide is used.

Number of insecticide sprays and BPH resurgence. In previous greenhouse resurgence studies, plants were sprayed 3 times at 10-day intervals. One, two, and three applications of methyl parathion and decamethrin were compared to determine whether the number of insecticide applications was related to degree of BPH resurgence. With methyl parathion, the level of resurgence as indicated by reproductive stimulation was significantly higher with two or three sprays than with one (Fig. 13).

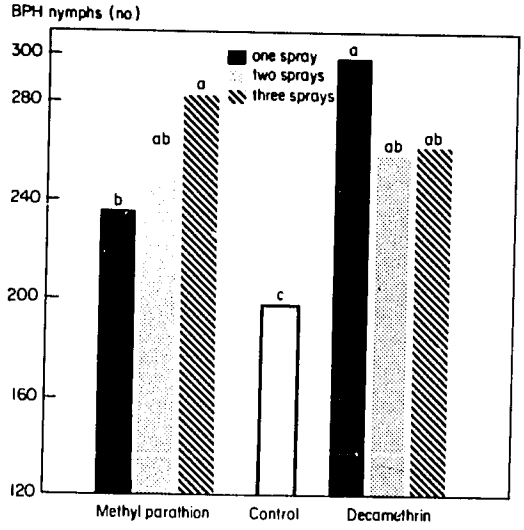
Table 20. Effect on brown planthopper resurgence of the interaction between rice varieties and insecticides. IRRI greenhouse, 1979.

	Resistance rating[a] (greenhouse)	Nymphs[b] (no.)
Varieties		
IR9093-211-6	MR	110.6 a
IR2307-72-2-2-1	MR	98.5 ab
CR157-392-284	MR	95.9 ab
IR9209-20-3-2	MR	95.0 ab
IR9201-91-2-2	MR	90.9 b
IR9209-181-2-2	MR	89.2 b
IR26	R	84.7 b
Mudgo	R	53.7 c
ASD7	R	52.3 c
Insecticides[c]		
Decamethrin		97.3 a
Methyl parathion		93.3 a
Perthane		73.7 b
Control		78.3 b

[a]R = resistant, MR = moderately resistant. Based on the greenhouse screening of 7-day-old seedlings. [b]Resulting from eggs laid in 7 days by 2 females placed on plants 15 days after last spraying. Means followed by a common letter are not significantly different from each other at the 5% level. [c]Insecticides were foliar sprayed on plants aged 20, 30, and 40 days.

Insecticides used in a spray sequence and BPH resurgence. An experiment designed to determine the effect on BPH resurgence of the insecticide sprayed last in a sequence showed the decisive role of that insecticide in inducing or preventing BPH resurgence (Fig. 14). When Perthane was used as the last spray, irrespective of the insecticides used in the previous sprayings, the reproductive rate of the hopper did not increase.

Influence on reproductive rate of exposure duration of BPH nymphal and adult stages to insecticide-sprayed rice plants. The reproductive rate of BPH was significantly higher when the hoppers were confined at their late nymphal (fourth- and fifth-instar to adult) and adult stages



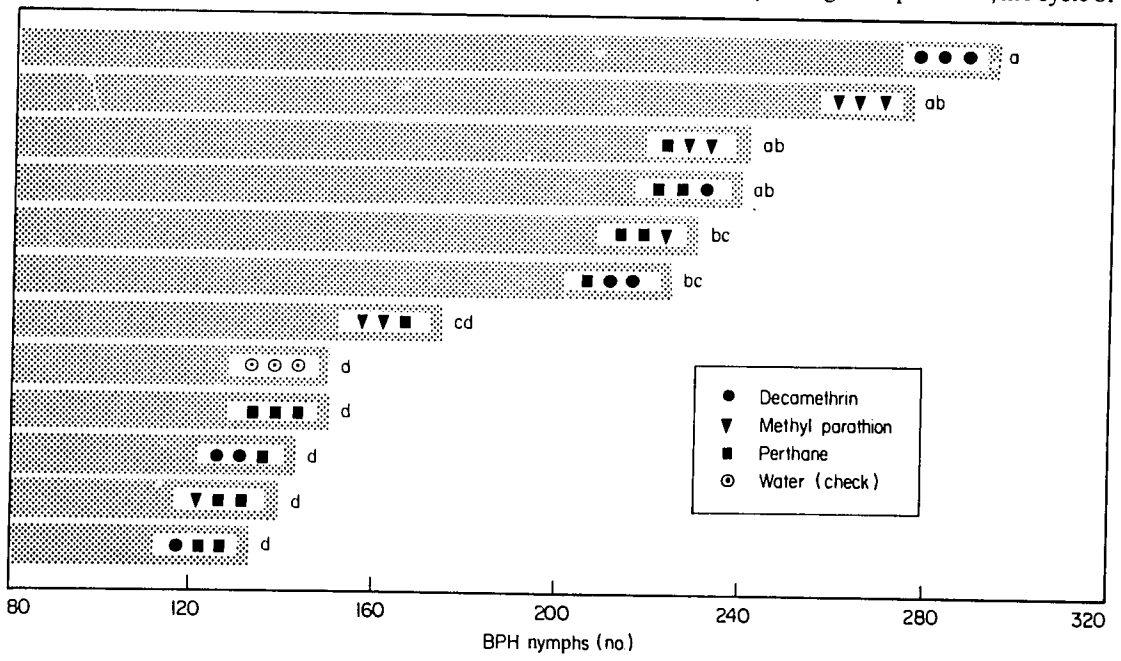
13. Number of insecticide sprays and brown planthopper (BPH) resurgence as indicated by reproductive stimulation of the insect, measured by nymphs that hatched from eggs from 2 gravid females allowed to oviposit on plants for 7 days beginning 15 days after the last spraying. IRRI greenhouse, 1979.

on plants sprayed with insecticides, rather than at the first-instar to adult or the second-instar to adult stages (Table 21). The interaction between insecticides and stages of exposure had a significant effect on BPH reproduction.

Insecticide-induced whitebacked planthopper resurgence. In previous greenhouse studies insecticides were shown to stimulate reproduction on WBPH. In a 1979 field study, where decamethrin at 10 g a.i./ha was applied 4 times to IR20 at 15-day intervals, a WBPH resurgence ratio — the number of WBPH in treated plots divided by the number of WBPH in control plots — of 137 occurred. Although the total number of BPH in both treated and control plots was higher than that of WBPH, the resurgence ratio of the BPH was only 100. This indicates a pest control problem with WBPH in fields treated with certain insecticides for various insect pests.

TIMING OF INSECTICIDE APPLICATION FOR BPH CONTROL

In the 1978—79 dry season, various times of insecticide application for BPH control were tested. Decamethrin was applied 5 times at 14-day intervals to all treatments to cause a buildup of the BPH. Perthane was sprayed for BPH control at various times based on peak light-trap catches, life cycle of

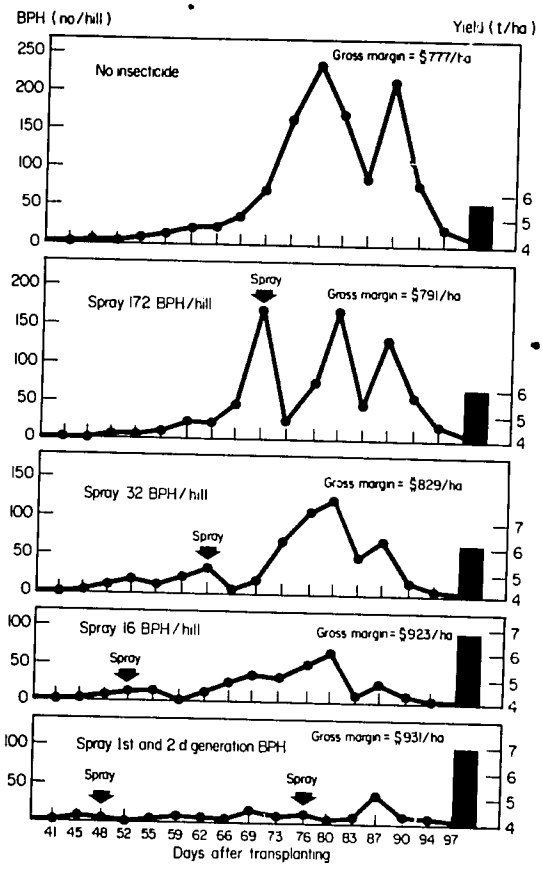


14. Reproductive rate of the brown planthopper (BPH) as influenced by insecticides used in a spray sequence. Nymphs hatched from eggs laid in 7 days by 2 gravid females. Insects were released 10 days after the last spraying. IRRI greenhouse, 1979. Sequences followed by a common letter are not significantly different from each other at the 5% level.

Table 21. Reproductive rate of brown planthopper as influenced by exposure of different nymphal stages and adult to insecticide-sprayed rice plants. IRRI, 1979.

Stages of exposure	Reproductive rate[a] (no. of nymphs hatched)				
	Methyl parathion	Decamethrin	Diazinon	Perthane	Control
First instar to adult	336.7 c	363.3 d	291.7 a	140.3 b	225.3 a
Second instar to adult	375.3 c	386.0 cd	297.0 a	169.0 ab	225.0 a
Third instar to adult	422.3 b	407.3 bc	309.7 a	178.3 ab	262.0 a
Fourth instar to adult	438.0 ab	448.3 ab	334.3 a	192.7 a	247.7 a
Fifth instar and adult	450.3 ab	461.7 a	316.7 a	188.3 a	236.3 a
Adult	472.7 a	484.3 a	315.3 a	188.7 a	252.7 a

[a]In a column, means followed by a common letter are not significantly different at 5% level. Insecticides were foliar sprayed on plants aged 20, 30, and 40 days. Insects were placed on plants at 10 days after last spraying.



15. Timing of insecticide application for brown planthopper (BPH) *Nilaparvata lugens* control. IR22 was transplanted 26 Dec 1978. All plots received 5 applications of decamethrin (a) resurgence-inducing insecticide) at 10 g a.i./ha to increase BPH populations. Perthane for BPH control was sprayed at 0.75 kg a.i./ha at days after transplanting indicated by the arrows. Victoria, Laguna, Philippines, 1979.

the insect, economic injury level, and on a calendar schedule (Table 22).

The BPH generally migrate to the crop at 20—40 DT and are caught in light traps. Insecticide applications were timed to coincide with the first or second BPH generation determined from field observations and light-trap catches. Times of application and BPH populations are shown in Figure 15.

Yields and gross margin of profit were highest in plots treated when the BPH were in the first and second generation, or when the population first reached 10 or 16/hill. One application at 16 BPH/hill provided yields equal to those with 4 calendar-based sprays (Table 23). This study confirmed an earlier cage study where the economic injury level of the BPH was found to be about 20 insects/hill. Yield losses at 16 BPH/hill were 0.18 t/ha, and losses at 32 BPH/hill were 0.86 t/ha. A loss of 0.86 t/ha would be about 4 times the cost of 1 insecticide application to control the BPH.

LIGHT TRAP CATCHES FOR TIMING OF STEM BORER CONTROL

In 1979 yellow stem borer moths were monitored in light traps to determine their utility in timing insecticide applications for stem borer control. Kerosene-fueled light traps were installed at 3 sites within 2—6 km of each other. Trap catches within a field were not related to time after transplanting the field but rather to a calendar date (Fig. 16). Although the three sites were transplanted at different dates, peak catches of the yellow stem borer *Tryporyza incertulas* occurred 22—24 February at all sites. Egg-mass counts in the field were attempt-

Table 22. Brown planthopper (BPH) populations on IR22 as influenced by timing of Perthane application at 0.75 kg a.i./ha. Victoria, Laguna, Philippines, 1978–79 dry season.

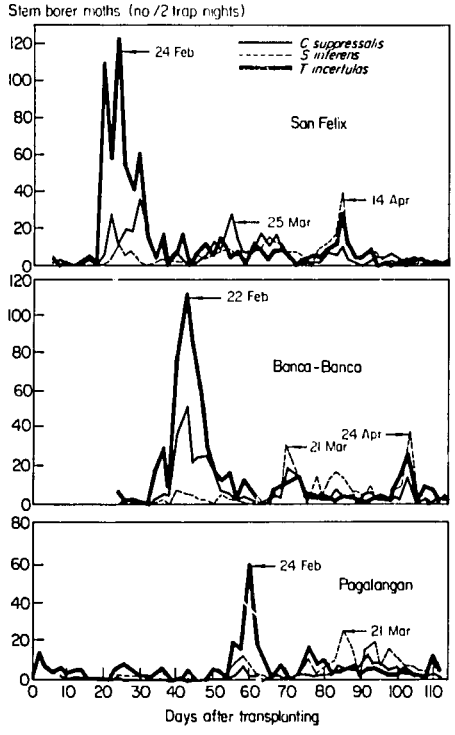
Application time	Brown planthoppers[a] (no./20 hills)								
	41 DT	48 DT	55 DT	62 DT	69 DT	76 DT	83 DT	90 DT	98 DT
Based on light-trap catches									
Spray 15 days after peak BPH catch in light trap	4 ab	8 a	9 abc	15 bcd	10 bcd	10 bc	44 abc	107 ab	24 a
Based on BPH life cycle									
Spray on appearance of 1st generation BPH	2 ab	7 abc	5 bcd	10 cd	11 bcd	15 bc	47 ab	56 bcd	13 b
Spray on appearance of 2d generation BPH	2 ab	7 abc	13 ab	24 abcd	46 abc	132 abc	15 cd	15 ef	1 f
Spray on appearance of 1st and 2d generation BPH	4 a	7 abc	7 abc	9 d	14 bcd	15 bc	11 d	11 f	3 defg
Based on BPH nymphal population									
Spray when BPH average 10/hill	3 a	10 ab	4 bcd	11 bcd	9 cd	4 c	11 d	43 bcd	10 bc
Spray when BPH average 16/hill	2 ab	9 ab	16 a	16 bcd	38 abcd	52 abc	11 d	12 f	2 fg
Spray when BPH average 32/hill	2 ab	12 a	14 a	32 a	22 abcd	114 abc	55 ab	13 cdef	5 cdef
Spray when BPH average 172/hill	2 ab	8 ab	10 abc	26 ab	173 a	79 abc	48 abc	60 abc	5 cdef
Calendar based									
Spray twice at 20-day intervals starting 21 DT	1 ab	4 bcd	4 bcd	12 bcd	13 bcd	20 abc	59 ab	45 bcdef	6 cde
Spray 3 times at 20-day intervals starting 21 DT	1 b	2 d	2 d	14 bcd	2 d	20 abc	14 d	20 def	3 efg
Spray 4 times at 20-day intervals starting 21 DT	1 ab	3 cd	4 cd	15 bcd	4 d	39 abc	46 bcd	15 f	1 g
Control	2 ab	5 bcd	12 ab	21 abcd	73 ab	235 ab	88 a	80 ab	9 bcd

[a] In a column, means followed by a common letter are not significantly different from each other at the 5% level. DT = days after transplanting.

Table 23. Economics of chemical control of the brown planthopper (BPH) on IR22 as affected by timing of insecticide application. Victoria, Laguna, Philippines, 1978–79 dry season.

Application time[a]	Grain yield (t/ha)[b]	Insecticide + labor ($)	Gross margin[c] ($)	Benefit: cost for insecticide[d]
Based on light trap catch				
Spray 15 days after peak BPH catch in light trap	6.01 cd	16	807	2.9
Based on BPH life cycle				
Spray on the appearance of 1st generation BPH	6.32 abcd	16	850	5.6
Spray on the appearance of 2d generation BPH	6.60 abc	16	888	8.0
Spray on the appearance of 1st and 2d generation BPH	7.03 a	32	931	5.8
Based on BPH nymphal population				
Spray when BPH average 10/hill	6.92 ab	16	932	10.7
Spray when BPH average 16/hill	6.85 ab	16	923	10.1
Spray when BPH average 32/hill	6.17 bcd	16	829	4.3
Spray when BPH average 172/hill	5.89 d	16	791	1.9
Calendar-based				
Spray twice at 20-day intervals starting 21 DT	6.02 cd	32	793	1.5
Spray 3 times at 20-day intervals starting 21 DT	6.75 abc	48	877	3.1
Spray 4 times at 20-day intervals starting 21 DT	6.77 ab	64	864	2.4
Control	5.67 d	0	777	–

[a]All treatments were sprayed 5 times at 14-day intervals with decamethrin at 10 g a.i./ha in 300 liters water to induce BPH buildup. Replicated 4 times. First and second generation nymphs were sprayed 48 and 76 days after transplanting (DT). Treatment based on light-trap catch was sprayed 48 DT. All treatments at indicated schedules were sprayed with Perthane at 750 g a.i./ha in 300 liters water. [b]Means followed by a common letter are not significantly different from each other at 5% level. [c]Value of crop/ha less cost of insecticide applications. [d]Value of grain yield in treatment less value of grain yield in control, divided by cost of insecticide applications.



16. Stem borer catches in kerosene light traps in 3 barrios of Victoria, Laguna, Philippines, 1979. The barrios are about 5 km away from each other.

ed after peak light trap catches of the moths to determine the need for insecticide application. Such counting proved difficult. Despite the few egg masses counted, many deadhearts were later visible.

NEEM SEED OIL FOR LEAF FOLDER CONTROL

The effects of oil from the neem tree *Azadirachta indica* A. Juss on orientation, feeding, oviposition, hatching, and parasitization of the leaf folder *Cnaphalocrocis medinalis* were studied.

Orientation. To test repellency, first-instar larvae were allowed a choice between leaf-cuts from the treated and the control plants. Significantly lower percentages of larvae were recorded on leaf-cuts from plants sprayed with 12% or higher concentration of neem oil than on leaves from the conrol plants (Table 24).

Feeding. To evaluate neem oil's antifeedant effect, 10 first-instar larvae were enclosed in vials, each with a leaf-cut from the treated or control plants. The higher the concentration of neem oil, the greater was the reduction in feeding and excretion. Excretion was almost the same for larvae fed

Table 24. Orientation of first-instar rice leaf folder larvae allowed a choice between rice leaves (TN1) sprayed with neem oil and leaves sprayed with liquid detergent solution.[a] IRRI laboratory, 1979.[b]

Treatment	3 passes of ULV[c] spray		Paired t-test	6 passes of ULV spray		Paired t-test
	Larvae (%) recorded on leaves[d]		Absolute mean difference	Larvae (%) recorded on leaves[d]		Absolute mean difference
	Treated	Control		Treated	Control	
Water	43.3 a	56.7	13.34*	78.6 a	21.4	57.2**
3% neem oil	41.3 a	58.7	17.36	43.0 b	57.0	14.0
6% neem oil	39.3 a	60.7	20.99	28.5 b	71.5	43.0
12% neem oil	31.3 ab	68.7	37.34*	23.7 b	76.3	52.6**
25% neem oil	21.4 b	78.6	57.30**	21.6 b	78.4	58.2**
50% neem oil	22.0 b	78.0	56.00**	21.4 b	79.1	57.2**

[a]Neem oil was emulsified in 1.66% liquid detergent solution and sprayed on TN1 rice plants 3 h before the experiment. The control was sprayed with 1.66% liquid solution. [b]In a column, means followed by a common letter are not significantly different from each other at the 5% level; the percentage data for each treatment, excluding control, were used for analysis of variance to get the significant differences across the 6 treatments. To show differences between treated and control for each experiment, a paired t-test was used. Av of 10 replications, 15 larvae/replication, conducted at 26–28°C, 75–80% relative humidity, and 12 h photoperiod. [c]Ultralow-volume. [d]Newly emerged larvae were released in the middle of a moist filter paper-lined 9 cm-diameter petri dish, which had 6 equidistant, alternating, radially-arranged, 3-cm-long leaf-cuts from treated and control plants. Larvae on leaf-cuts were counted after 24 h.

on leaves from the control and from the 25% neem oil-treated potted plants that had been exposed to sunlight for 2—4 days (Table 25), an indication that sunlight rapidly degraded neem oil's antifeedant property.

Oviposition and hatching. When given a choice for oviposition, leaf folder moths laid one-third less eggs on neem oil-treated plants than on the control plants, indicating neem oil's oviposition-deterrent effect. The hatchability of eggs laid on treated plants also decreased significantly as the oil concentration increased. To confirm these results, 0- to 10-hour-old leaf folder eggs on rice leaves were dipped once separately in emulsions of 12, 25, and 50% neem oil, and 50% maize oil. Hatchability of eggs in all neem oil emulsions was inhibited but that in maize oil was unaffected (Table 26).

Table 25. Degradation of neem oil's antifeedant property by sunlight, based on dry weight of excreta of rice leaf folder larvae on rice plants sprayed with neem oil. IRRI, 1979.

Neem oil concentration (%)	Excreta (mg/10 larvae per 24 h) on leaves from sprayed plants exposed to sunlight for[a]		
	0 day	2 days	4 days
0[b]	0.238	0.163	0.180
25	0.075	0.171	0.173
Av	0.156	0.167	0.176
Difference	−0.163**	0.008	−0.007

[a]Differences in feeding activity on neem oil-treated and untreated plants exposed to sunlight were compared using paired t-test, av of 20 replications, 10 newly emerged 1st-instars/replication. For each treatment, larvae were enclosed in 1.5 x 10-cm vials, each with a 5-cm-long leaf-cut from a TN1 rice plant that had been sprayed with 3 passes of emulsified neem oil (in 1.66% liquid detergent solution) with an ultralow-volume applicator. Sprayed plants were exposed continuously to outdoor sunlight for indicated days. Wt of excreta oven-dried for 24 h. [b]Sprayed with 1.66% liquid detergent solution, 3 passes with an ultralow-volume applicator.

INDIGENOUS PLANT EXTRACTS FOR CONTROL OF RICE INSECTS

A systematic search for commonly occurring pest-resistant plant taxa, and the extraction, isolation, and identification of the chemicals involved in plant defenses were initiated with a view to their possible use to control plant pests in the field. An extract of a plant indigenous to much of Asia was tested in the laboratory against the BPH and other insects and pathogens.

Brown planthopper, whitebacked planthopper, and green leafhopper. Topical application of the extract at even the low dose 5 μg/insect caused a significantly higher mortality than in the control

Table 26. Effect of topical application of neem oil on hatching of rice leaf folder eggs. IRRI laboratory, 1979.

Treatment[a]	Eggs hatched[b] (%)
0% (control)[c]	83.6 a
12% neem oil	13.2 b
25% neem oil	10.9 b
50% neem oil	5.8 b
50% maize oil	67.6 a

[a]Leaves of CR94-13 rice variety with 0- to 10-h-old eggs were dipped once in emulsified neem or maize oil and kept in moist filter paper-lined petri dishes at 29–30°C and 70% relative humidity, for a 12-hour photoperiod. Hatched eggs were counted after 4-day incubation. [b]Means followed by a common letter are not significantly different from each other at the 5% level. [c]1.66% liquid detergent solution.

Table 27. Effect of topical application of a plant extract on planthopper and leafhopper pests of rice. IRRI insectary, 1979.[a]

Dose (μg/insect)	Mortality (%) at 24 h after treatment[b]		
	Brown planthopper[c]	Whitebacked planthopper[d]	Green leafhopper[d]
0.0 (control)[e]	6 a	10 a	4 a
0.1	30 b	30 b	2 a
1.0	38 b	26 b	4 a
5.0	66 bc	68 c	12 b
10.0	94 d	94 d	32 c
20.0	98 d	96 d	46 cd
50.0	100 d	100 d	52 d

[a]In a column, means followed by a common letter are not significantly different from each other at the 5% level. Av of 5 replications, 10 insects/application. [b]Treated hoppers were caged on TN1 rice seedlings. [c]Newly emerged brachypterous females. [d]Newly emerged adults. [e]Treated with acetone.

Table 28. Relative mortality of first-instar nymphs of brown planthopper, whitebacked planthopper, and green leafhopper caged on Taichung Native 1 rice seedlings sprayed with a plant extract. IRRI insectary, 1979.[a]

Quantity of extract sprayed (mg/10 seedlings per pot)	Mortality (%) at 24 h after caging[b]		
	Brown planthopper	Whitebacked planthopper	Green leafhopper
0.0 (control)[c]	7 al	0 al	7 al
0.1	30 bl	10 bl	13 bl
1.0	87 cl	90 cl	43 cll
5.0	90 cl	93 cl	100 dl
10.0	100 cl	100 cl	100 dl
20.0	100 cl	93 cl	100 dl

[a]Means followed by a common letter in a column, and by a common Roman numeral in a row, are not significantly different at the 5% level. Av of 3 replications, 10 nymphs/replication. [b]Insectary-reared nymphs were caged on potted seedlings sprayed with the extract. [c]Sprayed with acetone.

Table 29. Effect of vapor of a plant extract on eggs of rice bugs and whorl maggots. IRRI laboratory, 1979.

Concentration (μg/4-cm-diam filter paper disc)	Hatchability[a] (%)	
	Rice bug[b]	Whorl maggot[c]
0.0 (control)[d]	79 a	97 a
0.1	64 ab	50 b
1.0	39 bc	55 b
5.0	33 bc	10 c
10.0	40 bc	13 c
20.0	35 bc	5 c
50.00	28 c	–

[a]In a column, means followed by a common letter are not significantly different from each other at the 5% level. Eggs borne on rice leaves were kept for hatching in 5-cm-diam petri dishes lined with extract-treated, moist filter paper disc. [b]Av of 3 replications, 25 0- to 1-day-old eggs/replication. [c]Av of 4 replications, 10 freshly laid eggs/replication. [d]Acetone only.

(Table 27). Nymphal mortality was high even when the nymphs were not treated directly but caged on plants that had been sprayed with the extract (Table 28).

Rice bug and whorl maggot. Low doses of the extract were ineffective on the rice bug *Leptocorisa* sp., but increasing the extract dose to 50 μg/nymph gave significantly high mortality of third-instar nymphs. The vapor of the extract even at fairly low concentrations significantly reduced the hatching of rice bug eggs (Table 29). Whorl maggot *Hydrellia sasakii* flies and their eggs were highly susceptible to the extract. Flies suffered significant mortalities even at low doses, and egg hatchability was drastically reduced after exposure to the extract vapors.

Leaf folder. The extract had profound effects on the behavior and physiology of the leaf folder *Cnaphalocrocis medinalis*. Significantly lower percentages of first-instar larvae were recorded on the extract-treated leaves than on the control leaf, regardless of extract concentration (0.0001 to 20 μg/leaf piece) (Table 30). Even starved, fifth-instar larvae did not feed well on treated leaves, as indicated by significantly lower quantities of their dried excreta on treated than on control leaves (Table 31).

Treatment of fifth-instar larvae with even low doses (1 μg/larva) of the extract resulted in pronounced aberrations of form and behavior, and enhanced mortality during metamorphosis; the

Table 30. Orientational response of rice leaf folder larvae allowed simultaneous access to Taichung Native 1 rice leaves treated with a plant extract of different concentrations. IRRI laboratory, 1979.

Concentration (μg/2.5-cm-long leaf piece)	Arrivals (%)[a] on leaf pieces
0.0 (control)[b]	40.4 a
0.0001	6.8 cd
0.001	16.2 b
0.01	13.8 bc
0.1	7.1 cd
1.0	4.2 d
5.0	4.5 d
10.0	3.8 d
20.0	3.2 d

[a]Means followed by a common letter are not significantly different from each other at the 5% level. Av of 5 replications, 50 first-instars/replication. Larvae were released in the middle of a 14-cm-diam petri dish which had treated and control leaf pieces arranged radially and equidistantly. [b]Treated with acetone.

Table 31. Quantity of food ingested by rice leaf folder larvae, as reflected by dry weight of their excreta on rice leaves treated with a plant extract.[a] IRRI insectary, 1979.

Concentration (μg/10 5-cm-long leaf pieces)	Dry wt excreta/ 10 larvae per 24 h (mg)[b]
0.0 (control[c]	11.64 a
0.0001	9.18 a
0.001	9.27 a
0.01	8.34 a
0.1	2.88 b
1.0	1.97 bc
5.0	0.94 cd
10.0	0.41 d
20.0	0.22 d

[a]Water-satiated, overnight-starved, 5th-instar larvae were caged on 9-cm-diam petri dishes containing extract-treated TN1 rice leaves. Means followed by a common letter are not significantly different from each other at the 5% level. Av of 5 replications, 10 larvae/replication. [b]Dry wt excreta = (dry wt excreta of 10 fed larvae less dry wt excreta of 10 unfed larvae) in 24 h. [c]Treated with acetone.

severity of abnormalities increased with the dose of the extract.

Oviposition was strongly deterred when gravid leaf folder moths were caged on rice plants sprayed with the extract at fairly low rates. Hatchability was also greatly reduced whether the leaf folder eggs were treated directly or exposed to the vapor of the extract (Table 32, 33). Hatching was prevented either early at the blastoderm stage, at blastokinesis, or because of the failure of the fully formed embryo to break the chorion, depending on the age of the egg and dose of the extract.

Green hairy caterpillar and caseworm. The eggs of the green hairy caterpillar *Rivula atimeta* and the caseworm were highly susceptible to the extract. No eggs hatched when they were exposed to the extract vapor even at very low concentrations. In a control, hatchability was high.

Striped stem borer. Extremely low doses of the plant extract disrupted the normal development of fifth-instar striped stem borer *Chilo suppressalis* larvae. Treating all larvae with the extract at 1 μg/larva resulted in abnormal insects, which died prematurely. Striped stem borer eggs were also highly susceptible to topical treatment with the extract; almost all eggs failed to hatch at relatively low doses, but in the control hatchability was 100%.

Predators. The plant extract was relatively safe to the common predators of rice hoppers. The mirid bug *Cyrtorhinus lividipennis* was somewhat susceptible to higher doses but the spider *Lycosa pseudoannulata* suffered no significant mortality after topical application of 50 μg/spider. The predatory bug *Microvelia atrolineata* was not adversely affected when confined to extract-contaminated water.

INTEGRATED PEST MANAGEMENT

Plant injury by insects. *Brown planthopper.* The economic injury level (EIL) for BPH has been difficult to determine. Earlier work (1972, 1973, 1974 annual reports) set a tentative economic threshold of 1 insect/tiller. Yield losses due to different BPH densities were measured in field cages in 1978. Based on damage done during one BPH generation in the dry season, the EIL at the reproductive phase of plant growth was < 1 tiller. But during the wet season with its lower yield potential, the EIL was < 1/tiller at the tillering phase, and < 4/tiller at the

Table 32. Effect of topical application of a plant extract on eggs of rice leaf folder. IRRI laboratory, 1979.[a]

Dose (μg/batch of eggs)	Hatchability[b] (%)
0.0 (control)[c]	87 a
0.1	81 a
1.0	49 b
5.0	10 c
10.0	0 d
20.0	0 d
50.0	1 d

[a]Means followed by a common letter are not significantly different from each other at the 5% level. Av of 3 replications, 50 freshly laid eggs/replication. [b]Hatched eggs were counted after 5-day incubation. [c]Treated with acetone.

Table 33. Effect of vapor of a plant extract on eggs of rice leaf folder. IRRI laboratory, 1979.[a]

Concentration (μg/4-cm-diam filter paper disc)	Hatchability[b] (%)
0.0 (control)[c]	90 a
0.0001	77 b
0.001	64 b
0.01	34 c
0.1	26 c
1.0	5 d
5.0	3 d
10.0	2 d
20.0	2 d

[a]Means followed by a common letter are not significantly different from each other at the 5% level. Av of 5 replications, 50 freshly laid eggs/replication. [b]Hatched eggs were counted after 5-day incubation. [c]Acetone only.

Table 34. Grain weight of IR20 plants in field cages as affected by brown planthopper (BPH) infestation level (starting with 1st-instar nymphs and ending with adults 1 mo later). IRRI, 1978.

BPH density (no./tiller)	Grain wt (g/4 hills) when infestation was at:		
	Tillering stage	Reproductive stage	Maturation
	Dry season		
4	–	73 c	98 a
1	–	92 b	104 a
0.25	–	105 a	118 a
0 (control)	–	116 a	120 a
	Wet season		
4	16 c	27 b	50 a
1	43 b	60 a	55 a
0.25	60 a	64 a	57 a
0 (control)	66 a	70 a	62 a

reproductive phase. During maturation the yield losses obtained were not significant (Table 34). The results showed that economic thresholds must be related to crop age and season. The threshold should increase with plant age, and be higher in the wet season than in the dry.

During the 1979 dry season a rice crop suffered hopperburn due to the BPH. Just as hopperburn started, a typhoon occurred. During the typhoon and associated period of cloudy weather, hopperburn increased more rapidly than expected. Probably the reduced photosynthesis during cloudy weather prevented the plants from coping with the drain of photosynthates caused by BPH feeding. This relationship between hopperburn and cloudy weather was investigated in a field experiment using black (shaded) and white cloth cages. Plants in black cages suffered more hopperburn than plants in white cages, an indication that weather conditions affect EIL.

Rice leaf folder. In greenhouse cages, at densities ranging from 1 larva/2—6 tillers during the tillering phase of growth, each leaf folder larva damaged 2.5 leaves. Based on earlier studies (1975 and 1976 annual reports) the estimated EIL is between 2 and 6 larvae/hill.

Varietal resistance to the BPH and insecticide susceptibility. It was observed that BPH feeding on a moderately resistant (MR) variety weigh less than those feeding on a susceptible variety. Biotype 2 BPH were reared on IR26 (susceptible) and ASD 7 (MR) and tested for susceptibility to acephate, carbofuran, and Perthane.

Susceptibility to the insecticides was based on LD_{50} values. Because the insects reared on the MR variety were smaller and highly sensitive to the acetone solvent used, larger insects had to be selected. The BPH reared on the MR variety ASD 7 showed greater susceptibility to insecticides. The results indicated a possibility of integrating MR varieties and low rates of insecticides when the BPH population reaches the EIL.

Selective toxicity of insecticides. Insecticides selectively more toxic to the pest than to its natural enemies are needed in an integrated pest management program. In 1979 the LD_{50} values of rice insects and natural enemies topically treated with insecticides were determined (Table 35). From the LD_{50} values obtained, the relative toxicity of the insecticide to the pest and predator was determined (Table 36).

Yield loss studies. *Farmers' fields.* Yields in insecticide-treated and untreated plots of IR22, an insect-susceptible variety, and IR36, an insect-

Table 35. Toxicity of topically applied insecticides, based on LD_{50}[a] values. IRRI laboratory, 1979.

Insecticide	LD_{50} (µg/g)					
	Lycosa	*Cyrtorhinus*	Brown planthopper	Green leafhopper	Whitebacked planthopper	Leaf folder[b]
Carbofuran	0.95	0.59	0.54	0.42	0.32	6.33
MIPC	12.76	2.82	1.52	1.50	1.81	30.44
Methyl parathion	29.25	6.93	6.12	8.28	1.84	5.82
Perthane	[c]	39.53	1.87	12.49	5.27	–
Carbaryl	6.94	0.50	1.45	0.96	1.04	–
Decis	0.07	0.37	1.02	0.04	0.30	–
UC 54229	9.66	9.47	2.34	2.55	2.34	–
FMC 35001	2.90	4.19	2.06	1.03	2.54	–

[a]Mean lethal dosage. [b]Dashes mean no test was conducted. [c]No LD_{50} up to 5,000 ppm.

Table 36. Relative toxicity of insecticides to rice insect pests and natural enemies. IRRI, 1979.

Insecticide	Relative toxicity[a]							
	Lycosa pseudoannulata				*Cyrtorhinus lividipennis*			
	BPH	WBPH	GLH	LF	BPH	WBPH	GLH	LF
Carbofuran	0.6	0.3	0.4	6.7	0.9	0.5	0.7	10.7
Decamethrin	14.6	4.3	0.6	–	2.8	0.8	0.1	–
Carbaryl	0.2	0.2	0.1	–	2.9	2.1	1.9	–
MIPC	0.1	0.1	0.1	2.4	0.5	0.6	0.5	10.8
Perthane	Safe[b]	Safe	Safe	–	0.1	0.1	0.3	–
FMC 35001	0.7	0.9	0.4	–	0.5	0.6	0.3	–
UC 54229	0.2	0.2	0.3	–	0.3	0.3	0.3	–
Methyl parathion	0.2	0.1	0.3	0.2	0.9	0.3	1.2	0.8

[a]LD_{50} of pest (BPH = brown planthopper, WBPH = whitebacked planthopper, GLH = green leafhopper, and LF = leaf folder) ÷ LD_{50} of predator (the spider *Lycosa pseudoannulata* or the mirid bug *Cyrtorhinus lividipennis*). The higher the number, the greater the relative toxicity to the natural enemies. Dashes mean no test was conducted. [b]No LD_{50} up to 5,000 ppm.

resistant variety, were determined in farmers' fields (Table 37). Tungro incidence was high in both seasons. There was no tungro virus in the IR36 plots but leaf folder, an insect to which IR36 is not resistant, severely damaged the unprotected plots.

Effect of whorl maggot damage on yield components. Insecticide-protected and unprotected plots in a screenhouse were infested with whorl maggot flies and the effect of subsequent larval damage on yield components was determined (Table 38). Whorl maggot damage stimulated tiller production but decreased the number of filled grains. There was no difference in grain yields.

In tests of yield loss on TN1, IR36, and IR40 no loss could be attributed to the whorl maggot.

Crop stage at which insect-caused yield losses occur. A preliminary study investigated the crop loss from insects occurring at each growth stage. Yield losses were greatest on the control plots, which received no insecticide (Fig. 17). Loss at the ripening stage and in the integrated pest management (IPM) plot was insignificant.

Insect population and damage were generally low in most treatments, but tungro virus was severe (Table 39).

The results indicated the importance of protecting the vegetative stage against tungro when a susceptible variety is planted. There was a relationship between number of green leafhoppers at 20 DT and percentage of hills infested with tungro virus. A preliminary EIL of 0.5 GLH/sweep in the early vegetative stage (transplanting to 30 DT) is suggested when tungro virus is endemic in an area.

The economics of the various treatments are given in Table 40. Gross profit was high in the maximum protection treatment, but net gain was highest in the IPM plots because of a minimum amount of properly timed insecticide applications. Benefit-cost ratios for insecticide use were highest in the IPM and no-seedbed-protection treatments.

Economics of the integrated pest management approach to rice insects. Two IPM experiments were conducted in farmers' fields. In the first experiment, the IPM method was tested on an insect- and virus-susceptible variety (IR22), a resistant variety (IR36), and a breeding line (IR4570). The

Table 37. Rice yields[a] in fields untreated and treated with insecticides. Victoria, Laguna, Philippines, 1979 wet season.

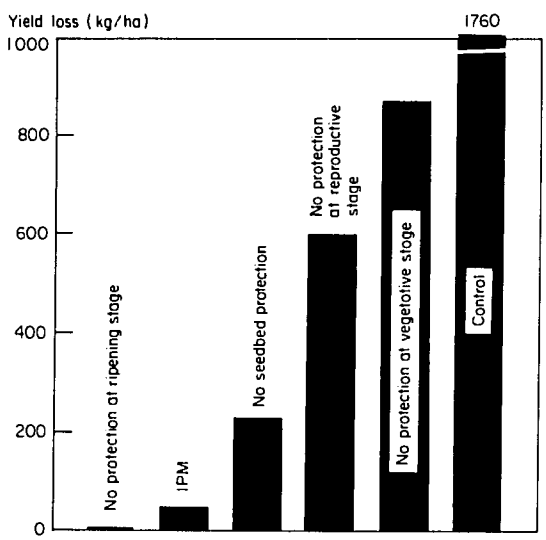
Variety	Yield (kg/ha)		Loss (kg/ha)	Loss (%)
	Maximum protection[b]	No protection		
IR22	4658 a	3676 b	982	21
IR36	4514 a	3158 b	1356	30

[a]All means within a row followed by a common letter are not significantly different from each other at the 5 level. [b]Carbofuran soil-incorporated before transplanting, 2 carbofuran broadcast applications at 25 and 55 days after transplanting (DT), Perthane spray at 65 DT, and carbaryl spray at 80 DT. All applications were at 0.75 kg a.i./ha.

Table 38. Impact of rice whorl maggot damage on the yield components of a moderately resistant (IR40) and a moderately susceptible variety (IR36).[a] IRRI screenhouse, 1979.

Yield components[b]	Protected[c]	Unprotected[d]	Difference
Productive tillers (no./0.25 m^2)			
IR36	50.1	61.8	−11.7*
IR40	52.8	67.7	−14.9*
Filled grains (no./panicle)			
IR36	76.3	60.2	16.1*
IR40	78.7	59.3	19.4**
100-grain wt (g)			
IR36	2.06	1.98	0.08
IR40	1.95	1.94	0.01
Grain wt (g/0.25 m^2)			
IR36	78.5	74.4	4.1
IR40	81.2	78.7	2.5

[a]Av of 3 replications. [b]Based on 4 adjacent hills at 3 sites (12 hills)/replication and computed by using formula for yield components. [c]Carbofuran 3% granules were soil-incorporated at 2.0 kg a.i./ha. [d]Protected 45 days after transplanting with carbofuran 3% granules.



17. Yield losses when insecticides were applied at economic injury levels and when various growth stages of IR22 rice were not protected. IPM = integrated pest management. Yields indicated are yields in maximum protection plots less yields of the following insecticide applications: seedbed: foliar sprays of 0.04% monocrotophos 5 days after seedling emergence and 1 day before transplanting; vegetative stage: spray of 0.75 kg a.i. monocrotophos/ha 5 days after transplanting (DT) and broadcast applications of diazinon granules at 1.0 kg a.i./ha at 10 and 35 DT; reproductive stage: sprays of 0.75 kg a.i. endosulfan/ha 55 and 75 DT; ripening stage: sprays of 0.75 kg a.i. carbaryl/ha 85 and 105 DT; IPM: foliar spray of 0.75 kg a.i. monocrotophos/ha 6 and 16 DT as prophylactic against tungro virus vectors and 1 spray of 0.75 kg a.i. endosulfan/ha when economic injury level for stem borer deadhearts was reached; control: no insecticide. Victoria, Laguna, Philippines, 1979 wet season.

latter two have moderate resistance to stem borers and resistance to tungro virus, GLH, and BPH. IPM was compared to no-insecticide and maximum protection treatments (Table 41).

BPH populations were extremely low in the resistant varieties and never reached the EIL of 20/hill in the susceptible IR22. The stem borer deadheart threshold was reached and endosulfan was applied in the IPM plots. Leaf folder damage was severe in plots receiving no insecticide in IR36 and IR4570, but the endosulfan spray for stem borer controlled it in the IPM plots. Rice bugs greatly surpassed the economic injury level of 2 bugs/m^2, but carbaryl sprays in the IPM plots did not provide control.

Yields in IPM plots were not significantly different from those on the maximum protection plots for all varieties (Table 42). Gross profit was highest in maximum protection treatments, but because of the high cost of such protection, the benefit-cost ratio for insecticide use in IR36 and IR4570 was highest in the IPM treatments. Raising the stem borer deadheart EIL and more effective control of the rice bug should improve the net return of the IPM treatments.

In the second experiment, in the same general area as the first, the IPM approach was compared to maximum protection and the farmers' level of insect protection at two fertilizer rates on resistant varieties IR36, IR40, and IR42. Insect populations and virus incidence were extremely low and yields within each fertilizer rate were similar (Table 43).

Table 39. Insect population, insect damage and grain yield in rice plots receiving insecticide treatment at various growth stages of IR22.[a] Victoria, Laguna, Philippines, 1979 wet season.

Treatment	Whorl maggot damage[b]		GLH[c]/10 sweeps		Stem borer deadhearts ( )	BPH[d]/20 hills	Leaves damaged by leaf folder ( )	Tungro virus (hills infected)	Grain yield (t/ha)
	16 DT	30 DT	20 DT	40 DT	50 DT	65 DT	76 DT	93 DT	
Maximum protection[e]	1 b	2 bc	6 ab	35 cd	2 b	97 c	9 abc	2 c	4.90 a
Maximum protection except in seedbed	1 b	1 c	3 bc	20 d	2 b	83 c	4 bc	4 c	4.67 a
Maximum protection except at vegetative stage	3 a	6 a	9 a	116 ab	9 a	102 bc	5 bc	15 ab	4.02 ab
Maximum protection except at reproductive stage	2 ab	2 bc	3 bc	26 d	3 b	149 ab	32 a	3 c	4.30 a
Maximum protection except at ripening stage	1 b	2 bc	4 bc	35 cd	2 b	87 c	3 c	7 bc	4.97 a
Integrated pest management[f]	1 b	3 b	2 c	68 bc	7 a	56 d	2 c	0 c	4.85 a
Control	3 a	6 a	11 a	137 a	8 a	170 a	19 ab	36 a	3.14 b

[a]In a column, means followed by a common letter are not significantly different from each other at the 5% level. DT = days after transplanting. [b]1 = 1–2 leaves/hill damaged, 9 = > 50 of leaves damaged with some leaf breaking. [c]Green leafhopper *Nephotettix virescens*. [d]Brown planthopper *Nilaparvata lugens*. [e]Maximum protection consisted of the following insecticide applications – seedbed: foliar sprays of 0.04 monocrotophos 5 days after seedling emergence and 1 day before transplanting, vegetative stage: spray of 0.75 kg a.i. monocrotophos/ha 5 DT and broadcast applications of 1.0 kg a.i. diazinon granules/ha 10 and 35 DT; reproductive stage: sprays of 0.75 kg a.i. endosulfan/ha 55 and 75 DT; ripening stage: sprays of 0.75 kg a.i. carbaryl/ha 85 and 105 DT. [f]Foliar spray of 0.75 kg a.i. monocrotophos/ha 6 and 16 DT as a prophylactic for control of tungro virus vectors and 1 spray of 0.75 kg a.i. endosulfan/ha 53 DT when economic injury level for stem borer deadhearts was reached.

Table 40. Comparison of the economics ($) of rice insect pest control when insecticides are applied on a calendar-based schedule at various growth stages or when economic injury levels are reached. Victoria, Laguna, Philippines, 1979 wet season.

Treatment	Insecticide applications (no.)	Cost ($) of insecticide application		Gross profit ($)	Net gain[b] ($)	Gain ($) from insecticide[c]	Benefit-cost ratio[d]
		Labor[a]	Insecticide				
Maximum protection[e]	9	14	126	671	531	101	0.7
Maximum protection except in seedbed	7	10	109	681	562	132	1.1
Maximum protection except at vegetative stage	7	10	95	589	484	54	0.5
Maximum protection except at reproductive stage	6	10	50	551	491	61	1.0
Maximum protection except at ripening stage	7	13	123	640	504	74	0.5
Integrated pest management	3	7	79	664	578	148	1.7
Control	0	0	0	430	430	–	–

[a]$0.27/hour. Cost to spray 1 ha = $2.20; cost to broadcast granules = $1.10. [b]Gross profit less cost of insecticide application. [c]Net gain of treatment less net gain of control. [d]Gain from insecticide ÷ cost of insecticide application. [e]Maximum protection consisted of the following insecticide applications – seedbed: foliar sprays of 0.04% monocrotophos 5 days after seedling emergence and 1 day before transplanting; vegetative stage: spray of 0.75 kg a.i. monocrotophos/ha 5 days after transplanting (DT) and broadcast applications of 1.0 kg a.i. diazinon granules/ha at 10 and 35 DT; reproductive stage: sprays of 0.75 kg a.i. endosulfan/ha 55 and 75 DT; ripening stage: sprays of 0.75 kg a.i. carbaryl/ha at 85 and 105 DT. Foliar sprays of 0.75 kg a.i. monocrotophos/ha at 6 and 16 DT as prophylactic for control of tungro virus vectors and 1 spray of 0.75 kg a.i. endosulfan/ha at 53 DT when stem borer deadhearts economic injury level was reached.

Table 41. Insect populations and damage in an insect-susceptible variety (IR22), a resistant variety (IR36), and a breeding line (IR4570).[a] Masapang, Laguna, Philippines, 1979 wet season.

Level of insect protection	Whorl maggot damage[b] 16 DT	GLH[c] (no./10 sweeps) 23 DT	Deadhearts[d] ( ) 49 DT	BPH[e] (no./20 hills) 51 DT	65 DT	79 DT	Leaf folder[f] damaged leaves ( ) 68 DT	Tungro virus infected hills (%) 72 DT	Rice bugs/ 2 m² 43 DT	Whiteheads ( ) 93 DT	Gross yield (t/ha)
IR22											
No insecticide	4 a	5 a	4 a	86 a	142 a	13 a	10 a	23 a	15 a	0.1 a	3.676 a
Integrated pest management[g]	1 b	5 a	6 a	80 a	83 ab	13 a	3 ab	4 b	13 a	0.2 a	4.106 ab
Maximum protection[h]	1 b	2 a	0 b	36 a	42 b	0 b	0 b	0 b	15 a	0.4 a	4.658 b
IR36											
No insecticide	4 a	4 a	2 a	15 a	6 a	2 a	50 a	0 a	21 a	1.0 a	3.158 a
Integrated pest management[g]	1 b	5 a	1 ab	7 a	1 b	1 a	5 b	0 a	16 a	0.6 a	4.147 b
Maximum protection[h]	1 b	3 a	0 b	0 b	0 b	0 b	4 b	0 a	15 a	0.7 a	4.514 b
IR4570											
No insecticide	3 a	5 a	4 a	6 a	2 a	2 a	26 a	0 a	43 a	1.3 b	4.217 a
Integrated pest management[i]	1 a	7 a	5 a	5 a	1 ab	2 a	3 b	0 a	23 a	0.6 b	4.726 a
Maximum protection[h]	1 a	4 a	0 b	1 a	0 b	1 a	2 b	0 a	28 a	4.4 a	4.857 a

[a]Means within a column for each variety are not significantly different from each other at the 5% level. DT = days after transplanting. [b]1 = 1–2 leaves damaged/hill, 9 = > 50% leaves damaged/hill with leaf breaking. [c]Green leafhopper *Nephotettix virescens*. [d]Caused primarily by yellow stem borer *Tryporyza incertulas*. [e]Brown planthopper *Nilaparvata lugens*. [f]*Cnaphalocrocis medinalis*. [g]Diazinon granules at 1.0 kg a.i./ha broadcast at 5 DT as prophylactic for whorl maggot and stem borer control; endosulfan 0.75 kg a.i./ha spray at 55 DT when stem borer deadhearts economic injury level was reached and 2 sprays of carbaryl 0.75 kg a.i./ha at 77 and 82 DT when rice bug economic injury level was reached. [h]Carbofuran granules at 0.75 kg a.i./ha soil-incorporated before transplanting; carbofuran granules at 0.75 kg a.i./ha broadcast at 25 and 55 DT; Perthane 0.75 kg a.i./ha spray at 65 DT, and carbaryl 0.75 kg a.i./ha spray at 80 DT. [i]Same as [g] above except no carbaryl was applied.

Table 42. Economics of 3 levels of insect control in 3 varieties of irrigated wetland rice. Masapang, Laguna, Philippines, 1979 wet season.[a]

Insect control level	Yield (t/ha)	Gross profit[b] ($)	Cost of labor[c] ($)	Cost of insecticide ($)	Net return[d] ($)	Gain or loss ($) in income from insecticide[e]	Benefit-cost ratio[f] for insecticide
IR22							
No insecticide	3.676 a	504	0	0	504	–	–
IPM[g]	4.106 ab	563	8	53	502	–2	–0.03
Maximum protection[h]	4.658 a	638	7	106	525	21	0.19
IR36							
No insecticide	3.158 b	433	0	0	433	–	–
IPM[g]	4.147 a	568	8	53	507	74	1.21
Maximum protection[h]	4.514 a	618	7	106	505	72	0.64
IR4570							
No insecticide	4.217 a	578	0	0	578	–	–
IPM[i]	4.726 a	647	4	36	607	29	0.73
Maximum protection[h]	4.857 a	665	7	106	552	–26	–0.23

[a]All means in a column for each value are not significantly different from each other at the 5% level. [b]Based on price of rough rice at $137/metric ton. [c]Per hectare costs of $1.00 for 1 broadcast or soil incorporation and foliar spray application at $2.00 each. [d]Value of rice less cost of insecticide application. [e]Net return of integrated pest management (IPM) or maximum protection less net return of no insecticide. [f]Net return ÷ cost of insecticide application. [g]Applications based on economic injury levels. Diazinon 1.0 kg a.i./ha broadcast 5 days after transplanting (DT) as prophylactic for whorl maggot and stem borer control, endosulfan 0.75 kg a.i./ha spray at 55 DT when stem borer deadheart economic injury level was reached, and 2 sprays of carbaryl 0.75 kg a.i./ha 77 and 82 DT when rice bugs economic injury level was reached. [h]Carbofuran 0.75 kg a.i./ha soil-incorporated before transplanting, carbofuran 0.75 kg a.i./ha broadcast at 25 and 55 DT; Perthane 0.75 kg a.i./ha spray at 65 DT and a carbaryl 0.75 kg a.i./ha spray at 80 DT. [i]Same as [g] above except no carbaryl sprays were applied.

Because of the low level of insects and the high cost of insecticide, there was a low net return in the maximum protection plots. Net returns at the farmer and IPM level were about equal.

CULTURAL CONTROL OF RICE INSECT PESTS

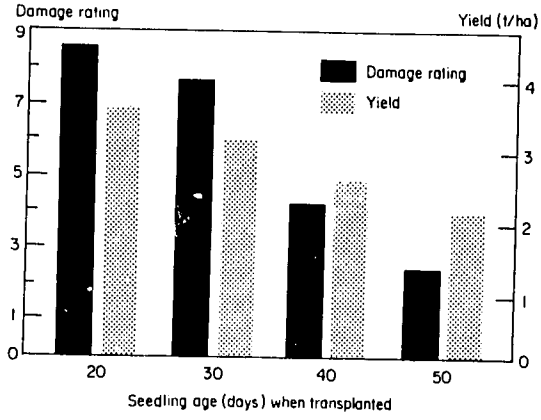
Seedling age and whorl maggot control. Seedlings aged 20, 30, 40, and 50 days were transplanted the same day and whorl maggot damage ratings taken at 25 DT. Damage decreased with increase in seedling age (Fig. 18). Yield also decreased.

Fertilizer management to minimize whorl maggot damage. Three levels of nitrogen were applied in a greenhouse study to determine the rate of recovery of rice plants from whorl maggot damage. Recovery was higher and most rapid in the

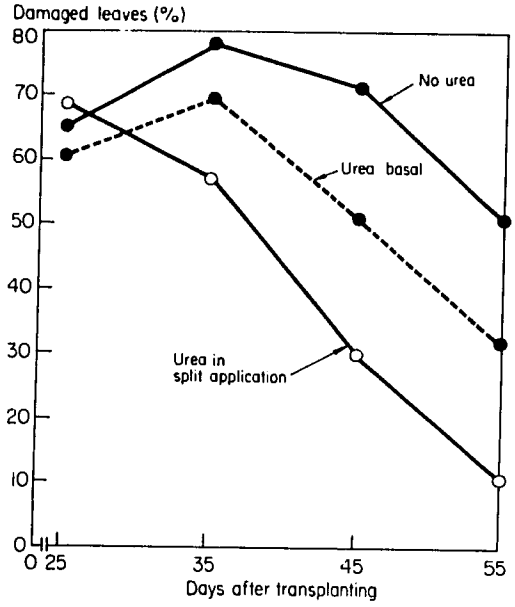
Table 43. Economics of 3 methods of insect control and 2 fertilizer rates on insect-resistant varieties in irrigated wetland. Victoria, Laguna, Philippines, 1979 dry season.

Insect control[a]	Yield (t/ha)	Gross return ($/ha)	Cost of insecticide ($/ha)	Net return ($/ha)
	84-10-0 kg NPK/ha			
IPM	5.25	719	56	663
Farmers'	5.22	715	16	699
Max protection	5.58	765	170	595
	120-30-30 kg NPK/ha			
IPM	5.93	812	56	756
Farmers'	5.42	743	16	727
Max protection	5.74	786	170	616

[a]IPM = integrated pest management.



18. Whorl maggot damage and yield of IR36 as influenced by seedling age at time of transplanting. Seedlings at four ages were planted at the same time. Whorl maggot damage ratings taken at 25 days after transplanting. IRRI, 1979 dry season.



19. Effect of method of nitrogen application on the rate of recovery of variety TN1 from rice whorl maggot damage, based on percentage of damaged leaves. Nitrogen was applied as urea at 120 kg/ha. In the basal application urea was soil incorporated before transplanting. The split treatment was applied 3 times (60, 30, 30 kg N/ha): at planting, and at 25 and 35 days after transplanting. IRRI greenhouse, 1977.

plants receiving a split application of urea (Fig. 19).

Short growth duration for BPH control. Third-generation BPH nymphs, occurring about 75 DT, usually cause hopperburn. The early-maturing breeding line IR10154-89-3-3 harvested at 75 DT was compared to the intermediate-duration variety IR20 (harvested 100 DT) to determine whether the very early-maturing line could escape hopper damage. Decamethrin was sprayed to induce BPH populations in the two treatments. The very early-maturing line was harvested before BPH populations reached the economic injury level of 20/hill, but the BPH population on IR20 sprayed with decamethrin reached 300/hill and 24% of the plants were hopperburned. The study indicates the possibility of avoiding crop damage by BPH by using very early-maturing varieties.

SEX PHEROMONES

Research on sex pheromones was conducted in collaboration with the Tropical Products Institute (TPI), London, UK.

Development of pheromone traps. The sex pheromone of *Chilo suppressalis* was identified in 1975. In 1979 it was found that *Chilo polychrysus* virgin females in water-oil traps attracted males of the species, but not males of *C. suppressalis*. That suggests that the sexes of *C. polychrysus* communicate by a sex pheromone. In 6 trap-nights, *C. polychrysus* females attracted 95 males of their species, and *C. suppressalis* females attracted 133 males of their species. The insects caught were identified by wing venation patterns.

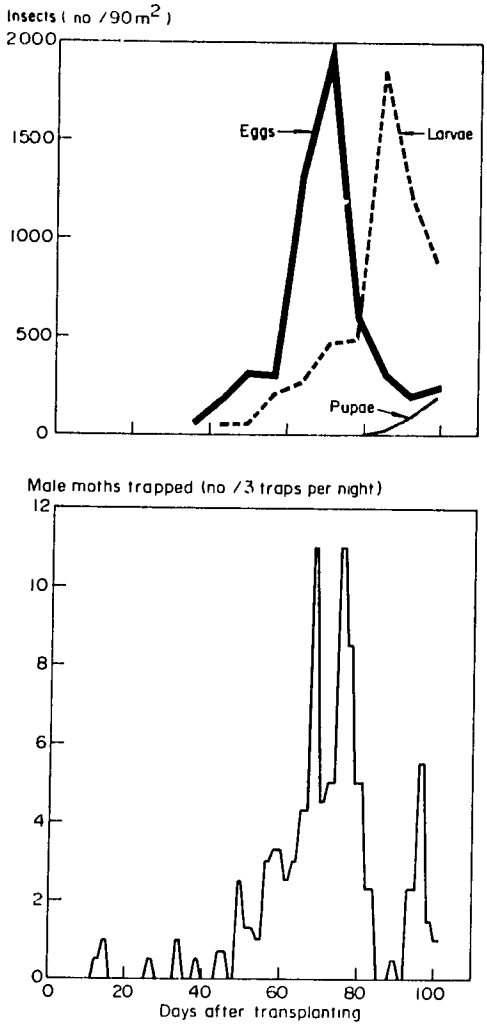
In field-cage trials, virgin female adult caseworms *Nymphula depunctalis* in water-oil traps attracted 8 male moths out of 105 released. Males in traps did not attract released females. Thus, the female of this species probably has a sex pheromone.

The female sex pheromone of *Sitotroga cerealella*, a stored grain pest, has been identified previously by other workers. By chance we discovered that *(Z)*-9-tetradecen-1-ol acetate attracted male moths in a rice storage building, and therefore must be a parapheromone of this species. This chemical, dispensed from polyethylene vials mounted in triangular sticky traps placed in a rice storage facility, attracted most male moths at a dose of 10 μg, a level significantly better than 1 μg or 100 μg.

The female sex pheromone of the rice leaf folder *Cnaphalocrocis medinalis* has been tentatively identified by TPI, in collaboration with the Central Agricultural Research Institute in Sri Lanka, as a two-component mixture. The field attractiveness of the two compounds was tested at IRRI using rubber septa as dispensers in water-oil traps. Male moths were attracted to one of the two compounds.

Attempts were made to improve the design of pheromone traps. In some trials using rubber septum dispensers loaded with 10 μg pheromone, funnel-shaped traps caught as many *C. suppressalis* male moths as water-oil traps. The Pherocon trap also appeared promising.

Monitoring pest behavior with pheromone traps. Observations in two crops at IRRI and one in a farmer's field showed that the number of eggs laid did not correlate directly with the number of male moths of *C. suppressalis* caught in pheromone traps. However, the peak number of moths caught occurred at the same time as the peak egg density on the crop. A peak in larval density developed 2 weeks later (Fig. 20). Thus, pheromone traps could be used to indicate when the maximum number of damaging larvae is present in the crop.



20. Comparison of *Chilo suppressalis* density on rice selection IR127-80-1 and moth catches in sex pheromone traps. IRRI, 1979 wet season.

Mating disruption for pest control. Actual disruption of *Chilo suppressalis* mating by pheromone-mimic compounds *(Z)*-9-tetradecenyl formate (TDF) and *(Z)*-11-hexadecenyl formate (HDF) placed in vials in field cages was demonstrated in 1978 (1978 annual report). Those compounds are more stable than the pheromones. In 1979, a maximum of 4 pairs of *C. suppressalis* moths were placed in 16-m^2 cages every other day. We found that 1 mg of compound per vial (8 vials/m^2), releasing at least 1 g/ha per day, prevented the oviposition of fertile eggs for 4 weeks. Even a dosage as low as 0.1 mg/vial, releasing at least 0.2 g/ha per day, disrupted mating by 75% or more for 4 weeks.

A preliminary experiment to test the disruption caused by the formates, singly and together, showed that HDF alone caused almost as much disruption as TDF + HDF in the ratio 4.5:1, but TDF alone was a relatively poor disruptant.

BIOLOGICAL CONTROL OF INSECTS

Insects parasitic on hoppers. *Parasites of eggs.* Parasites of planthoppers parasitize all ages of host eggs equally (1978 annual report). In 1979 tests, *Gonatocerus* sp. clearly preferred young to old eggs of *Nephotettix virescens* (Table 44) and thus limited its importance as a biological control agent. In an insectary, females of the species each laid 17 eggs in 2 days, 12 on the first day after emergence. Egg parasites go through a life cycle in less than 2 weeks.

A newly discovered parasite of BPH eggs is *Tetrastichus* sp., a wasp of the family Eulophidae. This insect is parasitic only during its early larval period, but later the larva emerges from a BPH egg and preys upon other eggs. Even though *Tetrastichus* sp. was not abundant in IRRI fields, its capacity to kill several pest eggs during a larval period helped suppress pest numbers.

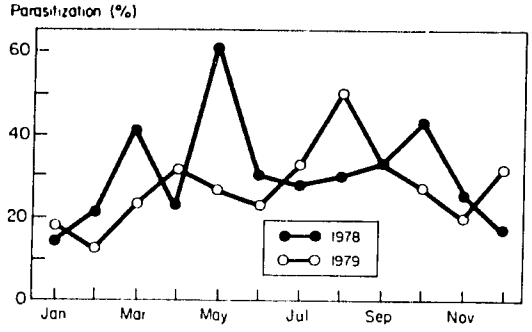
BPH egg parasitization at several sites and crop ages at IRRI in 1978 averaged 31% (1978 annual report). In 1979 the average in wetland rice of constant crop age (about 30 DT) was 28%. Small monthly fluctuations in parasitization in 1978 and 1979 showed that egg parasites were abundant year-round despite variations in season, cropping pattern, and pest abundance (Fig. 21). The substantial mortality of BPH eggs caused by parasites is apparently predictable.

In 1979 the parasite *Anagrus* sp. was dominant

Table 44. Host age preference of the parasite *Gonatocerus* sp. on *Nephotettix virescens* eggs. IRRI laboratory, 1979.

Age (days) of host eggs	Parasitism (%) after 2 days[a]
1–2	67 a
2–3	69 a
3–4	16 b
4–5	14 b
5–6	26 b
6–7	15 b

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



21. Parasitization of brown planthopper eggs by mymarid and trichogrammatid parasites. IRRI wetland rice fields, 1978-79.

over *Oligosita* sp. in both seasons; thus *Anagrus* was the most important BPH egg parasite at IRRI. A simple key for identifying the genera of hopper egg parasites was developed for routine use.

The potential for BPH egg parasitization in a BPH-resistant crop was measured in a farmer's field of IR42 not treated with insecticides. Egg parasitization was at the same level as in BPH-susceptible crops at IRRI, and *Anagrus* was more common than *Oligosita*.

Parasites of nymphs and adults. Simple keys for identifying all the parasite species in the three groups Dryinidae, Pipunculidae, and Strepsiptera were prepared to hasten the sorting of routine collections.

Insect diseases. *Fungal pathogens of hoppers.* A new project on the microbial control of hoppers, especially BPH, with fungal pathogens was initiated in collaboration with the Boyce Thompson Institute for Plant Research, Ithaca, New York, USA.

Table 45. Hatching failure of brown planthopper (BPH) and green leafhopper (GLH) eggs when caged with adults of the predator *Cyrtorhinus lividipennis*. IRRI greenhouse, 1979.

Treatment		Unhatched eggs (%) after 3 days[a]	
Prey eggs	Predator present	BPH	GLH
BPH	√	83 a	
BPH		27 b	
GLH	√		79 a
GLH			38 bc
BPH + GLH[b]	√	90 a	62 ab
BPH + GLH[b]		20 b	23 c

[a]In a column, means followed by a common letter are not significantly different from each other at the 5% level. [b]90% significantly higher than 62%, and 20% insignificantly different from 23%, at the 5% level.

Several pathogens — *Metarhizium anisopliae, Beauveria bassiana, Paecilomyces farinosus,* and *Entomophthora sphaerosperma* — showed pathogenicity to BPH in laboratory bioassays, especially when plants were first sprayed with a spore suspension before the insects were caged on them. *M. anisopliae* was also sprayed onto field plots of rice infested with BPH, but only a maximum of 10% of the BPH became infected at the highest concentration of spores applied.

Microbial control with Bacillus thuringiensis. A commercial formulation of *Bacillus thuringiensis* (BT), Bactospeine (cream 8,500 iu Ak/mg) applied as a foliar spray in the greenhouse killed as many as 30% of caseworm *Nymphula depunctalis* larvae (third and fourth instar) in 1 day. Even at the low dosage of 0.5 g/200 ml water, 100% of the larvae died in 3 days. Damage to plants stopped a few hours after treatment, but death of the pest occurred later. A similar experiment with rice leaf folder *Cnaphalocrocis medinalis* larvae indicated that Bactospeine was slightly more toxic to leaf folders than to caseworms.

Predators of hoppers. *Bugs. Cyrtorhinus lividipennis* is a predator primarily of hopper eggs (1978 annual report). It attacks both BPH and GLH eggs. But when given a choice, it preferred BPH eggs (Table 45).

The small veliid bug *Microvelia atrolineata* is commonly found on the water surface of flooded rice fields. Different water levels did not affect its density as long as the field remained saturated. Because *Microvelia* prefers to kill small hopper nymphs (1978 annual report), its impact on the pest population should be greatest right after eggs hatch. This was confirmed in a preliminary greenhouse cage experiment with BPH where the pest population was reduced by *Microvelia* only immediately after a hatch. *Microvelia* can survive for as long as 27 days without prey, and probably does not feed on dead hoppers floating on the water.

Microvelia is a mobile insect. It not only walks rapidly on water, but is regularly caught in flight (light or sticky) traps. It is common in wetland fields, often averaging more than 150/m^2 from maximum tillering stage of the crop until near crop maturity. The development of an angular trap placed on the soil facilitated field sampling.

Spiders. When the hopper predator *Lycosa*

Table 46. Prey preference by one predatory adult spider *Lycosa pseudoannulata* when offered brown planthopper (BPH), whitebacked planthopper (WBPH), and green leafhopper (GLH) 3d- and 4th-instar nymphs caged on plants. IRRI greenhouse, 1979.

Prey available daily		Daily prey mortality[a] (%)		
Species	No. of each species	BPH	WBPH	GLH
BPH + WBPH	20	21	49**	–
BPH + GLH	20	20	–	36*
WBPH + GLH	20	–	52*	28
BPH + WBPH + GLH	10	22	49*	22

[a]All mortality values are significantly higher than those obtained in the control with no spiders. Within a row the value with asterisks is significantly higher (* = 5% level, ** = 1% level) than the other values. Data based on observations for 8 or 6 days.

pseudoannulata was caged with nymphs of BPH, WBPH, and GLH, it preferred WBPH to BPH and GLH, and possibly GLH to BPH (Table 46). This helped explain why WBPH and GLH in the rice field are less serious pests than BPH.

When *Lycosa* is caged not only with BPH or GLH but also with *Cyrtorhinus lividipennis*, *Lycosa* attacks both pest and beneficial insects, even preferring *Cyrtorhinus* to GLH – 48% mortality vs 26% (Table 47). *Lycosa* killed more *Cyrtorhinus* than GLH (73% vs 29%) or BPH (71% vs 44%), an indication that there is little value in augmenting *Cyrtorhinus* in nature if *Lycosa* is present.

The density fluctuations of spiders in five farmers' fields were observed near IRRI. Before transplanting, the spiders were more abundant on levees than in the field. Possibly because of different levee management practices, the spiders were more abundant on farmers' levees than on IRRI levees. After transplanting, spider density on levees fluctuated in a rather inconsistent manner, but spiders in the field slowly became more abundant. Field density was as high as 100 spiders/m^2, even in a BPH-resistant crop. The most common spider species in farmers' and IRRI fields were *Callitrichia formosana* and *Lycosa pseudoannulata*. Spiderlings were usually more abundant than adult spiders.

Identification of hopper predators. Cage experiments provided preliminary information on the identity and predation capacity of hopper preda-

Table 47. Mortality of 20 brown planthopper (BPH) 3d- and 4th-instar nymphs and 20 green leafhopper (GLH) 5th-instar nymphs and newly emerged adults caged daily on plants with 20 adults of the predatory bug *Cyrtorhinus lividipennis* and 1 adult predatory spider *Lycosa pseudoannulata*. IRRI, 1979.

Treatment				Daily mortality[a] ( )		
BPH	GLH	*Cyrtorhinus*	*Lycosa*	BPH	GLH	*Cyrtorhinus*
				BPH		
√				0 d		
√		√		5 c		1 c
√			√	44 a		
√		√	√	24 b		35 b
		√	√			71 a
				GLH		
	√				0 c	
	√	√			7 b	2 c
	√		√		29 a	
	√	√	√		26 a	48 b
		√	√			73 a

[a]Within a column and for one pest species, means followed by a common letter are not significantly different from each other at the 5% level. Based on observations for 6 days.

tors. The artificial conditions in such experiments, however, prevented realistic estimates of field predation behavior. To overcome that problem, development of a serological technique for predator identification was attempted. Protein (antigen) was extracted from BPH adults and injected into the lymph nodes of rabbits. After a few weeks, antiserum from rabbit blood was tested for antibodies to BPH antigen by a double diffusion technique using an agar plate with wells. The precipitates showed a titer as high as 1:4,900.

After preparing antigen from GLH and WBPH, it was found that the crude BPH antiserum also reacted with the GLH and WBPH antigens. Therefore the antibodies nonspecific to BPH were precipitated out by adding GLH and WBPH antigens to the antiserum, and a BPH specific antiserum was produced.

The identification of prey species from their remains in predator guts was tried using this technique. Extracts from spider and *Cyrtorhinus* predators previously fed BPH showed a positive reaction in the test, indicating that the test could be used for prey identification. Further research is needed to determine if the test can measure the quantity of prey eaten and the frequency of feeding.

Ducks. Ducks can control BPH (1978 annual report). Preliminary trials to measure the size of duck herd needed to control BPH showed that 10 ducks/70 m² in a 4-h day significantly reduced the pest population (Table 48). At this feeding rate, at least 700 or maybe more than 1,000 ducks/ha would be needed to control in 4 days a pest population of 78 BPH/hill.

Predators of other pests. Eggs of the rice leaf folder *Cnaphalocrocis medinalis* on potted plants placed in either wetland or dryland fields at IRRI suffered about 70% mortality in 1 day. This high mortality was probably caused by predacious beetles and spiders.

Cyrtorhinus lividipennis bugs each caused 3 or 4% mortality per day to *Chilo suppressalis* eggs in petri dishes. About 30% of field-collected egg masses appeared to be damaged by this bug. Many first instar *C. suppressalis* larvae were killed by spiders *Lycosa pseudoannulata* and by adult coccinellid beetles *Menochilus sexmaculatus* when placed together in petri dishes.

Food web of the brown planthopper. The natural enemy relationships (food web) for the BPH in the Philippines was determined as a basis from which to learn more about the biological control possibilities for this pest (Fig. 22). Predator-parasite relationships for 76 taxa were determined for 1977–79 from sites in 4 Philippine provinces. Parasites were reared from BPH, and predator records were obtained from field observations or cage studies. Specimens were sent to taxonomists worldwide for species confirmation.

Five egg parasites belonging to Mymaridae and Trichogrammatidae were recorded; species of *Anagrus*, however, were the most common. Only one egg predator — the mirid bug *Cyrtorhinus lividipennis* — was found. *Gonatocerus*, a mymarid egg parasite, recorded elsewhere in Asia from BPH, was host specific to the GLH and was never reared from BPH eggs.

Four species of dryinids, one strepsiptera, one undetermined mite, one nematode, and one eulophid were recorded. The dryinids and the eulophid are both parasitic and predatory in their habits.

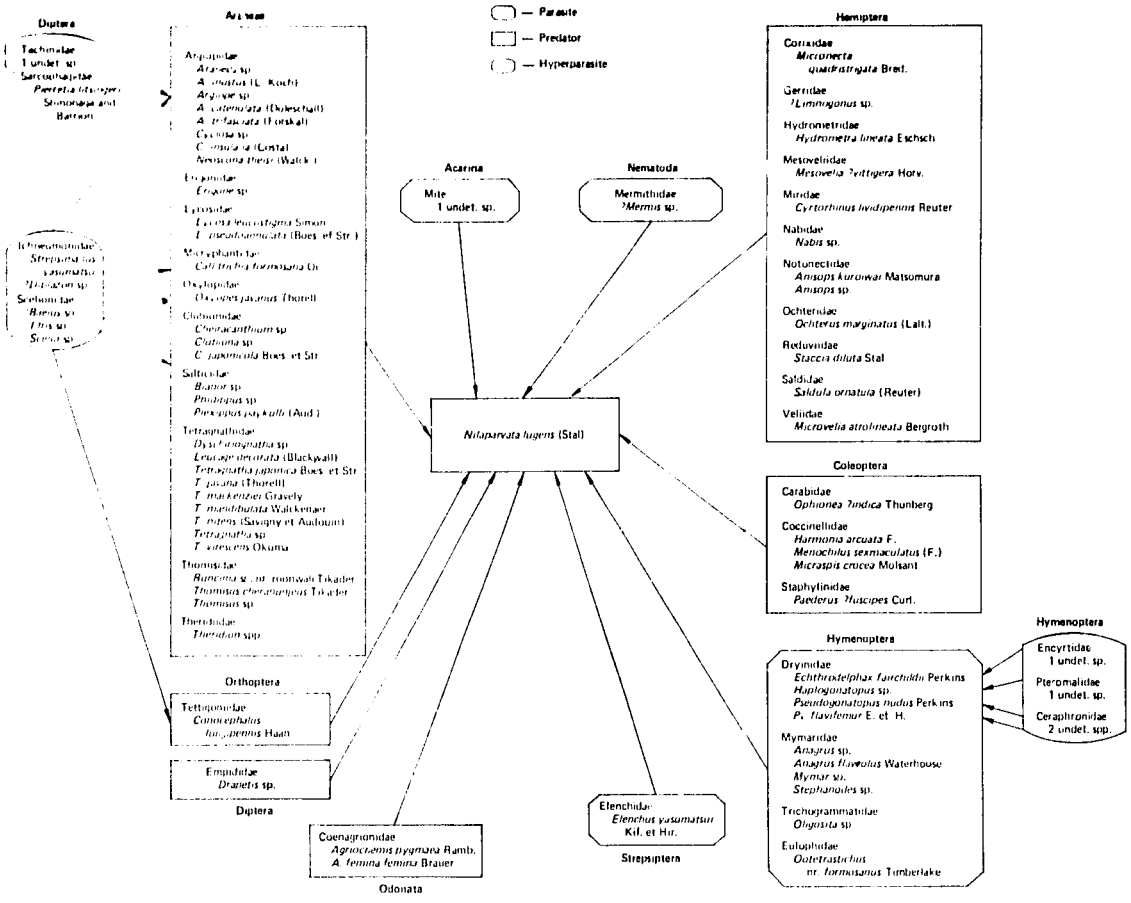
Most of the natural enemies attacking BPH nymphs and adults were predators. Spiders are the most numerous natural enemies representing 48% of the recorded species; 31 representing 10 families have been found. *Theridion* prey on BPH in weedy rice hunds but have never been found in a rice field. Twelve species of true bugs (Heteroptera), five beetles (Carabidae, Coccinellidae, Staphylinidae), two damsel flies (Coenagrionidae), a katydid (Tettigoniidae), and a dance fly (Empididae) make up the rest of the predators.

Secondary natural enemies completed the food web. Four hyperparasitic wasps (Ceraphronidae, Encyrtidae, and Pteromalidae) attacked all four dryinid species and a scelionid wasp parasitized the eggs of *Conocephalus*. Seven parasites attacking

Table 48. Reduction of brown planthopper density by adult ducks herded for 4 h in 70 m² plots of rice (16 hills/m²) at about 70 days after transplanting. IRRI, 1979 wet season.

Ducks (no./70 m²)	Brown planthoppers[a] (no./hill)
20	39 a
10	43 a
4	68 ab
0	74 b

[a]Means followed by the same letter are not significantly different from each other at the 5% level.



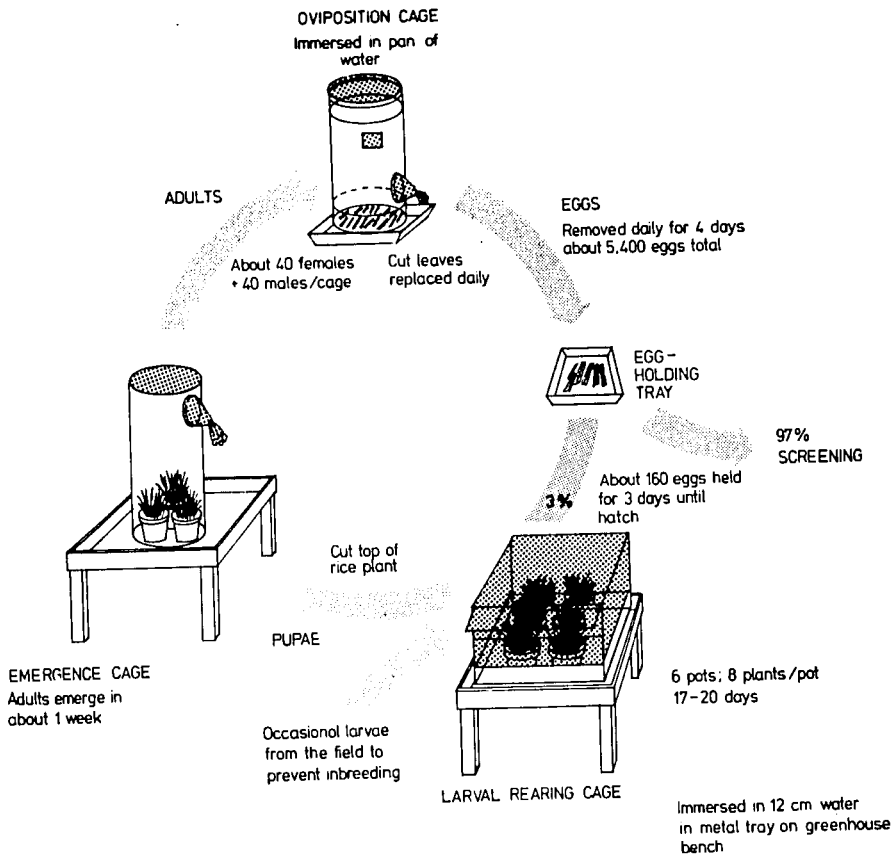
22. Food web of the brown planthopper *Nilaparvata lugens* (Stal) in the Philippines.

spider egg masses were: *Baeius*, *Idris*, and *Scelio* (Scelionidae), *Strepsimallus yasumatsui* and *Diplazon* (Ichneumonidae), *Pierretia* litsingeri (Sarcophagidae) and an undetermined tachinid fly. In addition, spiders were highly cannibalistic and readily devoured one another when other prey was not available.

MASS REARING OF INSECTS

Rice caseworm. Although the rice caseworm *Nymphula depunctalis* is a widely distributed rice pest in Asia, little is known about its ecology and control. A mass-rearing method was developed to produce caseworms for insecticide and varietal resistance screening programs at IRRI (Fig. 23). Females were found to oviposit on the undersides of cut rice leaves floating on water. Four cage designs were tested in a non-airconditioned room offering a range of relative humidity (RH) to determine the optimal requirements for maximum egg production per female. Moths preferred an aerated cage at 83-87% RH. That consisted of a mylar plastic cylinder 25 cm in diameter and 54 cm high with mesh top, with side windows and sleeves. The cage bottom was set in water. About 30 leaves 10 cm long and cut from 3-week-old IR36 plants were individually placed on the water, leaving about 1-cm distance between them to provide room for females to oviposit.

One cage with 40 pairs of moths produced about 5,400 eggs in 4 days. Each day the leaves with eggs were put in shallow egg-holding trays with the eggs submerged. Eggs hatched in 3 days and the larvae fed on the cut leaves. To renew the culture, 3% of the eggs (about 160) were introduced into a larvae-



23. Procedure for mass-rearing the rice caseworm on rice plants in the greenhouse. IRRI, 1979.

rearing cage to produce the 80 adults. The rest (97%) were harvested for use in screening.

In the larvae-rearing cage — a wooden frame with mesh sides set on a metal tray in 12-cm water —larvae developed in 17-20 days before pupation on 3- to 4-week-old plants in 5-6 clay pots (8 plants/pot). The pupae attached themselves to the lowest leaf sheaths on the plants. The pots were removed and placed in an adult emergence cage. For ease of collection the tops of the plants were cut so that the emerging moths would rest on the side of the cage rather than on the plants. Adults emerged in about 1 week to resume the cycle.

Yellow rice borer. In 1979 a moderate degree of success was achieved in rearing the yellow rice borer on caged and potted IR29 rice plants in a greenhouse. About 50% of first-instar larvae placed on 40-day-old plants at 1 larva/2 tillers emerged as adults about 1 month later. The sex ratio was about 1:1.

BPH honeydew as a sugar source for the adult leaf folder. In the development of a mass-rearing technique to provide leaf folder larvae for varietal resistance and insecticide screening studies, it was found that leaf folder adults required an exogenous source of sugar. Longevity and fecundity were decreased when a sugar source was not available. Honey as a source of sugar greatly increased the longevity of adults caged in the laboratory.

Sources of sugar available to the leaf folder in the field have not been determined, but the honeydew excreted by BPH on infested plants is a possible source. Evaluation of the nutritional value of honeydew in two experiments indicated that adult longevity and fecundity were increased when leaf folder adults were caged with BPH (Table 49). In experiment II with less leaf folders per BPH, there

Table 49. Effect on longevity (days) and fecundity of varying the number of leaf folder moths in cages containing at least 80 honeydew-producing brown planthopper (BPH).[a] IRRI laboratory, 1979.

Experimental conditions					
Treatment[b]	Leaf folder moths (no./cage)	Mean longevity ± S.E. (days)	Mean no. of eggs[c] (± S.E.) per		Total no. of eggs laid
			Initial ♀	♀-day	
Experiment I					
Water only	18–20	3.20 ± 0.10 a	3.55 ± 1.15 a	0.98 ± 0.25 a	175
Water + BPH[d]	18–20	4.07 ± 2.20 b	9.65 ± 2.20 b	2.12 ± 0.52 b	312
Experiment II					
Water only	8	3.50 ± 0.35 c	4.96 ± 2.44 c	1.45 ± 2.02 a	139
Water + BPH[d]	8	5.03 ± 0.23 d	40.00 ± 6.31 d	7.75 ± 1.33 b	1119

[a]In a column and within an experiment values not followed by the same letter differ significantly from each other: a vs b, significant at 5% level; c vs d, significant at 1% level. [b]Each treatment included 6 cages and an initial total of 58 moths of each sex in experiment I and 7 cages and an initial total of 28 moths of each sex in experiment II. The numbers of females and males, respectively, accounted for by the end of the experiment follow: experiment I – water only, 56 and 53; water plus BPH, 55 and 56; experiment II – water only, 27 and 28; water plus BPH, 26 and 28. [c]Initial ♀ = total no. of eggs produced ÷ total no. of moths initially in test, ♀-day = total no. of eggs produced ÷ no. ♀ x days of survival of each ♀. This takes into account mortality. [d]The infested plants were replaced daily.

was an eightfold increase in number of eggs laid in the cage with BPH compared to the cage where only water was supplied. The results indicate the possibility of the leaf folder moth utilizing BPH honeydew as a source of sugar.

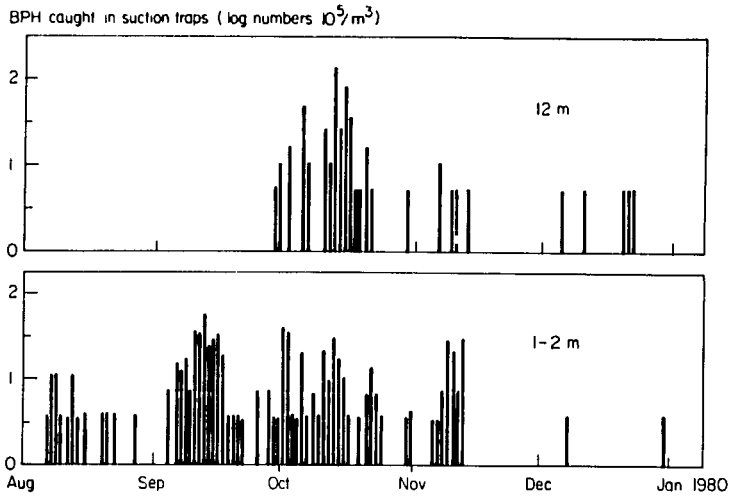
COLLABORATIVE STUDIES ON BROWN PLANTHOPPER MIGRATION

Brown planthopper dispersal and migration. A collaborative project between the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), the Center for Overseas Research (COPR), and IRRI was established in 1979 to monitor populations of BPH and other major planthopper and leafhopper pests of rice, initially at a single site and later in adjacent areas representing typical rice-growing environments. Only data for BPH are presented here.

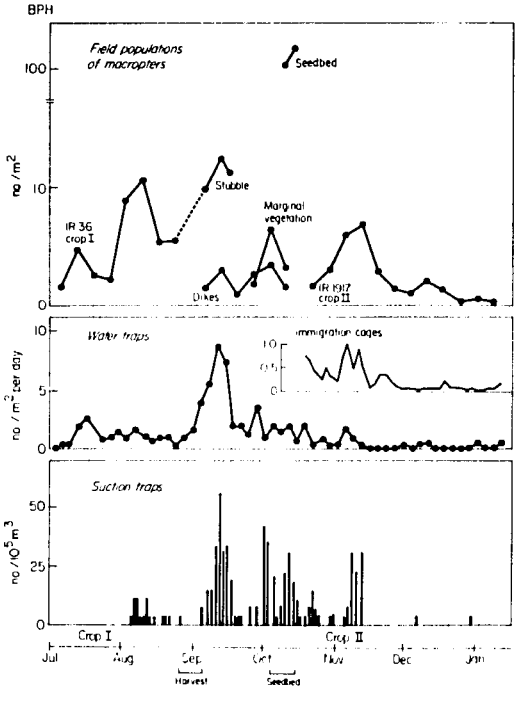
Studies began in May 1979 on a 2-ha farm in a mixed rice and coconut producing area near Liliw, Laguna. The farmer followed his normal agronomic practices, but without pesticide use, while a detailed sampling program was undertaken to monitor aerial activity, immigration, and the status of the resident population. During May–September, IR36, a variety resistant to field populations of BPH, was grown. In the October-February season, IR1917, which is susceptible to BPH, was grown to provide more opportunity for populations to develop on the crop.

Studies began too late to determine the BPH source in the first season. Aerial activity was monitored both at the height of the surrounding tree canopy (about 11 m) and just above the crop (1 and 2 m from ground level). Figure 24 shows patterns of BPH activity in those two situations. The peak in flight activity at 12 m apparent in mid-October coincided with the time of transplanting the crop. The series of corresponding smaller peaks at 1-2 m above ground level suggested immigration of insects flying in the airstream above the area. Green water traps were used to monitor the rate of immigration and catches (Fig. 25). It corresponded well with those from the low-level suction traps, particularly for the major peak in September. At the start of the second crop, roofless mesh enclosures were also used to measure immigration. Immigration rates determined with them showed the same pattern as in water traps but with greater sensitivity. The roofless mesh method registered catches where none were apparent in water traps.

Insect populations throughout the first crop period were estimated using the commercially produced D-Vac suction sampler and the FARMCOP, an aspirator developed at IRRI. Low numbers were recorded although the presence of brachypterous adults in the first sample at 36 DT showed that immigration occurred below the level of detection of the water traps in the first 20-25 DT. The presence of brachypterous forms indicated that a BPH population can survive and multiply on IR36, although at a low level. The peak of macropters in mid-July was associated with a peak in water trap catches and was assumed to be a second wave of immigration because insufficient

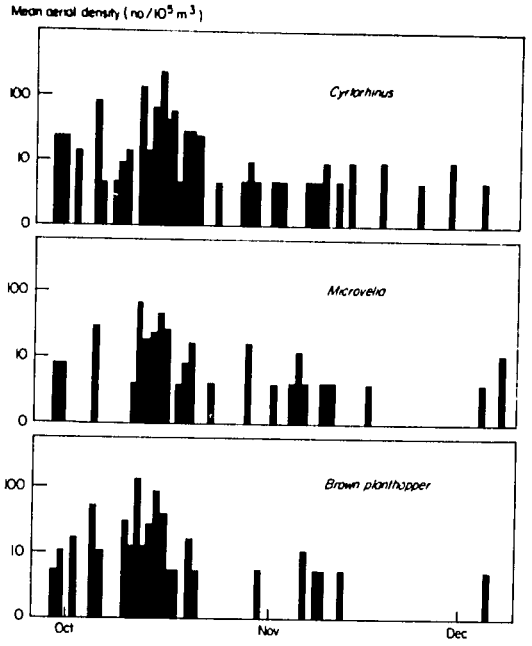


24. Aerial activity of brown planthoppers above a rice farm at Liliw, Laguna, Philippines, 1979.



25. Field populations of macropterous brown planthopper (BPH) at Liliw, Laguna, Philippines, in relation to immigration rates shown by water traps and aerial activity measured with suction traps at 1-2 m above the ground, 1979.

fifth-instar nymphs were present on the crop to account for their generation. At the time a second, larger peak occurred in mid-August (78 DT), BPH nymphs were more abundant and, although insufficient in number to fully account for the adults on the crop, they probably contributed to the number in combination with a low but consistent immigration rate shown by water trapping. The small peak in suction trap catches associated with declining populations of adults on the crop, and low water trap catches may have represented emigration, although some losses may have been due to predation by large populations of the spider *Callitrichia*. From this point populations of BPH nymphs dropped to a very low level; however, macropters were still present, the highest numbers being recorded concurrently with major peaks in water trap and suction trap catches in mid-September, some 10 days after harvest (Fig. 25). This clearly showed a large immigration onto the stubble, which had very few green shoots. Samples taken from adjacent vegetation and dikes, between crops and throughout land preparation, showed that an adult population was maintained at the site throughout the period. Numbers reaching $180/m^2$ were recorded on the seedbed for the second crop and included many gravid, mated females, although oviposition success was low. This high insect den-



26. Aerial activity of brown planthopper and its major predators at 12 m above the ground. Liliw, Laguna, Philippines, 1979.

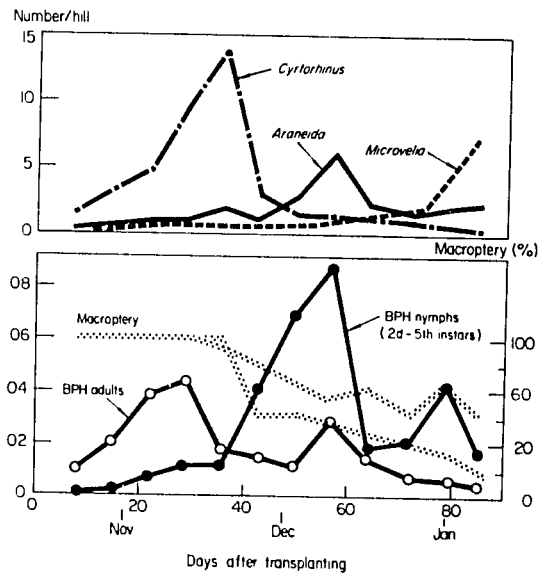
sity was associated with peak activity in the high-level suction trap.

During the second cropping season, immigration occurred during the first 30 DT, giving maximum adult populations of 0.43/hill. Considering the high fecundity of the insect and the susceptible nature of the rice variety, the potential for development of a high population of BPH existed. The data suggest, however, that population growth was severely limited by predation. Associated peaks of immigration and population maxima of *Cyrtorhinus lividipennis* and *Microvelia atrolineata* were observed (Fig. 26, 27). Parasitism by Strepsitera was also common, reaching 30% in adult insects.

The adult maximum BPH population at 30 DT was composed almost entirely of macropters. Peak populations of *Cyrtorhinus*, a facultative egg predator, exceeded those of BPH by some 35:1 and occurred during the period in which oviposition by immigrant females would have been at its maximum so that high egg mortality probably occurred. The high mortality of nymphs of the first generation was associated with a peak in the population of *Microvelia*, and the number of adults produced — predominantly brachypterous — was much lower than the initial immigrant population. This decline continued throughout the crop period. The absence of further detectable immigration resulted in extremely low populations.

Wing morphism in brown planthoppers. The role of various factors, particularly the age and physiological status of the rice host plant, nymph density *(crowding)*, and parents' wing type, in determining BPH wing morphism was investigated because other environmental factors such as weather and climate are not very critical in the tropics.

Physiological status and age of host plant. The progeny of the insectary-reared, brachypterous biotype 2 were predominantly (83—89%) brachypterous and less (11—17%) macropterous on the test plants irrespective of plant age and physiological status (Table 50). The progeny of the field-collected brachypterous hoppers increased significantly in macroptery from 24% on 25-day-old healthy plants to 45% on 80-day-old partially hopperburned plants. The progeny of the field-collected macropterous parents developed into a uniformly high, 42—43%, macropterous population irrespec-



27. Populations of brown planthopper (BPH) nymphs, brachypterous and macropterous adults, and their major predators at Liliw, Laguna, Philippines, during the second growing season of 1979.

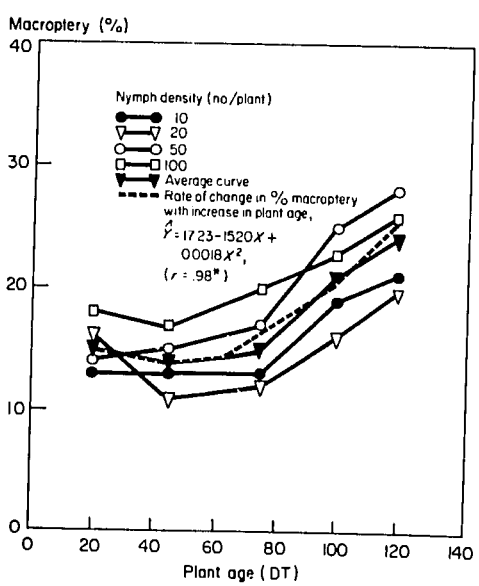
Table 50. Influence of host plant's age and physiological status on wing morphism in progenies of insectary-reared brachypters, and field-collected brachypters and macropters of brown planthopper. IRRI insectary, 1978–79.

Female parents	Plant age (DT) and physiological status[a]	Wing morphism[b] (% macroptery)	Progeny (no.)			
			Brachypterous		Macropterous	
Brachypterous (biotype 2)	25 H	12 a	10	25	4	1
	80 H	11 a	17	11	3	2
	80 PHB	17 ab	12	12	4	1
Brachypterous (field-collected)	25 H	24 abc	4	24	7	2
	80 H	32 bcd	6	19	6	4
	80 PHB	45 d	1	19	12	3
Macropterous (field-collected)	25 H	43 cd	16	15	13	3
	80 H	43 cd	3	15	12	3
	80 PHB	42 cd	6	14	10	5

[a]DT = days after transplanting, H = healthy, PHB = partially hopperburned. [b]Remaining percentage of insects were brachypterous. Means followed by a common letter are not significantly different from each other at the 5% level; av of 4 replications, 10 first instars/replication.

tive of age and physiological status of the host plants. Altogether, the progeny of the field population, irrespective of parents' wing morph and plant's physiological status, developed into a significantly greater proportion of macropterous hoppers than that developing from the progeny of insectary-reared brachypterous hopper parents.

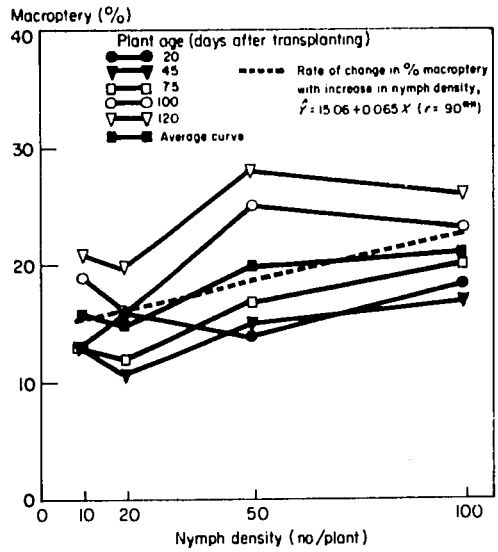
Host plant's age and nymph density per plant. Despite the host plant's senescence, the progenies of the insectary-reared, brachypterous biotypes 1 and 2 parents did not show as distinct a trend toward macroptery as that shown by the field-collected brachypters' progeny, which increased in macroptery as the age of the TN1 host plant increased. A combination of the results of percentage of macroptery in progenies of the three brachypterous populations showed a curvilinear increase — macroptery percentage was low and nearly identical on TN1 plants at the vegetative and reproductive stages of growth (20 to 75 DT), but increased significantly when nymphs were reared on plants at the ripening phase (100 to 120 DT) (Fig. 28).



28. Influence of plant age (days after transplanting) on wing morphism in brown planthopper progeny reared at different nymph densities. IRRI insectary, 1978-79.

The effect of crowding, in terms of significantly increased macroptery, was evident in biotype 1 progeny only at the density of 50 or more nymphs/plant. However, at even low densities, the percentage of macroptery in progenies of brachypterous biotype 2 and of the field population was equal to or higher than that of the biotype 1 progeny reared at the density of 100 nymphs/plant. The overall percentage of macroptery in the progeny of the field population was nearly twice as high at all nymph densities as that in the progenies of brachypterous biotypes 1 and 2. Regression analysis of the percentage of macroptery in progenies of the three populations showed a significant linear increase in macroptery in relation to nymph density (Fig. 29).

Inheritance of wing morphism. BPH progenies, produced and reared on senescent hosts, developed into varied proportions of macropterous and brachypterous individuals, depending on the wing type of the parents (Table 51). Although the



29. Influence of nymph density on wing morphism in brown planthopper progeny reared on rice plants of different ages. IRRI insectary, 1978-79.

host plants' senescence caused a general increase in macroptery, X^2 analysis showed that the progeny of brachypterous parents were significantly less macropterous than the progeny of macropterous parents. This was true for both biotypes 1 and 3, but in biotype 2 the percentage of macroptery in the progeny of brachypterous parents was nearly as high as that in the progeny of macropterous parents. The male-to-female ratio in both brachypterous and macropterous progeny developed on senescent hosts was nearly 1:1, indicating that wing morphism was not sex-linked.

Long-distance brown planthopper migration in the Philippines. Studies of BPH migration in the Philippines were initiated in 1979. To monitor migrating BPH and other insects, two successive interisland voyages were made along fixed sea routes. The first voyage was 27 June—6 July and covered the Manila-Cebu, Cebu-Surigao, Surigao-Butuan, Butuan-Cebu, and Cebu-Manila routes. Wind-propelled, revolving type nylon nets (0.5 m diam, 2 m long) were installed: 1 at the bow, 2 at the mast, 2 at the flying bridge, and 1 at the stern of the ship.

The second voyage was 3—11 October 1979 and covered the Manila-Masbate, Masbate-Cebu, Cebu-Cagayan de Oro, Cagayan de Oro-Iligan, Iligan-Cebu, and Cebu-Manila routes. In addition to the wind-propelled nylon nets installed in the first voyage, 4 cross-shaped, sticky board traps (0.45 × 0.45 m each) were installed on the flying bridge of the ship and insect catches were monitored morning, noon, and afternoon. The procedure for operating the nylon net was the same as above. For both voyages the nets and traps were exposed for trapping insects from 10 minutes after sailing, until 10 minutes before docking.

Insects caught on interisland sea routes. On the first voyage, 255 insects representing 82 species, and 7 araneids representing 4 spider species were collected. Among the insects caught, the most numerous were dipterans (59%), followed by hemipterans (23%), hymenopterans (13%), coleopterans (3%), and lepidopterans, orthopterans, and psocopterans (2%). Minute araneids belonging to the families Argiopidae, Dictynidae, and Tetragnathidae were also recorded.

Among the hemipterans caught, 59% belonged to 5 species of the family Aphididae, 19% belonged

Table 51. Inheritance of parents' wing morphs by brown planthopper progeny reared on senescent rice host plant. IRRI insectary, 1979.

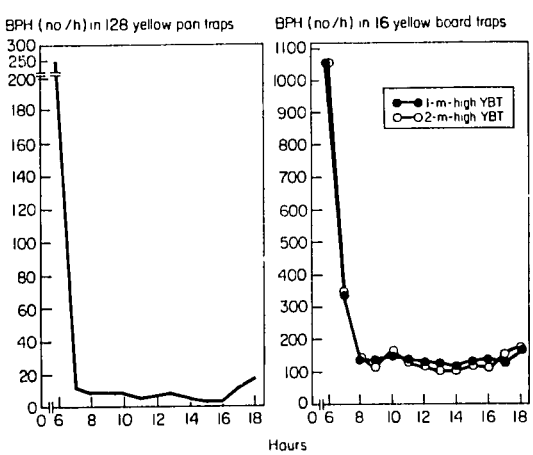
BPH population[a]	Parents' wing morph[b]	Mating pairs (no.)	Wing morphs in progeny[c] (no.)		Macroptery (%)	X^2[d]
			Brachypters	Macropters		
Biotype 1	Br	5	40 + 36	75 + 66	65	9.19**
	Ma	4	2 + 1	54 + 44	97	
Biotype 2	Br	4	9 + 18	83 + 68	85	0.122
	Ma	7	13 + 46	199 + 202	87	
Biotype 3	Br	4	92 + 48	151 + 137	67	5.785**
	Ma	4	7 + 15	67 + 78	87	

[a]Field population was excluded from this test to avoid biotype heterogeneity. [b]Br = brachypterous, Ma = macropterous. [c]Progenies of biotypes 1, 2, and 3 were reared on senescent TN1, Mudgo, and ASD7 rice hosts. [d]X^2 values were computed from the weighted means; ** = highly significant.

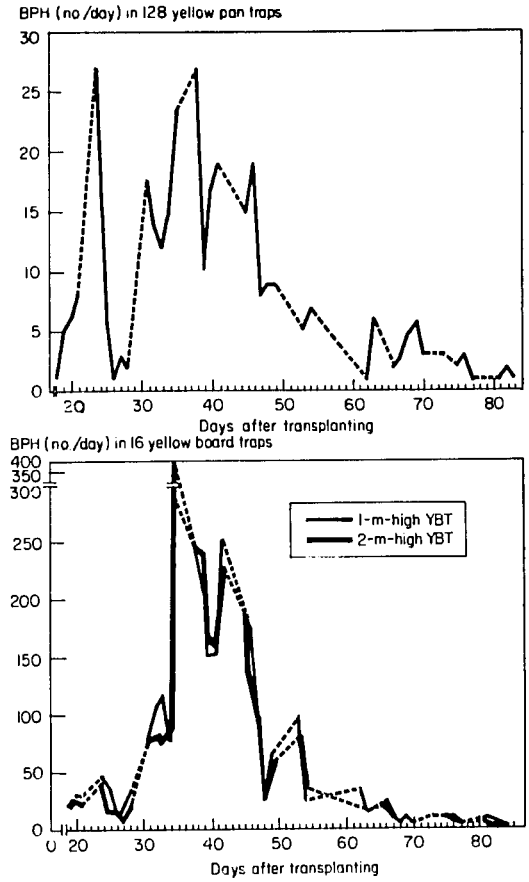
to Delphacidae, and the remainder were representatives of other hopper and bug families. The delphacids represented BPH *N. lugens*, WBPH *Sogatella furcifera*, *Sogatella eupompe*, *Sogatodes pusanus*, and two unidentified individuals of *Sogatella* species. WBPH was much more numerous and was caught on more routes than BPH, which was caught on the Cebu-Manila route. WBPH catches included both male and female individuals. The solitary BPH caught 5 July was a female.

On the second voyage, 183 insects and 5 araneids were caught. The delphacids included both males and females of the following: *N. lugens*, *Nilaparvata bakeri*, *S. furcifera*, *Sogatella panicicola*, *S. pusanus*, and a few other unidentified delphacids. The cicadellids were represented by individuals of *Recilia dorsalis*, *Nephotettix virescens*, *Cicadulina bipunctella*, common leafhopper pests of rice, and other unidentified leafhoppers. The sticky trap catches were generally bigger than insect catches in nylon nets, but the nylon nets were easier to operate.

BPH, WBPH, and other rice hoppers were caught mostly on the Manila-Cebu and Cebu-Manila routes, which lie in the path of the southwest monsoon — a warm moist air mass that flows constantly from the Indian Ocean toward the Philippines during the wet season.



30. Trends in hourly catches of immigrant macropterous brown planthoppers in IR1917-3-17 rice fields with yellow pan traps (YPT) and yellow board traps (YBT). Hopper numbers are based on cumulative hourly catches in 128 1-m-high YPT and on 16 1- and 2-m-high YBT, each set for 40 trapping days, excluding weekends and holidays. IRRI, 1979.



31. Trends in daily catches of immigrant macropterous brown planthoppers in IR1917-3-17 rice fields with yellow pan traps (YPT) and yellow board traps (YBT). Hopper numbers are based on daily cumulative catches in 128 1-m-high YPT and on 16 1- and 2-m-high YBT set for 40 trapping days (solid lines), excluding weekends and holidays (broken lines). IRRI, March-May 1979.

BPH flight activity. Immigration of macropters is the first step toward BPH colonization of new rice fields. BPH invasion flights were monitored in IRRI fields planted with IR1917-3-17, a BPH-susceptible rice selection. Beginning 18 DT, the immigrant hoppers were trapped daily for 40 consecutive days, except on weekends and holidays in yellow pan traps (YTP) and yellow board traps (YBT).

Comparison of cumulative hourly catches showed that the maximum number of BPH macropters was recorded at 0600 hours, indicating that invasion flight activity peaked around sunrise

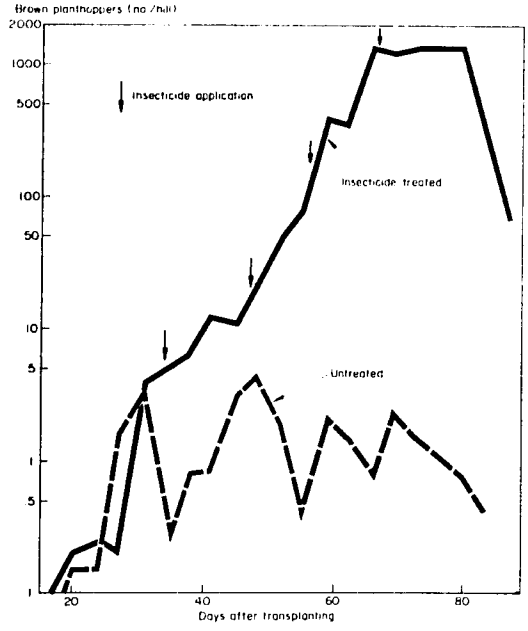
(Fig. 30). This was the trend for both types of traps – YPT, which were closed overnight, and YBT, which were left uncovered at night. Somewhat higher catches on YBT than in YPT was attributed to much greater trapping surface area and to strategic location of YBT against the prevailing wind.

The trend in hourly catches of hoppers and their number in 1- and 2-m high YBT were almost identical, suggesting that the height of traps did not change their trapping efficiency.

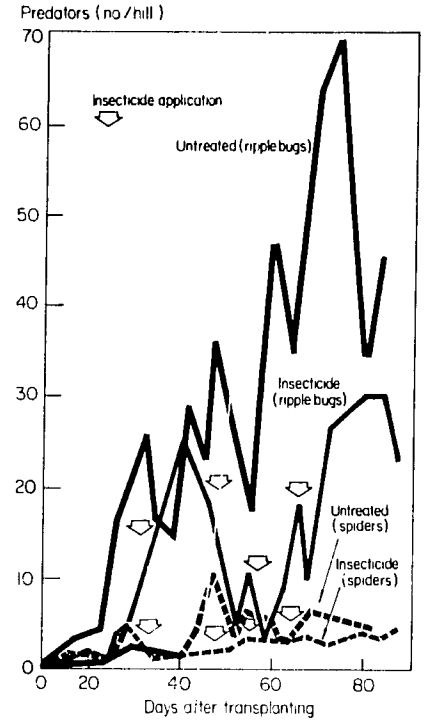
Daily monitoring of hoppers through 40 trapping days, based on cumulative number of hoppers in catches in 128 YPT or on 16 YBT, showed that immigration activity occurred mostly during the vegetative stage of crop growth (Fig. 31). This trend in hopper catches in both kinds of traps was identical, but the YPT were much cheaper and easier to operate.

OUTBREAKS OF PLANTHOPPERS

Brown planthopper. To help understand the mechanism, or mechanisms, of BPH outbreaks, the survival of natural field populations of BPH was monitored in several susceptible varieties in IRRI and nearby farmers' fields.



32. Density of brown planthoppers (nymphs plus adults) on the susceptible variety IR20 untreated or treated with insecticide (diazinon at 0.75 kg a.i. ha was sprayed first, followed by 3 sprays of decamethrin at 8 g a.i. ha). IRRI, 1979 dry season.



33. Densities of predatory ripple bugs and spiders in wetland rice fields untreated or treated with insecticide (decamethrin at 8 g a.i. ha sprayed at 47, 56, and 66 DT). IRRI, 1979 dry season.

Survival of BPH eggs and nymphs was low; the average survival from the egg through the nymphal stage was usually less than 10%. Preliminary observations showed that adults also survived poorly in the field. Reproduction did not appear to compensate for these low survival rates, and the populations naturally declined. Evidently natural control by predation and parasitism substantially suppressed the pest population.

The abundance and survival of BPH and two important predator species were compared in two IRRI fields – one treated with insecticides and a nearby one left untreated. The BPH population in the untreated field remained small, and survival of eggs and nymphs was only 3%. In the treated field pest density was high and survival was about 20%, ultimately causing hopperburn (Fig. 32). Because of insecticide treatment, the abundance of some natural enemies such as spiders and ripple bugs

(mostly *Microvelia*) decreased (Fig. 33). This decrease was a possible major cause of the increase in BPH survival and of the pest population explosion. In an experiment in greenhouse cages, decamethrin, the main insecticide applied in the field, killed the important predatory spider *Lycosa pseudoannulata* within 1 day.

Insecticide-induced resurgence may be a cause of BPH outbreaks. Several cases of hopperburn in farmers' fields in 1979 were studied, and in every case insecticides had been applied to the fields.

Whitebacked planthopper. It is commonly expected that WBPH is a pest only of young plants. For more than 2 months WBPH were reared on susceptible plants of specific ages in a greenhouse. The insects survived and multiplied equally well on all plant ages. Evidently some factor other than plant age, possibly natural enemies, prevents a WBPH population from increasing as the crop grows.

Control and management of rice pests

Weeds

Agronomy Department

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WEED CONTROL IN RICE FIELDS

Research to identify herbicides that would complement other direct methods of weed control in wetland rice continued at IRRI and at the Maligaya, Bicol, and Visayas research stations of the Philippine Bureau of Plant Industry.

Transplanted rice. Infestations of *Echinochloa crus-galli* ssp. *hispidula*, *Echinochloa glabrescens*, *Cyperus difformis*, and *Monochoria vaginalis* were common at all sites. *Scirpus maritimus* and *Paspalum distichum* were present at IRRI, *Cyperus imbricatus* and *Sphenoclea zeylanica* at Bicol.

At Bicol, the yields of all the herbicide-treated plots were significantly higher than those of the untreated plots; at Maligaya, they were comparable to those of the hand-weeded plots (Table 1). At IRRI, plots treated with the new herbicides R-24216, NCL 2,4-D, and R-34018 yielded significantly less than the hand-weeded plots.

At Bicol and the Visayas during the wet season, all herbicide treatments gave yields comparable to those of the hand-weeded plots and significantly higher than those of the untreated plots (Table 2).

Direct-seeded irrigated rice. In the dry season at Maligaya and Bicol, all the herbicide-treated plots yielded significantly higher than the untreated plots (Table 3). In the wet season, at Maligaya and the Visayas, all herbicide treatments gave significantly higher yields than the untreated control (Table 4). Yields at IRRI were generally low because the crop lodged badly at flowering stage.

Dryland rice. Herbicide trials in dryland rice continued at IRRI and in a farmer's field in Batangas during the 1979 wet season. The weed species predominant in both sites were *Digitaria ciliaris*, *Eleusine indica*, and *Commelina benghalensis*. Also present at IRRI were *Rottboellia exaltata*, *Cleome rutidosperma*, *Calopogonium mucunoides*, and *Cyperus rotundus*. In Batangas, *Cyperus iria* and *Ageratum conyzoides* were present.

Most herbicide treatments without hand weeding provided moderate to adequate weed control at IRRI and the Batangas site and gave grain yields comparable to those from hand weeded checks, and significantly higher than those of the untreated control (Table 5). Oxadiazon and X-150 adequately controlled all weed species, except *C. rotundus*, and were moderately to completely safe to the crop, respectively. Hand weeding of herbicide-treated plots increased their weed control

Table 1. Effects of granular herbicides applied before weed emergence – 4 days after transplanting (DT) – on yield of IR42 rice at IRRI, the Maligaya Rice Research and Training Center, and the Bicol Rice and Corn Experiment Station of the Philippine Bureau of Plant Industry, 1979 dry season.

Treatment[a]	Rate (kg a.i.[b]/ha)	Yield[c] (t/ha) IRRI	Maligaya	Bicol
Naproanilide – thiobencarb	1.0 – 0.7	6.0 a	6.4 ab	6.9 ab
EXP 3391	0.25	5.9 a	6.4 ab	6.2 cd
Pendimethalin	0.75	5.1 ab	6.7 ab	6.8 ab
Bifenox – 2,4-D EE	2.0 – 0.66	5.4 ab	6.7 ab	6.3 bc
Hand-weeded check	–	5.0 ab	6.3 ab	7.1 a
Molinate – simetryn – MCPB	1.8 – 0.1 – 0.1	4.8 ab	7.0 a	6.4 bc
Pretalachlor	0.5	5.6 a	6.5 ab	5.6 d
2,4-D IPE	0.8	3.4 cd	6.7 ab	6.7 abc
Oxyfluorfen	0.25	4.0 bc	6.5 ab	5.6 d
R-22523	2.0	5.8 a	d	d
DPX 4432	0.075	5.7 a	d	d
EF 5004	3.5	5.7 a	d	d
R-24216	1.5	3.2 cd	d	d
NCL 2,4-D	0.28	2.4 de	d	d
R-34018	1.5	1.2 e	d	d
Untreated check	–	1.4 e	5.9 b	4.3 e

[a]A spaced dash (–) means that 2 or more herbicides were formulated on the same carrier and applied as a single treatment. EE = ethyl ester. Hand-weeded check = weeded 20 and 40 DT. IPE = isopropyl ester. [b]Active ingredient. [c]Av of 4 replications/site. In a column, means followed by the same letter are not significantly different at 5% level. [d]Not tested.

Table 2. Effects of granular herbicides applied before weed emergence – 4 days after transplanting (DT) – on yield of IR42 rice at IRRI, the Maligaya Rice Research and Training Center, the Bicol Rice and Corn Experiment Station, and the Visayas Rice Experiment Station of the Philippine Bureau of Plant Industry, 1979 wet season.

Treatment[a]	Rate (kg a.i.[b]/ha)	Yield[c] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Bifenox – 2,4-D EE	2.0 – 0.66	4.8 a	5.8 a	3.9 ab	5.3 ab
Hand-weeded check	–	4.6 ab	5.6 a	4.6 a	5.2 ab
Pretalachlor	0.5	4.6 ab	5.7 a	4.3 ab	5.2 ab
Molinate – simetryn – MCPB	1.8 – 0.1 – 0.1	4.0 abcd	6.0 a	3.7 b	5.3 ab
Naproanilide – thiobencarb	1.0 – 0.7	4.4 abc	5.6 a	4.0 ab	5.1 ab
Piperophos – 2,4-D IPE	0.33 – 0.17	4.0 abcd	5.6 a	4.3 ab	5.3 ab
EXP 3391	0.25	3.7 bcd	5.8 a	3.8 b	5.4 a
2,4-D IPE	0.8	3.4 cd	5.8 a	3.6 b	5.3 ab
Pendimethalin	0.75	d	5.9 a	3.8 b	4.9 b
NCL 2,4-D	0.7	4.8 a	d	d	d
R-22523	2.0	4.8 a	d	d	d
EF 5004	3.5	4.2 abcd	d	d	d
Untreated check	–	3.3 d	5.4 a	2.6 c	4.0 c

[a]A spaced dash (–) means that 2 or more herbicides were formulated on the same carrier and applied as a single treatment. EE = ethyl ester. Hand-weeded check – weeded 20 and 40 DT. IPE = isopropyl ester. [b]Active ingredient. [c]Av of 4 replications/site. In a column, means followed by the same letter are not significantly different at 5% level. [d]Not tested.

Table 3. Effects of early postemergence (6 days after seeding) application of granular herbicides on yield of direct-seeded, flooded IR42 rice at IRRI, the Maligaya Rice Research and Training Center, and the Bicol Rice and Corn Experiment Station of the Philippine Bureau of Plant Industry, 1979 dry season.

Treatment[a]	Rate (kg a.i.[b]/ha)	Yield[c] (t/ha)		
		IRRI	Maligaya	Bicol
Molinate – simetryn – MCPB	1.8 – 0.1 – 0.1	6.4 a	5.6 b	6.9 a
Butachlor + 2,4-D IPE	0.75 + 0.5	5.7 ab	6.9 a	5.7 a
Naproanilide – thiobencarb	1.0 – 0.7	6.0 ab	6.9 ab	6.4 a
Piperophos – 2,4-D IPE	0.33 – 0.17	4.9 abc	7.1 a	6.0 a
Pretalachlor	0.5	5.6 ab	6.5 ab	6.8 a
X-52 – 2,4-D IPE	2.1 – 0.75	5.2 ab	4.6 c	6.1 a
Bifenox – 2,4-D EE	2.0 – 0.66	5.4 ab	3.8 c	6.4 a
EXP 3391	0.25	4.6 bc	4.2 c	6.5 a
Thiobencarb – 2,4-D IPE	1.0 – 0.5	5.7 ab	3.7 c	5.7 a
EF 5004	3.5	5.7 ab	d	d
DPX 4432	0.075	5.1 ab	d	d
NCL 2,4-D	0.28	3.6 cd	d	d
R-22523	2.0	3.1 d	d	d
R-24216	1.5	2.4 de	d	d
R-34018	1.5	2.4 de	d	d
Untreated check	–	1.6 e	2.6 d	3.0 b

[a]A spaced dash (–) means that 2 or more herbicides were formulated on the same carrier and applied as a single treatment. A plus (+) means the chemicals were applied separately at about the same time. IPE = isopropyl ester. EE = ethyl ester. [b]Active ingredient. [c]Av of 4 replications/site. In a column, means followed by the same letter are not significantly different at 5% level. [d]Not tested.

significantly over those treated with herbicides alone (Table 6).

At IRRI, *R. exaltata* was not controlled by butachlor and dinitramine, and its heavy regrowth in the propanil treatment caused zero yield. Propanil was also extremely toxic to rice and the weeds regrew faster than the crop could recover. Herbicide injury to the crop was generally relatively higher in Batangas than at IRRI because of the excessive moisture in the soil at germination time.

Table 4. Effects of early postemergence (6 days after seeding) application of granular herbicides on yield of direct-seeded flooded IR42 rice at IRRI, the Maligaya Rice Research and Training Center, the Bicol Rice and Corn Experiment Station, and the Visayas Rice Experiment Station of the Philippine Bureau of Plant Industry, 1979 wet season.

Treatment[a]	Rate (kg a.i.[b]/ha)	Yield[c] (t/ha)			
		IRRI	Maligaya	Bicol	Visayas
Molinate – simetryn – MCPB	1.8 – 0.1 – 0.1	2.1 a	5.2 abc	4.6 a	4.8 ab
Thiobencarb – 2,4-D IPE	1.0 – 0.5	2.0 ab	5.5 ab	4.5 a	5.0 ab
Butachlor + 2,4-D IPE	0.75 + 0.5	1.9 ab	5.5 ab	3.6 ab	5.0 ab
Naproanilide – thiobencarb	1.0 – 0.7	1.8 ab	5.8 ab	3.4 bc	4.7 b
Pretalachlor	0.5	1.3 bc	5.9 ab	3.3 bc	4.5 b
X-52 – 2,4-D IPE	2.1 – 0.75	1.2 bc	5.2 abc	4.0 ab	4.9 ab
Bifenox – 2,4-D EE	2.[illegible] – 0.66	1.3 bc	4.7 bc	3.0 bc	5.3 a
Piperophos – 2,4-D IPE	0.33 – 0.17	0.8 c	6.0 a	3.3 bc	4.4 b
EXP 3391	0.25	0 d	4.2 c	3.0 bc	4.5 b
EF 5004	3.5	1.2 bc	d	d	d
Untreated check	–	0 d	1.9 d	2.3 c	3.9 c

[a]A spaced dash (–) means that 2 or more herbicides were formulated on the same carrier and applied as a single treatment. IPE = isopropyl ester. A plus (+) means the chemicals were applied separately at about the same time. EE = ethyl ester. [b]Active ingredient. [c]Av of 4 replications/site. In a column, means followed by the same letter are not significantly different at 5% level. [d]Not tested.

Table 5. Effects of liquid herbicides applied before crop and weed emergence on weed control, crop tolerance, and yield of IR9575 rice under upland conditions at IRRI and in a farmer's field in Batangas Province, Philippines, 1979 wet season.

Treatment[a]	Rate (kg a.i.[b]/ha)	IRRI			Batangas		
		Weed wt[c] (g/m²)	Toxicity rating[d]	Yield[c] (t/ha)	Weed wt[c] (g/m²)	Toxicity rating[d]	Yield[c] (t/ha)
Pendimethalin fb hand weeding	2.0	32 bcd	2	1.2 abc	39 cd	4	3.5 a
Oxadiazon fb hand weeding	1.0	29 bcd	2	1.4 a	21 bc	4	3.1 abc
X-150 fb hand weeding	4.0	11 a	0	1.4 a	8 a	0	3.0 abcd
Butralin fb hand weeding	2.0	26 bcd	2	1.2 abc	21 bc	4	3.1 abc
X-150	4.0	113 fghi	0	1.4 a	173 ef	0	2.9 abcd
Propanil fb hand weeding	3.0	78 def	7[e]	1.1 abcd	44 cd	2[e]	3.1 abc
Oxyfluorfen fb hand weeding	0.5	38 bcde	6	1.2 abc	18 bc	5	2.9 abcd
Butachlor fb hand weeding	2.0	29 bcd	3	0.8 de	10 b	6	3.2 ab
Three hand weedings	–	16 ab	0	1.2 abc	14 bc	0	2.7 abcde
Two hand weedings	–	46 cde	0	1.2 abc	30 cd	0	2.7 abcde
One hand weeding	–	107 fgh	0	0.9 bcde	90 de	0	3.0 abc
Dinitramine fb hand weeding	1.5	26 bcd	5	1.2 abc	77 de	8	2.6 abcde
Oxadiazon	1.0	79 efg	2	1.2 abc	280 fg	4	2.6 abcde
Oxyfluorfen	0.5	114 fgh	6	0.8 de	372 fg	5	2.1 cdef
Pendimethalin	2.0	228 hij	2	0.7 e	645 g	4	2.0 cdef
Butralin	2.0	163 ghij	2	0.9 cde	490 fg	4	1.8 def
Butachlor	2.0	217 ghij	3	0 f	387 fg	6	2.1 bcdef
Propanil	3.0	285 j	7[e]	0 f	374 fg	2[e]	1.6 ef
Dinitramine	1.5	269 ij	5	0 f	666 g	8	1.1 fg
Untreated check	–	281 j	0	0 f	578 g	0	0.5 g

[a]fb = followed by. Hand weeding follow-up was done 5 wk after emergence (WE). Propanil was applied 2 WE. Three hand weedings = 2, 5, and 8 WE. Two hand weedings = 2 and 5 WE. One hand weeding = 3 WE. [b]Active ingredient. [c]Av of 3 replications. In a column, means followed by the same letter are not significantly different at 5% level. [d]Taken at 1 WE. Scale: 0 – 10; 0 = no toxicity, 10 = complete kill. [e]Taken 1 wk after propanil application.

Among the herbicides tested, dinitramine was the most toxic. It reduced initial crop stand by about 80%. Toxicity with propanil was not pronounced in Batangas.

Three hand weedings at IRRI and two at Batangas were optimum for weed control. However, one hand weeding seemed adequate for grain yield at both locations.

The plots at IRRI suffered from a month of drought shortly before maximum tillering, which

Table 6. Effect of follow-up hand weeding in herbicide treatments on weed weight and rice yield.[a] IRRI and Batangas Province, Philippines, 1979.

Herbicide	IRRI				Batangas			
	Weed wt (g/m^2)		Yield (t/ha)		Weed wt (g/m^2)		Yield (t/ha)	
	UW	W	UW	W	UW	W	UW	W
X-150	113	11**	1.4	1.4	173	8**	2.9	3.0
Oxadiazon	79	29**	1.2	1.4	280	21**	2.6	3.1**
Pendimethalin	228	32**	0.7	1.8**	645	39**	2.0	3.0*
Oxyfluorfen	114	38**	0.8	1.2**	372	28**	2.1	2.9
Butralin	163	26**	0.9	1.2*	490	21**	1.8	3.1**
Butachlor	217	27**	0	0.4**	387	10**	2.1	3.2*
Propanil	285	78**	0	1.1**	374	44**	1.6	3.1**
Dinitramine	269	26**	0	1.2**	666	77**	1.1	2.6**

[a]UW = unweeded, W = weeded.

is reflected in yields generally lower than in Batangas.

HERBICIDE SCREENING

During the 1979 wet season, herbicide screening in transplanted and wet-seeded (direct-seeded) rice under irrigated and rainfed conditions continued. Herbicide rates and times of application were varied to further evaluate herbicides for safe and economical use in these rice cultures.

Irrigated transplanted rice. The weeds in transplanted irrigated rice included *Echinochloa crus-galli* ssp. *hispidula*, *E. glabrescens*, *Monochoria vaginalis*, and *Cyperus iria*.

All herbicide treatments gave yields comparable with those of the hand-weeded check and significantly higher than those of the untreated control (Table 7). Yields of plots treated with the same herbicide or with different herbicides did not vary significantly with time of application. Liquid and granular herbicides performed similarly. Among the new chemicals tested, KCO_{23}, KCO_{25}, and oxadiazon-propanil showed promising results.

Rainfed transplanted rice. In the rainfed trials, a different weed flora was present —

Table 7. Effect of different herbicides on weed control and yield of transplanted IR36 rice grown under irrigated conditions. IRRI, 1979 wet season.

Herbicide treatment[a]	Application		Weed wt[d] (g/m^2)			Yield[e] (t/ha)
	Rate (kg a.i.[b]/ha)	Time[c]	Broadleaf weeds	Grasses	Sedges	
Thiobencarb – 2,4-D EC	1.0 – 0.5	4 DT	5	4	2	4.7 a
Oxadiazon – 2,4-D IOE[f]	0.125 – 0.125	PP	6	2	3	4.6 a
KCO_{23} G	1.0	4 DT	4	1	1	4.4 ab
Oxadiazon (25% a.i.) EC	0.5	4 DT	1	1	1	4.3 ab
Oxadiazon (12% a.i.) EC	0.4	PP	1	33	2	4.3 ab
KCO_{25} G	1.0	4 DT	8	1	2	4.0 ab
KCO_{23} G	1.0	PP	14	28	1	3.8 ab
Oxadiazon – 2,4-D IOE[f]	0.15 – 0.15	4 DT	1	60	1	3.8 ab
KCO_{23} G	1.0	8 DT	2	24	3	3.8 ab
Thiobencarb – 2,4-D IPE G	1.0 – 0.5	4 DT	4	1	1	3.7 ab
Pendimethalin EC	0.75	4 DT	1	7	1	3.7 ab
Oxadiazon – propanil EC	0.6 – 1.8	4 DT	1	11	3	3.6 ab
KCO_{25} G	1.0	PP	41	7	8	3.5 ab
Oxadiazon – 2,4-D IOE[f]	0.15 – 0.15	PP	1	35	0	3.5 ab
Pendimethalin EC	0.75	PP	1	49	2	2.3 bc
Hand-weeded control	Twice	15 + 30 DT	3	0	5	3.7 ab
Untreated control	–	–	5	84	29	1.2 c

[a]A spaced dash (–) means that 2 herbicides were formulated on the same carrier and applied as a single treatment. EC = emulsifiable concentrate. IOE = isooctyl ester. G = granule. IPE = isopropyl ester. [b]Active ingredient. [c]DT = days after transplanting; PP = preplanting application. [d]Taken at heading stage of grasses. [e]Av of 2 replications. Means followed by the same letter are not significantly different at 5% level. [f]Applied without dilution with a sprinkler bottle.

Echinochloa colona, Leptochloa chinensis, Fimbristylis littoralis, and *C. iria.* Yields were lower than in irrigated rice trials. Except in the oxadiazon — 2,4-D IOE and pendimethalin treatments, all herbicides applied before planting were not as effective as those applied after planting. Generally the preplanting herbicide treatments yielded lower than the postplanting treatments.

The highest yield was from plots treated with pendimethalin at 4 days after transplanting (DT) (Table 8). A continuously dry condition for several days may have inactivated preplanting herbicides.

Irrigated wet-seeded rice. The common weed species present in the irrigated wet-seeded plots were *E. colona, E. crus-galli* ssp. *hispidula, M. vaginalis, L. chinensis,* and *C. iria.*

Some postseeding herbicides slightly damaged the rice; however, the crop recovered and gave reasonable yields. Only the X-150 and propanil treatments gave significantly higher yields than the untreated control. The other herbicides, except thiobencarb – 2,4-D, likewise provided adequate weed control, showed high crop selectivity, and produced higher grain yield than the untreated control (Table 9).

Rainfed wet-seeded rice. The rainfed plots were almost continuously flooded for several weeks and the weeds present were similar to those in irrigated plots. Preplanting herbicides were also toxic to rainfed wet-seeded rice. Almost all the herbicide-treated plots yielded significantly higher than the untreated control (Table 10).

Dryland rice. During the 1979 wet season, several herbicides and herbicide combinations applied as mixed formulations or as follow-up treatments were tested on dryland rice.

Rice yields varied with herbicide combinations (Table 11). In most cases, rates of application did not significantly affect the yields in plots treated with preemergence butachlor at 1.5 and 2 kg a.i./ha and thiobencarb at 2 and 3 kg a.i./ha.

Plots treated with propanil yielded substantially higher when the herbicide was applied once at high dosage (3.0 kg a.i./ha) than when it was applied in split doses at lower rates (1.5 kg a.i./ha at 10 days after emergence [DE] followed by 1.5 kg a.i./ha at 20 DE) because the high-dosage treatment completely killed the weeds. The rice plants suffered burning but recovered completely.

All preemergence chemical treatments that had 2,4-D combined in the formulation, such as thiobencarb – 2,4-D IPE and piperophos – 2,4-D IPE, were severely toxic to germinating rice. Where 2,4-D was used as a single formulated postplanting herbicide following up preemergence application of butachlor and thiobencarb, it gave good control of broadleaf weeds. However, grasses, specifically *Digitaria* spp., that escaped from

Table 8. Effect of different herbicides on weed control and yield of transplanted IR36 rice grown under rainfed conditions. IRRI, 1979 wet season.

Herbicide treatment[a]	Application		Weed wt[d] (g/m²)		Yield[e] (t/ha)
	Rate (kg a.i.[b]/ha)	Time[c]	Grasses	Sedges	
Pendimethalin EC	0.75	4 DT	44	206	2.7 ab
KCO_{25} G	1.0	4 DT	99	26	2.4 ab
Oxadiazon (25% a.i.) EC	0.4	4 DT	61	3	2.3 abc
KCO_{23} G	1.5	4 DT	112	4	2.3 abc
Pendimethalin EC	0.75	PP	62	16	2.2 abc
Thiobencarb – 2,4-D IPE EC	1.0 – 0.5	4 DT	140	11	2.1 abc
Piperophos – 2,4-D IPE EC	0.5 – 0.25	4 DT	45	102	2.1 abc
Oxadiazon – propanil EC	0.6 – 1.8	10 DT	96	8	2.0 abc
Butachlor EC	1.0	4 DT	21	7	2.0 abc
Thiobencarb EC	3.0	4 DT	44	2	1.9 abc
Oxadiazon – 2,4-D IOE[f]	0.125 – 0.125	PP	82	11	1.8 abc
Thiobencarb – 2,4-D IPE G	1.0 – 0.5	4 DT	101	18	1.7 bc
Hand-weeded control	Twice	15 + 30 DT	0	10	3.1 a
Untreated control	–	–	214	117	0.9 c

[a]EC = emulsifiable concentrate, G = granule. A spaced dash (–) means that 2 herbicides were formulated on the same carrier and applied as a single treatment. IPE = isopropyl ester, IOE = isooctyl ester. [b]Active ingredient. [c]DT = days after transplanting; PP = preplant application. [d]Taken at heading stage of grasses. [e]Av of 2 replications. Means followed by the same letter are not significantly different at 5% level. [f]Applied without dilution with sprinkler bottle.

Table 9. Effect of different herbicides on weed control and yield of wet-seeded IR36 rice grown under irrigated conditions. IRRI, 1979 wet season.

Herbicide treatment[a]	Application		Weed wt[d] (g/m²)			Visual toxicity rating[e]	Yield[f] (t/ha)
	Rate (kg a.i.[b]/ha)	Time (DS[c])	Broadleaf weeds	Grasses	Sedges		
X-150 EC	2.0	6	1	7	7	0	4.4 a
Propanil EC	3.0	10	1	5	3	5	4.3 a
Butachlor + propanil EC	0.5 + 0.75	10	2	13	1	2	4.2 ab
KCO_{25} G	1.0	10	1	6	2	1	4.2 ab
Thiobencarb – propanil	1.0 – 0.1	10	2	2	2	2	4.1 ab
Thiobencarb EC	2.0	10	4	5	0	0	3.7 ab
Butachlor G	0.5	10	5	5	10	2	3.4 ab
KCO_{23} G	1.0	10	1	5	1	0	3.3 ab
Butachlor EC	0.5	10	2	77	1	2	2.8 ab
Thiobencarb – 2,4-D IPE G	1.0 – 0.5	6	15	70	1	7	2.2 ab
Untreated control	–	–	2	107	7	–	1.7 b

[a]EC = emulsifiable concentrate. A plus (+) indicates that the 2 liquid herbicides were tank-mixed and applied as a single treatment. G = granule. A spaced dash (–) means that 2 herbicides were formulated on the same carrier and applied as a single treatment. IPE = isopropyl ester. [b]Active ingredient. [c]Days after seeding. [d]Taken at heading stage of grasses. [e]Scale: 0–10; 0 = no toxicity, 10 = complete kill. [f]Av of 2 replications. Means followed by the same letter are not significantly different at 5% level.

Table 10. Effect of herbicides on weed control and yield of wet-seeded IR36 rice grown under rainfed conditions. IRRI, 1979 wet season.

Herbicide treatment[a]	Application		Weed wt[d] (g/m²)			Visual toxicity rating[e]	Yield[f] (t/ha)
	Rate (kg a.i.[b]/ha)	Time (DS[c])	Broadleaf weeds	Grasses	Sedges		
Thiobencarb EC	2.0	10	0	8	3	0	3.7 a
Thiobencarb – 2,4-D IPE G	1.0 – 0.5	6	1	97	2	8	3.1 ab
X-150 EC	2.0	6	1	3	1	0	2.8 abc
KCO_{25} G	1.0	10	1	42	2	2	2.7 abc
Propanil EC	3.0	10	0	41	7	3	2.7 abc
Thiobencarb – propanil	1.0 – 0.5	10	8	28	1	3	2.7 abc
Butachlor G	0.5	10	3	37	2	2	2.4 abc
KCO_{23} G	1.0	10	0	160	3	4	2.0 bcd
Butachlor + propanil EC	0.5 + 0.75	10	1	42	73	4	2.0 bcd
Butachlor EC	0.5	10	4	80	8	4	1.5 cd
Untreated control	–	–	4	25	47	–	0.8 d

[a]EC = emulsifiable concentrate. A spaced dash (–) means that 2 herbicides were formulated on the same carrier and applied as a single treatment. IPE = isopropyl ester. G = granule. A plus (+) indicates 2 liquid herbicides were tank-mixed and applied as a single treatment. [b]Active ingredient. [c]Days after seeding. [d]Taken at heading stage of grasses. [e]Scale: 0–10; 0 = no toxicity, 10 = complete kill. [f]Av of 2 replications. Any 2 means followed by the same letter are not significantly different at 5% level.

the preemergence application of butachlor and thiobencarb, dominated the plots at a later stage of crop growth, causing also zero yield.

In another experiment, the same herbicide treatments were each supplemented with 1 hand weeding 30 days after rice emergence to determine the differences in yield between the hand-weeded and the nonweeded chemical treatments.

When these herbicides and herbicide combinations received additional hand weeding, most of the treatments gave substantial yield increase (Table 12).

Control of *Cyperus rotundus*. During the 1979 wet season some preemergence and postemergence herbicides were screened at IRRI for the control of *Cyperus rotundus* in upland rice. Two preemergence herbicides — K-1441 and K-3185 — were incorporated into the topsoil during final tillage and two postemergence herbicides — bentazon and 2,4-D — were sprayed on the foliage. Sequential applications of bentazon and 2,4-D were also tested. Pendimethalin was used to control the annual weeds, mainly *Rottboellia exaltata, Calopogonium muconoides, and Commelina ben-*

Table 11. Effects of preemergence and postemergence herbicides on weed control, crop tolerance, and yield of IR43 rice grown under upland conditions. IRRI, 1979 wet season.

Herbicide treatment[a]	Application[b]		Weed wt[c] (g/m²)			Visual toxicity rating[d]	Yield[c] (t/ha)
	Rate (kg a.i./ha)	Time	Broadleaf weeds	Grasses	Sedges		
Butachlor fb propanil	2.0 fb 2.0	PE fb 15 DE	2 c	25 c	16 ab	6	2.5 a
Thiobencarb – propanil	3.0 – 1.5	10 DE	2 c	22 abc	20 a	6	2.4 a
Propanil	3.0	15 DE	1 c	10 c	15 ab	7	2.4 a
Butachlor fb propanil	1.5 fb 2.0	PE fb 15 DE	2 c	10 c	29 a	6	2.3 a
Propanil – fenoprop	1.15 – 1.75	10 DE	1 c	23 bc	9 ab	6	2.3 a
Thiobencarb fb propanil	3.0 fb 2.0	PE fb 15 DE	1 c	17 bc	24 a	5	2.1 ab
Thiobencarb fb propanil	2.0 fb 2.0	PE fb 15 DE	4 bc	36 abc	23 a	6	2.0 ab
Thiobencarb – propanil	2.0 – 1.0	10 DE	2 c	29 abc	17 ab	4	1.9 ab
Propanil fb propanil	1.5 fb 1.5	10 fb 20 DE	2 c	36 abc	36 a	5	1.8 ab
Thiobencarb – prometryn	2.5 – 0.5	PE	33 a	101 ab	34 a	3	1.3 b
Butachlor fb 2,4-D amine	2.0 fb 0.5	PE fb 20 DE	2 c	175 a	9 ab	1	0.6 c
Thiobencarb alone	3.0	PE	22 ab	174 a	10 ab	0	0.3 c
Thiobencarb – 2,4-D IPE	1.0 – 0.5	PE	2 c	147 abc	21 a	10	0.0 c
Thiobencarb – 2,4-D IPE	2.0 – 1.0	PE	23 ab	152 a	46 a	9	0.0 c
Piperophos – 2,4-D IPE	1.65 – 0.85	PE	30 a	162 a	96 a	10	0.0 c
Thiobencarb fb 2,4-D amine	3.0 fb 0.5	PE fb 20 DE	5 bc	166 a	8 ab	2	0.0 c
Hand-weeded control	–	15 fb 30 DE	1 c	6 c	2 b	0	2.7 a
Untreated control	–	–	11 abc	188 a	10 ab	0	0.0 c

[a]fb = followed by. A spaced dash (–) means 2 herbicides were formulated on the same carrier and applied as a single treatment. IPE = isopropyl ester. [b]a.i. = active ingredient. DE = days after emergence. PE = pre-emergence. [c]Av of 2 replications. In a column, means followed by the same letter are not significantly different at 5% level. [d]Taken at 2 wk after herbicide application. Scale: 0–10; 0 = no toxicity, 10 = complete kill.

Table 12. Effects of follow-up hand weeding on herbicide treatments on rice yield. IRRI, 1979 wet season.

Herbicide treatment[a]	Application[b]		Yield (t/ha)		
	Rate (kg a.i./ha)	Time	Chemical alone	Chemical + 1 hand weeding	Difference
Butachlor fb propanil	2.0 fb 2.0	PE fb 15 DE	2.5	2.9	0.4
Thiobencarb – propanil	3.0 – 1.5	10 DE	2.4	3.4	1.0**
Propanil	3.0	15 DE	2.4	2.5	0.2
Butachlor fb propanil	1.5 fb 2.0	PE fb 15 DE	2.3	3.2	0.9*
Propanil – fenoprop	1.15 – 1.75	10 DE	2.3	2.4	0.1
Thiobencarb fb propanil	3.0 fb 2.0	PE fb 15 DE	2.1	3.5	1.4**
Thiobencarb fb propanil	2.0 fb 2.0	PE fb 15 DE	2.0	2.8	0.9*
Thiobencarb – propanil	2.0 – 1.0	10 DE	1.9	2.3	0.4
Propanil fb propanil	1.5 fb 1.5	10 fb 20 DE	1.8	2.8	0.9*
Thiobencarb – prometryn	2.5 – 0.5	PE	1.3	2.3	1.0*
Butachlor fb 2,4-D amine	2.0 fb 0.5	PE fb 20 DE	0.6	2.5	1.8**
Thiobencarb alone	3.0	PE	0.3	2.5	2.2**
Thiobencarb – 2,4-D	1.0 – 0.5	PE	0.0	2.9	2.9**
Thiobencarb – 2,4-D	2.0 – 1.0	PE	0.0	0.0	0.0
Piperophos – 2,4-D	1.65 – 0.85	PE	0.0	0.0	0.0
Thiobencarb fb 2,4-D amine	3.0 fb 0.5	PE fb 10 DE	0.0	1.9	1.9**
Hand-weeded control	–	15 fb 30 DE	2.7	–	–
Untreated control	–	–	0.0	–	–

[a]fb = followed by. A spaced dash (–) means 2 herbicides were formulated on the same carrier and applied as a single treatment. [b]a.i. = active ingredient. PE = preemergence. DE = days after emergence.

ghalensis.

Yields of from 1.0 to 1.5 t/ha were obtained from plots treated with 2,4-D applied alone and sequentially with bentazon, which controlled *C. rotundus* by about 50% (Table 13). Yields, however, were less directly influenced by extent of *C.*

Table 13. Effects of preemergence and postemergence herbicides on the control of *Cyperus rotundus*, crop tolerance, and yield of IR9575 grown under upland conditions. IRRI, 1979 wet season.

Treatment[a]	Application[b]		Weed wt (g/m²)				Toxicity rating[c]	Yield[d] (t/ha)
	Rate (kg a.i./ha)	Time	*C. rotundus*		Annual weeds			
			6 WE	At harvest	6 WE	At harvest		
Hand-weeded check	–	2 fb 5 WE	0	12	0	129	0	1.5 a
2,4-D	0.5	3 WE	56	13	5	54	0	1.4 a
Bentazon fb 2,4-D	1.0 fb 0.5	2 fb 4 WE	43	23	2	14	0	1.3 ab
2,4-D	1.0	2 WE	39	22	1	45	5	1.1 b
2,4-D fb bentazon	0.5 fb 1.0	2 fb 4 WE	30	52	1	68	0	1.1 b
2,4-D fb 2,4-D	0.5 fb 0.5	2 fb 4 WE	30	23	17	57	0	1.0 b
2,4-D	0.5	2 WE	29	9	2	71	0	1.0 b
2,4-D	1.0	3 WE	60	71	5	120	3	1.0 b
Bentazon	2.0	3 WE	16	1	12	266	0	0.7 c
Bentazon	1.0	3 WE	81	7	17	435	0	0 d
K-1441	3.0	PPI	71	1	147	367	6	0 d
K-3185	3.0	PPI	26	4	81	263	8	0 d
K-3185	1.5	PPI	74	2	90	362	5	0 d
K-1441	1.5	PPI	86	11	41	230	4	0 d
Pendimethalin	2.0	2 DS	99	3	34	317	0	0 d
Untreated check	–	–	85	1	210	475	0	0 d

[a]Pendimethalin at 2.0 kg/ha was applied at preemergence to all plots, except the check, to control annual weeds. fb = followed by. [b]a.i. = active ingredient. WE = weeks after crop emergence. PPI = preplanting incorporation. DS = days after seeding. [c]Taken at 1 WE and 1 wk after application of postemergence herbicides. Scale 0–10; 1 = no toxicity, 10 = complete kill. [d]Av of 3 replications. Means followed by the same letter are not significantly different at 5% level.

rotundus control than by regrowth of the annual weeds.

FACTORS AFFECTING CULTIVAR COMPETITIVENESS AGAINST WEEDS

Cultivar. When 10 rice cultivars were sown at 100 kg/ha in rows spaced 25 cm apart and subjected to different weeding treatments, the cultivar grown did not affect total weed weight at maximum flowering of the weeds when the plots were not weeded or were weeded two or three times. When the plots were weeded once, weeds growing in association with IR38 and IR46 had significantly greater weight than weeds growing with IR28, IR36, IR40, IR42, IR44, and IR2823-399-5-6.

Yields were not analyzed because of severe rat damage.

Cultivar and seeding rate. When 3 rice cultivars (IR36, IR42, and IR2823-399-5-6) were dry seeded at 100 kg/ha in rows spaced 15, 25, and 35 cm apart, and subjected to various weeding regimes, weed weight at maximum flowering of the weeds (80 DE) was unaffected by cultivar grown and plant spacing for all weeding regimes. When the plots were weeded once 80 DE, there was no significant difference in weed weight between cultivars. But when the crops were not weeded or were weeded two or three times, differences in weed weights between cultivars were significant. In the unweeded plots fewer weeds grew in association with IR42 than with IR2823-399-5-6. In the plots weeded three times, fewer weeds grew in association with IR36 than with IR42. In the plots weeded twice fewer weeds grew in association with IR2823-399-5-6 than with IR42. No other differences were significant.

The differences in weed growth were not reflected in grain yield. When the plots were not weeded, the cultivar produced no grain (Table 14). At the other levels of weeding, IR2823-399-5-6 yielded significantly higher than the other cultivars. In plots weeded twice, IR42 yielded significantly higher than IR36.

Seeding rate and seeding method. In Iloilo, IR36 was either broadcast or sown at 80, 120, and 160 kg/ha in rows spaced 25 cm apart. The major weeds present were *Echinochloa colona* and *Leptochloa chinensis* in untreated plots and *Commelina diffusa* in pendimethalin-treated plots.

The method and rate of seeding had no effect on weed weight 65 DE. The average weed weight

Table 14. Weed weight and grain yield of rice as affected by cultivar grown and weeding regime.[a] IRRI, 1979 wet season.

Treatment[b]	Weed wt[c] (g/m^2)	Yield[d] (t/ha)		
		IR36	IR42	IR2823-399-5-6
Weeded three times 2, 5, and 8 WE	10.0 d	2.5 a	2.6 a	4.0 a
Weeded twice, 2 and 5 WE	14.2 c	1.9 ab	2.7 a	4.1 a
Weeded once, 2 WE	54.0 b	1.4 b	1.4 b	3.0 b
Not weeded	429.0 a	0 c	0 c	0 c

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]WE = weeks after crop emergence. [c]At max flowering of the weeds. Av of 3 replications, 3 row spacings, and 3 cultivars. Analysis based on transformed data. [d]Av of 3 replications and 3 row spacings.

Table 15. Effects of planting method, seeding rate, and weed control method on yield of dry-seeded IR36 rice.[a] Iloilo Province, Philippines, 1979 wet season.

Treatment[b]	Yield (t/ha) at seeding rate of		
	80 kg/ha	120 kg/ha	160 kg/ha
Broadcast-seeded			
Weeded once, 3 WE	4.9 a	4.9 a	4.2 ab
Weeded twice, 2 and 5 WE	3.8 ab	4.8 a	5.1 a
Pendimethalin PE fb hand weeding 5 WE	3.6 ab	3.5 a	3.0 ab
Pendimethalin PE	1.8 bc	0.9 b	2.8 b
Unweeded	0.0 c	0.0 b	0.0 c
Row-seeded			
Weeded once, 3 WE	3.8 ab	4.7 a	5.2 a
Weeded twice, 2 and 5 WE	4.7 a	6.2 a	4.6 a
Pendimethalin PE fb hand weeding 5 WE	3.1 ab	2.4 b	4.7 a
Pendimethalin PE	2.1 bc	0.5 b	1.9 b
Unweeded	0.4 c	0.3 b	0.0 b

[a]Av of 3 replications. In a column, in each planting method, means followed by a common letter are not significantly different at the 5% level. [b]WE = weeks after crop emergence; PE = preemergence, pendimethalin applied at 2 kg active ingredient/ha; fb = followed by.

across planting methods and seeding rates in the unweeded check plots was 452 g/m^2. The effect of this heavy weed growth was reflected in the low yield of the unweeded plots (Table 15). Thus, with high weed densities, rice seeding rates up to 160 kg/ha will not aid in weed control.

METHODS OF LAND PREPARATION FOR WEED CONTROL IN DRY-SEEDED RICE

Stale seedbed. In Pangasinan Province, method of seeding (broadcast or drilled in rows spaced 35 cm apart) and seeding rate (100 or 150 kg/ha) had no significant effect on weed population or crop yield. The effects of method of land preparation (conventional vs stale seedbed) and postplanting weeding on weed control were also examined.

Use of the stale seedbed technique reduced the number of weeds, primarily *E. colona*, by 59% and the fresh weed weight by 78% 2 weeks after crop emergence (WE) (Table 16). Butachlor application decreased grassy weeds by 30% but had no effect on the fresh weed weight at 6 WE.

Hand weeding of the butachlor-treated plot 3 weeks after treatment took an equivalent of 456 hours/ha in the conventionally prepared plots and 246 hours/ha in the stale seedbed plots.

In the conventionally prepared plots the yield of the plots treated with butachlor followed by hand weeding was significantly higher than that of the plots treated with butachlor only or that of the unweeded plots, which did not differ significantly

Table 16. Effects of method of land preparation and weeding regime on the weight of weeds and yield of dry-seeded IR36 rice.[a] Pangasinan Province, Philippines, 1979 wet season.

Weed control method[b]	Fresh weed wt (g/m^2)	Yield (t/ha)
Conventional land preparation		
Butachlor PE fb hand weeding 3 WE	80 b	3.2 a
Butachlor PE	1172 a	2.1 b
No weeding	1120 a	1.7 b
Stale seedbed		
Butachlor PE fb hand weeding 3 WE	44 b	2.1 a
Butachlor PE	228 a	1.7 a
No weeding	244 a	1.7 a

[a]Av of 3 replications, 2 seeding methods, and 2 rates of seeding. In a column in each land-preparation method, means followed by a common letter are not significantly different at the 5% level. [b]Butachlor applied at 2.0 kg active ingredient/ha; PE = preemergence; WE = weeks after crop emergence; fb = followed by.

from each other (Table 16). Yields in the stale seedbed plots were lower than those in the conventionally prepared plots because the crop suffered more from zinc and iron deficiency and moisture stress.

In another trial, the weeds were allowed to grow for several weeks after land preparation and were killed either with paraquat or by an additional plowing and harrowing. At 6 WE, the fresh weights of weeds in all the weed-control treatments in the stale seedbed plots were significantly lower than those in the conventionally tilled plots. The differences in fresh weights of weeds between the stale seedbed methods used were not significant. Treatment with herbicides and with herbicides followed by hand weeding significantly reduced weed weight in the conventionally tilled plots and the stale seedbed plots where paraquat was used (Table 17).

In a similar trial in Iloilo Province, where the major weeds were *Cyperus iria* and *Ludwigia* sp., the unweeded plots did not yield significantly lower than the hand-weeded check when either paraquat or glyphosate was used to kill the newly emerged weeds before planting. However, yields were significantly depressed by weeds when the land was prepared conventionally or the newly emerged weeds were killed by plowing and harrowing. The herbicides used in these plots (thiobencarb, butralin, pendimethalin, and dinitramine) failed to control the weeds adequately. As a result yields from plots treated with these compounds were not significantly different from that of the untreated check.

Land preparation during the dry season. After harvest of transplanted rice, three land-preparation treatments were tested:

- the field was kept weed free by tillage until dry-seeded rice was planted,
- mungbean was planted following conventional land preparation and the land tilled immediately after mungbean harvest during the dry season,
- mungbean was planted following conventional land preparation and the field was not plowed after mungbean harvest until the rainy season.

Land preparation to keep the land weed free dur-

Table 17. Fresh weed weight 6 wk after crop emergence and yield of dry-seeded IR36 rice as affected by land-preparation and weed-control methods.[a] Pangasinan Province, Philippines, 1979 wet season.

Weed control treatment[b]	Weed wt (g/m^2)			Yield (t/ha)		
	Conventional land preparation	Stale seedbed		Conventional land preparation	Stale seedbed	
		Paraquat[c]	Plow-harrow		Paraquat[c]	Plow-harrow
Thiobencarb, 3.0 kg a.i./ha PE fb hand weeding 3 WE	120 c	14 c	22 b	3.4 a	3.3 a	3.2 a
Butachlor, 2.0 kg a.i./ha PE fb hand weeding 3 WE	72 c	16 c	26 b	2.8 b	3.1 a	3.0 ab
Thiobencarb, 3.0 kg a.i./ha PE	600 b	94 b	212 a	2.1 c	3.0 a	3.0 ab
Butachlor, 2.0 kg a.i./ha PE	782 ab	170 b	184 a	2.0 c	2.8 a	2.8 ab
No weeding	1052 a	296 a	266 a	1.4 d	2.9 a	2.5 b

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]a.i. = active ingredient; PE = preemergence; fb = followed by; WE = weeks after crop emergence. [c]Applied at 0.5 kg a.i./ha.

ing the dry season led to a significant reduction in the number of *C. rotundus* 2 WE and in their weight 6 WE. Postemergence herbicides used to control *C. rotundus* significantly reduced weed weight only when the land was prepared at the start of the rainy season (Table 18). When land was prepared after mungbean, the postplanting application of a herbicide did not significantly reduce *C. rotundus* infestation. Broadleaf weeds were also controlled by the postemergence herbicide application but grasses were not controlled by any treatment.

CONTROL OF IMPORTANT WEEDS IN DRY-SEEDED RICE

C. rotundus. In the Lipit Area, Pangasinan Province, different methods of land preparation following a mungbean crop that had been grown on conventionally tilled land had no effect on the number of *C. rotundus* or the other weeds 2 WE. Ten WE, the weight of *C. rotundus* was substantially reduced by bentazon applied 2 WE, by bentazon applied 2 WE followed by 2,4-D 3 WE, and by hand weeding 2 and 5 WE (Table 19). 2,4-D applied at 2 WE at 0.5 kg a.i./ha had no effect on *C. rotundus*. The broadleaf weed population, primarily *C. diffusa* and *Alternanthera sessilis*, was greatly reduced by 2,4-D and by bentazon followed by 2,4-D.

The growth of grasses, primarily *E. colona*, increased in the plots treated with bentazon followed by 2,4-D, which greatly suppressed the *C. rotundus* and broadleaf weeds. Weed growth was enhanced despite a preemergence application of butachlor to all plots, except the unweeded ones, to control annual weeds. Butachlor controlled only about 70% of the grassy weeds and the remaining ones grew vigorously and competed severely with the crop, resulting in yield reductions.

The average yield from the weeded plots was low (2.5 t/ha) because of moisture stress. Even

Table 18. Effect of land-preparation and weed-control methods on the fresh weight of *Cyperus rotundus* 6 wk after emergence (WE) of dry-seeded rice.[a] Pangasinan Province, Philippines, 1978–1979 dry season and 1979 wet season.

Weed control method[b]	Time of application (WE)	Fresh wt of *C. rotundus* (g/m²)		
		Weed-free fallow	Plowed after mungbean harvest	Plowed at start of rain
Unweeded	–	136 a	328 a	596 a
2,4-D, 0.5 kg a.i./ha	2	118 a	178 a	300 ab
Bentazon, 2.0 kg a.i./ha	2	46 a	88 a	160 bc
2,4-D, 0.5 kg a.i./ha fb 2,4-D, 0.5 kg a.i./ha	2 fb 4	104 a	154 a	66 c
Hand weeded	3	58 a	106 a	198 abc

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]a.i. = active ingredient; fb = followed by.

Table 19. Effect of postemergence herbicide application on the control of *Cyperus rotundus* and annual weeds 10 wk after emergence (WE) and on the yield of dry-seeded rainfed bunded rice.[a] Pangasinan Province, Philippines, 1979 wet season.

Treatment[b]	Weed wt (g/m²)				Yield (t/ha)
	Cyperus rotundus	Broadleaf weeds	Grasses	Total	
Hand weeding, 2 and 5 WE	148	18	18	184	2.5
Bentazon, 2.0 kg a.i./ha fb 2,4-D, 0.5 kg a.i./ha	56	22	1336	1414	1.1
Bentazon, 2.0 kg a.i./ha	128	508	898	1534	0.5
2,4-D, 0.5 kg a.i./ha	470	104	436	1010	0.3
Untreated	468	854	710	2032	0.0

[a]Av of 3 replications and 5 land-preparation methods. [b]a.i. = active ingredient; fb = followed by.

though the treatment in which bentazon was followed by 2,4-D greatly suppressed the *C. rotundus* and broadleaf weeds, the inability of the preemergence herbicide to control the grasses caused the 1.4-t/ha yield reduction (Table 19).

C. rotundus can be controlled adequately by tillage or herbicides but such information is of little use without control of annual grasses in dry-seeded rice.

Trianthema portulacastrum. *T. portulacastrum* in dry-seeded rice in the Caaringayan area, Pangasinan, overtops the rice plants within 2 to 3 weeks of emergence. Two preemergence and three postemergence herbicides were tested in a field where there was about 90% *T. portulacastrum*. The other weeds were primarily *E. colona* and *C. rotundus*.

Neither the preemergence application of butachlor nor that of thiobencarb controlled *T. portulacastrum* although both delayed its emergence slightly (Table 20). Likewise, postemergence application of MCPA and 2,4-D had no effect on the weed. Propanil applied 5 or 10 days after crop emergence (DE) almost completely controlled it. Only those plots treated with propanil yielded significantly higher than the unweeded check.

At 5 WE, when *T. portulacastrum* was starting to die because of insect attack and the other weeds were becoming more competitive, all plots were weeded to determine the effect of *T. portulacastrum* control on yield. None of the herbicides tested reduced the grass or sedge population.

HERBICIDE USE

Herbicide rates for dry-seeded rainfed rice. The effectiveness of different rates of butachlor and thiobencarb was determined in a dry-seeded rice trial in Pangasinan Province. Neither herbicide significantly reduced the rice stand at any of the rates used. The lowest rates of herbicides were as effective as the highest rates and resulted in a significant reduction in the number of grasses, primarily *E. colona*, and broadleaf weeds, primarily *C. diffusa* 2 WE.

At 6 WE, the initial weed control by herbicide application was no longer apparent. Even at 3 WE, considerable time had to be spent in removing the weeds from the plots previously treated with herbicide (Table 21). The use of herbicides saved 23-49% of the time spent on weeding.

Yields from all plots that received herbicide treatment followed by hand weeding were not significantly different from that of the hand-weeded check but were significantly higher than those from the plots treated with herbicide alone and the unweeded check. Of the plots treated with herbicide alone, only those treated with thiobencarb at 2.0 kg a.i./ha and those treated with butachlor at 1.5 kg a.i./ha yielded significantly higher than the unweeded check (Table 21).

A preemergence herbicide treatment followed by a hand weeding results in high yields in dry-seeded rice. Results from this trial suggest that it should be possible to reduce the rate of butachlor

Table 20. Effect of different herbicide treatments on the control of *Trianthema portulacastrum* and other weeds and on the yield of dry-seeded IR36 rice.[a] Pangasinan Province, Philippines, 1979 wet season.

Treatment[b]	Rate (kg a.i.[c]/ha)	Time of application[d]	*T. portulacastrum* (no./m^2) (14 DE)	Yield (t/ha)
Propanil	3.0	5 DE	22 b	3.6 a
Propanil	3.0	10 DE	14 b	3.5 ab
Weeded twice	–	21 fb 35 DE	230 a	3.4 abc
Butachlor	2.0	PE	166 a	3.2 abcd
Thiobencarb	3.0	PE	184 a	3.1 abcd
2,4-D	0.5	10 DE	206 a	2.8 abcd
Weeded once	–	35 DE	282 a	2.5 c
MCPA	0.5	10 DE	272 a	2.5 cd

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]All herbicide-treated plots were weeded 35 days after crop emergence (DE). [c]a.i. active ingredient. [d]fb followed by; PE preemergence.

Table 21. Fresh weed weight 6 wk after emergence, time required for weeding 3 wk after crop emergence (WE), and yield of dry-seeded rice IR36, as affected by different weeding treatments.[a] Pangasinan Province, Philippines, 1979 wet season.

Treatment[b]	Herbicide rate[c] (kg a.i./ha)	Weed wt (g/m^2)	Time required for weeding 3 WE (man-h/ha)	Yield (t/ha)
Butachlor fb HW, 3 WE	2.0	350 b	778	5.0 a
Thiobencarb fb HW, 3 WE	2.5	460 b	750	4.9 a
Thiobencarb fb HW, 3 WE	3.0	406 bc	639	4.7 a
Butachlor fb HW, 3 WE	1.0	364 b	944	4.7 a
Thiobencarb fb HW, 3 WE	2.0	292 bc	653	4.6 a
Hand-weeded 2 and 5 WE	–	114 c	1292[d]	4.4 a
Butachlor fb HW, 3 WE	1.5	366 b	1000	4.3 a
Thiobencarb	2.0	1184 a	–	3.0 b
Butachlor	1.5	1500 a	–	2.3 b
Thiobencarb	2.5	1666 a	–	1.8 bc
Thiobencarb	3.0	2034 a	–	1.8 bc
Butachlor	2.0	1584 a	–	1.7 bc
Butachlor	1.0	1434 a	–	1.6 bc
Unweeded	–	1706 a	–	0.4 c

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]fb = followed by; HW = hand weeding. [c]a.i. = active ingredient. [d]First hand weeding only.

to 1.5 kg a.i./ha and that of thiobencarb to 2.5 kg a.i./ha.

Herbicide combinations for weed control in dry-seeded rainfed rice. The application of preemergence herbicides must be followed by a hand weeding to give sustained weed control and maximum yields. In Iloilo, the possibility of eliminating the follow-up hand weeding by using herbicide combinations was examined in four fields. Residual herbicides (butachlor, butralin, and thiobencarb) were either applied preemergence and followed by a contact herbicide (propanil) at the two- to three-leaf stage of the grassy weeds, or applied in combination with the propanil at the two- to three-leaf stage of the grassy weeds.

In one field, *E. colona* grew so intensely that none of the herbicide treatments controlled it. In 2 fields where the dry weights of weed at crop harvest were 126.7 and 353.2 g/m^2, all the herbicide-treated plots, except those treated with a combined application of butachlor and propanil, yielded as well as the hand-weeded check and significantly higher than the untreated check.

In the fourth field, where the dry weight of weeds at crop harvest was 751.8 g/m^2, all the plots where the residual herbicide was applied in combination with the contact herbicide yielded significantly higher than the unweeded check and not significantly lower than the hand-weeded plot. None of the plots where the herbicide was applied sequentially yielded significantly higher than the unweeded check.

Herbicide damage to dry-seeded rainfed rice. When applied immediately after seeding or after a rain had initiated germination, all herbicides caused some damage to IR36. Dinitramine caused the greatest damage at both these application times. Pendimethalin applied immediately after seeding was the second most toxic, and oxadiazon applied after a germinating rain, the third. When applied 4 days after the germinating rain, the herbicides caused little damage to IR36. When applied 4 DE, they caused no damage.

The time of herbicide application had no effect on the degree of weed control achieved with butachlor and thiobencarb (Table 22). Oxadiazon gave the best weed control when it was applied 4 days after the germinating rain. Pendimethalin and dinitramine when applied immediately after seeding gave the poorest weed control.

Weed weights in plots where the herbicides were applied immediately after seeding were not significantly lower than that in the unweeded check. When the herbicides were applied immediately after the germinating rain, only pendimethalin significantly reduced weed weight.

Table 22. Effect of time of herbicide application on total weed weight 3 wk after crop emergence.[a] IRRI, 1979 wet season.

Time of application	Total weed wt (g/m^2)				
	Butachlor (2.0 kg a.i./ha)	Pendimethalin (2.0 kg a.i./ha)	Oxadiazon (1.75 kg a.i./ha)	Dinitramine (1.5 kg a.i./ha)	Thiobencarb (2.0 kg a.i./ha)
Immediately after seeding	105.6 a	308.2 a	124.6 a	205.4 a	158.2 a
Immediately after germinating rain	120.0 a	78.0 b	125.0 a	143.4 ab	126.4 a
4 days after germinating rain	172.2 a	115.8 b	43.0 b	89.8 b	112.0 a
4 days after emergence	154.8 a	103.4 b	127.4 a	88.8 b	159.0 a

[a]Av of 3 replications. In a column, means followed by the same letter are not significantly different at the 5% level. The av weed wt in the unweeded check was 196.6 g/m^2. a.i. = active ingredient.

Plots treated with oxadiazon and dinitramine 4 days after the germinating rain had significantly lower weed weight than the unweeded check. Only dinitramine applied 4 DE significantly reduced weed weight.

Either the degree of weed control achieved with all herbicides was so poor or their residual effect was so short that all plots had to be weeded 4 WE to prevent total crop failure.

The time required for weeding, averaged across all times of herbicide application, ranged from 1,107 hours/ha for oxadiazon to 1,504 hours/ha for thiobencarb, compared with 1,759 hours/ha for the plot that had received no herbicide. There was some variation in the time required for weeding depending on the degree of weed control achieved but in all instances, except one, hand weeding following herbicide application required more than 1,000 hours/ha. When oxadiazon was applied 4 days after the germinating rains, hand weeding required only 933 hours/ha.

Crop yields were low in all cases. The average yield was 1.0 t/ha. The plot that was hand weeded 2 and 5 WE yielded only 0.9 t/ha; the plot that was weeded 4 WE yielded only 0.2 t/ha. The only treatment involving a herbicide that yielded as well as the hand-weeded check across all application methods was oxadiazon.

Cultivar tolerance for herbicides. Herbicide injury in rice is influenced by the location of the first node in relation to the treated soil layer. Cultivars whose first nodes are near the soil surface (those with long mesocotyls) are susceptible to preemergence herbicides while those with short mesocotyls are tolerant. BR118-3B-17, which has a short mesocotyl, was previously found to be tolerant of pendimethalin, butachlor, and thiobencarb, while BR223-B-3, which has a long mesocotyl, was susceptible to these herbicides. Both cultivars have TKM6 as a parent. The other parent of BR118-3B-17 is Habiganj Aman VII and the other parent of BR223-B-3 is Habiganj Aman II. Table 23 shows the mesocotyl and coleoptile lengths of these cultivars and Nam Sagui 19 planted 4 cm deep.

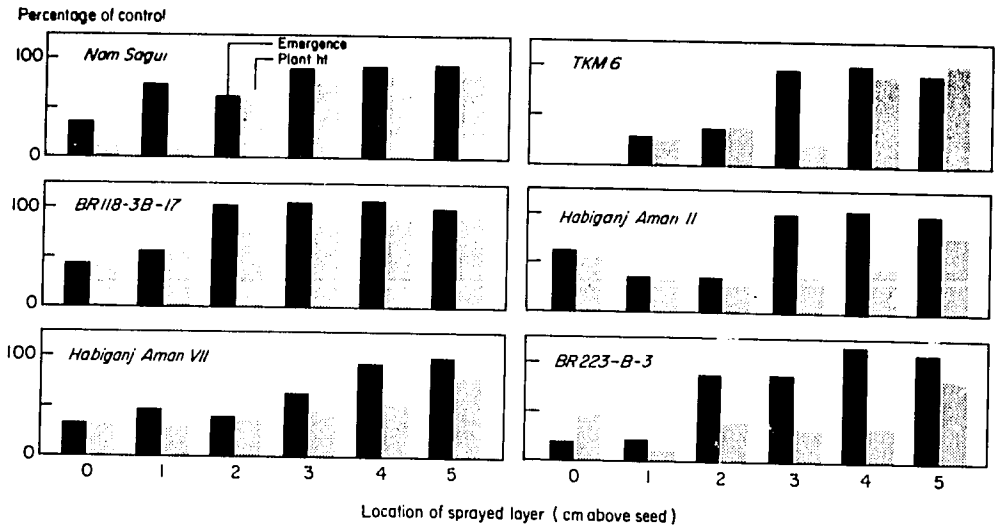
These cultivars showed no visible injury when they were seeded 5 cm deep and the soil surface was treated with 2 kg a.i. butachlor/ha (Fig. 1). As the sprayed layer moved closer to the seed, stand and plant height progressively decreased. When the seed was sprayed directly with the herbicide, TKM6 was completely killed and the other cultivars showed marked stand reduction. Habiganj Aman II and BR223-B-3, on the other hand, showed greater reduction in emergence and more injury when the soil 1 cm above the seed was sprayed.

When pendimethalin was sprayed directly onto the seed, all the cultivars were killed (Fig. 2). Injury decreased with distance of the sprayed layer from the seed. When the herbicide was applied 4 or 5 cm above the seed, all cultivars appeared normal.

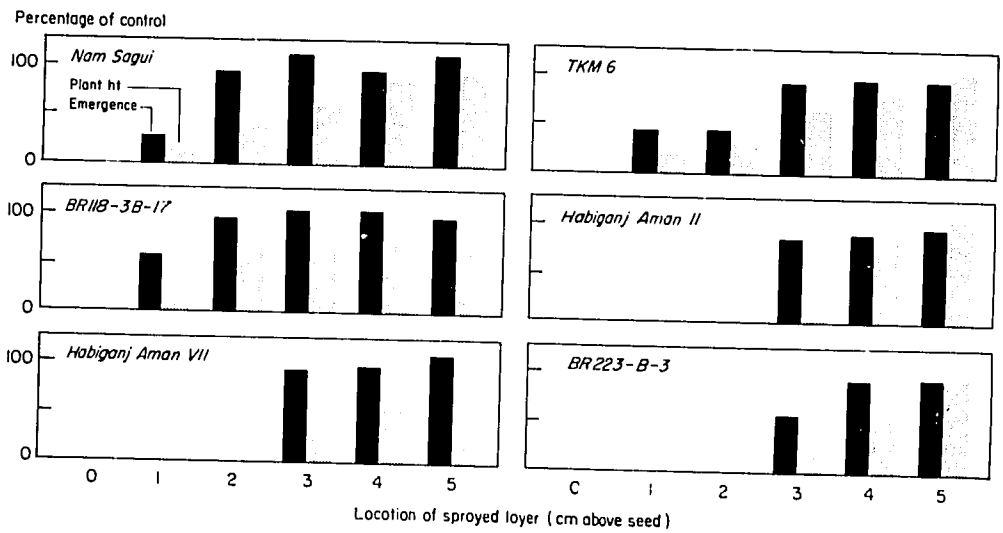
Habiganj Aman VII, Habiganj Aman II, and

Table 23. Coleoptile and mesocotyl lengths of various rice cultivars planted approximately 4 cm deep. IRRI greenhouse trial, 1979.

Cultivar	Mesocotyl length (mm)	Coleoptile length (mm)
Habiganj Aman II	30	10
BR223-B-3	26	14
Habiganj Aman VII	18	22
TKM6	10	30
Nam Sagui 19	7	34
BR118-3B-17	6	34



1. Influence of location of 2 kg butachlor ha on emergence and plant height of rice cultivars expressed as percent control. IRRI greenhouse trial, 1979.

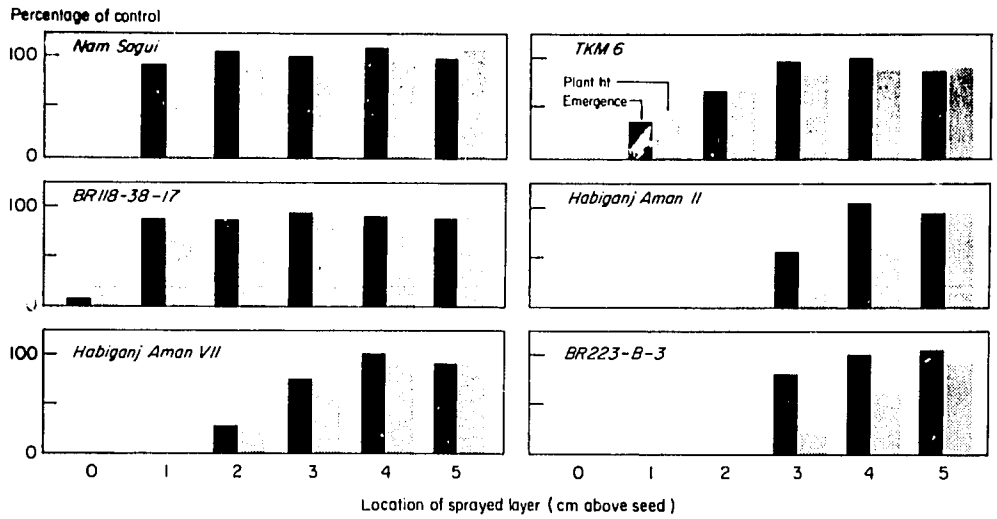


2. Influence of location of 2 kg pendimethalin ha on emergence and plant height of rice cultivars expressed as percent of control. IRRI greenhouse trial, 1979.

BR223-B-3 survived when the sprayed layer was located 3 cm above the seed. They did not survive when the sprayed layer was closer to the seed. The other cultivars survived when the sprayed layer was located 1 cm above the seed.

When seeded 5 cm deep all cultivars were unaffected by the herbicide thiobencarb (Fig. 3). The nearer the sprayed layer to the seed, the greater were the injury and stand reduction for all cultivars. However, the differences between cultivars were marked. Habiganj Aman II and BR223-B-3 survived when the sprayed layer was 3 cm above the seed; Habiganj Aman VII when it was 2 cm above the seed; and TKM6 and Nam Sagui 19 when it was 1 cm above the seed. BR118-3B-17 emerged even when the herbicide was applied directly to the seed.

Seedling mesocotyl length and herbicide resis-



3. Influence of location of 2 kg thiobencarb ha on emergence and plant height of rice cultivars expressed as percent of control. IRRI greenhouse trial, 1979.

tance. In the greenhouse it was observed that the mesocotyls of cultivars that were susceptible to preemergence herbicides were slightly shorter, whereas those of resistant cultivars were slightly longer in flooded plots than in drained plots (Table 24). Thus the resistant cultivars should be slightly more sensitive to the herbicides under flooding than under drained conditions.

In experiments on the effects of ethylene and carbon dioxide on seedling morphology of various rice cultivars, it was observed that cultivars that differ greatly in mesocotyl or coleoptile growth rates, when exposed to various gas-level manipulations, usually retain those differences in relative growth rates. Added ethylene usually promoted growth more than did added carbon dioxide although the two were usually complementary and synergistic (Table 25).

Use of antidotes to overcome herbicide injury. Phytotoxicity of herbicides such as butachlor and thiobencarb to susceptible rice cultivars can be partially overcome by the use of herbicide antidotes such as naphthalic anhydride (NA).

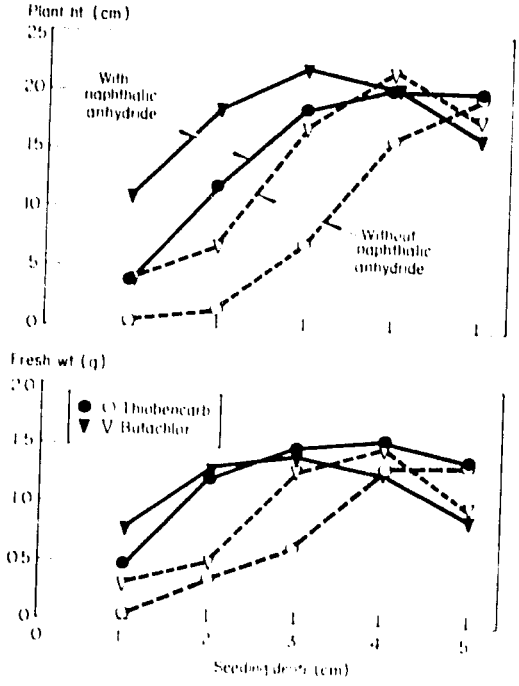
Without NA, the tolerance of both IR36 and Salumpikit for butachlor and thiobencarb increased with depth of seeding (Fig. 4, 5). Protection was partial when seed treated with NA were

Table 24. Effect of heavy watering (flooded) or very light watering (drained) on the mesocotyl and coleoptile lengths of rice cultivars susceptible or tolerant to herbicides when planted 4 cm deep. IRRI greenhouse trial, 1979.

Cultivar	Mesocotyl length (mm)		Coleoptile length (mm)	
	Flooded	Drained	Flooded	Drained
		Susceptible		
IR42	17	30	23	10
IR40	18	22	22	18
IR36	18	25	22	15
BR223-B-3	23	31	17	9
		Resistant		
Kurkaruppan	6	15	34	25
BR118-3B-17	10	9	30	31
Nam Sagui 19	13	8	27	32
BKN6986-147-2	15	13	25	27

Table 25. Effect of ethylene and carbon dioxide on seedling morphology of 2 rice cultivars 7 days after germination. IRRI greenhouse trial, 1979.

Treatment	IR5105-156-2-3		IR5105-3-3-1	
	Mesocotyl length (mm)	Coleoptile length (mm)	Mesocotyl length (mm)	Coleoptile length (mm)
Untreated check	15	32	26	18
$+CO_2-C_2H_4$	8	24	23	16
$-CO_2+C_2H_4$	10	21	15	16
$+CO_2$	20	45	26	18
$+C_2H_4$	23	46	27	16
$+CO_2+C_2H_4$	26	50	33	16
$-CO_2$	10	25	12	10
$-C_2H_4$	8	22	11	12
$-CO_2-C_2H_4$	8	13	11	13



4. Plant height and fresh weight of IR36 seedlings sprayed with thiobencarb or butachlor at 4 kg/ha. The seeds were planted 1-5 cm deep, with or without naphthalic anhydride as a herbicide antidote. The anhydride was 1% of the seed weight applied as a dry powder. IRRI greenhouse experiment, 1979.

planted only 1 cm deep. The adverse effects of the herbicides were overcome at a much shallower planting when the protectant was used than when it was not.

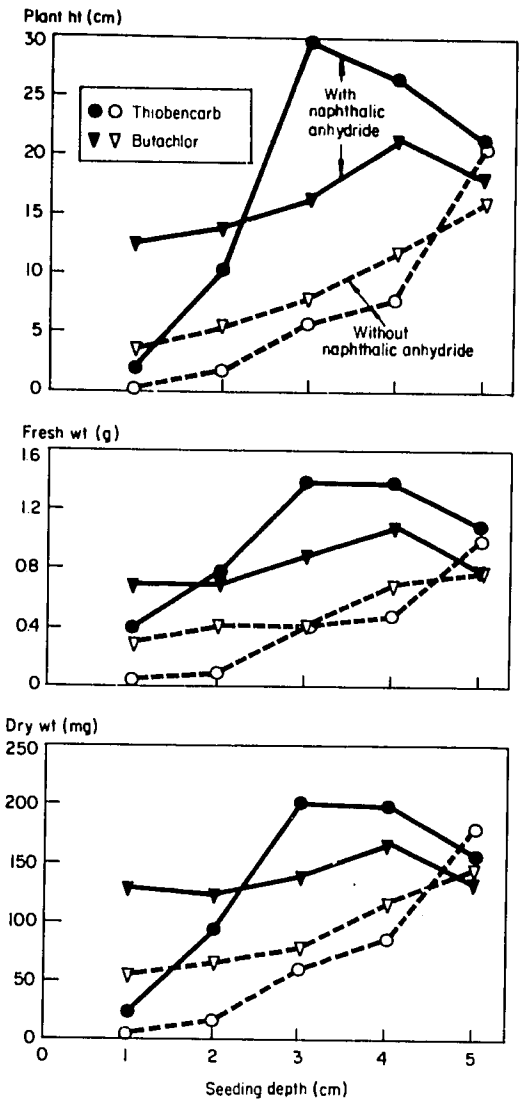
However, herbicide and cultivar interactions occur. NA gives Salumpikit greater protection against thiobencarb than against butachlor (Fig. 5). For IR36 (Fig. 4) the reverse was observed.

EFFECTS OF TIME OF HARROWING AND WEED CONTROL ON YIELDS OF IRRIGATED RICE

The effect of time of harrowing and different control methods on weed control and yields of transplanted and wet-seeded IR36 was studied at IRRI during the 1979 dry season. The field was plowed once and harrowed once at three different times: immediately after plowing, 7 days after plowing, and 14 days after plowing. Plowing was adjusted so that transplanting and seeding were done at the same time.

Transplanted rice. Twenty-one-day-old rice seedlings were transplanted 20 cm apart and treated with thiobencarb + 2,4-D IPE with and without a hand weeding follow-up, and as hand-weeded and untreated checks.

Degree of weed control varied significantly with the control method used, regardless of whether harrowing was done immediately, 7 days, or 14 days after plowing in transplanted rice (Table 26). Plots treated with thiobencarb + 2,4-D with a hand weeding follow-up and the hand-weeded check had significantly less weed infestation than plots treated with herbicide only. Without hand weeding, thiobencarb + 2,4-D did not significantly give better weed control than the untreated check. Yields did not differ significantly among the weed control treatments when harrowing was done 14



5. Plant height, fresh weight, and dry weight of Salumpikit sprayed with thiobencarb or butachlor at 8 kg/ha. The seeds were planted 1-5 cm deep, with or without anhydride as a herbicide protectant. The anhydride was 1% of the seed weight applied as a dry powder. IRRI greenhouse experiment, 1979.

days after plowing.

Wet-seeded rice. For wet-seeded IR36 (broadcast onto puddled soil) the X-52 – 2,4-D treated plots harrowed shortly after plowing, the thiobencarb – 2,4-D treated plots harrowed 7 days after plowing, and the propanil-treated plots harrowed 14 days after plowing had significantly lower weed weights than the untreated control (Table 27). However, contrary to results in transplanted rice, no differences in yield among herbicide treatments were observed when plots were harrowed either immediately or 7 days after plowing.

In general, the net effects of the different weed control measures on weed control and grain yields in both transplanted and wet-seeded rice did not vary significantly from one harrowing treatment to another. Across all harrowing treatments, however, significant increases in weed control and yields were significantly higher in the treated than in the untreated plots. These results suggest the superiority of direct weed control methods, such as hand weeding or the use of herbicides, or both, over an indirect method, such as varying of harrowing time.

MANAGEMENT AND CONTROL OF *SCIRPUS MARITIMUS*

Field experiments begun in the 1974 dry season were continued in 1979. During the 1979 dry season, the herbicide-treated and rotary-weeded plots yielded significantly higher than the untreated control (Table 28). For continuous transplanted rice, the highest yield of 3.0 t/ha from plots that received 2 rotary weedings was significantly higher than the 1.7 t/ha from plots treated with bentazon. The heavy population of the annual grasses and sedges and *S. maritimus* resulted in zero yield for the untreated check.

In a cropping pattern where maize was intercropped with soybean during the dry season, only the herbicide-treated plots had statistically higher soybean yield than the untreated control.

In a cropping pattern where maize was planted alone during the dry season, the yield differences between treatments were not significant. A high population of the annual grasses, mostly *Echinochloa* sp., and sedge *Fimbristylis littoralis*, did not greatly affect maize yield in the untreated control.

During the wet season, in the continuous transplanted rice pattern, the highest yield (2.0 t/ha) was statistically similar to that from plots that received two rotary weedings (1.1 t/ha) (Table 29). No yield was obtained from the untreated control because a high population of annual grass and sedge built up in addition to the higher population

Table 26. Effects of time of harrowing and herbicide treatments on weed control and yield of transplanted IR36 rice. IRRI, 1979 wet season.

Weed control treatment[a]	Rate (kg a.i.[b]/ha)	Time (DT[c])	Weed wt[d] (g/m²) Tillage[e] T_1	T_2	T_3	Weed control mean	Yield[d] (t/ha) Tillage[e] T_1	T_2	T_3	Weed control mean
Thiobencarb – 2,4-D fb hand weeding	1.0 – 0.5	4 fb 30	7 b	7 b	6 b	6	4.0 a	3.6 a	3.1 a	3.5
Hand-weeded check	–	20 fb 30	7 b	11 b	7 b	8	2.8 ab	3.6 a	3.2 a	3.2
Thiobencarb – 2,4-D	1.0 – 0.5	4	86 a	74 a	63 a	80	2.2 b	2.2 b	3.0 a	2.5
Untreated check	–	–	174 a	175 a	228 a	192	1.5 b	2.4 ab	2.4 a	2.1
Tillage mean[d]			68 a	70 a	76 a	72	2.6 a	3.0 a	3.0 a	2.8

[a]A spaced dash (–) means that 2 herbicides were formulated on the same carrier and applied as a single treatment. fb = followed by. [b]Active ingredient. [c]Days after transplanting. [d]Av of 3 replications. In a column or row, means followed by the same letter are not significantly different at 5% level. [e]One plowing fb 1 harrowing immediately (T_1), 7 days (T_2), and 14 days (T_3) after plowing.

Table 27. Effects of time of harrowing and herbicide treatments on weed control and yield of wet-seeded, flooded IR36 rice. IRRI, 1979 wet season.

Weed control treatment[a]	Rate (kg a.i.[b]/ha)	Time (DS[c])	Weed wt[d] (g/m²) Tillage[e] T_1	T_2	T_3	Weed control mean	Yield[d] (t/ha) Tillage[e] T_1	T_2	T_3	Weed control mean
X-52 – 2,4-D G	1.4 – 0.5	7	29 b	74 a	76 ab	60	3.4 a	2.5 a	3.9 a	3.3
Propanil EC	3.0	12	64 ab	77 ab	41 b	61	3.6 a	3.2 a	3.6 a	3.5
Thiobencarb – 2,4-D G	1.0 – 0.5	7	104 ab	52 b	99 ab	86	2.8 a	2.8 a	3.0 ab	2.8
Untreated check	–	–	145 a	108 a	174 a	135	2.1 b	3.1 a	2.4 b	2.5
Tillage mean[d]			80 a	78 a	98 a	85	3.0 a	2.9 a	3.2 a	3.0

[a]A spaced dash (–) means 2 herbicides were formulated on the same carrier and applied as a single treatment. G = granule. EC = emulsifiable concentrate. [b]Active ingredient. [c]Days after seeding. [d]Av of 3 replications. In a column or row, means followed by the same letter are not significantly different at 5% level. [e]One plowing followed by 1 harrowing immediately (T_1), 7 days (T_2), and 14 days (T_3) after plowing.

Table 28. Effects of weeding methods and cropping patterns on crop yield and population density of *Scirpus maritimus* and other weeds. IRRI, 1979 dry season.

Cropping pattern, weeding treatment[a]	Yield per ha[b]	Weeds (no./m²) Grasses	Broadleaf weeds	Sedges	*Scirpus maritimus*	*Cyperus rotundus*
Continuous transplanted rice	*Rice (t)*					
Rotary weeding	2.94 a	4	0	9	18	0
Bentazon (2 kg a.i./ha)	1.67 b	463	3	136	72	0
No weeding	0.00 c	245	18	896	295	0
Dryland crop transplanted rice	*Maize (ears) + soybean (kg)*					
Hand weeding	40,500 a + 452 a	84	1	2	15	4
Butachlor (2 kg a.i./ha) fb bentazon (1 kg a.i./ha)	33,000 a + 234 b	173	0	0	0	0
No weeding	22,000 a + 85 c	227	2	22	57	8
Dryland crop-dry-seeded-rainfed-bunded rice	*Maize (ears)*					
Hand weeding	35,000 a	87	13	60	5	5
Butachlor fb bentazon	31,500 a	70	20	0	11	59
No weeding	25,000 a	436	42	150	9	26

[a]a.i. = active ingredient. fb = followed by. [b]Av of 2 replications. Within each cropping pattern, means followed by the same letter are not significantly different at the 5% level.

Table 29. Effects of weeding method and cropping pattern on yield and population density of *Scirpus maritimus* and other weeds. IRRI, 1979 wet season.

Cropping pattern, weeding treatment[a]	Yield[b] (t/ha)	Weeds (no./m²)				
		Grasses	Broadleaf weeds	Sedges	*Scirpus maritimus*	*Cyperus rotundus*
Continuous transplanted rice						
Bentazon (2 kg a.i./ha)	2.04 a	667	5	233	72	0
Rotary weeding	1.14 ab	66	1	50	23	0
No weeding	0.00 b	574	4	1462	278	0
Dryland crop – transplanted rice						
Rotary weeding	1.88 a	46	6	27	18	0
Bentazon (2 kg a.i./ha)	1.28 a	318	8	172	2	0
No weeding	0.25 b	357	10	435	146	0
Dryland crop – dry seeded, rainfed bunded rice (1st planting)						
Hand weeding	1.46 a	4	18	34	2	26
Butachlor (2 kg a.i./ha)	0.00 b	223	62	0	3	36
No weeding	0.00 b	1029	113	579	3	0
Dry-seeded – rainfed bunded rice (2d planting)						
Hand weeding	–	5	11	20	2	15
Butachlor (2 kg a.i./ha)	–	30	43	0	4	31
No weeding	–	171	139	445	4	24

[a]a.i. = active ingredient. [b]Av of 2 replications. Within each cropping pattern, means followed by the same letter are not significantly different at the 5% level.

of *S. maritimus*.

In the dryland crop-transplanted rice pattern, the treated plots also yielded significantly higher than the untreated control.

In the first crop of dry-seeded rainfed bunded rice following maize, the only yield (1.5 t/ha) obtained was that from the plots hand weeded twice. Because of a buildup of the broadleaf *Phaseolus lathyroides*, butachlor as preemergence treatment and the untreated control gave no yield. Although butachlor initially controlled the grasses and sedges, it did not affect the broadleaf weeds and *C. rotundus* population. The second planting of dry-seeded rainfed bunded rice was disregarded after the weed count was taken because of the crop's poor stand establishment. Butachlor controlled most of the annual weeds but not *C. rotundus*, which was present because of poor accumulation of water in the plot.

Control of *Scirpus maritimus* with variety, til-

Table 30. Effects of herbicides on the control of *Scirpus maritimus* and annual weeds and on yield of transplanted rices. IRRI, 1979 dry season.

Herbicide treatment[a]	Herbicide application		Weed wt[d] (g/m²)		Yield[d] (t/ha)
	Rate (kg a.i.[b]/ha)	Time (DT[c])	*S. maritimus*	Annual weeds[e]	
Weed-free check	–		0 a	0 a	5.1 a
Butachlor fb bentazon	1.0 fb 1.0	4 fb 28	11 bcd	37 a	5.1 a
Butachlor fb 2,4-D fb hand weeding	1.0 fb 0.5	4 fb 28 fb 40	9 bc	10 a	5.1 a
Butachlor fb 2,4-D	1.0 fb 1.0	4 fb 28	24 de	20 a	5.1 a
Butachlor fb 2,4-D fb hand weeding	1.0 fb 1.0	4 fb 28 fb 40	5 b	8 a	5.0 a
Butachlor fb 2,4-D	1.0 fb 0.5	4 fb 28	42 e	33 a	4.7 a
Butachlor	1.0	4	108 f	33 a	3.9 b
2,4-D	1.0	28	18 cd	135 b	3.7 b
Untreated check	–	–	112 f	196 b	2.6 c

[a]fb = followed by. [b]Active ingredient. [c]Days after transplanting. [d]Av of 3 replications, 2 varieties, and 2 tillage levels. In a column, means followed by the same letter are not significantly different at 5% level. [e]*Echinochloa spp.*, *Monochoria vaginalis*, and *Cyperus difformis*.

Table 31. Effects of variety and tillage on *S. maritimus* control and grain yield. IRRI, 1979 dry season.

Treatment	Weed wt[a] (g/m²)			Yield[a] (t/ha)		
	IR36	IR42	Mean	IR36	IR42	Mean
One plowing + 1 harrowing	43 a	31 a	37	4.1 a	5.0 a	4.5
One plowing + 2 harrowings	33 a	39 a	36	3.9 b	4.9 a	4.4
Mean	38 a	35 a		4.0 b	5.0 a	

[a]Av of 3 replications and 9 herbicide treatments. In a row, means followed by the same letter are not significantly different at 5% level.

lage, and herbicide. During the 1979 dry season, the effects of variety, tillage, and herbicide on the control of *S. maritimus* in transplanted rice was studied at IRRI. Wet-bed seedlings of IR36 and IR42 were planted on plots with two land preparation treatments — one plowing plus one harrowing and one plowing plus two harrowings. Final harrowing in both cases was a week after plowing. Herbicide treatments were laid out on the variety and tillage treatments.

All herbicide treatments provided adequate weed control and gave yields significantly higher than that of the untreated check (Table 30). Yields from plots treated with 2,4-D, where both *S. maritimus* and the annuals were controlled, were similar to those obtained from the bentazon treatment and the weed-free check. Yields were markedly lower in plots where only *S. maritimus* was removed by a sole application of 2,4-D or only the annual weeds were removed by a sole application of butachlor than where both weed groups were controlled. The results suggest that under a mixed-weed situation where one herbicide cannot control all weeds, herbicides must be combined to obtain maximum yield return.

The interaction between variety and tillage was not significant (Table 31).

Irrigation and water management

Irrigation Water Management Department

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IRRIGATION SYSTEM MANAGEMENT IMPROVEMENT

Development of a methodology for improvement of an irrigation system continued in the 2,500-ha Lower Talavera River Irrigation System (LTRIS) project in collaboration with the National Irrigation Administration (NIA). The research component was completed in the 1979 dry season, after which an evaluation of the system's performance without IRRI researchers' intervention was started.

One measure of the physical performance of the system was the water utilization efficiency (WUE) calculated from the weekly water-balance components. High rainfall caused the 1978 wet season average WUE to drop to 45%. In the 1979 dry season, essentially no rainfall interfered with system operation, and average WUE rose to a high 73% (Table 1).

The yields from the system, by sections numbered sequentially from head to tail, for the period before to after implementation of the research project indicate the production with respect to position (Table 2). In four out of five seasons after implementation of the new management techniques, the tail section, represented by laterals G, H, and I, had either the highest yield or the yield that was not significantly different from the highest.

The management of the system was based on a week-by-week calculation of the water requirement through the conveyance network as target flows and control of the structures to deliver those amounts. For the 1978 wet season and the 1979 dry season, the interference of rainfall in the rainy season caused a wide divergence between actual water flow and target water flow (calculated without a prediction for rainfall) but there was a close correspondence between actual and target water flows in the dry season (Fig. 1). Transplanting took 11 weeks in the wet season and 10 weeks in the dry. Such farming activities adversely influenced not only the water delivery and distribution schedules in the system, but also the yields, particularly in lateral A in the dry season, where the delay in planting was most pronounced. To offset the overprediction of target allocations caused by delay in transplanting, actual water releases were closely patterned to the observed farming activities at considerable savings of water in weeks 9 to 14 and 34 to 39.

Tertiary level water distribution problems. Detailed 1979 dry-season observations were made in three rotational areas in LTRIS selected from the upstream, middle, and the tail ends of three tertiary canals. Data on irrigation inflows, crop water requirements, and farmers' water-related behavior were collected daily. In addition, the existing phys-

Table 1. Weekly mean irrigation (IR), rainfall (RN), evapotranspiration (ET), seepage and percolation (S&P), and water utilization efficiency (WUE), Nueva Ecija, Philippines, 1978 wet season and 1979 dry season.

Date	IR (mm/day)	RN (mm/day)	ET (mm/day)	S&P (mm/day)	WUE[a] (%)
		1978 wet season			
24–30 Aug	9.8	21.6	2.5	5.1	24.2
31 Aug–6 Sep	4.7	8.3	2.9	4.1	53.8
7–13 Sep	2.7	10.3	2.8	5.4	63.1
14–20 Sep	2.2	12.7	3.1	5.5	57.7
21–27 Sep	2.1	13.3	3.0	4.9	51.3
Weighted av	4.3	13.3	2.9	5.0	44.8
		1979 dry season			
1– 7 Mar	14.4	0	5.7	4.9	73.6
8–14 Mar	14.4	0	5.7	4.3	69.4
15–21 Mar	14.3	0	5.7	4.1	68.5
22–28 Mar	14.3	0	5.6	4.1	67.8
29 Mar–4 Apr	14.1	0	5.9	5.0	77.3
5–11 Apr	13.9	0	6.2	5.3	82.7
Weighted av	14.2	0	5.8	4.6	73.2

[a]Calculated using the equation: $WUE = (\frac{ET + S\&P}{IR + RN}) \times 100$.

Table 2. Mean crop-cut grain yield in consecutive sections of Lower Talavera River Irrigation System (LTRIS) from 1976 wet season through 1979 wet season, Nueva Ecija, Philippines.

Section	Lateral canal	Mean crop-cut grain yield[a] (t/ha)					
		1976[b] wet season	1977 wet season	1978 dry season	1978[c] wet season	1979 dry season	1979 wet season
1	A	2.2 a	4.2 a	2.5 a	1.7 ab	2.5 a	3.3 ab
2	B	2.6 a	4.3 a	2.4 a	1.6 b	2.8 b	3.5 b
3	D, F	3.7 b	4.3 a	3.1 a	1.9 ab	3.0 b	3.8 a
4	E	4.1 b	4.5 a	3.3 a	2.0 a	3.0 b	4.5 c
5	G, H, I	2.4 a	4.9 a	3.2 a	1.9 ab	2.8 b	4.0 a
Weighted av		3.0	4.4	2.9	1.8	2.8	3.8

[a]Separation of means within a column by Duncan's multiple range test, 5% level. [b]Benchmark season prior to management improvement. [c]Yields reduced as a result of typhoon.

ical characteristics of the sites, such as soil type, topography, and farm ditch density and gradient were thoroughly documented.

A new variable was identified to represent the water supplied to paddies relative to the crop's need for water. This relative water supply (RWS) was defined as:

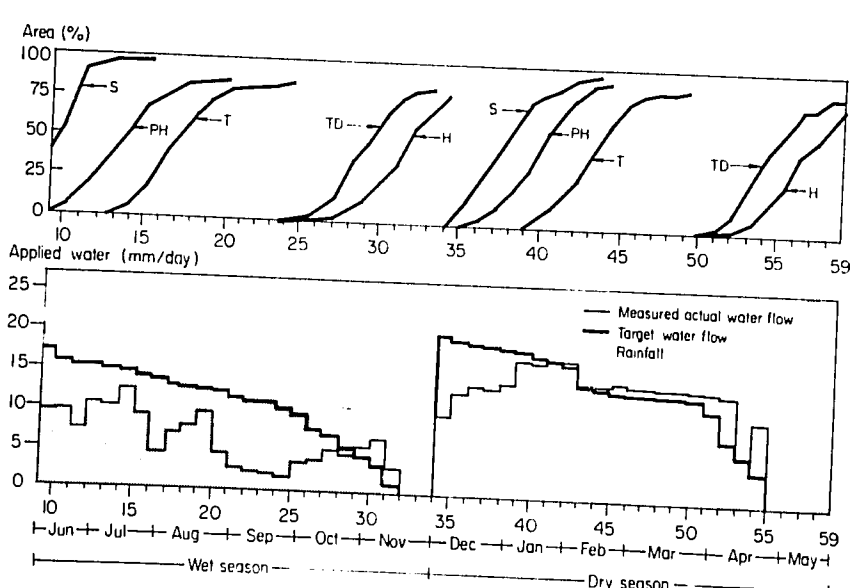
$$\text{RWS} = \frac{\text{Irrigation} + \text{rainfall}}{\text{Evapotranspiration} + \text{seepage and percolation}}$$

The most important factors affecting the availability of water on the farms were found to be (Table 3):

- paddy elevation relative to the turnout bed level,
- accessibility of the supply ditch,
- percentage of sand in the soil, and
- farm ditch density.

Further analysis showed that overland distance of the farm from the turnout becomes a problem in water distribution only when there is inadequate hydraulic head for gravity flow to the farm. This has important implications for design of irrigation water distribution systems because the current procedure does not properly account for higher elevation fields.

Farmers' usual irrigation behavior such as check-



1. Farming activities, average daily water target flow, measured actual flow, and rainfall, by weekly intervals. Lower Talavera River Irrigation System, 1978 wet and 1979 dry seasons. S = land soaking, PH = plowing and harrowing, T = transplanting, TD = terminally drained, H = harvesting.

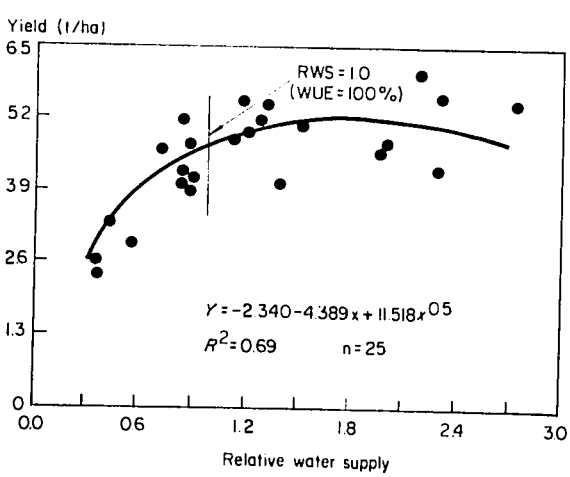
Table 3. Relative water supply regression relationship based on physical parameters from Lateral A of LTRIS, Philippines, 1979 dry season.

Variable	Estimated coefficients	T-statistic	R^2 decomposition[a]	Means
Constant (a)	0.384	–	–	–
Percent sand fraction in the soil (S)	−0.012*	−2.33	7.52	35.95
Paddy elevation relative to the turnout (Er), m	0.461**	3.58	17.70	1.55
Farm ditch density (FD), m/ha	0.006*	2.25	6.98	61.74
Farm ditch gradient (FG), m/100 m	0.258	0.47	0.31	0.23
Paddy overland distance from the turnout (OL), 100 m	0.006	0.13	0.02	5.60
Accessibility of the (supply) farm ditch – dummy (A)	0.400**	3.07	13.04	
Interaction (Er x OL)	−0.041*	−2.80	10.80	
Coefficient of determination (R^2)	75.2%			
F-statistic	7.78**			

[a]Adjusted for all other factors.

ing water flow, cutting embankments, closing and opening of turnout gates at will, and disturbing measuring devices are significantly associated with the farm ditch gradient. The inadequate slope of the farm ditch represents a serious problem for farmers which is caused by inadequate attention to topography in the design and construction of the system.

A production function for relative water supply as an input to rice yield was developed (Fig. 2). The fact that more than 69% of the yield variability could be accounted for by the water-supply aspect alone reemphasizes its importance in rice production.



2. Yield as a function of relative water supply (RWS). Lower Talavera River Irrigation System, Nueva Ecija, Philippines, 1979 dry season. WUE = water use efficiency.

A new technique to obtain farmer cooperation. An information campaign was conducted in the LTRIS system to elicit the cooperation and positive participation of the farmers in the improved system management activities. The initial stages of the campaign included farmer meetings and personal contacts among researchers, farmers, and system personnel. In the 1978 wet season, a specially designed water management calendar was introduced. The calendar follows the monthly sequence of expected farming activities based on NIA water delivery schedule, and had local language rhymes and drawings emphasizing improved water management practices. In 1979 the calendar's effectiveness was evaluated in relation to the farmers' irrigation behavior and their adoption of improved water management practices. Two particularly significant relationships were associated with the scores farmers received on level of effectiveness of the calendar. The level of effectiveness of the calendar was significantly associated with the low level of negative water management behavior of the farmers. Likewise, a significant relationship existed between the calendar's effectiveness and the credibility of NIA field personnel as an information source (Table 4).

WATER-USE PATTERNS IN DIFFERENT SCALES OF PUMP SYSTEMS

Pumps of different discharge capacities and service areas using water from surface sources were studied

Table 4. Distribution (%) of farmer's score on level of effectiveness of irrigation water management calendar with respect to negative behavior and source credibility score, LTRIS, Philippines, 1979.

Variable	Distribution (%) by level of effectiveness		
	High (10–20)	Low (0–9)	
Negative irrigation benavior			
High (> 10)	3.55	1.78	
Low (< 9)	89.94	4.73	
(N = 169)			$X^2 = 11.24^*$
Source information credibility			
High (8–14)	90.06	4.68	
Low (0–7)	3.51	1.75	
(N = 171)			$X^2 = 11.42^*$

to evaluate the effectiveness of their pumping schedules in relation to rainfall, and the pattern of irrigation water distribution and use efficiency in their service areas. Two large, three medium, and two small pump systems adjacent to the medium ones in Bulacan Province, Philippines, were studied for two consecutive seasons in 1977 and 1978, and two large pump systems were studied in Bangladesh during the 1978 dry season. The Bulacan small pumps were privately owned and operated, whereas two medium ones belonged to farmer cooperatives and one was privately owned. All large systems, both in the Philippines and Bangladesh, were nationally owned and operated.

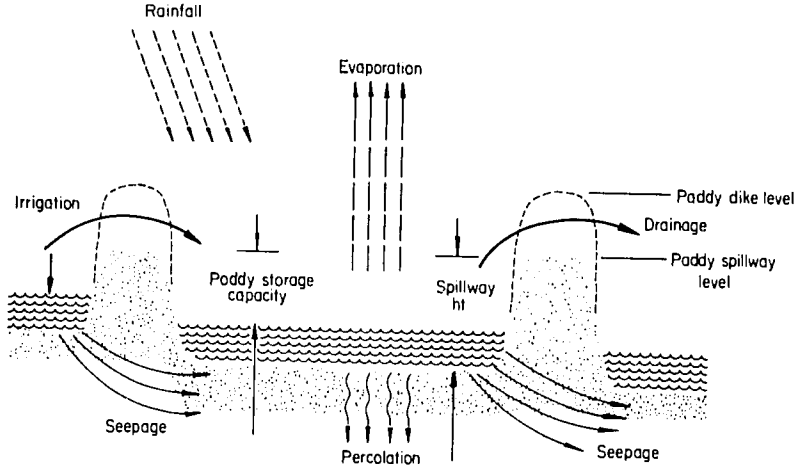
Philippine pump systems. The amount of water supplied to each pump system's service area was determined by measuring actual discharge rates and operating hours. Daily rainfall amounts and evaporation rates were measured at representative sites.

An index of water adequacy at different parts of the service area of the medium and large systems was obtained from a network of selected observation paddies representing farms at the head, middle, and tail of the main canal. Seepage and percolation (S&P) losses of water were measured in sample paddies.

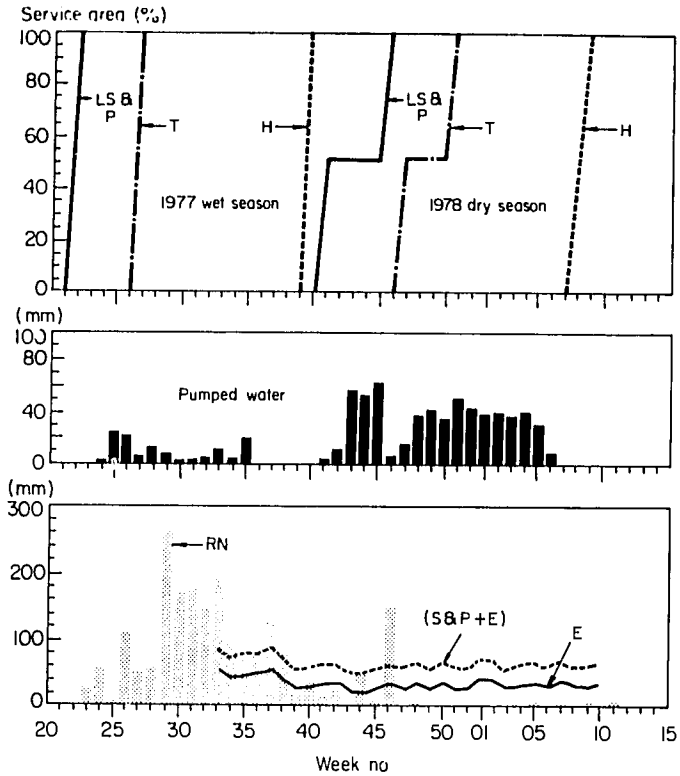
Detailed farming activities in the observation paddies were monitored and spillway heights maintained by farmers for paddy water management were recorded. Use of fertilizers was recorded through farmer interviews. Yields from the observation paddies were obtained by crop-cut samples.

Effective rainfall amounts were calculated by use of a daily water budgeting method for each sample paddy. The components used are shown in Figure 3. It was assumed that when irrigation supply and rainfall occurred on the same day, all irrigation water supply up to the top level of paddy spillway was effective. Computation was based on a large number of sample paddies monitored and budgeted daily to obtain a representative value of the effective rainfall. It provided a useful estimate of the effectiveness of rainfall in the service areas, which was extremely important in the evaluation of the pump system's performance.

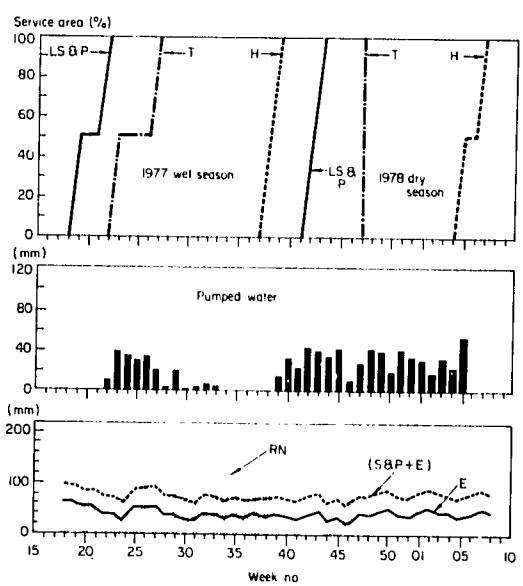
The estimation of effective rainfall allowed the



3. Paddy-level water balance components used to determine effective rainfall.



4. Pumped water, rainfall (RN), evaporation (E), and seepage and percolation (S&P) requirements, and progress of farming activities for a small-scale (Victor) pump system, Bulacan, Philippines. LS = land soaking, P = land preparation, T = transplanting, H = harvesting.



5. Pumped water, rainfall (RN), evaporation (E), and seepage and percolation (S&P) requirements, and progress of farming activities for a small-scale (Coding) pump system, Bulacan, Philippines. LS = land soaking, P = land preparation, T = transplanting, H = harvesting.

determination of irrigation efficiency (IE) defined as:

$$IE = \frac{(ET + S\&P) - R_e}{Ir} \times 100$$

where ET is evapotranspiration, S&P is seepage and percolation, R_e is amount of effective rainfall, and Ir is the irrigation water supply. Use of the IE equation removed the site specificity of the use of WUE as an index of irrigation performance because irrigation water supply was compared with the net irrigation requirement (the numerator). The equation could, therefore, be used to compare the performance of a project for different years having different rainfall amounts and also to compare IE of different projects in the same year or for different years.

Water use for land preparation. The timing of wet season land preparation and transplanting to obtain maximum benefit from the monsoon rains during the crop growth period is particularly important in pump irrigation systems. The land preparation water use aspect was analyzed in detail for all the three scales of pump systems. A weekly moving average of the fraction of total service area undergoing land preparation activities that week was considered. Water use for any part of an area already transplanted was not accounted during land preparation, but during the crop growth stage.

Figures 4 and 5 show the dynamics of pumping and farming activities in relation to rainfall amounts on a weekly basis during both the wet and dry seasons for the two small-scale systems. Both started land preparation early in the wet season and used early rainfall effectively, which helped achieve an 85% R_e during the land preparation time (Table 5).

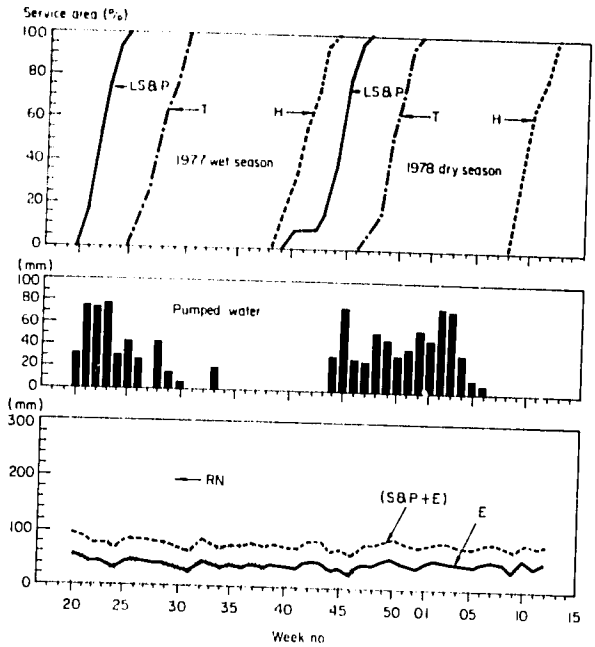
On the average, about 3.8 times more water was pumped for land preparation in the small systems in the dry season than in the wet despite 16% higher rainfall in the dry season. The reason was that in the dry season the average effective rainfall was low (52%) in these systems and one of them (Victor) took 11 weeks to complete land preparation for the whole service area in the dry season, compared with about 6 weeks in the wet season (Fig. 4).

Figures 6—8 show that two (Halina and Angat) of the three medium-scale systems made excellent use of rainfall for land preparation in the wet season. There was greater use of the pump in the third

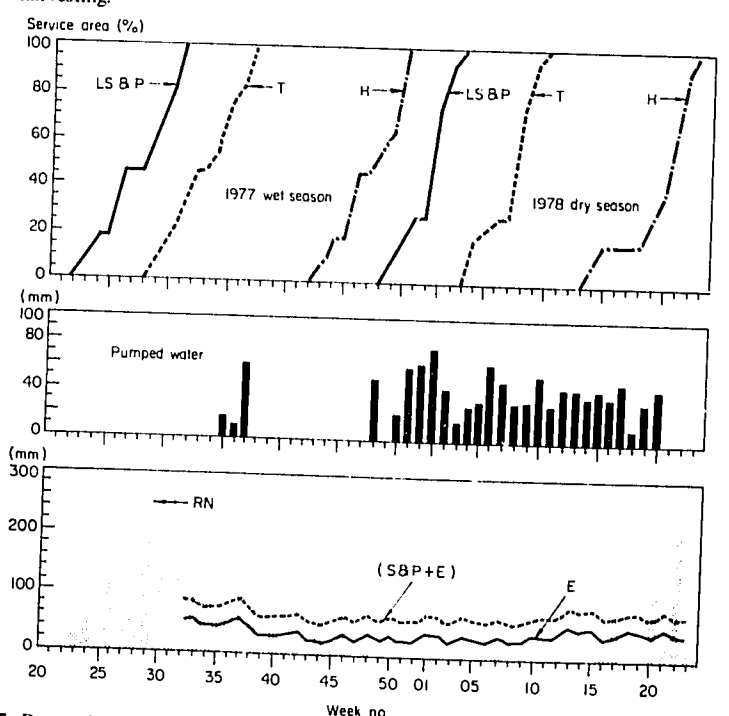
Table 5. Average amounts of water pumped, rainfall amounts, and their effectiveness during land preparation and crop growth periods for different scales of pump systems, Bulacan, Philippines, 1977 wet and 1978 dry seasons.

Pump scale	Av service area (ha)	Land preparation period			Crop growth period			Total	
		Pumped water used (mm)	Av rainfall (mm)	Effective rainfall[a] (%)	Pumped water used (mm)	Av rainfall (mm)	Effective rainfall[a] (%)	Pumped water used (mm)	Weighted effective rainfall (%)
				Wet season					
Large	472.2	139[b]	538[b]	61	93	1692	40	232	45
Medium	61.5	189	630	64	104	1264	50	293	55
Small	4.0	67	193	95	95	1385	54	162	58
				Dry season					
Large	472.2	232	224	74	848	0	–	1080	74
Medium	61.5	315	112	50	525	97	37	840	42
Small	4.0	253	224	52	365	0	–	618	52

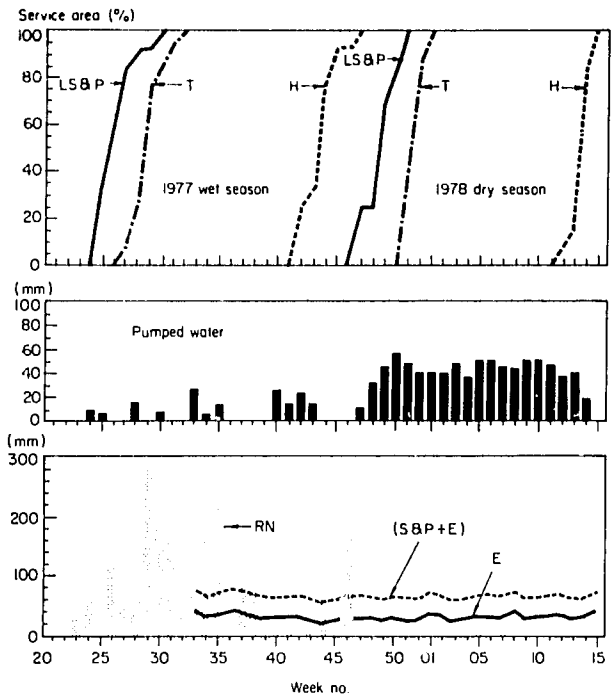
[a]Weighted av values. [b]Because no pumping was done for BPIP system, these values are shown for the BPE system only.



6. Pumped water, rainfall (RN), evaporation (E), and seepage and percolation (S&P) requirements, and progress of farming activities for a medium-scale (Halina) pump system, Bulacan, Philippines. LS = land soaking, P = land preparation, T = transplanting, H = harvesting.



7. Pumped water, rainfall (RN), evaporation (E), and seepage and percolation (S&P) requirements, and progress of farming activities for a medium scale (Angat) pump system, Bulacan, Philippines. LS = land soaking, P = land preparation, T = transplanting, H = harvesting.



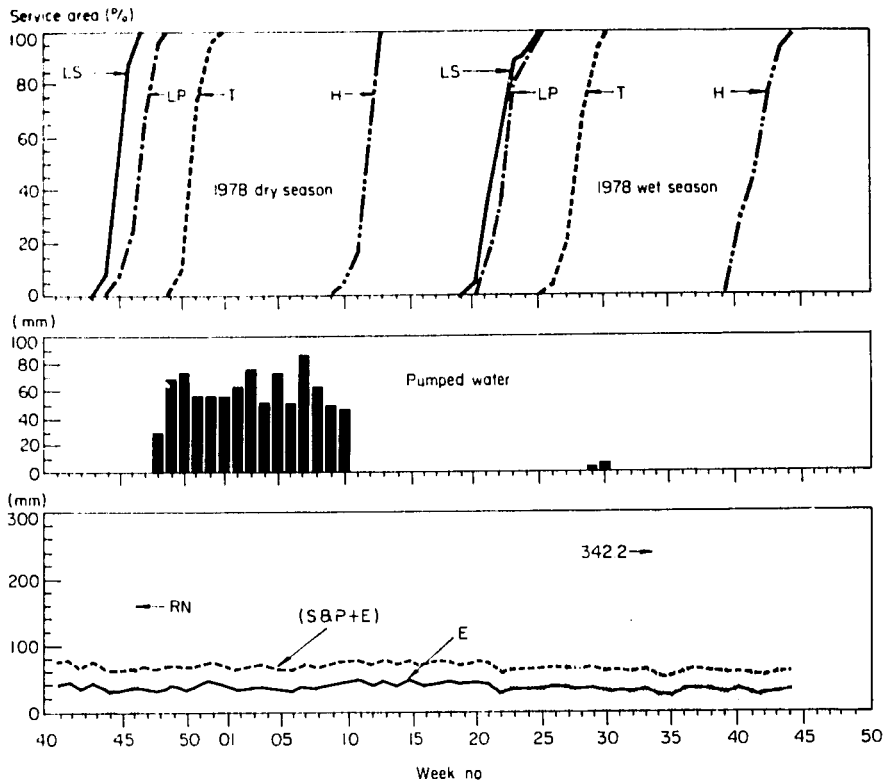
8. Pumped water, rainfall (RN) evaporation (E), and seepage and percolation (S&P) requirements, and progress of farming activities for a medium-scale (Safari) pump system, Bulacan, Philippines. LS = land soaking, P = land preparation, T = transplanting, H = harvesting.

system (Safari) because rainfall was lower than requirements. As the figures indicate, all three systems did some overpumping during crop growth period.

The Halina system had more than 500 mm of rain in the 1978 dry season, but because most of it occurred late in the season it was not of much relief to the pumping requirement (Fig. 6). The Safari system encountered shortage of water in the river and substantial pumping could not be done after week 4 in the 1978 dry season (Fig. 8). Some areas that were transplanted late suffered severe water stress. Many farmers used small pumps to obtain water from a creek. The amounts of water pumped by the small pumps were not measured. Therefore, the total pumped water recorded in the crop growth period for the Safari system during the dry season was less than the actual amount and also substantially less (386 mm) than the average of 595 mm for the two other medium-scale systems.

Of the two large-scale pumps, one (BPIP) did not do any significant amount of pumping in the 1978 wet season (Fig. 9). Weekly rainfall amounts were distributed quite favorably from start of land soaking to end of transplanting. This gave a high R_r (95%) in the system during land preparation. In contrast, substantial pumped water was used in the other large-scale system (BPE) despite the 37% higher average rainfall (538 mm) in areas undergoing land preparation than in the BPIP system (Fig. 10).

The upper portions of Figures 4—10 show farming activities. The average horizontal distance between the lines LS (land soaking), or LS and P (land preparation) and T (transplanting) represents the time an average farmer had taken between the start of land soaking and the start of transplanting. An average farmer in a smaller system took significantly less time to complete land preparation than his counterparts in larger systems in the wet season (Table 6). There was, however, no significant difference in time for land preparation among farmers of the medium-scale and small-scale pump systems in the dry season. Also farmers in the larger systems maintained higher spillway heights than those in the smaller systems. This practice by the farmers, likely



9. Pumped water, rainfall (RN), evaporation (E), and seepage and percolation (S&P) requirements, and progress of farming activities for a large-scale (BPIP) pump system, Bulacan, Philippines. LS = land soaking, P = land preparation, T = transplanting, H = harvesting.

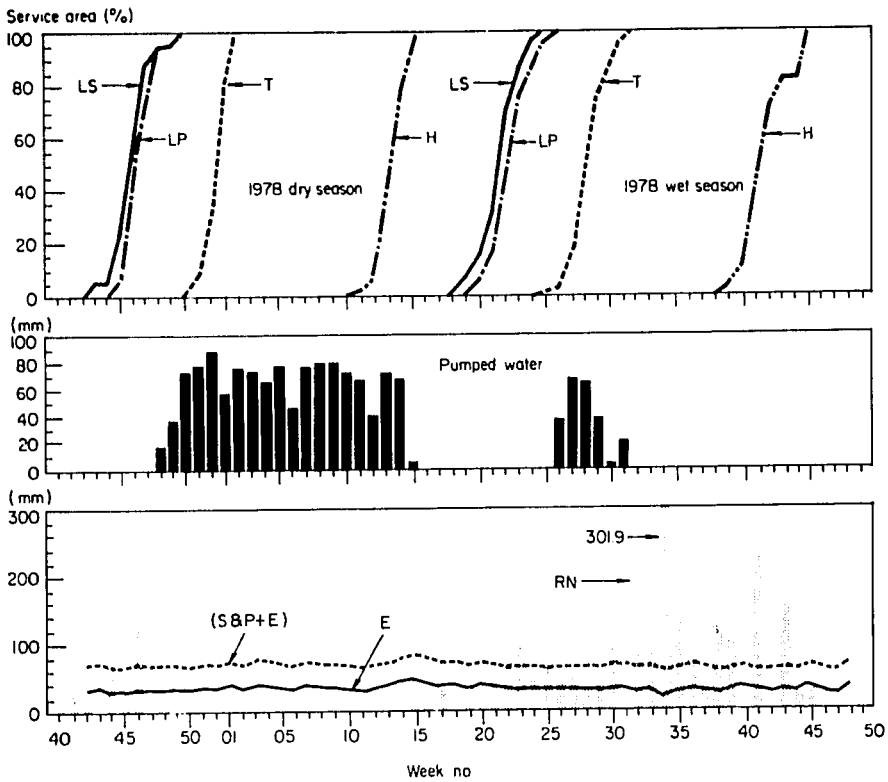
to be related to a greater degree of uncertainty in the timely obtaining of water in a larger system, resulted in a tendency to store more water in the paddy.

•*Efficiency of the outstanding Angat system.* The privately owned Angat medium-scale system was highly efficient in using water, especially during land preparation. In that system, an average of 321 and 268 mm water was used for completion of land preparation from the combined sources of pump and rainfall during the wet and dry seasons, respectively. This meant that the Angat system used 46% less water in the wet season and 27% less in the dry than the average of the other 2 medium-scale systems. Compared with large-scale systems, the Angat system used about 32% less water for land preparation during both seasons.

One major reason for less water requirements for land preparation by Angat-system farmers was that all, except those located in depressed areas where water control was difficult, used 15- or 16-day-old *dapog* (mat) seedlings whereas in all other systems farmers used the older wet-bed seedlings. Because it is a common practice for farmers to start seedbed and land preparation about the same time, the Angat-system farmers had to prepare land in a much shorter time once their seedbed had been started.

The average duration of land preparation by a farmer in the Angat system was 22 days in the wet season and 21 days in the dry compared with an average of 40 days in the wet season and 38 days in the dry, in the other 2 community-owned medium-scale pump systems. A comparison with other types of systems shows that farmers in a gravity irrigation system in Nueva Ecija Province in 1977 took an average of 41 days and Bulacan rainfed farmers during 1977 and 1978 wet seasons 39 days to complete land preparation.

The owner of the Angat system pump encour-



10. Pumped water, rainfall (RN), evaporation (E), and seepage and percolation (S&P) requirements, and progress of farming activities for a large-scale (BPE) pump system, Bulacan, Philippines. LS = land soaking, P = land preparation, T = transplanting, H = harvesting.

aged farmers to plant the same variety of rice so that crop growth duration would be the same and pumping would not have to be extended for some farmers. Use of dapog seedlings was reported by farmers in the system as economical because the cost of labor for pulling and bundling the seedlings was lower than that for wetbed seedlings. Farmers in the system paid the pump owner a water fee equivalent to 15% of harvest. In contrast, a farmer in the government-owned pump system like BPIP and BPE is charged about 200 kg grain/ha per season as water fee.

• *Water use and effective rainfall.* In the wet season, the effectiveness of rainfall use during land preparation was high (85%) for small-scale systems mainly because of that period's smaller weekly rainfall amounts. Its effectiveness during crop growth was also higher in the small-scale systems than in the other systems.

The 1978 dry season rainfall amounts during

Table 6. Average number of days taken by a farmer to prepare his land, and the height of his spillway in the paddy. Bulacan, Philippines. 1977 wet and 1978 dry seasons.

Pump system size	Days (no.) to complete land preparation[a]		Paddy spillway ht (mm)	
	Wet season	Dry season	Wet season	Dry season
Large (275–685 ha)	46.8 a	43.3 a	99	97
Medium (22–135 ha)	40.3 b	37.8 b	87	88
Small (2–6 ha)	34.0 c	35.8 b	79	79

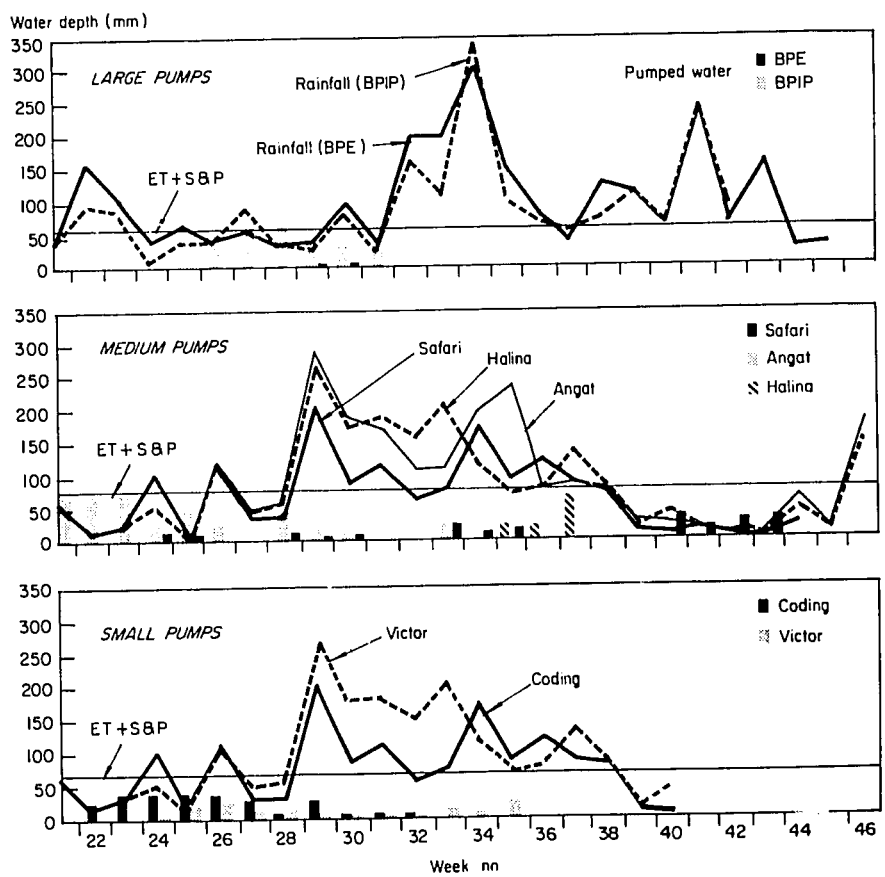
[a]Separation of means within a column by least significant difference test, 5% level.

land preparation were high (224 mm) in the large- and small-scale systems. However, the large systems had a much higher average effective use (74%) of the same amount of rainfall than the small-scale systems (52%) during the period (Table 5). The reason for this difference is that in both small systems, most of the dry season rainfall was as one single rainfall of high intensity during the weeks of continuous pumping (Fig. 4, 5). Between the large-scale systems, the BPIP had a less effective dry season rainfall (61%) because most of the rainfall was in 1 week, whereas about the same total rainfall was distributed over a period of 3 weeks in the BPE system (Fig. 10). The result was higher (88%) effective use during land preparation in BPE and a weighted average effectiveness of 74% for the large pumps (Table 5).

Among the medium-scale systems, Halina had almost no rainfall during land preparation in the dry season, whereas both Safari and Angat systems received substantial amounts. For both systems effective rainfall was 50% because of high intensity; in the case of Safari, rainfall occurred in the week following 2 weeks of substantial pumping (Fig. 7, 8).

Water use in crop growth period. In the wet season the small systems frequently pumped small amounts during the crop growth period when weekly rainfall amounts exceeded the water requirement for ET and S&P (Fig. 11). Such small-amount but unnecessary pumping was also evident in medium-scale pumps, but not in the big systems.

In the dry season, the large systems pumped the most water (848 mm) during the crop growth peri-



11. Use of the different pumps during weeks of excess and deficit amounts of rainfall in relation to water requirement (evapotranspiration [ET] + seepage and percolation [S&P]), during crop growth period. Bulacan, Philippines. 1977 wet season.

Table 7. Paddy water status, average nitrogen use, and yield in pump systems of different scales, Bulacan, Philippines, 1977–78.

Pump scale	Days without standing water	Av N use (kg/ha)	Yield[a] (t/ha)
	Wet season		
Large	3	45.0 a	3.5 a
Medium	13	63.2 b	4.0 b
Small	8	68.9 b	4.5 c
	Dry season		
Large	8	55.6 a	3.8 a
Medium	21	64.3 bc	4.0 a
Small	31	65.2 a c	3.4 a

[a]Separation of means in a column for each season by least significant difference test, 5 level.

ods. The small systems pumped only 365 mm and the medium systems used an average of 525 mm from pump sources (Table 5). Part of the system use difference can be assigned to higher conveyance losses that are involved in larger systems.

The smaller amounts of pumped water used in the small systems resulted in close to 100% IE for the whole dry season, indicating possibilities of water deficits in the service areas during the season. Water status observation in selected paddies showed a higher number of days without standing water in the small systems than in others in the dry season (Table 7) and yields also seemed to be affected. As expected from the pumping schedules (Fig. 9, 10) the large-scale systems maintained a high IE of 85% in the dry season, and 65% in the wet.

The Bangladesh pump systems. Two Bangladesh pump irrigation systems were studied in the 1978 dry season for comparison of water use and allocation patterns. The Ganges-Kobodak (G-K) project served 26,000 ha and the Dacca-Narayanganj-Demra (D-N-D) project served 3,027 ha. Both projects lifted water from rivers and distributed it by gravity. Flood control dikes protected the service areas. The projects were operated and managed by the same national agency following a common model for technical infrastructure operation as well as extension services. Both had been in operation for more than 10 years at the time of the study.

In the G-K project, 3 of 13 secondary canals of the main canal were selected as samples — S_1K, the first secondary from the main representing the upstream or top end, the second sample, S_6K, the middle section, and $S_{12}K$, the tail of the project area. From each secondary, three tertiary canals were sampled, which likewise represented the top, middle, and tail portions of the secondary canals' service areas. Flows were measured at the intakes of each sample secondary and tertiary canal and three sample paddies from each chosen tertiary area were used for S&P measurements. Rainfall amounts and evaporation rates were measured at one site for each sample secondary canal service area.

The middle tertiary of the second sample secondary (T_4/S_6K) was chosen for intensive water adequacy monitoring through daily observation of 36 selected paddies evenly distributed in the service area.

In the D-N-D project, which has six secondary canals, the head, middle, and tail of the system were represented by secondaries DL_1, DL_3, and NR_2. Water delivery into the canals was measured as in the G-K project. Water adequacy status for each canal area was monitored by daily observation of 36—55 sample paddies depending on the service area of the canal. Likewise, S&P losses were measured at 6—11 paddies for each canal service area. Daily rainfall amounts and evaporation rates were measured near the pump house.

The unit of analysis for IE estimations was the tertiary canal service area for the G-K project, and the secondary canal service area for the D-N-D project. In either case, the analysis was done on the unit that received water from the last agency-controlled water delivery structure.

Breakdown of a major power transformer caused an unusual 4-week water crisis in the G-K project during the transplanting period. Subsidiary pumps could supply only 30—50% of the normal flow to the main canal. Most upstream farmers intervened in the irrigation agency's attempt to ration water supply and kept their control over the operation of the gates. The first tertiary (T_1/S_1K) of the first secondary had 32% more water diverted to it during that crisis than before. During the same period, the tertiaries in the middle and end sections had a flow reduction that ranged from 50 to 93% of the precrisis discharge. In general, the greater the distance of the tertiaries from the water source, the greater was the water shortage.

Irrigation efficiency of the system. To calculate IE during crop growth period effective rainfall

Table 8. Area irrigated, average irrigation water supply per unit area and irrigation efficiency (IE) in selected tertiary canals in the Ganges-Kobodak (G-K) and secondary canals in the Dacca-Narayanganj-Demra (D-N-D) irrigation projects, Bangladesh, 1978 dry season.

Project and canal	Irrigated area (ha)	Water requirement[a] (mm/day)		Av irrigation water supply[b] (liters/s per ha)		IE (%)
G-K						
S_1K	165.2	9.43		2.97		17.7
T_1			9.30		3.46	
T_2			9.54		2.44	
T_3A			9.46		3.00	
S_6K	217.5	8.88		2.59		28.0
T_1B			8.63		1.28	
T_4			8.82		2.33	
T_8			9.19		4.17	
$S_{12}K$	156.3	8.95		1.68		40.2
T_1			8.13		2.15	
T_6			7.83		1.20	
T_8			10.90		1.69	
Total	539.0					
Weighted av		9.11		2.41 (20.82)		28.4
D-N-D						
DL_1	662.8	7.73		1.10		77.5
DL_3	251.3	7.45		1.06		68.4
NR_2	384.9	7.00		1.13		65.3
Total	1299.0					
Weighted av		7.46		1.10 (9.50)		72.1

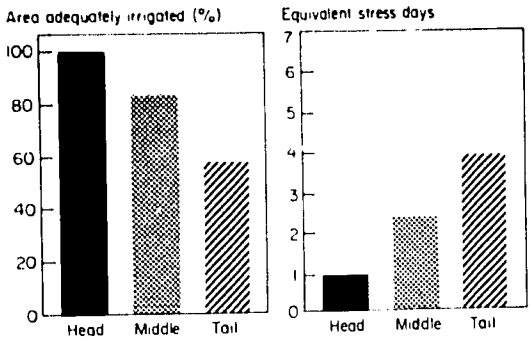
[a]Water requirement is the sum of requirements for evapotranspiration and seepage and percolation.
[b]Each figure within parentheses is the equivalent amount of water in millimeters per day.

data, which were not available, were assumed rather conservatively. For rainfall amounts less than 70 mm, 55% of rainfall was assumed effective. Forty-five percent effectiveness was assumed for weekly rainfall values between 70 and 140 mm and 35% effectiveness for weekly rainfall values greater than 140 mm.

The calculated IE at the service areas of each sample canal for both the projects are shown in Table 8. The reason for low IE for G-K was that the average water supply was much higher than the requirement for ET plus S&P. Water diverted to the intakes of the sample canals was 60—172% higher, and the weighted average water supply was about 122% higher than the field requirements (Table 8).

Water use in the D-N-D project was much better and differences in IE among the three sample canals were small (Table 8). In this project the average water delivery amounts in the sample canals exceeded the field water requirements for ET plus S&P by about 27% which helped achieve the high IE.

Water allocation and distribution. As evidenced in Table 8, the average rate of water supply per hectare in the G-K project was higher in the upstream secondary than in those in the middle and tail. The trend was the same for the individual tertiary allocations, with some exceptions resulting mostly from smaller than planned areas actually transplanted in those because of the water crisis during transplanting time and no efforts being made to reduce the tertiary allocation to match the smaller needs of the reduced planted area. The tertiary T_4/S_6K, which was intensively monitored for water adequacy study, showed considerable maldistribution in the service areas of its various sections (Fig. 12) despite the fact that the water supply to the intake of this tertiary was 126% higher than the field water requirement of 8.92 mm/day for meeting ET plus S&P needs. The distribution inequity was caused by consistent overuse of water in certain sections of the service area. Although the pattern of distribution inequity depicted by T_4/S_6K was not exactly representative for the whole of the project area, a similar or even more serious distribution inequity existed in the project.



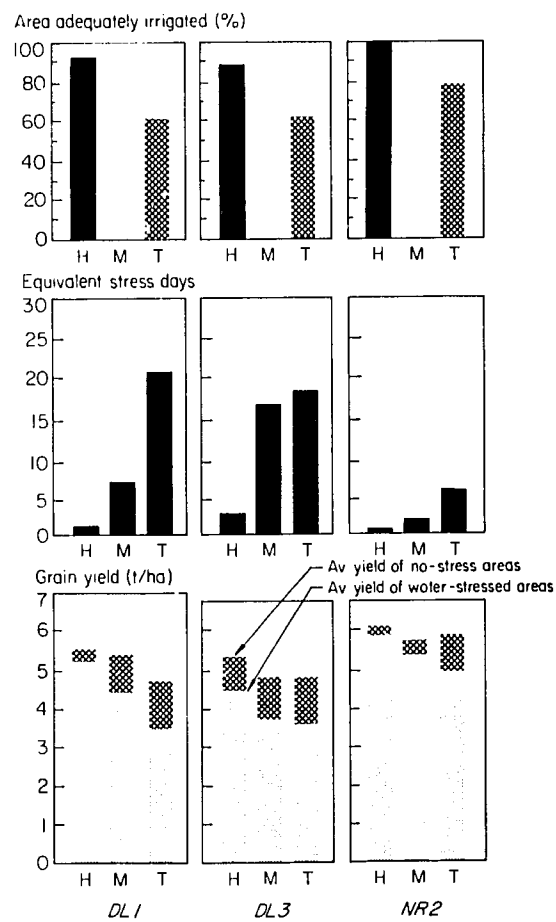
12. Percentage of area adequately irrigated and corresponding equivalent stress days in different sections of the service area of canal T_4 S_6K of the G-K Project during 2 months of the crop growth period. Bangladesh, 1978 dry season.

The number of stress days, i.e. days exceeding three during which a paddy had no standing water (Fig. 12), was calculated on the basis of weighted average of stress days prorated over the relevant service area. Thus, although the whole of the last section service area of T_4/S_6K suffered an equivalent stress period of about 4 days only during the 2-month measurement period, specific paddies or sub-areas experienced much longer water stresses.

The D-N-D project's water distribution was similarly affected by the distance of a section from the source of water within a secondary canal. Relative to the service area of the first section, progressively more areas suffered from water shortage in the middle and tail section in all three laterals studied (Fig. 13). As in the G-K project, the noncooperation of the upper-reach farmers with the D-N-D personnel hampered the establishment and practice of an equitable water-sharing system for all farmers under the command of a turnout or gate. The upper-reach farmers illegally blocked the distributory canal to divert more water to their fields. Such malpractices happened more at night.

The average number of stress days suffered during the crop growth period at each paddy belonging to different sections of the three D-N-D laterals are shown in Figure 13. Lateral NR_2, despite its being the last from the main canal, had the best water distribution among the three laterals. However, it had the lowest IE of 65.3% (Table 8). The lateral intake received 39% excess water flow over the whole season relative to the field water requirements for ET and S&P. The middle portion of lateral DL_3 suffered more water stress than expected (Fig. 13) because of elevated fields that could not be irrigated with the normal head of water in the farm ditch.

The smaller D-N-D project's performance was much superior to that of the G-K project in all respects. The key determining factor in the higher IE for the D-N-D project was the delivery in the canal of flow reasonably higher than field water requirements, unlike in the G-K project where deliveries were highly excessive. None of the two projects used water-measuring devices to allocate water from the main to the laterals and beyond. But the main canal of the D-N-D project was used as a reservoir and the pumping schedule was maintained on the basis of the fall of water level in the



13. Percentage of area adequately irrigated, corresponding equivalent stress days at different sections during the season and yields of 3 selected laterals in the D-N-D Project. H = head, M = middle, T = tail sections. Bangladesh, 1978 dry season.

main canal. A better means of communication to the pumping plant regarding field water needs also exists in this project, and the system is small with the pump house at more or less the middle of the main canal, which makes it possible to quickly suspend pumping when field demand has been met for a number of days or when there is significant rainfall in the area. The G-K project, in contrast, has a 73-km main canal, is devoid of a system of flow monitoring at any level, and suffers from lack of control for water allocation according to actual field needs.

RESOURCE USE AND PERFORMANCE OF LARGE IRRIGATION SYSTEMS IN NORTHEASTERN THAILAND

The primary objective of the Northeast Thailand irrigation water management research in 1979 was to obtain benchmark data on existing irrigation system operations and resource use in irrigated agriculture. The study included the Nam Phong-Nong Wai project, the Lam Pao project, and three selected tank irrigation projects.

Nam Phong-Nong Wai. The Nam Phong-Nong Wai Project is near Khon Kaen on the Nam Phong River, with a service area of about 24,000 ha. The 1984 service area goal is 48,000 ha. With the unimproved tertiary subsystems as a control, the two intensity models provided a basis for comparison of effectiveness in operational performance. The intensive improvement model included land consolidation, farm roads, and farm ditch improvement whereas the extensive model included only ditch improvement. Fourteen tertiary units were intensively monitored to povide the evaluation.

Seasonal cropping intensity is seen in Table 9. The intensive improved areas had the highest overall average seasonal cropping intensity (92%) with 80% as the dry season average. The overall average for extensive improvement and unimproved areas were essentially the same — 68 and 64%. Except in the extensive improved areas, farmers tended to increase dry season cropping intensity — 11% from 1978 to 1979 in intensively improved areas and 7.8% in unimproved areas. The system was designed for 200% annual cropping intensity and has been in operation for 10

Table 9. Seasonal Cropping Intensity in the Nam Phong-Nong Wai Irrigation Project sample units for 1977 wet season through 1979 wet season. Khon Kaen, Thailand.

Type of area and name of tertiary unit	Seasonal cropping intensity (%)				
	1977 wet	1978 dry	1978 wet	1979 dry	1979 wet
Intensive improved area					
Kotha 1	100.0	79.2	100.0	70.5	100.0
Kotha 2	100.0	65.1	98.9	67.1	100.0
Praku 3	100.0	79.8	100.0	98.1	100.0
Praku 5	100.0	66.9	100.0	111.7	100.0
Mean[a]	100.0	74.2	99.8	85.2	100.0
Extensive improved area[b]					
FTO 3L/1R	100.0	49.5	100.0	0.0	100.0
FTO 02	100.0	39.5	99.8	0.0	100.0
FTO 04	100.0	37.4	100.0	0.0	100.0
FTO 21	100.0	24.6	100.0	0.0	100.0
Mean[a]	100.0	39.0	100.0	0.0	100.0
Unimproved area					
Taonor	100.0	18.9	100.0	50.6	100.0
Dong Pong[c]	100.0	1.7	100.0	0.0	100.0
Don Du	100.0	7.0	100.0	34.9	100.0
Phu	100.0	4.7	100.0	43.9	100.0
Kok Noi	100.0	3.5	100.0	16.6	100.0
Mean[a]	100.0	5.5	100.0	13.3	100.0
Overall mean[a]	100.0	32.7	99.9	39.5	100.0

[a]Weighted mean based on the area proportions of each unit out of the total in each type of area. [b]No 1979 dry season water supply, therefore no crop. [c]No 1979 dry season crop due to ongoing improvements. In 1979 wet season this has changed to the extensive improved category.

Table 10. Rice yields in Nam Phong-Nong Wai Irrigation Project sample units for 1977 wet season through 1979 wet season. Khon Kaen, Thailand.

Type of area and name of tertiary unit	Rice yield (t/ha)				
	1977 wet	1978 dry	1978 wet[a]	1979 dry	1979 wet
Intensive improved area					
Kotha 1	2.88	1.38	3.31	1.76	3.30
Kotha 2	2.49	1.10	2.29	2.25	3.27
Praku 3	2.21	2.60	F	3.43	3.81
Praku 5	2.41	2.03	F	3.68	3.41
Mean[b]	2.52	2.13	2.91	3.10	3.46
Extensive improved area[c]					
FTO 3L/1R	2.63	1.83	1.19	–	3.69
FTO 02	2.08	1.11	F	–	3.55
FTO 04	3.00	2.45	1.50	–	4.40
FTO 21	3.09	2.67	F	–	4.01
Mean[b]	2.71	1.94	1.29	–	3.87
Unimproved area					
Tao Nor	3.09	[d]	2.28	2.00	2.86
Dong Phong[e]	2.88	[d]	F	–	3.51
Don Du	2.85	1.76	1.36	2.58	3.07
Phu	2.92	0.90	1.59	1.76	2.94
Kok Noi	2.47	2.16	0.66	1.78	2.58
Mean[b]	2.78	1.67	1.26	1.95	2.98
Overall mean[b]	2.69	2.03	1.62	2.69	3.34

[a]Flooding (F) caused only partial yield in each unit; F indicates no yield obtained. [b]Weighted mean based on the proportions of area planted to rice of each unit out of the total in each type of area. [c]No 1979 dry season water supply, therefore no crop. [d]No rice crop but vegetables and upland crops grown. [e]No crop in 1979 dry season due to ongoing improvement. In 1979 wet season, this was included under extensive improved unit.

years.

The average 5-season, 1977 wet to 1979 wet, rice yield in the system was 2.47 t/ha, which was considerably higher than Thailand's national 1977 average of 1.4 t/ha or the Northeast regional average of 0.9 t/ha. The highest mean yield for the 5 seasons occurred in the intensive improved area (2.82 t/ha) and was followed closely by the extensive improved areas (2.45 t/ha) and the unimproved areas (2.13 t/ha). An upward trend in yields appeared, with overall mean yields reaching 3.34 t/ha in the 1979 wet season (Table 10).

The engineering performance of the irrigation system is indicated by a 2-year overall mean WUE of 59% (Table 11). The intensive and extensive improvement areas had essentially the same efficiency — 58 and 60%. The unimproved area had a poorer mean performance (46%) and was greatly influenced by the low efficiency of dry season upland crop irrigation in 1978. This reflects the average tertiary level performance for wetland rice irrigation systems in the region.

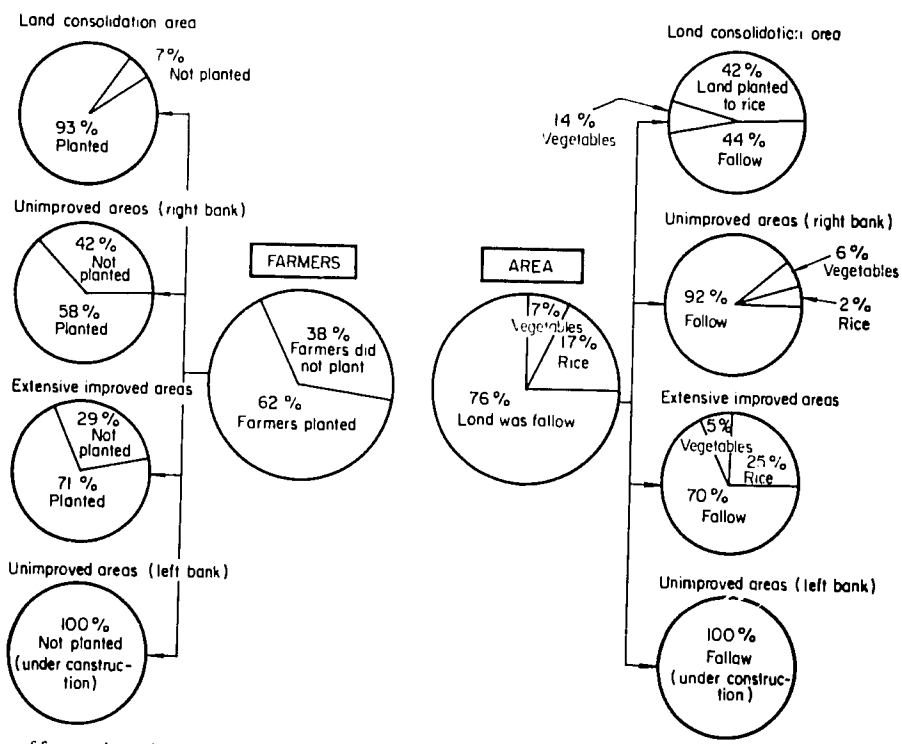
Dry season cropping and yield-limiting factors. A detailed study in the 1978 dry season determined the factors that significantly contributed to dry season cropping intensity and rice yield. Comparisons were made across the three types of tertiary irrigation facilities. All 13 tertiary units (Table 9) were monitored for cropping intensity and water supplied and used. A subsample of 66 farmers practicing dry season rice farming was intensively monitored. An individual paddy on each subsample farm was selected at random and the rice crop was observed throughout its growth period for water status, inputs used, and insect and disease damage. Yield was measured by crop-cutting.

In the sample units, 24% of the land was cultivated by 62% of the farmers (Fig. 14). Multiple linear regression was used to screen for the variables that significantly contribute to rice crop yields, dry season rice cropping intensity, and overall dry season cropping intensity. The factors that significantly contributed to the variability of dry season cropping intensity were electrical conductivity of

Table 11. Water utilization efficiency (WUE) in Nam Phong-Nong Wai Irrigation Project sample units for 1977 wet season through 1979 wet season. Khon Kaen, Thailand.

Type of area and name of tertiary unit	WUE (%)				
	1977 wet	1978 dry	1978 wet	1979 dry	1979 wet
Intensive improved area					
Kotha 1	n.a.[a]	62.7	61.3	59.4	81.0
Kotha 2	n.a.	31.9	40.5	35.3	60.5
Praku 3	97.8	n.a.	n.a.	n.a.	55.8
Praku 5	70.0	n.a.	46.0	95.0	50.1
Mean[b]	87.2	52.1	51.4	66.1	63.9
Extensive improved area[c]					
FTO 2L/1R	n.a.	48.7	59.1	–	40.6
FTO 02	n.a.	82.0	87.6	–	64.0
FTO 04	n.a.	77.4	76.3	–	79.8
FTO 21	n.a.	28.9	66.5	–	43.7
Mean[b]		56.7	69.4	–	52.8
Unimproved area					
Tao Nor	n.a.	7.5	42.7	56.4	24.7
Dong Phong[d]	n.a.	3.2	n.a.	–	38.0
Don Du	n.a.	n.a.	79.0	n.a.	66.2
Phu	n.a.	n.a.	n.a.	60.1	41.0
Kok Noi	n.a.	n.a.	82.6	23.0	88.9
Mean[b]		6.7	75.6	41.2	58.5
Overall mean[b]	87.2	52.6	67.1	57.4	58.5

[a]n.a. = no available data. [b]Weighted mean based on the crop area proportions of each unit out of the total in each type of area. [c]No 1979 dry season water supply, therefore no crop. [d]No 1979 dry season crop due to ongoing improvements.



14. Percentage of farms planted and crop areas cultivated among 180 sample farmers in the dry season in Nam Phong-Nong Wai Irrigation Project, Khon Kaen, Thailand, 1978.

Table 12. Major factors affecting rice cropping intensity in Nam Phong-Nong Wai Irrigation Project, Khon Kaen, Thailand, 1978 dry season.

Factor	Project N = 62	Intensive N = 33	Extensive N = 29
	Regression coefficient	Regression coefficient	Regression coefficient
Intercept	131.214	60.774	100.002
Farm size (ha)	−15.305**	−28.375**	−14.396**
Family labor	0.107	–	−1.566
Years of farming experience	−0.950*	−1.259	−1.288*
Years of experience with HYV	3.884	5.701	4.474
Education	0.737	6.925	8.406
Age	0.297	0.411	0.723
Land value (Baht/ha)	−0.095	−0.350	–
Rice income (Baht/farm)	0.390**	0.453	0.382
Expenditure on chemicals (Baht/ha)	−0.040	0.010	−0.026
N (kg/ha)	0.850	0.859	1.692
P_2O_5 (kg/ha)	−0.919	−0.954	−2.045
Relative water supply	−457.461	−777.067	−1719.785*
Clay (%)	−0.218	0.249	−1.726
pH	−7.180	6.097	9.772
Electrical conductivity (mmho/cm)	21.490*	18.135	–
Organic matter (%)	7.006	6.495	34.723
P availability (ppm)	1.089*	−1.236	1.093
CEC (meq/100 g)	0.677	−0.177	1.279
K (meq/100 g)	−81.906	−57.634	–
Whitehead tillers (%)	0.892	−14.089	11.880
Rat damage (%)	−0.164	0.061	−1.765
Weed (%)	−0.090	0.065	0.272
Date of transplanting	−0.139	0.823	−1.378
R^2	0.767**	0.862**	0.906*

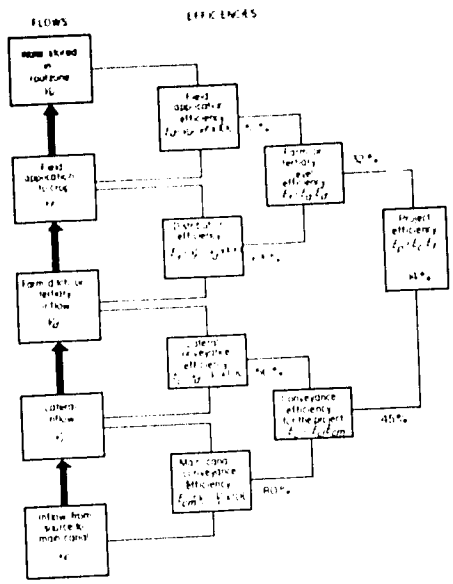
soil solution, available phosphorus, farm size, years of farming experience, farm income, and relative water supply (Table 12).

The factors that significantly contributed to the variability of the dry season rice yield were weed infestation, available potassium, pH, percentage of organic matter, cation exchange capacity, date of transplanting, rat damage, whitehead tillers, years of farming experience, and farmer's age (Table 13). The overall regression relationships had coefficients of determination of 0.47, 0.97, and 0.87 for the project, the intensive improved area, and extensive improved area.

Lam Pao Irrigation Project. The Lam Pao Project is near Kalasin in Northeastern Thailand on the Lam Pao River, a tributary of the Mekong. The reservoir has a storage capacity of 1.26 billion m^3. The system served 11,500 ha in 1979. The total proposed service area is 50,000 ha when completed in the mid1980s.

Two portions of the system were monitored for four cropping seasons. The first was a small lateral (1L1) with an area of 811 ha and 7 tertiary units. The second was a 5,733-ha unit of the Lam Pao River floodplain divided into 4 sections of 209, 2,889, 1,228, and 1,407 ha by natural or man-made structures. Rice yields averaged 2.87 t/ha for the 4 seasons monitored (Table 14). Mean wet-season yields were 3.0 t/ha and the dry-season average was 2.69 t/ha. The dry-season yields were lower because of water stress and the low level of inputs used by farmers.

In the 1979 dry season, flows were measured into the main canal, lateral canals, farm ditches (tertiaries), and farmers' fields. Soil moisture utilization was measured as the difference of root zone moisture content immediately before irrigation and 2 days after for dryland crops or as water used by evapotranspiration plus seepage and percolation during that period for wetland rice. The results of that set of measurements indicate the state of irrigation in the Lam Pao system (Fig. 15). The



15. Components of efficiency observed for the Lam Pao Project, Northeast Thailand, 1979 dry season.

product of the tertiary level efficiency and the project conveyance efficiency provided an overall dry-season project efficiency of 14%.

These levels of efficiency in the Lam Pao project were precedented but they were much lower than normally expected in large-scale irrigation systems. The disparity between actual efficiency (14%) and expected efficiency (30 to 48%) at the project level represented a serious waste of water.

Tank irrigation systems. The study in Northeast Thailand found water and land resources underutilized in tank irrigation projects. Dry-season cropping was closely associated with landscape position and topography. Cropping intensities for the three tank systems studied were 81, 86, and 102%. The major reason of farmers for not growing a dry-season crop was either *no water* or *insufficient water availability*. The second and third most common reasons were *insufficient labor* (15%) and *other employment* (10%).

Eighty-one percent of the farmers perceived

Table 13. Major factors affecting rice yield in Nam Phong-Nong Wai Irrigation Project, Khon Kaen, Thailand, 1978 dry season.

Factor	Project N = 62	Intensive N = 33	Extensive N = 29
	Regression coefficient	Regression coefficient	Regression coefficient
Intercept	1.227	−3.672	−6.838
Farm size (ha)	0.090	0.194	0.092
Family labor (active member)	0.081	0.161	0.136
Years of farming experience	0.041**	0.074**	0.033*
Years of experience with HYV	0.091	−0.222	−0.138
Education	−0.277	–	0.157
Age of farmer	−0.045**	−0.052*	−0.041*
Land value (Baht/ha)	−0.008	0.005	–
Rice income (Baht/farm)	–	−0.003	–
Expenditure on chemicals (Baht/ha)	−0.001	–	−0.001
N (kg/ha) application	0.039	0.026	−0.091
P_2O_5 (kg/ha) application	0.030	−0.026	0.038
Relative water supply (1/WUE)	4.941	–	–
Clay (%)	0.018	0.049	–
pH	–	−0.232	1.850*
Electro-conductivity (mmho/cm)	−0.163	0.337	−8.107
Organic matter (%)	–	−0.196	2.132*
P availability (ppm)	0.011	0.118	−0.034
CEC (meq/100 g)	−0.039	−0.096	−0.123**
K (meq/100 g)	5.286	8.311*	14.296
Whitehead tillers (%)	0.039	–	0.519**
Rat damage (%)	0.012	0.018	−0.072*
Weed (%)	−0.013*	−0.012	−0.011
Date of transplanting	0.008	0.093*	0.015
R^2	0.471**	0.974**	0.871**

Table 14. Rice yield of the Lam Pao Irrigation Project sample units and sections for 1978 dry season through 1979 wet season. Northeastern Thailand.

Lateral or section	Rice yield (t/ha)				
	1978 dry	1978 wet[a]	1979 dry	1979 wet	Mean
Lateral 1L-1					
Unit 02	–	2.72	2.06	2.78	2.52
03	–	2.94	[b]	3.11	3.03
04	[b]	2.67	3.23	3.48	3.08
05	[b]	2.55	[b]	2.67	2.61
06	–	2.00	[b]	3.09	2.55
07	[b]	2.79	1.00	2.69	2.16
09	–	2.17	[b]	2.75	2.46
Mean[c]	–	2.51	1.88	2.99	2.64
Section					
I	–	2.33	–	3.29	2.81
II	1.89	2.99	–	3.42	2.77
III	–	2.75	–	3.37	3.06
IV	–	1.77	3.83	3.53	3.04
Mean[a]	1.89	2.62	3.83	3.43	2.90
Overall mean[a]	1.89	2.61	3.49	3.38	2.87

[a]Flooding caused only partial yield in each service area. [b]No rice crop, but vegetables and upland crops grown. [c]Weighted mean based on the area proportions of each unit or each section out of the total area in that category.

causes of insufficient irrigation water at the farm level. The most common was insufficient water supply at the tank reservoir (15%), farm's location in an unfavorable position at the tail of the system or not adjacent to the canal (12%), and possession of an upland area not served by the system (12%). Other responses included blockage of water flow by other individuals in the system (7%), poor layout of the irrigation system (6%), and canal's destruction and nonrepair (5%).

A survey of the water availability at the three tank systems revealed that the reservoir capacity was largely unused (Table 15). The total releases of water in the dry season (January through May) were 7.2% of the total capacity of the tank for Huai Aeng, 10.2% for Huai Kaeng, and 4.4% for Huai Sathot. The percentage of capacity that was reached as the minimum dry season storage volume was 39.7% for Huai Aeng, 36.3% for Huai Kaeng, and 21.5% for Huai Sathot. This means that 5.5 times more water could have been released at Huai Aeng, 3.5 times at Huai Kaeng, and 4.9 times at Huai Sathot. This serious underutilization of storage capacity is largely due to the lack of coordination between the tank gatekeeper who releases the water and the farmers who are supposed to give formal demands for water needs.

A water management training program was organized in 1979 for zonemen of three major irri-

Table 15. Reservoir stage, volume of storage, and monthly irrigation release in the 3 tank irrigation systems of Northeastern Thailand, 1978 dry season.

Date	Reservoir stage (m)	Estimated storage volume ($m^3 \times 10^3$)	Monthly total release ($m^3 \times 10^3$)
		Huai Aeng	
1 Jan	2.29	13,890	190
1 Feb	2.05	12,500	541
1 Mar	1.77	10,490	346
1 Apr	1.52	9,500	81
1 May	1.35	8,700	409
		Huai Kaeng	
1 Jan[a]	–	–	–
10 Feb	4.08	13,800	295
1 Mar	3.93	12,600	711
1 Apr	3.66	11,800	472
1 May	3.31	9,950	1,322
		Huai Sathot	
1 Jan	3.57	3,550	[a]
1 Feb	3.43	3,300	75[b]
1 Mar	3.27	3,050	165
1 Apr	3.16	2,800	132
1 May	3.05	2,500	144

[a]No data available. [b]Left main canal only.

gation systems in the Northeast and three tank irrigation system personnel. The zonemen are responsible for areas of 1,600 ha and need both rice production and water management training according to their job description, but they mainly come from a construction management background.

The training program was organized under the leadership of the Royal Irrigation Department with significant inputs by the Khon Kaen Rice Station, the UNDP/FAO Kalasin Pilot Farm, the Northeast Agricultural Extension Office, and the Cooperative Promotion Department.

WATER MANAGEMENT TRAINING

A 1979 irrigation water management training course had 24 participants from Bangladesh, Indonesia, Malaysia, Philippines, Sri Lanka, and Thailand. The participants were primarily irrigation or agricultural engineers with irrigation project operation and management or research responsibilities.

The 6-week training course, in addition to having intensive lecture-discussion-group session activities, included a 2-week rice production training course and 10 days of practical irrigation system management improvement exercise in the LTRIS subproject of the Upper Pampanga River Integrated Irrigation System in Central Luzon in cooperation with NIA.

Soil and crop management

Soil characterization

Soil Chemistry Department

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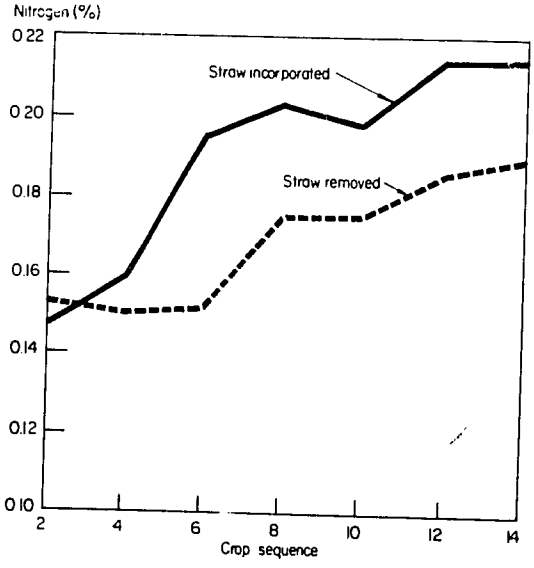
INCREASING THE NITROGEN SUPPLY OF RICE SOILS

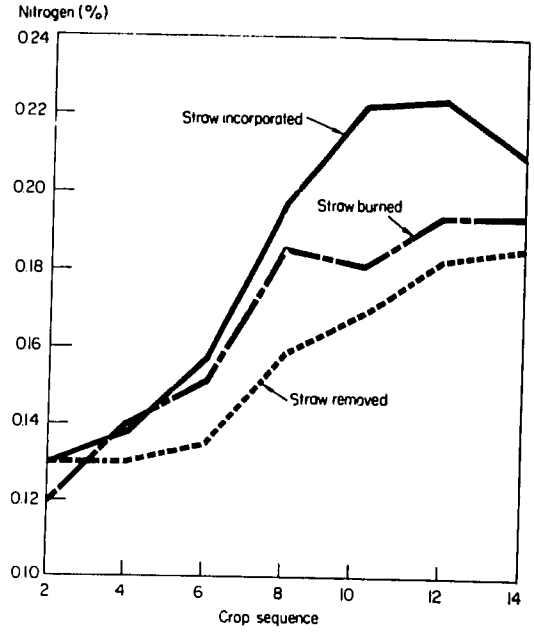
Results from long-term experiments on straw and water management confirmed the benefit (1978 annual report) from straw incorporation and flood fallowing on a soil's nitrogen supply. It was also found that growing two wetland rice crops a year caused a slow and steady increase in soil nitrogen content even in the absence of straw.

Straw management. The effect of straw incorporation on the nitrogen content of the soil was studied under three water regimes. In a second experiment the effects of three methods of straw management on the nitrogen content of the soil under the usual water regime were studied. In both experiments straw incorporation resulted in increased soil nitrogen (Fig. 1, 2). There was a steady increase in soil nitrogen content over time, even in the absence of straw.

Water management. Three soils — Luisiana clay (pH 4.8, organic matter: 2.9%), Maahas clay (pH 6.6, organic matter: 2.4%), and Pila clay loam (pH 7.6, organic matter: 1.5%) — were subjected to dry fallow (the standard practice) and flood fallow in steel (200-liter) drums. After the 24th crop the average nitrogen content of the flood-fallowed soils was 0.186% and that of the dry-fallowed soils was 0.126%. The increase, which was highly significant, amounted to 1,200 kg N/ha or 50 kg N/ha per season.



1. Effect of straw management on the total nitrogen content of Maahas clay during 7 years, averaged for 3 water treatments in the field. IRRI, 1972-79.



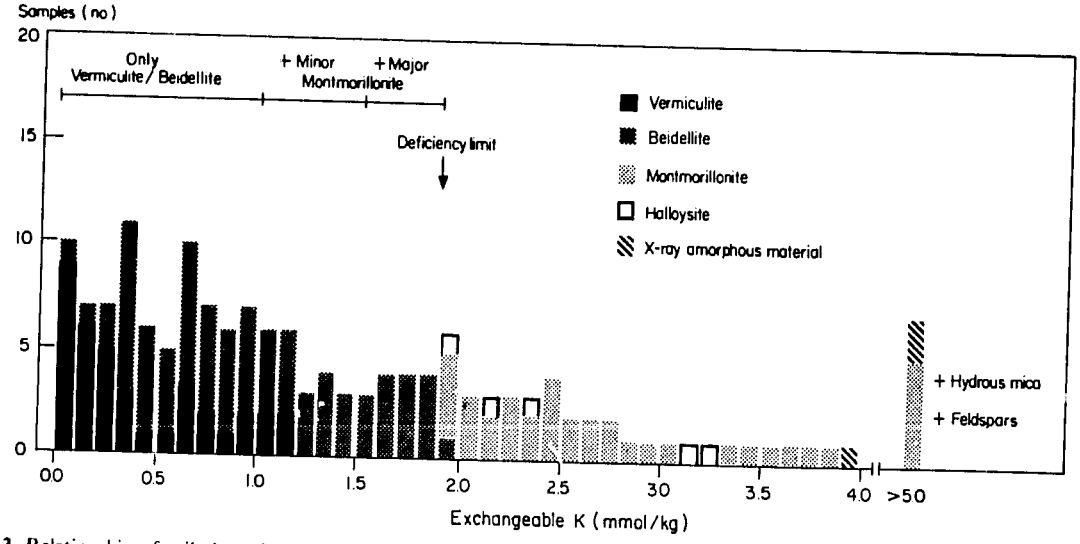
2. Effect of straw management on the nitrogen content of Maahas clay during 7 years, averaged for 5 varieties in the field. IRRI, 1972-79.

CLAY MINERALOGY AND NUTRIENT AVAILABILITY IN WETLAND RICE SOILS

Clay composition. The clay fractions of 160 surface soil samples from 12 major rice-growing pro-

Table 1. Distribution of the mineral species in 160 clay samples analyzed. IRRI, 1979.

Mineral species	Number
Dominant (>50%)	
Smectite (montmorillonite or beidellite)	81
Vermiculite	61
Metahalloysite	9
X-ray amorphous material	5
Kaolinite	2
Major (20–50%)	
Hydrous mica	2
Minor (<20%)	
Feldspars	4



3. Relationship of soil clay mineralogy to exchangeable (K) values. IRRI, 1979.

vinces in the Philippines were analyzed by X-ray diffractometry (Table 1).

Montmorillonite was found in soils developed from volcanic ash and appeared to be of synthetic origin. Beidellite was abundant in the soils developed from parent materials other than volcanic ash and appeared to be a transformation product of vermiculite with which it was often associated. Both beidellite and vermiculite appeared to contain interlayer material. X-ray amorphous iron oxides or hydroxides were present in almost all the samples. Clay fractions from soils containing dominant halloysite contained significantly more iron oxides than the other samples.

Clay mineralogy and exchangeable potassium. A close association between the content of exchangeable potassium and clay composition was observed (Fig. 3). The data associate potassium deficiency with the presence of vermiculite or beidellite, and potassium adequacy mainly with montmorillonite and, to some extent, with halloysite and X-ray amorphous materials.

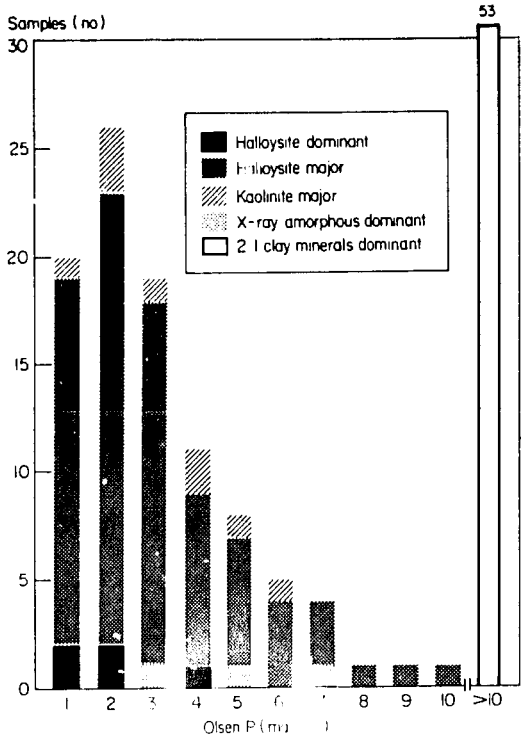
The relationship between exchangeable potassium and the presence of vermiculite confirmed earlier findings that vermiculite fixes potassium. But an association between a low content of exchangeable potassium and dominant beidellite has not been reported. Because beidellite in the soils studied appeared to be a transformation product of vermiculite, it would have mainly a tetrahedral layer charge and a possible residual mica core, both of which could be responsible for potassium fixation.

Clay composition and available phosphorus. All the soils with abundant (dominant or major) halloysite, kaolinite, or X-ray amorphous material had low available phosphate content (Olsen P values <5 mg/kg), but as the proportion of these components decreased, the available phosphorus content increased. In soils where these components occurred in minor proportions, Olsen P values ranged from 5 to 10 mg/kg, indicating moderate levels of available phosphate. None of the samples with Olsen P values above 10 mg/kg (adequate available phosphate) contained detectable amounts of these components in the clay fraction (Fig. 4).

Vermiculite and beidellite, whose presence was associated with a low content of exchangeable potassium, were the dominant minerals in 103 samples, indicating that fixation of applied potassium and ammonium fertilizers may be widespread in Philippine wetland rice soils. Soils dominant in montmorillonite do not appear to have nitrogen, phosphorus, or potassium fixation problems.

ZINC AVAILABILITY IN WETLAND RICE SOILS

Zinc deficiency and excess chromium. Some zinc-deficient wetland rice soils contain large



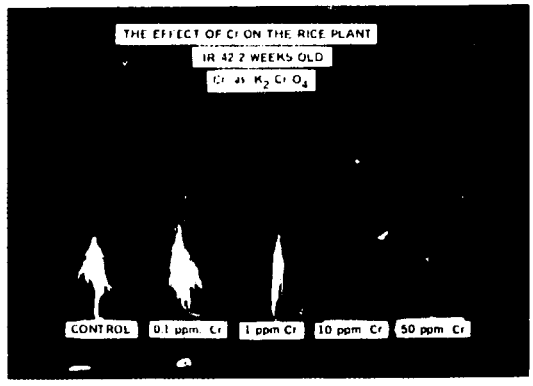
4. Relationship of soil [illegible] mineralogy to Olsen P values. IRRI, 1979.

amounts of chromium. In one Hydraquent, where zinc deficiency was severe, the total chromium content was 0.185% (that for normal soils is <0.01%). To ascertain whether excess chromium aggravated zinc deficiency, rice was grown in culture solution with increasing amounts of chromium. Chromium at 0.1 ppm benefited rice; at 1 ppm it was toxic (Fig. 5), but less toxic as Cr^{3+} than as CrO_4^{2-}

Distribution of zinc. Fractionation of zinc in a zinc-deficient soil (a Tropaquent with pH 8.1, organic carbon: 5.2%, total zinc: 96 ppm, and available zinc: 0.5 ppm) revealed the following distribution:

Fraction	%
Residual mineral	94
Strong organic complexes	4.6
Weak organic complexes	0.8
Exchangeable zinc	0.6
0.1 *N* HCl extractable	0.4

Zinc fractions and plant uptake. Copper-acetate-extractable zinc (zinc weakly bound to soil organic matter) correlated highly (r = .98***) with electro-ultrafiltration (EUF)- extractable zinc. EUF-extractable zinc and copper-acetate-extractable zinc correlated highly with plant uptake (r = .82**).



5. The effect of four levels of chromium on 2-week-old IR42 seedlings. IRRI, 1979.

CHEMICAL CHARACTERISTICS OF COASTAL SALINE SOILS

Analysis of soil samples from 14 experimental sites in farmers' fields with coastal saline soils revealed these ranges:

pH	3.9-7.8
Electrical conductivity of the saturation extract (mmho/cm)	1-16
Organic matter (%)	2.0-15.4
Nitrogen (%)	0.07-0.46
Cation exchange capacity (meq/100 g)	20.3-45.6
Exchangeable potassium (meq/100 g)	0.6-3.1
Olsen phosphorus (ppm)	2-41
Available zinc (ppm)	0.8-3.4

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 about half were zinc deficient. At 5 of 14 sites, the salt-tolerant variety IR42 yielded 3.9-6.2 t/ha with moderate amounts of fertilizer.

Table 2. Influence of calcium carbonate and manganese sulfate on pH, electrical conductivity (EC), and the concentration of Fe^{2+} in the soil solutions 0 and 16 weeks after submergence; and on yield of IR42 on an acid sulfate soil in the greenhouse. IRRI, 1979 wet season.

$CaCO_3$ (%)	$MnSO_4$ (ppm Mn)	pH		EC (mmho/cm)		Fe^{2+} (ppm)		Yield[a] (g/pot)	
		0	16	0	16	0	16	Straw	Grain
0	0	3.0	5.7	8.1	11.0	14	4200	13 b	7 c
0.4	0	3.6	6.2	5.1	5.1	5	910	39 a	23 b
0.4	500	3.4	6.1	8.2	6.4	8	1100	40 a	34 a

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

AMELIORATION OF AN ACID SULFATE SOIL

Greenhouse experiment. Because the main problems for rice culture on acid sulfate soils are aluminum toxicity in the early stages of growth and iron toxicity later, calcium carbonate and manganous sulfate were tested as amendments for such a soil (Sulfaquept with pH 3.5, EC_e: 1.0 mmho/cm, Fe: 2.5%, Mn: 0.001%, organic C: 1.2%). Calcium carbonate was added to increase pH and depress the concentrations of water-soluble aluminum and iron; manganous sulfate was added to physiologically antagonize the effects of excess iron.

Table 2 shows that calcium carbonate at 0.4% increased pH, depressed electrical conductivity and water-soluble iron, and increased yield. The best treatment was calcium carbonate plus manganous sulfate.

Table 2 also shows a high soil electrolyte content due apparently to aluminum sulfate. Calcium carbonate lowered the electrolyte content.

Field experiment. Treatments similar to those in the greenhouse were imposed on the same soil in a replicated field experiment. Yields with IR26 were 1.6 t/ha without either calcium carbonate or manganese, 2.0 t/ha with 0.4% $CaCO_3$ only, and 2.2 t/ha with 0.4% $CaCO_3$ and 500 ppm Mn.

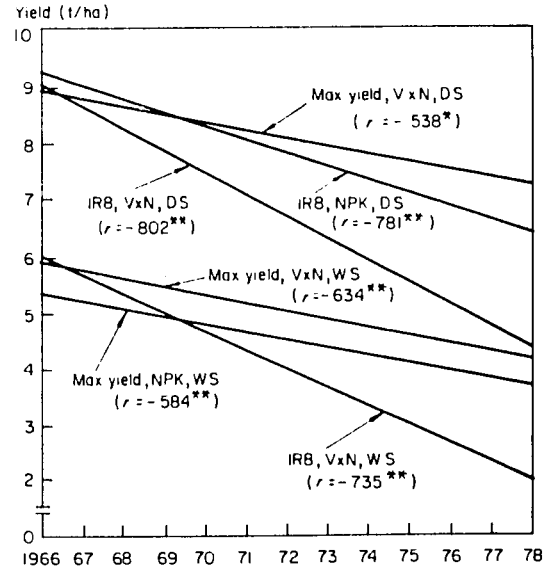
SOIL PROBLEMS AT IRRI

Rice yields on the old IRRI farm have declined during 1966-78 (Fig. 6). Soil factors associated with the decline were identified as alkalinity, salinity, boron toxicity, and zinc deficiency. Table 3 summarizes analyses of irrigation water from IRRI reservoirs.

Alkalinity. The pH in 1962 ranged from 5.1 to 6.5 with a mean of 5.96; in 1977 the corresponding figures were 5.6 to 7.9 and 6.76. In 1962 only 16 plots had pH values exceeding 6.5, the optimum for rice; in 1977 the pH of 188 plots exceeded 6.5. The pH increase was caused by irrigation of a poorly drained soil (Maahas clay) with alkaline irrigation water.

Salinity. Twenty-four plots had EC (1:1) values exceeding 4 mmho/cm; 16 had 2-4 mmho/cm. Salinity was caused by the use of irrigation water with an EC >750 mmho/cm in poorly drained soils.

Boron toxicity. The hot-water-soluble boron content over most of the farm was >3 ppm and increasing. Boron toxicity symptoms were observed in 61 blocks on the old farm. Rice plants showing symptoms contained >30 ppm boron in



6. Trends of maximum yield on the IRRI farm in 2 series of experiments in 2 seasons, 1966-78. D. S. = dry season, W. S. = wet season.

Table 3. Analysis of irrigation water from 15 reservoirs or pumps at IRRI, averaged for 5 samples taken from March to August 1979.

Reservoir	pH	Electrical conductivity (μmho/cm)	Boron (ppm)	Potassium	Sodium	Calcium	Magnesium	Bicarbonate	Sulfate	Chloride
				meq/liter						
H	8.3	692	3.5	0.56	3.1	1.8	2.2	4.6	1.92	2.51
J	8.0	718	4.1	0.59	3.4	1.8	2.2	4.3	1.89	2.45
K	8.2	716	4.4	0.59	3.7	1.7	2.2	3.6	1.98	2.70
L	8.1	778	4.5	0.64	4.1	2.0	2.1	3.7	0.21	3.13
MN I	7.9	862	4.8	0.69	4.7	2.1	2.1	5.0	0.25	3.52
MN II	8.2	792	4.5	0.61	4.2	1.6	1.9	4.1	0.23	3.21
300	7.8	838	5.2	0.69	4.5	2.1	2.2	4.9	0.24	3.52
500	7.3	805	5.5	0.72	4.5	2.2	2.2	5.0	0.24	3.55
2000	7.6	728	3.8	0.56	3.2	2.2	2.3	5.9	0.20	1.97
3019	8.0	360	2.2	0.30	1.6	1.4	1.2	2.5	0.12	0.70
3023	7.5	690	3.5	0.54	2.7	2.0	2.2	5.1	0.19	1.92
CS	7.5	606	2.7	0.72	2.7	1.9	2.3	5.5	0.15	1.27
CP	6.9	674	2.7	0.66	2.7	1.9	2.8	5.5	0.16	1.13
L-UP-IPB	8.0	494	2.7	0.51	1.8	1.8	1.6	3.7	0.12	1.04
U-UP-IPB	8.3	450	2.4	0.38	1.9	1.4	1.5	3.4	0.17	1.13

the shoot at panicle initiation. The soils contained 5-14 ppm hot-water-soluble boron and the interstitial water, 2-5 ppm.

Boron toxicity at IRRI is due to irrigation with high-boron deep-well water.

Reclamation of a boron-toxic IRRI soil. The effects of two soil physical conditions, two sources of irrigation water and leaching were studied in greenhouse pots. Table 4 shows that soil drying increased boron removal and rice yield. Leaching with tap water reduced the boron content of the soil and soil solution.

Zinc deficiency. Of 255 plots sampled, 124 were zinc deficient (<1 ppm available zinc). Zinc deficiency was observed visually in 117 blocks.

Zinc deficiency at IRRI is due to one or more of the following causes:

- decrease in solubility of zinc due to increase in soil pH,
- adsorption by the carbonate of calcium and magnesium that have accumulated,

Table 4. Effects of soil physical condition, water source, and leaching at 1 cm/day for 11 weeks on the growth of IR40 and its boron content, boron removal, and boron content of the soil. IRRI greenhouse, 1979 wet season.[a]

Treatment	Yield[b] (g/pot)		Plant boron (ppm) 6 WT	Boron removed[c] (mg/pot)	Boron (ppm)	
	Straw	Grain			Soil after experiment	Soil solution 6 WT
Puddled						
Tap water, no leaching	34 d	24 d	35	4	5.8	1.7
Tap water, with leaching	32 d	20 d	20	61	5.4	1.1
Reservoir water, no leaching	32 d	20 d	48	10	10.5	4.6
Reservoir water, with leaching	34 d	22 d	48	137	9.0	4.2
Dried						
Tap water, no leaching	57 b	52 ab	31	7	6.8	1.5
Tap water, with leaching	63 a	55 a	28	95	5.5	0.7
Reservoir water, no leaching	53 c	43 c	52	12	12.2	3.9
Reservoir water, with leaching	60 a	50 b	49	160	10.8	3.2

[a]WT = weeks after transplanting. [b]In a column, any two means followed by the same letter are not significantly different from each other at the 5% level. [c]In leachate.

- adsorption or precipitation by silica, which is present in concentrations as high as 220 ppm in the soil solution, and
- continuous cropping of wetland rice.

Excess potassium. The content of exchangeable potassium in soil samples from 255 blocks was 0.4-2.1 meq/100 g (mean, 1.06). Excess potassium aggravates boron toxicity and may be a yield-limiting factor at IRRI.

NITROGEN-SUPPLYING POWER OF IRRI SOILS

The mean yields in plots with no fertilizer nitrogen for 67 dry-season and 56 wet-season experiments were 5.05 and 3.91 t/ha. If 20 kg nitrogen is needed to produce 1 t grain and if the efficiency of nitrogen absorption is 50%, and if the contributions of irrigation water and rain are small, the IRRI wetland rice fields release 360 kg N/ha a year. The accepted figure for IRRI soils is about 120 kg N/ha a year.

Soil and crop management

Soil fertility management: microbiological studies

Soil Microbiology Department

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HETEROTROPHIC NITROGEN FIXATION

Distribution of aerobic nitrogen-fixing bacteria that require a low level of nitrogen in wetland and dryland plants. The occurrence of aerobic nitrogen-fixing bacteria in the roots or other tissues of various wetland and dryland plants was surveyed. The roots of wild and cultivated wetland rice (*O. sativa*, *O. australiensis*, and *O. punctata*) and a weed (*Monochoria vaginalis*) had a high percentage of aerobic heterotrophic nitrogen-fixing bacteria (Table 1). The roots of dryland plants (*Cassia tora*, *Zea mays*, *Sorghum vulgare*, *Panicum maximum*, *Digitaria smutsii*, *Paspalum plicatulum*) had a low percentage (0.3%) of aerobic nitrogen fixers. The roots of dryland rice had an intermediate number of aerobic nitrogen fixers, probably due to soil wetness.

Contribution of basal portion of shoot in nitrogen fixation associated with wetland rice. Using the varieties IR26, JBS236, and Khao Lo, nitrogen fixation by plants from which roots were removed just before a 5-hour acetylene reduction assay (ARA) was compared with that by intact plants. The acetylene reduction activity of rootless plants accounted for from 100 to 40% of that by intact plants, depending on rice varieties and growth stage. The relative rate by rootless plants was higher at the early seedling stage than at a later growth stage, and IR26 showed the least nitrogen fixation in the shoot. In vitro tests of various parts of the shoot revealed that nitrogen fixation was mostly in the portion (a few cm from the base) of the stem and outer leaf sheath that are in contact with the soil and floodwater. The population level of nitrogen fixers in those parts was similar to that in the root.

Effect of nitrogen fertilizer on heterotrophic nitrogen fixation in long-term fertility trials. Heterotrophic nitrogen fixation in the plow layer of soil in no-fertilizer plots and complete (NPK)- fertilizer plots in long-term fertility trials

Table 1. Occurrence of fixed nitrogen-requiring nitrogen-fixing bacteria in wetland plants. IRRI, 1979.

Plant, and plant part[a]	Aerobic heterotrophs (no./g fresh wt)	N_2 fixers (%)	Achromobacter-like N_2-fixing bacteria (%)
Aquatic weed			
Monochoria vaginalis			
Roots	9.7×10^5	50	45
Rice			
Latisail (field A)			
Roots	9.2×10^7	84	78
Stem	3.0×10^7	49	22
Latisail (field B)			
Roots	5.4×10^6	20	11
Stem	1.2×10^7	22	1
Khao Lo			
Roots	2.7×10^8	75	50
Stem	5.5×10^7	59	5
IR26 (field B)			
Roots	8.6×10^6	45	40
Stem	1.1×10^7	20	0
IR26 (field A)			
Outer leaf sheath (basal)	9.7×10^7	15	0
Wild rice			
Oryza australiensis (field A)			
Roots	7.3×10^6	75	40
Stem	2.8×10^7	9	4
Rhizome	2.4×10^7	49	44
Oryza punctata (field A)			
Roots	8.7×10^7	90	23

[a]Field A was flooded and unfertilized for 4 years. Field B was newly converted to wetland.

was measured by ARA. ARA values for unfertilized and NPK-fertilized plots were almost equal. The acetylene reduction activity associated with wetland rice (IR36) was also measured in the two treatments (Table 2). At a later stage, the activity was higher in fertilized plots, probably because of the larger biomass in such plots. It appears that heterotrophic nitrogen fixation in the soil and root is less responsive to fertilizer than is autotrophic nitrogen fixation in floodwater. The results show that nitrogen fertilizers are compatible with heterotrophic nitrogen fixation in a paddy soil.

Effect of the rice plant on nitrogen balance in flooded soil. In preliminary experiments, the possibility that a high root mass in a given weight of soil may result in a significantly positive nitrogen balance after one crop of rice was studied.

Twenty seedlings of IR8 were transplanted on 2.5 kg soil and grown to maturity in the greenhouse. The root mass per unit weight of soil at harvest was no greater than that obtained with 2 seedlings transplanted on 9.0 kg soil. The nitrogen balance per pot was 78 mg N for fallow and light-exposed surface of pots, 70.3 mg N for planted and light-exposed, 21.3 mg N (not significant) for fallow and black cloth on the surface of pot, and 47 mg N for planted and black cloth on surface. Although a statistically significant nitrogen balance was obtained in one crop, no treatment differences were observed. Blue-green algae grew better in fallow pots than in planted pots and light-dependent acetylene reduction activity was higher in fallow pots. This trend appeared in nitrogen balance.

Effect of straw on nitrogen balance in flooded soil. A preliminary experiment examined the possibility of rice straw incorporation into flooded soil to stimulate nitrogen fixation by heterotrophic and phototrophic nitrogen fixers.

Table 2. Acetylene reduction activity associated with IR36 in long-term fertility plots. IRRI, 1979.

Days after transplanting	Acetylene reduction activity (mmol C_2H_4/m^2 per day)	
	No NPK	With NPK
19	0.22	0.32
45	0.43	0.31
62	0.36	0.63
86	0.12	0.23
Average	0.28	0.37

Table 3. Effect of straw incorporation on nitrogen balance of flooded rice soil after 3 crops of rice. IRRI, 1979.

Treatment		Nitrogen balance (mg N/pot)	Nitrogen increase in straw[a] (mg N/g straw)
Exposed to light	Straw incorporated		
+	–	390 b	
+	+	586 a	2.2
–	–	162 c	
–	+	519 ab	4.0

[a] Excluding nitrogen content of straw.

Straw (30 g/10 kg dry soil) was incorporated 2-3 weeks before transplanting IR28 (Table 3). The data suggest that straw incorporation enhanced the positive nitrogen balance by increasing nitrogen fixation. Previous unpublished data indicated that straw incorporation into flood fallow pots did not have a statistically significant effect on nitrogen balance. Thus, the rice plant appears necessary to increase positive nitrogen balance by straw incorporation.

AUTOTROPHIC NITROGEN FIXATION

Fate of biologically fixed nitrogen. A preliminary field experiment studied the fate of algal nitrogen in the paddy. An algal mass, composed mainly of *Gloeotrichia*, was grown in a small pond and labeled with ^{15}N-nitrate. An algal mass with 8.95% dry matter, 1.2% N in dry matter, and 8.89% ^{15}N was obtained and 4.75 kg of fresh algal mass was incorporated into a 1-m^2 plot. With IR26 grown in a flooded soil, recovery of ^{15}N in the grain, straw, and root of the first crop was 14.7% of ^{15}N applied as algal mass. In the second crop, the recovery was only 2.26%. Although ^{15}N remaining in soil was not analyzed, the preliminary experiment suggested low availability of algal nitrogen to a rice crop.

Deep placement of nitrogen fertilizer and algal nitrogen fixation. Nitrogen fixation of blue-green algae in the floodwater and on the soil surface is inhibited when nitrogen fertilizers are broadcast in the paddy. Experiments with deep placement of urea tested its compatibility with algal nitrogen fixation.

From the treatments control (no nitrogen), urea supergranule deep placement (one 3-g granule/4 hills, 10 cm deep or 87 kg N/ha), urea broadcast

(58 kg N/ha basal, 29 kg N/ha after panicle initiation), ammonium sulfate broadcast, and sulfur-coated urea broadcast (87 kg N/ha basal), the percentages of the acetylene reduction activity over the control were 70 (urea deep placement), 0 (urea broadcast), 17 (ammonium sulfate broadcast), and 27 (SCU broadcast). This trend was also reflected in the number of aerobic nitrogen-fixing blue-green algae. However, the total algal biomass estimated by chlorophyll measurement was greatest in the presence of mineral nitrogen in floodwater because of growth of unicellular green algae caused by fertilizer nitrogen.

To confirm the results of the field experiment and to verify their validity in different soils under different environmental conditions, pot experiments were done in a controlled environment (35° day/29°C night temperatures) and humidity (70%) with representative acidic, neutral, and alkaline soil types. One set of pots was exposed to sunlight, and the other was shaded to 84% light reduction. Fertilizer treatments were control, urea supergranule placed 10 cm deep (1 granule/pot), and broadcast urea (0.46 g N/pot) (Table 4). Across all soils and light intensities, the acetylene reduction activity was strongly inhibited by surface application of urea. Apart from exceptionally high acetylene reduction activity and the growth of *Cylindrospermum*, the dominant nitrogen-fixing algal flora in urea deep placement and in the control were the same. The deep placement of urea supergranules does not disturb the natural algal nitrogen-fixing system.

Nitrogen enrichment at the surface of flooded soil. An attempt was made to ascertain if the surface (0-4 mm) layer of flooded soil during a rice crop has an accumulation of nitrogen, presumably derived from the phototrophic nitrogen-fixing biomass. Recycling of nitrogen from lower depths of the soil profile was prevented by weeding and removal of dying rice leaves from the plants.

A preliminary greenhouse experiment with Maligaya soil (total N – 0.07%) tested the technique. While total nitrogen in the soil profile was 0.071-0.073%, total nitrogen content in the surface (0-4 mm) soil increased to 0.098% after 1 rice crop when the surface was exposed to light. When the surface of pots was covered by black cloth, accumulation of nitrogen in the surface was not detected.

A similar test was made in the field in a 1-m^2 plot surrounded by metal fence, but the data were too variable to be meaningful.

Epiphytic blue-green algae on wetland rice, aquatic weeds, and deepwater rice. Visual and microscopic observations, microbial counting, and ARA were made on shallow-water rice, submerged weeds, and deepwater rice to determine epiphytic growth of blue-green algae. *Gloeotrichia*, *Nostoc*, *Calothrix*, and *Anabaena* were observed on the surface of the submerged part of the rices Chara and Najas.

Older parts of the hosts appeared to have more rough surface and supported more epiphytic blue-green algae. Chara supported more epiphytic algae than Najas. Old, rough nylon strings also supported epiphytic algal growth.

As shown previously (1977 annual report), the nodal roots of deepwater rice support blue-green algae. The acetylene reduction activity of various parts of deepwater rice grown in a deepwater tank at IRRI was measured under light and dark. Activity in the dark was far smaller than that with light (Table 5). The nodal roots that developed under the leaf sheaths (inner root) of the floating parts had highest specific acetylene reduction activity, but the contribution of leaf sheaths was evaluated highest because of a large biomass. *Gloeotrichia*,

Table 4. Nitrogen-fixing activity[a] in 3 soils as affected by fertilizer management. IRRI, 1979.

Fertilizer management	Acetylene reduction activity (μmol C_2H_4/m^2 per hour)					
	Luisiana (pH 5)		Maahas clay (pH 7)		Tiaong (pH 8)	
	Shaded	Unshaded	Shaded	Unshaded	Shaded	Unshaded
Control	6.0	1.0	4.8	5.4	24.0	62.0
Deep placement of urea	4.1	1.3	7.5	170.0	25.0	41.0
Broadcast urea	0.6	2.3	0.4	0.8	7.7	7.7

[a]Measured 15 days after fertilizer application by 1 hour incubation with 10% C_2H_2 in ambient air. A whole pot surface was subjected to acetylene reduction assays.

Table 5. Light-dependent acetylene reduction activity on the component parts of deepwater rice at the maturing stage. IRRI, 1979.

Component part	Biomass (g fresh wt/plant)	Acetylene reduction activity with light[a] (nmol C_2H_4/h)	
		Per g	Total
Floating			
Exposed root	2.50	24.00	60
Leaf sheath	62.00	52.00	3,200
Inner root	0.25	69.00	17
Stem	98.00	2.00	196
Submerged			
Exposed root	64.00	0.46	29
Leaf sheath	15.00	12.00	180
Inner root	1.30	3.00	4
Stem	100.00	0.30	30

[a] Difference from acetylene reduction activity in the dark, measured under air + 10% C_2H_2.

Nostoc, *Anabaena*, and *Calothrix* were found on the nodal roots and leaf sheaths. *Nostoc* colonies were frequently present at the points of lateral branches of roots. *Nostoc* and *Calothrix* were also found in the cavities of senescent leaf sheaths. Algal growth in the cavities of dead or senescent leaf sheaths was also found in Thailand for deepwater rice and submerged grasses. Mainly because of the greater biomass available for colonization, deepwater rice supports nitrogen fixation of agricultural significance (10-20 kg N/ha) by epiphytic algae.

Effect of predation on blue-green algae. Phenomena such as poor growth of blue-green algae despite favorable conditions, imbalanced population structures of some paddy fauna, failure of algal inoculation, quick destruction of algal bloom, and the lack of exploitation of predator-prey relationship as a possible method for increasing nitrogen fixation prompted investigation of predator-algae relations in the paddy. In a preliminary trial, preference for some algal species and the feeding rate of the ostracods that preyed on blue-green algae were studied.

Tolypothrix tenuis 1482/3a, *Tolypothrix* sp. 26, *Calothrix* sp. 184, *Aulosira* sp. 68, and *Anabaena* MH were cultured in media and ^{14}C-labeled algal cells were collected by feeding ^{14}C-bicarbonate. Specific radioactivity in terms of dry weight of algae was determined. Ostracods of the genus *Cypris* were used as a predator and fed ^{14}C-labeled cells. Feeding rate, determined in relation to the animal's body size, was greatest on *Tolypothrix* sp. 26 > *Tolypothrix* 1482/3a > *Aulosira* sp. 68 > *Calothrix* sp. 184 > *Anabaena* MH. The rates increased as the size of the animal increased except in *Tolypothrix* 1482/3a, where the increase was more than that expected from the increase in animal body weight. Younger cultures (*Anabaena*) were more readily ingested than old ones.

Feeding rates of ostracods were markedly affected after treatment with a small dose of lindane (γ-BHC). Lindane at 0.01 ppm stimulated feeding, but 0.1 ppm greatly inhibited the feeding rate for *Tolypothrix* sp. 1482/3a and *Aulosira* sp. 68.

AZOLLA-ANABAENA SYMBIOSIS

Dual culture of rice and azolla with wide row spacing. Azolla was grown during the growth cycle of rice to examine nitrogen fixation by azolla and response of rice to azolla incorporation. Narrow (13.3 cm) rows were alternated with wide (53 cm) rows. Distance between hills in a row was 6.6 cm. This spacing gave 50 hills/m^2. *Azolla pinnata* from Bangkok was grown as inoculum. Treatments were 1) no azolla, no chemical nitrogen, 2) 107 kg N/ha as ammonium sulfate, and 3) azolla incorporation. Superphosphate (27 kg P_2O_5/ha) was applied as basal dressing and mixed with soil and 5.3 kg P_2O_5/ha was applied on the surface just after azolla was inoculated. Inoculum added was 300 to 360 g/m^2. Furadan granules (2% a.i.) were applied at 13.4 g/m^2 for each inoculation. Whenever the surface was covered by azolla, the plots were drained and all azolla was incorporated with the soil.

In the 1979 dry season, IR26 and six crops of azolla were grown. Total fresh weight of azolla was 54.5 t/ha (2.4 t/ha dry weight) and total nitrogen incorporated as azolla was 110 kg/ha. Because of high soil fertility after conversion of the plots to wetland from dryland, there was no difference in yield among treatments. Average grain yield was 6.4 t/ha.

In the 1979 wet season, IR42 and 4 crops of azolla amounting to 36 t/ha fresh weight (2.0 t/ha dry wt or 72 kg N/ha) were grown. The nitrogen

Table 6. Maximum fresh weight and N content of Azolla strains[a] grown in unshaded plots for 4 seasons, and meteorological data. IRRI, 1979.

Strain	May–Jun		Sep–Oct		Dec–Feb		Apr–May	
	Fresh wt (kg/m²)	N content[b] (g/m²)	Fresh wt (kg/m²)	N content (g/m²)	Fresh wt (kg/m²)	N content (g/m²)	Fresh wt (kg/m²)	N content (g/m²)
A.p. Banaue	1.3 b (23)[c]	3.7	1.5 c (25)	4.0 b	1.4 b (25)	4.1 a	0.9 c (25)	2.7 a
A.p. Bicol	1.6 ab (30)	4.6	1.6 c (20)	4.7 ab	1.4 b (25)	4.1 a	1.0 bc (25)	2.8 a
A.p. Bangkok	1.8 a (21)	3.4	2.4 a (42)	4.8 a	1.9 a (25)	4.7 a	1.4 a (35)	2.9 a
A.p. Malaysia	1.6 ab (30)	4.4	1.9 b (35)	4.7 ab	1.3 b (23)	3.9 a	1.0 bc (25)	3.0 a
A.p. Bogor	1.2 b (14)	3.7	1.7 bc (25)	4.5 ab	1.4 b (23)	4.4 a	1.1 b (21)	3.5 a
A.f. Hawaii	0.8 c (40)	1.9	–		0.9 c (21)	2.7 b	0.2 e (19)	0.5 c
A.f. California	–		–		0.6 c (23)	2.7 b	0.2 e (14)	0.4 c
A.m. California	–		0.50 d (23)	1.2 c	0.7 c (21)	2.0 b	0.5 d (21)	1.6 b
Meteorological data (daily av for 6 wk)								
Solar radiation (cal/m²)	454		395		418		521	
Air temp (0°C) max	31.8		30.9		28.8		32.3	
min	24.3		23.2		21.6		23.9	
Sunshine duration (h)	5.6		4.3		7.2		8.2	
Rainfall (mm)	4.6		18.1		0.2		8.6	

[a] In a column, means followed by a common letter are not significantly different from each other at 5% level. [b] Estimated from the average N percent from 3 other seasons. [c] The numbers in parentheses indicate the days when maximum biomass was obtained.

plot received 60 kg N/ha. Rice growth in the azolla plots was best in the second season. Grain yields were 5.7 t/ha in azolla plots, 4.5 t/ha in nitrogen fertilizer plots, and 3.7 t/ha in control plots. The treatments were significantly different from each other.

In the 1979 experiments, azolla showed nitrogen-fixing ability resulting in 70-110 kg N/ha per rice crop.

Temperature response of azolla strains. Azolla strains were grown in controlled environment to screen them for tolerance for high temperature. Day/night temperature levels were 26°/18°, 33°/25°, and 37°/29°C. Relative humidity was 75%, and light intensity was 30 klux. In most strains and species, growth was best at 22°C. *Azolla filiculoides* (2 strains) showed narrow temperature requirement, while *Azolla pinnata* Vietnam Green I, Thailand TDA # 17, and Malaysia were regarded as superior strains.

Growth performance of azolla strains in the field as affected by season and shading. In an attempt to determine azolla strains with better growth in the field, the growth performance of 8 types of azolla (5 strains of *A. pinnata*, 2 of *A. filiculoides*, and 1 strain of *A. mexicana*) was examined 4 times a year in an open and 50%-shade field.

Based on maximum fresh weight (Table 6), *Azolla pinnata* from Bangkok was best. From April to May when solar radiation and temperature were highest, azolla growth was poorest. No difference in nitrogen content was observed among *A. pinnata* strains, but the nitrogen content of azolla from Bangkok was constantly lower than that of other *A. pinnata* strains. Growth of azolla other than *A. pinnata* was poor.

Response of azolla strains to phosphorus. To grow azolla in a paddy, the addition of phosphorus is essential. The various azolla species and strains were compared by continuous flow culture at 0.03 ppm P. Great growth variation among strains and species was observed. Growth rate decreased in the order: *A. pinnata* Bangkok; *A.p.* Kathmandu, Nepal; *A.p.* Malaysia; *A.p.* Cuttack, India; *A.p* China, Fukien red; *A.p.* La Van Vietnam; *A.p.* Serigor, Bangladesh; *A.p.* Bogor, Indonesia; *A. filiculoides* Hawaii, and *A. caroliniana* California.

Table 7. Nitrifier population and nitrifying capacity of soils from long-term fertility trials. IRRI, 1979 wet season.[a]

	Oxidized layer			Reduced layer		
	8 DT	41 DT	5 DH	8 DT	41 DT	5 DH
	Log number of Nitrosomonas cells/g dry soil					
Nonfertilized	2.1	3.1	3.2	2.1	3.4	3.2
With NPK	4.0	3.6	3.7	2.2	3.1	3.5
	Nitrification (%) due to added ammonium N after 4 days incubation					
Nonfertilized	12	13	8	14	10	8
Fertilized	26	42	31	9	9	5

[a]DT = days after transplanting, DH = days after harvest.

NITROGEN TRANSFORMATION

Nitrification in paddy fields. Ammonium applied in the paddy is oxidized to nitrate in the surface oxidized layer, followed by denitrification loss. Surveys on the nitrifier population and its nitrifying capacity were made in the IRRI long-term fertility plots (unfertilized and NPK fertilized) (Table 7). *Nitrosomonas* was highest in the oxidized layer of fertilized plots followed by that in the reduced layer and both layers of the unfertilized plots, suggesting that ammonium fertilizer addition enhanced the nitrifier in the oxidized layer. But the increase was no more than 10 times, suggesting that nitrification may take place only at thin surface layers in the oxidized layer or that nitrification may take place without multiplication of nitrifiers. The increase of *Nitrosomonas* in the reduced layer was probably due to migration to the surface layer because of weeding, farming activities, and biotic activities of soil animals.

In another field and in a study in cooperation with scientists from the International Fertilizer Development Center, *Nitrosomonas* number changed in response to surface application of urea and ammonium sulfate in comparison with deep placement of urea. The results did not clearly demonstrate the increase of the nitrifier in the oxidized layer after surface application of nitrogen fertilizer. Because of technical difficulties in taking measurements from the oxidized layer exclusively and of disturbance of the oxidized layer by farming practices, the surveys of nitrifier populations and activity of nitrification in the oxidized layer may have limited value.

Nitrification was measured in fields with less disturbance. Because nitrate formed by nitrification in a paddy soil quickly disappears by simultaneous denitrification, it is impossible to follow nitrification by measuring nitrate. When ^{15}N-labeled nitrate is added to an extent that exceeds denitrification rate, nitrification rate is measured by the dilution of ^{15}N in nitrate and denitrification is also determined by the decrease of nitrate.

In a test of the effect of nitrate on nitrification with ^{15}N-labeled ammonia as substrate, nitrification was not affected by up to 20 ppm NO_3-N. After removal of floodwater, a soil core was taken by a 1.7-cm-diameter tube. The surface 1 cm of soil was left in the tube and 10 ml of 20 ppm ^{15}N labeled NO_3-N added. Soil cores were then incubated in the field for 1 or 3 days. Soil cores taken from the field were frozen for storage. Several core samples were mixed before analysis. The water extract was filtered and passed through H-type cation exchange resin to remove ammonium and the NO_3-N in the leachate converted to ammonium by Devarda alloy. ^{15}N in NH_4-N was determined by emission spectroscopy (Table 8). Nitrification rate is lower than denitrification rate.

These data are the first experimental results showing nitrification rate in situ in a flooded soil.

Effect of soil condition during the dry season on nitrogen availability. The 1976 and 1977 annual reports indicated an influence of soil moisture conditions during the dry season on availability of nitrogen in the succeeding wet-season wetland rice. In 1977 pot experiments, rice was grown in wetland condition. The pots were subjected to flooding with rice, field moisture capacity with rice,

Table 8. Nitrification and denitrification rate of paddy soil measured by in situ method.[a] IRRI, 1979.

Time	Treatment[b]	Nitrification (g N/ha per day)	Denitrification (g N/ha per day)
1 wk after transplanting	20.8 kg N/ha	470 ± 50	1090 ± 47
	+ N-serve	170 ± 90	440 ± 165
1 wk before harvest	20.8 kg N/ha	460 ± 25	1000 ± 170
	+ N-serve	270 ± 100	500 ± 160

[a]Av of 3 replications and its standard error. [b]Ammonium nitrogen added just before assay.

Table 9. Frequency of occurrence of fungi from washed root segment of dryland rice, using Czapek-Dox agar medium. IRRI, 1979.

Fungus	Frequency of occurrence		
	Rotated plots (after 5 seasons fallow)	Rotated plots (after 9 seasons fallow or other crops)	Continuously cropped (12th crop of rice)
Fusarium	23.3[a]	9.8	12.9
Curvularia	0.8	3.6	0.8
Monocillium	3.3	3.6	3.0
Aspergillus	1.7	0.9	0.0
Penicillium	1.7	0.0	0.0
Other genera[b]	0.0	1.8	0.8
Sterile hyaline	38.3	33.0	24.2
Sterile dark	18.3	21.4	31.8
Unidentified	2.5	0.9	0.0
Segments (no.)	120	112	132
Total isolates	109	84	97
Segments colonized	875	71	73

[a]Percent of the root segments colonized by each group. [b]Include *Cephalosporium, Cylindrocarpon, Mucoraceae,* and *Trichoderma.*

or air-drying. Before the following wet season, pots were flooded for varying periods (from 2 to 35 days) or alternately flooded and dried.

As in previous experiments, initial rice growth after flooding of air-dried soil was retarded compared with growth in continuously flooded pots, but the final yield of rice was highest in pots with air-drying in the dry season.

Longer flooding of air-dried soil before growing the wet-season wetland rice lessened the initial growth inhibition. The growth of wetland rice for which the soil moisture was at field capacity during the dry season was poorest from the beginning until harvest. A cycle of wet and dry treatment decreased the availability of soil nitrogen. The farmers' practice of flooding a paddy a long time before wet-season rice appears to bring about better growth of rice at its early stage and increased use of soil nitrogen. Growing a rice crop in the dry season may increase fertilizer requirement for wet-season rice by decreasing soil nitrogen availability.

MICROBIOLOGY OF DRYLAND RICE AFFECTED BY SOIL SICKNESS

In cooperation with visiting scientists from the Tropical Agriculture Research Center, Ministry of Agriculture, Japan, the mycoflora of roots of dryland rice in rotation with other crops and in continuous rice cropping were surveyed. The percentage of washed root segments from which fungi grew was measured and the genera of the fungi were identified (Table 9).

Spore-forming fungi grew from 17 to 31% of the root segments irrespective of the history of rice cropping. Two-thirds of them are *Fusarium;* other genera are *Curvularia, Aspergillus,* and *Penicillium,* but they are rare. On the other hand, most fungi grown from root segments were sterile forms and the frequency of dark mycelium fungi was higher in continuously cropped plots than in rotated plots. *Pyrenochaeta, Pythium,* and *Phytophtora* that are common on dryland rice roots in Japan were not found at IRRI.

The frequency of occurrence of *Fusarium* on the root in rotated and continuously cropped plots did not differ. However, the species composition had a distinct nature in accordance with the history of dryland rice. Fusaria on the roots of plants from rotated plots were composed almost exclusively of *F. oxysporum,* while those from continuously cropped plots were mostly *F. moniliforme.* Because *F. moniliforme* is known to express weak but wide pathogenicity to various plants, its predominance on the root of dryland rice that was affected by soil sickness may attract the attention of plant pathologists.

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Soil fertility and fertilizer management

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NITROGEN FERTILIZER EFFICIENCY

Agronomy and Soil Chemistry Departments

Research on increasing the efficiency of nitrogen fertilizer continued to receive major attention in soil fertility research. In studies in collaboration with the International Fertilizer Development Center (IFDC), new fertilizer materials developed by IFDC and those from commercial sources were evaluated extensively with various cultural practices.

Placement of fertilizer nitrogen. *Dry season.* The third trial of the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) was continued at IRRI in the 1979 dry season. Prilled urea and sulfur-coated urea (SCU) applied with a plow-sole applicator, broadcast and incorporated SCU forestry grade, and supergranule placement were compared with urea applied in split doses. IR36, an early-maturing variety, and IR46, a medium-maturing variety, were the test cultivars.

In both varieties an increase of less than 2 t/ha resulted from the first 54 kg N/ha, and about 1 t/ha from 87 kg N/ha over 54 kg N/ha (Table 1). Yields of both varieties with 87 kg N/ha applied as prilled urea and SCU by a plow-sole applicator, and SCU forestry grade broadcast and incorporated were similar to yields with 120 kg N/ha applied as ammonium sulfate and urea in split doses.

At 54 kg N/ha, the yield was significantly higher from SCU applied with a plow-sole applicator than from split-applied urea, but was similar to that of SCU and SCU forestry grade broadcast and incorporated, supergranule placement, and urea by a plow-sole applicator. The trend was the same for 87 kg N/ha.

Wet season. The fourth INSFFER trial in the 1979 wet season had IR36 and IR46 as test cultivars. At 27 kg N/ha, IR36 yields were significantly higher with broadcast and incorporated SCU and supergranule placement than with split-applied urea (Table 2). With IR46, supergranule placement was much more effective than broadcast and incorporated SCU. Split-applied urea did not yield any higher than the no-nitrogen control. At

Table 1. Effects of forms, rates, and methods of nitrogen application on rice grain yield. Third trial of the International Network on Soil Fertility and Fertilizer Evaluation for Rice, IRRI, 1979 dry season.

Treatment[a]	Grain yield (t/ha)		
	IR36	IR46	Mean[b]
No fertilizer nitrogen	3.5	4.5	4.0 g
	54 kg N/ha		
Urea split application[c]	5.5	5.9	5.7 f
Urea by plow-sole applicator	6.4	7.2	6.8 e
SCU[d] broadcast and incorporated	6.6	6.7	6.6 e
SCU[d] by plow-sole applicator	6.8	6.9	6.9 de
SCU[e] broadcast and incorporated	6.6	6.7	6.6 e
Supergranule placement	6.7	6.7	6.7 e
Sulfur-coated supergranule	5.1	6.1	5.6 f
	87 kg N/ha		
Urea split application[c]	7.0	7.0	7.0 cde
Urea by plow-sole applicator	7.4	7.6	7.6 ab
SCU[d] broadcast and incorporated	7.3	7.4	7.3 bcd
SCU[d] by plow-sole applicator	7.7	7.7	7.7 ab
SCU[e] broadcast and incorporated	7.4	7.9	7.6 ab
Supergranule placement	7.4	7.4	7.4 bc
	120 kg N/ha		
Ammonium sulfate split application[c]	7.9	8.0	8.0 a
Urea split application[c]	7.3	7.9	7.6 ab

[a]SCU = sulfur-coated urea. [b]Any 2 means followed by the same letter are not significantly different from each other at the 5% level. [c]2/3 broadcast and incorporated at planting, 1/3 topdressed 5–7 days before panicle initiation. [d]Ordinary. [e]Forestry-grade.

Table 2. Effects of forms, rates, and methods of urea application on rice grain yield. Fourth trial of the International Network on Soil Fertility and Fertilizer Evaluation for Rice, IRRI, 1979 wet season.

Treatment	Grain yield[a] (t/ha)		
	IR36	IR46	Mean
No fertilizer nitrogen	3.3 f	3.6 e	3.4
27 kg N/ha			
Urea split application[b]	3.8 d	4.0 de	3.9
SCU[c] broadcast and incorporated	5.0 bc	4.3 cd	4.6
Supergranule placement	4.7 c	5.0 abc	4.8
54 kg N/ha			
Urea split application[b]	5.1 bc	4.5 bcd	4.8
Urea broadcast and incorporated	4.8 bc	4.8 abc	4.8
SCU[c] broadcast and incorporated	5.9 a	5.1 ab	5.5
Supergranule placement	5.8 a	5.0 ab	5.4
87 kg N/ha			
Urea split application[b]	5.4 ab	5.1 ab	5.3
Urea broadcast and incorporated	5.9 a	5.2 a	5.6
SCU[c] broadcast and incorporated	6.1 a	4.4 cd	5.2
Supergranule placement	6.1 a	3.6 e	4.8

[a]In a column, means followed by a common letter are not significantly different from each other at the 5% level. [b]2/3 broadcast and incorporated at planting, 1/3 topdressed 5–7 days before panicle initiation. [c]Sulfur-coated urea, ordinary.

87 kg N/ha, all the treatments performed equally well with IR36, but caused lodging and hence lower yield in IR46.

Forms of urea and application methods for efficient nitrogen use in rice. Results of the study on the effect of forms of urea and application methods showed that fertilized plots gave a highly significant average grain yield increase over the unfertilized control (Table 3).

The average grain yield of all fertilizer treatments was 4.4 t/ha at 27 kg N/ha and 4.7 t/ha at 54 kg N and 87 kg N/ha. The experiment showed no significant yield differences either among the tested nitrogen rates or among the application treatments. The nonsignificant yield differences were probably due to the high total nitrogen content of the soil (0.22%) at the study site.

Placement of fertilizer nitrogen. Experiments with IR36 rice in the 1979 dry and wet seasons in two farmers' fields evaluated nitrogen placement techniques on an Ultisol and a Vertisol. The texture and chemical characteristics of the soils are given in Table 4. The performance of an IRRI-developed plow-sole applicator using prilled urea and SCU was also evaluated.

Dry season. At Lucban, Quezon (clay, Ultisol, pH 5.5), the highest yield of 5.7 t/ha was obtained

Table 3. Effect of urea forms and application methods on IR44 yield. IRRI, 1979 wet season.

Treatment[a]	Grain yield[b] (t/ha)
No fertilizer nitrogen	3.4 c
27 kg N	
Split application of urea[c]	4.1 bc
SCU (forestry grade), broadcast and incorporated	4.6 ab
Silica-coated urea, broadcast and incorporated	4.6 ab
Placement as supergranules	4.3 b
Placement as conditioned sulfur-coated supergranules	4.5 ab
54 kg N	
Split application of urea[c]	4.2 b
SCU (forestry grade), broadcast and incorporated	4.9 ab
Silica-coated urea, broadcast and incorporated	4.9 ab
Placement as supergranules	4.8 ab
Placement as conditioned sulfur-coated supergranules	4.7 ab
87 kg N	
Split application of urea[c]	4.6 ab
SCU (forestry grade), broadcast and incorporated	5.1 a
Silica-coated urea, broadcast and incorporated	4.3 b
Placement as supergranules	4.9 ab
Placement as conditioned sulfur-coated supergranules	4.6 ab

[a]SCU = sulfur-coated urea. [b]In a column means followed by the same letter are not significantly different at the 5% level. [c]2/3 broadcast and incorporated at planting, 1/3 topdressed 5–7 days before panicle initiation.

Table 4. Characteristics of soils for trials under the International Network on Soil Fertility and Fertilizer Evaluation for Rice. Farmers' fields in Teresa (Rizal) and Lucban (Quezon), Philippines, 1979.

Criterion	Dry season		Wet season	
	Teresa	Lucban	Teresa	Lucban
pH (1:1)	6.7	5.5	7.0	5.4
Organic matter (%)	1.9	2.8	1.8	2.7
Total nitrogen (%)	0.13	0.20	0.12	0.20
Available phosphorus (ppm Bray No. 2)	8	6	7	7
Exchangeable potassium (meq/100 g)	0.58	0.10	0.66	0.18
Cation exchange capacity (meq/100 g)	20	31	33	18
Texture	Clay	Clay	Clay	Clay
Soil taxonomy (order)	Vertisol	Ultisol	Vertisol	Ultisol

with SCU forestry grade; however, all rates, sources, and methods of nitrogen application gave comparable grain yields. At Teresa, Rizal (clay, Vertisol, pH 6.7), urea applied in split doses and with a plow-sole applicator gave yields comparable with those from urea briquet placement at 54 kg N/ha, and those from SCU (ordinary) applied with a plow-sole applicator at 87 kg N/ha (Table 5).

Wet season. At Lucban (clay, Ultisol, pH 5.4) at the same rate of application, almost all sources and methods of placement of nitrogen showed no significant grain yield differences. At Teresa (clay, Vertisol, pH 7.0), SCU broadcast and incorporated and placement of urea briquets at 87 kg N/ha gave significantly higher yields than the rest of the methods and rates of nitrogen application (Table 6).

Forms of urea and application methods for increasing nitrogen efficiency in rice. During the 1979 dry season, IRRI research evaluated modified urea materials and their application techniques for increasing fertilizer nitrogen efficiency in IR36 under two planting methods.

Transplanted rice. Seven fertilizer treatments at the rate of 65 kg N/ha and a control (no fertilizer nitrogen) were evaluated in transplanted rice.

The fertilized plots gave significantly higher yield than the unfertilized control (Table 7). The highest yield of 6.0 t/ha with efficiency of 46 kg rough rice/kg N was obtained from urea marbles placed 10 to 12 cm deep at the center of every 4 hills.

Direct-seeded rice. Fertilized plots of direct-seeded rice gave significantly higher yields than the unfertilized plots (Table 8). At 54 kg N/ha, SCU broadcast and incorporated gave significantly higher yield than other forms of urea and methods

Table 5. Effects of sources and methods of nitrogen application on IR36 rice grain yield. Third trial of the International Network on Soil Fertility and Fertilizer Evaluation for Rice, Teresa (Rizal) and Lucban (Quezon), Philippines, 1979 dry season.

Treatment[a]	Grain yield[b] (t/ha)	
	Teresa	Lucban
No fertilizer nitrogen	2.3 h	3.7 b
54 kg N/ha		
Urea, split application	3.7 fg	5.1 a
Urea, plow-sole applicator	3.3 g	5.4 a
SCU_1, broadcast and incorporated	4.4 cde	5.2 a
SCU_1, plow-sole applicator	4.0 def	5.0 a
SCU_2, broadcast and incorporated	4.0 def	5.1 a
Urea briquet	3.8 efg	5.4 a
87 kg N/ha		
Urea, split application	4.0 def	5.3 a
Urea, plow-sole applicator	4.0 def	5.4 a
SCU_1, broadcast and incorporated	5.3 a	5.4 a
SCU_1, plow-sole applicator	4.5 bcd	5.5 a
SCU_2, broadcast and incorporated	5.2 a	5.7 a
Urea briquet	5.0 ab	5.0 a
120 kg N/ha		
Ammonium sulfate, split application	4.8 abc	5.6 a
Urea, split application	5.3 a	5.6 a
CV (%)	9.1	7.8

[a]SCU = sulfur-coated urea. For split application, 2/3 of the fertilizer was broadcast and incorporated at planting time, 1/3 was topdressed 5–7 days before panicle initiation. [b]In a column, any 2 means followed by a common letter are not significantly different at 5% level.

Table 6. Effects of sources and methods of nitrogen application on IR36 rice grain yield. Fourth trial of the International Network on Soil Fertility and Fertilizer Evaluation for Rice, Teresa (Rizal) and Lucban (Quezon), Philippines, 1979 wet season.

Treatment[a]	Grain yield[b] (t/ha)	
	Teresa	Lucban
No fertilizer nitrogen	2.4 g	3.5 d
27 kg N/ha		
Urea, split application	3.0 f	4.6 bc
SCU, broadcast and incorporated	3.4 ef	4.7 abc
Urea briquet	3.6 de	4.9 abc
54 kg N/ha		
Urea, split application	3.3 ef	4.5 c
Urea, broadcast and incorporated	3.3 ef	4.7 abc
SCU, broadcast and incorporated	4.2 bc	4.7 abc
Urea briquet	3.9 cd	5.0 ab
87 kg N/ha		
Urea, split application	3.8 cde	4.8 abc
Urea, broadcast and incorporated	3.6 de	4.7 abc
SCU, broadcast and incorporated	4.7 a	5.1 a
Urea briquet	4.5 ab	5.0 ab
CV (%)	9.3	6.7

[a]SCU = sulfur-coated urea. For split application, 2/3 urea was broadcast and incorporated at planting time, and 1/3 was topdressed 5–7 days before panicle initiation. [b]In a column, means followed by a common letter are not significantly different at the 5% level.

Table 7. Effect of forms of urea and application methods on the grain yield of transplanted wetland rice. IRRI, 1979 dry season.

Treatment	Grain yield[a] (t/ha)
No fertilizer nitrogen	3.0 d
Split application of urea	5.0 c
Band placement of urea with fertilizer applicator from Taiwan	5.5 abc
Urea marbles (2–4 mm), broadcast and incorporated	5.8 ab
Urea marbles (6–8 mm), broadcast and incorporated	5.9 ab
SCU (forestry grade), broadcast and incorporated	5.2 bc
Placement as urea marbles (15–20 mm)	6.0 a
Placement as urea supergranules	5.8 ab

[a]Means followed by a common letter are not significantly different at the 5% level. CV = 8.5%.

of application, except prilled urea at 120 kg N/ha applied basally.

Application methods of urea and modified urea materials. During the 1979 dry season, an IRRI experiment evaluated the effects of urea, modified urea materials, and their application methods on the growth and yield of IR36 and IR42 at two spacings (20 × 20 cm and 40 × 5 cm).

There were no significant differences in grain yield between the two spacings and the two varieties tested. The data averaged for both varieties and spacings showed significantly higher yields from the fertilized plots than from the unfertilized. Differences in grain yields due to the forms of urea fertilizer and application methods tested were observed (Table 9). In general, grain yields increased significantly with increase in nitrogen level from 54 to 87 kg/ha regardless of urea source and application technique. The results suggest that rice yields can be increased by increasing the rate of nitrogen application and by better fertilizer management practices.

Urea placement and spacing with a fertilizer applicator for wetland rice. The bucket-type fertilizer applicator (from China) was evaluated in an experiment with IR44 at IRRI during the 1979 wet season. Treatments are outlined in Table 10. The desired rate and spacing of the urea fertilizers for each plot were not achieved because the machine failed to scoop the urea pellets or granules or the

Table 8. Effect of forms of urea and application methods on the grain yield of direct-seeded wetland rice. IRRI, 1979 dry season.

Treatment[a]	Grain yield[b] (t/ha)
No fertilizer nitrogen	2.8 d
Split application of urea[c]	4.9 bc
Plow-sole application of prilled urea	5.5 b
Split application, urea marbles (2–4 mm)[c]	4.9 bc
Sulfur-coated urea, broadcast and incorporated	6.2 a
Plow-sole application of sulfur-coated urea	5.3 b
Urea marbles (2–4 mm), broadcast and incorporated	4.9 bc
Urea marbles (6–8 mm), broadcast and incorporated	4.8 bc
Prilled urea, 2/3 10 DS + 1/3 40 DS[d]	4.4 c
Prilled urea, broadcast and incorporated	6.7 a

[a]All nitrogen applications were at the rate of 54 kg N/ha except broadcast and incorporated prilled urea, which was at 120 kg N/ha. [b]Means followed by a common letter are not significantly different at the 5% level. [c]2/3 broadcast and incorporated at planting time and 1/3 topdressed 5–7 days before panicle initiation. [d]DS = days after sowing. CV = 9.0%.

Table 9. Effect of urea and modified urea materials and their application methods on rice grain yield. IRRI, 1979 dry season.

Treatment[a]	Grain yield (t/ha)		T-mean[b]
	54 kg N/ha	87 kg N/ha	
No fertilizer nitrogen	–	–	3.1 d
SCU, broadcast and incorporated	5.3	5.9	5.6 a
Placement as sulfur-coated supergranules	5.3	5.8	5.5 ab
SCU, plow-sole application	5.3	5.7	5.5 ab
Split application of urea[c]	5.2	5.7	5.4 ab
Placement as urea supergranules	5.1	5.4	5.3 b
Urea, plow-sole application	4.5	5.2	4.8 c
Split application of urea[c] (120 kg N)	–	–	5.8 a

[a]SCU = sulfur-coated urea. [b]Means followed by a common letter are not significantly different at the 5% level. Av for 2 varieties (IR36, IR42) and 2 spacings (20 x 20 cm, 40 x 5 cm spacing). [c]2/3 basal incorporated before transplanting, 1/3 topdressed 5–7 days before panicle initiation.

pellets or granules clogged the discharge opening of the machine.

Except for treatments 4, 5, and 8, the fertilized plots gave significantly higher yields than the unfertilized control plot (Table 10). Yields in the fertilized plots did not differ significantly, but treatments 4, 5, and 8 yielded significantly less than the rest of the fertilized treatments (no. 2, 7, 9, and 10).

Forms of urea fertilizer and seedling age for increasing fertilizer nitrogen efficiency in transplanted wetland rice. During the 1979 wet season, an IRRI trial tested the response to four forms of urea fertilizer of transplanted rice in continuously flooded fields. Twenty- and 40-day-old seedlings of early-maturing IR36 and intermediate-maturing IR42 were used.

No fertilizer was applied in the seedbed, but carbofuran at the rate of 1.0 kg a.i./ha was broadcast and incorporated before the pregerminated seeds were sown. Before transplanting, all forms of urea fertilizer at the rate of 1 kg N/ha were broadcast uniformly and incorporated thoroughly. Phosphorus and potassium fertilizers (20 kg P_2O_5/ha and 20 kg K_2O/ha) and 5 kg $ZnSO_4$/ha were also applied basally in all plots. Weed and insect control were optimum. All seedlings were transplanted at the same time.

With 20-day-old IR36 seedlings, all plots that received nitrogen from various forms of urea except those applied as SCU marble (6 to 8 mm in diameter) produced yields significantly higher than those of plots without nitrogen (Table 11). Grain yields from fertilized 40-day-old seedlings were

Table 10. Effect of placement and spacing of urea with a fertilizer applicator from the People's Republic of China (PROC) on the yield of IR44. IRRI, 1979 wet season.

Treatment					
No.	Form of urea	Application method	Urea spacing (cm)	Nitrogen rate[b] (kg/ha)	Grain yield[a] (t/ha)
1	Urea supergranule 1 g	Placement[c] at 3–7 cm	40 x 40	29 (22)	4.2 ab
2	Urea supergranule 1 g	Placement at 3–7 cm	20 x 40	58 (26)	4.6 a
3	Urea supergranule 2 x 1 g	Placement at 3–7 cm	40 x 40	58 (40)	4.3 ab
4	Urea pellet 1 x 1 g	Placement at 3–7 cm	40 x 40	29 (19)	3.8 bc
5	Urea pellet 1 x 1 g	Placement at 3–7 cm	20 x 40	58 (40)	4.0 abc
6	Urea pellet 2 x 1 g	Placement at 3–7 cm	40 x 40	58 (38)	4.4 ab
7	Sulfur-coated urea supergranule 1 g	Placement at 3–7 cm	40 x 40	29 (26)	4.6 a
8	Sulfur-coated urea supergranule 1 g	Placement at 3–7 cm	20 x 40	58 (30)	3.8 bc
9	Sulfur-coated urea supergranule 2 g	Hand placement[d]	40 x 40	58 (57)	4.7 a
10	Urea	Split application	Broadcast	29	4.6 a
11	Urea	Split application	Broadcast	58	4.4 ab
12	Control			0	3.3 c

[a]Means followed by a common letter are not significantly different at the 5% level. [b]Values enclosed in parentheses are the actual rate of nitrogen applied with the fertilizer applicator, av of 4 replications. [c]With PROC machine (3–7 cm soil depth). [d]Deep placement (5–7 cm soil depth) was done by hand because the size of the 2-gram sulfur-coated urea supergranule was inappropriate for the machine.

Table 11. Effect of forms of urea on the grain yield of IR36 and IR42 transplanted as 20- and 40-day-old seedlings at 3–4 seedlings/hill, 20 x 20 cm spacing. IRRI, 1979 wet season.

Treatment	Grain yield[a] (t/ha)				T-means
	IR36		IR42		
	20-day-old	40-day-old	20-day-old	40-day-old	
No fertilizer nitrogen	3.6 b	2.5 c	2.6 c	3.1 c	3.0
Prilled urea	4.8 a	3.5 b	3.8 ab	4.0 ab	4.0
Ordinary sulfur-coated urea	5.2 a	4.6 a	4.3 a	4.2 ab	4.6
Sulfur-coated urea (forestry grade)	5.4 a	5.0 a	3.8 ab	4.5 a	4.7
Sulfur-coated urea marble (6–8 mm diam)	3.7 b	3.3 b	3.3 b	3.6 bc	3.5
Mean	4.5	3.8	3.6	3.9	

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

significantly higher than those from the unfertilized plots. With IR36, the 20-day-old seedlings generally gave higher yields than the 40-day-old seedlings, regardless of fertilizer treatments. The yield difference between the two seedling ages was significant (Table 11).

The results suggest that to increase the number of croppings per year, 40-day-old seedlings of early-maturing IR36 may be planted, provided that efficient forms or sources of fertilizer nitrogen are used. Furthermore, the number of seedlings may be increased to compensate for a possible decrease in yield due to the use of older seedlings, which have a slow recovery rate after transplanting.

NITROGEN FERTILITY OF SOILS

Agronomy Department

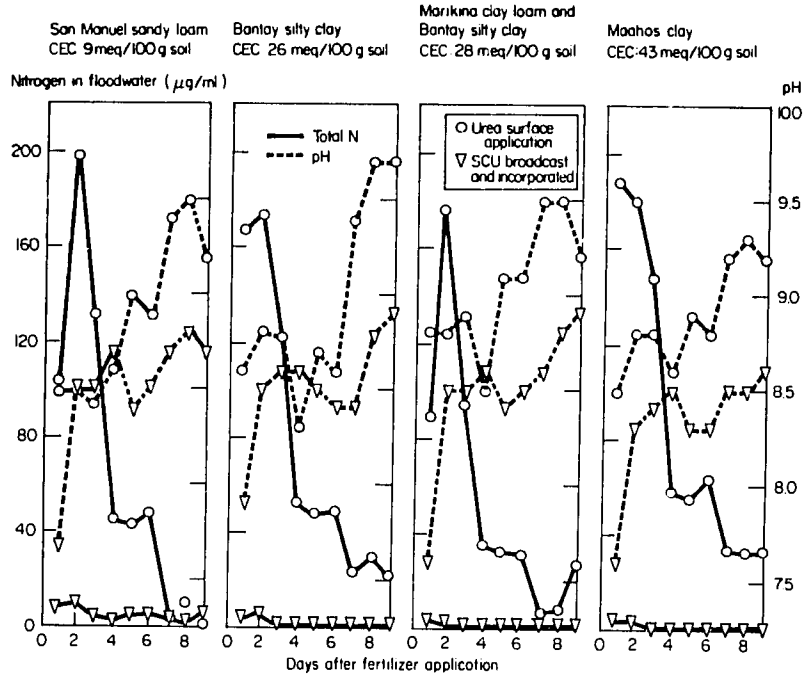
pH and nitrogen content of floodwater and ammonia volatilization loss. An outdoor drum experiment late in the dry season (May-June) evaluated the effect of soil texture and CEC on nitrogen content of the floodwater and ammonia volatilization loss. Five soils with varying CEC and soil textures were used (Table 12). Five treatments were compared: prilled urea, SCU broadcast and incorporated, prilled urea surface applied, urea supergranule placement, and unfertilized control. Urea-nitrogen and ammonium-nitrogen content, pH, and temperature of the floodwater were measured for several days starting immediately after fertilizer application.

The different soils had similar trends in floodwater pH after fertilizer application (Fig. 1). The values were higher with surface-applied urea than with broadcast and incorporated SCU. The average nitrogen content of floodwater was high (180-200 μg N/ml) on the second day after urea application, but dropped to 40 μg N/ml or less on the fourth day. The nitrogen content of floodwater after incorporation of SCU was very low (10 μg N/ml).

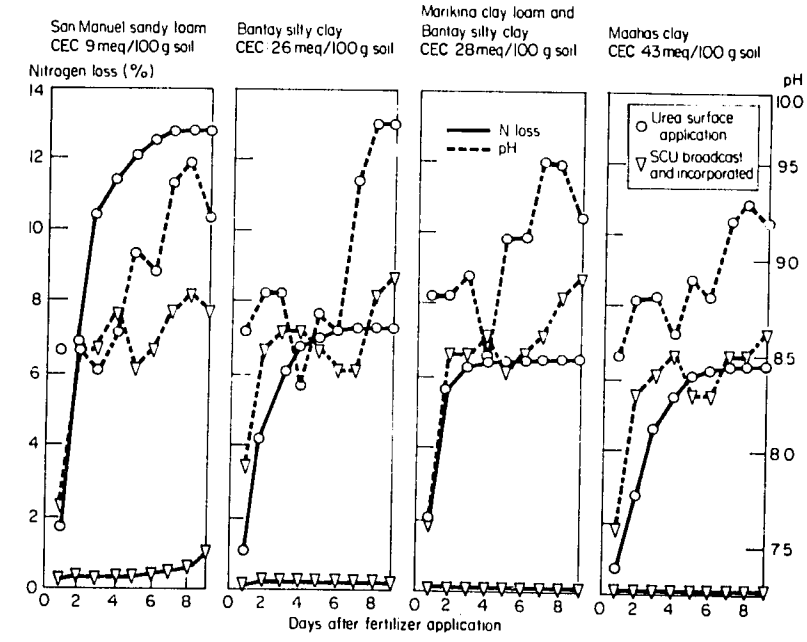
High nitrogen content and high pH of the floodwater aggravated nitrogen loss through ammonia volatilization. Such loss was always higher with surface-applied urea than with SCU broadcast and incorporated (Fig. 2). The loss was highest (13.2%) in San Manuel sandy loam with

Table 12. Characteristics of Philippine rice soils used for ammonia volatilization studies in outdoor drums. IRRI, 1979.

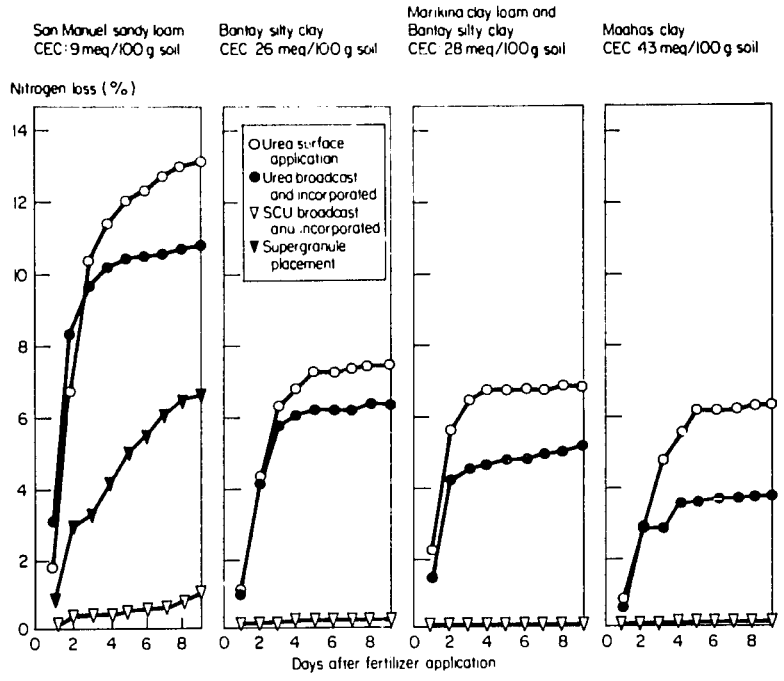
Soil	pH	Soil texture	Cation exchange capacity (meq/100 g)	Nitrogen (%)	Organic matter (%)	Available phosphorus (ppm) Bray	Exchangeable cations (meq/100 g)				Total zinc (ppm)
							Calcium	Magnesium	Potassium	Sodium	
Maahas clay	6.5	Clay	43	0.17	3.15	12	15.6	7.4	1.34	0.50	132
Bantay silty clay	6.5	Clay loam	31	0.22	0.22	63	20.6	5.9	0.43	0.34	161
Marikina clay loam	6.2	Clay loam	26	0.22	4.20	115	13.3	7.5	0.32	0.51	76
Bantay silty clay	6.0	Silty clay	26	0.13	2.26	69	13.3	7.2	0.24	1.21	91
San Manuel sandy loam	6.8	Sandy loam	9	0.11	2.29	17	5.4	2.6	0.04	0.19	28



1. Changes in urea-nitrogen + ammonium nitrogen concentration and pH of floodwater as affected by cation exchange capacity and texture of the soil. Large-drum experiment, IRRI, 1979 late dry season.



2. Ammonia volatilization loss and pH of floodwater as affected by cation exchange capacity and texture of the soil. Large-drum experiment, IRRI, 1979 late dry season.



3. Ammonia volatilization loss from different forms of urea as affected by cation exchange capacity and texture of the soil. Large-drum experiment, IRRI, 1979 late dry season. Nitrogen loss as ammonia was negligible with supergranule placement in silty clay, clay loam, and clay soils.

low CEC and lowest (6.2%) in Maahas clay with the highest CEC. This indicates that soil texture and CEC greatly affect nitrogen loss as ammonia. Nitrogen loss from SCU was negligible in all the soils probably because of the low nitrogen content and low pH of the floodwater.

The effect of CEC and texture of the soil on nitrogen loss was determined in a large-drum experiment (Fig. 3). The loss from urea fertilizer increased as the CEC decreased. Ammonia volatilization loss reached its peak on the second day when the nitrogen content of floodwater was also highest. Ammonia volatilization loss was consistently higher in surface-applied urea than in urea broadcast and incorporated during final land preparation. Placement of urea supergranule in the coarse-textured Pangasinan soil with low CEC caused nitrogen loss of 6.5%, with the loss increasing gradually from the day of application. The data indicate that modified urea — SCU and supergranule — minimizes ammonia volatilization loss in clayey soil. In coarse-textured soil, slow-release nitrogen fertilizer is better for minimizing losses as ammonia.

INCREASING NITROGEN FERTILIZER EFFICIENCY

Soil Chemistry and Agronomy Departments

The effect of time and mode of nitrogen application on fertilizer efficiency was studied in the wet and dry seasons. A best-split application of ammonium sulfate or urea broadcast and incorporated before transplanting with a further dose at panicle initiation was compared with a common farmer practice of a broadcast dose without incorporation 21 days after transplanting with a further dose at panicle initiation. These treatments were compared with slow-release SCU and deep placement of urea supergranules.

In both seasons deep placement of urea supergranules gave highest yields. In the dry season, delayed application of the initial nitrogen reduced yield 0.3-0.5 t/ha, whereas in the wet season the effect was insignificant (Table 13). Similarly, delayed availability of nitrogen through the use of SCU (basal or delayed) reduced yield in the dry season but, compared with best-split urea, increased yield in the wet season.

Table 13. Effect of time and mode of nitrogen fertilizer applications on the yield of IR36 (dry season) and IR44 (set season) and on fertilizer nitrogen recovery. IRRI, 1979.

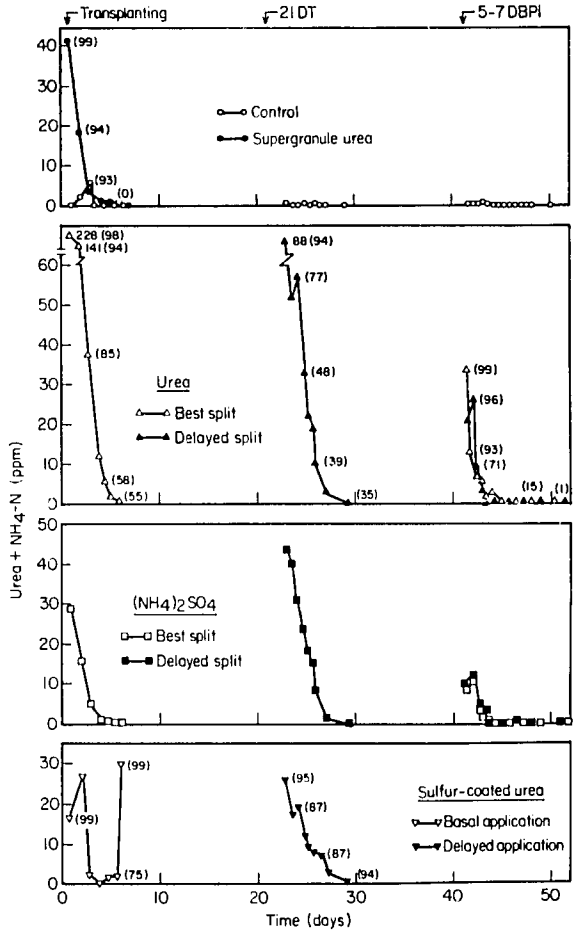
Treatment	Fertilizer timing[a]			Dry season[b] (87 kg N/ha)		Wet season[b] (54 kg N/ha)	
	0 DT	21 DT	PI	Grain yield (t/ha)	Apparent N recovery (%)	Grain yield (t/ha)	Apparent N recovery (%)
No nitrogen				4.1 e		3.1 d	
Prilled urea (best split)	2/3	0	1/3	5.7 b	44 bc	4.0 c	35 c
Prilled urea (farmer split)	0	2/3	1/3	5.4 c	23 d	3.8 c	36 c
Ammonium sulfate	2/3	0	1/3	5.9 b	52 b	4.1 c	50 bc
Ammonium sulfate	0	2/3	1/3	5.4 c	32 cd	3.8 c	36 c
SCU[c]	All	0	0	5.8 b	46 b	4.9 ab	78 ab
SCU	0	All	0	5.1 d	30 d	4.4 bc	69 ab
Urea supergranule (deep placement)	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 for the supergranules which were placed 10 cm deep, 1/4 hills. All 21 DT and PI applications were broadcast directly into the floodwater. [b]In a column, any two means followed by the same letter are not significantly different from each other at the 5% level. [c]Sulfur-coated urea, forestry grade.

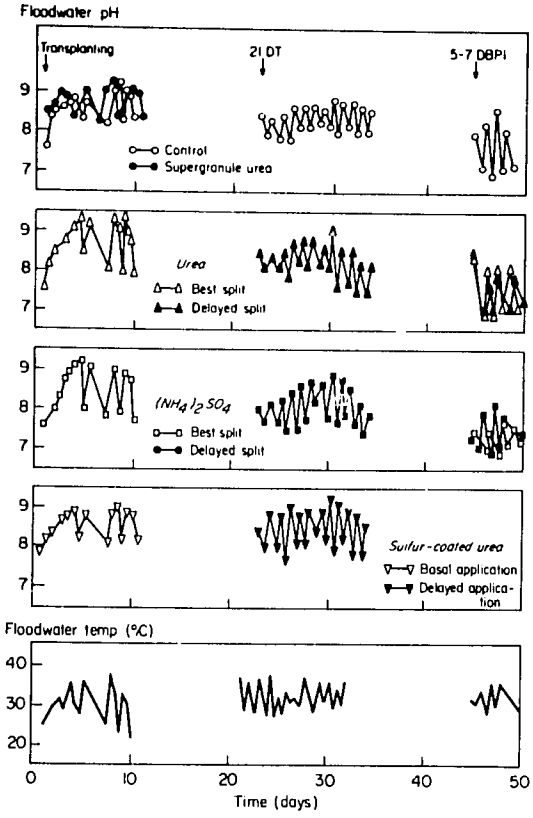
In both seasons broadcast urea and ammonium sulfate were inefficient (23-52% recovery), suggesting that extensive losses of these fertilizers occurred. In the dry season, immediately after fertilizer incorporation and when only a thin layer of floodwater was present, prilled urea produced high concentration of nitrogen in the floodwater (228 ppm) compared with ammonium sulfate and SCU (Fig. 4). The supergranules deep-placed produced 41 ppm of floodwater nitrogen presumably due to upward diffusion of urea in the hole made during placement. The floodwater pH at 21 days after transplanting was higher during the first few days of rapid nitrogen disappearance than it was at transplanting (Fig. 5), which indicated that ammonia volatilization from delayed application may have been greater than that from basal.

The floodwater data for the wet season showed trends similar to those for the dry season except that concentrations of nitrogen were much lower (Fig. 6, 7), possibly because of lower rate of nitrogen application and dilution of floodwater by extensive rainfall. The lower concentrations of urea at 21 days after transplanting conformed with the relatively better yield with delayed urea application in the wet season than that in the dry season. The same was true for the SCU, which produced lower floodwater nitrogen concentrations in the wet season and was more effective in the wet season than in the dry (Table 13).

The potential nitrification-denitrification from the treatments was determined by measuring the flux of nitrous oxide (N_2O). N_2O is a minor pro-



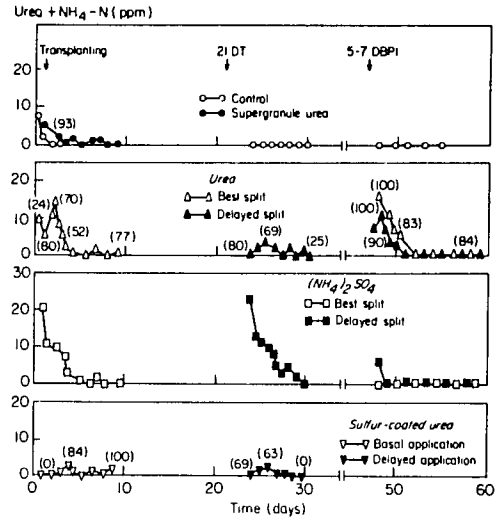
4. Effect of time and mode of nitrogen fertilizer application on the concentration of (urea + NH_4)-N in floodwater. IRRI, 1979 dry season. The numbers in parentheses show the urea-N as a percentage of urea plus NH_4-N. DT = days after transplanting, DBPI = days before panicle initiation.



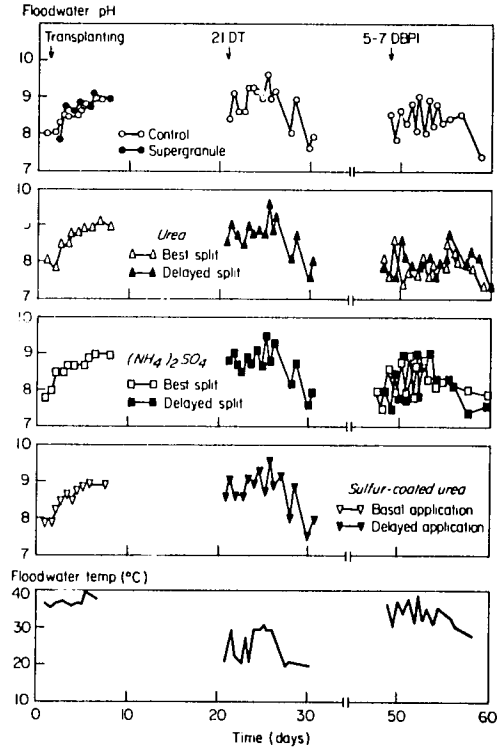
5. Effect of time and mode of nitrogen fertilizer application on floodwater pH. Floodwater temperatures at 0900 and 1400 hours are also shown. IRRI, 1979 dry season. DT = days after transplanting, DBPI = days before panicle initiation.

duct of nitrification-denitrification, but it is a potential pollutant of the stratospheric ozone layer and has been the subject of much recent research. Relatively small N_2O fluxes (<100 ng/m^2 per second) were detected in the dry season (Fig. 8) although the data showed that nitrification-denitrification was occurring in response to fertilizer application.

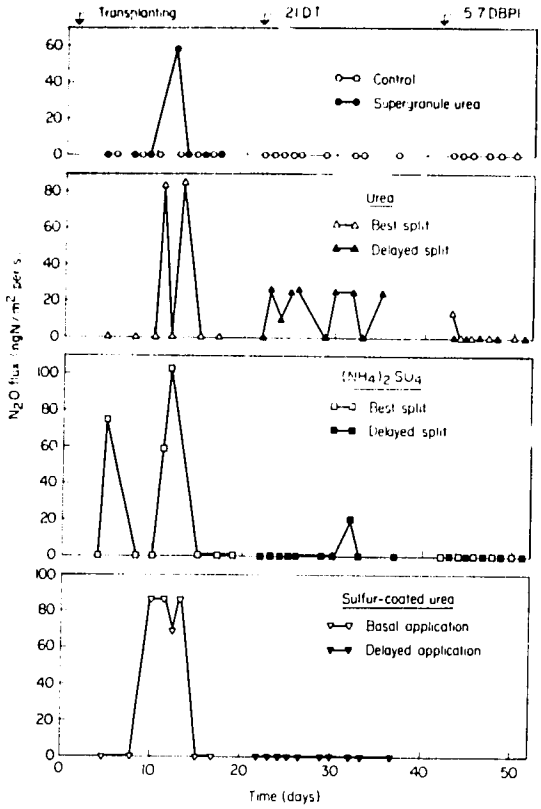
In all treatments producing high floodwater nitrogen levels, N_2O was evolved after a lag of 8 days. The lag period was less for ammonium sulfate than for urea, presumably because the latter had to be hydrolyzed to ammonium before nitrification-denitrification could take place. The N_2O fluxes were low in the morning and increased during the day. Within 5-6 days fluxes were zero. The 21 DT and panicle initiation applications produced higher N_2O fluxes from urea than from ammonium sulfate.



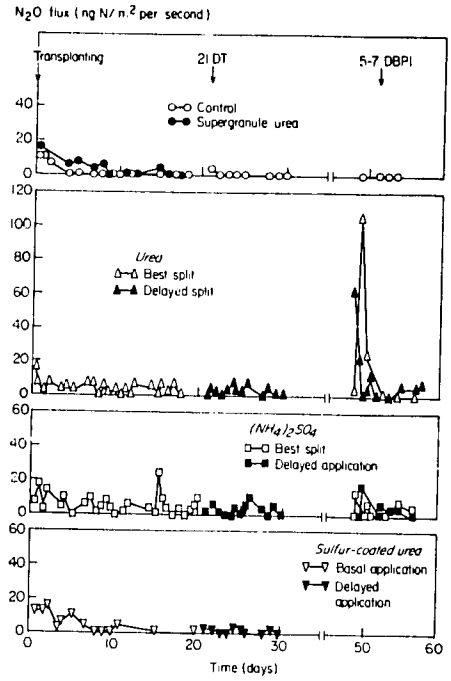
6. Effect of time and mode of nitrogen fertilizer application on (urea + NH_4)-N concentration in floodwater. Clay soil, IRRI, 1979 wet season. The numbers in parentheses show the urea-N as a percentage of urea plus NH_4-N. DT = days after transplanting, DBPI = days before panicle initiation.



7. Effect of time and mode of nitrogen fertilizer application on floodwater pH. Floodwater temperatures at 0900 and 1400 hours are also shown. Clay soil, IRRI, 1979 wet season. DT = days after transplanting, DBPI = days before panicle initiation.



8. Effect of time and mode of nitrogen fertilizer application on nitrous oxide (N_2O) flux. IRRI, 1979 dry season. DT = days after transplanting, DBPI = days before panicle initiation.



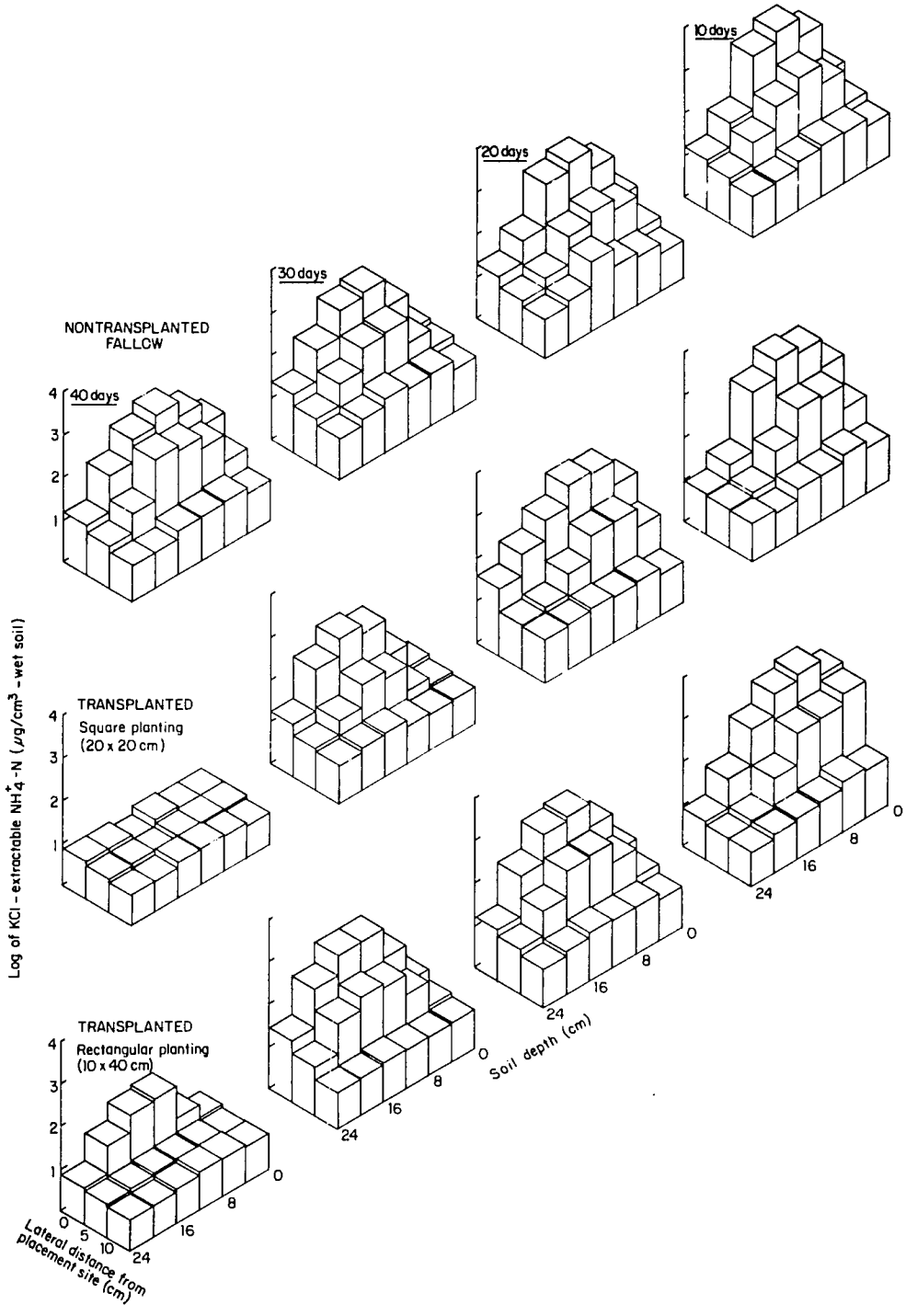
9. Effect of time and mode of nitrogen fertilizer application on nitrous oxide (N_2O) flux. IRRI, 1979 dry season. DT = days after transplanting, DBPI = days before panicle initiation.

The wet season generally had lower N_2O fluxes (Fig. 9). The smaller fluxes were detected because the measuring instrument (infrared gas analyzer) was operated at a higher level of sensitivity. A large diurnal fluctuation was measured and the rate dropped to zero within 1-2 days.

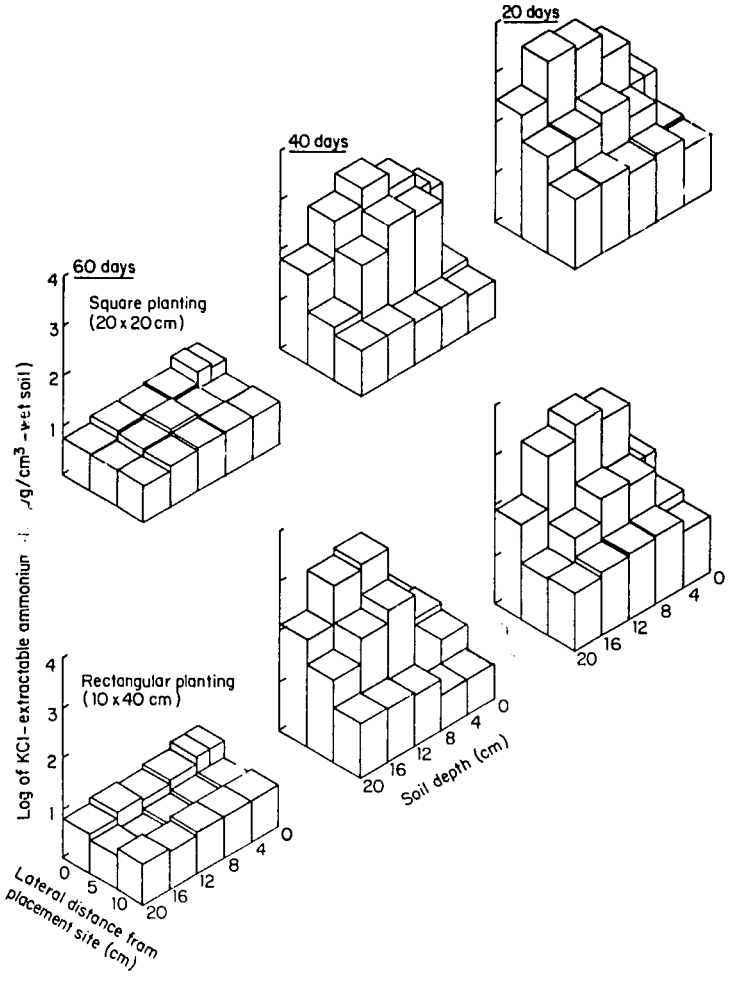
Movement and distribution of deep-placed urea in a wetland soil *(Agronomy)*. Field experiments were continued during the 1979 dry season to study the effects of depth of placement, plant spacing, and season on the movement and spatial distribution of ammonium nitrogen after deep placement of supergranule urea (SGU) in a wetland rice soil. The SGU was placed 2 DT at soil depths of 5, 10, and 15 cm in nontransplanted and in transplanted plots with square and rectangular plantings. The data on spatial distribution of ammonium nitrogen after SGU placement at 10-cm depth only are shown in Figure 10.

Ten and 20 days after deep placement of SGU, the distribution patterns of ammonium nitrogen were similar to those observed in the 1978 wet season. In square and rectangular plantings most of the nitrogen was absorbed by rice plants (IR42) 20 through 40 days after placement at the 5-cm depth. But for SGU placed 10 and 15 cm deep, and for rectangular planting, absorption of ammonium nitrogen was apparently delayed and some ammonium nitrogen was found in the vicinity of urea placement site 40 days later. The data suggest that by adopting the proper combination of urea placement depth and plant spacing, it may be possible to partially control the availability of deep-placed nitrogen so as to sustain continuous supply of nitrogen to a wetland rice.

The data on spatial distribution of ammonium nitrogen also indicated that absorption of ammonium nitrogen after deep placement of urea



10. Distribution of NH_4^+-N after placement of supergranule urea at ~ 10-cm depth in wetland fallow and transplanted rice plots. IRRI, 1979 dry season.



11. Distribution of NH_4^+ after deep placement of 2-g supergranule urea 10 cm deep in a wetland rice having square (20 x 20 cm) and a rectangular (10 x 45 cm) planting geometry. IRRI, 1978 wet season.

was faster during the 1979 dry season than during the 1978 wet season (Fig. 10, 11). This indicates that climatic factors may have influenced the distribution of ammonium nitrogen and eventually its use effiiciency in wetland rice.

LONG-TERM FERTILITY EXPERIMENTS

Agronomy Department

IRRI. The 1979 long-term fertility experiments at IRRI completed the 30th and 31st crop in 1979. In the dry season IR8, IR36, and IR42 gave a favorable yield response to the application of 140 kg N/ha (Table 14). However, only the response of IR42 and IR36 was significant. The response to 30 kg P_2O_5/ha was relatively small; that to 30 kg K_2O/ha was practically nil.

During the wet season, the response to 30 kg P_2O_5 or 30 kg K_2O or to a combination of both was not significant.

BPI stations. The summarized data for Maligaya and Bicol in the dry season showed a significant yield response of 2.6 to 2.8 t/ha with complete fertilizer over nitrogen alone (Table 15).

Table 14. Effects of NPK fertilization on the grain yields of IR8, IR36, and IR42 in the 31st (dry season) and 32d (wet season) consecutive crops. IRRI, 1979.

Fertilizer (kg/ha)			Yield[a] (t/ha)			
N	P_2O_5	K_2O	IR8	IR36	IR42	Mean
			Dry season			
0	0	0	3.4 c	3.5 c	3.0 b	3.3
140[b]	0	0	6.6 a	7.0 ab	6.6 a	6.7
0	30	0	4.4 b	4.2 c	3.2 b	3.9
0	0	30	3.6 c	3.6 c	3.1 b	3.4
140[b]	30	0	7.3 a	6.3 b	7.2 a	6.9
140[b]	0	30	7.1 a	6.7 ab	6.6 a	6.8
140[b]	30	30	6.9 a	7.2 a	6.9 a	7.0
140[bc]	30	30	7.1 a	6.3 b	6.5 a	6.6
Mean			5.8	5.6	5.4	
			Wet season			
0	0	0	3.1 a	3.1 c	3.8 c	3.3
60[b]	0	0	3.6 a	4.6 ab	4.6 a	4.3
0	30	0	3.1 a	3.6 c	3.8 c	3.5
0	0	30	3.3 a	3.7 c	3.9 bc	3.7
60[b]	30	0	3.7 a	4.5 b	4.1 bc	4.1
60[b]	0	30	3.6 a	4.6 ab	4.1 bc	4.1
60[b]	30	30	3.6 a	5.1 a	4.4 ab	4.4
60[bc]	30	30	3.7 a	4.6 ab	5.0 a	4.4
Mean			3.5	4.2	4.2	

[a]In a column under each season, any 2 means followed by a common letter are not significantly different from each other at the 5% level. Av of 4 replications. [b]Includes 40 kg N/ha topdressed at panicle initiation in the dry season and 20 kg N/ha in the wet season. [c]Compost (10.0 t/ha + inorganic 24 kg N/ha compost + 116 kg N/ha inorganic for dry season; 34 kg N/ha compost + 36 kg N/ha inorganic for wet season).

The wet-season data for the three BPI stations showed 1.1 to 1.2 t/ha increases in grain yield for complete fertilizer over nitrogen alone (Table 15).

Maligaya. In the dry season both IR8 and IR42 produced 8.0 t/ha at 140 kg N, 60 kg P_2O_5, and 90 kg (60 + 30) K_2O/ha at Maligaya. With all three varieties, the response to potassium in combination with nitrogen and phosphorus was not significant beyond 60 kg K_2O/ha (Table 15). The average response of the 3 varieties to complete fertilizer over nitrogen was 2.7 t/ha. Both NP and NK treatments gave similar grain yields; however, there were minor differences in response among the three varieties.

The wet-season results were similar to those of the dry season. The marked response of 2.7 t/ha grain yield was obtained with NPK over nitrogen application alone (Table 15). As in the dry season, IR8 again produced the highest yield of 6.1 t/ha in the wet season.

Bicol. In the dry season in Bicol, the highest yield of 7.7 t/ha was obtained with IR8. IR42 yielded 7.9 t/ha when it received complete fertilizer. Complete fertilizer gave a response of 2.4 t/ha over nitrogen fertilizer alone (Table 15). With any variety, the difference in response to NP and NK was not significant.

In the wet season, IR42 produced 0.9 t/ha higher yield than IR36 and 1.8 t/ha higher than IR8 (Table 15). For the three varieties, the responses to NP, NK, or NPK over N alone were significant. However, the differences in yields between NP, NK, or NPK were not significant.

Visayas. There was no dry-season trial in the Visayas because of lack of water.

In the wet season, IR36 produced 4.6 t/ha with complete fertilizer. When complete fertilizer included 90 kg K_2O/ha applied in split doses the yield of IR8 was significantly higher than that with complete fertilizer with only 60 kg K_2O/ha applied basally. With IR8 and IR36 the NK treatment gave significantly higher yield over N alone (Table 15).

Farmers' field. The sixth and seventh crops at Luisiana (Ultisol, pH 4.7) and the sixth crop at Tanay (Vertisol, pH 7.4) were harvested in 1979. The 1979 dry-season crop was not planted in

Table 15. Effect of NPK fertilization on the grain yields of IR8, IR36, and IR42 rices in the 23d (dry season) and 24th (wet season) crops in the long-term fertility experiments at Maligaya Rice Research and Training Center, Maligaya, Nueva Ecija Province; Bicol Rice and Corn Experiment Station, Bicol region; and Visayas Rice Experiment Station, Iloilo Province, IRRI-BPI Cooperative Experiments.

Fertilizer[b] (kg/ha) $N{\cdot}P_2O_5{\cdot}K_2O$	Yield[a] (t/ha)							
	Maligaya				Bicol			
	IR8	IR36	IR42	Mean	IR8	IR36	IR42	Mean
				Dry season				
0 – 0– 0	3.4 d	2.9 c	3.3 d	3.3 d	3.2 c	3.0 c	3.7 d	3.3 d
140 – 0– 0	5.1 c	4.1 bc	5.0 c	4.7 c	5.0 b	4.2 b	4.9 c	4.7 c
140 –60– 0	6.2 c	5.1 b	5.8 bc	5.7 b	5.9 b	5.2 b	6.2 b	5.7 b
140 – 0–60	6.4 bc	5.1 b	5.0 c	5.5 bc	5.5 b	4.6 b	5.8 bc	5.3 b
140 –60–60	7.9 ab	7.3 a	7.2 ab	7.4 a	7.5 a	6.4 a	7.7 a	7.2 a
140[c]–60–60+30	8.1 a	7.2 a	8.0 a	7.8 a	7.7 a	6.6 a	7.9 a	7.4 a
Mean	6.2	5.3	5.7		5.8	5.0	6.0	
				Wet season				
0– 0– 0	3.4	3.1 d	3.2 c	3.2 d	2.0 b	2.8 a	2.4 d	2.4 c
70– 0– 0	4.1 bc	3.8 c	4.2 b	4.1 c	2.3 a	3.6 a	3.9 bcd	3.3 b
70–60– 0	5.4 a	4.7 b	4.9 a	5.0 b	3.5 a	3.9 a	5.2 ab	4.2 a
70– 0–60	4.5 b	4.3 bc	3.7 bc	4.2 c	2.4 ab	3.5 a	4.8 abc	3.6 ab
70–60–60	6.1 a	5.6 a	5.4 a	5.7 a	3.7 a	4.0 a	5.3 a	4.4 a
70–60–60+30	5.7 a	5.6 a	5.4 a	5.6 a	2.5 ab	3.6 a	5.4 a	3.8 ab
Mean	4.9	4.5	4.5		2.7	3.6	4.5	

	Visayas				Summary			
	IR8	IR36	IR42	Mean	IR8	IR36	IR42	Mean
		Dry season[d]				*Two sites*		
0– 0– 0					3.3 c	2.9 c	3.5 c	3.2 d
140– 0– 0					5.0 b	4.2 b	5.0 b	4.7 c
140–60– 0					6.0 b	5.1 b	6.0 b	5.7 b
140– 0–60					6.0 b	4.9 b	5.4 b	5.4 b
140–60–60					7.7 a	6.8 a	7.4 a	7.3 a
140–60–60+30					8.0 a	6.9 a	7.9 a	7.6 a
Mean					6.0	5.1	5.9	
		Wet season				*Three sites*		
0– 0– 0	1.6 c	1.4 d	1.7 c	1.6	2.4	2.4	2.4	2.4
70– 0– 0	2.7 b	3.4 b	2.6 b	2.9	3.0	3.6	3.6	3.4
70–60– 0	2.6 b	4.5 a	3.9 a	3.7	3.8	4.4	4.7	4.3
70– 0–60	3.5 a	2.2 c	2.7 b	2.8	3.4	3.3	3.7	3.5
70–60–60	3.5 a	4.6 a	3.7 a	3.9	4.4	4.8	4.8	4.7
70–60–60+30	4.1 a	4.6 a	4.0 a	4.2	4.1	4.6	5.0	4.5
Mean	3.0	3.4	3.1					

[a]In a column, any 2 means followed by a common letter are not significantly different from each other at the 5% level. Av of 3 replications. [b]All treatments except 0–0–0 $N{\cdot}P_2O_5{\cdot}K_2O$ include 40 kg N/ha topdressed at panicle initiation in the dry season and 30 kg N/ha in the wet season. [c]10 t compost/ha applied every cropping season, with the balance applied as inorganic nitrogen to make up for the rate stipulated for that season. [d]No trial because there was no water.

Tanay because storms in 1978 heavily damaged the irrigation dam.

Dry season. At Luisiana, the dry-season response to phosphorus application (NPK vs NK) was 0.9 and 2.2 t/ha yield increase in IR42 and IR36; that to nitrogen application (NPK vs PK) was 2.7 and 2.8 t/ha in IR36 and IR42 (Table 16). Only nitrogen gave a significant response.

Wet season. In Luisiana in the wet season, only nitrogen applied singly on IR36 gave significant yields. The trend in IR42 was the same (Table 16). In Tanay the highest yields were mostly from the NP plots (Table 17).

PHOSPHORUS SOURCE TRIALS IN FARMERS' FIELDS

Agronomy Department

Experiments to evaluate sources of fertilizer phosphorus on flooded IR36 rice continued in 1979 in three farmers' fields.

Table 16. Effects of NPK on the grain yield of IR36 and IR42 rices in the 6th (dry season) and 7th (wet season) consecutive crops. Luisiana, Laguna, Philippines, 1979.

Fertilizer treatment (kg/ha)			Yield[a] (t/ha)	
N	P_2O_5	K_2O	IR36	IR42
		Dry season		
0	0	0	3.2 c	2.7 c
120	0	0	4.4 b	5.3 b
0	40	0	3.4 c	2.9 c
0	0	40	3.1 c	2.8 c
120	40	0	6.0 a	5.5 ab
0	40	40	3.8 bc	3.3 c
120	0	40	4.3 b	5.2 b
120	40	40	6.5 a	6.1 a
		Wet season		
0	0	0	2.4 c	2.6 c
60	0	0	3.1 ab	3.2 bc
0	40	0	2.6 bc	2.9 bc
0	0	40	2.5 c	2.6 c
60	40	0	3.4 a	3.8 a
0	40	40	3.0 abc	3.2 bc
60	0	40	3.1 ab	3.3 b
60	40	40	3.5 a	3.9 a

[a]In a column, any 2 means followed by a common letter are not significantly different from each other at the 5% level. CV = 11.5% for the dry season, and 11.7% for the wet.

Table 17. Effects of NPK on the grain yield of IR36 and IR42 rices in the 6th (wet season) crop. Tanay, Rizal, Philippines, 1979 wet season.

Fertilizer treatment (kg/ha)			Yield[a] (t/ha)	
N	P_2O_5	K_2O	IR36	IR42
0	0	0	2.0 b	2.0 cd
60	0	0	3.7 a	3.6 b
0	40	0	2.4 b	3.4 bc
0	0	40	2.0 b	2.6 d
60	40	0	3.4 a	4.3 a
0	40	40	2.4 b	3.4 bc
60	0	40	3.6 a	3.9 ab
60	40	40	3.4 a	3.8 ab

[a]In a column, any 2 means followed by a common letter are not significantly different from each other at the 5% level. CV = 11.6%.

Dry season. At Teresa (pH 6.4, available P [Bray 2]: 8.0 ppm), phospal and local guano fertilizer gave yields comparable to that of superphosphate at the highest rate of P_2O_5 application (Table 18). The same results were observed for local guano fertilizer in Lucban soils (pH 5.5, available P [Bray 2]: 6.0 ppm). This has been the trend since the first crop in the 1977 wet season in Lucban and since the second crop in the 1978 dry season in Teresa (Fig. 12).

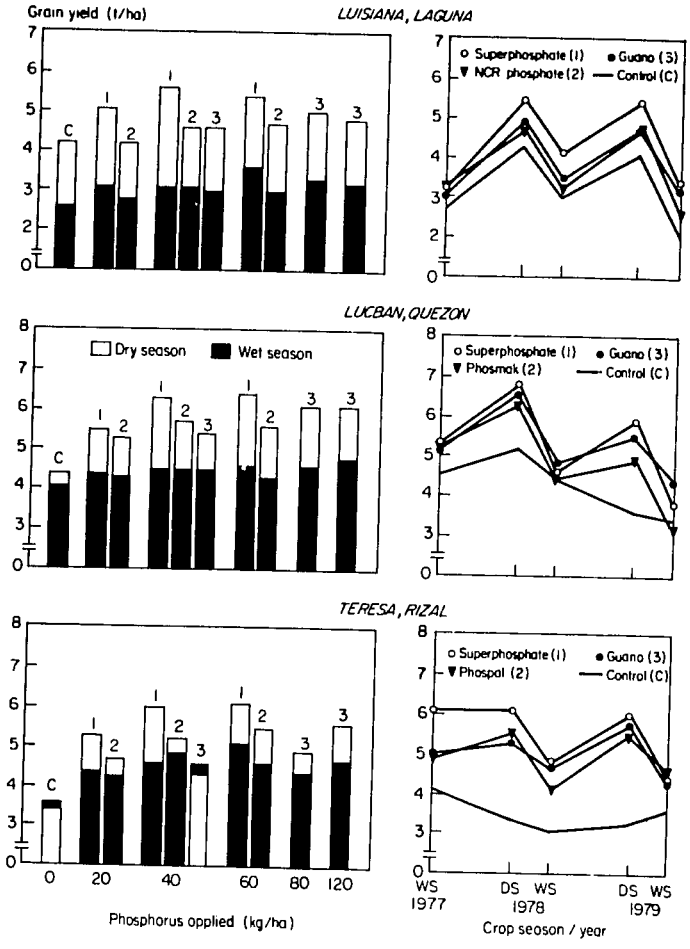
At Luisiana (pH 4.8, available P [Bray 2]: 6.0 ppm), superphosphate gave consistently higher yields than all phosphorus sources even at the start of cropping (Fig. 12). However, the performance of the local guano fertilizer at 80 kg P_2O_5/ha, NCR phosphate and superphosphate at 60 kg P_2O_5/ha on the fourth crop, 1979 dry season, are comparable (Table 18). However, at Lucban guano fertilizer at 120 kg P_2O_5/ha proved superior to all other phosphorus sources.

Dry-season croppings showed increase in yields

Table 18. Effects of different sources of fertilizer phosphorus on the grain yield of the fourth (dry season) and fifth (wet season) crops of IR36. Farmers' fields in Luisiana (Laguna), Lucban (Quezon), and Teresa (Rizal), Philippines, 1979.

Source of fertilizer phosphorus	Rate (kg P_2O_5/ha)	Grain yield[a] (t/ha)					
		Luisiana		Lucban		Teresa	
		Dry season	Wet season	Dry season	Wet season	Dry season	Wet season
No phosphorus	–	4.1 de	2.2 f	3.6 d	3.4 cd	3.3 f	3.7 c
Superphosphate	20	5.1 abc	2.8 cde	4.9 bc	3.5 cd	4.9 cd	4.1 bc
	40	5.6 a	3.1 abc	5.9 a	3.7 bcd	6.2 a	4.4 ab
	60	5.4 ab	3.4 a	5.9 a	3.8 bc	5.8 ab	4.5 ab
HRP[b]	20	3.7 e	2.5 ef	4.4 c	3.5 cd	4.7 de	4.3 abc
	40	4.1 de	2.5 ef	4.7 bc	3.8 bc	5.1 cd	4.7 a
	60	4.7 bcd	2.6 de	4.8 bc	3.2 d	5.5 bc	4.6 ab
Guano (LRP)[c]	40	4.4 cde	2.9 bcd	4.8 bc	4.1 ab	4.2 e	4.5 ab
	80	5.0 abc	3.2 ab	5.4 ab	3.9 abc	5.0 cd	4.2 abc
	120	4.7 bcd	3.2 ab	5.5 ab	4.4 a	5.8 ab	4.2 abc
CV (%)		10.3	8.7	9.9	8.5	9.2	7.9

[a]In a column, any 2 means followed by a common letter are not significantly different from each other at the 5% level. [b]Highly reactive phosphate (North Carolina rock phosphate in Luisiana, Phosmak in Lucban, and Phospal in Teresa). [c]Less reactive phosphate.



12. Grain yield of IR36 in phosphorus sources trial. Luisiana (Laguna), Lucban (Quezon), and Teresa (Rizal), 1977 wet season – 1979. Nitrogen rates: 80 kg N/ha in the wet season, and 140 kg N/ha in the dry. P_2O_5 rates: superphosphate, Phosmak, Phospal at 60 kg/ha; guano at 120 kg/ha.

from all phosphorus sources with the increase in application from 40 to 80 kg P_2O_5/ha for guano, and from 20 to 40 kg P_2O_5/ha for the rest.

Wet season. At the Teresa and Luisiana sites, the local guano fertilizer was equally effective as superphosphate especially at the highest rate of phosphorus application (Table 18).

RATES AND TIME OF APPLYING PHOSPHORUS AND POTASSIUM

Agronomy Department

The second and third crops of the trial at Lucban (Quezon) and Bugallon (Pangasinan) were continued during the 1979 crop year to evaluate response to nitrogen, phosphorus, and potassium at varying levels in both dry- and wet-season croppings with IR36. Results for both seasons are in Table 19.

DETERMINING POTASSIUM AND AMMONIUM DYNAMICS IN WETLAND RICE SOILS BY USING THE ELECTRO-ULTRAFILTRATION TECHNIQUE

Agronomy Department

Potassium dynamics. Two important soil parameters that determine potassium mobility — the potassium concentration of the soil solution

Table 19. Effects of NPK fertilization on the grain yield of IR36. Lucban (Quezon) and Bugallon (Pangasinan), Philippines, 1979.

Fertilizer treatment (kg/ha)			Yield[a] (t/ha)			
			Lucban		Bugallon	
N[b]	P_2O_5	K_2O	Dry season	Wet season	Dry season	Wet season
N	60	60	6.3 a	4.1 a	3.6 a	3.6 a
O	60	60	3.7 e	3.4 c	2.7 c	2.9 ab
N	0	60	4.7 cd	3.1 d	2.6 c	3.0 a
N	60	0	5.4 bc	3.5 bc	2.8 bc	1.6 c
N	30	60	5.7 ab	3.6 b	3.8 a	3.7 a
N	60	30	6.0 ab	4.0 a	2.8 bc	3.3 a
N	0	0	4.2 de	3.5 bc	1.8 d	2.0 bc
N[c]	60	60	–	–	3.3 a	3.6 a
N	60	60+No Zn	–	–	3.7 ab	3.4 a

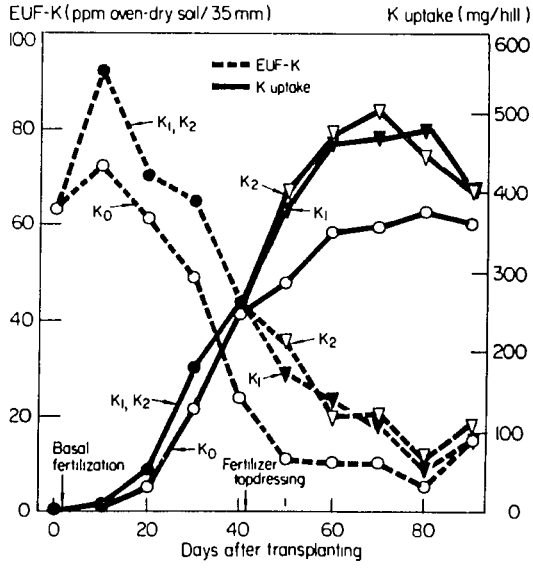
[a]In a column, any 2 means followed by a common letter are not significantly different at the 5% level. [b]Nitrogen rates were 60 kg/ha in the wet season and 120 kg/ha in the dry. [c]For Bugallon only, 30 kg N/ha in the wet season and 60 kg N/ha in the dry.

and the potassium buffer capacity — can simultaneously be determined by the electro-ultrafiltration (EUF) technique. The EUF technique measures the desorption and solubility rates of ions from soil particles. Soils are extracted with dionized water under an external electrical field. By adequate variation of voltage (50, 200, or 400 V) and timing (0-45 min), the total extractable nutrients can be separated into several definable fractions: water soluble, easily exchangeable, and strongly adsorbed forms.

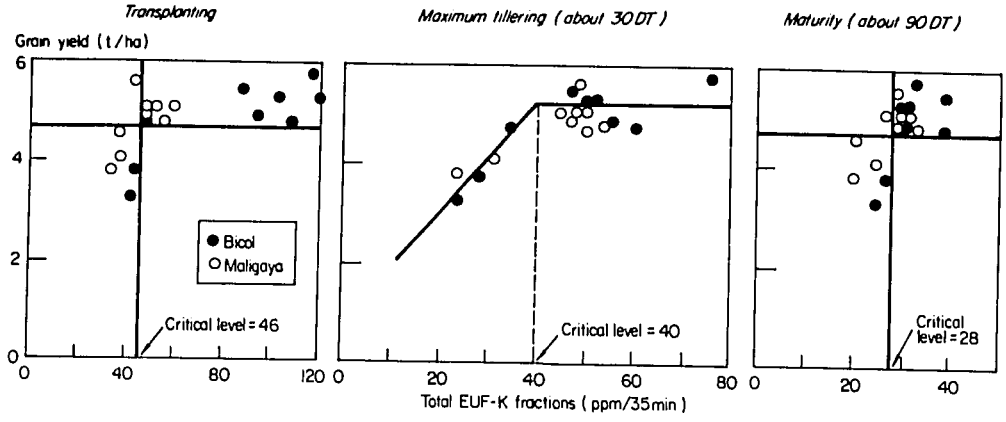
Periodic measurements during the growing season of IR36 indicate that EUF-extractable soil potassium (EUF-K) was maximum at transplanting then declined steadily, reaching a minimum 80 DT (Fig. 13). The slight increase of EUF-K at 90 DT indicates a net potassium release from the soil. The initial exchangeable potassium was recovered 1 month after harvest. The EUF-K correlated well with the potassium uptake pattern of the crop (Fig. 14), indicating that the EUF-K is available to the plant. The highest K uptake rate occurred between maximum tillering and heading (20-60 DT), which amounted to 88% of total potassium uptake, regardless of the potassium treatment.

The importance for grain yield production of the quantity of available soil potassium at maximum tillering is indicated by the best correlation between grain yield and EUF-K values at that stage compared to the correlations at transplanting or at maturity. The critical EUF-K decreased in the course of the growing season because of potassium uptake by the crop (Fig. 14).

In potassium experiments at five Philippine sites (Table 20), the EUF-K highly significantly correlated with the rice yield response to potassium application (Fig. 15), whereas the correlation between the exchangeable potassium and the relative yield was considerably weaker (Fig. 16).



13. Electro-ultrafiltration extractable potassium (EUF-K, wet soil analysis) and K uptake (aboveground parts) of IR36 during the 1978 wet season in the phosphorus experiment at Bicol station, Philippines. K-treatments were K_0 (without fertilizer K), K_1 (60 kg K_2O/ha, basal), and K_2 (60 + 30 kg K_2O, applied in 2 doses: basal and at panicle initiation). All plots received 70 kg N/ha (including 30 kg N/ha topdressed at panicle initiation) and 60 kg P_2O_5/ha (basal). The 1st and and the 5th soil samplings were done shortly before fertilizer application.

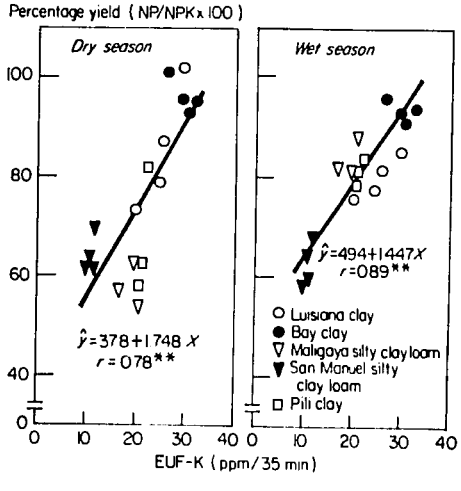


14. Critical electro-ultrafiltration extractable potassium (EUF-K) at 3 growth stages of IR36 during the 1978 dry season at the long-term fertility experiments at the Bicol and Maligaya stations, Philippines. The soil samples were taken at 15-cm depth from the NP- and NPK-plots. The EUF-K values were obtained from analysis of air-dried samples. DT = days after transplanting.

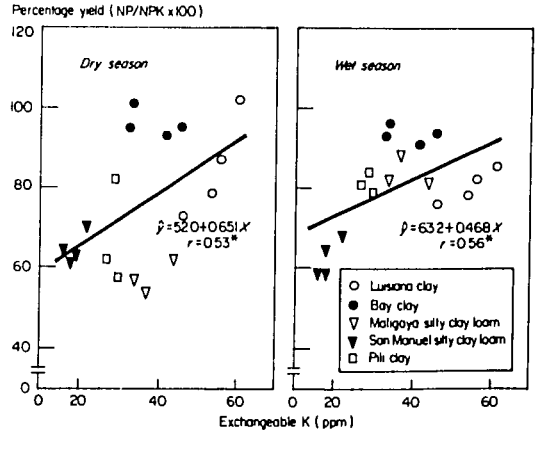
The results suggest that potassium dynamics of wetland rice soils may be satisfactorily evaluated by using the EUF technique.

Ammonium dynamics. Ammonium nitrogen is stable under reduced soil conditions and represents the main nitrogen form for the nutrition of wetland rice. That suggests that nitrogen availability in wetland soils may be governed by the ammonium dynamics in soils. To determine the ammonium dynamics in soils, the EUF technique, which has successfully characterized the K dynamics in soils, was used.

All extractions used wet soil samples. Laboratory investigation showed almost quantitative



15. Relationship between electro-ultrafiltration extractable potassium (EUF-K) and relative yields of IR26 and IR36 at sites in the Philippines. Soil samples from Bugallon and Lucban were taken just before installing the experiment (1978 wet season). Soil samples from Tanay, Maligaya, and Bicol were taken from the NP plots at about 2 weeks after harvest of the 1977 dry season crop. Yield data were from 1978 wet season-1979 dry season for Bugallon and Lucban (IR36), and from 1977 dry and wet seasons (IR26) for Tanay, Maligaya, and Bicol. The K soil test values were obtained from analysis of air-dried samples.



16. Relationship between exchangeable potassium (K) and relative yields of IR26 and IR36 at 5 sites in the Philippines, 1977-78.

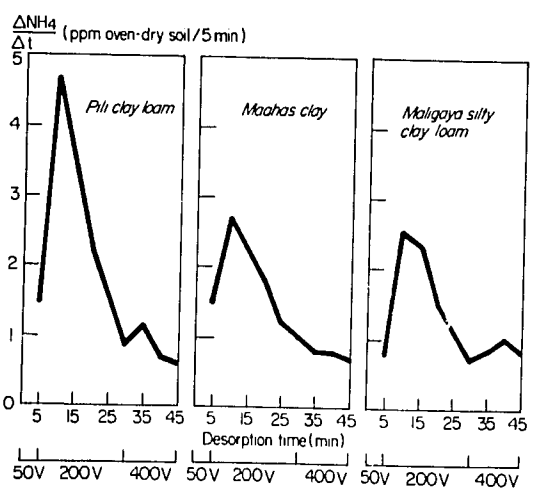
Table 20. Some physicochemical properties of the soils in the potassium experiments at Bugallon (Pangasinan), Lucban (Quezon), Tanay (Rizal), and at 2 stations of the Philippine Bureau of Plant Industry at Maligaya and Bicol, 1977 and 1978 experiments.

	San Manuel	Luisiana	Bay	Maligaya	Pili
Soil texture	Silty clay loam	Clay	Clay	Silty clay loam	Clay
pH (1:1 H_2O)	7.4	5.8	7.4	6.5	4.6
Organic matter (%)	2.49	2.83	2.19	2.06	3.17
Total N (%)	0.17	0.20	0.17	0.11	0.18
CEC[a] (meq/100 g)	32.0	20.0	40.0	29.4	27.4
Exchangeable K (ppm)	19	54	39	50	41
Soil order	Entisol	Ultisol	Vertisol	Alfisol	Vertisol

[a]Cation exchange capacity.

recovery of added ammonium (2-h incubation time) in the EUF extract after 45 minutes of EUF, indicating that no significant ammonia losses occur during the EUF process.

In Figure 17, the EUF-NH_4 desorption curves depicting the ammonium dynamics in three wetland rice soils in the Philippines are presented. One distinctive peak was obtained — that after 10 minutes of EUF. It represents the very loosely bound soil ammonium. A much higher peak was recorded for the Pili clay than for the Maahas clay and Maligaya clay, indicating that ammonium mobility was in decreasing order: Pili clay > > Maahas clay > > Maligaya silty clay loam. The higher values of the total EUF-NH_4 fractions than the exchangeable ammonium suggest that some of

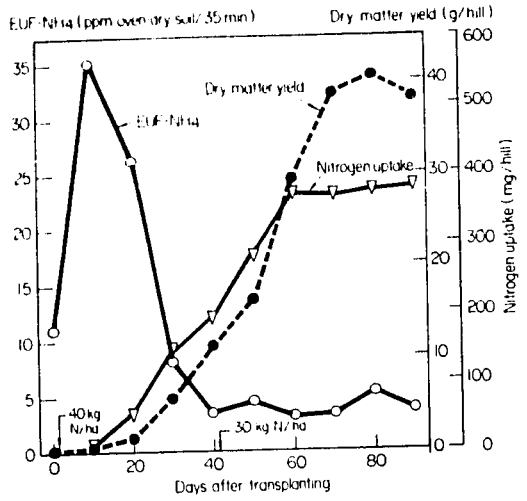


17. Electro-ultrafiltration ammonium (EUF-NH_4) desorption curves of Pili clay loam, Maahas clay, and Maligaya clay soils in the Phillipines. The soil samples were taken at 15-cm depth from the N_0 (without fertilizer N) plots at transplanting of the 1979 dry season crop. The ordinate shows the NH_4 rates released, the abscissa the conditions of NH_4 release, which means different voltages and application times (wet soil extraction, 15°C). The total EUF-NH_4 fractions amounted to 17 ppm for Bicol, 13 ppm for IRRI, and 12 ppm for Maligaya soils; the corresponding values for exchangeable NH_4 were 14, 13, and 9 ppm.

Table 21. Some physicochemical properties of the soils in the N experiments at the IRRI lowland farm (Maahas clay) and the Philippine Bureau of Plant Industry stations at Bicol (Pili clay loam) and Maligaya (Maligaya clay). Mean of all plots. 1979 wet season.

	Maahas clay	Pili clay loam	Maligaya clay
Soil texture	Clay	Clay	Silty clay loam
pH (1:1 H_2O)	6.8	5.1	5.8
Organic matter (%)	3.03	3.27	2.50
Total N (%)	0.18	0.20	0.13
Cation exchange capacity (meq/100 g)	43.8	33.9	32.5
Exchangeable K (meq/100 g)	1.19	0.21	0.18
N supplying capacity[a] (ppm)	131	127	70
Clay mineral composition	Amorphous materials, mainly allophanes	Montmorillonite (practically all)	Montmorillonite (dominant) Vermiculite (major) Halloysite (minor)
Soil series	Maahas	Pili	Maligaya
Soil orders	Inceptisol	Vertisol	Alfisol

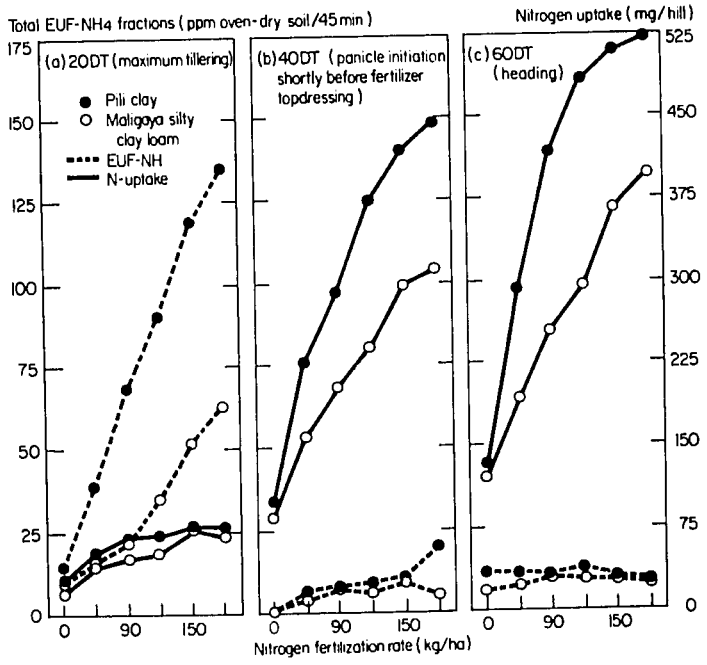
[a]NH_4 produced by anaerobic incubation of air-dried soils under flooded conditions for 2 weeks at 30°C (the soil samples were taken after harvest of the dry season crop).



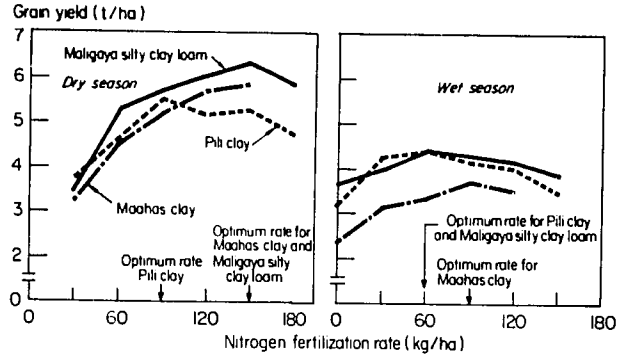
18. EUF-NH_4, dry matter yield and nitrogen uptake (aboveground parts) of IR36 during the 1978 wet season in the K experiment at the Bicol Rice and Corn Experiment Station in the Philippines (av of 9 plots). All plots received N at 70 kg N/ha applied in 2 doses: 40 kg N/ha basal (shortly after the 1st soil sampling) and 30 kg N/ha topdressed at panicle initiation (shortly after the 5th soil sampling).

the ammonium extracted at 400 V might have originated from the nonexchangeable sites. At 400 V, the 3 soils showed distinct differences in their ammonium desorption patterns. That suggests ammonium selective binding sites were present in the Maligaya silty clay loam (2d peak after 40 min) and also to a lesser degree in the Pili clay (2d peak after 35 min) but were absent in the Maahas clay (no 2d peak). This is consistent with the fixing capabilities of the clay minerals present in the soils as indicated by their clay mineralogical composition (Table 21).

The EUF-NH_4 in the soil and nitrogen in the plant were monitored during the 1978 wet season on Pili clay loam. The EUF-NH_4 at 10 DT increased considerably after the basal nitrogen fertilization, then declined sharply reaching minimum level at 40 DT and remained practically the same until maturity (Fig. 18). The decline in EUF-NH_4 coincided with the rapid nitrogen uptake by the plant, indicating that the depletion of EUF-NH_4 mainly resulted from the nitrogen uptake by the crop.



19. Total EUF-NH_4 fractions and N uptake of IR36 at 3 different growth stages during the 1979 dry season at the Bicol Rice and Corn Experiment Station (Pili clay loam) and Maligaya Rice Research and Training Center in the Philippines (Maligaya clay) as affected by N fertilization. For the N treatments fertilizer N was applied in 2 doses: basal and at panicle initiation (30 kg N/ha for all N-treatments). DT = days after transplanting.



20. N response curves of IR36 at the IRRI farm (Maahas clay) and 2 stations of the Philippine Bureau of Plant Industry: Bicol Rice and Corn Experiment Station (Pili clay loam) and Maligaya Rice Research and Training Center (Maahas clay). Av of 4 years: 1976-1979 dry and wet seasons. For the N treatments, fertilizer N was applied twice: basal and at panicle initiation (30 and 20 kg N/ha for dry and wet seasons, respectively).

The increase in EUF-NH_4 following nitrogen fertilization was much higher in the Pili clay than in the Maligaya silty clay loam (Fig. 19a). EUF-NH_4 at 20 DT correlated well with the nitrogen uptake at 40 or 60 DT. However, the EUF-NH_4 at 40 and 60 DT was much reduced indicating rapid disappearance of fertilizer nitrogen and extensive depletion of soil NH_4 by plant uptake between 20 and 40 DT.

Nitrogen response curves of IR36 at the three stations indicate that nitrogen fertilizer requirement is considerably lower for Pili clay loam than for Maahas clay and Maligaya silty clay loam (Fig. 20) for the dry season, although this was less apparent in the wet season. This is consistent with their relative values of EUF-NH_4 at transplanting (Fig. 17).

The results suggest that measurement of EUF-NH_4 at the beginning of the growing season may add useful information on the nitrogen requirement of rice.

ZINC RESPONSE OF WETLAND RICE IN A CALCAREOUS SOIL

Agronomy Department

Transplanted rice. *Dry season.* Field experiments at Tiaong, Quezon, evaluated the effect on transplanted and direct-seeded rice of zinc oxide and

Table 22. Zinc response on a calcareous soil as affected by various zinc management practices in transplanted rice. Tiaong, Quezon, Philippines, 1979 dry season.

Zinc source	Method of application	Rate of application (kg Zn/ha)	Grain yield[a] (t/ha)		
			IR36	IR42	Av
Zinc oxide	Seedling soaking (dapog)	2.2	5.7 a	5.9 a	5.8 a
Zinc oxide	Seedling dip	3.2	5.2 ab	5.7 a	5.5 a
Zinc oxide	Seedling soaking (dapog)	1.6	5.2 ab	5.0 b	5.1 b
$ZnSO_4 \cdot 7 H_2O$	Broadcast and incorporated	11	5.2 ab	4.8 b	5.1 b
Zinc oxide	Seedling soaking (dapog)	1.0	4.9 b	4.8 b	4.8 b
No zinc	–	–	0.0 c	0.0 c	0.0 c

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

Table 23. Zinc response on a calcareous soil as affected by various zinc management practices in direct-seeded rice. Tiaong, Quezon, Philippines. 1979 dry season.

Zinc source	Method of application	Rate of application (kg Zn/ha)	IR36 grain yield[a] (t/ha)
Zinc oxide	Seed coating	1.6	4.7 a
$ZnSO_4 \cdot 6\ H_2O$	Broadcast and incorporated	4.5	4.4 a
$ZnSO_4 \cdot 7\ H_2O$	Broadcast and incorporated	2.3	4.1 ab
$ZnSO_4 \cdot 7\ H_2O$	Seed coating (paste soil)	0.5	3.6 b
No zinc		–	0.0 c

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

zinc sulfate applied by different methods and at different rates. The soil had pH 8.4, 9.6% organic matter, and 0.04 ppm available zinc.

Results confirmed 1978 findings (1978 annual report). Dapog seedlings raised in zinc oxide suspension at 2.2 kg Zn/ha produced an average yield of 5.8 t/ha. Seedlings dipped in zinc oxide solution at 3.2 kg Zn/ha produced 5.5 t/ha (Table 22). Dapog seedlings raised in lower rate of zinc oxide or transplanted in soil where 11 kg Zn/ha as $ZnSO_4 \cdot 7\ H_2O$ had been incorporated produced significantly lower yields. Where no zinc was added, no grains were produced.

Applying zinc oxide suspension to dapog seedbeds is preferred by farmers to dipping seedlings after they are pulled from wet beds because it does not require much time and labor.

Direct-seeded rice. *Dry season.* In direct-seeded rice, yields were 4.7 t/ha from seeds coated with zinc oxide at 1.6 kg Zn/ha and 4.4 t/ha from field application of $ZnSO_4 \cdot 7\ H_2O$ at 4.5 kg Zn/ha (Table 23). Lower rates gave lower yields and when no zinc was applied, no grains were produced.

Soil and crop management

Rice culture

Agronomy Department

RICE CULTURE 322
Physical and chemical properties of rainfed rice soils as affected by cropping systems and crop residue management 322

Physical and chemical properties of rainfed rice soils as effected by cropping systems and crop residue management. Three experiments at IRRI on silty clay soils (pH 6.4-6.0, organic matter: 3.9-3.6%, total nitrogen: 0.2%, cation exchange capacity: 47-48 meq/100 g soil) and on sandy clay loam (pH 7.0, organic matter: 2.0%, total nitrogen: 0.1%, cation exchange capacity: 27 meq/100 g soil) studied the effect of cropping systems on the physical (soil tilth, quality of puddling, soil moisture tension) and chemical (change in soil fertility, nutrient concentration in soil solution) properties of rainfed rice soils. Dry-season crops soybean (UPLB-SY2), cowpea (EG2), maize (DMR2), and sorghum (Cosor 3) were planted in one or two sequences before cultivation of rainfed IR36.

Soil tilth. Soil tilth was determined by measuring soil moisture contents at the shrinkage and plastic limits of soil samples collected after harvesting the dry-season crops. Cropping systems and crop residue management did not affect significantly the range of optimum soil moisture contents of a heavy-textured soil for ease of tillage (Table 1). On a light-textured soil, however, the effects of cropping systems and crop residue management treatments were significant.

Apparent specific volume. The change in the soil's apparent specific volume after land preparation was determined by using the equation

$$ASV = mV_w + 1/p_s$$

where ASV is the apparent specific volume of the soil, m is the weight of soil moisture per unit weight of oven-dry soil, V_w is the specific volume of soil moisture (cm^3/g), and p_s is the particle density of soil (g/cm^3).

Land preparation, cropping systems, and crop residue management significantly affected the apparent specific volume of a heavy-textured soil (Table 2). The puddled plots had significantly

Table 1. Effects of cropping systems and crop residue management on ranges of soil moisture contents for ease of tillage. IRRI, 1979 wet season.

Cropping systems and crop residue management	Soil moisture content (%) at Plastic limit	Shrinkage limit	Percent of soil moisture content for ease of tillage
	Silty clay[a]		
After cowpea with			
Rice straw incorporated	38 a	25 a	13 a
Rice straw mulch	38 a	24 a	14 a
After sorghum with			
Rice straw incorporated	40 a	23 a	17 a
Rice straw mulch	38 a	25 a	13 a
Weedy fallow			
Residue incorporated	38 a	24 a	14 a
	Sandy clay loam[b]		
After soybean-cowpea with			
Residue incorporated	31 a	30 a	1 a
Residue mulch	32 a	30 a	2 a
After maize-sorghum with			
Residue incorporated	32 a	29 a	3 ab
Residue mulch	32 a	28 a	4 ab
Weedy fallow			
Residue removal	32 a	27 a	5 b

[a]The experimental plots were planted to IR28 before cowpea and sorghum cultivation. Rice straw was incorporated or mulched in the plots planted to cowpea or sorghum. [b]The experimental plots were planted to soybean and maize before cowpea and sorghum cultivation, respectively. Soybean or maize residues were incorporated or mulched in the plots planted to cowpea-sorghum. Means followed by the same letter are not significantly different from each other at the 5% level.

Table 2. Changes in apparent specific volume (Δ ASV) of a silty-clay (cm^3/g) soil[a] due to land preparation, cropping systems, and crop residue management. IRRI, 1979 wet season.

Cropping systems and crop residue management	Δ ASV (cm^3/g)	
	Nonpuddled	Puddled
0–10 cm depth		
After soybean with		
Residue incorporated	0.13 a	0.27 b
Residue mulch	0.14 a	0.25 b
After maize with		
Residue incorporated	0.16 a	0.31 b
Residue mulch	0.17 a	0.28 b
Av land preparation	0.15 a	0.28 b
10–20 cm depth		
After soybean with		
Residue incorporated	0.05 ab	0.10 cd
Residue mulch	0.03 a	0.07 bc
After maize with		
Residue incorporated	0.03 a	0.09 cd
Residue mulch	0.04 ab	0.12 d
Av land preparation	0.04 a	0.10 b

[a]Soil samples were collected at active tillering (14 days after transplanting for the puddled plots or 34 days after sowing for the nonpuddled). In a column, means followed by the same letter are not significantly different from each other at the 5% level.

higher Δ *ASV* than the nonpuddled plots.

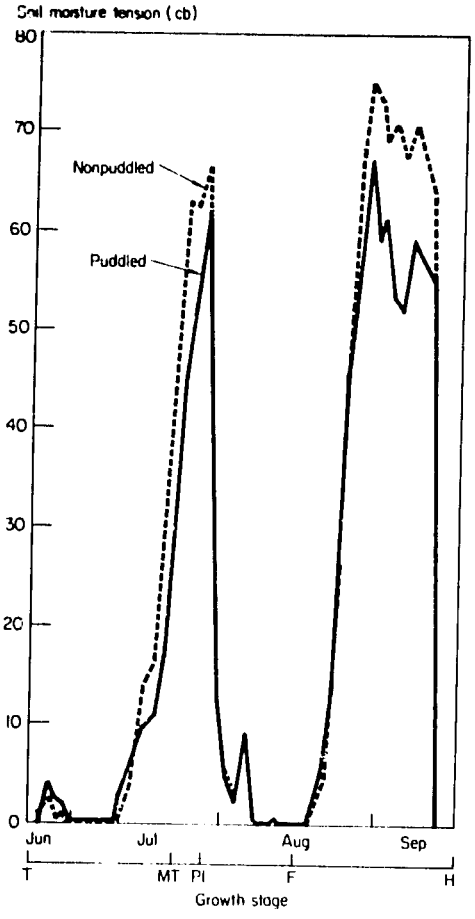
Dry cultivation of the light-textured soil decreased both its true and apparent specific volumes because of reduction in its porosity and void ratio (Table 3). The highest decrease was caused by incorporation of leguminous crop residues in contrast to that of nonleguminous crops.

Soil moisture tension. Soil moisture tension was measured by tensiometers in each plot of 2 replications at depths of 10-20 cm. IR36 suffered from moisture stress during the vegetative and reproductive growth periods. In the heavy-textured soil, soybean residue incorporation (0.7 t/ha) was not as effective as maize residue incorporation (3.0 t/ha) in reducing soil moisture stress in nonpuddled plots. This could be due to the lower amount of organic material applied, hence lower moisture retention. Maize residue incorporation, on the other hand, increased soil moisture stress in the puddled plots, whereas soybean residue incorporation markedly decreased soil moisture stress. The incorporation in the puddled plots of maize stalks, which are resistant to decomposition, created more

Table 3. Changes in true and apparent specific volume of a sandy loam soil due to cropping systems and crop residue management.[a] IRRI, 1979 wet season.

Cropping systems and crop residue management	Changes in specific volume[b] (cm^3/g)		Change in porosity (%)	Change in void ratio
	True	Apparent		
Urea (54 kg N/ha)				
After soybean-cowpea				
Residue incorporated	0.083 a	-0.051 d	-3 a	0.17 a
Residue mulch	0.033 a	-0.023 bc	1 ab	0.07 ab
After maize-sorghum				
Residue incorporated	0.026 a	-0.033 cd	-1 ab	-0.12 ab
Residue mulch	0.033 a	-0.020 abc	-1 ab	0.07 ab
Weedy fallow	0.043 a	0.010 ab	5 b	0.22 b
SCU-21[c] (54 kg N/ha)				
After soybean-cowpea				
Residue incorporated	0.103 a	-0.013 ab	-5 a	0.22 a
Residue mulch	-0.093 a	0.020 abc	-4 a	0.16 a
After maize-sorghum				
Residue incorporated	-0.033 a	-0.030 c	1 ab	-0.12 ab
Residue mulch	-0.040 a	0.013 ab	2 ab	0.12 ab
Weedy fallow	-0.013 a	-0.003 a	-3 a	-0.14 a

[a]Soil samples were collected at maximum tillering stage. In a column, means followed by the same letter are not significantly different from each other at the 5% level. [b]True specific volume = 1/bulk density. [c]Sulfur-coated urea.



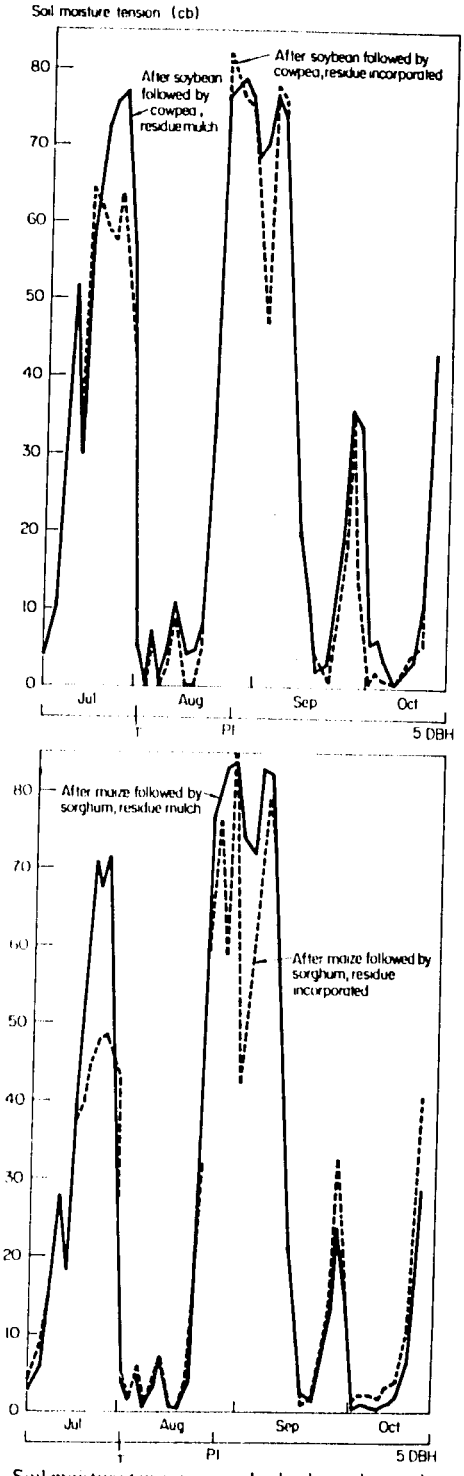
1. Soil moisture tension in silty clay soil during the growing period of IR36 as affected by land preparation (puddled and nonpuddled). IRRI, 1979 wet season. T = transplanting, MT = maximum tillering, PI = panicle initiation, F = flowering, H = harvest.

soil cracks than in the nonpuddled plots. The average of the effects of all treatments confirmed earlier results that puddling reduced soil moisture stress (Fig. 1).

In the light-textured soil, incorporation of cowpea and sorghum residue was more effective than mulch treatments in reducing soil moisture stress (Fig. 2).

Fertility status and nutrient composition. After harvest of the dry-season crops, soil samples were collected and analyzed for soil fertility parameters and exchangeable cations.

Cropping systems increased pH, and decreased cation exchange capacity (CEC), organic matter content, total nitrogen, carbon-nitrogen ratio, and



2. Soil moisture tension in sandy clay loam during the growing period of IR36 as affected by cropping systems and crop residue management (incorporation and mulch of cowpea and sorghum residues). IRRI, 1979 wet season. T = transplanting, PI = panicle initiation, DBH = days before harvest.

Table 4. Changes in the fertility status[a] of silty clay and sandy clay loam soils due to cropping systems (av of crop residue management and nitrogen sources) and nitrogen sources (av of cropping systems and crop residue management). IRRI, 1978–79 wet season.

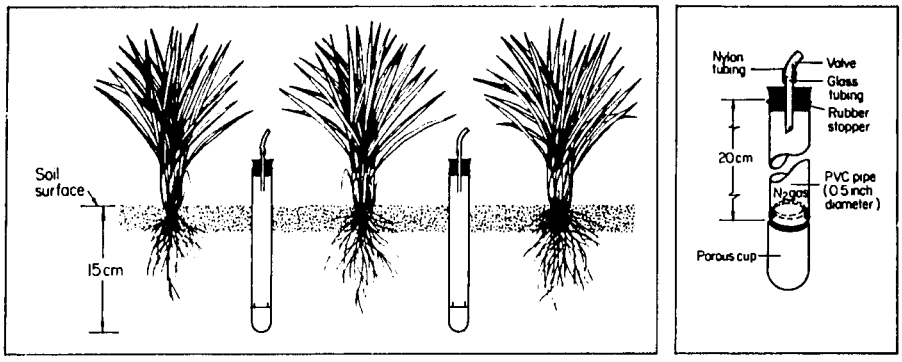
Cropping systems and nitrogen sources[b]	pH	CEC (meq/100 g soil)	Organic matter (%)	Total nitrogen (%)	Carbon-nitrogen ratio	Available P (ppm)
		Silty clay				
Effect of cropping systems[c]						
After rice-cowpea	0.3 a	-1.6 b	-1.3 a	-0.02 a	-4.1 a	-5 a
After rice-sorghum	0.3 a	-0.1 a	-1.0 a	-0.01 a	-3.8 a	-4 a
Weedy fallow	0.4 a	-1.9 b	-1.4 a	-0.04 a	-4.2 a	-5 a
Effect of N sources						
Urea	0.3 a	-1.2 a	-1.2 a	-0.02 a	-4.1 a	-5 a
SCU-21	0.3 a	-1.2 a	-1.2 a	-0.02 a	-3.9 a	-4 a
		Sandy clay loam				
Effect of cropping systems						
After soybean-cowpea	-1.1 a	0.7 a	0.3 a	0.02 ab	-0.2 a	35 a
After maize-sorghum	-1.1 a	0.8 a	0.4 a	0.03 b	0.03 ab	61 a
Weedy fallow	-1.1 a	0.9 a	0.2 a	0.01 a	0.3 b	21 a
Effect of N sources						
Urea	-1.0 a	0.1 a	0.3 a	0.02 a	0.04 a	47 a
SCU-21	-1.1 a	1.2 b	0.3 a	0.02 a	0.04 a	34 a

[a]pH (1:1 soil/water), cation exchange capacity (CEC) (1N NH_4OAc, pH 7), organic matter (Walkley-Black), total nitrogen (Kjeldahl), available phosphorus (Bray). In a column, means followed by the same letter are not significantly different from each other at the 5% level. [b]SCU = sulfur-coated urea. [c]The experimental plots on silty clay were planted to IR28 before cultivation of cowpea and sorghum, and urea or SCU-21 was applied; the rice straw was incorporated or mulched in the plots planted to cowpea and sorghum. The experimental plots on sandy clay loam were to be planted to puddled transplanted rice, with basal application of urea or SCU-21. However, rainfall was not adequate to puddle the plots. Soybean and maize were grown instead. Soybean and maize residues were incorporated or mulched in the plots planted to cowpea and sorghum, respectively.

Table 5. Changes in the exchangeable cations[a] in silty clay and sandy clay loam soils due to cropping systems (av of crop residue management and nitrogen sources) and nitrogen sources (av of cropping systems and crop residue management). IRRI, 1978–79 wet season.

Cropping systems[b] and nitrogen sources	meq/100 g soil				ppm	
	Ca^{2+}	Mg^{2+}	K^+	NH_4^+	Fe^{3+}	Zn^{2+}
		Silty clay				
Effect of cropping systems						
After rice-cowpea	0.4 a	0.8 a	0.2 a	0.05 a	1.6 a	-0.2 a
After rice-sorghum	1.2 b	0.8 a	0.2 a	0.05 a	3.5 b	-0.2 a
Weedy fallow	1.0 b	0.7 a	0.2 a	0.06 a	2.8 b	-0.3 a
Effect of nitrogen sources						
Urea	0.5 a	0.6 a	0.2 a	0.05 a	2.8 a	-0.3 a
SCU-21	1.5 b	0.9 b	0.2 a	0.06 a	2.4 a	-0.2 a
		Sandy clay loam				
Effect of cropping systems						
After soybean-cowpea	-1.5 a	-0.7 a	0.05 a	0.05 a	7.1 a	-5.4 a
After maize-sorghum	-1.3 a	-0.7 a	0.09 a	0.05 a	7.1 a	-5.3 a
Weedy fallow	-1.5 a	-0.8 a	0.03 a	0.06 a	7.4 a	-5.3 a
Effect of N sources						
Urea	-1.6 b	-0.8 b	0.09 a	0.06 a	7.1 a	-5.3 a
SCU-21	-1.2 a	-0.6 a	0.04 a	0.04 a	7.1 a	-5.3 a

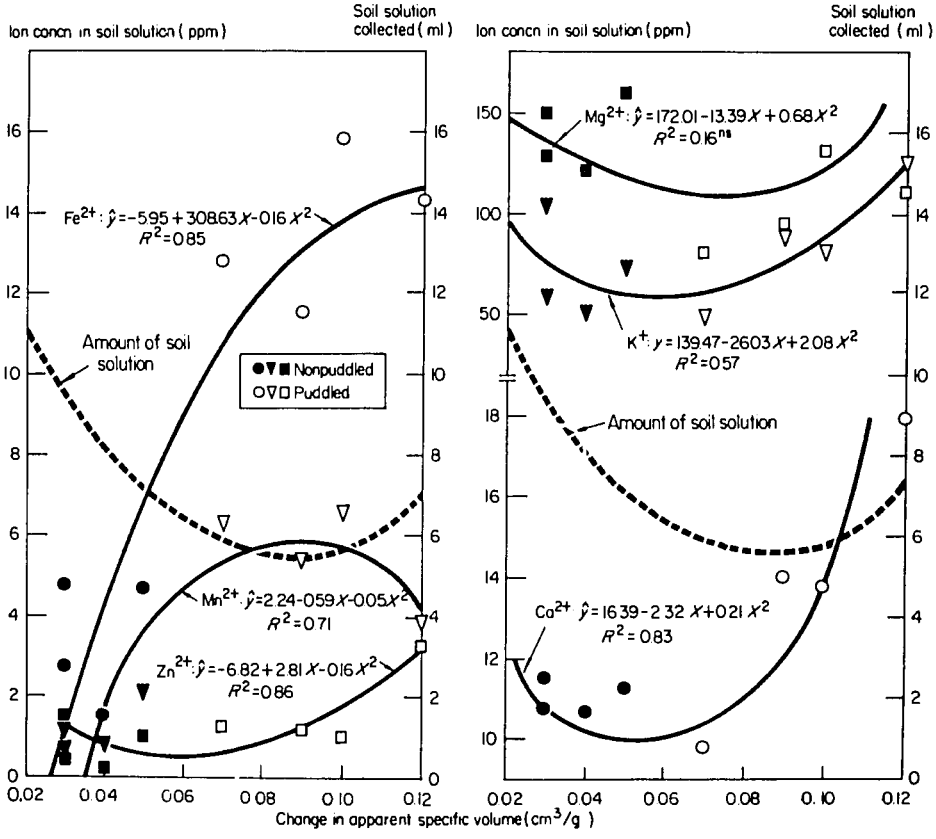
[a]Ca^{2+}, Mg^{2+}, K^+, Fe^{3+}, and Zn^{2+} (1N NH_4OAc, pH 7, extractable); NH_4^+ (KCl extractable). In a column, means followed by the same letter are not significantly different from each other at the 5% level. [b]The experimental plots on silty clay were planted to IR28 before cultivation of cowpea and sorghum, and urea or SCU-21 was applied; the rice straw was incorporated or mulched in the plots planted to cowpea and sorghum. The experimental plots on sandy clay loam were to be planted to puddled transplanted rice, with basal application of urea or SCU-21. However, rainfall was not adequate to puddle the plots. Soybean and maize were grown instead. Soybean and maize residues were incorporated or mulched in the plots planted to cowpea and sorghum, respectively.



3. Sampling device for collecting soil solution. IRRI, 1979.

available phosphorus of the silty clay soil. In general, the effects of cropping systems on the soil fertility parameters did not differ significantly (Table 4). The effect of cropping systems on exchangeable cations is summarized in Table 5.

Concentration of nutrients in soil solution. Soil solution was collected from the plots of the silty clay soil at active tillering of IR36 to determine



4. Relationship between the change in the apparent specific volume of a silty clay soil and the concentrations of Fe^{2+}, Mn^{2+}, Zn^{2+}, Ca^{2+}, Mg^{2+}, and K^+ in soil solution collected at the active tillering stage of IR36 rice. IRRI, 1979 wet season.

Ca^{2+}, Mg^{2+}, K^+, NH_4^+, NO_3^-, Fe^{2+}, Mn^{2+}, and Zn^{2+} concentrations. Oxidation was prevented by introducing nitrogen gas in the sampling tubes (Fig. 3).

The soil solution was collected when the plots were saturated with rainwater; hence, the major factor in determining the amount of soil solution collected in the sampling tubes was the capillary conductivity of the soil. As shown in Figure 4, the tubes in the nonpuddled plots with Δ *ASV* of 0.03-0.05 cm^3/g collected more water. As Δ *ASV* increased to 0.06-0.09 cm^3/g, the amount of soil solution collected decreased. Further increase in Δ *ASV* (>0.10 cm^3/g) increased the amount of soil solution collected. These three soil conditions were classified as:

ΔASV = 0.03-0.05 cm^3/g = granulated
ΔASV = 0.06-0.09 cm^3/g = paste
ΔASV = >0.10 cm^3/g = muddy

The incorporation of soybean residue (0.7 t/ha) and removal of maize residue (3.0 t/ha) before puddling of the plots containing 60% clay produced a muddy condition; other treatments produced a paste condition. Nonpuddling of land always produced a granulated condition in all cropping systems and crop residue management treatments.

The concentrations of Fe^{2+}, Mn^{2+}, and Zn^{2+} were high in the paste and muddy soils. The concentrations of Ca^{2+}, Mg^{2+}, and K^+ were lowest in the paste soil. The concentrations of NH_4^+ and NO_3^- were highest in the paste soil, following the equation

$$\hat{Y} = -1.45 + 1.53X - 0.11X^2; R^2 = 0.51$$

where $\hat{Y}$ is the concentration of NH_4^+ and X is Δ *ASV*.

Environment and its influence

Plant Physiology Department and Office of Rice Production Training and Research

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CLIMATIC ADAPTABILITY OF INDICA-JAPONICA RICES

Plant Physiology Department

Indica-japonica crosses have characteristics intermediate between indica and japonica and may be adapted to wider geographic regions than an indica or japonica. The adaptability of indica-japonica crosses was evaluated in collaborative tests of yield performance at Suweon, Korea (37°N); Taichung, Taiwan (24°N); Hyderabad, India (17°N); and Los Baños, Philippines (14°N). At the early stages of vegetative growth, daily mean temperature varied from 16°C at Taichung (1st crop) and Suweon to 28°C at Los Baños (Fig. 1).

Grain yield. Grain yield ranged from 4.0 t/ha for Jinheung in the wet season at Los Baños to 8.4 t/ha for Suweon 258 in rabi (dry season) at Hyderabad (Table 1). There was not much difference between IR36 (indica) and indica-japonica crosses in mean yields at different sites, although the grain yield of Jinhueng (japonica) was significantly lower. Despite large differences in temperature regimes, mean yields at sites varied only from 5.4 t/ha in the wet season at Los Baños to 6.8 t/ha at Suweon and Los Baños (dry season). IR36 and the indica-japonica crosses showed wide adaptability to different climatic environments.

Crop duration. All the varieties except Jinheung had similar duration in the field (Table 2). The field duration of Jinheung was 122 days at Suweon, but was shorter at other sites, indicating the variety's sensitivity to high temperature.

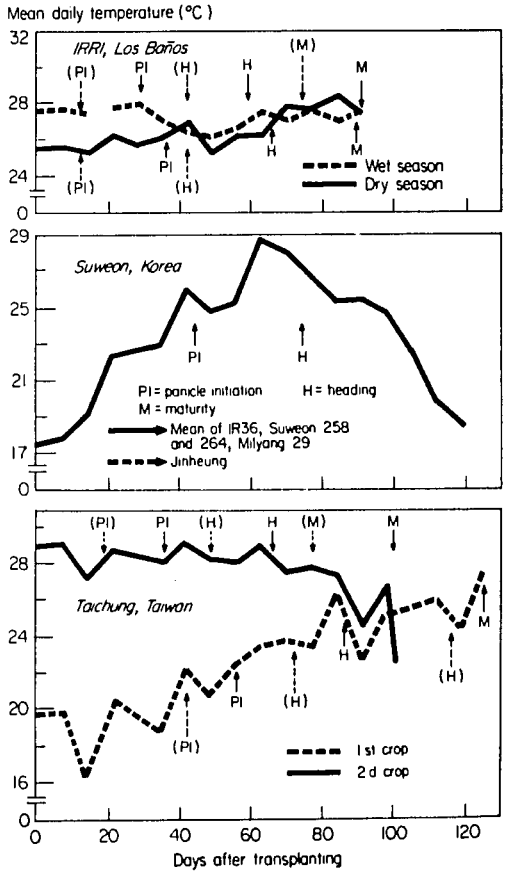
Leaf area growth. At Los Baños, maximum leaf area index (LAI) was about 8 for IR36, but only 3.5 for Jinheung (Fig. 2). The leaf growth of IR36 was faster than that of Jinheung at Los Baños but it was slower at Suweon. This indicated that high temperature caused fast growth in IR36 but slowed that in Jinheung. In contrast, low temperature caused fast leaf area growth in Jinheung, but slowed leaf growth in IR36. Thus, the small maximum LAI of Jinheung at Los Baños was attributed to both short crop duration and the detrimental effect of high temperature on leaf growth.

Total dry matter production. Total dry matter production varied from about 8 t/ha in the second crop at Taichung to 16 t/ha in the dry season at Los Baños (Table 3). The total dry matter production of Jinheung was consistently lower than that of the others except at Suweon.

Harvest index. The harvest index of a variety is usually considered a varietal character. But the harvest index is affected by environment (Table 4). For example, the harvest indices of IR36 varied from 0.45 at Los Baños to 0.57 in the first crop at Taichung. This means a grain yield difference of 1.2 t/ha for 10 t/ha of total dry matter production.

Crop-climate interrelationship. To account for differences in grain yields among varieties, sites, and seasons, a simple regression model was constructed based on these considerations:

- Total dry matter production (W) is proportional to crop duration (D) and mean daily solar radiation ($\bar{S}$).



1. Daily mean temperature during the crop period at 3 sites where indica-japonica crosses were tested. 1979.

Table 1. Grain yield of indica (I), indica-japonica (I-J), and japonica (J) rice varieties at different sites at various seasons, 1978–79.

Variety	Grain yield (t/ha)						
	Suweon, Korea	Taichung, Taiwan		IRRI, Los Baños		Hyderabad, India, in rabi	Mean
		1st crop	2d crop	Wet	Dry		
IR36 (I)	6.65	6.82	6.70	5.74	7.13	7.07	6.68
Suweon 258 (I-J)	7.20	5.98	5.74	6.28	7.99	8.36	6.92
Suweon 264 (I-J)	6.31	6.19	6.14	5.64	6.67	6.08	6.17
Milyang 29 (I-J)	7.54	6.20	5.83	5.46	6.60	6.88	6.42
Jinheung (J)	6.04	5.39	4.89	4.00	5.41	4.87	5.10
Mean	6.75	6.12	5.82	5.42	6.76	6.65	6.25

Table 2. Field duration of indica (I), indica-japonica (I-J), and japonica (J) rice varieties at different sites and seasons, 1978–79.

Variety	Field duration (days)					
	Suweon, Korea	Taichung, Taiwan		IRRI, Los Baños		Hyderabad, India, in rabi
		1st crop	2d crop	Wet	Dry	
IR36 (I)	119	129	107	90	90	108
Suweon 258 (I-J)	122	121	98	90	94	108
Suweon 264 (I-J)	115	121	98	88	90	108
Milyang 29 (I-J)	118	129	98	89	90	108
Jinheung (J)	122	116	77	74	76	91
Mean	119	123	96	86	88	105

- Grain yield = total dry matter × harvest index (HI).

To test the above relationship, W/D was plotted against $\bar{S}$ as shown in Figure 3. W/D is linearly related to $\bar{S}$ with a correlation coefficient of 0.94. On the basis of the regression model,

$$\text{Estimated yield} = [a + b\bar{S}]\, D \cdot HI$$

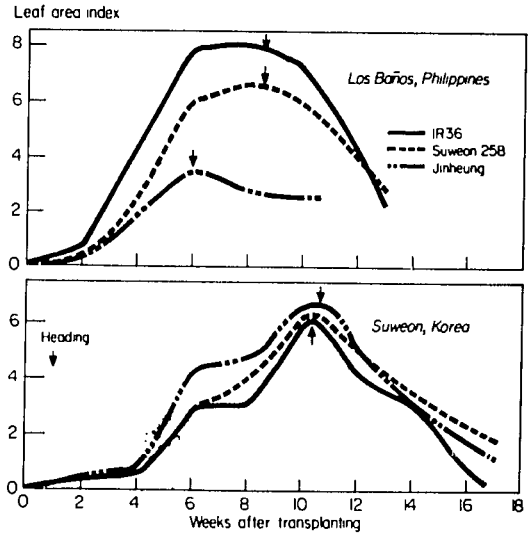
Estimated yields agreed well with measured yields ($r = 0.78^{**}$).

The equation indicates that the yields of a given variety can be accounted for by crop duration, mean daily solar radiation during the crop period, and harvest index. The equation is empirical, but it clarifies important yield determinants in the crop-climate interrelationship.

BIOENERGETIC COMPARISON OF CROP YIELDS

Plant Physiology Department and Rice Production Training and Research

Crop yields can be compared in terms of the amount of glucose or energy from which the harvested organ is produced. Seven crop species were grown at IRRI in the 1977 dry season. Irrigation



2. Leaf area growth of 3 varieties at Suweon, Korea, and Los Baños, Philippines, 1978-79.

Table 3. Total dry weight of indica (I), indica-japonica (I-J), and japonica (J) rice varieties at different sites and cropping seasons, 1978–79.

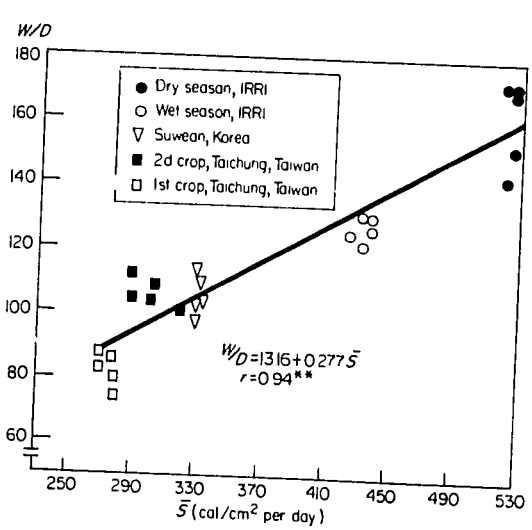
Variety	Total dry wt (t/ha)						
	Suweon, Korea	Taichung, Taiwan		IRRI, Los Baños		Hyderabad, India, in rabi	Mean
		1st crop	2d crop	Wet	Dry		
IR36 (I)	11.7	10.3	11.2	11.2	13.7	11.1	11.5
Suweon 258 (I-J)	12.7	10.7	10.7	11.8	16.1	13.3	12.6
Suweon 264 (I-J)	11.8	10.4	10.3	11.6	15.4	10.6	11.7
Milyang 29 (I-J)	13.4	9.5	11.0	10.8	15.3	11.9	12.0
Jinheung (J)	13.3	9.6	7.8	9.4	10.8	8.1	9.8
Mean	12.6	10.1	10.2	11.0	14.3	11.0	11.5

Table 4. Harvest indices of indica (I), indica-japonica (I-J), and japonica (J) rice varieties at different sites and seasons, 1978–79.

Variety	Harvest index						
	Suweon, Korea	Taichung, Taiwan		IRRI, Los Baños		Hyderabad, India, in rabi	Mean
		1st crop	2d crop	Wet	Dry		
IR36 (I)	0.49	0.57	0.52	0.45	0.45	0.55	0.50
Suweon 258 (I-J)	0.49	0.56	0.46	0.45	0.42	0.54	0.49
Suweon 264 (I-J)	0.46	0.51	0.51	0.41	0.37	0.49	0.46
Milyang 29 (I-J)	0.48	0.56	0.46	0.43	0.37	0.49	0.46
Jinheung (J)	0.39	0.48	0.52	0.35	0.43	0.52	0.45
Mean	0.46	0.54	0.49	0.42	0.41	0.52	0.47

was provided to ensure maximum crop growth under high incident solar radiation.

Agronomic yield and dry matter production. Total dry matter production ranged from 6.4 t/ha for soybean to 15.6 t/ha for maize (Table 5). The economic yields are considered good for those crops. The low wheat yield was attributed to high temperatures during the growing season.



3. Relationship between solar radiation and dry matter production of indica, indica-japonica, and japonica rice varieties at different sites. W = total dry matter production, D = crop duration, $\bar{S}$ = mean daily solar radiation.

Bioenergetics of crop yields. Glucose is the product of photosynthesis. When it is converted to protein, lipid, and carbohydrate, conversion efficiency can be defined as:

$$\text{Conversion efficiency (g/g)} = \frac{\text{wt of compound produced}}{\text{wt of glucose used}}$$

The reported conversion efficiencies are 0.38 for protein, 0.31 for lipid, and 0.84 for carbohydrate.

The chemical composition of harvested organs of the eight crops is shown in Table 6. Using the conversion efficiencies and the chemical composition data allows computation of grams of glucose needed to produce a gram of the harvested organ (glucose equivalent). For example, 2.50 g of glucose is necessary to produce 1 g of groundnut, whereas only 1.37 g of glucose is needed to produce 1 g of rice (Table 6).

Comparison of yields among different crops. Multiplying the dry weight yield by glucose equivalent gives the amount of glucose

Table 5. Yields, dry matter, harvest index, and growth duration of 8 crops. IRRI, 1977 dry season.

Crop	Variety	Total dry matter production (t/ha)	Harvest index	Economic yield (t/ha)[a]	Growth duration (days)
Wetland rice	IR36	13.9	0.43	8.65	107
Dryland rice	IR36	14.3	0.33	6.68	118
Wheat	Acc. No. 4073	8.5	0.31	3.14	84
Maize	UPCA Var. 1	15.6	0.39	7.10	98
Sorghum	B8417	14.6	0.48	8.28	90
Soybean	Clark 63	6.4	0.47	3.56	84
Groundnut	Moket	8.1	0.36	3.47	112
Sweet potato	Georgia Red	10.4	0.60	26.70	126

[a]At 14% moisture for wetland and dryland rice; at 15% for wheat, maize, sorghum, soybean, and groundnut, fresh weight for sweet potato.

Table 6. Composition of harvested organs of 8 crops. IRRI, 1977.

Crop	Proteins (%)	Lipids (%)	Carbohydrate (%)	Ash (%)	Glucose equivalent (g/g)
Wetland rice[a]	11.1	1.9	85.7	1.3	1.37
Dryland rice[a]	11.8	1.9	85.0	1.3	1.38
Wheat	18.1	1.8	77.7	2.4	1.47
Maize	10.8	4.5	83.4	1.3	1.42
Sorghum	8.3	3.1	86.9	1.7	1.35
Soybean	37.7	19.2	36.5	6.6	2.04
Groundnut[a]	28.0	45.9	23.5	2.6	2.50
Sweet potato	5.6	0.3	89.2	4.9	1.22

[a]Husked or shelled.

needed to produce the harvested organ (glucose value). In this way, yields of different crops can be compared on the same physiological basis. Figure 4 compares yields of the eight crops in terms of dry matter and glucose value. Sorghum was the most productive on the bases of dry weight yield and glucose value; maize was the second most productive and wetland rice, the third. The dry weight yield of soybean per crop was about one-half that of wetland rice. In terms of glucose value, however, the yield of soybean per crop was about 75% that of wetland rice. On a per-day basis, the yield of soybean becomes 95% that of wetland rice.

These computations indicate that the apparent low yield of soybean is due, not to lower efficiency in producing seeds, but to production of seeds that contain more lipid and protein. Bioenergetically, then, the yield of soybean is comparable to that of wetland rice.

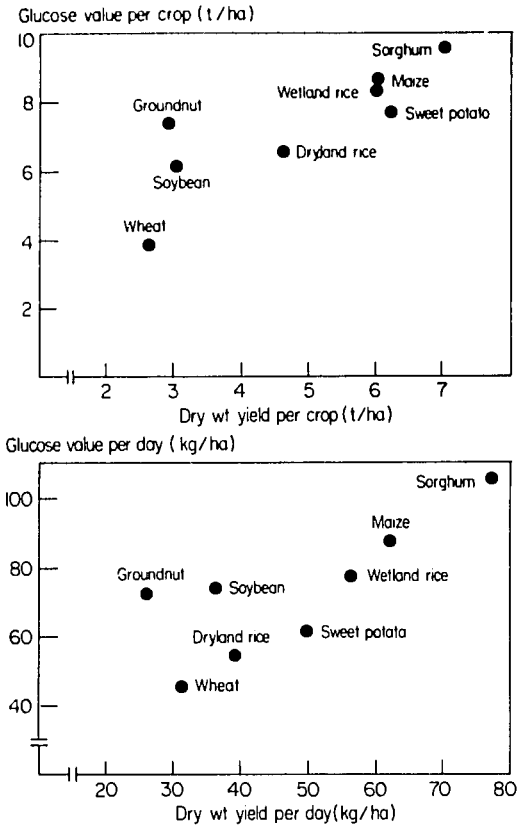
EFFICIENCIES OF NUTRIENTS FOR CROP YIELD

Plant Physiology Department and Rice Production Training and Research

The efficiency of a nutrient for crop yield is defined thus:

$$\text{Nutrient efficiency (kg/kg)} = \frac{\text{wt of harvested organ}}{\text{wt of nutrient absorbed by crop}}$$

From the same eight crops used for the bioenergetics study of crop yield, samples were taken and analyzed for five nutrients. The maximum amount of nutrients absorbed during growth was computed (Table 7). Differences in yield of harvested organs



4. Relationship between agronomic yield and bioenergetic yield of 8 crops. IRRI, 1979 dry season.

and in the amount of nutrients absorbed by crops caused large differences in efficiency of nutrients (Table 8).

Nutrient efficiency was converted to relative efficiency (RE):

$$\text{Relative efficiency} = \frac{\text{efficiency of a particular crop}}{\text{av efficiency of 8 crops}}$$

For example, the average nitrogen efficiency of 8 crops was 30.8; thus, relative nitrogen efficiency for wetland rice was 44/30.8, or 1.43. Using the RE values, an overall average efficiency of five nutrients was computed:

$$\text{General efficiency} = \frac{\text{sum of 5 RE values}}{5}$$

General efficiency values thus calculated ranged from 1.67 for wetland rice to 0.48 for groundnut. In other words, wetland rice was the most efficient and groundnut the least efficient in use of the five nutrients to produce yield.

This discussion does not consider nitrogen fixation by soybean and groundnut. If that is taken into account, the efficiency of soil and fertilizer nitrogen for soybean and groundnut would be much higher than those given in Table 8.

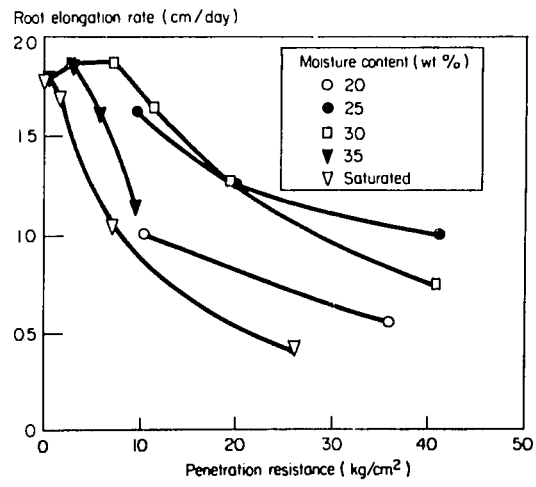
EFFECTIVE ROOTING DEPTH OF RICE CROPS

Plant Physiology Department

Effective rooting density is tentatively defined as 0.5 cm/cm^3. When water uptake rate is 0.01 cm^3/cm per day, a rice root fragment of 0.5 cm/cm^3 can extract 0.5 mm water/day from a 10-cm soil layer. This amount of water is about 10% of the total daily evapotranspiration (5 mm) of a rice crop under moderate levels of solar radiation.

Factors affecting root growth. The root elongation rate of rice seedlings ranges from 0.4 to 1.9 cm/day, depending on soil penetration resistance and water content. As shown in Figure 5, for the same penetration resistance, a soil water content of about 25-30% permits faster root elongation of rice seedlings than a saturated soil. At a 20% soil water content, water supply becomes subnormal for root elongation.

Water regimes and percolation have a significant effect on root elongation. Dryland conditions favor



5. Relationship between root elongation rate, soil penetration resistance, and soil moisture content. IRRI, 1979.

Table 7. Maximum amount of nutrients absorbed during growth of 8 crops. IRRI, 1977 dry season.

Crop	Amount absorbed (kg/ha)				
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Wetland rice	168	22	154	26	20
Dryland rice	216	20	210	23	19
Wheat	136	18	206	22	13
Maize	167	25	223	39	29
Sorghum	161	37	188	32	27
Soybean	222	17	125	51	23
Groundnut	269	24	125	90	34
Sweet potato	124	20	219	80	27

Table 8. Efficiency of elements in producing the harvested organ. IRRI, 1977.

Crop	Efficiency of elements (kg/kg)					General efficiency[a]
	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	
Wetland rice	44	335	48	291	365	1.67
Dryland rice	27	289	27	246	298	1.24
Wheat	20	150	13	122	203	0.72
Maize	36	242	27	155	209	1.05
Sorghum	44	191	38	223	259	1.27
Soybean	14	177	24	60	134	0.63
Groundnut	11	125	24	33	86	0.48
Sweet potato	50	321	29	79	236	1.15
Av	30.8	229.8	28.8	151.1	223.8	

[a]The sum of relative efficiency (RE) values for 5 nutrients divided by 5.

$$RE = \frac{\text{efficiency of a particular crop}}{\text{av efficiency of 8 crops}}$$

deeper root growth than submerged conditions (Fig. 6). In submerged soils, percolation stimulates deep root growth. Deeper root growth under dryland and well-drained submerged conditions was attributed to greater supply of oxygen to rice roots. Thus, even for rice, an external supply of oxygen appears important for root elongation.

Rooting depth in farmers' fields. The rooting depth of rice crops in farmers' fields at different sites was investigated by core sampling (Table 9). Based on 0.5 cm/cm^3 as the effective rooting density, rooting depth in wetland fields ranged from 30 cm for an IRRI field to 70 cm in Calauan, Laguna. Because the same variety was planted, the differences observed in rooting depth were attributed to differences in environment. At Calauan, the sample was taken from a field adjacent to a deep drainage canal, which suggested that better percolation stimulated a deep root growth.

At Tubigan (Laguna) and San Miguel (Bulacan), penetration resistance was also measured along the soil profile. Lower penetration resistance values were perhaps a factor that allowed deeper root growth at San Miguel (Fig. 7).

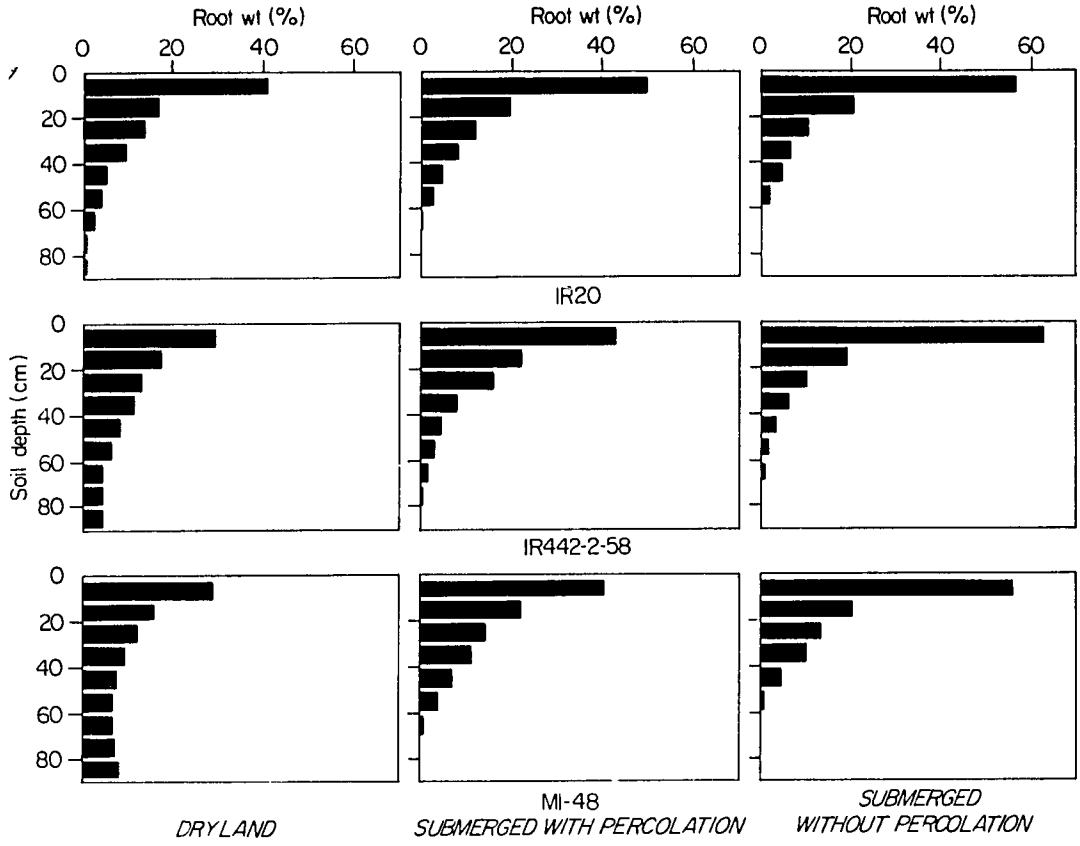
In dryland fields, the rooting depth ranged from 35 cm to deeper than 80 cm and both variety and environment were considered responsible for the differences. Rooting depth in wetland fields was not much different from that in dryland fields.

ROOT GROWTH IN A WETLAND FIELD

Plant Physiology Department

To study root growth in flooded soils, IR36 was planted at 20- × 20-cm spacing in an IRRI wetland field. Root samples were taken by core sampling 42 days after sowing (DS), 54 DS (panicle initiation), 77 DS (heading), and 104 DS (maturity).

Vertical root distribution at different growth stages. Root density and effective rooting depth in

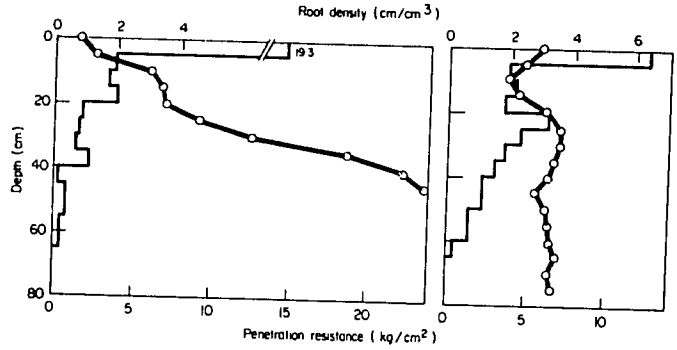


6. Effect of soil water regimes on vertical root growth of 3 varieties grown in the root box. IRRI, 1979.

Table 9. Root density of rice crops at IRRI and in farmers' fields. Philippines, 1979.

Place	Variety	Soil texture[a]	Root density (cm/cm³) at depth (cm) of								
			0–5	10	20	30	40	50	60	70	80
Wetland fields											
Lian, Batangas	IR36	LiC	–	7.7	5.9	1.2	1.0	0.3			
Santa Barbara, Pangasinan	IR36	SiC	–	21.1	5.7	2.0	0.6	0.4			
Leeneck, Nueva Ecija	IR36	HC	–	12.7	3.5	2.4	1.2	0.8			
IRRI, F block	IR36	–	–	9.4	6.5	1.5	0.2				
Calauan, Laguna	IR36	–	37.2	11.0	3.7	1.7	1.1	0.7	0.6	0.7	0.2
San Miguel, Bulacan	IR36	LiC	6.4	1.9	2.0	2.8	1.7	1.1	0.7		
Tubigan, Laguna	IR36	LiC	19.3	1.9	1.9	0.9	0.9	0.3	0.3		
Dryland fields											
San Joaquin, Batangas	IAC 5100	LiC	13.3	12.5	5.4	1.6	0.5				
	IR5631-57-2	LiC	12.9	8.9	4.6	1.6	1.1	0.3			
	B44b-50-2-2-5-1	LiC	12.7	7.9	5.3	2.1	1.5	0.4			
Tagaytay, Cavite	C22	LiC	16.7	9.5	4.3	2.4	1.5	1.5	1.4	1.1	0.7
Lalaan I, Cavite	C22	HC	17.8	7.9	2.2	0.7	0.7	0.8	0.6	0.2	

[a]LiC = light clay, SiC = silty clay, HC = heavy clay.



7. Vertical root distribution of IR36 and soil penetration resistance at 2 farmers' fields: Tubigan, Laguna (left), and San Miguel, Bulacan (right). 1979.

the four growth stages did not significantly differ (Table 10), which suggests that the physical size of the root system of an IR36 crop reaches a maximum at 42 DS. Effective rooting depth was around 30 cm at all growth stages. The data indicate that IR36 attains its maximum ability to intercept topdressed nitrogen fertilizer before panicle initiation.

Lateral and vertical root distribution at heading. To study both lateral and vertical root distribution, root samples were taken at distances of 0, 5, and 10 cm from the center of the hill. When expressed in weight, the root density in the first 5-cm soil layer varied from 29×10^{-4} g/cm^3 at 0 cm from the center of the hill to about 5×10^{-4} g/cm^3 at 10 cm (Table 11). When expressed in length, however, the root density values at the sampling sites were about the same—20 to 22 cm/cm^3. The data clearly indicated a need for root length measurement when root growth is related to water and nutrient absorption. Interestingly, except in the top 5-cm layer, root density was significantly higher at some distances from the center of the hill than right under the hill.

Penetration resistance at different soil depths. Penetration resistance at different growth stages and soil depths was measured with a cone penetrometer. In the soil layer from 0 to 25 cm, the greatest penetration resistance was only 11.1 kg/cm^2. This suggested that high root density in the surface soil layers cannot be attributed to high penetration resistance.

Table 10. Vertical distribution of root density at different stages of growth of IR36 grown in a wetland field. IRRI, 1978.

Growth stage[a]	Root density (cm/cm3) at depth (cm) of							
	0–5	5–10	10–15	15–20	20–25	25–30	30–40	40–50
28 Nov 1978 (42 DS)	22.7	7.9	1.8	0.9	0.7	0.5	0.3	0.1
10 Dec 1978 (54 DS)	22.2	6.4	2.3	1.6	1.0	0.7	0.2	0.2
2 Jan 1979 (77 DS)	21.6	5.0	1.6	1.2	1.1	1.2	0.4	0.2
29 Jan 1979 (104 DS)	19.0	4.7	1.5	1.0	0.9	0.8	0.5	0.2

[a]Days after sowing.

Table 11. Lateral and vertical root distribution at heading of IR36 grown in wetland fields. IRRI, 1978.

Penetration (cm) from the center of hill	Depth (cm) 0–5	5–10	10–15	15–20	20–25	25–30	30–40	40–50	50–60	Total
				Root wt (x 10^{-4} g/cm^3)						
0	29.05	0.77	0.24	0.22	0.13	0.09	0.06	0.01		
5	6.62	2.30	0.73	0.30	0.30	0.25	0.09	0.08		
10	4.70	1.54	0.48	0.38	0.28	0.22	0.05	0.01		
Mean	13.50	1.54	0.48	0.30	0.24	0.19	0.07	0.03		16.35
% of total	82.6	9.4	2.9	1.8	1.5	1.2	0.4	0.2		
				Root length (cm/cm^3)						
0	22.4	2.3	1.1	1.0	0.7	0.6	0.4	0.1	–	
5	20.3	5.5	2.1	1.2	1.2	1.4	0.5	0.4	0.1	
10	22.2	7.3	1.7	1.3	1.4	1.6	0.4	0.2	0.1	
Mean	21.6	5.0	1.6	1.2	1.1	1.2	0.4	0.2	0.1	32.4
% of total	66.7	15.4	4.9	3.7	3.4	3.7	1.2	0.6	0.3	

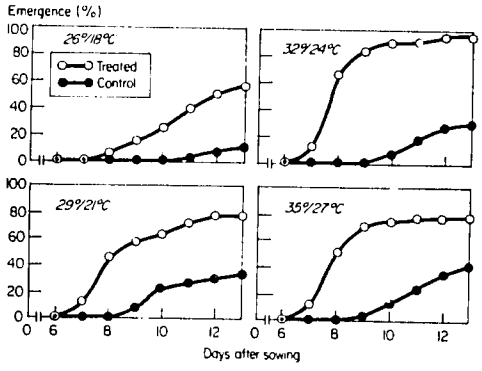
CHEMICAL CONTROL OF SEEDLING EMERGENCE FROM FLOODED SOILS

Plant Physiology Department

Action of calcium peroxide. With direct sowing of wetland rice, particularly when the seeds are covered with soil, about 5 ppm oxygen is required for normal growth of leaves and roots. Use of calcium peroxide provides molecular oxygen to growing organs in flooded soils. When in contact with water, calcium peroxide releases oxygen:

$$2\ CaO_2 + 2H_2O \rightarrow 2\ Ca(OH)_2 + O_2$$

Effect of calcium peroxide on the rate and percentage of seedling emergence. Uncoated seeds and those coated with calcium peroxide before sowing had slower seedling emergence at lower temperatures (26°/18°C and 29°/21°C) (Fig. 8). But the coating increased the rate of seedling emergence considerably at all the temperatures.



8. Effect of calcium peroxide seed coating on IR36 seedling emergence from flooded soils at different temperatures. Seeding depth: 1 cm; water depth: 5 cm. IRRI. 1979.

Table 12. Effect of calcium peroxide seed coating on seedling growth of 6 varieties at 29°/21°C.[a] IRRI, 1979.

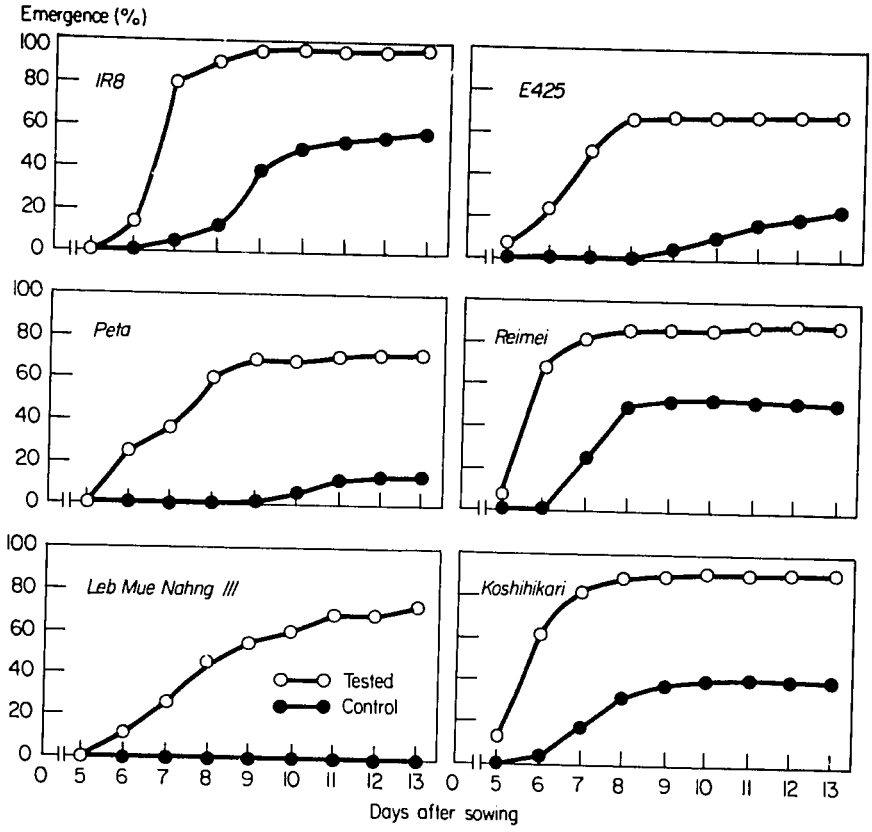
Variety	Shoot length (cm) Control	Shoot length (cm) Treated	Root length (cm) Control	Root length (cm) Treated
IR8	20.2	29.5	8.8	13.0
Peta	12.6	24.3	4.3	7.7
Leb Mue Nahng 111	0.0	23.8	0.0	7.5
E425	15.5	23.6	5.0	9.6
Reimei	25.2	25.2	7.0	7.2
Koshihikari	23.5	27.4	8.8	8.9

[a]2 weeks after sowing.

Table 13. Seedling emergence of stored calcium peroxide-coated dry rice seeds.[a] IRRI, 1979.

Weeks stored	Seedling emergence (%) Treated	Seedling emergence (%) Control	Germination (%) of seeds used
0	78	10	88
1	86	2	99
2	80	9	92
3	77	3	99
4	85	12	97
6	82	7	98
8	75	7	96
10	84	5	93

[a]Depth of seeding was 1 cm; water depth was 5 cm. Observation ended 14 days after seeding.



9. Effect of calcium peroxide seed coating on seedling emergence of 6 varieties from flooded soils at 29°/21° C. Seeding depth: 1 cm; water depth: 5 cm. IRRI, 1979.

Table 14. Seedling emergence of stored calcium peroxide-coated, presoaked rice seeds. IRRI, 1979.

Days stored	Seedling emergence (%)
0	92
1	88
4	85
6	94
12	91
20	88
25	90
35	91

Varieties differ in their ability to emerge from flooded soils (Fig. 9). Seedling emergence ranged from 0% for Leb Mue Nahng III to about 60% for IR8. When seeds were coated with calcium peroxide, the rate of seedling emergence increased and percentages of emergence increased to 70 and 95%. Because seedling emergence was faster, shoot and root length of seedlings were also better (Table 12).

Duration of storage of coated seeds. There are two ways of coating seeds with calcium peroxide — coating dry seed and coating presoaked seed. After seeds are coated, they can be stored for 10 weeks without decrease in percentage of seedling emergence (Table 13). Seeds soaked in water for 48 hours before coating with calcium peroxide can be stored safely for more than 1 month (Table 14).

Constraints on rice yields

Agricultural Economics, Agronomy, and Irrigation Water Management Departments

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Since 1974 rice scientists — working as teams composed of agronomists, economists, and statisticians — have identified factors limiting rice yields in farmers' fields in six Asian countries. The findings of this research coordinated by IRRI scientists have been published in two volumes. The first, *Constraints to high yields on Asian rice farms: an interim report,* was published in 1977. In 1979, *Farm-level constraints to high rice yields in Asia: 1974-77* was published.

ENVIRONMENTAL AND MANAGEMENT CONSTRAINTS

Agricultural Economics Department

In 1979, data from the Constraints Project were analyzed to identify the causes of variability in yields across farms in Nueva Ecija province, Philippines.

Accounting for yield differences. Experiments on the Nueva Ecija farms were classified according to farmers' yields. The 25% of sites with the highest farmers' yields and the 25% with the lowest were identified for the wet and dry season. The yields and yield gaps are shown in Figure 1. The total differential of the production function was used to examine the causes of the yield differences. The difference in yield between the high- and low-yield situations is the sum of the yield differences due to the differences in the levels of input factors at the two sites. In mathematical form, if output Y is dependent on the levels of managed inputs (X_i) and site-specific environmental factors (Z_j), the production is generally specified as:

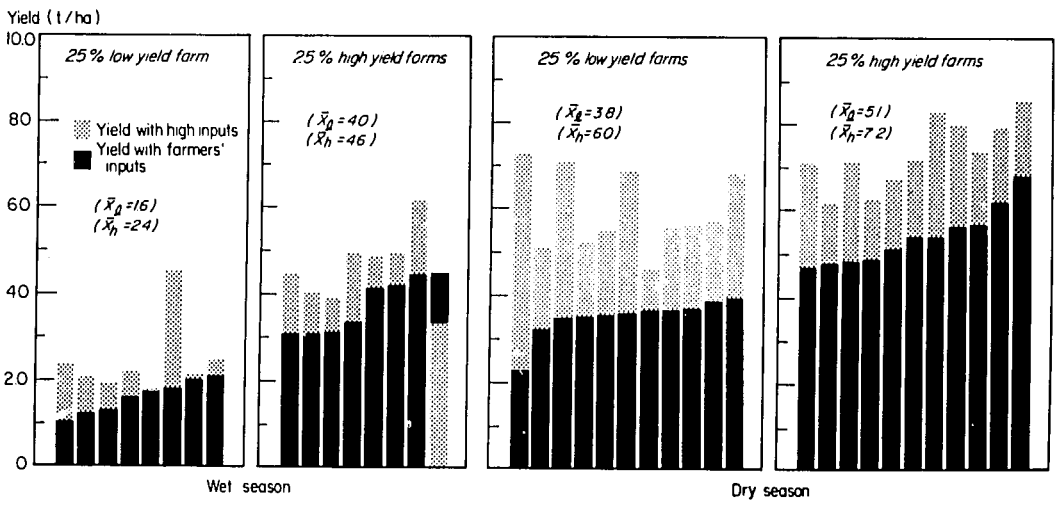
$$Y = f(X_i, Z_j) \qquad i = 1,\ldots, k; j = 1,\ldots, n.$$

The factors included in the production function and the model estimated are listed in Table 1. This model is a reduced version of the comprehensive production function described in IRRI's 1978 annual report. The differential, dY, is defined from the production function:

$$dY = \frac{\partial Y}{\partial X_1} dX_1 + \ldots + \frac{\partial Y}{\partial X_k} dX_k + \frac{\partial Y}{\partial Z_1} dZ_1 + \ldots + \frac{\partial Y}{\partial Z_n} dZ_n \qquad (1)$$

The partial regression coefficients estimated for the production function provide the numerical values of the partial derivatives $(\partial Y/\partial X_i)$. The values of $dX_1, dX_k, dZ_1, \ldots, dZ_n$ are taken to be the differences in the mean values of the inputs and environmental factors between the high-yield and the low-yield farms. Substituting these values in equation 1 provides an estimate of the yield difference (dY) between the high- and low-yielding groups.

When both sides of equation 1 are divided by the actual mean difference in yield G, we derive the percentage of the yield differences accounted for by each managed input and environmental factor. That is,



1. Yield and yield gaps on low- and high-yield farms with farmers' input, by season, Nueva Ecija, Philippines, 1974-77.

$$\frac{dY}{G} = \frac{\partial Y}{\partial X_1}\frac{dX_1}{G} + \ldots + \frac{\partial Y}{\partial K_k}\frac{dX_k}{G} + \ldots + \frac{\partial Y}{\partial Z_1}\frac{dZ_1}{G} + \frac{\partial Y}{\partial Y_n}\frac{dZ_n}{G} \quad (2)$$

or approximately expressed as

$$\frac{\Delta Y}{G} = b_i\frac{\Delta X_1}{G} + \ldots + b_k\frac{\Delta X_k}{G} + \ldots + c_i\frac{\Delta Z_1}{G} + \ldots + c_n\frac{\Delta Z_n}{G} + \gamma_i\frac{\Delta Q_i}{G} \quad (3)$$

where b_i and c_i are the partial regression coefficients, γ_i the interaction term coefficients, and Q_i are interactions between managed inputs and the environmental factors. The ΔX_i and ΔZ_i actually occurring in the study areas were calculated from data recorded from the low- and high-yield farms during the agronomy experiments.

Contributions to yield differences. Following the procedure described, the reduced production function estimated (Table 1) was used to examine the yield difference between high- and low-yield farms during the wet and dry seasons. The results are shown in Table 2. The estimated differences in yield between the high- and low-yield groups are 2.36 t/ha in the wet season and 1.31 t/ha in the dry. About 1.7 t/ha (70%) of the wet-season difference was explained by the differences in the measured variables. For the dry season, differences in the factors included in the equation explained 97% of the total yield difference (1.3 t/ha).

In the wet season the environmental factors were the major factors causing yield differences among farms. In the dry season the proportion of the total attributed to interaction of managed inputs with environmental factors was greater than in the wet.

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

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

Independent variable	Partial regression coefficients[a]	
	Comprehensive model	Reduced model
Fertilizer (quadratic) (F^2)	0.038***	0.029***
Insecticide (I)	0.445***	0.472***
Weed control (W)	0.298	0.691**
Seedling age (A)	7.973***	10.144***
Fertilizer x pest damage ($F \times P$)	0.117***	0.115***
Disease damage (D)	-36.780***	-25.769***
Fertilizer x disease ($F \times D$)	-0.215***	-0.251***
Organic matter (M)	419.9***	184.068***
Soil texture (T)	-7.722***	
Soil phosphorus (H)	2.641***	2.455***
Fertilizer x water stress ($F \times S$)	-0.168***	-0.207***
Solar radiation (R)	88.297***	99.492***
Fertilizer x solar radiation ($F \times R$)	0.967***	0.829***
Typhoon dummy	-356.0***	-416.371***
Av F efficiency	-4.469***	-1.996***
Av I efficiency	-0.656***	0.469***
Individual farmer F efficiency	included	not included
Constant term	1400	1248
$\bar{R}^2$	.698	0.640
F ratio (15/3260)		388.934***
Standard error		990.109

[a]Coefficient is significant at the 1% level (***), the 5% level (**), the 10% level (*).

Table 2. Accounting for yield differences between low- and high-yield farms with farmers' input, 1974–77 wet and dry seasons, Nueva Ecija, Philippines.

Class	Elements[a]	Wet season t/ha	Wet season %	Dry season t/ha	Dry season %
Mean yield difference		2.36	100.0	1.31	100.0
Components of explained yield difference		1.67	70.7	1.28	97.7
Inputs		(0.07)	(3.0)	(0.34)	(25.9)
	F	−0.04	−1.7	0.32	24.4
	W	.04	1.7	.02	1.5
	I	.01	0.4	−.02	−1.5
	A	.06	2.5	.02	1.5
Weather		(0.99)	(41.9)	(0.46)	(35.1)
	SR	0.67	28.4	.09	6.9
	DT	0.38	16.1	.41	31.3
	SL	−0.06	−2.5	−.04	−3.1
Pest and disease		(0.35)	(14.9)	(0.17)	(12.9)
	P	0.13	5.5	0.17	12.9
	D	0.22	9.3	0	0
Soils		(−0.05)	(−2.2)	0.02	(1.5)
	OM	−0.06	−2.5	0.02	1.5
	EP	0.01	0.4	0	0
All interactions		(0.31)	(13.1)	(0.29)	(22.1)
Unexplained difference		0.69	29.3	0.04	2.3

[a]For explanation of the elements, see Table 1.

- no cash constraints, and
- a cash constraint that the farmer required a return of $1 on the last dollar invested (Table 3).

For the unconstrained situation ($\lambda = 0$), the optimal level of fertilizer was reached at a higher level of fertilizer than that 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 the optimal levels were small with both the researchers' and the farmers' efficiency in the wet season. For the cash constraint situation ($\lambda = 1$) in the wet season (other than for the low-yield environment or farmers' efficiency), the yield differences between the farmers' and the

Table 3. Estimated optimum at 2 rates of discount and farmers' fertilizer use of different farm yield groups. Nueva Ecija, Philippines, 1974–77.[a]

Season	Yield group	Optimal F λ = 0	Optimal F λ = 1	Farmers' F-level	Predicted yield (Y) λ = 0	Predicted yield (Y) λ = 1	Predicted yield (Y) Farmers'	Yield difference[b] Δ0	Yield difference[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 $0.14/kg, fertilizer at $0.52/kg in the wet season and $0.54/kg in the dry. [b]Where $\Delta 0 = Y\lambda = 0 - Y_{farmers'}$, $\Delta 1 = Y\lambda = 1 - Y_{farmers'}$, and λ is the return on the last dollar invested in fertilizer.

Table 4. Inputs used by farmers and researchers in Laguna, Philippines, constraints experiments, 1979.

Input level[a]	Fertilizer (kg/ha)			Insect control[b] (no. of field application)		Weed control (no.)			Disease control[c]
	N	P	K	F	G	Chemical	Rotary	Hand weeding	
				Dry season					
Farmers'	68	5	5	1.3	0.3	1.0	1.3	1.0	0
Intermediate	90	30	30	0.3	1.7	1.0	1.3	1.0	1.0
High	120	30	30	3.0	3.0	1.0	1.3	1.0	5.0
				Wet season					
Farmers'	65	15	7	2.3	0	1.0	1.0	1.0	0
Intermediate	50	30	30	1.0	2.3	1.0	1.0	1.0	1.0
High	75	30	30	3.0	3.0	1.0	1.0	1.0	5.0

[a]Intermediate for insect control is equivalent to managed level. [b]F = foliar application, G = granular. [c]Intermediate treatment consisted of early dapog treatment with benomyl-mancozeb combination; high treatment involved applications of the same fungicides at 3, 15, 30, and 45 days after transplanting and at flowering.

cash-constrained optima were small.

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

The analysis demonstrated two points:

- The response to farm inputs, like fertilizer, is greater under more favorable environments — as in the dry season — when there is higher solar radiation, fewer typhoons, and lower incidence of pests.
- For the farmer facing a cash constraint, the yield and profit difference is small between the farmers' level of fertilizer use and that identified through the production function analysis of the constraints trials.

However, if the efficiency of farmers' use of fertilizer could be increased to the researchers' level, then it would be profitable for the farmer to increase fertilizer use.

Table 5. Mean yields for wet- and dry-season constraints experiments. Sta. Cruz, Laguna, Philippines, 1979.

Input level	Sites (no.)	Mean yields (t/ha)	
		Wet season	Dry season
Farmers'	3	3.8	4.5
High	3	5.0	6.1

In the less ideal environment of the wet season, the researchers' technology was not clearly superior to the farmers' in Nueva Ecija. It is in the dry season that it appears that the economic potential of modern varieties is not being realized.

CONSTRAINTS ANALYSIS

Agricultural Economics and Irrigation Water Management Departments

Three dry- and three wet-season sites were established in Victoria, Laguna, Philippines, to evaluate the response of rice to major inputs following the concepts used in earlier constraints experiments. The designs included a change of previous constraints experiments, with disease management included as a factor in the treatments.

The levels of inputs used by the farmers and the researchers are listed in Table 4. Water regimes were monitored and water balances were favorable in both seasons. Those, coupled with high levels of radiation and no serious typhoons, resulted in moderate yields for the farmers' and the researchers' input levels (Table 5).

Production function analysis. To examine the effects of the inputs included in the experiments, a quadratic response function of the following form was fitted to the dry- and wet-season data:

$$Y = b_0 + b_1 N + b_2 N_2 + b_3 P + b_4 K + b_5 DI1 + b_6 DI2 + b_7 DM1 + b_8 DM2$$

where

Y is yield rough rice in kilograms per hectare,

N is kilograms nitrogen,
P is P_2O_5,
K is K_2O,
DI is a dummy variable equal to 0 for the farmers' practice and to 1 for the two insect control treatments,
DM is another dummy variable equal to 0 for the farmers' disease management and to 1 for the two disease (fungicide) control treatments.

The estimated equations are shown in Table 6. Model I, which includes all the experimental factors as terms, provides an impression of the single effects of the factors included in the experiment. Yield response to nitrogen and insect management were significant in the dry season. In contrast, the high level of insect control was the only factor at the researchers' level that had a significant effect in the wet season. Although the fungicide treatments (benomyl) were not assessed as statistically significant in either season, the factor had a greater impact on yield in the wet season than in the dry. The production functions were re-estimated retaining the significant terms in the dry season plus the nonlinear term for nitrogen (Model II).

An analysis of the high profit level of nitrogen for the wet and dry seasons provided levels beyond the range of the experimental observations (i.e. 206 kg N ha for the dry season and 115 kg for the wet), which reflected the excellent growing conditions prevailing in both seasons. Analysis of the insect management strategies showed that the incremental costs of two pest management strategies beyond the farmers' current practices were not profitable (Table 7).

Technical and economic efficiency. In collaboration with IRRI scientists, a research scholar from Sri Lanka developed an alternative procedure to measure the difference between the researchers' and the farmers' level of technical efficiency in fertilizer application to rice.

A model that utilized the concept of efficiency-specific production function was developed to define an index of farm-level technical efficiency.

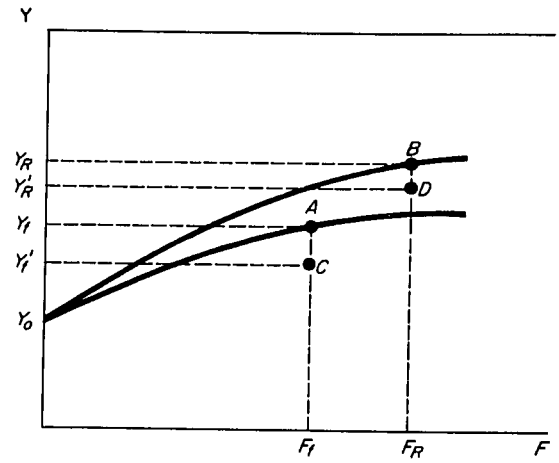
Table 6. Production functions estimated from Victoria, Laguna, Philippines, constraints experiments, 1979.

Independent variable	Symbol	Partial regression coefficient[a]			
		Dry season		Wet season	
		Model I	Model II	Model I	Model II
Nitrogen (linear term)	N	20.241**	20.100**	9.159	10.924
		(4.473)	(4.516)	(1.359)	(1.648)
Nitrogen (quadratic term)	N^2	−0.042	−0.039	−0.038	−0.030
		(1.367)	(1.345)	(0.535)	(0.429)
P_2O_5	P	3.034		14.205	
		(0.510)		(1.624)	
K_2O	K	−2.425		−4.302	
		(0.408)		(0.587)	
Managed insect control dummy	$DI1$	310.484*	309.705*	35.643	104.452
		(2.137)	(2.189)	(0.254)	(0.789)
High insect control dummy	$DI2$	510.162*	548.182*	506.280*	720.262**
		(2.559)	(3.266)	(2.685)	(4.493)
Early fungicide treatment dummy	$DM1$	28.592		296.999	
		(0.101)		(1.144)	
Continuous fungicide treatment dummy	$DM2$	127.147		386.667	
		(0.449)		(1.489)	
Constant term		3482.959	3490.325	2895.080	3041.722
Adjusted R^2		0.530	0.542	0.441	0.429
F		21.146	43.251	15.151	27.886
Standard error		670.507	662.040	618.270	625.217

[a]Figures in parentheses are t-values.

Table 7. Economic performance of managed and high insect control compared with farmers' current practices in Victoria, Laguna, Philippines, constraints experiments, 1979.

Insect control level	Increase or decrease (S/ha) from farmers' current practices		
	Output value	Input cost	Profit
	Dry season		
Managed	42	69	−27
High	75	164	−89
	Wet season		
Managed	14	84	−70
High	98	177	−79



2. Efficiency functions and actual performance at researchers' (Y'_R) and farmers' (Y'_f) levels.

Based on the concept shown in Figure 2, two approaches to the estimation of the efficiency functions were attempted. In the first approach all data were pooled and a single equation, incorporating a dummy variable to distinguish between farmers' and researchers' results, was estimated. In the second approach, the differences between the farmers' and the researchers' use of inputs and production of outputs were used as independent and dependent variables, respectively. Appropriate manipulation of the variables produced an unbiased estimate of average efficiency.

To make the required shift from a measure of average efficiency to an index of individual farm efficiency, the difference between each farmer's and the researcher's deviations of actual result from the expected was assumed to be the result of the farmer's deviation from the average level of efficiency. Thus, it was possible to rank the farmers in order of relative efficiency.

Various socioeconomic variables were then regressed against the values of the indices to identify factors that might influence the efficiency of input use by farmers. The principal variables used were a dummy for the respondents' main occupation, the number of seasons for which they had transplanted rice, the percentage of family labor employed full time in rice transplanting, a dummy for agricultural education, and the number of seasons of fertilizer use.

The use of various models generated a range of results. The main finding was that technical efficiency alone resulted in farmers losing between 0.3 and 0.7 t of rice/ha at the average farm-level use of 91 kg N/ha. This indicated that farmers were between 66% and 85% efficient in their use of fertilizers, a situation suggesting significant potential gains.

The efficiency indices computed from the different regression equations were very highly correlated; therefore, only one was used for further analysis. Table 8 gives the levels of inputs and outputs for

Table 8. Examples of results achieved by farmers with varying levels of technical efficiency, Sri Lanka.

Level of efficiency	Nitrogen applied (kg/ha)		Yield (t/ha)	
	Researcher's level	Farmer's level	Researcher's level	Farmer's level
High	35.93	51.97	1.6	2.9
	77.48	62.14	1.8	3.9
Average	77.48	79.24	2.0	2.1
	91.91	81.17	3.5	3.4
Low	106.35	153.43	5.0	3.1
	91.91	61.36	4.7	3.7

Table 9. Ranking of goals and associated achievement levels for a hypothetical tenant farmer in Iloilo, Philippines, 1979.

Rank	Goal description	Desired achievement level	
		Unit	Quantity
1	To produce a basic quantity of rice sufficient for family sustenance	tons	1.2
2	To accumulate cash for food supplies, education, and other priority demands of the household	$/year	360
3	To minimize borrowings from relatives and friends	$/year	35
3	To minimize borrowings from a landlord	$/year	200
4	To avoid being indebted to others	$/year	min
5	To generate as large a cash surplus as possible	$/year	max

selected farms. These illustrate the typical differences between farmer and researcher achieved by farmers with high, average, and low technical efficiency.

The regressions estimated in the final stage indicated that the main socioeconomic factors explaining technical efficiency were the respondents' main occupation and the percentage of family labor employed full time in rice farming. The occupation variable indicated that respondents whose main occupation was not rice farming were more technically efficient. No attempt was made to determine if the result was caused by problems in the data set or if it reflects the actual situation. The other variables behaved as expected. Technical knowledge of fertilizer use and experience with transplanting for a number of seasons explained a much smaller amount of the variability in efficiency.

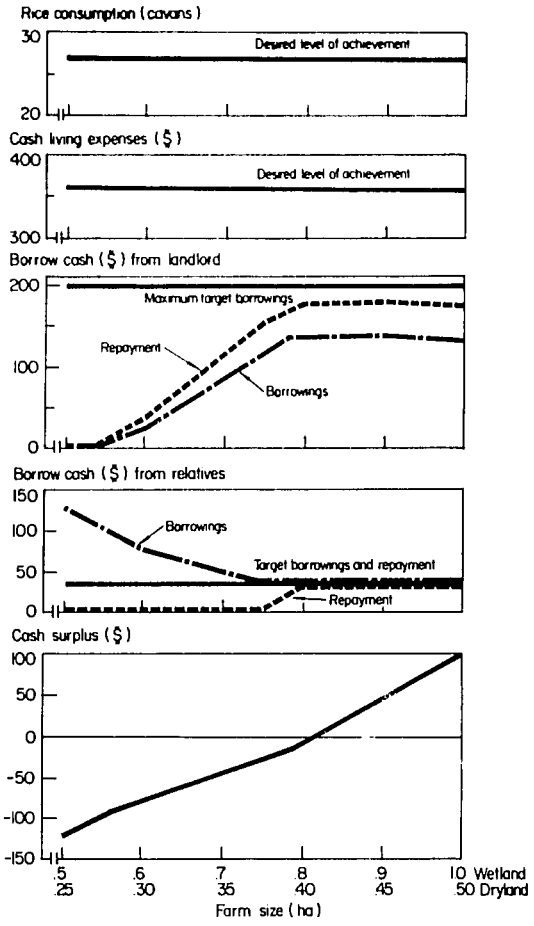
The major advantage noted for the method is that it does not require collection of complex data in addition to those currently being gathered in the constraints project. Although limited success was achieved, the level of explanation of technical efficiency by socioeconomic factors was not as high as desired.

Farm-level constraints. Analysis of the socioeconomic constraints surveys has yielded mixed results in explaining *why* farmers use the level of inputs they do. In collaboration with the Cropping Systems Program, a series of farm-level models were developed to examine farm-level (i.e. the resource structure, circumstances, and demands of the household) constraints to production. A linear goal programming model of a low-resource farmer, with data obtained from the Philippine Cropping Systems Outreach Site at Iloilo, is reported here.

The ranking of goals and the associated achievement levels of these goals for the household are listed in Table 9. Given the household's assumed land base, the farmer can fully achieve the goals of meeting family rice requirements and obtaining cash for basic household expenses, without falling into debt, given his technical and resource constraints. A cash surplus of $102 was predicted. The impact of farm size and the operator's access to credit on the farmers' cropping patterns and the families' liquidity position were then examined.

Farm size and goal achievement. Increasing population pressures and land fragmentation through inheritance have resulted in decreasing size of tenanted holdings in Iloilo. Thus, to evaluate the impact of landholding on goal achievement, farm size was parametrically reduced from 1.5 ha to 0.75 ha (Fig. 3). Because farm size was regarded as a preemptive priority, the optimal farm plan identified the rice technology that maximized returns to land relative to capital.

When farm size (in terms of rice land) was reduced to 0.82 ha, the farm business was no longer able to generate a cash surplus over and above that required to meet household and farm operating costs. Indeed, as farm size decreased further, the farmer was unable to repay all his loans and still meet his priority household needs. Repayment to the landlord is a preemptive priority in the sense that the loan is redeemable at the next harvest.



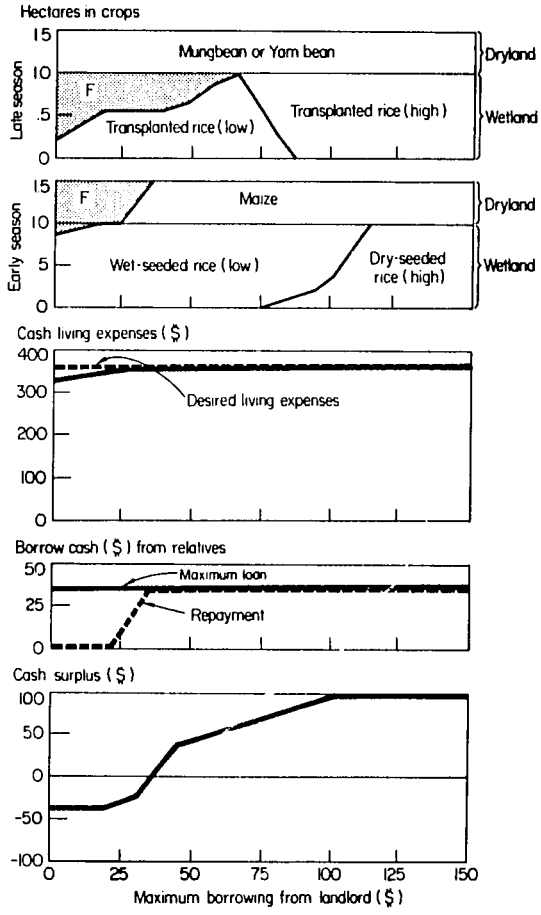
3. Relationship between goal achievement and cultivated area. Iloilo, Philippines, 1979. 1 cavan = 44 kg.

Therefore, the farmer shifts to borrowing less from his landlord and more from his relatives and friends; he increasingly defaults on his loans from the latter sources and begins to fall into indebtedness.

Access to credit. Because credit is important in farm operations, the impact of its availability on the farm plan and the farmer's capacity to achieve his goals was explored. For the purpose of the analysis, the maximum of $35/year available from relatives and friends was entered as a preemptive priority, and maximum borrowings from the landlord (which must be repaid at 100% interest) were parameterized from zero until it became non-limiting.

The results are shown in Figure 4. As access to credit diminished, the cropping pattern shifted from a capital-intensive to a less capital-intensive technology. At a credit supply of $62 from the landlord, a portion of the rice land remained vacant — the late-season rice crop was reduced in area because of the cost of hired labor required to transplant that crop. At a credit limit of about $30, the farmer could not achieve his target of $360 a year for living expenses, although sufficient rice continued to be produced to meet family consumption and still leave a surplus for sale.

A comparison of Figures 3 and 4 shows that when land was the scarce resource relative to capital, the capital-intensive technology continued to be attractive at the small farm examined. But if capital



4. Relationship between credit availability, goal achievement, and cropping patterns. IRRI, 1979. F = fallow.

was scarce relative to land, there was a rapid shift from the *modern* to the lower-cost (and as a result, lower yield) methods of producing the rice crop.

BIOLOGICAL CONSTRAINTS

Agronomy Department

Studies on biological constraints to high rice yields in farmers' field continued in four Philippine provinces. Levels of inputs are given in Table 10.

Nueva Ecija, dry season. Dry-season trials in Nueva Ecija were on 15 pump-irrigated farms. Most farmers used herbicides, and all used either foliar spray or granular insecticides.

Yields with farmers' inputs ranged from 3.9 to 7.9 t/ha and averaged 6.1 t/ha (Table 11). With high inputs, yields varied from 4.4 to 8.5 t/ha and averaged 6.9 t/ha. The average yield gap of 0.8 t/ha was low but significant. A declining trend in size of yield gap on some farms was attributed largely to increased use of inputs, particularly nitrogen fertilizer.

The contributions of test factors to the yield gap were determined from two trials. The average levels of inputs used by the two farmers are shown in Table 12. From these trials, the average yield increase from high inputs was 1.4 t/ha (Table 13). Of that increase, 62.5% was from fertilizer and 25% from insect control.

Timing of nitrogen fertilizer application was tested with four levels of nitrogen at two levels of insect and weed control practices. Results from 5 farms showed that the researchers' timing gave 0.5 t/ha higher yields than the farmers' timing regardless of the amount of nitrogen applied (Table 14) and confirmed earlier findings that farmers were applying fertilizer nitrogen inefficiently.

Nueva Ecija, wet season. Wet-season trials in Nueva Ecija were on 5 pump- and 3 canal-irrigated farms (Table 10). Three farmers applied granular insecticides and one farmer had no insect control at all. Four farmers controlled weeds by hand weeding or by herbicides; the others did not control weeds.

Yields at the farmers' level of inputs ranged from 3.3 to 6.6 t/ha and averaged 5.0 t/ha (Table 11). With high inputs, yields ranged from 4.6 to 7.7 t/ha and averaged 6.5 t/ha. The water shortage at the heading stage on two farms resulted in substantial yield reduction at all input levels. The average yield gap was 1.5 t/ha. On the basis of 3 trials, the yield

Table 10. High and farmers' levels of inputs in yield-constraints experiments in farmers' fields at 4 Philippine sites, 1979.

Province	Input level	Sites (no.)	Fertilizer (kg/ha)			Weed control[a]		Insect control[b]	
			N	P_2O_5	K_2O	M	C	F	G
			Dry season						
Nueva Ecija	Farmers'	15	118	36	14	0.3	0.7	2.1	1.2
Nueva Ecija	High	15	150	40	30	1.0	1.0	1.6	3.0
Laguna	Farmers'	11	66	8	8	1.7	0.6	1.0	0
Laguna	High	11	150	40	30	1.0	1.0	1.0	3.0
Camarines Sur	Farmers'	10	80	18	7	0.9	0.6	2.1	0
Camarines Sur	High	10	150	40	30	1.0	1.0	2.6	3.0
Iloilo	Farmers'	9	83	4	1	0.6	1.0	1.7	0
Iloilo	High	9	150	40	30	0.7	1.7	3.6	3.0
			Wet season						
Nueva Ecija	Farmers'	8	58	31	10	0.2	0.2	1.1	0.4
Nueva Ecija	Intermediate	8	70	30	20	--	--	0.9	2.0
Nueva Ecija	High	8	100	40	30	1.0	1.0	2.0	3.0
Laguna	Farmers'	6	75	4	4	2.0	0.8	2.2	0.7
Laguna	Intermediate	6	70	30	20	–	-	1.0	2.0
Laguna	High	6	100	40	30	1.0	1.0	1.0	3.0
Camarines Sur	Farmers'	6	62	19	9	0.7	1.2	3.0	0
Camarines Sur	Intermediate	6	70	30	20	--	--	3.1	2.0
Camarines Sur	High	6	100	40	30	1.0	1.0	3.1	3.0
Iloilo	Farmers'	5	49	22	10	0.8	0.2	2.2	0.2
Iloilo	Intermediate	5	70	30	20	–	--	1.6	2.0
Iloilo	High	5	100	40	30	0.3	0.9	1.9	2.7

[a]Data show average number of mechanical weeding operations (M) – either by hand or by rotary weeder – or chemical weedicide (C) applications. [b]Data show average number of foliar (F) sprays – MIPC, monocrotophos, Brodan, methyl parathion, etc. – or of granular (G) applications – lindane, carbofuran, diazinon, etc. – to paddy water. The main field crops were treated. In some cases, seedbeds were also treated.

Table 11. Average yields with farmers', high, and economically recoverable gap (ERG) inputs in yield-constraints experiments in farmers' fields, in 4 Philippine provinces, 1979.

Province	Sites (no.)	Grain yield (t/ha)			Yield gap (t/ha)
		Farmers' inputs	High inputs	ERG inputs	
		Dry season			
Nueva Ecija	15	6.1	6.9	6.6	0.8
Laguna	11	4.7	6.6	6.1	1.9
Camarines Sur	10	4.8	6.2	6.2	1.4
Iloilo	9	3.6	5.0	4.6	1.4
		Wet season			
Nueva Ecija	8	5.0	6.5	5.9	1.5
Laguna	6	3.8	4.3	3.7	0.5
Camarines Sur	6	4.3	5.5	5.2	1.2
Iloilo	5	4.7	5.6	5.0	0.9

gap averaged 1.8 t/ha (Table 13), 60% of which was due to improved fertilizer application and the rest was equally divided between insect control and weed control (Fig. 5). The contribution of improved insect control to the yield gap despite the low level of farmers' insect control (Table 12) was due partly to the absence of damaging rice pests and the use of insect-resistant IR42 by all farmers. Im-

Table 12. Levels of inputs used in yield gap and input combination experiments in selected farmers' fields, in 4 Philippine provinces, 1979.

Province	Input level	Sites (no.)	Fertilizer (kg/ha)			Weed control[a]		Insect control[b]	
			N	P_2O_5	K_2O	M	C	F	G
			Dry season						
Nueva Ecija	Farmers'	2	112	29	9	0	1.0	2.0	0.5
Nueva Ecija	Intermediate	2	100	30	20	–	–	2.0	2.0
Nueva Ecija	High	2	150	40	30	1.0	1.0	2.5	3.0
Laguna	Farmers'	3	17	6	6	1.7	1.0	0	0
Laguna	Intermediate	3	100	30	20	–	–	1.0	2.0
Laguna	High	3	150	40	30	1.0	1.0	1.0	3.0
Camarines Sur	Farmers'	3	99	17	5	0.7	1.0	1.7	0
Camarines Sur	Intermediate	3	100	30	20	–	–	2.7	2.0
Camarines Sur	High	3	150	40	30	1.0	1.0	2.7	3.0
Iloilo	Farmers'	5	78	7	2	0.6	1.0	2.2	0
Iloilo	Intermediate	5	100	30	20	–	–	3.0	2.0
Iloilo	High	5	150	40	30	0.8	1.0	3.6	3.0
			Wet season						
Nueva Ecija	Farmers'	3	41	28	10	0.3	0	1.0	0
Nueva Ecija	Intermediate	3	70	30	20	–	–	0.7	2.0
Nueva Ecija	High	3	100	40	30	1.0	1.0	1.0	3.0
Laguna	Farmers'	3	87	3	3	2.0	1.0	2.3	0.7
Laguna	Intermediate	3	70	30	20	–	–	1.0	2.0
Laguna	High	3	100	40	30	1.0	1.0	1.0	3.0
Camarines Sur	Farmers'	3	74	13	13	0.7	1.0	3.0	0
Camarines Sur	Intermediate	3	70	30	20	–	–	3.1	2.0
Camarines Sur	High	3	100	40	30	1.0	1.0	3.1	3.0
Iloilo	Farmers'	3	49	22	10	1.0	0.3	2.0	0.3
Iloilo	Intermediate	3	70	30	20	–	–	1.3	2.0
Iloilo	High	3	100	40	30	0.7	1.0	2.0	2.7

[a]Data show average number of mechanical weeding operations (M) – either by hand or by rotary weeder – or chemical weedicide (C) applications. [b]Data show the average number of foliar (F) sprays – MIPC, monocrotophos, Brodan, methyl parathion, etc. – or of granular (G) applications – lindane, carbofuran, diazinon, etc. – to paddy water. The main field crops were treated. In some cases, seedbeds were also treated.

Table 13. Relative contribution of 3 inputs (fertilizer, weed control, and insect control) to the improvement of rice yields in farmers' fields in project areas in 4 Philippine provinces, 1979.

Province	Sites (no.)	Yield (t/ha)			Contribution[a] (t/ha) of			
		Farmers' input	High inputs	Difference	Fertilizer	Weed control	Insect control	Residual
			Dry season					
Nueva Ecija	2	5.8	7.2	1.4	1.0	0.2	0.4	−0.2
Laguna	3	4.2	6.3	2.1	1.8	0.2	0.7	−0.6
Camarines Sur	3	5.2	6.3	1.1	0.9	0	0.3	−0.1
Iloilo	5	4.2	4.7	0.5	0.9	0.2	0.3	−0.9
			Wet season					
Nueva Ecija	3	5.7	7.5	1.8	1.2	0.4	0.4	−0.2
Laguna	3	4.3	4.8	0.5	−0.1	0.6	−0.2	0.2
Camarines Sur	3	4.3	5.9	1.6	1.1	0.6	0.4	−0.5
Iloilo	3	4.6	5.5	0.9	1.1	0	0.4	−0.6

[a]Measured as yield decrease from high input due to a reduction from high to farmers' level of each input.

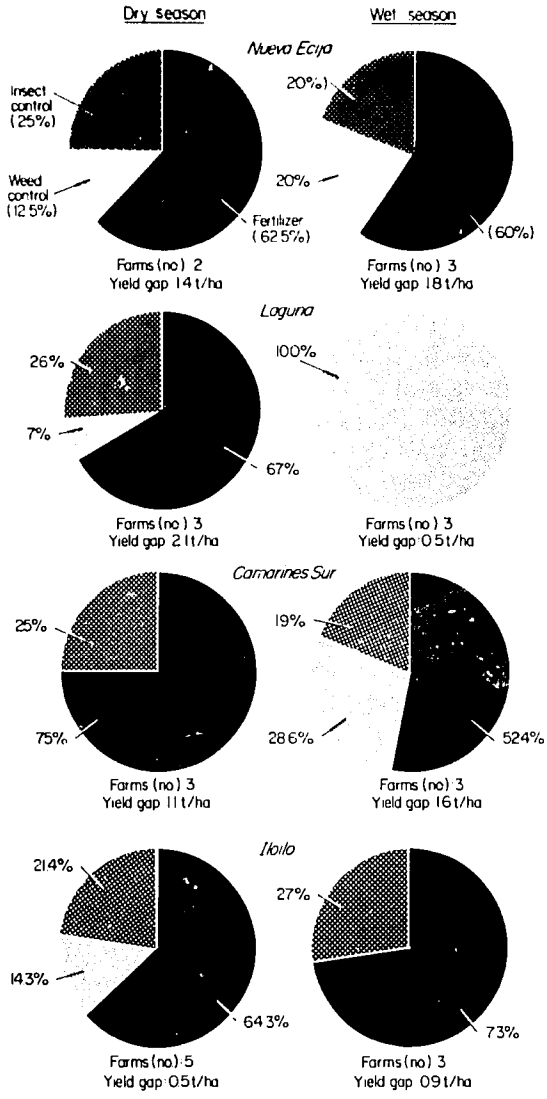
proved weed control made a significant contribution to the yield gap on only one farm.

The farmers' timing of fertilizer application was compared with the researchers' timing at four levels of nitrogen under high levels of insect and weed control on one canal- and four pump-irrigated farms. Yield differences among nitrogen rates were not appreciable (Table 14) because lodging was severe on two farms. In addition, one farm suffered from severe drought at the heading stage. Although

Table 14. Yield with farmers' and researchers' timing of application of farmers' level and test levels of nitrogen in project areas in 4 Philippine provinces, 1979.

Province	Sites (no.)	Time of N application[a]	Nitrogen applied (farmers' level)		Yield[c] (t/ha)			
			Rate (kg/ha)	Timing[b] (DT)	Farmers' level	I-1	I-2	H
			Dry season					
Nueva Ecija	5	R	121		5.6	5.3	5.8	5.9
Nueva Ecija	5	F	121	8, 38	5.2	4.8	5.3	5.3
Laguna	5	R	109		5.2	5.0	5.7	6.2
Laguna	5	F	109	16, 42, 67	4.6	4.6	5.3	5.8
Camarines Sur	2	R	87		5.1	4.9	5.1	5.3
Camarines Sur	2	F	87	0, 45	5.1	5.2	4.9	5.1
Iloilo	2	R	64		5.2	4.6	5.4	5.2
Iloilo	2	F	64	20, 45 (15, 70 DS)	5.1	5.0	5.3	5.4
			Wet season					
Nueva Ecija	5	R	60		6.5	6.2	6.4	6.4
Nueva Ecija	5	F	60	10, 35	6.1	5.9	6.2	6.3
Laguna	4	R	55		4.8	4.1	4.6	4.6
Laguna	4	F	55	18, 50	4.3	4.3	4.6	4.5
Camarines Sur	4	R	55		4.7	4.5	4.5	4.1
Camarines Sur	4	F	55	0, 45	4.8	4.6	4.5	4.1
Iloilo	6	R	80		5.8	5.3	5.6	5.9
Iloilo	6	F	80	15, 50 (15, 60 DS)	5.5	5.4	5.7	5.8

[a]R = researchers', F = farmers'. [b]DT = days after transplanting, DS = days after seeding. Researchers' timing on N application – dry season: 3 equal split applications; basal broadcast and incorporated, 20–30 DT, and 5–7 days before panicle initiation. Researchers' timing in the wet season: 2 equal split applications; basal broadcast and incorporated, and 5–7 days before panicle initiation. [c]Test rates of nitrogen: for dry season, intermediate levels were I-1 = 50 kg N/ha, I-2 = 100 kg N/ha, high level (H) = 150 kg N/ha. For wet season: I-1 = 40 kg N/ha, I-2 = 70 kg N/ha, H = 100 kg N/ha. Dry season data are averages of farmers' and high levels of insect and weed control, while wet-season data are averages of high levels of insect and weed control only.



5. Relative contribution of 3 inputs (insect control, fertilizer, and weed control) toward the improvement of rice yields in farmers' fields in 4 Philippine provinces, 1979 dry and wet seasons.

the average yield advantage of the researchers' fertilizer timing ranged only from 0.1 to 0.4 t/ha, the difference was consistently positive.

Laguna sites, dry season. Dry-season Laguna experiments were on eight canal-irrigated, one pump-irrigated, and two canal-pump-irrigated farms (Table 10). Most farmers applied fertilizer in split applications; only one farmer made a single basal application. Four farmers applied 100 kg N/ha or more and two applied no fertilizer. All farmers practiced one rotary weeding followed by hand weeding, and six applied herbicide. Six farmers did not control insects at all and the rest used at least one foliar spray. No farmer used granular insecticide. Most farmers transplanted IR36 or IR42.

Farmers' yields ranged from 3.5 to 6.0 t/ha and averaged 4.7 t/ha. With high inputs, yields ranged from 5.0 to 7.7 t/ha and averaged 6.6 t/ha. The average yield gap was 1.9 t/ha (Table 11).

Observations on 3 farms where the nitrogen applied by the farmers averaged only 17 kg/ha (Table 12) indicated that the high level of fertilizer gave a significant contribution on all farms. The high level of fertilizer contributed 67% to the yield increase, improved insect control contributed 26%, and improved weed control accounted for 7% (Fig. 5). The 17 kg N/ha was extremely low for a dry-season crop.

Farmers' and researchers' timing of fertilizer application with four nitrogen levels and two levels of insect and weed management practices were tested on five farms. The only significant interaction observed was between fertilizer and timing of application (Table 14). In general, the researchers' timing of fertilizer application significantly increased yields over the farmers' timing.

Laguna sites, wet season. Experiments in Laguna were on four canal-irrigated and two pump-irrigated farms (Table 10). Nitrogen was commonly split into two applications; no farmer used a single basal application. Most farmers practiced rotary weeding followed by hand weeding; four supplemented those methods by at least one herbicide application. All farmers applied foliar insecticides (averaging two applications) and three used granular insecticides. Either IR36 or IR42 was planted.

Yields with farmers' inputs varied from 2.0 to 4.8 t/ha and averaged 3.8 t/ha. With high inputs, yields ranged from 1.7 to 5.9 t/ha, and averaged 4.3 t/ha (Table 11). Table 13 shows a significant yield gap of 0.5 t/ha, but factor contributions were not significant. High weed control contributed 100% to the yield gap (Fig. 5).

Farmers' and researchers' timing of fertilizer application were tested at four nitrogen levels on four farms only at the high level of insect and weed control. Researchers' timing of nitrogen application produced higher average yield than the farmers' timing only at farmers' fertilizer level (Table 14).

Differences in yields between researchers' and farmers' timing of application with other nitrogen levels were neither appreciable nor consistent.

Camarines Sur sites, dry season. Dry-season experiments in Camarines Sur were on 10 pump-irrigated farms (Table 10). Most farmers controlled weeds by one rotary or hand weeding in addition to herbicides. Insect pests were controlled by 1 to 4 foliar sprays, averaging 2.1 applications. No farmer used granular insecticides.

Yields at high input levels were higher than those at farmers' levels on all farms. Yields at farmers' level of inputs ranged from 2.9 to 6.4 t/ha and averaged 4.8 t/ha (Table 11). With high inputs, yields ranged from 3.8 to 7.8 t/ha and averaged 6.2 t/ha. The average yield gap was 1.4 t/ha.

The contribution of separate test factors to the yield gap was determined from three trials. The average yield gap was 1.1 t/ha (Table 13). Fertilizer accounted for 75% of the yield gap, insect control accounted for 25% (Fig. 5).

The wide yield gap was attributed largely to the low levels of fertilizer applied by the farmers (Tables 10 and 12). The average yield from the economically recoverable gap input combination was 6.2 t/ha (Table 11).

Farmers' and researchers' timing of nitrogen fertilizer application were compared at four levels of nitrogen and two levels of insect and weed management practices on two pump-irrigated farms. Yield for farmers' timing of fertilizer was similar to that for researchers' timing (5.1 t/ha) with the farmers' nitrogen level (Table 14).

Camarines Sur sites, wet season. Wet-season yield-constraints experiments in Camarines Sur were on six pump-irrigated farms (Table 10). Some farmers relied solely on herbicides for weed control, although most used rotary or hand weeding in addition. Insect control consisted mainly of applications of foliar sprays at the frequency of three applications.

On all farms, yields at farmers' level of inputs were lower than those at high level. Yields under the farmers' level ranged from 3.7 to 5.3 t/ha and averaged 4.3 t/ha (Table 11). Those at high level of inputs averaged 5.5 t/ha. The wide yield gap was due to the farmers' inadequate levels of fertilizer, especially nitrogen (Table 10).

The contribution of the three test factors to the yield gap was determined for three farms (Fig. 5). The average yield gap was 1.6 t/ha (Table 13).

In tests of researchers' and farmers' management of fertilizer nitrogen on four farms, yields for farmers' management of nitrogen did not vary much from the yields obtained by researchers (Table 14). Farmers' timing of nitrogen application (basal and 45 days after transplanting) almost coincided with researchers' timing.

Iloilo sites, dry season. Dry-season experiments in Iloilo were on nine communal-pump-irrigated farms (Table 10). Most farmers did not apply potassium fertilizer. All used herbicides and five had an additional hand weeding. On the average, the farmers used 2 foliar insecticide applications. All grew IR36 direct-seeded onto a puddled soil.

Farmers' yields varied from 1.8 to 4.7 t/ha and averaged 3.6 t/ha (Table 11). With high inputs, the yields ranged from 3.1 to 6.6 t/ha and averaged 5.0 t/ha. Low yields from all input levels on some farms were caused by drought.

From trials to determine the relative contributions of the three inputs to the yield gap, the average yield increase from the application of high inputs over the farmers' inputs was only 0.5 t/ha (Table 13). For this yield difference, fertilizer contributed 64.3%; insect control, 21.4%; and improved weed control, 14.3% (Fig. 5).

Researchers' and farmers' nitrogen fertilizer application practices were tested on 2 pump-irrigated farms (Table 14).

Iloilo sites, wet season. Wet-season Iloilo trials were on three irrigated and two rainfed farms (Table 10). Farmers used mainly hand weeding to control weeds. One farmer used herbicide in combination with hand weeding, and one did no weeding. The average level of farmers' insect control was slightly higher than that for the dry season.

Yields with farmers' inputs ranged from 3.0 to 6.6 t/ha and averaged 4.7 t/ha (Table 11). With high levels of inputs, yields ranged from 3.2 to 8.3 t/ha and averaged 5.6 t/ha.

The contribution of each test factor to the yield gap was determined from a rainfed and two irrigated farms. The high level of inputs generated an average yield increase of 0.9 t/ha; 73% of that was from improved use of fertilizer and the remainder was from the high level of insect control (Fig. 5).

Results on six farms showed that yield differences between farmers' and researchers' timing of nitrogen application were not consistent across farms. On the average, the researchers' timing outyielded

the farmers' by as much as 0.3 t/ha but only at farmers' nitrogen level (Table 14). At other rates farmers were just as efficient as the researchers in the management of fertilizer.

SUPPLEMENTAL CONSTRAINTS EXPERIMENTS

Agronomy Department

In 1979 experiments were designed to evaluate the response of wetland rice to major farm inputs at the four sites, and to determine the degree of reduction on farmers' yields caused by weeds at two sites.

Yield response to major farm inputs, Nueva Ecija sites. *Dry season.* Dry-season experiments in Nueva Ecija province evaluated complete fertilizer (NPK) application, increasing levels of nitrogen, three insect control strategies, and fungicide treatments. Insect management levels formed the blocks for fertilizer treatments. The response to increasing levels of nitrogen (0, 60, 90, 120, 150 kg/ha), complete fertilizer (N-P-K at 120-30-30 kg/ha), and the removal of one major nutrient element at a time were evaluated at intermediate levels of pest management, and the effects of early and continuous fungicide applications were examined on the high input level treatments. The three levels of pest management were compared under farmers' and high levels of fertilizer. The experiment was on three pump-irrigated farms. The farmers' levels of inputs are in Table 15.

On the 3 farms, yields increased with increasing levels of nitrogen; the maximum yield (5.5 t/ha) was at 120 kg N/ha (Table 16). Yields at 150 kg

Table 15. Levels of inputs used in yield response trials in farmers' fields in 4 project areas in the Philippines, 1979.

Province	Sites (no.)	Input level	Fertilizer[a] (kg/ha)			Insect control[b]	
			N	P_2O_5	K_2O	F	G
		Dry season					
Nueva Ecija	3	Farmers'	146	48	7	3.3	1.3
Nueva Ecija	3	Intermediate		30	30	2.3	1.7
Nueva Ecija	3	High	120	30	30	2.7	3.0
Laguna	2	Farmers'	106	11	10	1.0	0
Laguna	2	Intermediate		30	30	2.0	2.0
Laguna	2	High	120	30	30	3.0	3.0
Camarines Sur	2	Farmers'	116	22	16	1.5	0
Camarines Sur	2	Intermediate		30	30	3.5	0
Camarines Sur	2	High	120	30	30	4.5	3.0
Iloilo	2	Farmers'	92	0	0	1.0	0
Iloilo	2	Intermediate		30	30	1.0	0
Iloilo	2	High	120	30	30	3.0	2.5
		Wet season[c]					
Nueva Ecija	3	Farmers'	61	30	17	1.3	1.0
Nueva Ecija	3	Intermediate		30	30	1.7	0
Nueva Ecija	3	High	75	30	30	3.0	3.0
Laguna	1	Farmers'	26	0	0	4.0	0
Laguna	1	Intermediate		30	30	2.0	2.0
Laguna	1	High	75	30	30	3.0	3.0
Camarines Sur	2	Farmers'	48	27	12	3.0	0
Camarines Sur	2	Intermediate		30	30	2.5	0
Camarines Sur	2	High	75	30	30	5.0	3.0
Iloilo	2	Farmers'	100	29	29	3.0	0
Iloilo	2	Intermediate		30	30	1.5	2.0
Iloilo	2	High	80	30	30	3.0	3.0

[a]Other test levels of nitrogen: 0, 60, 90, and 150 kg/ha for the dry season; 0, 25, 50, and 100 kg/ha for the wet season. Time of N application: 2 split doses, 2/3 basal broadcast and incorporated, and 1/3 at 5 to 7 days before panicle initiation. Phosphorus and potassium were applied basally. [b]Data show average number of foliar (F) sprays or of granular (G) applications to paddy water. The main field crops were treated. In some cases, seedbeds were also treated. [c]Other test levels of N for Iloilo differed from those of other study areas – 0, 40, 60, 100 kg/ha.

Table 16. Average grain yields at varying nitrogen levels from experiments in farmers' fields in 4 project areas in the Philippines, 1979.

Province	Sites (no.)	Grain yield[a] (t/ha)				
		Dry season				
		0 N	*60 kg N/ha*	*90 kg N/ha*	*120 kg N/ha*	*150 kg N/ha*
Nueva Ecija	3	3.6	5.0	5.2	5.5	4.9
Laguna	2	4.1	5.1	5.4	6.2	6.4
Camarines Sur	2	3.8	5.8	6.6	6.6	7.1
Iloilo	2	4.1	5.2	5.5	5.4	5.5
		Wet season[b]				
		0 N	*25 kg N/ha*	*50 kg N/ha*	*75 kg N/ha*	*100 kg N/ha*
Nueva Ecija	3	3.5	4.5	5.2	5.7	5.6
Laguna	1	4.7	4.7	4.4	4.0	3.6
Camarines Sur	2	3.7	4.3	4.6	4.7	4.9
Iloilo[b]	2	4.6	6.0	6.0	6.0	6.0

[a]All treatments received 30 kg/ha each of P_2O_5 and K_2O. [b]Wet-season N levels for Iloilo were 0, 40, 60, 80, and 100 kg/ha.

N/ha were substantially reduced because of severe lodging on one farm and late incidence of stem borer resulting from water shortage on two farms.

The intermediate level of insect control was not appropriate for use in evaluating yield response to increasing levels of nitrogen because it was ineffective in controlling insects, particularly the stem borer.

Among the fertilizer combinations tested, the application of NPK at the rate of 120-30-30 kg/ha gave the highest yield; the removal of nitrogen reduced the yield by 1.9 t/ha (Table 17).

The high level of insect control gave an added yield of 0.5 t/ha over the farmers' and intermediate levels (Table 18). Because there were no major disease problems at the test sites, untreated plots gave yields similar to those of plots with continuous fungicide applications (Table 19).

Wet season. Wet-season experiments in Nueva Ecija were on three farms; two were farms with dry-season experiments. The farmers' rates of fertilizer, particularly nitrogen, were about half of those for the dry season (Table 15). Farmers' insecticide use was also lower than in the dry season, with one farmer practicing no insect control. The high level of insect control added one granular insecticide

Table 17. Yield response of rice to nitrogen, phosphorus, and potassium in farmers' fields in 4 project areas in the Philippines, 1979.

Province	Sites (no.)	Grain yield[a] (t/ha)			
		NPK	PK	NK	NP
		Dry season			
Nueva Ecija	3	5.5	3.6	4.8	4.6
Laguna	2	6.2	4.1	6.2	6.1
Camarines Sur	2	6.6	3.8	6.1	6.1
Iloilo	2	5.4	4.1	4.6	4.6
		Wet season			
Nueva Ecija	3	5.7	3.5	5.5	5.4
Laguna	1	4.0	4.7	4.1	4.2
Camarines Sur	2	4.7	3.7	4.5	4.6
Iloilo	2[b]	6.0	4.6	5.5	6.0

[a]Fertilizer levels: 120 kg N/ha, 30 kg P_2O_5/ha, and 30 kg K_2O/ha for the dry season; 75 kg N/ha, 30 kg P_2O_5/ha, 30 kg K_2O/ha for the wet. [b]Fertilizer levels for the wet season: 80 kg N/ha, 30 kg P_2O_5/ha, and 30 kg K_2O/ha.

Table 18. Average grain yield at 3 levels of insect control from yield-constraints experiments in farmers' fields in 4 project areas in the Philippines, 1979.

Province	Sites (no.)	Grain yield[a] (t/ha)		
		Farmers' level	Inter-mediate	High
		Dry season		
Nueva Ecija	3	5.2	5.2	5.7
Laguna	2	5.2	5.7	6.0
Camarines Sur	2	6.6	6.6	6.4
Iloilo	2	4.0	4.6	4.4
		Wet season		
Nueva Ecija	3	5.2	5.4	5.7
Laguna	1	4.2	4.4	4.9
Camarines Sur	2	4.2	4.4	4.4
Iloilo	2	4.8	5.7	5.6

[a]Data are averages of farmers' and high levels of fertilizer, and weed control and 3 replications.

Table 19. Effect of fungicide applications on grain yields in the high-level treatment in experiments in farmers' fields in 4 project areas in the Philippines, 1979.

Province	Sites (no.)	Grain yield (t/ha)		
		Early application	Continuous application	Untreated control
		Dry season		
Nueva Ecija	3	5.8	6.1	5.9
Laguna	2	6.6	7.0	6.4
Camarines Sur	2	6.5	6.8	6.5
Iloilo	2	4.9	4.9	5.0
		Wet season		
Nueva Ecija	3	6.1	6.1	6.1
Laguna	1	5.1	4.6	5.2
Camarines Sur	2	4.9	4.7	4.6
Iloilo	2	6.4	6.3	6.0

application at late booting stage.

Yields increased with increasing levels of nitrogen up to 75 kg N/ha (Table 16). The application of complete fertilizer (75-30-30 kg NPK/ha) produced 5.7 t/ha while the removal of nitrogen in the package decreased the yield to 3.5 t/ha (Table 17).

The high level of insect control outyielded the farmers' level by 0.5 t/ha, and the intermediate level by 0.3 t/ha (Table 18). Early or continuous applications of fungicide on the high input level treatments gave no yield response (Table 19).

Yield response to major farm inputs, Laguna sites. *Dry season.* Dry-season experiments on two irrigated Laguna farms evaluated the response of transplanted rice to different levels of major farm inputs. The experimental procedures were the same as those for the Nueva Ecija sites. Levels of fertilizer, insect control, and weed control are shown in Table 15.

Grain yields from two trials increased with increasing levels of nitrogen (Table 16). However, the yield differences between the 60 and 90 kg N/ha and between 120 and 150 kg N/ha were not appreciable. Plots fertilized with complete fertilizer at the rate of 120-30-30 kg NPK/ha gave yields similar to those of plots that did not receive phosphorus or potassium fertilizer (Table 17). Without nitrogen, however, the yield decreased by 2.1 t/ha, implying that only nitrogen fertilizer should be applied on those sites.

The high level of insect control outyielded the farmers' and intermediate levels by 0.8 and 0.3 t/ha (Table 18). Continuous application of fungicides increased the yield by 0.6 t/ha over the untreated control. With early fungicide application, however, the yield increased only by 0.2 t/ha (Table 19).

Wet season. The experiment was repeated in the wet season on an irrigated farm. The farmer used generally lower levels of inputs, except insect control, than in the dry season (Table 15).

Yields decreased with increasing levels of nitrogen (Table 16). The response to complete fertilizer, nitrogen-potassium, and nitrogen-phosphorus were similar but yields were low (Table 17). The average yield of plots without nitrogen was higher, contradicting the dry-season findings.

As in the dry season, the high level of insect control gave higher yield than either the farmers' or intermediate levels (Table 18). But in contrast to the dry season, the continuous application of fungicides had no favorable effect on the yield. With early fungicide application, the average yield was comparable with that of the untreated control (Table 19).

Yield response to major farm inputs, Camarines Sur sites. *Dry season.* Experiments on two irrigated farms in Camarines Sur determined the yield response of rice to increasing levels of nitrogen, omission of either phosphorus or potassium, and three levels each of pest management and disease control. Methodology of the experiment was the same as for the Nueva Ecija sites.

The average levels of fertilizers used by the farmers are in Table 15. Weeds were controlled by rotary weeding in addition to herbicide application. Farmers controlled insect pests only by foliar sprays.

The average yield obtained with no fertilizer nitrogen was 3.8 t/ha. The yield increased proportionally to 7.1 t/ha with increasing nitrogen levels (Table 16).

Results further showed that nitrogen was the most limiting among the three major elements tested. Without nitrogen, the yield was reduced by as much as 2.8 t/ha; the absence of either phosphorus or potassium reduced the yield by 0.5 t/ha (Table 17).

Farmers' pest management appeared to be adequate; it slightly outyielded the high pest management by 0.2 t/ha (Table 18). Continuous fungicide application slightly increased yield over early application and untreated control by 0.3 t/ha (Table 19).

Wet season. Yield-response experiments for major farm inputs were repeated on two farms in Camarines Sur during the wet season (Table 15). Weeds were controlled either by rotary or hand weeding in addition to application of herbicides. Crops were protected from insect damage by foliar sprays.

On both farms, yield increased with increasing levels of nitrogen (Table 16). As in the dry season, nitrogen was the most limiting among the three major elements tested. Without nitrogen, the yield was reduced by 1.0 t/ha (Table 17).

Intermediate and high levels of pest management gave similar yields, slightly higher than that obtained at farmers' level (Table 18). Grain yield was slightly increased by early fungicide application but not by continuous application (Table 19).

Yield response to major farm inputs, Iloilo sites. *Dry season.* Dry-season experiments in Iloilo were on two pump-irrigated farms. The test factors and methodology were the same as those for Nueva Ecija. Both farmers did direct wet-seeding of rice. The levels of inputs used are shown in Table 15.

Increasing levels of nitrogen gave the maximum possible yield at 90 kg N/ha (Table 16).

Among the fertilizer combinations tested, the application of NPK produced the highest average yield and the removal of nitrogen reduced the yield to 4.1 t/ha (Table 17).

In pest management tests, the intermediate level produced the highest average yield (Table 18). Lack of adequate irrigation water to dissolve the granular insecticides contributed to the low yield response to high level of pest management. Because of the absence of disease at the test sites, the untreated control gave yields similar to those of treatments with fungicides (Table 19).

Wet season. Wet-season Iloilo experiments were on two canal-irrigated farms (Table 15).

Yields from increasing levels of nitrogen from the two farms differed greatly. At a fixed rate of 30 kg/ha each of P_2O_5 and K_2O, the treatment with no fertilizer nitrogen produced 3.3 t/ha on 1 farm, and 6.0 t/ha on the other. Yield differences between the two farms were even higher with increasing levels of nitrogen. Average yield with no fertilizer nitrogen was 4.6 t/ha (Table 16). Among the three fertilizer nutrients investigated, nitrogen was the most essential in increasing rice yield. Without nitrogen, the yield decreased by as much as 1.4 t/ha (Table 17). The high level of insect control gave an additional yield of 0.8 t/ha over that at the farmers' level (Table 18). On the high input levels, one application of fungicide at early growth stage (3 days after transplanting) gave an additional yield of 0.4 t/ha over the untreated control (Table 19).

Degree of yield losses caused by weeds, Nueva Ecija sites. *Dry season.* During the dry season, a simple experiment on five pump-irrigated farms in Nueva Ecija determined the degree of yield losses caused by weeds. The experiment maintained a 50-m^2 weed-free area within each farmer's paddy. The area was unleveed and kept weed free by hand weeding. The farmer followed his usual farming practices throughout the field including the test plot.

Two of the five farmers used herbicide only and one farmer used herbicide and hand weeding. Two farmers did no weed control. The number of hand weedings for the test plot averaged 2.4, which was equivalent to 204 labor-hours/ha.

Results indicated that on 3 of 5 farms, weeds reduced the farmers' yields substantially (Fig. 6). Yields were similar for both weed control practices on two farms. On the average, weeds accounted for a yield reduction of 0.7 t/ha (Table 20).

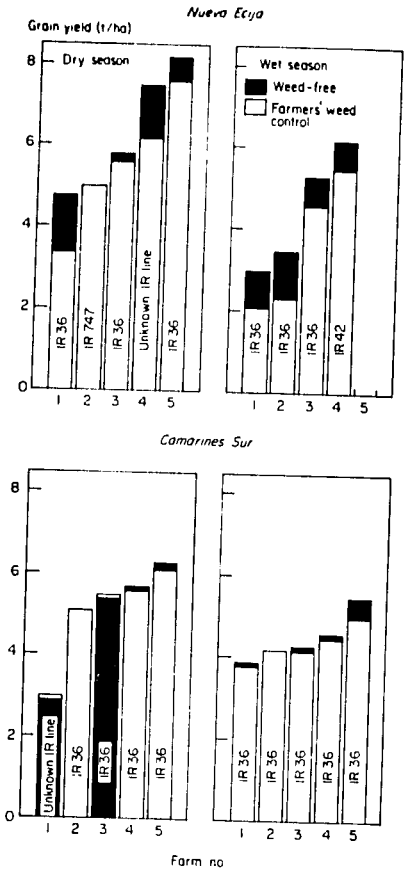
Wet season. During the wet season, the degree of yield losses caused by weeds was evaluated on 4 pump-irrigated farms. Among the four farmers, only one controlled weeds with herbicide. Three farmers did not control weeds. For the weed-free plot, hand weeding was done twice on each of the three farms; on one farm, a third hand weeding was necessary. An average 368 labor-hours/ha was needed to keep the test plots weed free.

There was a substantial reduction of farmers' yields caused by weeds (Fig. 6). The yield losses averaged 0.9 t/ha (Table 20).

Degree of yield losses caused by weeds, Camarines Sur sites. *Dry season.* Yield losses due to weeds were evaluated in Camarines Sur on five farms during the dry season with the same experimental procedures used in Nueva Ecija. The number of hand weedings to maintain a weed-free plot was equivalent to 240 labor-hours/ha.

In two of five farms, farmers' weed control outyielded the experimental weed control. Yields from the farmers' level of weed control ranged from 3.0 t/ha to 6.1 t/ha (Fig. 6).

At a high level of weed control, yields ranged



6. Reduction of farmers' yields caused by weeds in farmers' fields. Nueva Ecija and Camarines Sur provinces, Philippines, 1979 dry and wet seasons.

from 2.9 to 6.3 t/ha and averaged 5.1 t/ha (Table 20). The farmers' weed control was comparable with the level used by the researchers. This was supported by results in other constraints experiments where a high level of weed control did not contribute to the yield gap during the 1979 dry season.

Wet season. In the wet season, hand weeding done in addition to farmers' weed control practices was equivalent to 280 labor-hours/ha.

In four of five farms, yields at the high weed control level was higher than for farmers' weed control practices (Fig. 6). Yields for farmers' weed control ranged from 3.8 to 5.0 t/ha and averaged 4.3 t/ha. With a high level of weed control, the yield ranged from 3.9 to 5.5 t/ha and averaged 4.5 t/ha (Table 20).

Table 20. Yields from farmers' level and high level of weed control in farmers' fields in project areas in 2 provinces, Philippines, 1979.

Province	Sites (no.)	Yield[a] (t/ha)		
		Farmers' level	High level	Difference
		Dry season		
Nueva Ecija	5	5.6	6.3	0.7
Camarines Sur	5	5.1	5.1	0
		Wet season		
Nueva Ecija	4	3.6	4.5	0.9
Camarines Sur	5	4.3	4.5	0.2

[a]Fertilizer, insect control, and other cultural practices were at farmers' level. The high level of weed control consisted of a series of hand weedings.

Age of seedlings, cultural practices, and planting date as constraints on yield. *Farmers' fields.* During the 1979 dry season, experiments on four pump-irrigated farms in Nueva Ecija evaluated the influence of age of seedlings on grain yield of transplanted rice. Seedlings 20 to 60 days old, at 10-day intervals, were tested at farmers' and researchers' levels of cultural practices and 2 transplanting times (simultaneous and staggered with a 10-day interval after transplanting the youngest seedlings). Transplanting seedlings representing all ages coincided with the transplanting of 60-day-old seedlings under the staggered system.

Researchers' cultural practices included transplanting at 20- × 20-cm spacing, 3 to 4 seedlings/hill, shallow depth of transplanting, and good water management. The researchers' fertilizer levels were 100 kg N/ha, 30 kg P_2O_5/ha and 20 kg K_2O/ha. For 20- and 30-day-old seedlings, nitrogen was applied in 3 equal doses — basal broadcast and incorporated, 20 days after transplanting (DT), and 5-7 days before panicle initiation (DBPI). For 40-to 60-day-old seedlings, the nitrogen fertilizer was applied in 2 equal doses — basal broadcast and incorporated, and 5-7 DBPI. Phosphorus and potassium were applied basally and uniformly on all plots. Insect control consisted of three applications with granular insecticides and one or two foliar sprays. Weeds were controlled by granular 2,4-D at 4 DT and one hand weeding at 20 DT.

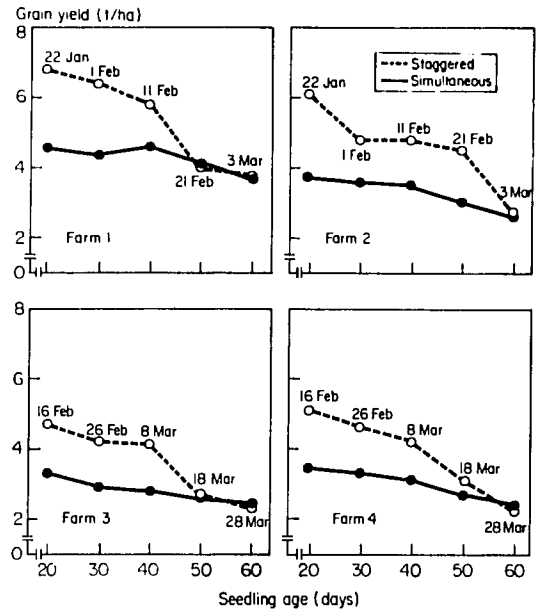
For the farmers' cultural practices, the traditional transplanting method was followed. The farmers' levels of fertilizer averaged 94 kg N/ha, 41 kg P_2O_5/ha, and 17 kg K_2O/ha, topdressed in 2

unequal doses varying from farm to farm, with the first application at 8 DT and the last at 50 DT. Farmers' insect control was at least two foliar insecticide applications; two farms used an additional granular application. Weeds were controlled by one hand weeding on two farms and by a combination of hand weeding and herbicide on the two other farms.

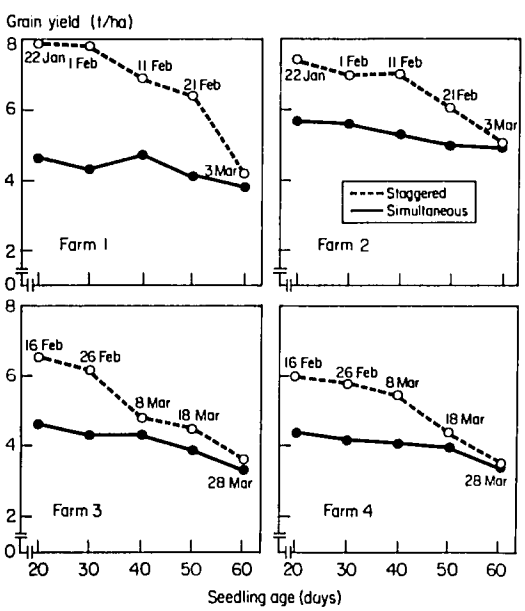
In the wet season, the yield responses of five seedling ages were evaluated on five farms only at researchers' cultural practices under two times of transplanting as in the dry season. The rate of nitrogen was reduced to 70 kg N/ha and applied in 2 equal doses – basal for all seedling ages, and at 20 DT for 50- to 60-day-old seedlings and 5-7 DBPI for 20- to 40-day-old seedlings. Other inputs, researchers' cultural practices, and experimental procedures used during the dry season were followed in the wet season.

Dry-season results showed that all interactions involving farms, except for the farm and seedling age interaction, were significant, indicating that the effects of the various test factors differed from farm to farm. For example, there was no significant yield difference between staggered and simultaneous transplantings of 60-day-old seedlings for all farms under both researchers' and farmers' cultural practices because the two times of transplanting coincided. But for 50-day-old seedlings, a significant difference was observed on all farms for the researchers' practices but not for the farmers' cultural practices. In the latter, a significant difference was observed on only one farm. In general, the yields for staggered transplanting were higher than those for simultaneous transplanting regardless of cultural practices (Fig. 7, 8). Low fertilizer efficiency brought about by water shortage reduced the yields substantially under simultaneous transplanting.

With researchers' cultural practices, yields of 20- and 30-day-old seedlings under staggered transplanting were not significantly different across all farms (Table 21). Compared with the 40- to 60-day-old seedlings, the 20-day-old gave significantly higher yields on all farms except one, where the yield difference between the 20- and 40-day-old seedlings was not significant. On the other hand, when seedlings were transplanted simultaneously, the 20-day-old seedlings significantly outyielded



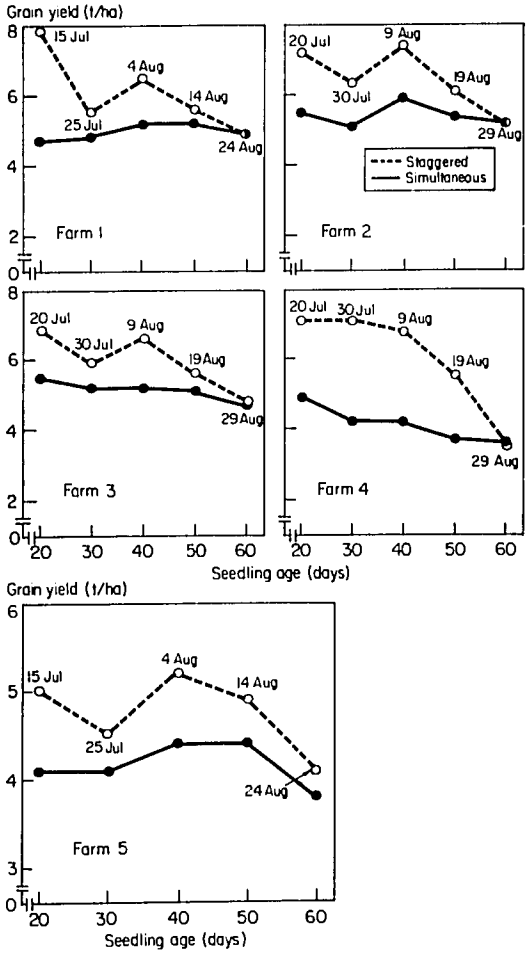
8. Grain yield of IR36 from staggered and simultaneous transplanting as influenced by age of seedlings grown under farmers' level of cultural practices. Nueva Ecija, Philippines, 1979 dry season. Dates of transplanting are indicated on the curves.



7. Grain yield of IR36 from staggered and simultaneous transplanting as influenced by age of seedlings grown under researchers' level of cultural practices. Nueva Ecija, Philippines, 1979 dry season. Dates of transplanting are indicated on the curves.

only the 50-and 60-day-old on all farms except 1, where the 50-day-old gave a yield similar to that of the youngest seedlings. Although the yields from seedlings of different ages were generally lower under farmers' cultural practices than under the researchers', the trend was similar for both the staggered and simultaneous transplanting (Fig. 7, 8).

During the wet season, the interaction between time of transplanting and seedling age was significant on all farms except one. As in the dry season, staggered transplanting gave generally higher yields than simultaneous transplanting except with 60-day-old seedlings (Fig. 9). Under staggered trans-



9. Grain yield of IR36 from staggered and simultaneous transplanting as influenced by age of seedlings grown under researchers' level of cultural practices. Nueva Ecija, Philippines, 1979 wet season. Dates of transplanting are indicated on the curves.

Table 21. Grain yields of IR36 as influenced by age of seedlings grown under farmers' (FCP) and researchers' (RCP) cultural practices, and different times of transplanting. Nueva Ecija, Philippines, 1979 dry season.

Seedling age (days)	Grain yield[a] (t/ha)									
	Farm 1		Farm 2		Farm 3		Farm 4		Av	
	RCP	FCP	RCP	FCP	RCP	FCP	RCP	FCP	RCP	FCP
				Staggered transplanting						
20	7.9 a	6.8 a	7.4 a	6.1 a	6.5 a	4.7 a	6.0 a	5.1 a	7.0	5.7
30	7.8 a	6.4 a	7.0 a	4.8 b	6.1 a	4.2 b	5.8 ab	4.6 b	6.7	5.0
40	6.9 b	5.8 b	7.0 a	4.8 b	4.8 b	4.1 b	5.5 b	4.2 b	6.0	4.7
50	6.4 c	4.0 c	6.1 b	4.5 b	4.5 b	2.7 c	4.4 c	3.1 c	5.4	3.6
60	4.2 d	3.8 c	5.0 c	2.7 c	3.6 c	2.3 c	3.5 d	2.2 d	4.1	2.8
				Simultaneous transplanting						
20	4.6 a	4.6 a	5.7 a	3.8 a	4.6 a	3.3 a	4.4 a	3.5 a	4.8	3.8
30	4.3 ab	4.4 ab	5.6 a	3.6 a	4.3 ab	2.9 ab	4.2 a	3.3 a	4.6	3.6
40	4.7 a	4.6 a	5.3 ab	3.5 a	4.3 ab	2.8 bc	4.1 a	3.1 ab	4.6	3.5
50	4.1 bc	4.1 bc	5.0 b	3.0 bc	3.9 b	2.6 bc	4.0 a	2.7 bc	4.2	3.1
60	3.8 c	3.7 c	4.9 b	2.6 c	3.3 c	2.4 c	3.4 b	2.4 c	3.8	2.8

[a]Farms 1 and 2 were first transplanted at the same time; farms 3 and 4 were also first transplanted at the same time but later by 25 days than the other 2. In a column, seedling age means under each farm, cultural practice, and time of transplanting followed by a common letter are not significantly different from each other at the 5% level.

Table 22. Grain yields of IR36 as influenced by age of seedlings grown under researchers' cultural practices and different times of transplanting. Nueva Ecija, Philippines, 1979 wet season.

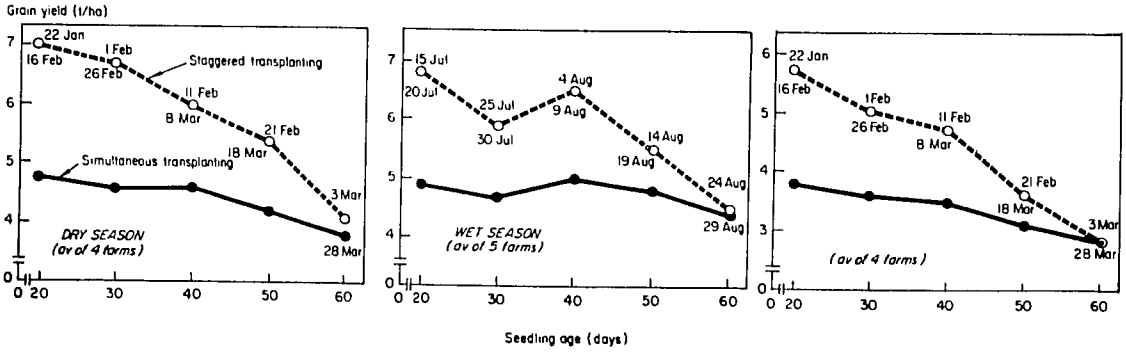
Seedling age (days)	Grain yield[a] (t/ha)					
	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Av
			Staggered transplanting			
20	7.8 a	7.2 a	6.8 a	7.1 a	5.0 a	6.8
30	5.5 c	6.3 b	5.9 b	7.1 a	4.5 b	5.9
40	6.5 b	7.4 a	6.6 a	6.8 a	5.2 a	6.5
50	5.5 c	6.1 b	5.6 b	5.5 b	4.9 a	5.5
60	4.9 d	5.2 c	4.8 c	3.5 c	4.1 c	4.5
			Simultaneous transplanting			
20	4.7 c	5.5 ab	5.5 a	4.9 a	4.1 ab	4.9
30	4.8 bc	5.1 b	5.2 ab	4.2 bc	4.1 ab	4.7
40	5.2 ab	5.9 a	5.2 ab	4.2 bc	4.4 a	5.0
50	5.2 a	5.4 ab	5.1 bc	3.7 c	4.4 a	4.8
60	4.9 abc	5.2 b	4.7 c	3.6 c	3.8 b	4.4

[a]Farms 1 and 5 were first transplanted at the same time; farms 2, 3, and 4 were also first transplanted at the same time but 5 days later than the 2 other farms. In a column, seedling age means under each farm and time of transplanting followed by a common letter are not significantly different from each other at the 5% level.

planting, the 20-day-old seedlings significantly outyielded the 30-day-old seedlings on 4 out of 5 farms, and the 40-day-old on 1 farm (Table 22). Yields from old seedlings (50 and 60 days) were generally lower than those from 20-day-old seedlings. Under simultaneous transplanting, the effect of seedling age on yield varied from farm to farm. On 4 farms, 20- and 30-day-old seedlings gave similar yields. Likewise, no yield differences were observed between 20- and 40-day-old seedlings on most of the test farms. The 20-day-old seedlings gave significantly higher yield than the 50- and 60-day-old seedlings on only 2 farms. A light drought caused yield reduction on two farms (farms 1 and 5), particularly from the younger seedlings.

From the 1979 trials, it appears that grain yields of early-maturing IR36 are affected not solely by age of seedlings, but more importantly by time of transplanting. As shown in Figure 10, delaying the transplanting of 20-day-old seedlings by 40 days reduced yield an average of 2.2 t/ha in the dry season and 1.9 t/ha in the wet season, even with inputs and cultural practices at researchers' level. However, the yields were similar for two batches of 60-day-old seedlings transplanted at the same time (Fig. 10).

The results suggest that environment in the main



10. Grain yield of IR36 from staggered and simultaneous transplanting as influenced by age of seedlings grown under farmers' level of cultural practices. Nueva Ecija, Philippines, 1979 dry and wet seasons. Dates of transplanting are indicated on the curves.

Table 23. Effect of seedling age on the grain yield of IR36 and IR42. IRRI, 1979 wet season.

Seedling age (days)	Grain yield[a] (t/ha)		A mean
	IR36	IR42	
20	4.5	3.6	4.1
40	3.8	3.9	3.8
Difference	0.7*	−0.3^{ns}	0.3^{ns}

[a]Av of 5 fertilizer treatments and 3 replications.

field has greater influence on the grain yield of rice than the environment in the seedbed.

IRRI. At IRRI another experiment was conducted with 20- and 40-day-old seedlings of early-maturing IR36 and intermediate-maturing IR42. Seedlings were transplanted during the 1979 wet season at 3 to 4 seedlings hill and 20- × 20-cm spacing.

With IR36, the grain yield for the 20-day-old seedlings was significantly higher than that for the 40-day-old. With IR42, the difference in grain yields between the two seedling ages was not significant (Table 23). The data suggest that under optimum conditions of water, fertilizer, and weed- and insect-free environments, varieties with longer growth duration suffer less than varieties that mature early.

ECONOMIC ANALYSIS OF CONSTRAINTS EXPERIMENTS

Agricultural Economics Department

Profitability of high inputs. Economic analysis of the high-input treatments in the 1979 constraints experiments confirmed the results reported in previous annual reports. The economic performance of intermediate and high-input treatments is summarized in Table 24.

The relative benefits attributed to increasing each of the three factors separately were also evaluated. The results again confirmed earlier results; the high fertilizer levels were highly profitable in the dry season in each province, raising average profits by more than $100/ha in 3 provinces (Table 25).

The effects of the intermediate level of fertilizer were variable: moderately raising profits in Laguna in the dry season, marginally raising profits in Camarines Sur, and lowering profits in Iloilo. The intermediate level of insect control gave results similar to those of the high level (Table 26).

Profitability and nitrogen-use efficiency. The profitability of applying nitrogen fertilizer at the recommended timing compared to farmers' current practices is shown in Table 27. The profitability of the two application methods was compared using the farmers' and the high levels of applied nitrogen. Except in Camarines Sur and Iloilo in the dry season, and Camarines Sur in the wet season, the recommended practice increased profits, again confirming the existence of technical inefficiency in fertilizer use (1978 annual report). The gap due to this technical inefficiency in fertilizer application methods was, however, more evident at the higher level of fertilizer usage where average profits increased in all provinces in the dry season.

Table 24. Economic performance of intermediate and high-level combinations of 3 inputs and farmers' levels of those inputs in constraints experiments in farmers' fields. Philippines, 1979.

Province	Sites[a] (no.)	Increase or decrease ($/ha) from						Sites (%) where profits increased	
		Intermediate inputs			High inputs				
		Output value	Input cost	Profit	Output value	Input cost	Profit	Intermediate	High
				Dry season					
Nueva Ecija	15 (2)	103	−20	123	112	95	17	100	60
Laguna	11 (3)	169	60	109	269	147	122	100	73
Camarines Sur	10 (3)	44	22	22	189	151	38	67	60
Iloilo	9 (5)	−19	27	−46	191	139	52	60	67
				Wet season					
Nueva Ecija	8	114	25	89	207	134	73	88	75
Laguna	6	−14	−6	−8	64	101	−37	50	34
Camarines Sur	6	123	20	103	175	127	48	100	67
Iloilo	5	37	18	19	124	125	−1	80	40

[a]Figures in parentheses are the number of sites in the dry season where intermediate input level treatments were included in the experiments.

Table 25. Economic performance of anticipated high levels of 3 separate inputs and farmers' current practices in yield constraints experiments in farmers' fields. Philippines, 1979.

Province	Sites (no.)	Increase or decrease ($/ha) from farmers' level								
		Fertilizer			Insect control			Weed control		
		Output value	Input cost	Profit	Output value	Input cost	Profit	Output value	Input cost	Profit
					Dry season					
Nueva Ecija	2	136	31	105	95	63	32	8	20	−12
Laguna	3	222	103	119	145	80	65	23	−4	27
Camarines Sur	3	116	57	59	56	75	−19	18	6	12
Iloilo	5	238	66	172	20	52	32	7	15	−8
					Wet season					
Nueva Ecija	3	180	43	137	80	83	−3	37	26	11
Laguna	3	19	38	−19	3	68	−65	59	−4	63
Camarines Sur	3	139	40	99	73	72	1	28	77	11
Iloilo	3	116	52	64	43	61	−18	5	8	3

Table 26. Economic performance of intermediate levels of fertilizer and insect control and of farmers' current practices in yield constraints experiments in farmers' fields. Philippines, 1979.

Province	Sites (no.)	Increase or decrease ($/ha) from farmer's level					
		Fertilizer			Insect control		
		Output value	Input cost	Profit	Output value	Input cost	Profit
			Dry season				
Nueva Ecija	2	83	5	78	49	5	44
Laguna	3	143	66	77	107	34	73
Camarines Sur	3	23	20	3	6	32	−26
Iloilo	5	24	29	−5	−2	18	−20
			Wet season				
Nueva Ecija	3	131	18	113	8	34	−26
Laguna	3	−22	12	−34	−19	22	−41
Camarines Sur	3	149	14	135	45	26	19
Iloilo	3	56	26	30	−6	15	−21

Table 27. Recommended timing of nitrogen application compared with farmer's current practices under 2 fertilizer levels. Philippines, 1979.

Province	Sites (no.)	Increase or decrease ($/ha) from farmers' current fertilizer use						Sites (%) where profits increased	
		Farmers' level			High				
		Output value[a]	Cost[b]	Profit	Output value	Cost	Profit	Farmers' level	High
				Dry season					
Laguna	5	82	14	68	55	9	46	80	80
Nueva Ecija	5	52	9	43	86	15	71	80	60
Camarines Sur	2	−6	−1	−5	37	7	30	50	50
Iloilo	2	−18	−3	−15	20	4	16	0	100
				Wet season					
Laguna	4	68	12	56	14	3	11	75	75
Nueva Ecija	5	53	10	43	8	2	6	100	60
Camarines Sur	4	−6	−2	−4	−7	1	−8	50	25
Iloilo	6	44	8	36	22	4	18	67	33

[a]Price of rough rice at $0.14/kg. [b]Includes labor cost plus one-sixth value of added yield.

Table 28. Maximum weed control compared with farmers' current practices. Philippines, 1979.

Province	Sites (no.)	Increase or decrease ($/ha) from farmers' current practices			Sites (%) where profits increased
		Output value[a]	Cost[b]	Profit	
		Dry season			
Nueva Ecija	5	95	51	44	60
Camarines Sur	5	4	42	−38	0
		Wet season			
Nueva Ecija	4	120	82	38	100
Camarines Sur	5	16	50	−34	0

[a]Price of rough rice at $0.14/kg. [b]Includes labor cost at $0.17/labor-hour plus one-sixth value of added yield.

In the wet season, the recommended timing of fertilizer at the high level was not clearly superior to the farmers' practice.

Profitability of maximum weed control. The profitability of maintaining a weed-free rice crop was evaluated in two provinces (Table 28).

Consequences of new technology

Agricultural Economics Department

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RICE HARVESTING AND THRESHING SYSTEMS AND INCOME DISTRIBUTION IN LUZON

A 1978-79 study investigated the process of changes in technology and contracts in the use of labor and capital for rice harvesting and threshing, and analyzed the effects of such changes on income distribution in rural communities.

The study covered seven provinces in Luzon — Bulacan, Nueva Ecija, Pangasinan, Pampanga, and Tarlac in Central Luzon; and Laguna and Rizal in the Southern Tagalog region. Those provinces form the largest, contiguous rice-producing area in the Philippines. Data were collected during surveys in February and July 1978. The sample contained many farms in the Central Luzon and Laguna loop surveys, conducted in 1966, 1970, and 1974 to collect data on rice production costs and returns.

Two harvesting and threshing systems. In the study area, two distinct systems of rice harvesting and threshing developed:

- *hunusan*, a traditional form of contract by which the crop is cut manually with sickles and the threshing is done by hand beating on wooden or bamboo plates. Harvesting and threshing labor receives a share of output. The share ranges from one-fourth to one-ninth, but one-sixth was the most common.
- *tilyadora*, which is characterized by the use of big threshing machines. Crop cutting and threshing became two separate operations. The crop is normally cut with sickles, bundled, and made into a big pile or *mandala* and threshed by *tilyadora*. Since the amount of output could not be ascertained at the stage of crop cutting, the harvesters were employed at a fixed daily wage rate (*upahan*) or at a fixed payment per certain area harvested (*pakyaw*). The threshing fee ranged from 4 to 6% of total palay threshed.

Details on the two systems were published in July 1979 as IRRI Research Paper Series 31, *Changes in rice harvesting systems in Central Luzon and Laguna*.

From *tilyadora* to *hunusan*. Concurrent growth of the share-tenancy system and the use of *tilyadora* suggested the hypotheses that the major factor underlying the diffusion of the *tilyadora* system in inner Central Luzon was the hacenderos' desire to reduce the transaction cost in the collection of share rent and that the *tilyadora* facilitated the conversion of the land tenure system from leasehold to share-tenancy.

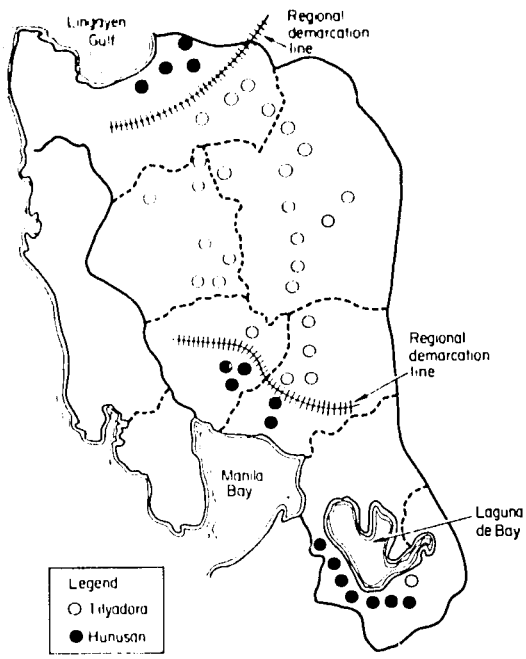
The best set of data for testing the hypothesis was from recent changes in the harvesting systems in inner Central Luzon. If the introduction of the *tilyadora* was based mainly on the hacenderos' desire to reduce the transaction cost involved in the collection of share rent, the system should have been abandoned because land reform programs converted the share-tenants into leaseholders or amortizing owners.

This was supported by data. The land reform operations based on the Agricultural Land Reform Code of 1963 (revised in 1971) and enforced by Presidential Decree No. 27 after the declaration of Martial Law resulted in the demise of rice haciendas mostly in the 1968-75 period. Correspondingly, major changes in harvesting systems occurred. Survey data show that the regional distribution of harvesting systems in 1968 (Fig. 1) was essentially the same as the traditional. By 1978, however, an entirely different pattern had emerged (Fig. 2).

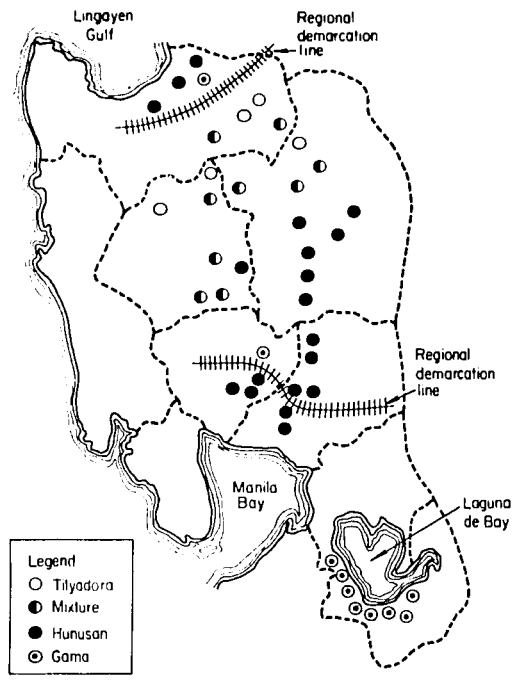
The most dramatic change was, as expected, a shift from the *tilyadora* to the *hunusan* system. In 1968, 96% of the sample farmers in inner Central Luzon used the *tilyadora* system; in 1978, however, the percentage declined sharply to 33 (Table 1). Most farmers shifted completely to the *hunusan* system with hand threshing for both wet and dry seasons, or adopted the new system in the wet season but used the traditional system in the dry season (mixture).

The shift in inner Central Luzon was not uniform. It was most complete in the eastern part of the region, especially in northern Bulacan and south to central Nueva Ecija, where most farmers adopted the *hunusan* system for both wet and dry seasons (Fig. 2).

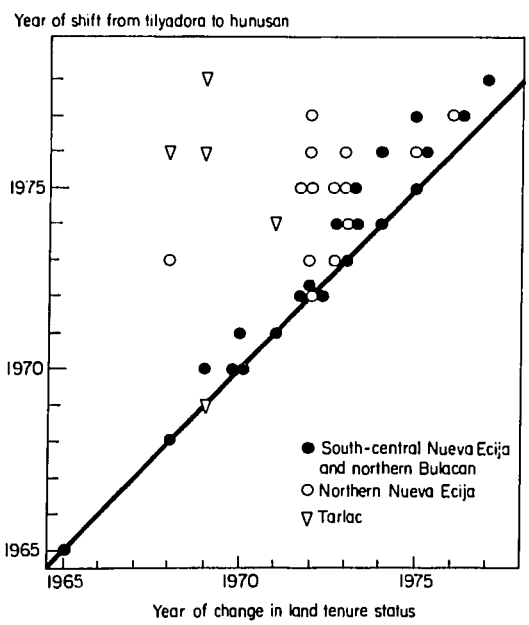
In the western part of inner Central Luzon, the diffusion of the new system was slower and adoption was for the wet season only. In Figure 3, the year of shift of sample farmers from the *tilyadora* system to the *hunusan* system is compared with the year of shift from their tenure status of sharecroppers to leaseholders or amortizing owners. Almost all observations in the sample from northern Bulacan and south to central Nueva Ecija are on the 45-degree line, implying that most farmers shifted



1. Regional distribution of different harvesting systems commonly used by municipalities in Luzon, Philippines, in 1968.



2. Regional distribution of different harvesting systems commonly used by municipalities in Luzon, Philippines, in 1978.



3. Relation between the year of shift in the harvesting system and the year of change in land tenure status. IRRI, 1979.

from the *tilyadora* to the *hunusan* system in the years when their tenure changed.

Sample observations from northern Nueva Ecija and Tarlac are located above the 45-degree line, indicating time lags in the shifts from the *tilyadora* to the *hunusan* system.

A regression equation was estimated with the year of adoption of *hunusan* H as a dependent variable and the year of tenure change T and regional dummies (D_n for northern Nueva Ecija and D_t for Tarlac) as independent variables. The least-square estimation with the sample of 40 farmers for which data are available resulted in

$$H = 4.78 + 0.942T + 1.614D_n + 4.606D_t, \quad R^2 = 0.68$$
$$(8.43) \quad (0.117) \quad (0.587) \quad (0.916)$$

where the figures inside parentheses are the standard errors of the estimated parameters, and R^2 is the coefficient of determination.

The results of the regression analysis show that the intercept is not significantly different from zero, and T's coefficient is not significantly differ-

ent from one at conventional levels. They support the hypothesis that the relation between H and T is the 45-degree line, i.e. the estimated relation between H and T implies that the shift from *tilyadora* to *hunusan* occurred as soon as the tenure status changed, except for regional time lags. The coefficients of D_n and D_t indicate that the shift in the harvesting system lagged behind the tenure change an average 1.6 years for farmers in northern Nueva Ecija and 4.6 years in Tarlac.

Because of the geographical affinity to its origin, the *hunusan* system first spread out in the eastern part of inner Central Luzon and then moved to the north and to the west (Fig. 4). The speed with which farmers in Bulacan and Nueva Ecija shifted from the *tilyadora* to the *hunusan* system after the land tenure change may partly be explained by the repulsion for *tilyadora* as a symbol of the exploiting system of the hacienda.

It was hypothesized that the accumulated frustration of farmers resulted in an overnight switch to hand threshing when they were emancipated by land tenure reform.

To test this hypothesis, a regression equation was estimated. The dependent variable was the time interval between the years of shift from *tilyadora* to hand threshing (H) and of change in the tenure status (T); the independent variable was the time interval between T and the year of introduction of the rice double-cropping system (M). It was expected that the longer the interval between T and M, the more clearly farmers would recognize the inefficiency of the *tilyadora* system and, thus, the shorter the interval betwen H and T.

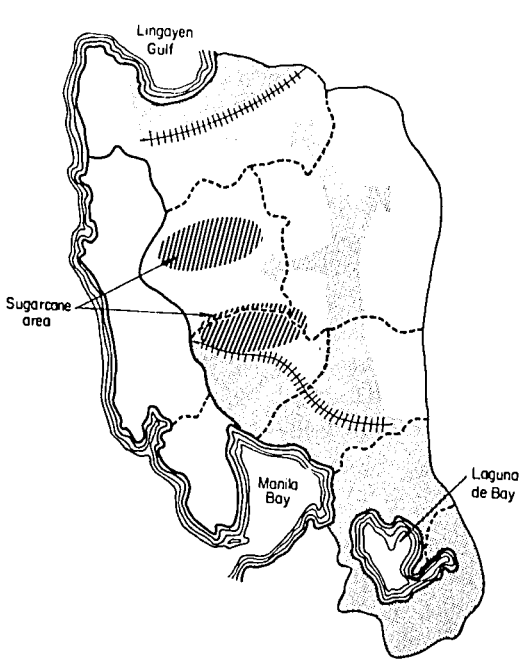
The least-square estimation based on the sample of 26 farmers for which data were available resulted in

$$(H - T) = \underset{(0.248)}{0.504} - \underset{(0.113)}{0.846}\,(T - M),\ R^2 = 0.57$$

where the figures in parentheses are the standard errors of the coefficients and R^2 is the coefficient of determination.

The results were consistent with the hypothesis, showing the significant effect of the time interval between tenure change and introduction of double-cropping to reduce the time lag between tenure change and the shift in the harvesting arrangement.

From *hunusan* to *gama*. Although the *hunusan* system was adopted in inner Central Luzon, it was replaced rapidly by the *gama* system in the coastal region (Table 1). *Gama* is an output-sharing arrangement similar to *hunusan*, except that the employment for harvesting and threshing is limited to workers who weeded the field without receiving wages. In 1968, 83% of sample farms in the coastal region used the *hunusan* system; by 1978 the percentage had declined to less than 50 with the spread of the *gama* system.



4. The pattern of diffusion of the *hunusan* system.

NEW RICE TECHNOLOGY, HARVESTING SYSTEMS, AND INCOME DISTRIBUTION IN JAVA

In Java the traditional *bawon* rice harvesting system, which allowed the sharing of output to all community members has been replaced by the *tebasan* system, which limits the participation to harvesting and reduces the share of harvesters. The change is attributed mainly to population pressure and new technology. A 1978-79 study examined the reason for change. Surveys in August and December 1978 covered 48 villages in 28 regencies, mostly in West and Central Java.

Shift from *bawon* to *tebasan*. In the traditional *bawon* system in Java, all community members

Table 1. Changes in rice harvesting arrangements in Central Luzon and Laguna, Philippines, 1968 to 1978. IRRI, 1979.

	Farmers using given arrangement					
	Coastal region		Inner Central Luzon		Total	
	No.	%	No.	%	No.	%
		1968				
Tilyadora system	0	0	68	96	68	72
Output sharing system:						
Hunusan	20	83	3	4	23	24
Gama	4	17	0	0	4	4
Mixture	0	0	0	0	0	0
		1978				
Tilyadora system	0	0	25	33	25	25
Output sharing system:						
Hunusan	11	44	36	48	47	47
Gama	14	56	8	11	22	22
Mixture	0	0	6	8	6	6

can participate in the rice harvest and receive a certain share of output. Harvested stalks are bundled and brought to the farmer's house where the harvesters receive a share (*bawon*). The harvesting is open to everybody and by tradition the farmer cannot limit the number of harvesters.

The *bawon* system has been rapidly replaced since 1970 by a system called *tebasan*. In it, farmers sell their standing crops to middlemen 7-10 days before harvest. The middlemen employ regular workers to harvest the purchased crops. The laborers receive cash wages and use sickles for higher efficiency. Harvesting cost is reduced.

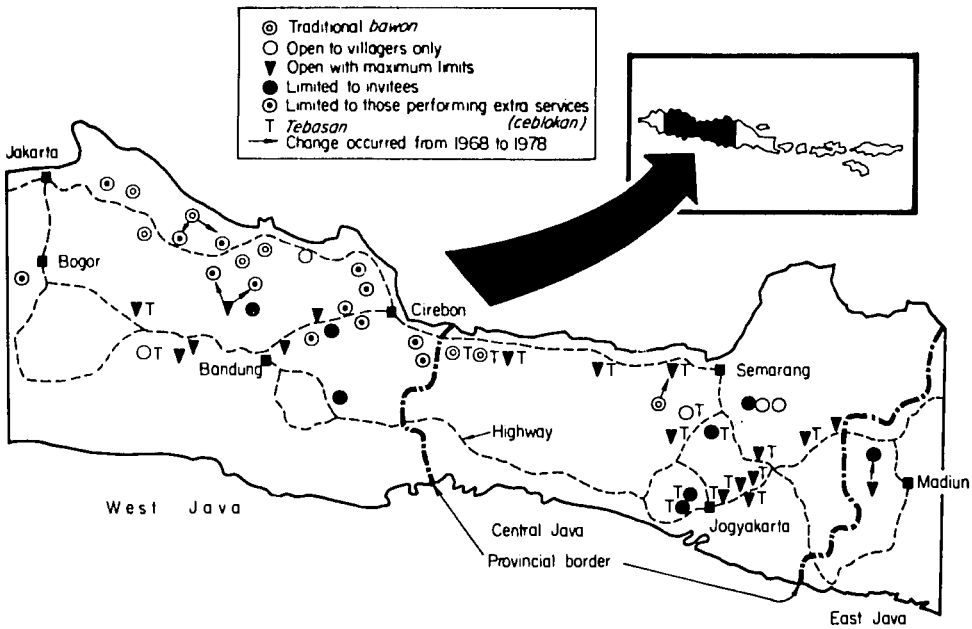
Figure 5 shows the geographical distribution of various types of rice harvesting systems based on the results of the Java surveys:

- The traditional *bawon* — everyone can participate in harvesting — which is a rather exceptional practice today and has been so for 10 years. In most cases, *bawon* harvesting ceased in 1968.
- The system nearest to the traditional concept of *bawon* harvesting as a communal activity where harvesting is open only to people in the same village.
- A system that does not limit participants to villagers, but imposes a certain maximum limit. Villagers who arrive at the harvesting site after the number is reached are rejected.
- A situation in which participants are limited to those who received invitations from farmers (mostly relatives and neighbors).
- A system called *ceblokan* that limits harvesters to those who perform such tasks as transplanting and weeding without pay.

Tebasan was practiced in 18 of the 48 sample villages. In all the *tebasan* villages, the system was practiced side by side with the *bawon* system. Sixteen of the 18 *tebasan* villages were in Central Java (Fig. 5).

It appears that the distribution of *tebasan* was inversely correlated with the distribution of *ceblokan*. In the sample all the *ceblokan* cases were in West Java; and no *tebasan* was reported in those villages. *Ceblokan* was most pervasive on the eastern border of West Java. The *bawon* system that coexisted most commonly with *tebasan* was the one open to all but with maximum limits. In Central Java, more than 90% of *tebasan* villages practiced it. Farmers had developed the practice to reject harvesters above certain limits because the growing population pressure had resulted in the participation of too many harvesters.

Control over harvesters. A basic hypothesis was that the primary purpose of farmers in adopting the *tebasan* system was to strengthen control over harvesters by limiting their number to an optimum level. Such a hypothesis is consistent



5. Geographical distribution of harvesting systems in Java.

with the fact that the *tebasan* system operated most commonly in the villages where the *bawon* system open with maximum limits was practiced. In those villages, the control over harvesters seemed less than optimum. Farmer respondents reported that their maximum limits were 20 to 30% larger than the numbers they considered optimum. In such a situation, it seemed reasonable to expect farmers to be motivated to adopt the *tebasan* system to increase their control over harvesters. The observation that *tebasan* had not penetrated into the *ceblokan* areas reflected the fact that farmers had no need to strengthen their control.

In fact, the average number of harvesters employed per hectare with the *bawon* system was much smaller for the types characterized by stronger control than for the types with looser control (Table 2). The difference supported the conjecture that *tebasan* was established in the areas where more strict controls had not been established as a village tradition — in areas with a need for farmers to tighten control over harvesting.

Modern varieties and adoption of the sickle. Survey data indicated that modern varieties facilitated the adoption of the sickle. Most respondents reported that they adopted the sickle within 3 years after the introduction of modern varieties;none used the sickle before the introduction of modern varieties (Table 3).

Table 2. Average number of harvesters employed per hectare under various types of the *bawon* system. Java, Indonesia.

Type of *bawon* system	Harvesters employed (no./ha)	
	Non-tebasan villages	*Tebasan* villages
Purely open (*bawon*)	200	120
Open to villagers only	67	190
Open to all with maximum limits	130	93
Limited to invitees	43	80
Limited to those performing extra services (*ceblokan*)	67	–

There was insufficient evidence to support the hypothesis that the use of the sickle facilitated the spread of *tebasan*. Respondents in the *tebasan* area reported almost unanimously that *tebasan* was common before the introduction of modern varieties and the sickle. The fact that the sickle was not a precondition for *tebasan* is clearly shown by the data in Table 4. There was not much difference in the pattern of use of the *ani-ani* and the sickle between *bawon* and *tebasan* users within the *teba-*

Table 3. Relation between the year of adoption of modern varieties (MV) and harvesting with a sickle. Java, Indonesia.

	Sickle adoption (no.)								Non-adoption	Total
	Before 1970	1970–72	1973	1974	1975	1976	1977	1978		
Year of MV adoption										
Before 1970	2				2	4				7
1970–72		1			3	3	1		4	12
1973			2		1		1	1	1	6
1974				1		1			1	3
1975					1	1	1			3
1976						6	3		1	10
1977							1		1	2
1978										0
Non-adoption									5	5
Total	2	1	2	1	7	15	7	1	13	48

san villages, and between the *tebasan* and non-*tebasan* villages. In most cases in the area where the sickle was introduced, the middlemen let their harvesters use both the traditional *ani-ani* knife and the sickle. There were cases where the middlemen forbade use of sickles which, they claimed, increased shattering loss.

Use of cash wages. Data showed no great difference in the form of wage payment between the *bawon* and the *tebasan* systems. In 1978, about 80% *of tebasan* cases still used the output-sharing contract (Table 5). Only 1 of the 18 *tebasan* cases used the system of fixed cash wage per day.

The fact that there was no significant difference in the use of harvesting tools between *bawon* and *tebasan* was highly consistent with the observation that the use of daily cash wage payment was a rare exception under the *tebasan* system.

Reduction of labor employment. The role of *tebasan* in limiting participants in harvesting was reflected by the difference in the number of harvesters employed per hectare between *bawon* and *tebasan* systems within the *tebasan* villages (Table 6). The number was smaller in the *tebasan* system irrespective of the choice of harvesting tools. Labor employment in terms of work hours was also less under *tebasan* than under *bawon*.

Reduction of harvesters' share. A clear ten-

Table 4. Distribution of sample villages by use of harvesting tools. Java, Indonesia, 1978.

Harvesting tool used	Non-*tebasan* villages		*Tebasan* villages			
			Under *bawon*		Under *tebasan*	
	No.	%	No.	%	No.	%
Ani-ani	6	20	10	56	7	39
Sickle	4	13	2	1	3	17
Ani-ani and sickle	20	67	6	33	8	44

Table 5. Distribution of sample villages by form of wage payment. Java, Indonesia, 1978.

Wage payment	Non-*tebasan* villages		*Tebasan* villages			
			Under *bawon*		Under *tebasan*	
	No.	%	No.	%	No.	%
Output sharing	30	100	16	89	14	78
Cash proportional to harvest	0	0	2	11	3	17
Fixed cash per day	0	0	0	0	1	5

Table 6. Average numbers of harvesters and work hours employed per hectare in the *bawon* and the *tebasan* systems in *tebasan* villages. Java, Indonesia, 1978.

Harvesting tool	Under *bawon* (1)	Under *tebasan* (2)	Difference (%)
	Harvesters (no./ha)		
Ani-ani	107	103	−4
Sickle	75	45	−40
Ani-ani and sickle	110	99	−10
Total	104	91	−12
	Work hours (no./ha)		
Ani-ani	544	529	−3
Sickle	400	340	−15
Ani-ani and sickle	497	453	−9
Total	512	463	−10

dency for harvesters to receive smaller shares of output under the *tebasan* system was observed (Table 7). Within the *tebasan* villages the share of harvesters was smaller under the *tebasan* system.

The tendency observed from the cross-section comparison was confirmed by the changes in harvesters' shares during the past decade. Table 8 compares changes in the average shares of harvesters from 1968-78 under the *bawon* system with the changes that would have occurred if all farmers in the *tebasan* villages shifted from the *bawon* to the *tebasan* system. The comparison demonstrates the significant effect of *tebasan* in reducing the share of harvesters, although this comparison provides the upper bound estimates on the impact of the introduction of the *tebasan* system.

The output shares of harvesters were kept at much higher levels in the non-*tebasan* villages, especially with the *ceblokan* system, than in the *tebasan* villages. The higher share rates do not mean that the wage rates were higher under the *ceblokan* system, but that the *ceblokan* workers received the larger amount of wage payment in kind for the larger amount of labor services including both harvesting and other obligatory tasks such as transplanting and weeding.

Decline of harvesters' income. It was observed that harvesters' share was reduced with the shift from the *bawon* to the *tebasan* system. According to the calculation in Table 9, the share of *tebasan* harvesters in the *tebasan* villages would have been 10% instead of 8% if their employers did not adopt the *tebasan* system.

EFFECT OF NEW RICE TECHNOLOGY ON FAMILY LABOR USE ON LAGUNA RICE FARMS

IRRI has collected data from a sample of 45 Laguna rice farmers 4 times since 1965. The first survey was before the introduction of modern rices. A number of changes in rice farming are shown in Table 10.

Changes in total labor use. Between 1965 and 1975, the introduction of modern varieties was associated with a 31% increase in labor per hectare (Table 11). However, between 1975 and 1978 total labor use declined with the increased use of chemicals for weeding and machines for land preparation and threshing. The decline in labor for land preparation was primarily a result of power tillers replacing the carabao for harrowing (Table 12).

Table 7. The distribution of harvesters' shares under the *bawon* and *tebasan* systems. Java, Indonesia, 1978.

Harvesters' share[a]	Non-*tebasan* villages		*Tebasan* villages			
			Under *bawon*		Under *tebasan*	
	No.	%	No.	%	No.	%
1/5 and above	7	23	0	0	0	0
1/6 to 1/8	9	30	5	28	0	0
1/9 to 1/11	12	40	8	44	6	35
1/12 to 1/14	1	3	2	11	5	29
1/15 to 1/17	0	0	3	17	5	29
1/18 or below	1	3	0	0	1	6
Total	30	100	18	100	17[b]	100
Av (%)	13.6		10.0		8.2	

[a]Cash payments proportional to the amount of harvest were converted into shares, assuming Rp 50/kg rough rice. [b]The case of fixed cash wage per day is excluded.

Table 8. Changes in average shares of harvesters from 1968 to 1978.[a] Java, Indonesia, 1978.

	Average shares (%) of harvesters		
	1968	1978	Difference
Tebasan villages:			
Under *bawon*[b]	11.2	10.0	1.2
Bawon to *tebasan*[c]	11.2	8.2	3.0
Non-*tebasan* villages:			
Ceblokan	18.2	16.3	1.9
Non-*ceblokan*	13.3	11.8	1.5
Total	15.3	13.6	1.7
Total			
Under *bawon*[b]	13.9	12.3	1.6
Bawon to *tebasan*[c]	13.9	11.6	2.3

[a]Share rates were adjusted for leniency under the system of *ani-ani* cutting and sharing in bundles, by assuming that harvesters' shares are higher by 10% in such a system than in sharing in threshold form (*gabah*). [b]It was assumed all farmers stayed with the *bawon* system. [c]It was assumed all farmers shifted from *bawon* to *tebasan* in *tebasan* villages during 1968–78.

The reduction in labor for harvesting and postharvest activities — although yields increased by nearly two-thirds — was due to the introduction of the axial-flow thresher in mid-1970s. Although mechanization decreased total labor use per hectare, the labor required for weeding the modern varieties nearly tripled from 1965 to 1975. Since 1975, weeding labor has declined with the more general use of herbicides as these materials have become more readily available and as their prices have fallen relative to that of labor.

Hired labor and family labor. Table 13 demonstrates that family labor declined steadily over the period of the survey, with the most dramatic reduction in land preparation and weeding (Fig. 6). The reduction in family labor for land preparation was associated with the introduction of the

Table 9. Estimation of the impact of technological and institutional changes on the shares of harvesters. Java, Indonesia, 1978.

	Total output (1)	Current input (2)	Value added: Total (1) – (2)	Value added: Farmers' share	Value added: Harvesters' share
Before new technology					
Physical quantity (kg/ha)	3000	120	2880	2580	300
Output share (%)	100	4[a]	96	86	10
Income share (%)			100	90	10
With new technology					
Physical quantity (kg/ha)	4000	470[b]	3530	3210	320
Output share (%)	100	12	88	80	8
Income share (%)			100	91	9

[a]Includes 30 kg seeds, 50 kg fertilizer (equivalent to 80 kg paddy), and 10% of fertilizer cost for chemical and other inputs. [b]Includes 30 kg seeds, 250 kg fertilizer (equivalent to 400 kg paddy), and 10% of fertilizer cost for chemical and other inputs.

Table 10. Changes in rice farming in Laguna, Philippines, between 1965 and 1978. IRRI, 1979.

	1965	1970	1975	1978
Farm size (ha)	2.3	2.2	2.3	2.3
Rice cropping index	1.8	1.7	2.0	2.0
Yield (t/ha per crop)	2.5	3.5	3.6	4.1
Cultivation of modern varieties (%)	0	96	100	100
Owner operators (%)	0	2.2	2.2	2.2
Leasehold farmers (%)	11.1	20.5	60.0	68.9
Share-tenant farmers (%)	86.7	77.3	31.1	15.6
Combination of the above farmers (%)	2.2	0	[illegible]	13.3

Table 11. Changes in labor use for rice production in Laguna, Philippines, 1965-78 wet season.

Farming operation	Labor use (man-days/ha)											
	Family labor				Hired labor				Total labor[a]			
	1965	1970	1975	1978	1965	1970	1975	1978	1965	1970	1975	1978
Land preparation	14.45	5.68	4.5	2.66	3.96	5.07	5.99	6.52	19.21	11.42	10.57	9.19
Repair or cleaning of dikes	3.82	3.85	3.47	3.31	0.25	0.89	1.13	1.53	4.2	4.94	4.73	5.19
Transplanting	0.21	0.04	0	0	9.64	10.64	11.28	10.04	9.85	10.68	11.28	10.04
Weeding	8.99	6.67	5.92	4.8	2.08	12.07	25.65	21.79	11.08	19.07	31.57	26.59
Fertilizing or spraying	0.92	1.53	2.32	1.7	0	0.09	0.52	0.74	0.92	1.65	2.98	2.58
Other preharvest operations[b]	3.67	7.59	4.89	3.56	0.71	1.46	9.73	0.42	4.47	9.07	14.74	4.19
Total preharvest labor	32.06	25.36	21.1	16.03	16.63	30.21	54.30	41.04	49.73	56.82	75.87	57.78
Harvesting, threshing, and postharvest activities	0.52	1.6	0.8	0.71	34.6	35.7	35.0	27.1	35.77	37.3	35.8	27.81
Total Labor	32.58	26.96	21.9	16.74	51.23	65.91	89.3	68.14	85.5	94.12	111.67	85.59

[a]Includes exchange labor. [b]Seedbed preparation, pulling and rolling of seedlings, replanting.

Table 12. Percentage of farmers who mechanized land preparation. Laguna, Philippines, 1965–78.

Operation	Farmers (%)			
	1965	1970	1975	1978
Plowing	0	11	20	47
Harrowing	24	69	89	93

power tiller, because the machine is rarely hired without an operator.

In absolute terms, family labor allocated to weeding was halved during 1965-78 and currently accounts for less than 20% of total weeding labor. Confirming observations by IRRI scientists, Laguna farmers claim that with modern varieties, weeding should be completed within a few days of fertilizer application — a task the family is unable to handle. As a result, weeding in 1978, like harvesting, threshing, and transplanting, was predominantly the task of hired laborers.

Operator's labor. The bulk of the decline in family labor is a result of the substantial reduction in the farm operator's labor committed to rice production (Table 13). Labor inputs by other family members are minor and have remained constant with the introduction of modern varieties.

Pre- and post-modern varieties production functions, incorporating farm-specific dummy variables were estimated to examine whether the productivity of management had increased as a result of the introduction of modern varieties. The whole-farm production functions were:

$$\log Y_i = \log b_0 + b_1 \log X_{1i} + \ldots . b_4 \log X_{4i} + b_5 \log IR_i + a_2 D_{2i} + \ldots . a_n D_{ni} + e_i.$$

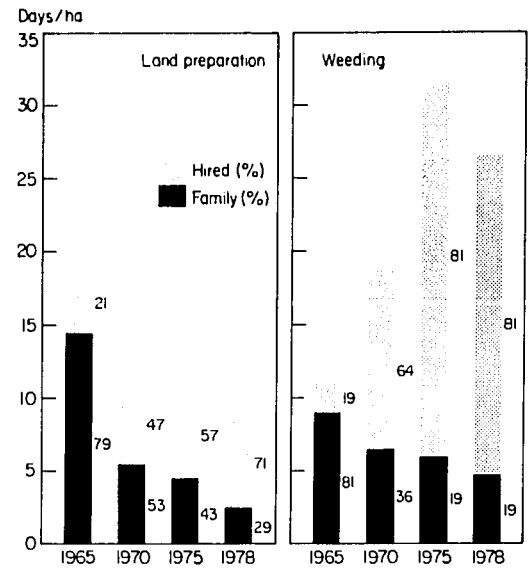
where

Y = farm rice output,
X_1 = days of labor per farm,
X_2 = present value of capital stock,
X_3 = expenditure on fertilizer, herbicide, and insecticide,
X_4 = area planted to rice,
IR = proxy for irrigation quality, to reflect the different quality of irrigation in each municipality,
$D_2 \ldots D_n$ = farm-specific dummy variables, and
e_i = error term.

The b_j and a_k are the estimated coefficients

Table 13. Preharvest family labor, broken down by family member. Laguna, Philippines, 1978.

Farming operation	Preharvest family labor (man-days/ha)											
	Operator				Other family members				Total			
	1965	1970	1975	1978	1965	1970	1975	1978	1965	1970	1975	1978
Land preparation	11.28	3.25	3.05	1.62	3.17	2.43	1.45	1.04	14.45	5.68	4.5	2.66
Weeding	6.55	3.61	2.79	2.06	2.44	3.06	3.13	2.74	8.99	6.67	5.92	4.8
Other preharvest operations	6.83	7.68	6.53	4.7	1.54	4.88	4.16	3.87	8.37	12.56	10.69	8.57
Total preharvest operations	24.66	14.54	12.37	8.38	7.15	10.37	8.74	7.65	31.81	24.91	21.11	16.03



6. Changes in the source of land preparation and weeding labor. Laguna, Philippines, 1965-78.

Table 14. Production function estimating log of rice production per farm, as a function of independent variables specified below (including management).[a]

Independent variable	New technology 1975 & 1978	Old technology 1965	Significant differences between new and old technology
Log farm size	0.54**	0.46**	
Log capital stock	0.01	−0.1**	**
Log labor	0.07	0.29*	
Log cash inputs	−0.02	0.13	**
Log proxy for irrigation quality	0.06**	0.04**	
Management dummies	0.34+	0.18**	**
Constant	1.73	0.25	
$\bar{R}^2$	0.65	0.60	

[a] **Means significant at 5% level; *, significant at 10% level; +, computed as the residual.

reported in Table 14. From the analysis, it is inferred that the new technology is significantly more responsive to good management and increased capital input.

Changes in farm family income. Average annual incomes of the farm family have increased (in real terms) since the introduction of modern varieties (Table 15). While real incomes from rice production have increased, a substantial proportion

Table 15. Average annual income, by source, Laguna, Philippines, 1965 and 1978.

Source	Current income[a] 1965 $	1965 %	1978 $	1978 %	Index of real income[b] vs 1965
Rice farming[c]	182	45	1,048	43	148
Hired agricultural work	10	2	60	2.5	156
Nonfarm salary	74	18	571	24	198
Nonfarm self-employment	68	17	206	9	78
Other crops or livestock	63	16	179	7.5	73
Nonlabor income	8	2	340	14	1,062
Total	404	100	2,404	100	153

[a]US$1 = ₱7.30 [b]Deflated by consumer price index outside Manila. [c]Net of paid-out costs.

Table 16. Allocation of paddy output to factors of production. Farm survey in Laguna, Philippines, 1965–78 wet season.

	Paddy output (kg/ha) 1965	1970	1975	1978	% change between 1965 and 1978
Earners					
Landlord	1073	1257	969	698	–35
Hired labor	573	1030	986	1307	128
Operator and family labor	484	272	207	217	–55
Operator's residual	195	451	848	1126	477
Current inputs	214	519	650	636	197
Factors					
Land	1195	1587	1082	901	–24
Labor					
Hired	511	854	942	1152	125
Operator and family	484	272	207	217	–55
Operator's residual	195	451	848	1126	477
Current inputs	153	364	582	588	284
Total output (kg/ha)	2540	3530	3661	3984	57

of the increment is attributed to salaried nonfarm jobs and nonlabor sources of income.

Changes in earnings among factors of production. An accounting procedure was used to allocate the distribution of rice earnings among the direct participants who grew the crop and among the factors of production committed to producing the crop. This allowed identification of which participants benefited from the modern technology, and how the benefits were related to owners of factors of production and institutional arrangements prevailing in a region undergoing technological changes.

The distribution of output among the factors contributing to the production of the rice crop are estimated in Table 16. Between 1965 and 1978, the landlords' share of earnings fell by 35%; the decline was attributed to land reform and the farmers' shift from being tenants to being leaseholders. The share of the rice produced accruing to hired laborers increased by 128% among earners and 125% among factors and the return to family labor fell by 55%. However, the operator's residual, which reflects the return to his management skills and farming resources, increased more than 400% in the period. The shift in real earnings between hired and family labor was partially due to the *gama* contract of hired laborers who weed the rice in exchange for the right to harvest the crop and receive in payment one-sixth of the produce.

Cropping systems program

Environmental description

Multiple Cropping Department and Cropping Systems Components of the Agricultural Economics and Plant Pathology Departments

EVALUATION OF CROPPING PATTERN DETERMINANTS 380
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EVALUATION OF CROPPING PATTERN DETERMINANTS

Cropping Systems Component of the Agricultural Economics Department

The Economics Committee of the Cropping Systems Working Group at a 1978 meeting started identifying and testing minimum data sets for cropping systems design. Through cross-site comparison the working group tried to identify relationships between hypothesized determinants of cropping systems and attributes of cropping systems adopted by farmers.

To test the methods to be used in the project, cropping systems on about 15 farms at each of 14 Philippine sites were analyzed and compared. A framework representing farmers' input-input and input-output relationships characterized the cropping systems. Following economics conventions, the relationships, as descriptors of cropping systems, are:

- land-use indices,
- labor-use indices,
- capital-use indices, and
- output indices.

The specific variables used with each class of descriptor, values, and standard deviations are in Table 1.

Determinants were grouped according to the level of aggregation at which they were measured and at which they influenced cropping systems, as follows:

- plot-level determinants,
- farm-level determinants, and
- village-level determinants.

Variables used as measures of each class of determinant, their mean values, and standard deviations are in Table 2.

Relationships between each descriptor of cropping systems and the entire set of hypothesized determinants were identified by regression analysis. For example, Table 3 shows the results of linear regressions of a reduced set of determinants on a

Table 1. Means and standard deviations of input and output indices of cropping systems on 207 farms at 14 Philippine sites, 1979.

Variable	Mean	Standard deviation
Land use		
Multiple cropping index	148	60
Cropping intensity index	0.47	0.18
Percentage area in rice	78	27
Percentage area in grain legumes	5	12
Percentage area in vegetables	7	15
Labor use		
Percentage labor hired	55	33
Days/ha, rice	206	412
Days/ha, nonrice crop	57	99
Technical inputs		
Value of cash inputs for rice ($/ha)	53	50
Value of cash inputs for nonrice crop ($/ha)	20	37
Nitrogen on rice (kg/ha)	18	45
Variety of rice (0 = local; 1 = improved)	0.47	0.34
Production and sale		
Value of rice produced ($/ha)	388	594
Value of rice sold ($/ha)	30	86
Value of nonrice crop produced ($/ha)	151	361
Value of nonrice crop sold ($/ha)	57	139
Rice yield (t/ha)	2.4	1.5

Table 2. Means and standard deviations of hypothesized determinants of cropping systems on 207 farms at 14 Philippine sites, 1979.

Variable	Mean	Standard deviation
Plot level, physical		
Topography (0 = flat; 1 = rolling)	0.28	0.45
Percentage clay	33	13
Percentage organic carbon	0.97	0.34
No. most with rainfall > 100 mm	7.5	2.9
Supplemental irrigation (0 = no, 1 = yes)	0.27	0.44
Farm-level, economic		
Farm size (ha)	1.53	1.22
Parcels (no.)	6.7	10.8
Family members (no.)	5.2	2.2
Adult farm workers in family (no.)	2.5	1.6
Livestock income ($/yr)	49	144
Off-farms income ($/yr)	170	475
Loans received ($/yr)	75	146
Value of workstock and equipment ($)	648	736
Operators' age (yr)	49.6	12.6
Operators' years in farming	27.0	14.0
Operators' years of education	5.7	6.1
Village-level, economic		
Man-land ratio	6.0	9.6
Wage rate for transplanting ($/day)	1.3	1.1
Price of nitrogen ($/kg)	0.53	0.08
Price of rice ($/kg)	0.14	0.01
Transport accessibility (1 = easy, 3 = difficult)	2.50	0.83

Table 3. Results of linear regression of selected hypothesized cropping system determinants on selected characteristics of cropping systems, 207 farms at 14 Philippine sites.[a] 1979.

Determinant	Land use		Labor days/ha		Material inputs ($/ha)		Value products sold ($/farm)	
	MCI	% area in vegetables	Rice	Fc	Rice	Fc	Rice	Fc
Plot level								
% oc	-46	6.7**	-160**	-29	-420**	-201**	-23	-250
% clay	0.40	0.23**	-1.8	1.2**	-0.004	8.2**	-0.16	42**
Irrigation	56**	3.3*	300**	31**	164	122**	14	645**
Farm level								
Farm size	1.4	-1.8**	160**	1.4	109**	12	8.3*	-116**
Parcels (no.)	-0.41	0.26**	0.001	1.4**	4.3**	0.72	0.66	-20**
Education	1.5**	-0.01	17**	-1.5	9.9**	-8.9	1.12	39**
Village level								
N price	190**	-5.3	810**	100	120	-3.4	45	2300**
Rice price	21**	11**	-155	56**	-60	170**	-26	800**
Wage rate	20**	0.37	36**	6.7	96**	34**	-3.4	89
Constant	-106	-59	494	-382	688	-1074	181	-4562
Adjusted R^2	0.47	0.58	0.43	0.33	0.37	0.58	0.02	0.49
F	21	33	21	12	16	33	1.6	23

[a]MCI = multiple cropping intensity (planted area ÷ farm size); Fc = field crops other than rice; oc = organic carbon in topsoil.

selection of descriptors. From the complete analysis of the descriptors and determinants shown in Tables 1 and 2, supplemental irrigation appeared the most important determinant of characteristics of rice-based cropping systems, followed by rice price, nitrogen price, farm size, percentage of clay, percentage of organic carbon, wage rate, number of parcels, livestock income, and education. Plot-level, farm-level, and village-level variables, both physical and economic, were among the highest ranked hypothesized determinants. Number of parcels per farm and farmer education appeared significant in fewer equations than the other independent variables. Farm-level determinants, as a whole, appeared less influential than other groups of variables. Input relationships reflecting land use, labor use, and cash use were about equivalently well explained, with about 65% of coefficients appearing significant in the regressions. Production relationships were poorly explained — only the amount of nonrice crops sold appeared to be strongly determined by the independent variables. Table 4 lists a ranking based on the percentage of coefficients that are significant.

Apparently physical factors measured at the plot level strongly determined the characteristics of cropping systems, and aggregative village-level factors such as prices and wages were also strongly related. Farm-level determinants appeared less important.

Input intensities were more clearly related to environmental factors than output intensity. This suggested that during cropping pattern design, the use of inputs should be closely examined for their fit to the environment.

Table 4. Relative importance of physical and economic features of the environment in explaining the characteristics of rice-based cropping systems, 14 Philippine sites, 1979.

Determinant	Descriptor	Significant coefficients (%)
Plot-level (physical)	Materials use	83
Village-level (economic)	Land use	80
Plot-level (physical)	Labor use	78
Plot-level (physical)	Land use	73
Village-level (economic)	Labor use	66
Farm-level (economic)	Cash use	58
Farm-level (economic)	Labor use	55
Village-level (economic)	Cash use	50
Plot-level (physical)	Production	42
Farm-level (economic)	Production	42
Village-level (economic)	Production	33
Farm-level (economic)	Land use	33

DISEASE SURVEYS

Cropping Systems Component of the Plant Pathology Department

Dryland rice-based cropping systems. *Rice.* During the 1979 rice-growing season, sheath blight [*Corticium sasakii* (Shirai) Matsumoto] was observed in two of six fields visited in Batangas Province, Philippines. Both fields were planted to Dagge, a local variety (Table 5). As in 1978, leaf smut (*Entyloma oryzae* H. & P. Sydow) was also observed in Dagge, with infection confined only on lower leaves.

Maize. No disease was recorded on maize, which was intercropped with rice.

Bush sitao. Fusarium stem and root rot (*Fusarium solani* f. sp. *phaseoli*) of bush sitao were observed in two fields.

Wetland rice-based cropping systems. *Rice.* Bacterial blight [*Xanthomonas oryzae* (U & I) Dowson] was observed on IR36 at Tigbauan, Iloilo, in 2 fields adjacent to an irrigation canal, with 10% incidence and 10-25% severity. Brown spot [*Cochliobolus miyabeanus)* (I & K) Drechsler ex Dastur] was recorded in a variety trial in Oton, Iloilo (Table 5).

In Manaoag, Pangasinan, no disease was recorded in farmers' fields. In a transplanted-rice variety trial, however, sheath blight and brown spot occurred at low levels.

Maize. No disease on maize was observed in Iloilo. In Pangasinan, downy mildew (*Sclerospora philippinensis* Weston) was prevalent. A ratooned field of sugarcane in Caaringayan had a 10% incidence of downy mildew, a possible source of inoculum for infection of maize planted before rice.

Mungbean. In Iloilo, no mungbean seedling disease was observed. Powdery mildew (*Erysiphe polygoni* D.C.), however, occurred as early as the bud stage, with infection rating reaching as high as 9 (Table 5).

In Pangasinan, Cercospora leaf spot (*Cercospora* spp.) was observed in a mungbean variety trial planted before rice. In mungbean planted after rice, 1% Sclerotium damping-off occurred in several fields. Powdery mildew with severity rating of 1 (with 1-5% of the leaf area infected) was observed on plants at early bud stage.

IRRI plots. In dryland rice-based cropping systems at IRRI, 1-5% Sclerotium damping-off occurred on yield trial plots of cowpea, mungbean,

Table 5. Diseases recorded[a] at Philippine cropping systems sites and at IRRI[b], 1977–79.

Crop	1977				1978				1979			
	Batangas	Iloilo	Pangasinan	IRRI	Batangas	Iloilo	Pangasinan	IRRI	Batangas	Iloilo	Pangasinan	IRRI
Rice	None	Leaf blast (1)	Bacterial leaf streak (3–5)	–	Leaf blast (1–5) Leaf smut (3–5)	Leaf blast (7–9); Bacterial blight (50%; 5) Kresek (5–10%)	Brown spot (1–5)	Sheath rot (–)	Sheath blight (5%; 3); Leaf smut (3–5)	Bacterial blight (10%; 3) Brown spot (1–3)	Sheath blight (5–10%; 3–5) Brown spot (1–3)	Sheath rot (100%); Stem rot (60%); Sheath blight (5–7)
Maize	Mosaic (<5%)	–	–	–	Downy mildew (<1%); Sheath blight (–); Curvularia leaf spot (–)	–	Downy mildew (5–80%); Bacterial blight, ? (1%)	–	None	None	Downy mildew (5–100%)	Sheath blight (17%; 1–3)
Sorghum	Sheath blight (25%; 3–7); Zonate spot (25%;–)	–	–	Sheath blight (–)	–	None	None	–	–	None	–	Sheath blight (80%; 1–5); Zonate spot (1–5); Phyllacora spot (5–9)

Cowpea	–	Sclerotium damping-off (1%)	Sclerotium damping-off (<1%)	Phytium damping-off (100%); Rhizoctonia damping-off (20%)	Powdery mildew (1–5) Cercospora leaf spot (7–9)	Cercospora leaf spot (1–3) Leaf rust (1–3)	Cercospora leaf spot (1–3) Leaf rust (1–3)	Leaf rust (3–9); Powdery mildew (1–9); Stem & root rot (5–40%)	–	None	–	Sclerotium damping-off (1–5%); Fusarium stem & root rot (100%)
Mungbean	–	–	Sclerotium damping-off (<1%); Cercospora leaf spot (–)	Cercospora leaf spot (–); Mosaic (–)	Powdery mildew (7–9); Cercospora leaf spot (1–5)	Powdery mildew (5–9); Cercospora leaf spot (–)	Powdery mildew (3–7); Cercospora leaf spot (1–3)	Powdery mildew (3–7); Cercospora leaf spot (1–5); Sclerotium damping-off (20–70%)	–	Powdery mildew (9)	Cercospora leaf spot (5–9); Sclerotium damping-off (<1%); Powdery mildew (1)	Cercospora leaf spot (5–9); Powdery mildew (–); Sclerotium damping-off (1–5%)
Soybean	–	Sclerotium damping-off (>50%)	–	Rust (–)	–	–	–	–	–	None	–	Sclerotium damping-off (50%); Rust (3–7)
Peanut	–	Mottle (20%)	–	Black spot (–); Mottle (–)	Rust (5–9)	Black spot (1–3); Leaf rust (1–3); Mottle (10%)	Black spot (1–3); Leaf rust (1–3); Mottle (10%)	Mottle (–)	–	None	–	–
Bush sitao	–	–	–	–	Fusarium stem & root rot (90%); Sclerotium stem & root rot (1%)	–	–	–	Fusarium stem & root rot (5–10%)	–	–	–
Sweet potato	–	–	–	–	None	–	–	Scab (100%)	–	None	–	–

[a] A dash indicates either no data taken or no crop grown at the site. A dash enclosed in parentheses indicates no disease rating recorded. Cropping pattern, research-managed, and farmers' fields were used in the survey; item in parentheses represents incidence if in % and severity if figures alone; incidence based on the ratio of infected plants to the total population x 100, severity on the following:

Disease scale:	Leaf spot (% leaf area affected)	Powdery mildew (% leaf area affected)	Leaf rust (intensity of pustules)	Sheath blight (stem area affected)
1	< 1%	1–5%	light	lower 1/4
3	1–5	5–25	moderately light	1/2
5	5–25	25–50	moderately heavy	3/4
7	25–50	50–75	heavy	whole stalk
9	> 50	> 75	severe	with stem rotting

[b] Only the field of Plant Pathology-Cropping Systems and Multiple Cropping Department considered.

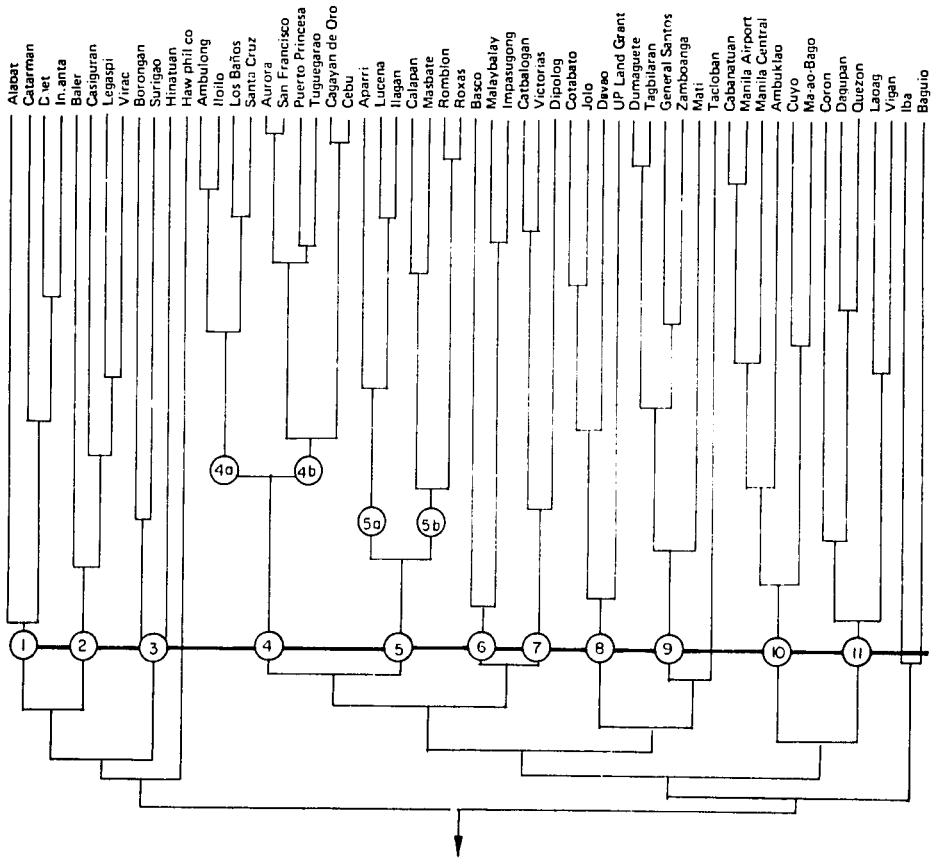
and bush sitao planted after rice where zero tillage was used for crop establishment. Two weeks later, stem and root rot were apparent only on cowpea. Based on disease incidence, Vita 3, TVX 289-46, and TVX 1836-19E appeared resistant, and PI 339587 and TVX 1836-187E susceptible. Microscopic examination of the infected plants and isolation of pathogen from disease tissues revealed the presence of *Fusarium* sp. A succession of soilborne pathogens occurred from one crop growth stage to another in the trial plot. *S. rolfsii*, observed during the seedling stage, was followed by *Fusarium* sp. during the early bud stage.

WEATHER PATTERN CLASSIFICATION

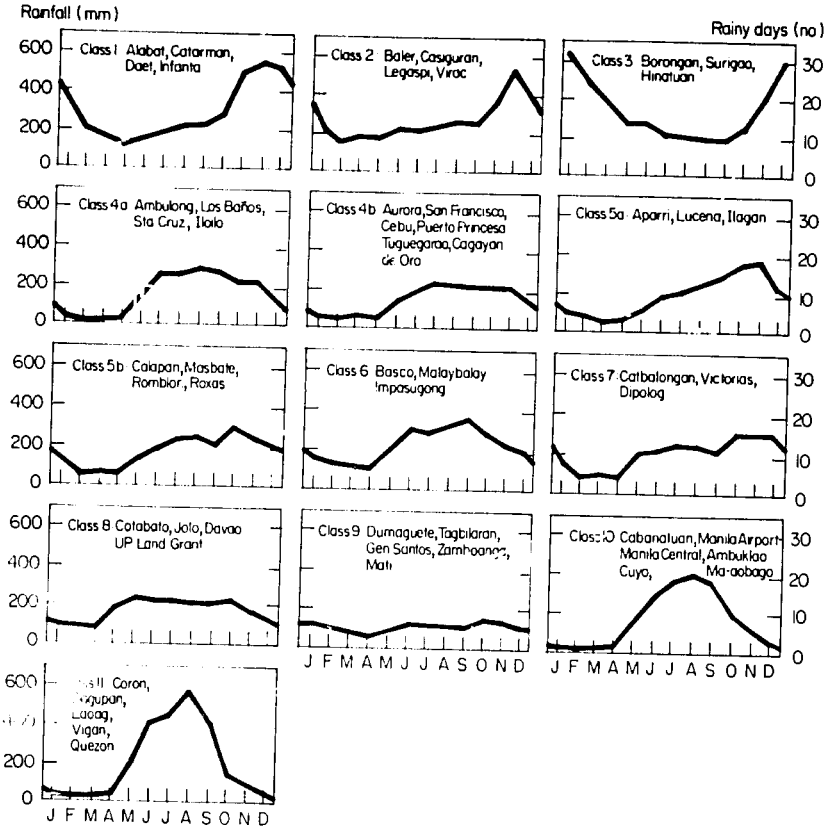
Multiple Cropping Department

In earlier climatic analyses, classification criteria were determined on the basis of general crop water requirements, with the monthly rainfall requirement of the rice crop assumed to be 200 mm or more, and that of dryland crops grown before or after wetland rice in cropping patterns, to be 100 mm or more (1977 and 1978 annual reports). In 1979, cluster analysis as an alternative to classifying stations on the basis of preestablished criteria was applied to data from 58 Philippine weather stations. The primary objective was to formulate classes of rainfall patterns and determine into which of them cropping systems research sites at IRRI and in Iloilo, Pangasinan, Batangas, and Cagayan would fall.

Mean monthly total rainfall and mean number of rainy days per month for all months were used in the cluster analysis. Monthly mean temperatures for January, May, and September were also included to obtain differentiation for months in which temperatures are generally extreme (Janu-



1. Cluster map of 58 Philippine weather stations, with total monthly rainfall, number of rainy days per month, and mean January, May, and September temperatures as classification variables.



2. Mean monthly rainfall and number of rainy days for 13 rainfall patterns determined by cluster analysis.

ary and May) and uniform (September). The SAS[1] hierarchical clustering procedure CLUSTER with the STANDARD option was applied. Eleven classes were defined, into which 54 of the weather stations were placed (Fig. 1). Figure 2 gives the mean monthly rainfall and number of rainy days for the classes.

- Classes 1, 2, and 3 had no pronounced dry period, and had 1 or more months of rainfall exceeding 500 mm.
- Classes 4 and 5 had seasonally dry periods, and 5-6 months of rainfall between 200 and 350 mm.
- Classes 6 and 7 had short dry seasons and wet seasons of 7-8 months with rainfall between 200 and 350 mm/month. Class 6 was distinctly cooler than Class 7.
- Class 8 had 7 months in which mean monthly rainfall was between 200 and 250 mm, and 4 months with mean monthly rainfall about 100 mm.
- Class 9 had no month with mean total rainfall exceeding 150 mm.
- Classes 10 and 11 had seasonally dry periods, and 4-5 months with rainfall exceeding 200 mm, of which July, August, and September totals exceeded 350 mm.

The distribution of these 11 classes generally corresponded to the distribution of wet- and dry-month classes on an agroclimatic map of the Philippines (1977 annual report).

Classes 4, 5, and 10 had rainfall patterns that appeared suitable for rainfed wetland rice-dryland crop patterns. Class 4 was further divided into subclasses 4a and 4b, class 5 into 5a and 5b. Because of low wet season rainfall, subclass 4a appeared to have less potential than 4b for pattern

[1]Barr, A. J., J. H. Goodnight, J. P. Sall, and J. T. Helwig. A user's guide to SAS 76. SAS Institute, Inc., Raleigh, N.C.

intensification. Subclass 5b had lower peak rainfall and more months with rainfall between 100 and 200 cm than subclass 5a. Classes 4b, 4a, 10, and 11 formed a continuum of rainfall patterns in which the major difference was the mean July-August-September rainfall. The July-September rainfall was 630 mm for class 4b, 800 mm for 4a, 1,120 mm for 10, and 1,430 mm for 11, suggesting that rainfed rice crops scheduled during this period would likely be more adequately supplied according to the ranking 11 > 10 > 4a > 4b.

The inclusion of the three monthly temperature means added some insight into the classes but was not decisive. The means could have been used to separate stations after a cluster analysis using only rainfall. The temperature variables appeared to separate class 6 from class 7, and Iba from Baguio. Figure 1 shows that class 6 was combined with class 7, and Iba was combined with Baguio just below the dashed line. Within class 6, Basco remained separate from Malaybalay and Impasugong, until slightly above the dashed line. Basco has a cool dry season whereas Malaybalay and Impasugong, which are in the south, are cool throughout the year because of high altitude.

TARGET-AREA DELINEATION

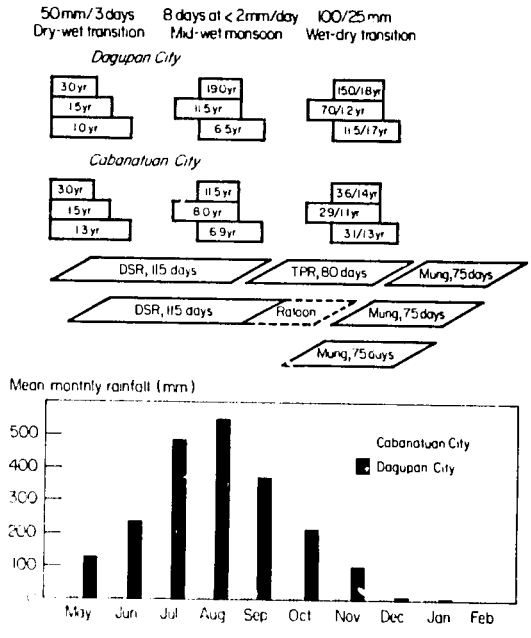
Multiple Cropping Department

The cropping patterns and associated component technology developed at a research site are believed to be agronomically adapted to a larger *target area*. In 1979 a methodological approach was developed to determine limits of the target area.

Studies in the Central Luzon Valley identified areas with physical conditions similar to the Manaoag cropping systems research site. The study examined rainfall patterns, soils, and irrigation. Data for the area were obtained from the Bureau of Soils, the National Irrigation Administration, and the Philippine Atmospheric, Geophysical, and Astronomical Services Administration.

Dry-seeded rice (DSR)-transplanted rice (TPR)-mung and DSR-mung were the main patterns for which areas of adaptation were sought. The field durations of these patterns, and of a DSR-ratoon rice-mung pattern are shown against the mean monthly rainfalls for two stations at the bottom of Figure 3.

As an initial approximation, the area considered



3. Crops and field durations, and mean monthly rainfall for Dagupan and Cabanatuan, Philippines, 1979.

in the study was bounded by the Lingayen Gulf to the northwest, and the 100-m elevation at the foothills of mountains to the east, north, and west. No preliminary physical boundaries to the south were set.

Rainfall patterns: area similarities. Whereas probabilities for dates of monsoon onset and retreat may be empirically determined, extrapolation of the probabilities over comparatively short distances within the area of study was questioned because of spatial gradients in rainfall pattern. The two transition periods April-June and October-December drew the most interest because the distribution of rainfall during those periods affects intensification of cropping patterns by extending crop production periods.

Although record lengths were extremely short for most analytical purposes, rainfall totals for sequential 10-day intervals during the transition periods were compared to provide a basis for preliminary judgments about extrapolation. In comparing stations with Manaoag, it was assumed that if factors causing transition-period weather disturbances were similar over the area, the pattern of showers and rainfall totals would be similar, but rainfall would not necessarily occur on the same day or even within 2 or 3 days.

Short-term rainfall records from 18 observation stations in the study area were used to determine similarity of transition rainfall patterns. For the dry-wet transition, rainfall totals for 8 successive 10-day periods, starting 1 April each year, when pooled over 4 years, gave 32 data pairs. For the wet-dry transition, rainfall totals for 8 successive 10-day periods, starting 1 October, were pooled to give 32 data pairs. As the first step in the analysis, a regression model was used to summarize the relationship between rainfall values at paired stations. The regression model was:

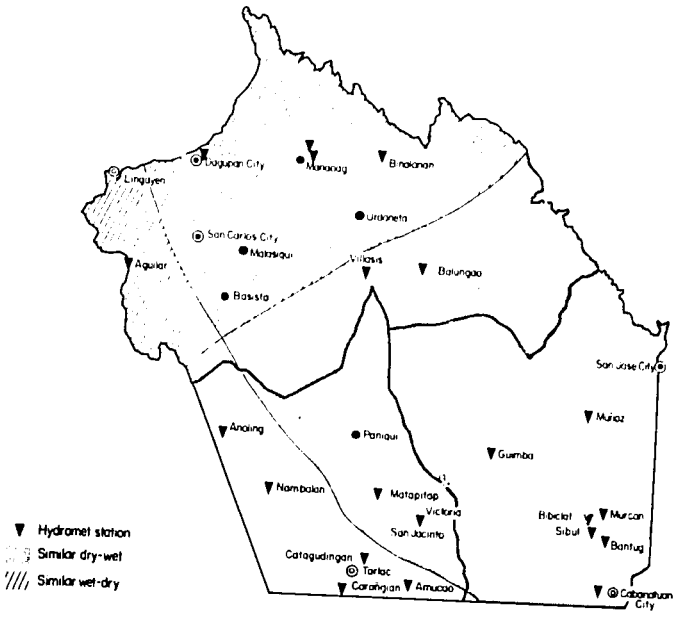
$$Y_{ij} = b_i X_{ij}$$

where X_{ij} was rainfall at Manaoag in the jth period of the ith year and Y_{ij} was rainfall at the paired station for the corresponding period and year. The b_i and R^2 from the regression models were used in cluster analysis to group stations that appeared similar to Manaoag in transition-period rainfall distribution. The coverage of years was limited because data for only 4 years were available for Manaoag and, in many cases, for other stations.

Preliminary regressions showed that, when left included in the computations, periods of high rainfall total produced high R^2 for all station pairs. When pairs of high values were deleted, R^2s decreased most appreciably for stations far from Manaoag. Tropical cyclones were the main source of high rainfall, and because these systems cover large areas, all stations received heavy rainfall in the same period. Because interest was in similarities in rainfall patterns as affected by local factors that promote convective rain cloud development, periods with rainfall exceeding 200 mm for either member of a pair were deleted in the final computations.

The b_is estimated for this model were regarded as indicating the average correspondence on rainfall totals over periods within years, and the R^2s were regarded as indicating the degree of correspondence in totals over all periods.

Three separate clusters were identified for each transition period. For each transition, one cluster was regarded as distinctly similar to Manaoag, and another cluster as distinctly dissimilar. The third cluster fell between the similar and dissimilar. One station did not join any cluster and was regarded as nonconforming. For both transitions, cluster numbers were mapped, and boundaries between similar and dissimilar areas were located. The net result was a map showing areas similar to Manaoag during both transitions, and similar in only one of the transitions (Fig 4).



4. Areas with dry-wet and wet-dry transitions similar to those of Manaoag, Philippines.

a map showing areas similar to Manaoag during both transitions, and similar in only one of the transitions (Fig. 4).

Rainfall patterns: annual recurrences. Empirical probabilities of selected rainfall variables during the transition periods would help judge the likely performance of cropping patterns over years, and aid in designing and testing potential replacement patterns.

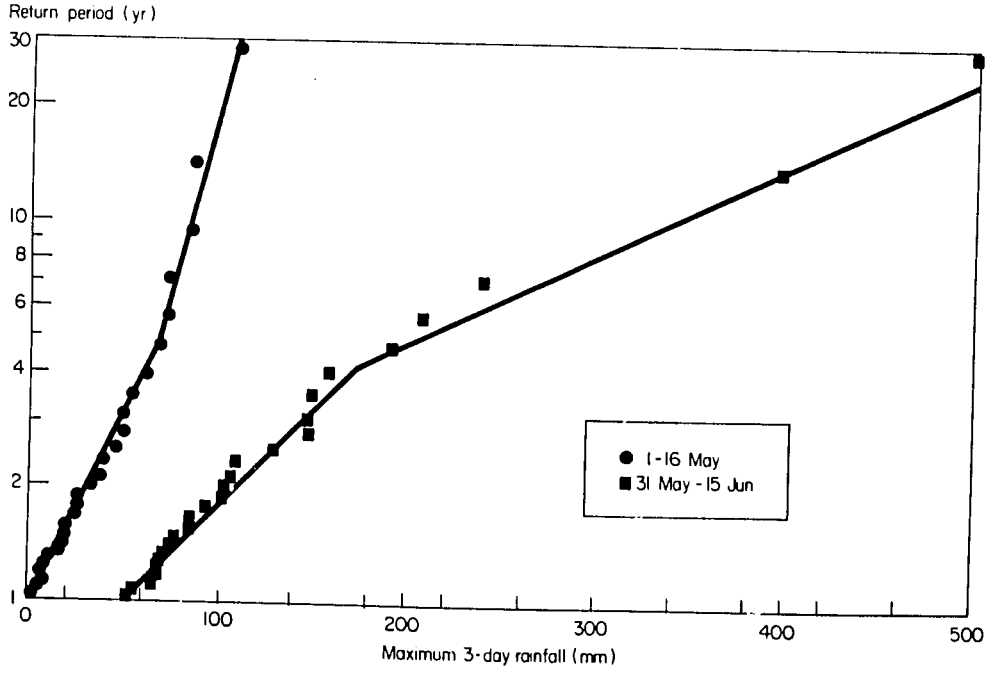
The dry-wet transition period. During the dry-wet transition, moderate rainfall within a sequence of 3 or fewer days produces a soil surface that is moist. Isolated light rains do not infiltrate the soil profile, and are quickly evaporated. Assuming that at least one 30- to 35-mm shower would fall in a 3-day period and that it would effectively moisten the previously dry soil, and that about 70% of the rain from other showers during the 3-day period would be lost by evaporation, leaving a total of 30-35 mm stored in the soil, a rainfall total of 50 mm/3-day period was set as the lower criterion.

Because it was judged too difficult to discriminate between occasional periods of heavy showers in an otherwise dry period and a few days of heavy rains in protracted rainy period, and too risky to assume the latter, no upper limit was established.

The expected frequency, in 2 or 3 days during the interval when a dry-seeded rice crop would be established, of rains totaling at least 50 mm/3 days was to be determined.

The wet-dry transition period. By assuming that only 25 mm rainwater could be safely stored in the 0-30 cm layer, that 20 mm could be stored in the 30-50 cm layer, that no significant amount of water would infiltrate below 50 cm, and that 5 mm would be lost by evapotranspiration each day of the 3-day period, any rainfall above 100 mm/3 days would have to fill macropores or be stored on the surface, leading to crop damage. As criteria for the late wet-monsoon period, 25 and 100 mm/3 days were used. The former is a level set in view of moisture requirements for emergence and the latter is set in view of the damaging effects of a brief period of heavy rains on a soil that is partially depleted in the root zone but near saturation below 50 cm.

Approximate probabilities for key transition period variables were determined by recurrence analysis. Long-term records from Cabanatuan (1950-78) and Dagupan (1949-75) were used for the analyses. Probabilities were calculated from



5. Return periods for maximum 3-day rainfall totals from 1--16 May and 31 May--15 June. Dagupan, Philippines.

Table 6. Return period plotting points for several Cabanatuan (Philippines) weather variables.

Return period (yr)	Ranked max rainfall total (mm) for 1 and 3 days, dry-wet transition						Ranked max rainfall total (mm) for 1 and 3 days, wet-dry transition					
	1–16 May		1–31 May		1 May–15 Jun		15 Oct–30 Nov		1–30 Nov		1 Nov–15 Dec	
	1 day	3 days	1 day	3 days	1 day	3 days	1 day	3 days	1 day	3 days	1 day	3 days
1.03	0	0	9	9	19	22	4	4	0	0	0	0
1.07	0	0	10	13	23	32	8	8	8	8	8	8
1.11	0	0	15	19	23	40	8	10	8	10	12	14
1.15	0	0	17	21	35	42	12	13	10	13	13	18
1.20	1	1	19	22	40	48	15	23	12	14	14	23
1.25	2	2	21	26	43	52	22	33	13	23	15	23
1.30	2	2	22	30	44	61	28	39	14	23	20	24
1.37	2	3	25	43	49	66	30	48	15	24	22	26
1.43	10	13	26	47	49	68	31	51	20	26	22	30
1.50	16	17	31	52	50	71	33	53	22	30	23	33
1.58	16	17	35	54	53	81	40	60	23	33	28	45
1.67	17	17	41	57	53	81	50	70	28	45	28	48
1.76	17	18	43	61	56	83	50	77	31	48	31	51
1.88	17	19	46	62	58	84	51	79	33	51	33	62
2.00	19	24	49	62	62	85	52	80	40	58	40	65
2.14	19	24	50	67	63	94	56	81	50	70	50	70
2.31	22	36	51	70	71	110	61	86	50	79	51	79
2.50	32	41	53	71	71	120	65	90	51	80	52	80
2.73	32	44	56	74	74	125	76	96	52	81	61	81
3.00	35	47	58	77	80	125	79	104	61	84	62	84
3.33	39	57	61	83	81	126	85	107	62	90	76	104
3.78	41	61	62	85	81	132	86	1[illegible]	76	104	79	107
4.29	43	71	62	92	82	137	93	149	79	107	85	107
5.00	43	77	74	95	87	149	94	161	85	107	93	145
6.00	53	80	80	120	100	160	98	161	93	149	94	149
7.50	62	85	87	126	185	210	122	169	94	161	98	161
10.00	80	95	100	132	197	334	124	183	98	161	122	161
15.00	87	120	197	334	226	583	145	196	122	169	139	169
30.00	100	126	226	583	526	600	231	306	145	183	145	183

the Weibull plotting formula:

$$W = \frac{m}{n+1}$$

where m is the rank of observation (in descending order) and n the number of years of observations. Recurrence diagrams were constructed using routine plotting procedures.

Comparisons of maximum 1-, 2-, and 3-day rainfall totals showed that there was little difference between point positions of 2- and 3-day totals. The 2- and 3-day totals fell to the right of the 1-day totals, reflecting the accumulation of rainfall during the passage of tropical cyclones. The lower points tended to follow a straight line, but the higher points drifted to the right, suggesting the involvement of two distributions, one for the frequent but relatively light transition-period showers and another for the infrequent but relatively heavy tropical cyclone rains. The drift was most noticeable for the longer, later dry-wet transition data, as illustrated by the contrast in Dagupan points for 1-15 May and 31 May-15 June (Fig. 5). Plotting the log of rainfall for the 1 May - 15 June data made the relationship more nearly linear. Because of the nature of rainfall patterns in the area, subsequent interpretations for cropping patterns in both the dry-wet and wet-dry transitions were based on 3-day totals, which were more meaningful agronomically than a 1- or 2-day total. Moreover, the differences between 1-, 2-, and 3-day totals were small at the lower end of the rankings, making the agronomic significance of a choice among 1-, 2-, or 3-day totals rather unimportant in the low range. Table 6 contains the Cabanatuan plotting points for:

- maximum 3-day rainfall totals for 1-16 May, 1-31 May, and 1 May-15 June and

Table 7. Return period plotting points for several Dagupan (Philippines) weather variables.

Return period (yr)	Ranked max rainfall total (mm) for 1 and 3 days, dry-wet transition						Ranked max rainfall total (mm) for 1 and 3 days, wet-dry transition					
	1-16 May		1-31 May		1 May–15 Jun		15 Oct–30 Nov		1–30 Nov		1 Nov–15 Dec	
	1 day	3 days	1 day	3 days	1 day	3 days	1 day	3 days	1 day	3 days	1 day	3 days
1.04	2	3	5	7	29	51	10	10	3	3	5	5
1.08	4	5	16	37	36	56	13	17	5	5	8	8
1.12	5	7	28	35	38	66	16	21	8	8	8	14
1.17	6	7	29	39	39	68	17	22	8	14	11	14
1.22	7	9	33	39	40	69	18	26	11	16	13	16
1.27	11	11	33	43	49	70	18	28	13	17	14	17
1.33	12	16	36	45	50	72	25	29	14	18	14	18
1.40	13	18	37	45	51	76	28	30	15	18	15	18
1.47	16	19	38	48	55	79	28	33	15	18	15	18
1.55	20	20	39	51	56	86	30	34	17	19	17	19
1.65	23	25	40	55	56	86	31	38	17	22	17	22
1.75	24	26	41	56	57	95	31	40	18	23	18	23
1.87	26	27	43	66	64	103	34	41	18	29	18	29
2.00	27	33	46	66	65	104	34	43	25	32	25	32
2.15	27	39	47	69	65	108	34	43	30	33	30	33
2.33	29	40	49	70	70	110	34	43	30	34	30	34
2.55	34	46	50	72	71	131	35	53	31	38	31	38
2.80	39	51	56	76	74	149	38	53	31	41	34	41
3.11	40	51	56	86	84	149	43	53	34	43	38	43
3.50	40	56	58	87	93	151	46	64	38	53	39	53
4.00	41	63	65	93	121	160	49	68	39	62	46	62
4.67	46	69	65	108	128	193	52	69	46	64	50	64
5.60	50	74	70	110	144	208	64	93	50	68	52	68
7.00	55	76	71	149	170	239	68	98	52	69	58	69
9.33	56	86	74	151	188	382	82	159	64	69	64	86
14.00	71	89	188	208	196	397	142	176	68	98	68	98
28.00	74	110	332	502	332	502	153	223	142	176	1[illegible]2	176

- maximum 3-day rainfall totals for 15 October-30 November, 1-30 November, and 1 November-15 December. The corresponding plotting points for Dagupan are shown in Table 7.

Soils. To determine the distribution of soils similar to those in Manaoag, physical descriptions and analytical data of soils in Pangasinan, Tarlac, and Nueva Ecija provinces were obtained from reconnaisance-level land and soil studies conducted by government agencies. Selected physical and chemical characteristics of the major soils found in the three provinces are shown in Table 8. The descriptions and data were compared with those for the Manaoag cropping systems research site. Three soil properties — dominant soil texture in the profile, drainage class, and organic matter content — were used to construct soil suitability groups for rainfed wetland rice-based cropping systems.

Soil texture. Four soil classes based on dominant profile texture were formed:

1. *Light* — soils with sand (s), fine sand (fs), or loamy fine sand (lfs) as dominant texture.
2. *Medium light* — soils with sandy clay loam (scl), clay loam (cl), or loam (l) as dominant texture.
3. *Medium heavy* — soils with silty loam (sil), silty clay loam (sicl), or clay loam (cl) as dominant texture.
4. *Heavy* — soils with silty clay (sic) or clay (c) as dominant texture.

Drainage. Four drainage classes were established:

1. *Well to excessive* — soils with no impediment to internal drainage throughout the soil profile, and generally brown to very dark gray-brown surface soil colors with none to few mottles that have high chroma.
2. *Moderately well* — soils with some internal

Table 8. Description and analytical data of soils in Pangasinan, Tarlac, and Nueva Ecija, Philippines.[a]

Soil type	Dominant profile texture	Color		Mottles	Drainage class	pH	OM (%)
		Surface	B-horizon				
Angeles fsl	sil	Gray brown	Gray	Few	Well to excessive	7.9	0.2
Annam cl	sic	Brown	Gray	Abundant	Poor	6.5	1.8
Bantog cl	c	Very dark gray	Grayish brown	Abundant	Poor	6.2	2.0
Bantog sil	cl	Brown to dark brown	Dark brown to light brown	Few	Poor	6.0	1.5
La Paz fs	fs	Gray brown	Gray	Few	Well	6.2	0.1
La Paz fsl	s	Dark gray	Dark gray brown	Few	Well	6.0	1.0
Luisita fs	sl	Dark brown		None	Excessive	–	0.2
Luisita fsl	sil	Very dark gray	Light gray	None	Well	6.9	1.8
Luisita sl	scl	Dark gray brown	Dark gray brown	Few	Moderate	5.5	1.2
Maligaya cl	c	Dark brown to brown	Dark brown to light brown	Few	Poor	5.6	1.8
Maligaya sil	sicl	Dark brown to brown	Light brown to gray brown	Few	Poor	7.0	1.8
Quingua sicl	sicl	Dark to pale brown	Dark to pale brown	Few	Moderate	6.3	1.7
Quingua sil	l	Dark gray	–	Few	Well	5.8	2.5
San Fabian cl	cl	Gray	Brown	Few	Poor	5.0	2.0
San Fernando c	c	Dark gray	Dark brown	Abundant	Very poor	6.8	1.5
San Manuel cl	c	Very dark gray	Dark to pale brown	Few	Moderate	7.3	1.2
San Manuel fsl	lfs	Brown	–	None	Well	6.0	1.8
San Manuel sicl	sicl	Brown to dark brown	Brown to dark brown	Abundant	Very poor	6.0	1.6
San Manuel sil	l	Very dark gray brown	Gray brown	Few	Very poor	7.0	1.2
Tarlac cl	cl	Dark gray	Grayish brown	Few	Poor	6.3	1.5
Tarlac scl	scl	Very dark gray brown	Dark gray brown	Few	Moderate	6.5	1.2
Umingan sil	sil	Dark gray	Brown	Abundant	Very poor	6.5	2.0
Zaragoza c	c	Dark gray	Grayish brown	Abundant	Very poor	5.4	2.4

[a] fsl = fine sandy loam, cl = clay loam, fs = fine sand, s = sand, sicl = silty clay loam, scl = sandy clay loam, c = clay, l = loam, sil = silty loam, sic = silty clay.

drainage restrictions due to a slowly permeable layer or a moderately high water table during the wet season, seepage from higher land , or a combination of these conditions. Surface soil colors range from very dark brown to very dark gray brown, with few dark red-brown to yellowish-brown mottles.

3. *Poor* — soils with fine texture, formation of a clay pan or hard pan, high water table at or near the surface during the rainy season, or seepage from higher ground, or a combination of these conditions. Surface-soil color ranges from very dark brown to very dark gray.
4. *Very poor* — soils with a water table at or near the surface for an extended period, because of layers that tend to drastically reduce percolation or low landscape position or both. The layer may be a hardpan, a clay pan, or a high clay horizon relatively close to the surface. The dominant surface color is dark gray with prominent clear yellowish-red mottles.

Organic matter. Soils were classified into three organic matter classes:

1. Low, < 1%
2. Medium, 1-2%
3. High, > 2%

Organic matter content was used to make adjustments in the classification of some soils that did not seem to fit the suitability classification on

Table 9. Suggested cropping patterns for suitability groups in rainfed conditions in Pangasinan, Tarlac, and Nueva Ecija, Philippines.[a]

Suitability group	Soils[a]	Suggested pattern[b]
1	Luisita fs, La Paz fs, San Manuel fsl, Angeles s	Upland crops
2	Quingua sil, La Paz fsl Angeles fsl, Quingua l	DSR-peanut GC-TPR-mung
3	Luisita sl, Luisita fsl Tarlac scl, Quingua sicl	DSR-peanut GC-TPR-mung
4	Tarlac cl, San Manuel sicl, San Manuel sil, San Fernando cl, Annam cl, San Fabian cl, Maligaya sil, Maligaya cl, San Manuel cl, Bantog sil	DSR-mung DSR-ratoon mung
5	Umingan sil, Bantog cl San Fernando c, Zaragoza c, Prenza sil	DSR-TPR

[a]fs = fine sand, fsl = fine sandy loam, s = sand, sil = silty loam, l = loam, scl = sandy clay loam, sicl = silty clay loam, cl = clay loam, c = clay.
[b]DSR = dry seeded rice, TPR = transplanted rice, GC = green corn (maize).

the basis of texture and drainage characteristics. For example, Quingua sil, with loam as the dominant profile texture, would normally be placed with other soils of medium-light texture and well-drained profiles. Because the Quingua sil had higher organic matter content than other soils in the group, it was moved into a moderately well-drained suitability group with medium-to-high organic matter content and medium-heavy soil texture.

Suitability groups for each soil are shown in Table 9. Not all combinations of texture and drainage are represented in the groups. A heavy textured soil with good to excessive drainage and light-textured soils with poor drainage were not found. In suggesting cropping patterns adapted to the suitability groups, a rainfall distribution similar to that in Manaoag was assumed — 3-4 wet months of not less than 200 mm rainfall/month and 5-6 dry months of not more than 100 mm.

Suitability group 1 — light textured, well to excessively drained soils that do not accumulate water, even at the peak of the wet season. These soils are not suitable for rice-based cropping systems.

Suitability group 2 — medium light-textured, well-drained soils that require a long period of rainfall to become fully recharged before 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, mungbean (or peanut) can be planted after a deep, rough plowing to increase infiltration capacity.

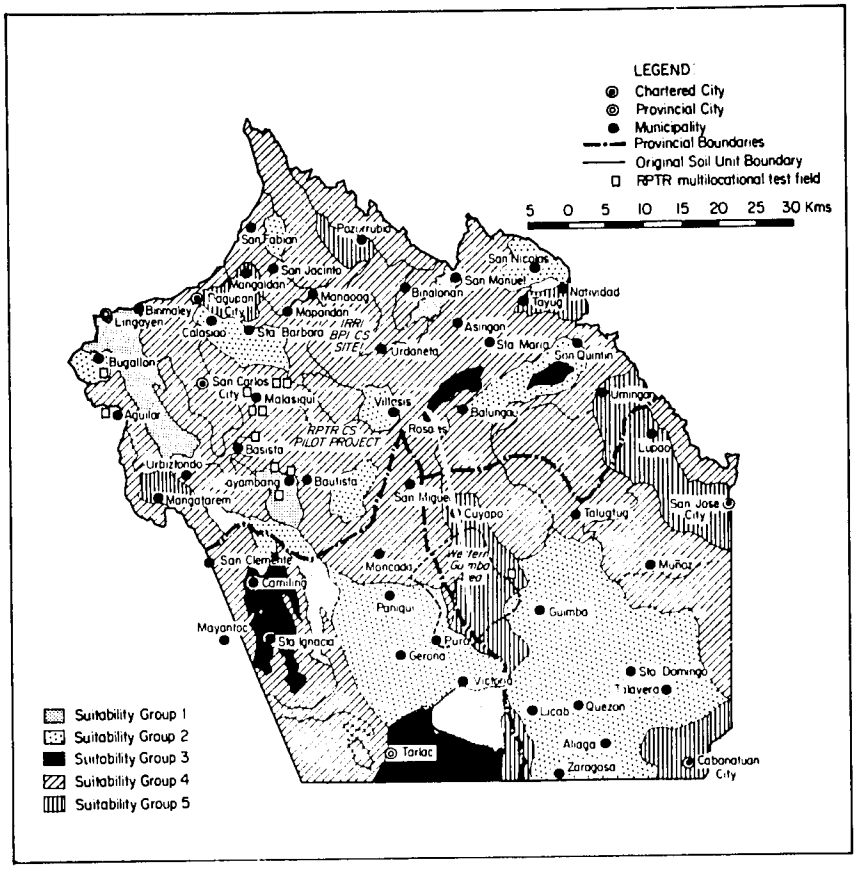
Suitability group 3 — medium, light-textured, moderately well-drained soils that flood earlier than soils in group 2. Although the same pattern described for suitability group 2 is suggested for this group, peanut planted shortly after rice harvest risks damage by late heavy rains. Rice crops in Group 3 should be subjected to less drought stress than those in Group 2.

Suitability group 4 — medium heavy-textured, poorly drained soils that flood earlier and remain excessively wet for dryland crops, compared with suitability Group 3 soils. The suggested basic pattern is DSR-mung but a variety with a duration somewhat longer than that of IR36 could 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 too wet to plant mungbean.

Suitability group 5 — heavy-textured, poorly and very poorly drained soils that remain too wet for dryland crops for a long period. Furthermore, heavy, poorly structured subsoils will often be unfavorable for the extensive root development important to dryland crop production. A double-rice crop 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. For the second crop, 34-day-old seedlings should be transplanted into puddled soil. To assure early DSR planting the following year, fields should be rough-plowed after TPR harvest.

The distribution of the soil suitability groups is shown in Figure 6. The boundaries on the map represent the predominant suitability group within the enclosed area, but other suitability groups will be found within the same area, sometimes in high proportions.

Irrigation systems. Because they affect field water regimes, water deliveries in irrigation systems were compared with typical field schedules of cropping patterns for rainfed and partially irrigated crops at the Manaoag site. At Manaoag, irrigation was necessary to obtain moderate to high TPR and mungbean yields in the DSR-TPR-



6. Soil suitability groups in the North Central Luzon Valley, Philippines.

mung pattern. In the DSR-mung pattern, satisfactory yields of both crops were achievable with rain alone as water source but irrigation assured a high mungbean yield potential.

The objective of the irrigation component study was to identify irrigation systems with regimes similar to the Lipit-Pao communal system regime, which delivers water from June to December, but with the September-December deliveries becoming progressively less reliable. Data on command areas and monthly delivery rates were obtained from the National Irrigation Administration (NIA) and provincial irrigation offices in Pangasinan, Tarlac, and Nueva Ecija.

Major gravity systems. The NIA operates 7 major gravity irrigation systems in the northern portion of the valley, covering a potential area of 133,000 ha (Table 10). The areas covered by the seven NIA systems are in Figure 7. On the basis of available data, the percentage area that could be irrigated, assuming one of three water delivery rates (1.0, 1.3, and 1.6 cm/ha per day, which correspond to rates of 1.15, 1.50, and 1.85 liters/sec per ha), was calculated on a monthly basis for each of the major NIA systems. The systems grouping was based on delivery patterns:

Group 1 — Upper Pampanga River Irrigation System (RIS), Districts 1, 2, and 3

Group 2 — Camiling RIS, Agno RIS, San Fabian RIS, and Domuloc (extension of San Fabian RIS)

Group 3 — Tarlac RIS, Ambayoan RIS, Dipalo (extension of Ambayoan RIS), and Lower Agno RIS.

The percentages of area served by the water system are shown as seasonal water-delivery patterns in Figure 8.

Topographic, soil, and water table factors will

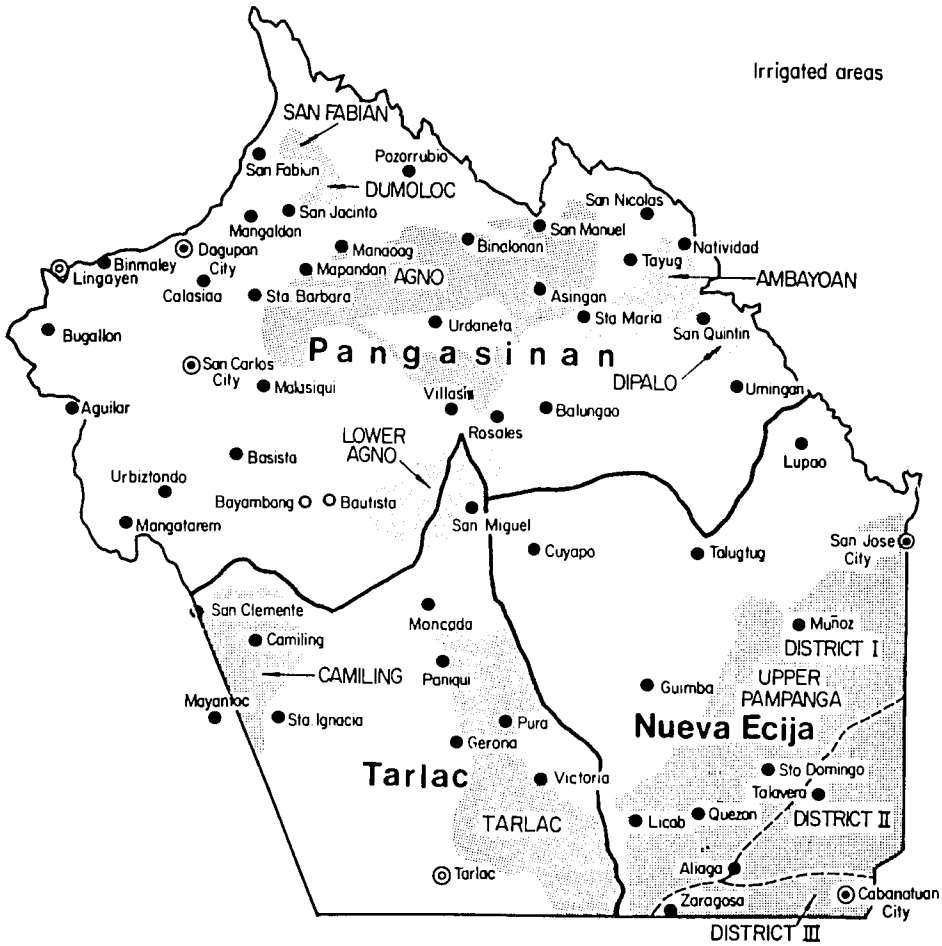
Table 10. National irrigation systems in the northern portion of Central Luzon Valley, Philippines.[a]

Irrigation system	Province	Command area (ha)
Upper Pampanga River District 1	Nueva Ecija	24,300
Upper Pampanga River District 2	Nueva Ecija	25,080
Upper Pampanga River District 3	Nueva Ecija	5,170[b]
Camiling River	Tarlac	4,630[b]
Tarlac River	Tarlac	8,010
Agno River	Pangasinan	18,510
Ambayoan-Dipalo River	Pangasinan	6,400
Lower Agno River	Pangasinan-Tarlac	9,450
San Fabian River	Pangasinan	4,170
Total		105,720

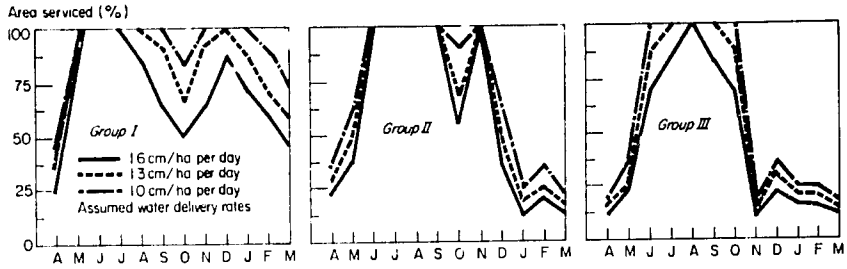
[a]Sources: National Irrigation Administration evaluation reports and working maps. [b]Approximate portion within the map boundary (Fig. 7).

modify water regimes that are otherwise determined principally by irrigation deliveries, and, therefore, lead to local deviations from the predominant patterns adapted to the area. Likewise, socioeconomic factors will determine the comparative advantage of other patterns (particularly the upland crop component) and also cause deviations.

Communal and other small systems. In addition to the NIA gravity systems, more than 350 small systems operated in the area, mostly on a communal basis and each generally covering less than 300 ha. Data available on the annual water delivery pattern of the small systems were meager, and the actual service areas not accurately determined. Nevertheless, the total area covered by these systems was about 70% of the area covered by the



7. Areas covered by large National Irrigation Administration irrigation systems in the northern portion of Central Luzon Valley, Philippines.



8. Estimated percentages of areas serviced by the system during the year, North Central Luzon Valley, Philippines.

large systems. Most of the small systems derived their water from streams and small rivers, and were rainfall pattern dependent. Most were expected to behave like the major system in Group 3, and the DSR-mung pattern was likely to be best adapted to most fields, and the DSR-TPR-mung pattern an alternative for a small percentage of fields located close to water sources.

Irrigation coverage for large and small systems totaled about 175,000 ha. Deducting the area covered by Group 1 from 175,000 and assuming 20% of the remainder as fully irrigated gave an area of about 90,000 ha covered by partial irrigation. Annual water-delivery patterns in the major systems and the strong reliance by communal systems on rainfall patterns suggested that in many systems, water would be in short supply during transition from the wet season to the dry and during the early dry season, and unavailable in all fields except those close to water sources throughout the dry season.

Under such seasonal water regimes, farmers could find the DSR-mung pattern a viable alternative to single rice crops now grown where water is not delivered beyond late September, and the DSR-TPR-mung a viable alternative to two TPR crops grown in areas where water is delivered up to December or January.

The 1979 approach to target-area determination was not objectively tested but it appeared to be a sound initial approximation. Use of the procedure was started for target areas for the Iloilo site and in the Cagayan Valley (Solana).

Cropping systems program

Design of cropping patterns

Multiple Cropping Department and Cropping Systems Component of the Entomology Department

A SECOND RAINFED WETLAND RICE CROP 398
YIELD LOSSES TO INSECT PESTS 400
Dry-seeded rice 400
Wet-seeded rice 400
Single transplanted rice 400
Second crop transplanted rice 403

A SECOND RAINFED WETLAND RICE CROP

Multiple Cropping Department

The double-cropping of short-duration varieties in wetland rainfed areas of central and southern Philippines has proved viable but production of the second crop has been lower and more variable (Table 1). Table 2 illustrates a variability in yield in planting-date experiments in both a drought year (1977) and a more normal year. Not only was 1977 a drought year but the first crop was also planted late because of a delayed onset of rains. Yield loss due to late planting ranged up to 140 kg/ha for each day that planting was delayed. A further penalty of late planting was declining returns to nitrogenous fertilizer application (Table 3).

In 1979 a crop simulation was assembled from 3 years of crop and soil water data. Figures 1 and 2 give examples of the water balance for two sites during the 1978-79 trials at Iloilo. The simulated values were generated from field data for each of the components in the equation:

$$SW_t = SW_{t-1} + RF - ET_a - SP + CP$$

where SW is soil water measured as depth of standing water or volumetric soil moisture in the top 30 cm of the soil profile and RF is rainfall.

ET_a is actual evapotranspiration equal to maximum evapotranspiration when standing water is present. Measurements taken from tank lysimeters indicated an average crop factor, against class A pan evaporation of 0.9-1.0. When the soil was below saturation, evaporation was treated as a fraction of the maximum according to the amount of soil moisture remaining. At the sites the rate of actual evapotranspiration fell below that for maximum evapotranspiration when the soil was just below saturation in the clay soil, but started its decline at a lower soil moisture for the lighter soil (Fig. 3).

Table 1. Yields of double-cropped rainfed rice in Iloilo, central Philippines, 1975–78.[a]

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

[a]From the Philippine Bureau of Plant Industry–International Rice Research Institute cropping systems outreach site.

Table 2. Effect of planting date on grain yield of IR36 in Iloilo, Philippines, 1977 and 1978 crop years.

Planting date[a]	Grain yield (t/ha)	
	Plateau	Plain
1977		
19 Oct	0.2 a	1.2 a
2 Nov	0.0 b	0.0 b
16 Nov	0.0 b	0.0 b
1978		
Early planting		
1 Sep	3.4 a	4.2 b[b]
15 Sep	2.9 ab	3.2 c[c]
2 Oct	2.8 ab	4.0 b[c]
14 Oct	2.5 b	5.0 a
Late planting		
18 Oct	2.3 a	4.2 a
4 Nov	1.9 a	4.0 a
12 Nov	0.7 b	2.5 b
30 Nov	–	0.0 c

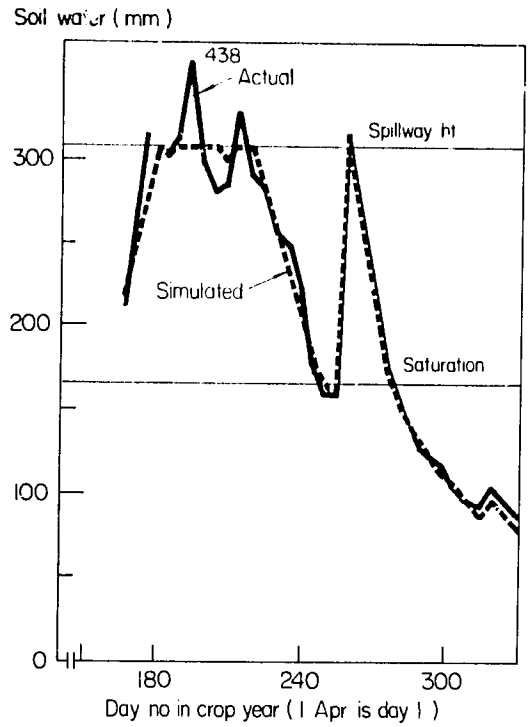
[a]For each year for early and late plantings in either column, separation of values by LSD, 5% level. [b]Infected by leaf scald. [c]Flood damaged shortly after planting.

SP is seepage and percolation, treated as a constant 0.5 mm/day for simulation purposes, but in reality fluctuating between -3.5 mm/day and 3 mm/day. The fluctuations in seepage and percolation values were resolved by measuring the two factors separately through dike seepage and perco-

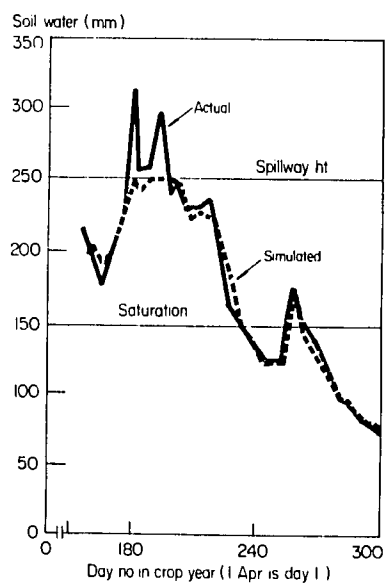
Table 3. Effects of planting date and rate of nitrogenous fertilizer on grain yield of IR36. Iloilo, Philippines, crop year 1978.

Nitrogen level (kg N/ha)	Grain yield[a] (t/ha) when crop was planted on							
	1 Sep	15 Sep	2 Oct	14 Oct	18 Oct	4 Nov	12 Nov	30 Nov
0	3.7 c	2.7 b	3.4 b	4.0 c	3.2 c	3.4 b	2.6 a	0 a
30	4.1 bc	3.1 ab	4.1 a	4.7 b	4.3 b	4.1 a	2.5 a	0 a
60	4.3 ab	3.3 ab	4.1 a	5.4 a	4.4 b	4.3 a	2.5 a	0 a
90	4.9 a	3.7 a	4.5 a	5.8 a	5.1 a	4.3 a	2.5 a	0 a
								CV = 13%

[a]Separation of means by LSD, 5% level.



1. Actual and simulated soil water balance for the plain position from 10 September 1978 to 9 February 1979, Iloilo, Philippines.



2. Actual and simulated soil water balance for the plateau position from 4 September 1978 to 31 January 1979, Iloilo, Philippines.

lation. With paddy-to-paddy seepage in equilibrium, as in a broad plain, seepage and percolation values tended toward that for percolation alone.

Capillary rise (CP) was computed from a family of curves for rate of upward water movement versus groundwater level according to soil type.

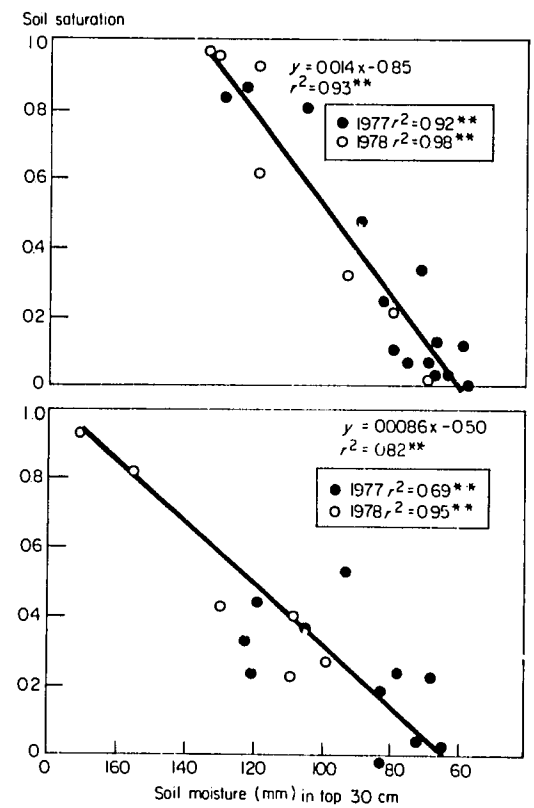
Yield estimates were derived according to the equations:

$$DM = TR \times T$$

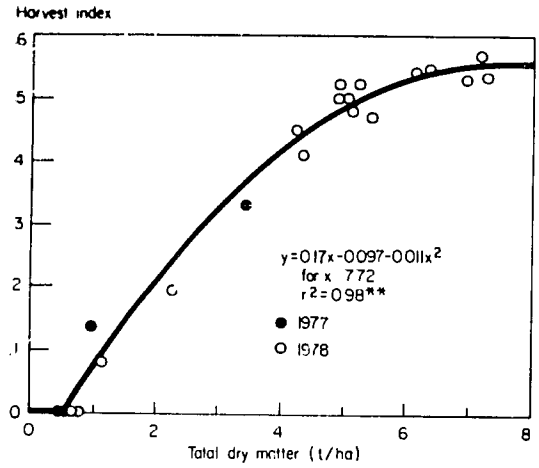
where DM is dry matter, accumulated daily. TR is transpiration ratio, and T is the crop transpiration. The transpiration ratio was corrected according to prevailing evaporative demand. Transpiration was accumulated daily as a fraction of ET_a according to the fraction of the canopy cover.

$$Y = DM \times HI$$

where Y is grain yield at ovendry weight and HI is



3. Relationship of actual and maximum evapotranspiration to soil moisture for silty clay loam (top) and clay (bottom). Crop years 1977-78, Iloilo, Philippines.



4. The relationship between harvest index and total dry matter for IR36 used in yield simulation of the second rainfed wetland rice crop. Iloilo, Philippines, 1978-79.

harvest index, which declined with dry matter at lower yield levels (Fig. 4). Grain yield was finally adjusted to 14% moisture content. A selection of estimated yields from the crop simulation were compared with actual rice yields (Table 4) from the cropping pattern trials at the Iloilo cropping systems outreach site.

YIELD LOSSES TO INSECT PESTS

Cropping Systems Component of Entomology Department

Yield responses to insecticide were calculated in cropping pattern trials in Iloilo and Pangasinan for 1975-79 (Table 5), and key insect pest populations were determined. The results are used to establish insect control recommendations for each crop in the cropping patterns

Dry-seeded rice. Highly variable year-to-year yield losses for Iloilo and Pangasinan were not entirely attributable to insect damage but to the differential dosages of carbofuran used each year: 1.5 kg a.i./ha in 1977, 1 kg a.i./ha in 1978, and 0.5 kg a.i./ha in 1979. Carbofuran has a direct effect on rice growth at dosages higher than 1 kg a.i./ha. Yield responses came only from rice that received vegetative-stage protection in all cases, even though late-season pests — *Tryporyza innotata* causing whiteheads, *Cnaphalocrocis medinalis*, and *Leptocorisa* — at times surpassed economic injury levels. The lack of yield response from plants that were protected at the reproductive and ripening stages was attributed either to inadequate technology to prevent whiteheads or to the leaf folder and rice bug's extremely low economic injury levels. In Pangasinan, dry-seeded rice escaped pest buildup because of the early planting date.

Even though carbofuran granules applied in seed furrows before sowing produced dramatic yield responses in 1977, the cost of applying 1.5 kg a.i./ha is considered excessive.

Wet-seeded rice. Early planting enabled the plants to escape insect pest buildup in the wet-seeded first rice crop. In years when plant establishment occurred in May or June, insect populations were below economic thresholds. Significant yield losses were recorded only in 1978 and 1979 on late-planted crops in Iloilo. These late plantings behaved more like a single rice crop in terms of the observed insect pests. A normal planting date saved a wet-seeded first rice crop from pest buildup.

Because key pests were highly variable in their year-to-year occurrence, a prophylactic insecticide treatment was not warranted.

Single transplanted rice. In Pangasinan the yield responses of single-crop transplanted rice were consistent over the 4-year period. The pest problems increased with the advance of the wet season. The occurrence of key pests — whorl maggot,

Table 4. Simulated and actual yields of the second rainfed rice crop in Oton-Tigbauan, Iloilo, Philippines, 1975 and 1976.

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

Table 5. Yield responses to insecticide and key insect pests from cropping patterns in Iloilo and Pangasinan, Philippines, 1975–79.

Variety	Year	Month planted	Fields (no.)	Yield (t/ha)		Yield loss			Key insect pests[b]
				Protected	Unprotected	t/ha	%	$/ha[a]	
				First rice crop, dry seeded – Pangasinan					
IR36	1977	May	8	6.3	5.5	0.8*	13	121	*C. med.*
IR36	1978	May–June	6	3.5	3.6	0	0	0	None
IR36	1979	May	6	4.4	4.1	0	0	0	None
				First rice crop, dry seeded – Iloilo					
IR36	1977	June	4	5.5	3.9	1.6*	29	241	*T. inn.* WH, *C. med.*
IR36	1978	April–June	6	5.0	4.0	1.0*	20	151	*T. inn.* DH, WH, *Lepto.*
IR36	1979	May	5	4.0	4.0	0	0	0	None
				First rice crop, wet seeded – Pangasinan					
IR28	1976	May	4	3.7	3.9	0	0	0	*T. inc.* WH, *H. sas., N. dep., C. med.*
IR36	1979	June	4	4.5	4.5	0	0	0	None
				First rice crop, wet seeded – Iloilo					
IR28	1976	May	6	5.1	5.1	0	0	0	None
IR36	1977	July	6	5.5	4.8	0	0	0	*T. inn.* WH, *C. med.*
IR36	1978	July–August	5	5.0	3.6	1.4*	28	211	*N. dep., T. inn.* WH
IR36	1979	July	4	2.9	2.2	0.7*	24	105	*N. dep., C. med., T. inn.* WH
				Single rice crop, transplanted – Pangasinan					
IR28	1976	July	5	5.4	3.8	1.6*	30	241	*T. inc.* DH, WH, *H. sas., N. dep.*
IR36	1977	August	7	4.8	3.9	0.9*	22	136	*N. dep., T. inc.* WH
IR36	1978	August	6	3.7	2.1	1.6*	43	241	*T. inc.* WH
IR36	1979	August	6	5.6	4.3	1.3*	23	195	*H. sas., T. inc.* WH
				Second rice crop, transplanted – Pangasinan					
IR28	1976	October	5	3.4	2.6	0.8*	24	121	*T. inc.* WH, *H. sas., N. dep., Lepto.*
IR28	1976	November	2	3.8	2.3	1.5*	39	226	*T. inc.* DH, *H. sas., N. dep.*
IR36	1977	October	6	1.9	1.8	0	0	0	*T. inc.* WH
IR36	1978	October	3	2.3	1.4	0.9*	39	136	None
IR36	1979	November	5	3.5	2.9	0.6*	17	90	None
				Second rice crop, transplanted – Iloilo					
IR28	1976	October	6	5.0	3.9	1.1*	22	164	*T. inn.* DH, WH, *N. dep., Lepto.*
IR36	1977	November	4	1.8	1.4	0.4*	22	60	*T. inn.* WH, *Lepto.*
IR36	1978	November	4	3.7	2.6	1.1*	30	166	*T. inn.* WH, *Lepto.*
IR36	1978	October	4	4.7	2.3	2.4*	51	362	*T. inn.* WH, *Lepto.*

Continued on next page

Table 5 continued

				Mungbean — Pangasinan					
CES14	1975–76	December	5	1.01	0.25	0.76*	75	416	*O. ph., M. sut., T. pal., Amr., A. crac., Maru.*
CES14	1976–77	December	6	0.90	0.20	0.70*	78	384	*O. ph., M. sut., A. crac., Maru.*
CESID-21	1977–78	November	4	1.23	0.40	0.83*	67	454	*O. ph., M. sut., T. pal., A. crac., Maru.*
CES1D-21	1977–78	December	4	1.61	0.04	1.57*	98	860	*O. ph., M. sut., T. pal., A. crac., Hel.*
CES1D-21	1977–78	January	4	1.16	0.11	1.05*	91	575	*O. ph., T. pal., A. crac., Etiel.*
CES1D-21	1978–79	December	4	1.41	0.32	1.09*	77	597	*O. ph., M. sut., T. pal., A. crac., Hel.*
CES1D-21	1978–79	January	4	0.88	0.07	0.81*	92	444	*O. ph., M. sut., T. pal., A. crac., Etiel.*
CES1D-21	1979–80	December	4	1.22	0.48	0.74*	61	459	*O. ph., M. sut., T. pal., A. crac., Hel.*
				Cowpea — Iloilo					
EG2	1975–76	December	2	0.30	0	0.30*	100	82	*O. ph., T. pal., A. crac., Maru.*
EG2	1976–77	December	3	0.16	0	0.16*	100	4	*O. ph., T. pal., A. crac., Maru.*
EG2	1977–78	December	4	0.10	0.01	0.09*	90	25	*O. ph., T. pal., A. crac., Maru.*
EG2	1978–79	December	4	0.42	0.07	0.35*	83	96	*O. ph., T. pal., A. crac., Maru.*
EG2	1979–80	December	4	0.44	0.09	0.35*	80	96	*O. ph., T. pal., A. crac., Maru.*
				Sorghum — Pangasinan					
Cosor 3	1976–77	December	3	2.2	1.7	0	0	0	None
Cosor 3	1978–79	December	3	3.8	3.1	0.7*	19	192	*Hel., R. maid.*
				Green maize before rice — Pangasinan					
SG22	1976	May	3	13.4[c]	17.0[c]	0	0	0	None
Macapuno	1979	April	6	5.9	6.1	0	0	0	*O. fur.*

[a]Commodity prices used in calculation: Rice $0.15/kg, mungbean $0.62/kg, cowpea, sorghum $0.27/kg. [b]*T. inn.* = *Tryporyza innotata* (white stem borer), *C. med.* = *Cnaphalocrocis medinalis* (leaf folder), *Lepto.* = *Leptocorisa* (rice bug), *T. inc.* = *Tryporyza incertulas* (yellow stem borer), *H. sas.* = *Hydrellia sasakii* (whorl maggot), *N. dep.* = *Nymphula depunctalis* (caseworm), DH = deadhearts, WH = whiteheads, *O. ph.* = *Ophiomyia phaseoli* (beanfly), *M. sut.* = *Medythia suturalis* (flea beetle), *T. pal.* = *Thrips palmi* (thrips), *Amr.* = *Amrasca biguttula* (leafhopper), *Maru.* = *Maruca testulalis* (bean pod borer), *Hel. Heliothis armigera* (corn earworm), *Etiel.* = *Etiella zinckenella* (lima bean pod borer), *O. fur.* = *Ostrinia furnacalis* (Asian corn borer), *R. maid.* = *Rhopalosiphum maidis* (maize leaf aphid). [c]No. marketable ears/ha.

caseworm, and yellow stem borer — was inconsistent from year to year. Because the yield responses were highly variable in terms of the growth stages affected, prophylactic insecticide treatments were not recommended.

Second crop transplanted rice. Despite the year-to-year yield variability due to drought, the second crop transplanted rice had a consistent response to soil-incorporated carbofuran. In most years, the stem borer and rice bug attacked in the later growth stages. The conclusion was that most of the yield increase came from a direct effect on rice growth rather than from insect control.

Late-season stem borer damage was consistent between years and sites, and control was warranted on crops yielding more than 3 t/ha. Although the rice bug was present on the late-planted rice, no yield increase was associated with its control.

Mungbean. Highly significant mungbean yield losses consistently occurred during both the preflowering (bean fly, flea beetle, thrips) and postflowering (pod borers, aphid) stages. There were some shifts in the pod borer species with the different months of planting but the recommendation remained the same — 0.25 kg a.i. monocrotophos/ha 2 and 12 DE, and 0.75 kg a.i. carbaryl/ha 25 and 35 DE. There was increasing evidence that *Thrips palmi* caused economic damage to mungbean.

Cowpea. Insect pests caused consistently high cowpea yield losses in both the preflowering (bean fly, thrips) and postflowering (aphid, pod borer) stages. The insect control recommendations were the same as those for mungbean.

Sorghum. Corn earworm and corn leaf aphid, the key insect pests of sorghum, were not consistent from year to year and were effectively controlled with a corrective application of 0.75 kg a.i. carbaryl/ha based on need.

Green maize before rice. There was no yield response to insecticide protection against the principal pest of maize, the Asian corn borer, whose populations were generally low.

Cropping systems program

Testing of cropping patterns

Cropping Systems Components of the Agricultural Economics and Entomology Departments

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ANALYSIS OF PATTERN TESTING

Cropping Systems Components of the Agricultural Economics and Entomology Departments

Tests of cropping patterns in Pangasinan have indicated that yields resulting from a given level of material and labor inputs are not normally distributed about the mean. Thus, analyses based on the mean performance of crops in pattern trials may overestimate or underestimate the true likelihood of profitable performance.

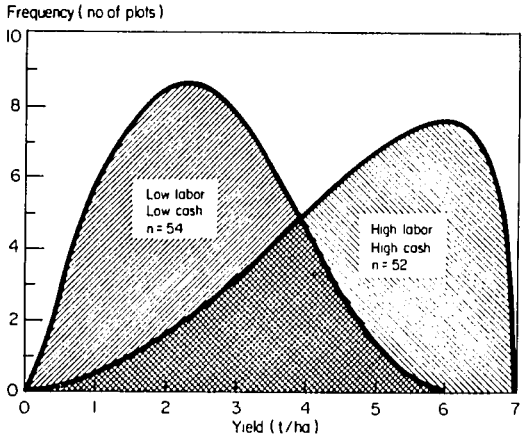
The theoretical statistical distribution of yield and profit was investigated on first and second rice crops in cropping pattern experiments in Pangasinan for the 1975-78 crop years.

Two implications of the statistical distributions were of interest:

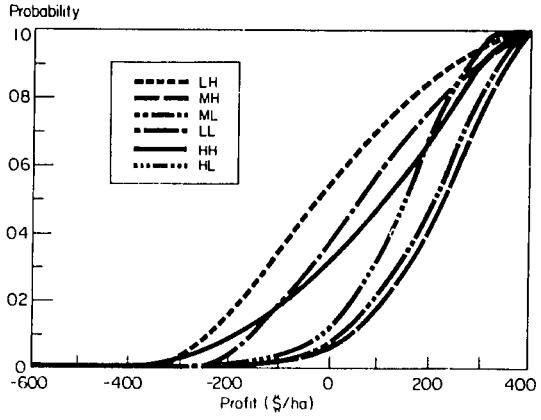
- What levels of technology appear to offer higher probabilities of profit for future cropping pattern design?
- How might the analyses of completed experiments for cropping pattern testing be revised to reflect probabilities of profit?

Experimental data were stratified into six cells showing combinations of low, medium, and high labor inputs, and low and high material inputs. Each cell contained 20-30 observations. Theoretical distributions were fitted by the method of moments to yield and profit in each cell. Different patterns of skewness observed in each stratum varied in a regular manner. As labor increased, skewness of the yield distribution moved from positive to negative at both levels of cash inputs. Similarly, at each level of labor, increases in cash inputs increased the negative skewness of yield distributions. The extreme case of low labor and low cash is compared to the case of high labor and high cash in Figure 1.

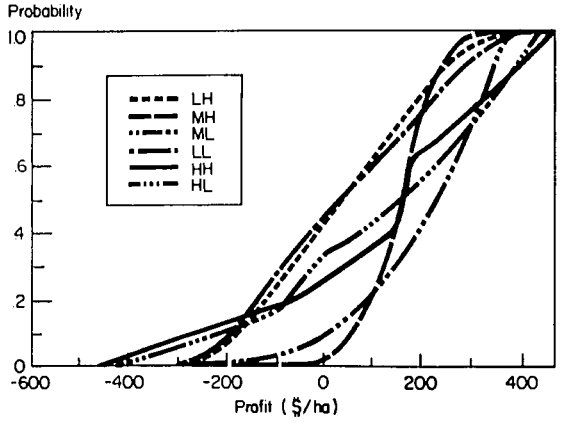
Plotted as cumulative functions, the probability distributions showed the likelihood of achieving various levels of yields and profits. Figures 2 and 3 show the cumulative probability functions for the first and second rice crops in Pangasinan, 1975-78. Data for the two crops show a similar ordering of



1. Comparison of statistical distributions fitted to frequency distributions of yields from plots on which low and high input levels were used on first rice crops, cropping pattern trials, Manaoag, Pangasinan, 1975-76 to 1977-78.



2. Cumulative density functions of profit, first crop. H = high, M = medium, L = low. Labor and cash, respectively.



3. Cumulative density functions of profit, second crop. H = high, M = medium, L = low. Labor and cash, respectively.

Table 1. Probabilities of obtaining yields less than or equal to 2 t/ha with various labor and cash inputs on first rice crops, cropping pattern trials, Manaoag, Pangasinan, Philippines, 1975–76 to 1977–78.

Cash input	Probability of obtaining yield ≤ 2 t/ha with		
	Low labor use	Medium labor use	High labor use
Low	0.38	0.02	0.01
High	0.42	0.01	0.04

Table 2. Probability of obtaining no profit with various levels of labor and cash inputs on first rice crops, cropping pattern trials, Manaoag, Pangasinan, Philippines, 1975–76 to 1977–78.

Cash input	Probability of obtaining no profit with		
	Low labor use	Medium labor use	High labor use
Low	0.38	0.07	0.14
High	0.53	0.07	0.32

functions. The results for yield and profit are summarized in Tables 1 and 2.

Low labor inputs combined with either low or high cash inputs were associated with relatively high probabilities of achieving yields of less than 2 t/ha. Other combinations of inputs had substantially lower and similar probabilities of achieving yields below the 2-t/ha minimum. Levels of technology with respect to the probability of loss were more strongly differentiated. Low levels of labor were associated with relatively high probabilities of loss. Medium levels of labor in combination with either low or high levels of cash inputs were least likely to be unprofitable.

Labor intensity was the main factor distinguishing profitable and unprofitable technologies. Low levels of management, particularly with respect to labor-intensive activities such as land preparation and weeding, were least likely to prove profitable. Medium levels of inputs offered the highest probability of profit.

Insect control recommendations *(Cropping Systems Component of the Entomology Department).* The criteria used to evaluate an insect control recommendation are profit, management limitations, farmer acceptability, compatability with other production practices, and stability over years and farms within years. The interplay of these factors was studied in the development of suitable insect control recommendations at the Pangasinan research site for the period 1975-79. Single-crop transplanted rice (TPR) and mungbean were used.

Table 3 gives the 1975-79 recommendations. The change in recommendations reflects the dynamic process involved in control of insects. A benefit-cost ratio > 2 was established as the point of attractiveness of insecticide usage for farmers.

Carbofuran application at the vegetative stage of TPR was recommended from 1975—78 against whorl maggot, caseworm, and stem borer (deadhearts), all common on the crop in Pangasinan. Even with low insect populations, there was a benefit from carbofuran. The dosage was reduced from 2 kg a.i./ha in 1975-76 to 1 kg a.i./ha in 1978-79, through a change in the method of application. Placing the granules in the root zone gave higher efficiency. Sprays were used in rainfed areas where carbofuran or other granules are not effective during the late season because of the low paddy water levels (< 5 cm) and the difficulty of incorporating carbofuran into the root zone after transplanting. Monocrotophos was not profitable in 1975-77 because of its high cost, and endosulfan was substituted in 1979 as the cheapest recommended sprayable insecticide for stem borers. Benefit-cost analyses from 1976-1979 were unfavorable (< 2) in 3 of the 4 years even though

Table 3. Development of insect control recommendations for single crop transplanted rice (TPR) and mungbean. Pangasinan, Philippines, 1975–79.[a]

Year	Single crop, TPR	Mungbean
1975	2 kg a.i. carbofuran G/ha, broadcast 5 DT; 0.75 kg a.i. monocrotophos/ha 35, 45, 55 DT	1 kg a.i. carbofuran G/ha, basal
1976	2 kg a.i. carbofuran G/ha, broadcast 5 DT; 0.75 kg a.i. monocrotophos/ha 35, 45, 55 DT	0.25 kg a.i. monocrotophos/ha 5, 15, 35 DE
1977	1.5 kg a.i. carbofuran G/ha, soil incorporated; 0.75 kg a.i. monocrotophos/ha 45 DT	0.25 kg a.i. endosulfan/ha 2, 12 DE; 0.75 kg a.i. carbaryl/ha 35, 45 DE
1978	1 kg a.i. carbofuran G/ha, soil incorporated	0.25 kg a.i. monocrotophos/ha 2, 12 DE; 0.75 kg a.i. carbaryl/ha 25, 35 DE
1979	1 kg a.i. carbofuran G/ha, soil incorporated; 0.75 kg a.i. endosulfan/ha 35, 45 DT	0.25 kg a.i. monocrotophos/ha 2, 12 DE; 0.75 kg a.i. carbaryl/ha 25, 35 DE

[a]DE = days after crop emergence, DT = days after transplanting.

Table 4. Economic analyses of recommended insect control practices 1976–79 in entomology trials for single crop transplanted rice.[a] Pangasinan, Philippines, 1975–79.

Year	Fields (no.)	Yield[b] (t/ha)			Recommended practice			
		Complete control	Recommended practice	Untreated	Benefit due to insecticide ($/ha)	Insecticide cost ($/ha)	Labor[c] (h/ha)	Benefit: cost
1976	5	4.74 a	5.42 a	3.75 b	250	129	52	1.8
1977	7	4.68 a	4.61 a	3.86 b	113	56	20	1.9
1978	6	3.67 a	3.14 b	2.39 c	113	31	4	3.5
1979	6	5.63 a	4.97 b	4.27 c	105	57	36	1.7

[a]Rice = US$0.15/kg. [b]Separation of means in rows by Duncan's multiple range test, 5% level. [c]Labor valued at US$0.14/h in benefit: cost ratio.

Table 5. Economic analyses of the recommended insect control practices 1976–79 in entomology trials for mungbean.[a] Pangasinan, Philippines, 1975–79.

Year	Fields (no.)	Yield[b] (t/ha)			Recommended practice			
		Complete control	Recommended practice	Untreated	Benefit due to insecticide ($/ha)	Insecticide cost ($/ha)	Labor[c] (h/ha)	Benefit: cost
1975	5	1.01 a	0.69 b	0.23 c	285	31	21	8.4
1976	6	0.90 a	0.23 b	0.19 b	24	15	32	1.2
1977	15	1.28 a	0.90 b	0.17 c	453	41	64	9.1
1978	7	1.18 a	1.13 a	0.22 b	564	28	64	15.2

[a]Mungbean = US$0.62/kg. [b]Separation of means in rows by Duncan's multiple range test, 5% level. [c]Labor valued at US$0.14/h in benefit: cost ratio.

consistently high (0.7-1.5 t/ha), meaning that insecticide costs were excessive (Table 4).

In 1975 carbofuran G was used for mungbean but it became apparent that granules were not as effective as sprays. In 1976 granules were replaced by monocrotophos sprays, which protected preflowering and postflowering growth stages. In 1977, endosulfan and carbaryl replaced monocrotophos because they were less expensive. However, endosulfan gave lower profits.

Application times were important for both preflowering and postflowering mungbean insect pests. Early applications were important for bean fly and flea beetle control at the preflowering stage. Pod borers were controlled with a low dosage of 0.75 kg a.i. carbaryl/ha if sprays were begun 25 days after crop emergence (DE). In 1978 the yields from the complete control and the recommended practice were equal and the recommended insect control gave a 15.2 benefit-cost ratio (Table 5).

Even though the 1978 mungbean insect control recommendations were specified rigidly as prophylactic sprays, there was extreme variability in the timing of insecticide to mungbean. Only 18% of the farmers followed the recommendations and those that did not, suffered significant yield losses (Table 6). Farmers were hesitant to spray until they saw pest problems; however, they did not know what

Table 6. Farmers' performance in applying the recommended insect control practice for mungbean in cropping pattern trials.[a] Pangasinan, Philippines, 1978.

Insecticide sprays (no.)		Farmers (%)	Yield (t/ha)	Crop failures (no.)
Preflowering (1–21 DE)	Postflowering (28–42 DE)			
1	0	8	0.06 b	2
1	1	26	0.22 b	4
1	2	18	0.61 a	1
2	0	8	0.40 ab	0
2	1	23	0.60 a	0
2	2	18	0.63 a	0

[a]The recommended practice is to spray 2, 12, 25, and 35 days after crop emergence (DE).

Table 7. Economic analyses of the recommended insect control practices 1976–79 in cropping pattern trials for single crop transplanted rice (TPR) and mungbean.[a] Pangasinan, Philippines, 1975–79.

Year	Fields (no.)	Insect control: Insecticide cost ($/ha)	Insect control: Labor[b] (h/ha)	Insect control: Total ($/ha)	Fertilizer cost ($/ha)	Total material cost ($/ha)	Variable cost ($/ha)	Yield (t/ha)
Single TPR								
1976	39	26	28	30	68	121	330	3.2
1977	20	54	21	57	81	156	343	3.6
1978	10	30	4	31	35	101	340	3.9
1979	–	–	–	–	–	–	–	–
Mungbean								
1975	26	52	39	57	29	108	207	0.7
1976	12	26	36	29	40	112	184	0.5
1977	26	57	70	67	42	146	260	0.9
1978	39	40	59	47	32	98	190	0.5

[a]Rice = US$0.15/kg, mungbean = US$0.62/kg. [b]Total cost of insect control includes labor valued at US$0.14/h.

signs to look for because they did not recognize the major pests.

Further analysis of costs and returns of the entomology and cropping pattern trials provided more insight into suitability of the insect control recommendations.

For single-crop transplanted rice (TPR), farmers in the cropping pattern trials were hesitant to apply insecticides costing more than $54/ha even though the recommendations often called for more (Table 7). However, for mungbean, farmers generally applied more insecticide than was recommended. The labor requirements in applying insecticide for both single-crop TPR and mungbean did not appear to be a constraint for either crop.

Farmers were willing to apply a higher value of fertilizer than insecticide for rice (Table 7). However, insecticide represented the major material cost in cropping pattern trials because fertilizer was relatively less important for mungbean. Total material costs were about equal for rice and mungbean but the total variable costs were much higher for rice than for mungbean, showing that rice has a much higher labor requirement.

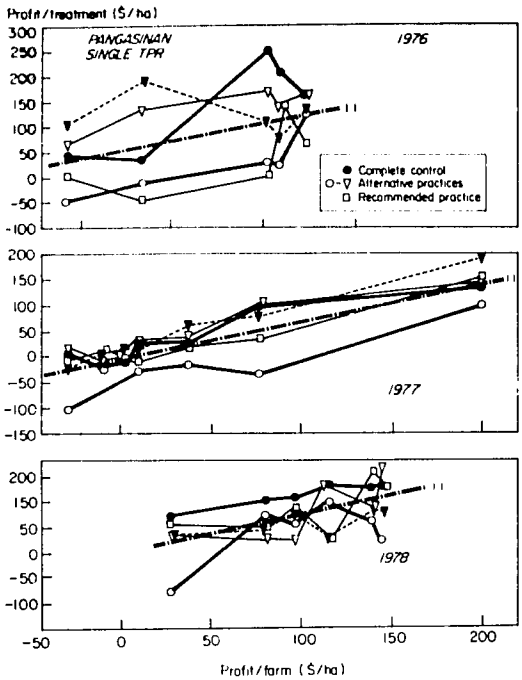
The low cropping pattern yields (Table 7) for rice in 1976 and 1977, compared with yields from recommended practices (Table 4,5) were partially traced to the misapplication by many farmers of insecticides, particularly carbofuran, and to late-season sprays. However, all farmers in 1978 applied carbofuran correctly on rice and actually obtained higher yields than those in the researcher-managed trials.

For mungbean, the 1978 entomology trials yielded 1.1 t/ha with a net return of $501/ha while the cropping pattern trials yielded 0.5 t/ha with a net return of $117/ha (Table 5, 7). The discrepancy was traced to the failure of farmers to properly time their insecticide applications (Table 6). Only 18% of the farmers sprayed at least twice during the recommended growth periods, and even they achieved suboptimal yields (0.6 t/ha).

The farmers recognized only pod borers, aphids, and defoliators as pests. They did not recognize bean fly, thrips, flea beetle, or leafhopper.

The farm-to-farm variability of the insect control practices was analyzed for single-crop TPR and mungbean across years for the entomology field trials using profit as the criterion. The recommended practice was compared to the complete control and alternative practices. Profits for these recommendations, averaged over all farmers, were analyzed and plotted in Figures 4 and 5 to show farm-to-farm variability for single-crop TPR and mungbean, respectively. Farms were ranked along the x-axis by average profits over all treatments and the profit from each treatment was graphed along the y-axis.

To test the farm-to-farm variability as the effect of farm environment, the data were analyzed by the Eberhart and Russell regression analysis. The *b* coefficients were analyzed by analysis of variance



4. Farm-to-farm economic performance of the insect control recommendations for single crop transplanted rice for 1976-78 in Pangasinan trials.

and there were no significant differences ($P \leq 0.01$) from treatment responses to environment for any year for both single-crop TPR and mungbean. The results indicated that the insect control treatments were equally effective on low- and high-profit farms.

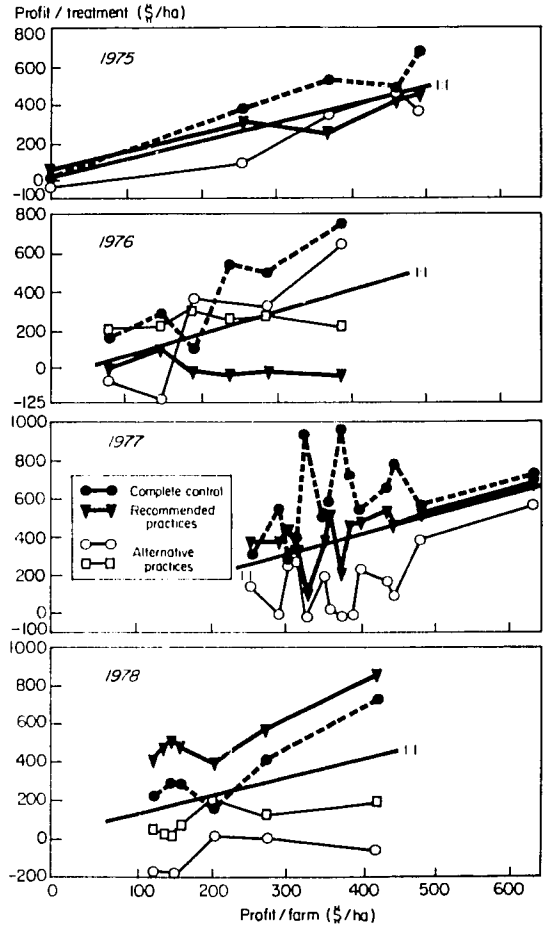
PATTERN TESTING

Cropping Systems Component of Agricultural Economics Department and Office of Rice Production Training and Research

Testing the *sorjan* system. *Sorjan*, a Javanese word, refers to a system of growing dryland crops on beds bordered by rice in flooded depressions. During the rainy season, two successive dryland crops should grow on beds, with two rice crops in the depressions. Residual moisture in the depressions enhanced by closer proximity of the soil surface to the water table, could support a third dry-season dryland crop.

The potential of the *sorjan* system was tested at IRRI and in trials in farmers' fields in Pangasinan. Beds were constructed by removing 25 cm soil from adjoining lowland strips, for a total 0.5 m differential between bed surfaces and sinks. Eight dryland crops, as indicated in Figure 6 and Table 8, were planted to identify those most suited to the system. The crops were rotated among the beds from season to season to benefit from the nitrogen-fixing properties of grain legumes and to avoid yield reduction on grain legumes resulting from possible allelopathic effects of successive plantings.

Two-meter-wide beds and sinks required about 4,500 hours of labor/ha for construction at IRRI at a relatively high assumed market wage rate and a total construction cost of $1,380/ha. The cost was apportioned to 6 successive rice and dryland crops,



5. Farm-to-farm economic performance of the insect control recommendation for mungbean for 1975-78 in Pangasinan trials.

Table 8. Costs and returns of crops planted in the *sorjan* system trial, IRRI, 1979.

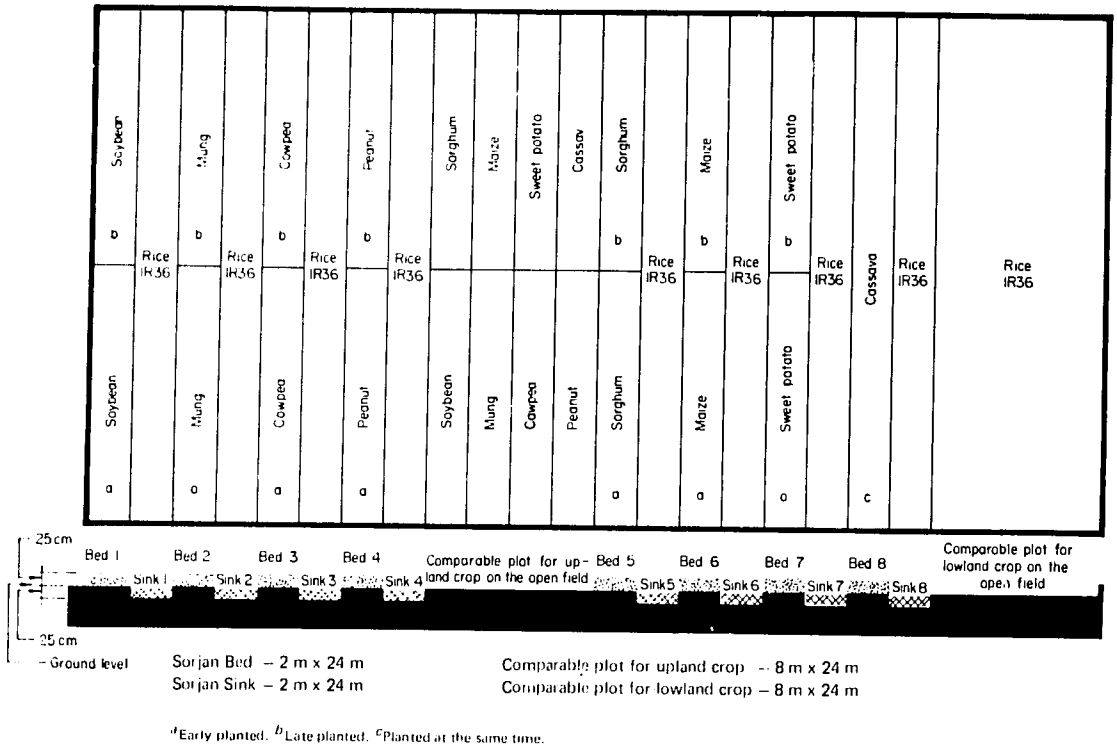
Crop	Yield (t/ha)	Variable cost ($/ha)			Returns ($/ha)	
		Labor excluding construction	Materials	Total including construction	Gross	Net
Soybean						
Jul–Sep	3.2	260	400	890	2640	1750
Oct–Dec	2.5	230	230	700	2050	1350
Mungbean						
Jul–Sep	1.2	430	340	1000	1240	240
Oct–Dec	1.7	720	130	1080	2110	1030
Cowpea						
Jul–Sep	0.9	390	340	960	1070	110
Oct–Dec	2.3	150	140	520	2800	2280
Peanut						
Jul–Sep	1.5	600	550	1380	1930	550
Sorghum						
Jul–Sep	4.3	220	350	800	650	−150
Oct–Dec	5.7	280	240	750	830	80
Maize						
Jul–Sep	15.8[a]	170	360	760	800	40
Oct–Dec	86.5[a]	50	160	440	1920	1480
Cassava						
Jul–Sep	21.0	300	350	880	3160	2280
Sweet potato						
Jul–Sep	5.0	170	350	750	1230	480
Oct–Dec	4.6	80	130	440	1140	700
Rice						
Jul–Sep	2.1	260	330	820	340	−480
Oct–Dec	1.7	300	80	610	270	−340
Jul–Sep (Monoculture)[b]	2.3	280	230	510	370	140

[a]Thousand marketable ears. First crop was reduced by theft and typhoon. [b]Dryland crops and rice were planted on normal level paddies but dryland crops did not establish well because of excessive moisture. The second rice crop could not be transplanted because of insufficient water for puddling.

for an investment of about $230/ha per crop for construction. In Pangasinan, where local labor was used and supervised according to local practices, the cost was about half — $120/ha per crop. Removal of the topsoil from depressions adversely affected the rice crops. Rats caused an estimated 20% yield loss on the first crop and 60% on the second crop. The sweet potato appeared to harbor rats and were deleted from the trials. A rice yield of 4.5 t/ha would be necessary to break even on the rice, considered alone. All dryland crops, except the first crop of sorghum, achieved sufficiently high returns to pay for the labor invested in construction and other labor and material costs.

First and second crops of soybean were outstanding. Second crops of mungbean, cowpea, and maize performed well along with a 5-month cassava crop. Labor costs were lower in the second season because minimum tillage techniques were used on the beds. Also, the material input costs were substantially reduced, particularly for insecticides.

Gains to the system were due primarily to the possibility of growing relatively high-value grain legume crops in the rainy season, and the high yields dryland crops achieved with ample water



[a]Early planted. [b]Late planted. [c]Planted at the same time.

6. Sorjan system trial at Block 600, Plot 607, IRRI farm, first crop, 1979-80.

and good drainage. Soybean did not yield well after rice on wetland soils because of the unfavorably short day length in the November-February period. Farmers in Pangasinan averaged about 0.2 t/ha from mungbean broadcast after rice. The mungbean crop on the Pangasinan *sorjan* trial yielded 3.1 t/ha.

Sunlight interception by dryland crops on the narrow 2-m beds contributed to yield, and insect damage may have been less because of the effects of intercropping. Depending on bed orientation, the wetland rice suffered some shading effects. An exact east-to-west orientation was the worst because of the inclination of light rays in the periods near the solstices. Rice, however, benefited from less lodging because of the protection from winds offered by bordering beds and crops, and from a more favorable evapotranspiration regime in the depressions. Measurements to verify the latter effect were initiated. Investigation of the effect of bed heights and widths on moisture relationships was also started.

Cropping systems program

Component technology development and evaluation

Multiple Cropping Department and Cropping Systems Components of the Agronomy, Entomology, Plant Pathology, and Soil Microbiology Departments

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WEED SCIENCE

Cropping Systems Component of the Agronomy Department

Effect of method of land preparation on weed growth. *Dryland crops.* In a trial in a dryland field at IRRI, weeds in some plots were controlled by different methods during the dry season, while other plots were left as a weedy fallow. At the start of the rainy season, all plots were plowed and harrowed, and rice and maize were seeded separately in each plot. Differences in the weed flora were due to the method of land preparation and the crops grown. The weedy fallow and the two plowings followed by one harrowing treatment were selected to illustrate those differences.

Thirty days after crop emergence, the weight of weeds in plots that had received 2 plowings and 1 harrowing during the dry season were only 3.8% less for rice and 17.7% less for maize than in plots left as a weedy fallow during the dry season (Table 1).

Plowing during the dry season resulted in change and diversification in the weed flora. In maize, *Cyperus rotundus* decreased in importance and annual weeds — *Eleusine indica* and *Amaranthus spinosus* — became much more important, accounting for 55.6% of the total weed weight. A similar change was observed in the rice plots.

Although the weed flora differed, crop yields were not significantly different between weeding regimes superimposed on the different land preparation methods, and the same amount of weeding was required to produce maximum yields.

In another dryland rice trial, the land was prepared in March, April, or May before planting in May. There was little difference in the total number of weeds or in the number of the different species when weed counts were taken in the unweeded plots 30 days after crop emergence (DE) (Table 2). When the land was prepared in May, the weed flora (based on weed counts) was somewhat different from what it had been when the land was prepared in April. The change was due primarily to an increase in the number of *C. rotundus* and, to a lesser extent, a decrease in the number of *Digitaria setigera* and *E. indica*.

No yields were obtained from plots that were not weeded, regardless of the time of land preparation (Table 3). Plots that were weeded twice yielded 2.1 t/ha when the land was prepared in March or April and only 0.5 t/ha when prepared in May. Early weed competition during the first 2 weeks before the first weeding was more severe in land prepared in May than in the land prepared in March or April. It was also difficult to distinguish between the rice and the weeds, and a large number of rice plants were removed during the first weeding operation. In all cases, the herbicides used did not give sustained weed control and poor yields were obtained from plots receiving herbicide treatments.

Dry-seeded rainfed wetland rice. In a similar trial with dry-seeded rainfed wetland rice, the time of land preparation had little effect on the number and weight of the major weed species — *Fimbristylis littoralis, Cyperus iria, Ludwigia octovalvis,* and *Paspalum distichum* — 1 week after crop emergence. By 30 DE, weeds in the unweeded plots that

Table 1. Weed weight 30 days after crop emergence in unweeded rice and maize plots as affected by method of land preparation during the dry season.[a] IRRI, 1978–79 dry season and 1979 wet season.

Weed species	Weed wt (g/m2)			
	Weedy fallow[b]		Two plowings + one harrowing[b]	
	Rice plot	Maize plot	Rice plot	Maize plot
Cyperus rotundus	254.8	282.0	121.8	52.2
Rottboellia exaltata	222.4	15.8	178.0	17.6
Digitaria sp.	138.8	52.4	120.2	61.0
Amaranthus spinosus	35.0	34.8	168.4	99.6
Eleusine indica	27.8	19.4	91.0	96.0
Commelina benghalensis	45.0	18.2	17.0	25.6
Total	723.8	422.6	696.4	352.0

[a] Av of 3 replications. [b] Land preparation method during the dry season.

Table 2. Effect of time of land preparation on the number of weeds per m², growing in association with unweeded dryland rice 30 days after crop emergence.[a] IRRI, 1979 wet season.

Weed species	Weeds (no./m²) in land prepared in		
	Mar	Apr	May
Cyperus rotundus	394.0	428.0	730.0
Digitaria setigera	164.6	160.0	95.4
Eleusine indica	72.6	76.0	4.0
Echinochloa colona	28.0	34.6	79.4
Amaranthus spinosus	51.4	26.0	16.6
Commelina benghalensis	23.4	21.4	8.0
Others[b]	29.2	34.0	65.2
Total	763.2	780.0	998.6

[a]Av of 3 replications. [b]*Commelina diffusa, Euphorbia hirta, Trianthema portulacastrum, Rottboellia exaltata, Portulaca oleracea, Calopogonium mucunoides, Cynodon dactylon, Ageratum conyzoides, Phyllanthus niruri,* and *Ipomoea triloba.*

were prepared in March were almost twice as many as those in plots that had been prepared in April or May. However, there was no significant difference in weed weight. The most important weeds 30 DE were *C. iria, F. littoralis,* and *E. colona.* The difference in weed number between the times of land preparation was due mainly to a much greater number of *F. littoralis* when the land was prepared in March.

Maize. The effect of method of land preparation, two preplant herbicides, and method of applying the preplant herbicide were examined in dry-season maize following dryland rice.

The predominant weeds in the trial area were *Cynodon dactylon, A. spinosus, Portulaca oleracea, C. rotundus,* and *Rottboellia exaltata.* Their proportion in the weed flora varied with the method of land preparation. There were more *C. dactylon* and less *A. spinosus, C. rotundus,* and *R. exaltata* in the no-tillage plots than in the conventionally tilled plots.

Limited soil moisture at planting caused difficulties in establishment of the maize in the no-tillage plots. But once established, the maize grew as well as or better than that in the conventionally tilled plots.

Weed weights taken at the tasseling stage of maize showed no significant difference between the methods of land preparation when the plots were weeded once, twice, or not at all. However, there were significantly more weeds in the maize crop, when paraquat was used to kill the weeds before planting in the no-tillage plots than when glyphosate was used or when the plots had been conventionally prepared.

The directed application of paraquat controlled the weeds effectively. Weed control with this treatment was equal to that obtained with two hand weedings and was better than that obtained with one hand weeding or no weeding. The weight of weeds in the plot weeded once was significantly less than that in the no-weeding plot.

When glyphosate at 1 kg a.i./ha and paraquat at 0.75 kg a.i./ha were applied before planting with the controlled droplet applicator (CDA), or when glyphosate at 2.0 kg a.i./ha was applied with a CDA or a boom sprayer, there was no significant difference in yield between weeding treatments (Table 4).

Effect of puddling and irrigation on weed growth. In a trial at IRRI, the effect of method of land preparation, irrigation, and weeding regime on weed growth and rice yield was studied. In puddled plots rice was transplanted at a 20 × 20-cm spac-

Table 3. Yield of dryland rice as affected by time of land preparation and weed control method.[a] IRRI, 1979 wet season.

Treatment[a]	Herbicide rate[b] (kg a.i./ha)	Yield[c] (t/ha) from land prepared in		
		Mar	Apr	May
Weeded twice, 2 and 5 WE	–	2.1 a	2.1 a	0.5 a
Weeded, 3 WE	–	1.3 b	0.7 b	0.3 ab
Propanil – fenoprop, 2- to 3-LSG	3	0.7 c	0.6 bc	0.3 ab
Propanil, 2- to 3-LSG	2	0.3 de	0.5 bcd	0.1 b
Fluorodifen PE	2	0.4 cd	0.2 de	0.0 b
Butachlor PE	2	0.2 de	0.3 cde	0.0 b
2,4-D, 2- to 3-LSG	1	0.2 de	0.0 e	0.0 b
No weeding	–	0.0 e	0.0 e	0.0 b

[a]WE = weeks after crop emergence, LSG = leaf stage of the grassy weeds, PE = preemergence. A dash (–) between herbicides indicates that they were formulated as a proprietary mixture. [b]a.i. = active ingredient. [c]Av of 3 replications. In a column, means followed by a common letter are not significantly different from each other at the 5% level.

Table 4. Effect on grain yield of maize of method of land preparation, rate and method of application of preplant herbicides, and postplant weed control.[a] IRRI, 1978–79 dry season.

Method of land preparation	Preplant herbicide and rate of application[b] (kg a.i./ha)	Method of application[c]	Grain yield (t/ha) with			
			Directed application of paraquat[d]	One hand weeding 3 WE	Two hand weedings 2 + 5 WE	No weeding
Zero tillage	Glyphosate 1.0	CDA	3.1 a	3.0 a	2.7 a	2.7 a
Zero tillage	Glyphosate 2.0	Boom sprayer	3.2 a	2.9 a	2.9 a	2.7 a
Zero tillage	Paraquat 0.75	CDA	2.9 a	3.0 a	2.8 a	2.5 a
Zero tillage	Glyphosate 2.0	CDA	2.9 a	3.0 a	2.5 ab	2.1 b
Zero tillage	Paraquat 0.75	Boom sprayer	3.1 a	2.4 bc	2.8 ab	2.1 c
Conventional tillage	–	–	2.7 a	2.3 ab	2.3 ab	2.1 b
Zero tillage	Paraquat 0.375	CDA	2.4 a	2.0 ab	2.4 a	1.8 b

[a]In a row, means followed by a common letter are not significantly different at the 5% level. [b]a.i. = active ingredient. [c]CDA = controlled droplet applicator. [d]0.5 kg a.i./ha applied 3 weeks after crop emergence (WE).

ing, and in unpuddled plots rice was dry-seeded at 100 kg/ha in rows 25 cm apart. The weed weight at rice maturity was greater in unpuddled and rainfed plots than in puddled irrigated plots (Table 5). The number of weed species was also higher.

The weed flora was greatly affected by the different treatments. *Monochoria vaginalis* and *Cyperus difformis* occurred only in puddled plots (Table 6). They were major weeds in irrigated plots but relatively minor weeds in rainfed plots.

Grasses predominated in unpuddled rainfed plots, and sedges predominated in puddled rainfed and unpuddled irrigated plots. Broadleaf weeds became more important in puddled irrigated plots.

Four weeds occurred under all four field conditions. *E. colona* accounted for 15% of the weed flora in unpuddled conditions but puddling considerably suppressed it. Puddled rainfed conditions were particularly favorable for the growth of *C. iria*, but puddling and irrigation virtually eliminated it from the weed flora; in unpuddled plots it was still a major component of the weed flora. *Lindernia anagallis* was the second most important weed in puddled rainfed plots, but was a relatively minor weed in the other plots. *L. octovalvis* was relatively unimportant under all four field conditions.

Weeds caused significant yield decrease in all plots except those puddled and irrigated. Within a weeding regime, the rice in unpuddled plots yielded significantly less than that in the puddled plots.

Effect of cropping patterns involving dryland crops on weed growth and crop yield. *Crops grown in well-drained fields.* In 1977 trials, different dryland cropping patterns resulted in different weed species dominating in the weed flora. The amount of weeding required for optimum yield varied between crops. The 1977 trial was continued in 1978 and 1979.

In the first crop in 1978, the major weeds were *A. spinosus* and *R. exaltata*. Minor weed species were *Ipomoea triloba*, *C. rotundus*, *E. indica*, *E. colona*, *Trianthema portulacastrum*, and *Digitaria* sp. In the unweeded plots, differences in total weed weight between the crops grown were not significant (Table 7).

In the rice-sorghum pattern, *A. spinosus* accounted for only 11.9% of the weed flora, but in the sorghum-sorghum-sorghum pattern it accounted

Table 5. Number of weed species and weight of weeds at rice maturity as affected by method of land preparation and irrigation.[a] IRRI, 1978 wet season.

Field condition	Weed species (no.)				Weed wt (g/m^2)
	Broadleaf weeds	Grasses	Sedges	Total	
Puddled irrigated	3	1	2	6	10.4
Puddled rainfed	5	3	5	13	34.6
Unpuddled irrigated	6	4	4	14	108.4
Unpuddled rainfed	9	6	4	19	162.6

[a]Av of 3 replications.

Table 6. Weed weight and importance value[a] of weed species in the unweeded plots at rice maturity as affected by method of land preparation and water regime. IRRI, 1978 wet season.

Weed species	Weed wt (g/m^2) for given field condition			
	Puddled irrigated	Puddled rainfed	Unpuddled irrigated	Unpuddled rainfed
Monochoria vaginalis	4.0 (38.5)	0.2 (0.6)	–	–
Ludwigia octovalvis	0.8 (7.7)	1.4 (4.2)	2.6 (2.3)	1.2 (0.7)
Murdannia nudiflora	–	–	9.2 (8.5)	0.8 (0.5)
Lindernia anagallis	0.8 (7.7)	5.4 (16.1)	6.4 (5.9)	2.0 (1.2)
Ipomoea triloba	–	–	4.2 (3.9)	11.4 (7.0)
Digitaria sp.	–	–	3.0 (2.8)	59.8 (36.8)
Eleusine indica	–	1.0 (3.0)	6.8 (6.3)	9.8 (6.0)
Echinochloa colona	0.2 (1.9)	2.2 (6.5)	16.2 (14.9)	24.6 (15.1)
Cyperus difformis	4.4 (42.3)	2.0 (6.0)	–	–
Cyperus iria	0.2 (1.9)	16.4 (48.8)	30.6 (28.7)	30.8 (18.9)
Cyperus compressus	–	1.6 (4.8)	17.8 (16.4)	1.8 (1.1)
Fimbristylis littoralis	–	1.8 (5.4)	9.2 (8.5)	9.2 (5.6)
Others	–	2.6	2.4	11.2
Total	10.4	34.6	108.4	162.6

[a]Importance value in parentheses.

for 94.5%. In the other cropping patterns it accounted for 65—75% of the weed flora, except in the rice-maize rotation where it accounted for 41.6% of the weeds. The opposite was observed with *R. exaltata*. The least weight (2.7%) occurred in the sorghum-sorghum-sorghum pattern and the highest (83.4%) in the rice-sorghum pattern. In the rice-maize pattern, there were almost equal amounts of *A. spinosus* and *R. exaltata*, but in the other patterns the weed flora was dominated by either *A. spinosus* or *R. exaltata*.

The greatest similarity (91.3%) in the weed flora was between the maize-rice-mungbean pattern and the mungbean-rice-mungbean pattern; the least similarity (16.5%) was between the sorghum-sorghum-sorghum pattern and the rice-sorghum pattern.

The total weight of weeds growing in association with the second crops in the different patterns in 1978 was much lower than that in the first crop (Table 8). The major weeds were again *A. spinosus* and *R. exaltata*, but the weed flora was more diversified than in the first crop. Weed weight was significantly greater in the sorghum crop in the rice-sorghum pattern than in either of the second rice crops or the sorghum crop in the sorghum-sorghum-sorghum pattern. *R. exaltata* was again most important in the rice-sorghum pattern, but least important in the mungbean-rice-mungbean pattern. It comprised a much greater proportion of the weed flora in the sorghum-sorghum-sorghum pattern than it had previously.

A. spinosus was more important when rice was grown as the second crop or in crops where rice had preceded the second crop. It was least important in the mungbean-mungbean-mungbean rotation where there was a buildup of *C. rotundus* and *Paspalum conjugatum*.

In the third crop in the rotation, the average total weed weight was about the same as in the second crop (Table 9). There was no significant difference in the weed weight between cropping patterns in the unweeded plots. The weed population was again diversified, the major weeds being *A. spinosus* and *R. exaltata*. The weight of *R. exaltata* was significantly greater when rice was the previous crop in the pattern, but *A. spinosus* was nearly twice as important in the maize-maize-maize pattern than in the other patterns.

In 1979, maize was planted as the first crop in all fields. Total weed weight was significantly lower in the plots that had a maize-maize-maize pattern and a rice-maize pattern than in the plots that had been planted to rice-sorghum and maize-rice-mungbean (Table 10). Most of the plots were dominated by *R. exaltata*, and *A. spinosus* had virtually disappeared. *R. exaltata* dominated in patterns in which rice had been grown. *I. triloba* became an important weed

Table 7. Effect of different cropping patterns on the weight of weeds growing in association with the first crop in the rotation in 1978.[a] IRRI, 1978 wet season.

Cropping pattern			Weed wt (g/m^2), 5 wk after crop emergence							
First crop	Second crop	Third crop	*Amaranthus spinosus*	*Ipomoea triloba*	*Rottboellia exaltata*	*Cyperus rotundus*	*Eleusine indica*	*Echinochloa colona*	Others[b]	Total
Rice	Maize	–	217.2 bc	14.8 ab	24.8 ab	0 b	0.4 bc	41.2 a	32.0	521.6 a
Maize	Rice	Mungbean	651.2 a	6.4 ab	179.2 ab	0.8 ab	3.2 ab	1.2 ab	8.0	850.0 a
Mungbean	Rice	Mungbean	253.6 ab	2.0 ab	49.6 b	1.6 ab	2.8 abc	0 b	28.4	338.0 a
Rice	Sorghum	–	91.6 bc	17.2 ab	639.6 a	0 b	0 c	16.0 ab	2.4	766.8 a
Maize	Maize	Maize	296.4 abc	3.2 ab	96.4 ab	0.8 ab	5.6 a	0.8 ab	52.8	456.0 a
Mungbean	Mungbean	Mungbean	373.6 ab	38.4 a	91.6 ab	2.8 ab	0 c	11.6 ab	16.0	534.0 a
Sorghum	Sorghum	Sorghum	532.4 a	0 b	15.2 b	4.8 a	0.4 bc	10.8 ab	0	603.6 a

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]*Trianthema portulacastrum* and *Digitaria* sp.

when rice was planted as the first crop in the pattern. All crops in the different cropping patterns in 1978 required weeding to produce the best yields (Table 11).

With rice planted first in the pattern, no yield was obtained when it was weeded once or twice because of severe weed competition and crop damage caused during weeding. The application of a preemergence herbicide reduced the weed population. Thus, yields from plots treated with herbicide followed by hand weeding were not significantly different from the yields of the weed-free check.

The cropping pattern used had some effect on crop yield. Sorghum yields were lower when sorghum followed sorghum than when sorghum followed rice.

In the 1978—79 dry season when maize was planted as the first crop in all plots and no weeding was done, there was no significant difference in crop yield due to previous cropping pattern or previous weeding practice.

In a second trial, 12 cropping patterns superimposed on 3 tillage and weed control levels were evaluated during the 1979 wet season. The treatments are described in Table 12.

Grain yields of maize and cowpea, regardless of the previous cropping pattern, were not significantly affected by tillage in both weeding levels (Table 12). Sorghum grain yields, however, were significantly higher for conventional tillage than for either minimum and no-tillage treatments with the exception of the sorghum plots previously planted to a maize + cowpea intercrop in weed control level 1. No significant differences in sorghum grain yield were observed among tillage treatments in weed control level 2 regardless of the previous cropping pattern. Maize yield in weed control level 2 was slightly higher in plots previously planted to cowpea than in continuous maize.

Total weed weights were lower in the cowpea crops than in crops in the other patterns. Dryland rice had the highest total weed weight regardless of weeding regime and previous cropping pattern. Two continuous maize crops had slightly higher total weed weight than maize preceded by cowpea at weeding level 1, but weed weights were about the same at weeding level 2.

In a third trial, the effect of plant density, cropping pattern, and tillage on weed population and yield of dryland crops was examined.

Table 8. Effect of different cropping patterns on the weight of weeds growing in association with the second crop in the rotation in 1978. IRRI, 1978 wet season.

Cropping pattern			Weed wt[a] (g/m²) 5 wk after crop emergence					
First crop	Second crop	Third crop	*Amaranthus spinosus*	*Rottboellia exaltata*	*Cyperus rotundus*	*Paspalum conjugatum*	Others[b]	Total
Rice	Maize	–	71.2 a	30.0 a	13.2 b	0 c	53.6	168.0 abc
Maize	Rice	Mungbean	42.0 ab	58.4 a	7.6 b	2.0 bc	25.2	135.2 bc
Mungbean	Rice	Mungbean	18.8 ab	10.8 a	10.4 b	6.0 bc	35.6	81.6 c
Rice	Sorghum	–	63.6 a	164.8 a	6.8 b	1.6 bc	50.8	287.6 a
Maize	Maize	Maize	14.8 ab	46.0 a	9.2 b	12.4 b	52.0	134.4 bc
Mungbean	Mungbean	Mungbean	13.6 b	82.8 a	36.8 a	66.0 a	41.6	240.8 ab
Sorghum	Sorghum	Sorghum	19.6 ab	34.0 a	16.0 b	0 c	37.6	107.2 bc

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]*Ipomoea triloba, Digitaria* sp., *Eleusine indica, Echinochloa colona,* and *Trianthema portulacastrum.*

Table 9. Effect of different cropping patterns on the weight of weeds growing in association with the third crop in the rotation in 1978. IRRI, 1978 wet season and 1978–79 dry season.

Cropping pattern			Weed wt[a] (g/m²) 5 wk after crop emergence			
First crop	Second crop	Third crop	*Amaranthus spinosus*	*Rottboellia exaltata*	Others[b]	Total
Maize	Rice	Mungbean	20.4 b	183.6 a	63.2	267.2 a
Mungbean	Rice	Mungbean	48.4 ab	106.0 a	59.6	214.0 a
Maize	Maize	Maize	72.4 a	10.8 b	58.4	141.6 a
Mungbean	Mungbean	Mungbean	33.2 ab	7.2 b	78.0	118.4 a
Sorghum	Sorghum	Sorghum	26.4 b	33.2 b	42.0	101.6 a

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]*Ipomoea triloba, Digitaria* sp., *Cyperus rotundus, Eleusine indica, Echinochloa colona, Ageratum conyzoides,* and *Portulaca oleracea.*

During the dry season, the grain yields of most crops were significantly higher at high plant population than at low (Table 13). The minimum tillage treatments gave significantly lower grain yield than either the conventional or no-tillage treatment. This was particularly evident at a low plant population as a result of heavy weed infestation. Maize had higher total weed weight than the other crops especially at a low plant population (Fig. 1). When cowpea was intercropped with maize, total weed weight was substantially reduced. At a high plant population, the total weed weight for the intercrop was lower than that for the rest of the crops.

During the wet season, tillage had no effect on the grain yields of the dryland crops reported (Table 14). Grain yields of the two maize crops were significantly higher at high plant population, but the grain yields of cowpea were not significantly affected by plant population. Dryland rice had the highest total weed weight among the crops regardless of plant population (Fig. 2).

Crops grown in fields with different ponding potentials. The effect of crop rotation and weeding regime on weed growth and crop yield in fields that differed only in their ponding potential was studied in an IRRI trial. Figure 3 shows the cropping sequences used in four fields. No weeding was done for any of the crops planted in September or October 1978. Before those crops, weeding treatments were:

- no weeding;
- weeding once, 3 weeks after seeding (WS) or transplanting (WT) for wet-seeded or transplanted rice, or 3 weeks after crop emergence (WE) for maize and mungbean; weeding 2 and 5 WE for dry-seeded rice;
- weeding, 3 and 5 WS or WT for wet-seeded or transplanted rice, or 3 and 5 WE for maize and mungbean; weeding 2, 5, and 8 WE for dry-seeded rice; and
- weed free.

In the land with a high ponding potential, the weight of weeds at the maximum flowering stage in the plots that had been weeded once or twice in

Table 10. Effect of different cropping patterns grown in 1977 and 1978 on the weed population growing in association with a maize crop grown in all plots as the first crop in 1979. IRRI, 1979 wet season.

Cropping pattern			Weed wt[a] (g/m²) 5 wk after crop emergence					
First crop	Second crop	Third crop	*Amaranthus spinosus*	*Ipomoea triloba*	*Rottboellia exaltata*	*Cyperus rotundus*	*Echinochloa colona*	Others[b]	Total
Rice	Maize	–	1.2 a	123.6 a	54.8 c	31.6 a	43.6 a	6.8	261.6 c
Maize	Rice	Mungbean	3.2 a	42.8 a	730.8 a	82.4 a	40.4 a	2.8	902.4 a
Mungbean	Rice	Mungbean	1.6 a	3.2 b	294.8 ab	53.6 a	12.0 a	59.6	424.8 bc
Rice	Sorghum	–	2.8 a	96.4 a	616.4 a	34.0 a	82.4 a	10.4	840.0 ab
Maize	Maize	Maize	21.2 a	0.4 b	135.2 bc	62.8 a	14.8 a	106.4	340.8 c
Mungbean	Mungbean	Mungbean	4.0 a	2.8 b	212.8 abc	120.4 a	76.0 a	32.8	448.8 bc
Sorghum	Sorghum	Sorghum	14.0 a	6.4 b	120.0 bc	130.4 a	176.4 a	67.6	514.8 bc

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]*Eleusine indica*, *Digitaria* sp.

Table 11. Grain yield of crops in different cropping patterns as affected by weed control treatments. IRRI, 1978.

Cropping pattern	Yield[a] (t/ha)				
	Weed free	Herbicide[b] fb[c] hand weeding[d]	Weeded twice[e]	Weeded once[f]	No weeding
Rice –	1.6 a	1.7 a	0 b	0 b	0 b
maize	2.0 a	1.8 a	1.8 a	1.8 a	0 b
Maize[g] –	5.8 a	5.6 a	5.3 a	4.7 a	1.4 b
rice –	2.0 a	1.8 a	1.8 a	1.8 a	0 b
mungbean	1.2 a	1.1 a	1.0 a	1.1 a	0.9 b
Mungbean –	1.2 a	0.9 b	1.3 a	0.4 c	0 d
rice –	2.1 a	1.9 ab	1.2 b	1.8 ab	0.6 c
mungbean	0.9 a	0.8 a	0.9 a	0.6 a	0 b
Rice –	1.5 a	1.5 a	0 b	0 b	0 b
sorghum	2.4 a	1.9 ab	2.1 a	1.1 b	0 c
Maize[g] –	5.6 a	5.2 a	5.6 a	4.8 a	1.8 b
maize –	1.7 a	1.4 a	2.1 a	1.5 a	0.3 b
maize	2.4 ab	2.6 ab	3.0 a	1.9 bc	1.7 c
Mungbean –	1.1 a	0.9 a	1.0 a	0.6 b	0 c
mungbean –	0.2 a	0.2 a	0.2 a	0.1 a	0 b
mungbean	1.0 a	0.9 a	2.0 a	0.8 a	0.5 b
Sorghum –	2.1 a	1.0 b	1.9 a	1.3 b	0.3 c
sorghum –	1.0 a	0.8 ab	0.9 ab	0.6 b	0.1 c
sorghum	0.4 ab	0.6 ab	0.5 ab	0.8 a	0.4 b

[a]Av of 3 replications. In a row, means followed by a common letter are not significantly different at the 5% level. [b]Atrazine at 2.0 kg a.i./ha for maize and sorghum, butachlor at 2.0 kg a.i./ha for rice and mungbean. [c]Followed by. [d]21 days after crop emergence (DE) for mungbean; 28 DE for maize, rice, and sorghum. [e]7 and 28 DE for maize and sorghum, 7 and 21 DE for mungbean, 14 and 28 DE for rice. [f]14 DE for mungbean, 21 DE for maize, rice, and sorghum. [g]Weight of ears.

previous crops was significantly lower (73.6 g/m² vs an average of 224 g) than that from the other treatments, which did not differ significantly from each other. There was, however, no significant difference in grain yield between treatments. The lowest yield (3.1 t/ha) was from the plots that had not been weeded previously, and the highest (3.8 t/ha) was from the plot that had been weeded 2 or 3 times in previous crops. *M. vaginalis* was the dominant weed in all plots, accounting for 93% or more of the weed flora on the basis of weed weight.

In the land with a low ponding potential, there was no significant difference between weed weights at maximum flowering in the transplanted rice crop. However, the yield (2.8 t/ha) of the plot that had not been weeded in previous crops was significantly lower than that (3.5 t/ha) of the plot that had been weeded once or twice per crop previously. No other differences were significant.

Differences in weed flora due to the previous

Table 12. Grain yield of dryland crops as affected by tillage and weeding levels. IRRI, 1979 wet season.

Cropping pattern[a]	Grain yield[b] (t/ha)							
	Weeding level 1[c]				Weeding level 2[d]			
	CT	MT	NT	Mean	CT	MT	NT	Mean
Maize (maize)	2.7[ns]	2.1[ns]	2.1[ns]	2.3	3.0[ns]	2.5[ns]	2.5[ns]	2.7
Maize (cowpea)	2.6[ns]	2.6[ns]	2.7[ns]	2.6	3.3[ns]	3.0[ns]	3.1[ns]	3.1
Cowpea (maize)	0.9[ns]	0.5[ns]	0.5[ns]	0.6	0.9[ns]	0.9[ns]	0.9[ns]	0.9
Cowpea (sorghum)	0.7[ns]	0.5[ns]	0.6[ns]	0.6	0.9[ns]	0.8[ns]	0.8[ns]	0.8
Cowpea (maize + mungbean)	0.7[ns]	0.4[ns]	0.5[ns]	0.5	0.9[ns]	0.8[ns]	0.9[ns]	0.9
Sorghum (sorghum)	1.7 a	1.2 b	1.2 b	1.4	1.9 a	1.5 a	1.8 a	1.7
Sorghum (maize + cowpea)	1.8 a	1.4 b	1.4 a	1.5	1.8 a	1.9 a	1.9 a	1.9
Sorghum (sorghum + mungbean)	1.8 a	1.2 b	1.1 b	1.4	1.8 a	1.7 a	2.0 a	1.8
Sorghum (mungbean)	1.9 a	1.3 b	1.2 b	1.5	1.9 a	2.0 a	1.9 a	1.9
Dryland rice (cowpea)	–	–	–	–	–	–	–	–
Dryland rice (maize + mungbean)	–	–	–	–	–	–	–	–
Dryland rice (sorghum)	–	–	–	–	–	–	–	–

[a]Crop in parentheses is that immediately preceding in pattern. Dryland rice was not included because of severe moisture stress at the reproductive stage. [b]In a row, for each weeding level, means followed by a common letter are not significantly different at the 5% level. CT = conventional tillage (1 plowing and 2 rototillings), MT = minimum tillage (1 plowing and 1 rototilling plus herbicide), NT = no tillage (herbicide application only). [c]One hand weeding for CT and herbicides alone for MT and NT. [d]Two hand weedings for CT and herbicides plus one hand weeding for MT and NT. ns = not significant.

Table 13. Grain yield of dryland crops as affected by tillage and plant population. IRRI, 1979 dry season.

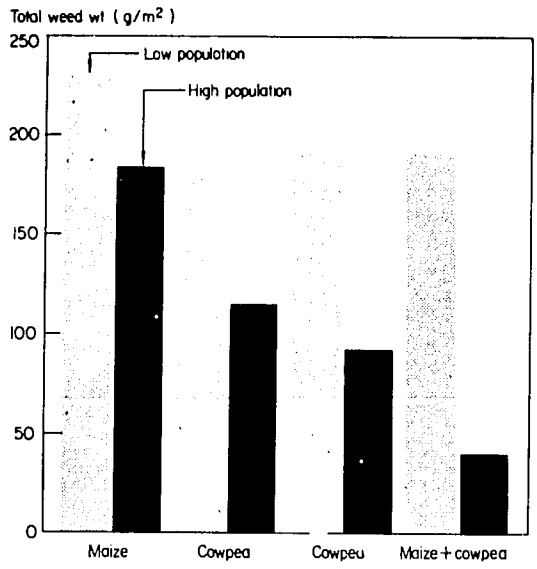
Treatment	Grain yield[a] (t/ha)											
	Maize			Cowpea			Maize + cowpea			Cowpea		
	P_1	P_2	Difference	P_1	P_2	Difference	P_1	P_2	Difference	P_1	P_2	Difference
Conventional tillage	2.2 a	3.1 a	0.9*	1.6 a	1.8 a	0.2	2.6 a + 0.9 a	3.0 a + 0.8 a	0.4 + 0.1	1.4 a	2.0 a	0.6**
Minimum tillage	1.2 b	1.8 b	0.6	1.0 b	1.6 a	0.6**	1.4 b + 0.9 a	2.1 a + 0.7 a	0.7 + 0.2	0.8 b	1.8 a	1.0**
No tillage	2.0 ab	3.2 a	1.2**	1.7 a	2.0 a	0.3*	2.2 ab + 0.9 a	3.0 a + 0.7 a	0.8* + 0.2	1.6 a	2.1 a	0.5**
Mean[b]	1.8 a	2.7 b		1.4 a	1.8 b		2.1 a + 0.9 a	2.7 b + 0.7 a		1.2 a	1.9 b	

[a]In a column, for each crop or the cropping pattern, means followed by a common letter are not significantly different at the 5% level. P_1 = low population, P_2 = high population. [b]In a row, for each crop or the cropping pattern, means followed by a common letter are not significantly different at the 5% level.

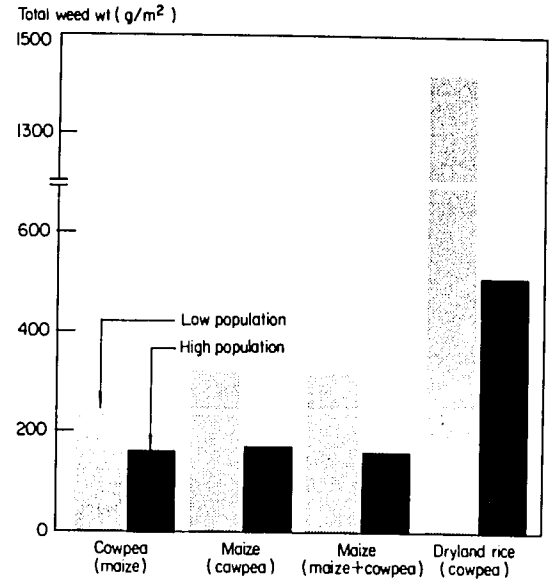
Table 14. Grain yield of dryland crops as affected by tillage and plant population. IRRI, 1979 wet season.

Treatment	Grain yield[a] (t/ha)								
	Cowpea (maize)			Maize (cowpea)			Maize (maize + cowpea)		
	P_1	P_2	Difference	P_1	P_2	Difference	P_1	P_2	Difference
Conventional tillage	1.0	0.9	0.1	3.8	5.2	1.4**	3.5	4.9	1.4**
Minimum tillage	0.8	0.9	0.1	4.0	5.2	1.2**	3.5	4.8	1.3**
No tillage	0.9	0.8	0.1	3.4	4.8	1.4**	3.6	5.3	1.7**
Mean[b]	0.9	0.8		3.7 a	5.1 b		3.6 a	5.0 b	

[a]Dryland rice was not included because of severe moisture stress at the reproductive stage. P_1 = low population, P_2 = high population. Previous crops are in parentheses. [b]In a row, for each crop or the cropping pattern, means followed by a common letter are not significantly different at the 5% level.



1. Total weed weight as affected by cropping pattern and plant population (av of 3 tillage treatments). IRRI, 1979 dry season.

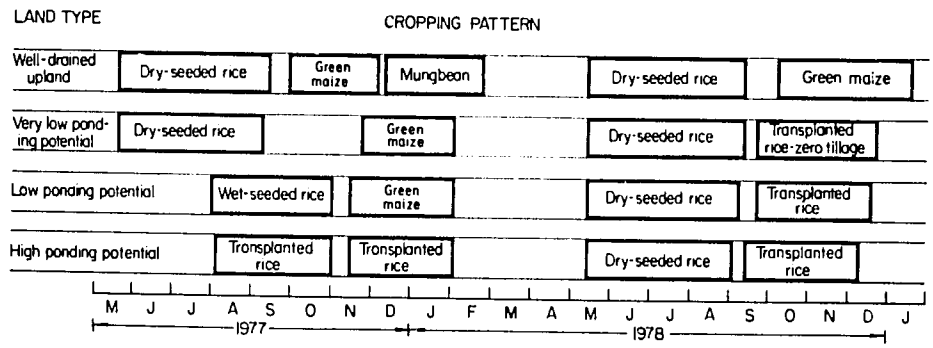


2. Total weed weight as affected by cropping pattern and plant population (av of 3 tillage treatments). IRRI, 1979 wet season. The crop in parentheses is that immediately preceding in pattern.

weeding treatments used were observed. *Echinochloa glabrescens* dominated in the fields where no weeding had been done in the previous crops or where crops had been weeded once or twice. *M. vaginalis* dominated when the previous crops had been maintained weed free, and *P. distichum* was most important when the previous crop had been weeded two or three times.

Where the rice was transplanted after paraquat application in land with a very low ponding potential, grasses predominated in all plots; but in land with a high ponding potential broadleaf weeds predominated. *E. colona* was the dominant weed in all plots. Its importance value (I.V.) decreased from 92.8 to 47.6 as the amount of weeding in the previous crops increased from none to a weed-free condition (Table 15). As a result, the diversity of the weed flora increased.

The number of weeds at maximum flowering did not differ between treatments, but weed weight was significantly higher in the plots that had not been weeded in previous crops than in the plots that had been maintained weed free or weeded two or three times in previous crops. Rice yield was significantly



3. Cropping patterns used in fields having different ponding potentials. IRRI, 1977-78.

Table 15. Effect of weeding regimes in previous crops on weed flora and yield of transplanted IR36 grown under zero tillage in land with a low ponding potential.[a] IRRI, 1978 wet season.

Weeding regime in previous crops	Weed count (no./m^2)	Weed wt (g/m^2)	Importance value of *Echinochloa colona*	Yield (t/ha)
Weed free	50.8 a	66.8 b	47.6	1.5 a
Two to three times	93.2 a	82.0 b	64.3	1.4 a
Once or twice	70.8 a	145.2 ab	76.6	0.4 b
None	51.2 a	353.2 a	92.8	0 b

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level.

Table 16. Effect of weed control treatments applied to previous crops on the importance values of the major weeds, on volunteer rice, and on total weed weight at maximum flowering of the weeds in a well-drained upland.[a] IRRI, 1978 wet season.

Species	No weeding	Weeded once or twice	Weeded two or three times	Weed free
		Importance value		
Cyperus rotundus	51.2	29.6	19.0	13.3
Digitaria ciliaris	27.9	11.1	16.2	20.4
Eleusine indica	11.0	29.5	41.5	29.9
Echinochloa colona	9.7	3.4	0.9	2.5
Volunteer rice	0.1	24.7	19.6	28.7
		Total weed wt (g/m^2)		
	339.2	239.6	218.8	205.6

[a]Av of 3 replications.

Table 17. Number of weed species growing in fields of different ponding potentials as affected by weeding regimes applied to previous crops. IRRI, 1978 wet season.

Land type	Weed species[a] (no.) in fields that were			
	Not weeded previously	Weeded once or twice previously	Weeded two or three times previously	Kept weed free
Well-drained dryland	8	12	11	14
Very low ponding potential	4	14	12	17
Low ponding potential	3	5	5	4
High ponding potential	2	4	2	4

[a]Av of 3 replications.

higher in the latter plots than in the plots that had received no weeding or had been weeded once or twice in previous crops (Table 15).

The major weeds varied depending on the previous weeding regime. *C. rotundus* dominated in plots that had not been weeded previously, but *E. indica* was much more important in the plots that had been weeded in the previous crops. Volunteer rice was also important in these crops (Table 16).

Due to drought stress and weed competition, yields from all plots were low (< 0.7 t/ha) and showed no significant yield effect from previous treatments.

Overall, more weed species were present in the well-drained dryland and in the land with a very low ponding potential than in the fields with low or high ponding potential at all levels of weeding (Table 17). Generally, more weed species were present in fields that had been weeded previously.

There was little similarity between the weed

communities growing in fields of different ponding potentials. The greatest coefficient of similarity in the plots that were maintained weed free or not weeded previously (59.5 and 23.2) occurred between the field with low ponding potential and that with high ponding potential. The well-drained dryland and the land with a low ponding potential had no weeds in common.

Herbicides for use under no-till conditions. *Promising herbicides.* During the 1979 wet season glyphosate and paraquat combinations were evaluated at different rates in combinations with residual postplanting herbicides alachlor, butachlor, and pendimethalin.

All treatments, regardless of glyphosate and paraquat rates with postplanting treatments, provided adequate weed control with no crop injury when rated at 1 and 3 WE (Table 18). Plots that did not receive postplanting treatments had greater weed infestation as shown by the low weed control ratings. Conventionally tilled plots had also more weed infestation, primarily *C. rotundus*, before the hand weeding operation was done.

Most of the pendimethalin-treated plots had significantly higher maize dry matter yield than the unweeded plots, but were similar to the conventional-tillage treatment that received one hand weeding.

No significant differences in weed weights were observed when rates of paraquat were compared. The low rate of glyphosate resulted in significantly lower broadleaf weed weight, but the reverse was observed for the sedge weed weight (Table 19).

Advanced herbicide evaluation. During the 1979 wet season the performance of promising herbi-

Table 18. Effect of herbicide application on weed control, crop tolerance, and dry matter yield of no-till maize.[a] IRRI, 1979 wet season.

Treatment[b]	Herbicide rate[c] (kg a.i./ha)	Dry matter yield (t/ha)	Weed control rating[d]		Toxicity rating[e]	
			1 WE	3 WE	1 WE	3 WE
Glyphosate fb paraquat + pendimethalin	0.75 fb 0.3 + 1.25	5.1 abcde	8	7	0	0
Glyphosate fb paraquat + pendimethalin	1.5 fb 0.3 + 1.25	6.4 a	10	9	0	0
Glyphosate fb paraquat + pendimethalin	0.75 fb 0.6 + 1.25	5.8 abc	9	8	0	0
Glyphosate fb paraquat + pendimethalin	1.5 fb 0.6 + 1.25	5.6 abcd	10	9	0	0
Glyphosate fb paraquat + hand weeding	0.75 fb 0.3	5.8 abc	6	3	0	0
Glyphosate fb paraquat + hand weeding	1.5 fb 0.3	5.6 abcd	8	4	0	0
Glyphosate fb paraquat + hand weeding	0.75 fb 0.6	5.2 abcd	6	4	0	0
Glyphosate fb paraquat + hand weeding	1.5 fb 0.6	5.4 abcd	6	4	0	0
Glyphosate fb paraquat + no weeding	0.75 fb 0.3	4.2 de	6	3	0	0
Glyphosate fb paraquat + no weeding	1.5 fb 0.3	4.2 de	6	4	0	0
Glyphosate fb paraquat + no weeding	0.75 fb 0.6	4.5 cde	5	3	0	0
Glyphosate fb paraquat + no weeding	1.5 fb 0.6	3.9 e	8	3	0	0
Conventional tillage + hand weeding	–	5.6 abcd	5	3	0	0

[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]fb = followed by. [c]a.i. = active ingredient. [d]Scale of 0–10:0 = no control, 10 = complete control. WE = weeks after crop emergence. [e]Scale of 0–10:0 = no toxicity, 10 = complete kill.

Table 19. Weed weight, by class, as affected by preplanting application of glyphosate and paraquat combinations in no-till maize (av for 3 replications and 5 postplanting treatments). IRRI, 1979 wet season.

Treatment	Herbicide rate[a] (kg a.i./ha)	Weed wt (g/m2)											
		Broadleaf weeds			Grasses			Sedges			Total		
		Glyphosate (kg a.i./ha)		Mean	Glyphosate (kg a.i./ha)		Mean	Glyphosate (kg a.i./ha)		Mean	Glyphosate (kg a.i./ha)		Mean
		0.75	1.5		0.75	1.5		0.75	1.5		0.75	1.5	
Paraquat	0.3	56	54	55	88	136	112	17	6	12	161	197	160
Glyphosate	0.6	24	60	42	135	99	117	8	5	6	166	163	164
Mean		40	57**		111	117		12**	5		164	179	

[a]a.i. = active ingredient.

cides in dry-season tests was evaluated. The residual postplanting herbicides alachlor, metolachlor, and pendimethalin were tested in combination with reduced rates of paraquat applied sequentially in two split doses, or glyphosate followed by paraquat as preplanting treatments on maize, cowpea, and sorghum under no-till conditions.

All three residual herbicides in combination with glyphosate followed by paraquat provided better weed control in all crops than paraquat, according to visual rating 2 WE (Table 20). No injury due to any herbicide combination was observed in any of the crops tested. Lower total weed weights and consistently higher yields in all the crops were observed from the best herbicide treatments, which were comparable to the hand-weeded cultivated or uncultivated checks. Among the crops tested, cowpea had significantly lower total weed weight than either maize or sorghum.

Because of heavy weed infestation, the unweeded no-till plots produced significantly lower yields in all crops compared to the best chemical or mechanical treatments. Significantly lower yield was observed only in sorghum when the best chemical treatments were compared with the unweeded cultivated check. Further comparison indicated that total weed weight was significantly lower with glyphosate followed by paraquat than with paraquat applied before planting as a split application (Table 21).

Herbicide screening. Several herbicides were evaluated in combination with paraquat and glyphosate in maize and a maize-mungbean intercrop in an uncultivated field during the 1979 dry season. The plots were irrigated.

Yields from plots treated with chemicals such as alachlor alone or with cyanazine, butachlor, metolachlor plus cyanazine, pendimethalin, and X-150 plus cyanazine as residual postplanting treatments after application of either paraquat or glyphosate were significantly higher than yields from the untreated uncultivated check plots planted to maize alone (Table 22). Although the same herbicide treatments produced numerically higher yield, they were not, however, significantly different from yields in the unweeded uncultivated check plots planted to maize-mungbean intercrop.

When the herbicides were further compared, those that were accompanied by a preplanting

Table 20. Effect of some promising herbicides on weed control, crop tolerance, and yield of dryland crops under no-till condition.[a] IRRI, 1979 wet season.

Treatment[b]	Herbicide rate[c] (kg a.i./ha)	Maize				Cowpea				Sorghum			
		Yield (marketable ears/ha)	Weed control rating[d] 2 WE	Toxicity rating[e] 2 WE	Total weed wt (g/m²)	Yield (kg/ha)	Weed control rating[d] 2 WE	Toxicity rating[e] 2 WE	Total weed wt (g/m²)	Yield (t/ha)	Weed control rating[d] 2 WE	Toxicity rating[e] 2 WE	Total weed wt (g/m²)
Paraquat fb paraquat + alachlor	0.5 fb 0.5 + 1.5	60,000 abc	7	0	300 bc	681 c	4	0	387 b	2.1 bc	5	0	724 a
Paraquat fb paraquat + metolachlor	0.5 fb 0.5 + 1.5	57,500 bc	6	0	366 bc	816 abc	6	0	93 bcd	2.4 ab	6	0	398 ab
Paraquat fb paraquat + pendimethalin	0.5 fb 0.5 + 1.5	56,000 c	4	0	652 ab	702 bc	5	0	105 bcd	1.4 cd	4	0	579 ab
Glyphosate fb paraquat + alachlor	1.0 fb 0.5 + 1.5	59,500 abc	6	0	207 bcd	853 abc	7	0	9 cd	2.4 ab	7	0	330 ab
Glyphosate fb paraquat + metolachlor	1.0 fb 0.5 + 1.5	60,000 abc	8	0	295 bc	921 abc	7	0	168 bcd	2.7 ab	7	0	109 bc
Glyphosate fb paraquat + pendimethalin	1.0 fb 0.5 + 1.5	63,500 a	7	0	89 cd	823 abc	8	0	15 cd	3.0 a	7	0	159 bc
Check													
Three hand weedings – no tillage	–	59,000 abc	7	0	121 cd	985 ab	8	0	6 cd	2.6 ab	7	0	125 bc
No weeding – no tillage	–	9,000 d	0	0	1,529 a	126 d	4	0	1,715 a	1.0 d	4	0	1,043 a
Three hand weedings–conventional tillage	–	57,500 bc	8	0	36 d	999 a	8	0	3 d	2.4 ab	5	0	38 c
No weeding – conventional tillage	–	61,000 ab	4	0	236 bc	726 abc	2	0	202 b	1.5 cd	5	0	645 a
Mean[f]					389 b				270 a				409 b

[a] In a column, means followed by a common letter are not significantly different at the 5% level. [b] fb = followed by. [c] a.i. = active ingredient. [d] Scale of 0–10: 0 = no control, 10 = complete control; WE = weeks after crop emergence. [e] Scale of 0–10: 0 = no toxicity, 10 = complete kill. [f] In a row, means followed by a common letter are not significantly different at the 5% level.

Table 21. Total weed weight in no-till upland crops as affected by different preplanting and postplanting herbicide treatments (av for 4 replications and 3 cropping patterns). IRRI, 1979 wet season.

Preplanting treatment[a]	Total weed wt (g/m²) with postplanting treatment of			Mean weed wt (g/m²)
	Alachlor	Metolachlor	Pendimethalin	
Paraquat fb paraquat	470	286	426	394
Glyphosate fb paraquat	182	190	88	153
Difference				241**

[a]fb = followed by.

Table 22. Effect of herbicide application on weed control, crop tolerance, and yield of maize under no-till condition.[a] IRRI, November 1978–February 1979.

Treatment[b]	Herbicide rate[c] (kg a.i./ha)	Maize					
		Yield (marketable ears/ha)	Weed control rating[d]		Toxicity rating[e]		Total weed wt[f] (g/m²)
			15 DE	45 DE	15 DE	45 DE	
Paraquat + alachlor/cyanazine	0.75 + 1.0/1.0	59,333 ab	7	6	0	0	132
Paraquat + butachlor	0.75 + 2.0	62,000 ab	6	6	0	0	100
Glyphosate + alachlor	1.5 + 2.0	62,666 ab	6	7	0	0	75
Glyphosate + metolachlor/cyanazine	1.5 + 1.0/1.0	66,000 a	8	6	0	0	72
Glyphosate + X-150/cyanazine	1.5 + 2.0/1.0	64,000 a	8	6	0	0	139
Glyphosate + pendimethalin	1.5 + 2.0	68,769 a	8	6	0	0	68
Check							
Hand weeding – no tillage	Hand weeded thrice	55,333 abc	8	9	0	0	23
No weeding – no tillage	–	25,333 d	4	2	0	0	269
Hand weeding – conventional tillage	Hand weeded twice	58,769 ab	8	9	0	0	16
No weeding – conventional tillage	–	50,667 abc	6	4	0	0	193
		Maize-mungbean intercrop					
		Yield (marketable ears/ha)	Weed control rating[d]		Toxicity rating[e]		Total weed wt[f] (g/m²)
			15 DE	45 DE	15 DE	45 DE	
Paraquat + alachlor/cyanazine	0.75 + 1.0/1.0	58,666 a	8	6	0	0	32
Paraquat + butachlor	0.75 + 2.0	64,000 a	8	6	0	0	21
Glyphosate + alachlor	1.5 + 2.0	58,102 a	8	6	0	0	11
Glyphosate + metolachlor/cyanazine	1.5 + 1.0/1.0	66,000 a	9	8	0	0	12
Glyphosate + X-150/cyanazine	1.5 + 2.0/1.0	59,436 a	8	6	0	0	98
Glyphosate + pendimethalin	1.5 + 2.0	66,000 a	8	6	0	0	62
Check							
Hand weeding – no tillage	Hand weeded thrice	61,333 a	9	8	0	0	13
No weeding – no tillage	–	50,000 a	5	4	0	0	185
Hand weeding – conventional tillage	Hand weeded twice	66,000 a	9	8	0	0	15
No weeding – conventional tillage	–	5,666 a	6	6	0	0	38

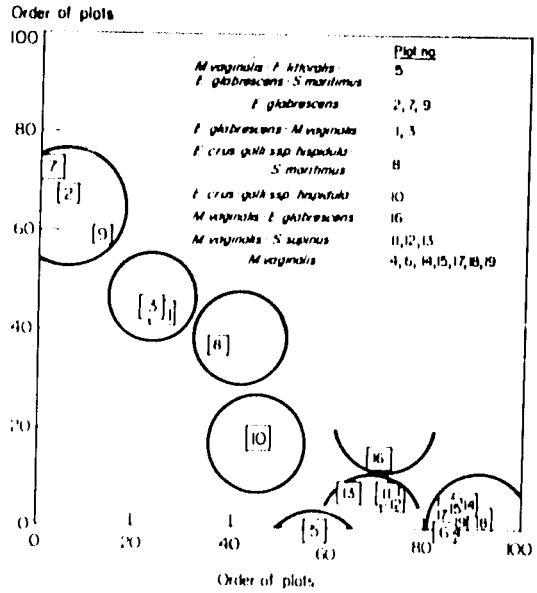
[a]In a column, means followed by a common letter are not significantly different at the 5% level. [b]Slash (/) indicates herbicides applied as tankmixed. [c]a.i. = active ingredient. [d]Scale of 0–10:0 = no control, 10 = complete control. DE = days after crop emergence. [e]Scale of 0–10:0 = no toxicity, 10 = complete kill. [f]Taken at heading stage of grasses.

treatment of paraquat had a higher average total weed weight than the same set of herbicides with a previous glyphosate treatment, regardless of cropping pattern.

Weeding of dryland crops planted at the end of the rainy season. The effect of postplanting methods of weed control on the yield of four crops planted in a dryland field at IRRI in November 1978 was studied. The major weeds growing in association with the crops were *C. rotundus*, *R. exaltata*, *A. spinosus*, and *Commelina benghalensis*.

In all crops, the lowest weed weights 60 DE were in the plots that were weeded twice or that had been interrow-cultivated or treated with a directed application of paraquat 3 WE and followed by a hand weeding 5 WE. There were significantly less weeds in these plots than in those that had been treated with paraquat or interrow-cultivated 3 WE. These plots had significantly less weeds than the no-weeding plots. The average weed weight in the unweeded plots across crops was 181.4 g/m^2. In the no-weeding plots, the lowest weed weight (160.6 g/m^2) was recorded in the mungbean plots, and the highest (201.4 g/m^2) was observed in the maize plots.

Cowpea and mungbean yields from the plots that were weeded twice were significantly higher than those from the unweeded plots (Table 23). Other differences were not significant. For maize, there was no significant difference in yield between the plots that were weeded and those not weeded, but for sorghum all the plots that received a weeding treatment, except those that received a directed application of paraquat 3 WE, yielded significantly higher than the unweeded check.



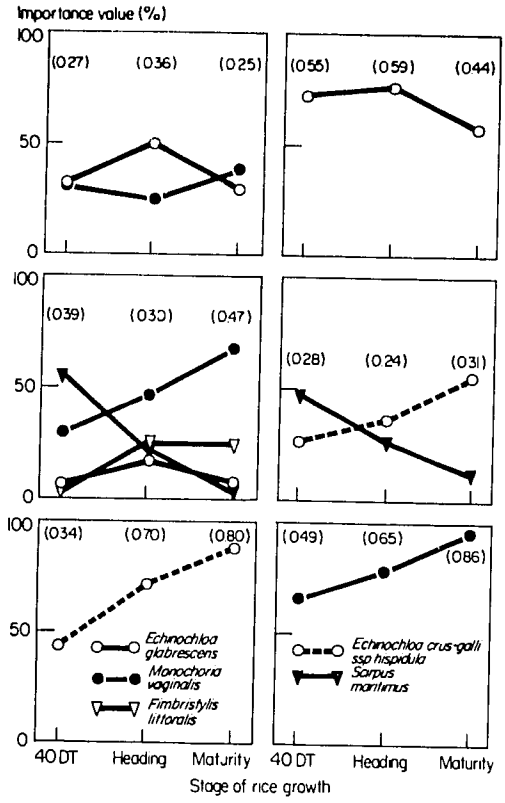
4. Distribution of sample plots based on floristic composition, using a two-dimensional ordination diagram. The dominant species in each plot is indicated by a square. The size of each square is related to its degree of dominance expressed as importance value, which is based on dry weight. The order of plots refers to their positions along the X- and Y-axes. Circles indicate probable boundaries of each community type on the ordination diagram. IRRI, 1978.

Weed communities growing in association with transplanted rice. Eight weed community types were identified growing in association with transplanted rice in 11 fields at IRRI in 1978 and 1979 (Fig. 4). The I.V. of the weed species based on weed weight in the different communities changed with time (Fig. 5). The I.V. of *F. glabrescens* increased from 40 DT until rice heading and then decreased

Table 23. Grain yield of dryland crops as affected by different weed control methods.[a] IRRI, 1978 wet season, 1978–79 dry season.

Weed control methods[b]	Grain yield (t/ha)			
	Sorghum	Cowpea	Maize	Mungbean
Hand weeded, 1 and 3 WE	3.8 a	3.4 a	2.4 a	1.7 a
Paraquat, 0.5 kg a.i./ha, 3 WE fb hand weeding 5 WE	3.8 a	2.5 ab	3.6 a	0.9 ab
Interrow cultivation 3 WE fb hand weeding 5 WE	3.6 a	3.2 ab	2.3 a	1.1 ab
Interrow cultivation 3 WE	3.7 a	2.5 ab	2.1 a	1.5 ab
Paraquat, 0.5 kg a.i./ha 3 WE	3.2 ab	2.5 ab	3.0 a	0.9 ab
No weeding	2.3 b	2.2 b	2.0 a	0.8 b

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]WE = weeks after crop emergence, fb = followed by, a.i. = active ingredient.



5. Effect of time of sampling on change in importance value based on dry weight of each weed community type. IRRI, 1978. DT = days after transplanting. Values in parentheses represent Simpson's index.

from heading to rice maturity. However, the I.V. of *M. vaginalis* and *Echinochloa crus-galli* ssp. *hispidula* increased from 40 DT to maturity, and *Scirpus maritimus* decreased from 40 DT. The results imply that different weeds should be sampled at different times to obtain the maximum information about them. But in a mixed weed vegetation, if weeds are to be sampled only once, they should be sampled at rice heading.

In these fields, the yield losses caused by weeds varied depending on the weed community types. The highest yield decrease due to weed competition was caused by the *E. crus-galli* ssp. *hispidula-S. maritimus* community, and the least by the *E. glabrescens* community (Table 24). The yield reduction caused by 100-g dry weight of weeds/m^2 was 42% and 10% for those community types.

PLANT PROTECTION

Cropping Systems Component of the Entomology and Plant Pathology Departments

Insecticide evaluation *(Entomology).* Insecticides were screened on maize seedlings and preflowering and postflowering mungbean for insect control, and on rice for possible growth stimulation effects.

Maize seedling protection. A trial planted in September 1979 in Batangas compared 8 insecticides applied as seed treatment at 5 and 10 g a.i./kg seed. Plant growth characteristics were measured to identify chemicals that were effective against the seedling maggot and also plant neutral. Bendiocarb and formetanate effectively controlled seedling maggot at both dosages and were plant neutral (Table 25). Carbofuran, cartap, and promecarb were phytotoxic at 10 g a.i./kg seed. Carbofuran at 10 g a.i. produced significantly taller plants,

Table 24. Relation between yield reduction and weed weight of different weed community types. IRRI, 1978–79.

Weed community type	Yield reduction ( ) at weed wt (g/m^2) of					Weed wt (g/m^2) required for 50% yield reduction
	100	200	300	400	500	
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

Table 25. Insecticide evaluation for yield loss assessment during the seed and seedling growth stages of maize.[a] Batangas, Philippines, 1979.

Insecticide	Formulation[b]	Dosage (g a.i./ kg seed)	Deadhearts (%) 28 DE	Germination (%)	Plant ht (cm) 30 DE
Bendiocarb	80 WP	10	3 a	86 abc	74 cd
Bendiocarb	80 WP	5	6 a	88 abc	78 abc
Carbofuran	30 ST	10	4 a	75 cd	85 a
Carbofuran	30 ST	5	3 a	89 abc	84 ab
Formetanate	50 WP	10	5 a	96 a	81 abc
Formetanate	50 WP	5	5 a	85 abc	71 cd
Chlorthiophos	25 SP	10	17 b	96 a	73 cd
Promecarb	38 SP	10	22 bc	60 e	72 cd
Phenthoate	40 SP	10	22 bc	80 bcd	78 bcd
Cartap	50 SP	10	18 bc	70 e	67 d
Methoxychlor	50 SP	10	25 bc	81 bcd	73 cd
Untreated			42 d	84 abc	74 bcd

[a]Av of 3 replications. DE = days after crop emergence. In a column, means followed by the same letter are not significantly different ($P \leq 0.05$) at the 5% level. [b]WP = wettable powder, ST = seed treatment, SP = soluble powder.

which supported the contention that it directly affects maize growth.

Insects of preflowering mungbean. Sprayable insecticides were screened in farmers' fields in Manaoag, Pangasinan, in 11 trials from 1977 to 1979 against the preflowering mungbean insect pest complex — bean fly *Ophiomyia phaseoli*, flea beetle *Medythia suturalis*, thrips *Thrips palmi*, leafhopper *Amrasca bigutulla*, and aphid *Aphis craccivora*. This complex is common on mungbean and cowpea throughout the Philippines.

Insect pressure was high in all trials and significant yield losses occurred in untreated plots. Monocrotophos gave the greatest yield increase in six of the eight trials (Table 26), but it was not significantly better than the synthetic pyrethroids — permethrin, decamethrin, cypermethrin, and fenvalerate — and phosalone, omethoate, oxydemeton-ethyl, ethion, phosmet, formothion, methyl-parathion, profenofos, cyanofenphos, and naled.

Insects of postflowering mungbean. During the 1977-78 crop year, 15 insecticides were tested in Pangasinan in 2 trials against the postflowering insect pest complex of mungbean. All plots received equal preflowering insecticide protection, and *Heliothis armigera* was particularly abundant.

Decamethrin was outstanding against *Heliothis* and other postflowering pests in both trials (Table 27). Subsequent trials showed that a dosage of 0.03 kg a.i./ha was effective if the insecticide was applied beginning 25 DE.

Rice growth stimulation by insecticide seed treatments *(Entomology).* Eight insecticides were evaluated for their effect on the growth of rice in a greenhouse experiment using heat-sterilized soil. The insecticides were applied as seed dressing (10 g a.i./kg seed) and the plants were enclosed in mylar film cages to prevent insect infestation.

Carbofuran significantly increased root weight, tiller number, percentage of productive tillers, grain weight, and 100-seed weight and promoted maturity (7 days earlier) compared with the untreated check (Table 28). Bendiocarb, promecarb, cartap, and formetanate stimulated rice growth, but to a lesser degree. Because insecticides are used to measure yield loss, it is important to choose chemicals that do not directly affect rice yields.

Insect pests and the continuous rice system *(Entomology).* A continuous cropping system of 14 plots planted to an insect pest-susceptible cultivar on a weekly basis was established at IRRI without insecticide in 1978. A double-cropped field that used the same cultivar without insecticide was included. Insect pests and natural enemies were monitored in the two systems on plants planted the same week to eliminate the effects of planting date.

Natural enemies of rice pests, notably spiders, are more favored in continuous cropping than in double-cropping (Fig. 6). In the continuous crop-

Table 26. Effect on yield of sprayable insecticides for control of preflowering mungbean insects.[a] Pangasinan, Philippines, 1977–79.

Insecticide[b]	Dosage (kg a.i./ha)	Yield	
		t/ha	Increase over untreated (%)
	Trial 1[c]		
Monocrotophos 16.8 EC	0.25	0.69 a	116
Carbaryl 85 WP	0.25	0.67 a	109
Endosulfan 35 EC	0.25	0.63 a	97
Untreated		0.32 b	
	Trial 2[c]		
Oxydemeton-ethyl 25 EC	0.25	0.97 a	67
Methyl-parathion 50 EC	0.25	0.96 a	66
Azinphos-ethyl 40 EC	0.25	0.92 a	59
Chlorpyrifos + BPMC 31.5 EC	0.25	0.89 a	53
Carbophenothion 30 EC	0.25	0.89 a	53
Mevinphos 19 EC	0.25	0.88 a	52
Monocrotophos 16.8 EC	0.25	0.87 a	50
Untreated		0.58 b	
	Trial 3[c]		
Monocrotophos 16.8 EC	0.25	0.87 a	58
Decamethrin 2.5 EC	0.02	0.85 a	55
Phosalone 35 EC	0.25	0.82 a	49
Untreated		0.55 b	
	Trial 4[c]		
Monocrotophos 16.8 EC	0.25	1.40 a	77
Omethoate 50 EC	0.25	1.36 a	72
Profenofos 40 EC	0.25	1.27 a	61
Perthane 45 EC	0.25	1.17 a	48
Methyl-parathion 50 EC	0.25	1.17 a	48
Cyanofenphos 25 EC	0.25	1.17 a	48
Naled 58 EC	0.25	1.16 a	47
Untreated		0.79 b	
	Trial 5[c]		
Monocrotophos 16.8 EC	0.25	1.47 a	81
Ethion 40 EC	0.25	1.33 a	64
Oxydemeton-ethyl 25 EC	0.25	1.31 a	62
Untreated		0.81 b	
	Trial 6[d]		
Monocrotophos 16.8 EC	0.25	1.46 a	100
Phosalone 35 EC	0.25	1.46 a	100
Phosmet 50 WP	0.25	1.42 a	95
Formothion 33 EC	0.25	1.29 a	77
Untreated		0.73 b	
	Trial 7[d]		
Monocrotophos 16.8 EC	0.25	1.06 a	126
Dimethoate 40 EC	0.5	0.93 b	98
Triazophos 40 EC	0.25	0.92 b	96
Fenthion 30 EC	0.25	0.90 b	91
Carbophenothion 30 EC	0.25	0.90 b	91
Chlorpyrifos + BPMC 31.5 EC	0.25	0.88 b	87
Carbaryl 85 WP	0.5	0.87 b	87
Untreated		0.47 c	

Continued on next page

Table 26 continued

Insecticide[b]	Dosage (kg a.i./ha)	Yield t/ha	Yield Increase over untreated (%)
	Trial 8[d]		
Permethrin 10 EC	0.02	1.01 a	60
Decamethrin 2.5 EC	0.01	0.98 a	56
Monocrotophos 16.8 EC	0.25	0.92 a	46
Cypermethrin 2.5 EC	0.02	0.87 a	38
Fenvalerate 3 EC	0.02	0.79 a	25
Untreated		0.63 b	

[a]All treatments including the control received maximum postflowering protection – 0.03 kg a.i. decamethrin/ha 25, 35, and 45 days after crop emergence (DE). Insecticides were applied 2 and 12 DE. Insecticides tested that did not adequately control insects were bendiocarb, pyridophenthion, cartap, MTMC, acephate, EPN, methidathion, quinalphos, chlordimeform, metalkamate, chlorpyrifos, phosphamidon, diazinon, methomyl, BPMC, MIPC, malathion, trichlorfon, methamidophos, dichlorvos, phenthoate, propoxur, leptophos, and tetrachlorvinphos, all at 0.25 kg a.i./ha. [b]EC = emulsifiable concentrate, WP = wettable powder. [c]Av of 3 replications. [d]Av of 4 replications.

ping, each time a plot was harvested and plowed to establish a new planting, only 1/14 of the field was disturbed. Spiders were easily relocated to adjacent undisturbed plots. When a double-cropped field was harvested and plowed, the entire area was disturbed and the spider population declined. Spider populations kept pace with those of hoppers where no insecticides were used. The green leafhopper, whitebacked planthopper, and brown planthopper numbers remained low even on the susceptible cultivar IET3877.

Other insects such as whorl maggot, stem borers, leaf folder, and rice bugs were well below economic injury levels in both continuous and double-cropping (Table 29). More stem borers were present in the continuous planting.

Plant protection in wetland rice-based cropping systems *(Entomology). Fertilizer effect on the*

Table 27. Evaluation of insecticides for assessment of yield loss due to postflowering insects of mungbean (CES 14).[a] Pangasinan, Philippines, 1977–78.

Insecticide[b]	Dosage (kg a.i./ha)	*Heliothis* Defoliation (%) 65 DE[c]	*Heliothis* Larvae (no./15 plants)	Damaged green pods (%)	Yield (t/ha)
		Trial 1[d]			
Decamethrin 2.5 EC	0.05	10 a	1 ab	0 a	1.66 a
Fenvalerate 3 EC	0.05	10 a	2 b	4 b	1.58 a
Methomyl 20 EC	0.75	10 a	1 ab	17 bc	1.43 a
Monocrotophos 16.8 EC	0.75	10 a	1 ab	15 bc	1.41 a
Acephate 40 EC	0.75	10 a	2 b	20 c	1.33 a
Carbaryl 85 WP	0.75	10 a	4 bc	28 c	1.21 a
Untreated		57 b	10 c	65 d	0 b
		Trial 2[e]			
Decamethrin 2.5 EC	0.05	5 a	0.3 a	0 a	1.78 a
Acephate 40 EC	0.75	5 a	8 b	18 b	1.47 b
Methomyl 20 EC	0.75	5 a	3 a	7 ab	1.43 b
Monocrotophos 16.8 EC	0.75	5 a	2 a	7 ab	1.37 b
Fenvalerate 3 EC	0.05	5 a	1 a	6 ab	1.34 b
Carbaryl 85 WP	0.75	5 a	3 a	19 b	1.21 b
Untreated		40 b	11 c	96 c	0.02 c

[a]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level. All plots including the untreated received preflowering insecticide – 0.25 kg a.i. monocrotophos/ha 2 and 12 DE. [b]EC = emulsifiable concentrate, WP = wettable powder. [c]Days after crop emergence. [d]Insecticides were applied 30 and 42 DE. Planting was 26 Nov 1977. [e]Insecticides were applied 30, 40, and 55 DE. Planting was 12 Dec 1977.

Table 28. Evaluation of insecticides' effect on the growth characteristics of IR36 rice.[a] IRRI greenhouse, 1979.

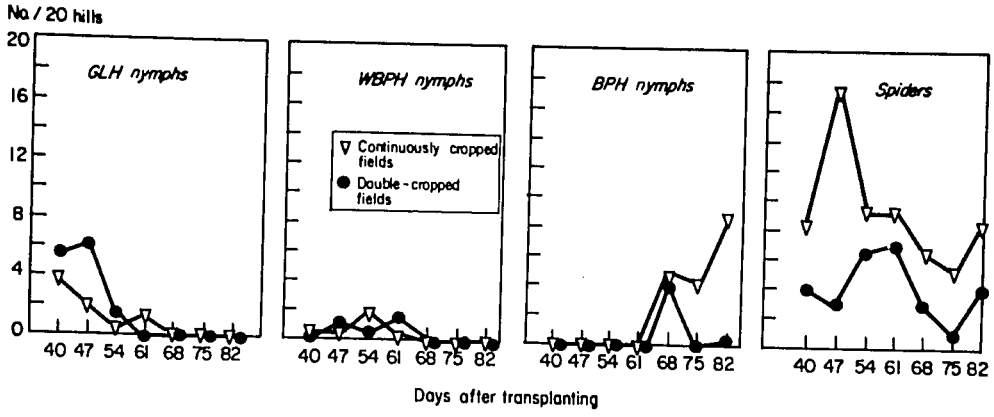
Insecticide[b]	Formulation[c]	Germination (%)	Seedling ht (cm) 21 DE	Seedling root wt (mg) 21 DE	Tillers (no.)	Productive tillers (%)	Days to flowering	Grain wt (g)	100-seed wt (g)
Carbofuran	2 F	90 abc	30.3 a	9.9 a	17.3 a	57.9 a	76 a	8.3 a	1.7 a
Bendiocarb	80 WP	75 bc	30.6 a	5.5 b	12.4 b	44.4 ab	78 abc	6.9 abc	1.4 ab
Phenthoate	40 SP	95 ab	28.7 ab	7.9 a	11.9 b	45.3 ab	79 abc	4.1 e	1.4 ab
Chlorthiophos	25 SP	65 c	28.9 ab	6.0 b	14.0 b	43.2 ab	78 abc	4.7 e	1.5 ab
Methoxychlor	50 SP	90 abc	28.0 b	5.5 b	10.9 b	42.1 b	84 c	4.1 e	1.5 ab
Cartap	50 SP	90 abc	28.6 b	5.8 b	13.3 b	39.9 b	81 abc	5.7 cd	1.5 ab
Formetanate	50 SP	95 ab	29.8 ab	4.4 b	11.4 b	42.3 ab	84 c	7.5 ab	1.6 ab
Promecarb	38 WP	75 bc	28.0 b	5.8 b	13.4 b	35.9 b	76 a	7.1 abc	1.5 ab
Untreated check		100 a	28.9 ab	4.5 b	11.2 b	35.9 b	83 bc	4.2 e	1.2 b

[a]Av of 4 replications. DE = days after seed emergence. In a column, means followed by a common letter are not significantly different at the 5% level. [b]10 g a.i./kg seed. [c]F = flowable, WP = wettable powder, SP = soluble powder.

Asian corn borer. A fertilizer trial in 1978 tested the effect of various nitrogen, phosphorus, and potassium rate combinations and timings on the Asian corn borer population at harvest. The results are presented in Table 30. There were no significant differences when the analysis was by Duncan's multiple range test at the 5% level but analysis of variance showed significant interactions for nitrogen and for split versus hilling-up methods of its application. Corn borer had a significantly ($P \leqslant 0.01$) positive response to nitrogen across all treatment levels. There was no response to phosphorus and potassium. When the *b* coefficients from regression analysis were tested, there were significantly ($P \leqslant 0.05$) fewer corn borer tunnels per plant when nitrogen was applied at hilling up (0.7) than when it was split (1.3) (basal plus hilling up). The rate of 60 kg N/ha at hilling up produced high yields and minimized corn borer damage.

Sorghum. Previous experience has shown only a few insect pests attack sorghum after rice in Pangasinan. The most prominent is corn earworm *Heliothis armigera*. The larvae feed on the developing grains. The low-cost treatment of 0.75 kg a.i. carbaryl/ha, recommended when more than 1 *Heliothis* larva/2 panicles is observed or when the aphid populations reach a rating of 7, was tested in 1978 and compared to a complete control based on prophylactic insecticide application. *Heliothis* and aphid numbers warranted one application of carbaryl during the milky stage; this low-cost treatment was as effective as maximum protection in controlling those pests (Table 31). There was no yield loss from ants or other soil pests. The untreated control, however, experienced a loss of $170/ha, including labor, giving a benefit-to-cost ratio of 17:1.

Mungbean. The recommended insect control practice for dry-season mungbean planted after wetland rice in Pangasinan — 0.25 kg a.i. monocrotophos/ha (2 and 12 DE), 0.75 kg a.i. carbaryl/ha (25 and 35 DE) — is aimed at the bean fly *Ophiomyia phaseoli*, flea beetle *Medythia suturalis*, and corn earworm *Heliothis armigera*. The recommendation was tested in 1978-79 with maximum protection in two planting dates representing the patterns maize-TPR-mungbean, and DSR-TPR-mungbean. Results in the 1977-78 crop year had shown a need to change the postflowering insecticide level by shifting the application timing



6. Population fluctuations of green leafhoppers (GLH), whitebacked planthoppers (WBPH), brown planthoppers (BPH), and spiders in continuously cropped and double-cropped fields of IET3877. IRRI, 1979 wet season.

Table 29. Incidence of 4 insect pests in continuous and double-cropped systems planted to the insect-susceptible cultivar IET3877 without insecticide. IRRI, 1979.

Cropping system	Whorl maggot grade (1–9)[a]	Stem borer (%)		Leaf folder damaged leaves (%)	Rice bugs (no./m^2)
		Dead-hearts	White-heads		
Continuous weekly cropping	3.5	4.8	0.7	0.7	2.3
Double-cropping	3.5	2.5	0.5	0.2	2.5

[a]1 = no damage, 9 = severe damage.

of carbaryl from 35 and 45 DE to 25 and 35 DE to control *Heliothis* (1978 annual report).

The 1978-79 results showed that the change in insecticide timing was sufficient to control *Heliothis* larvae as well as bean fly and flea beetle for both planting dates (Table 32). The recommended practice gave optimal insect control on the mungbean crops, which registered 77% yield losses for the December planting and 92% for January. Significant yield losses occurred in both the preflowering (62 and 71%) and postflowering stages (15 and 21%) for the December and January plantings. The insecticide used in the recommended practice cost $33/ha and the benefit-cost ratios were 17.6 for the December planting and 13.9 for January.

Cowpea. The insect control recommendation for cowpea planted as a third crop after 2 rainfed rice crops in Iloilo is 2 applications of 0.25 kg a.i. monocrotophos/ha (2 and 12 DE) followed by a postflowering spray of 0.75 kg a.i. carbaryl/ha 25 DE. This recommendation was evaluated against a high level insect-free treatment to show the potential yield gain from insecticide usage. Both the recommended and maximum control treatments included protection during the preflowering and postflowering growth stages. To evaluate the rela-

Table 30. Effect of nitrogen, phosphorus, potassium, and method of application on the Asian corn borer in green maize before rice.[a] Pangasinan, Philippines, 1978.

Treatment	Fertilizer		Corn borer tunnels (no./plant)
	N-P-K (kg/ha)	Application method	
1	0–0–0	–	0.8 a
2	0–30–0	Basal	0.8 a
3	0–30–0	Hilling up	0.8 a
4	0–0–30	Basal	0.9 a
5	0–0–30	Hilling up	0.8 a
6	60–0–0	Split	1.1 a
7	90–0–0	Split	1.3 a
8	60–30–30	Split	1.6 a
9	90–0–0	Hilling up	0.9 a
10	60–0–0	Hilling up	1.3 a
11	60–30–30	Hilling up	1.2 a

[a]Av of 7 farms. In a column, means followed by a common letter are not significantly different at the 5% level.

Table 31. Chemical insect control on sorghum (Cosor 3) planted after rainfed wetland rice.[a] Manaoag, Pangasinan, Philippines, 1978.

Treatment	Aphid rating[b]	*Heliothis* (no./100 panicles)	Yield (t/ha)
Complete control[c]	2.8 a	3.0 a	3.76 a
Postflowering protection only	2.8 a	3.3 a	3.68 a
Recommended practice – economic thresholds[d]	2.8 a	4.0 a	3.70 a
Untreated	9.0 b	11.8 b	3.08 b

[a]Av of 4 replications (fields). In a column, means followed by a common letter are not significantly different at the 5% level. [b]Scale of 1–9 per plant at hard dough stage: 1 = no aphids, 3 = several adults, 5 = several colonies, 7 = many distinct colonies, 9 = many coalesced and indistinct colonies. [c]Preflowering protection of 10 g a.i. carbaryl/kg seed and postflowering protection of 0.05 kg a.i. decamethrin/ha (2 sprays after flowering). [d]One application of 0.75 kg a.i. carbaryl/ha when 1 *Heliothis* larva/2 plants is surpassed.

tive insect pest pressure on each of the two growth stages, two additional treatments giving protection to only the postflowering stage were compared (Table 33).

The results indicated that the recommended level was suboptimal for the postflowering stage. There was a significant yield difference between the postflowering treatments representing the high and recommended levels of protection. Yield loss was not significant when the preflowering stage was not protected (treatment 1 vs 2), indicating that the bean fly pressure was not damaging. Cowpea was more tolerant of bean fly damage than was mungbean.

Dryland rice-based cropping systems *(Entomology). Chemical insect control in bush sitao.* Batangas farmers normally plant small fields to

Table 32. Evaluation of the chemical insect control recommendation for mungbean planting in December and January.[a] Manaoag, Pangasinan, Philippines, 1978–79.

Treatment	Bean fly (% infested plants) 25 DE		Flea beetle (% defoliation) 14 DE		*Heliothis* (no./25 plants)		Yield (t/ha)	
	Dec	Jan	Dec	Jan	Dec	Jan	Dec	Jan
Maximum protection[b] on preflowering and postflowering growth stages	22 a	7 a	7 a	5 a	3 a	3 a	1.41 a	0.88 a
Maximum protection on postflowering growth stage only	65 b	79 b	16 b	23 b	3 a	3 a	0.54 b	0.26 b
Recommended practice[c]	25 a	5 a	7 a	6 a	3 a	4 a	1.32 a	0.87 a
Untreated	74 b	80 b	18 b	24 b	24 b	14 b	0.32 b	0.07 b

[a]Av of 4 replications (fields) in each month of planting. DE = days after crop emergence. In a column, means followed by a common letter are not significantly different at the 5% level. [b]Preflowering protection of 0.5 kg a.i. monocrotophos/ha on 2, 9, and 16 DE, postflowering protection of 0.03 kg a.i. decamethrin/ha on 25, 35, and 45 DE. [c]Preflowering protection of 0.25 kg a.i. monocrotophos/ha on 2 and 12 DE, postflowering protection of 0.75 kg a.i. carbaryl/ha on 25 and 35 DE.

Table 33. Chemical insect control on cowpea (EG2) after rainfed wetland rice.[a] Iloilo, Philippines, 1978–79.

Treatment	Bean fly (% infested plants) 12 DE	Defoliation (%) 35 DE	Aphid rating[b] 49 DE	Leafhopper (no./plant) 49 DE	Plant ht (cm)	Yield (t/ha)
1. High level protection[c] for preflowering and postflowering periods	10 a	16 a	1 a	0.3 a	44 a	0.42 a
2. High level protection for postflowering only	42 b	12 a	2 a	0.7 b	40 ab	0.41 a
3. Recommended practice[d]	19 a	17 a	5 b	1.1 bc	41 ab	0.30 ab
4. Recommended level for postflowering only	54 bc	44 ab	5 b	1.8 bc	37 bc	0.17 bc
5. Untreated	70 c	48 b	7 c	2.1 c	34 c	0.07 c

[a]Av of 4 fields. DE = days after emergence. In a column, means followed by a common letter are not significantly different at the 5% level. [b]1–9 scale per plant: 1 = no aphids, 3 = adults only, 5 = several colonies, 7 = many distinct colonies, 9 = many colonies, coalesced and indistinct. [c]Preflowering protection of 0.5 kg a.i. monocrotophos/ha 2, 9, and 16 DE, postflowering protection of 0.03 kg a.i. decamethrin/ha 25, 35, and 45 DE. [d]Preflowering protection of 0.25 kg a.i. monocrotophos/ha 2 and 12 DE, postflowering protection of 0.75 kg a.i. carbaryl/ha 25 DE.

Table 34. Chemical insect control on bush sitao planted in May and November.[a] Tanauan, Batangas, Philippines, 1978.

Treatment	Bean fly larvae + pupae (no./plant) 13–21 DE	Aphid rating[b] 35 DE	Plant ht (cm)	Yield of green pods (t/ha)
	May planting, 6 fields			
Complete protection[c]	0 a	2.2 a	62 a	3.7 a
Recommended practice[d]	0.01 a	2.6 c	60 a	3.4 a
Untreated	0.1 b	2.0 a	57 a	2.2 b
	November planting, 3 fields			
Complete protection[c]	0.2 b	1 a	37 a	1.68 a
Recommended practice[d]	0 a	1 a	42 a	1.23 a
Untreated	0.7 c	1 a	23 b	0.23 b

[a]Within each planting date, means in columns followed by a common letter are not significantly different at the 5% level. DE = days after crop emergence. [b]1–9 scale per plant: 1 = no aphids, 3 = adults, 5 = several colonies, 7 = many distinct colonies, 9 = many colonies, coalesced and indistinct. [c]1% wt/wt carbofuran seed treatment, 0.05 kg a.i. fenvalerate/ha on 25, 35, and 45 DE. [d]0.25 kg a.i. monocrotophos/ha 2 and 12 DE, 1 kg a.i. carbaryl/ha 30 DE.

bush sitao in May with the onset of the monsoon rains. The yield response to insecticide of this planting was compared to that of a planting after rice in November, an introduced pattern. The yield response with complete protection was compared with that with the recommended practice, which had only preflowering protection. There was a distinct seasonality in insect pest abundance (Table 34). The early planting was attacked mainly by the aphid *Aphis craccivora*, which was relatively easier to control than the bean fly *Ophiomyia phaseoli*, which infested the dry-season planting. The bean fly in the November planting reduced plant stands and attacked the crop even at the green pod stage, producing a symptom similar to that of bacterial wilt.

The May planting showed the greatest yield potential and the least insect pest pressure. The November planting initially suffered from rains during the late rainy season and drought during the pod-filling period.

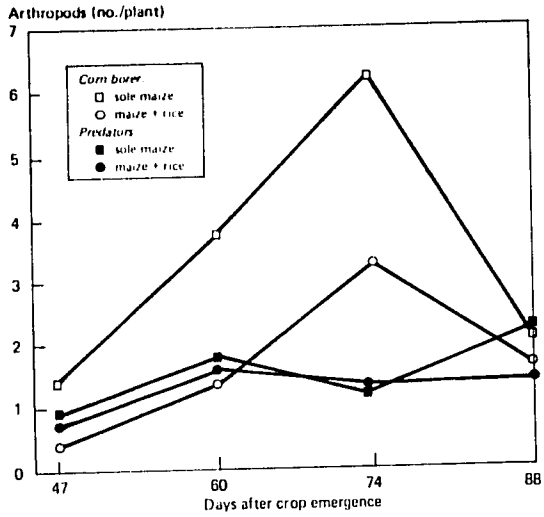
Intercropping and the Asian corn borer. A number of theories have been proposed to explain how intercropping reduces the Asian corn borer *Ostrinia furnacalis* populations on maize. Two field experiments in 1978-79 compared the corn borer populations on intercrop and sole crop treatments. In the first experiment the four treatments were maize + rice, maize + peanut, maize + bare soil, and dense sole crop maize. Row spacing was 1.5 m in the first 3 treatments and 0.75 in the dense sole crop. The maize population was 25,000 plants/ha for wide spacing and 100,000 plants/ ha in the dense sole crop. In the second experiment maize was spaced 1.5 m between rows in 4 treatments — maize + soybean, maize + rice, maize + bare soil (weeded), and maize + weeds (unweeded).

Egg masses were counted from 400 plants/replication at biweekly or weekly intervals in both experiments. Contrary to earlier results (1973 and 1975 annual reports), no significant differences were found between the intercrop and sole-crop treatments, either per maize plant or per unit area.

Corn borer larvae, pupae, and tunnels were counted at bimonthly or weekly intervals. In the first experiment, corn borers were significantly fewer in the peanut or rice + maize than in the maize sole crop (Fig. 7). Contrary to previous studies (1975 annual report), there was no difference in corn borer numbers (larvae, pupae, or tunnels) between wide-spaced (25,000 plants/ha) and narrow-spaced (100,000 plants/ha) sole crop.

In the second experiment there were no significant differences in corn borer numbers between any of the four wide-spaced treatments.

Natural enemy populations were monitored in the first experiment by enclosing whole plants with nets day and night at bimonthly intervals. There were no significant differences in predators (species or individuals) between intercrop and sole crop treatments (Fig. 7). Some previously recorded insects were observed to be efficient predators of the corn borer. A ladybird beetle [*Micraspis crocea* (Mulsant)] and a pentatomid bug (*Menida for-*



7. Effect of intercropping on the Asian corn borer, and a comparison of natural enemies sampled on maize plants intercropped with rice or as sole crop. IRRI, 1979.

mosa Westwood) preyed on egg masses.

Greenhouse and field trials demonstrated the dispersal behavior of corn borer larvae 1-3 days old. Upon hatching, the larvae first aggregated around the egg mass and moved together to the upper portions of the maize plant. A pioneer larva secretes a strand of silk, attaches it to a leaf, and dangles. The suspended pioneer larva swings in the wind currents and produces more silk (up to 1.5 m long) until it strikes an object or becomes airborne if the silk breaks. A bridge is formed if the larva strikes an adjacent plant with the silk still intact. The aggregating larvae have been observed to cross the silk bridge in tandem to the adjoining plants. If the pioneer larva struck a non-maize plant, it returned over the bridge to the original plant.

This dispersal behavior could explain how intercropping reduces corn borer populations — because of widely-spaced maize rows, or the greater distance between plants in intercropping than in sole cropping more larvae became airborne. Once airborne, the larvae may be blown away from the field. It was observed, however, that corn borers were significantly fewer in maize with companion crops than in maize + bare soil. There is no reason to believe wind currents would differ in intercropping systems with bare soil and with a companion crop.

Chemical disease control *(Plant Pathology). Seed treatment against damping-off of legumes.* Damping-off of legume seedlings caused by *Sclerotium rolfsii, Rhizoctonia solani*, and *Pythium debaryanum* occurred at research sites in Iloilo, Pangasinan, and at IRRI. Fungicides as seed treatments to control those organisms were tested in an IRRI greenhouse during 1979.

The results of tests against Sclerotium damping-off are summarized in Table 35. None of the chemicals exhibited phototoxicity in the trials.

Table 35. Efficacy of some fungicides applied as seed treatment on the incidence of Sclerotium preemergence damping-off in 2 trials. IRRI, 1979.

Fungicide	Pre-emergence damping-off (%)[a]					
	Cowpea		Mungbean		Soybean	
	1st	2d	1st	2d	1st	2d
Mancozeb	96.7 a	97.3 a	88.5 a	75.0 a	98.6 a	70.4 abc
CGA 48988	84.7 ab	97.3 a	70.1 bc	82.0 a	100.0 a	98.5 a
Terra Coat L-205	40.7 c	61.4 cd	64.9 c	82.8 a	73.7 b	42.2 bcd
Terra Coat ZN-2055	81.7 b	42.4 cd	37.1 d	50.9 abc	55.1 b	48.5 bcd
Vitavax 200	10.7 d	37.9 cd	1.0 f	37.0 bcd	8.4 cd	33.0 cd
Vitavax 300	5.7 d	26.5 d	2.1 f	20.0 d	5.3 d	20.0 d
Homai (NF 68)	75.3 b	67.0 bc	76.4 abc	74.0 a	100.0 a	59.3 bcd
Rovral	20.0 cd	40.9 cd	19.1 e	22.0 cd	49.1 b	44.1 bcd
Orthocide	37.7 c	47.0 cd	57.6 c	11.7 d	64.2 b	21.8 cd
H-719	5.3 d	75.8 abc	3.5 f	64.1 ab	27.0 c	55.2 bcd
Check	89.7 ab	95.4 ab	86.8 ab	81.7 a	100.0 a	83.7 ab

[a]% infection = $\frac{\text{total no. of seeds sown} - \text{no. of seedlings that emerged}}{\text{total no. of seeds sown}}$ x 100; data corrected based on percentage of seed germination and seedling emergence. Data were taken 7 days after sowing. Each figure represents the mean of 3 replications; analysis was based on values transformed to arcsin. Means followed by the same letter are not significantly different at the 5% level.

Table 36. Effect of seed treatments on the incidence of downy mildew and on maize yield at 2 planting dates.[a] Pangasinan, Philippines, 1979.

Variety	Rate of Ridomil 25 WP (g a.i./kg seed)	8 April 1979			25 April 1979		
		Downy mildew[b] (%)		Yield[c] (no. of marketable ears/23.4 m²)	Downy mildew[b] (%)		Yield[c] (no. of marketable ears/28.1 m²)
		34 DE	At harvest		34 DE	At harvest	
Macapuno (local)	0.50	0 a	0 a	64.25 a	0 a	0 a	81.25 a
	0.25	0.23 a	0.46 ab	64.25 a	0 a	2.03 ab	77.75 a
	0.125	0.33 a	1.33 b	60.75 a	1.66 a	3.56 b	81.25 a
	0	13.41 b	13.65 c	59.75 a	40.62 b	47.43 c	66.25 a
Sweet maize (susceptible)	0.50	0.50 a	1.25 a	53.25 a	0 a	2.68 a	62.33 a
	0.25	1.32 a	3.14 b	47.50 a	2.87 b	7.09 b	71.00 a
	0.125	4.91 b	9.01 c	46.25 a	11.04 c	21.90 c	63.50 a
	0	71.04 c	87.25 d	11.50 b	71.49 d	96.27 d	7.00 b

[a]Means followed by the same letter are not significantly different at the 5% level. [b]Based on the ratio of infected plants to the total population in middle rows/plot; analysis based on values transformed to arcsin. DE = days after emergence. [c]Analysis based on values transformed to $\log_{10}(x + 1)$.

Downy mildew of maize planted before rice. In Pangasinan, downy mildew occurs in late maize plantings (May to June). Planting earlier allows the crop to escape infection but increases the risks of drought because most maize fields are rainfed.

Ridomil 25 WP as seed dressing at rates ranging from 0.5 to 2.0 g a.i./kg seed has provided excellent control of the disease. A 1979 study in Pangasinan tested the efficacy of Ridomil at lower rates on Macapuno, a local variety, and on a sweet maize variety susceptible to downy mildew. Significant control of the disease was observed at a rate as low as 0.125 g a.i./kg seed (Table 36). The higher incidence of the disease during harvest for the late planting and on sweet maize was expected. The disease control on Macapuno variety was not reflected statistically in the yield for both planting dates, which suggested that the reduction in the number of marketable ears is insignificant at a disease incidence as high as 47%.

Macapuno appeared to have some tolerance for downy mildew.

Cropping systems and diseases *(Plant Pathology). Effect of maize and mungbean intercrop on Cercospora leaf spot of mungbean in a dryland field.* Mungbean was intercropped with maize at a two-row spacing at IRRI. The results indicated that two-crop intercropping did not minimize Cercospora leaf spot (Table 37).

Soil-borne diseases in wetland and dryland fields. Wetland and dryland fields were planted with wet-seeded rice and dry-seeded rice, respectively, and then inoculated with sheath blight at maximum tillering to ensure the presence of the disease for subsequent cropping. Moderate disease intensity resulted. After harvest, the fields were divided into WSR-TPR-TPR, WSR-TPR-mungbean, TPR-mungbean, and GM-TPR-mungbean patterns. The first crop in wetland fields (Table 38) showed that disease incidence and severity generally increased with time for WSR and TPR and WSR appeared to favor the disease more. On green maize, the disease was inconsistent in weeded and unweeded plots in all the cropping patterns used.

In another experiment, two strictly rainfed dryland fields at IRRI with a history of soil-borne diseases were used to determine the effect of crop-

Table 37. Effect of intercropping on the severity of Cercospora leaf spot and on grain yield of mungbean. IRRI, 1979.

Treatment[a]	Disease severity[b]			Yield (t/ha)
	33 DE	47 DE	61 DE	
Sole mungbean				
Treated	1.4	1.7	6.4	1.2
Untreated	1.5	3.7	–[c]	0.7
Mungbean + maize in 1.5-m row				
Treated	1.4	1.4	5.8	0.7
Untreated	1.6	4.0	–[c]	0.3
Mungbean + maize in 3.0-m row				
Treated	1.5	1.8	6.7	1.2
Untreated	1.6	3.8	–[c]	0.5

[a]Treated plants received 2 sprays of benomyl (0.30 g/liter water per spraying) at 29 and 43 days after emergence (DE). [b]On a leaf basis, using 4 lower leaves/plant, 6 plants sampled/plot. Each leaf was rated on a scale of 0 to 9: 0 = no infection, 1 = 1–5% leaf area infected, 3 = 6 to 25%, 5 = 26 to 50%, 7 = 51 to 75%, and 9 = 76 to 100%. [c]Complete defoliation.

Table 38. Incidence and severity of Rhizoctonia disease in first crop of 4 cropping patterns in a wetland field.[a] IRRI, 1979.

Cropping pattern[b]		15 Oct 1979		29 Oct 1979		12 Nov 1979		26 Nov 1979	
		I (%)	S	I (%)	S	I (%)	S	I (%)	S
WSR-TPR-TPR	Weeded	40.7	1.1	40.7	2.0	63.0	3.8	92.6	4.9
	Unweeded	33.3	1.0	40.7	2.8	63.0	3.5	77.8	4.9
WSR-TPR-mungbean	Weeded	40.7	1.3	44.5	2.5	77.8	7.2	70.4	4.8
	Unweeded	55.6	1.4	37.0	2.6	51.9	3.6	81.5	4.6
TPR-mungbean	Weeded	15.7	3.0	21.8	3.3	26.9	4.6	51.1	4.8
	Unweeded	16.8	2.7	25.0	3.3	28.2	4.6	48.8	5.0
GM-TPR-mungbean	Weeded	14.3	2.1	13.7	2.1	–[c]	–	–	–
	Unweeded	19.7	1.6	11.8	2.0	–	–	–	–

[a]I = incidence; based on the ratio of infected plants to the total population in sampled area in each plot x 100. S = severity; based on Standard Evaluation System for Rice scale of 1 to 9. [b]WSR = wet-seeded rice, TPR = transplanted rice, GM = green maize. [c]Green maize already harvested.

Table 39. Soil-borne diseases and their incidence and severity[a] at different observation dates in 2 dryland fields (DH7 and DC4) as affected by various cropping patterns.[b] IRRI, 1979.

Cropping pattern	Infection	Pathogen	Infection	Pathogen	Infection	Pathogen
	First crop, DH7					
	21 May		26 Jun		14 Aug	
Cowpea – cowpea – cowpea	Damping-off 28.4%	65.4% Rhizoc.[c]	Stem & root rot 5.4%	46.7% Rhizoc., 51.1% Fusar., 6.7% Scler.	None	–
Dryland rice – green maize – cowpea	None	–	None	–	Sheath blight[d] 2.4	
Dryland rice – cowpea – cowpea	None	–	None	–	Sheath blight 2.4	
	Second crop, DH7					
	11 June		12 Nov		19 Nov	
Cowpea – cowpea – cowpea	Damping-off 12.6%	48.2% Rhizoc.	Damping-off 0.4%	100% Rhizoc.	Stem & root rot 0.3%	100% Rhizoc.
Dryland rice – green maize – cowpea	None	–	None	–	None	–
Dryland rice – cowpea – cowpea	Damping-off 9.0%	56.3% Rhizoc.	Damping-off 1.0%	79.2% Rhizoc., 41.7% Pythium	Stem & root rot 0.1%	100% Rhizoc.
	First crop, DC4[e]					
	12 Jul		13 Aug		24 Sep	
Peanut – peanut – peanut	Damping-off 12.4%	16.7% Scler., 33.3% Rhizoc.	Damping-off 4.4%	11.6% Rhizoc., 11.7% Fusar.	Stem rot 0.1%	100% Scler.
Dryland rice – green maize – peanut	None	–	Sheath blight 3.3%	–	None	–
Dryland rice – peanut – peanut	None	–	Sheath blight 4.1%	–	None	–

[a]Infection figures followed by % indicate incidence, based on the ratio of infected plants to the total population x 100. Values for sheath blight denote severity, based on the Standard Evaluation System for Rice scale of 1–9. Rhizoc. = Rhizoctonia, Fusar. = Fusarium, Scler. = Sclerotium. [b]Each figure represents the mean of 4 replications. [c]65.4% of infected seedlings yielded Rhizoctonia growth on isolation plates. [d]No isolation was made for sheath blight; Rhizoctonia sp. has been known as the causal pathogen. [e]Data for DC4 are based on first crop alone. Data for the 27 Aug and 10 Sep plantings, which showed no infection, are omitted.

Table 40. Mycelial and sclerotial characteristics of *Rhizoctonia solani* isolates from various hosts grown on potato dextrose agar. IRRI, 1979.

Isolate from	Mycelia		Sclerotia			
	Color	Growth type	Color	Site of production	Type of formation	Number[a]
Maize	White	Aerial	Brown	Cover of petri dish	Solitary	27
Cowpea	Brown	Depressed	Brown	Cover and periphery of petri dish	Aggregated, minute, irrregular, crustlike	204
Mungbean	White	Aerial	Brown	Dispersed	Solitary	28
Wetland rice	White	Aerial	Brown	Dispersed	Solitary	228
Sorghum	White	Aerial	Brown	Dispersed	Solitary	234

[a]Mean of 3 replications.

ping patterns on such diseases. Data gathered in 1979 are in Table 39. There was a shift from *Rhizoctonia* and *Fusarium* in the pathogens isolated from infected plants. Only light to moderately light sheath blight infection was observed on dryland rice. In the two cropping patterns with cowpea as the second crop, a high percentage of *Rhizoctonia* was isolated from infected plants, although disease incidence decreased with time. The reducing effect of the first crop of rice on disease incidence in cowpea appeared to be negligible compared with the effect in the sequence with cowpea as the first crop.

Diseases and ratoon crop. In an attempt to establish a relationship between soil-borne diseases and a ratoon rice crop, data were taken from two IRRI ratooning experiments. Most of the varieties exhibited moderate reaction to sheath blight in the main crop, but the reaction was not reflected in the ratoon crop. The stem rot incidence was high but was not correlated with the ratoon stand. During a wet-season trial, the incidence of stem rot infection was higher and the data seemed to reveal some correlation between a good ratoon crop and low incidence of stem rot. No sheath blight was observed on the ratoon crop where the main crop was sprayed twice with benomyl.

Pathological relationship between rice disease pathogens and component dryland crops *(Plant Pathology).* Many plant pathogens have a wide host range that include rice, maize, sorghum, and grain legumes, and cropping patterns and related crop management have a significant impact on how a disease epidemic is developed. Work in 1979 included pathogenicity tests on component crops from which strains of pathogens were isolated.

Thanatephorus cucumeris *on rice and component dryland crops.* The cultural characteristics, growth rate at different temperatures, anastomosis, and pathogenicity on other component crops were compared for sheath blight strains isolated from various hosts.

Mycelial and sclerotial characters of 3- and 4-day-old cultures, respectively, were noted. Only the cowpea strain appeared distinct in producing brown mycelium exhibiting depressed type of growth, and crustlike sclerotia (Table 40), and for attaining the lowest growth rate at different temperatures (Table 41). The cowpea strain again differed from others when its anastomosis exhibited contact mycelial fusion. No anastomosis occurred among strains from different host crops, suggesting that various anastomosis groups might have been involved.

The results from pathogenicity tests are summarized in Table 42. Generally, no significant differences were observed among the strains on the basis of preemergence damping-off.

Sclerotium rolfsii *and component crops of the cropping systems.* Damping-off caused by *Sclero-*

Table 41. Linear growth of *Rhizoctonia solani* isolates from various hosts at various temperatures. IRRI, 1979.

Isolate from	Growth rate[a] (mm/day)			
	20°C	25°C	30°C	35°C
Maize	24.3	36.6	43.6	2.3
Cowpea	13.7	21.1	25.2	1.9
Mungbean	26.4	33.6	41.2	2.7
Wetland rice	25.2	39.3	45.7	6.9
Sorghum	16.9	29.3	41.7	5.2

[a]Mean of 3 replications.

Table 42. Incidence (%) and severity (lesion length) in different crops of diseases caused by *Rhizoctonia solani* isolates from various hosts. 1979.

Isolate from	Disease incidence or severity[a]					
	Rice		Maize	Sorghum	Mungbean	Cowpea
	Dryland	Wetland				
			Pre-emergence damping-off[b] (%)			
Rice – wetland	28.0 a		29.7 a	58.7 abc	100.0 a	100.0 a
Rice – dryland	13.3 a		22.7 a	27.0 c	59.7 c	38.3 b
Maize	25.3 a		19.7 a	42.0 abc	98.0 ab	98.0 b
Sorghum	14.0 a		20.3 a	37.7 bc	84.7 bc	60.3 b
Mungbean	15.3 a		19.7 a	72.3 a	87.0 b	98.7 a
Cowpea	42.3 a		37.7 a	69.7 ab	100.0 a	100.0 a
			Post-emergence damping-off[c] (%)			
Rice – wetland	65.4 a		51.7 ab	80.0 ab	90.8 a	76.7 b
Rice – dryland	17.1 b		35.0 bc	68.3 b	46.7 bc	51.7 bc
Maize	72.5 a		76.7 a	95.8 a	25.8 c	43.3 c
Sorghum	47.9 a		56.7 ab	95.8 a	61.8 b	46.7 bc
Mungbean	40.8 ab		60.0 a	96.8 a	38.3 bc	8.3 d
Cowpea	0 c		10.0 c	27.5 c	100.0 a	95.0 a
			Lesion length[c] (cm)			
Rice – wetland	17.6 a	19.9 a	27.7 a	28.6 a	1.9 a	6.8 b
Rice – dryland	11.9 bc	12.4 b	24.4 a	25.1 ab	2.8 a	12.6 a
Maize	15.4 ab	13.8 b	26.8 a	27.0 a	6.7 a	8.2 ab
Sorghum	12.6 bc	12.4 b	24.4 a	21.9 b	2.1 a	8.9 ab
Mungbean	19.1 a	19.6 a	23.9 a	24.8 ab	4.4 a	6.0 b
Cowpea	8.2 c	6.3 c	8.8 b	16.2 c	6.5 a	9.6 ab

[a]Each figure represents the mean of 3 replications. Analysis for pre- and post-emergence damping-off was based on values transformed to arcsin; means followed by a common letter are not significantly different at the 5% level. [b]Data taken 7 days after sowing. [c]Data taken 7 days after inoculation.

tium rolfsii on grain legume crops planted after rice is common. *S. rolfsii* isolated from various crops was inoculated on wetland rice and dryland crops. On the basis of seedling infection, the rice strain was the most pathogenic on mungbean, cowpea, and peanut. The strains from cowpea, peanut, and mungbean gave inconsistent results on the legume crops.

On mature plants, all the strains produced lesions of similar length on the tillers of both dryland and wetland rice and on the stem of mungbean. On maize, the peanut strain caused the lowest infection on the leaf sheath; on peanut, the mungbean strain caused the lowest incidence of stem rot.

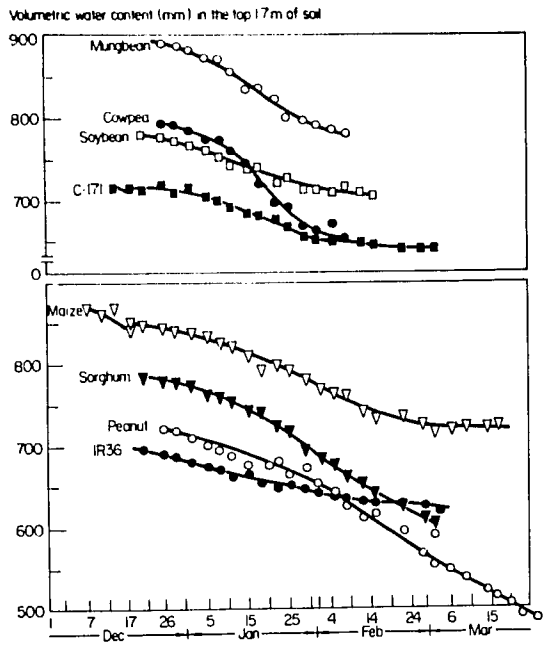
SOIL AND CROP MANAGEMENT

Multiple Cropping Department and Cropping Systems Component of the Soil Microbiology Department

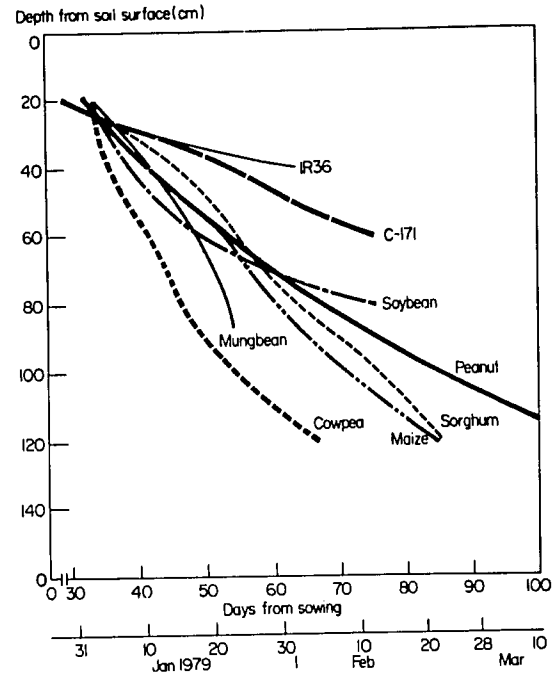
Water use of dryland crops following rice *(Multiple Cropping).* Crops grown after dryland rice often receive little or no rainfall during the growing season but are capable of producing grain using only stored soil water.

The ability of crops to extract soil water from a rainfed dryland site was compared at IRRI at the end of the 1978 wet season. A neutron moisture meter was used in access holes 1.8 m deep. The results (Fig. 8) show different starting values of soil water because of heterogenous soil. The rate of extraction and the amount ultimately extracted varied between species, with sorghum (178 mm in 78 days) and peanut (236 mm in 102 days) effective for both. Cowpea extracted water rapidly during part of its 66-day life cycle, but the total water extracted was only 140 mm. Soybean and two dryland rice varieties showed the lowest extraction (75 mm), none of which came from below 80 cm from the soil surface.

The effective rooting depth through time was also estimated from the neutron moisture measurements (Fig. 9). Cowpea showed extremely rapid



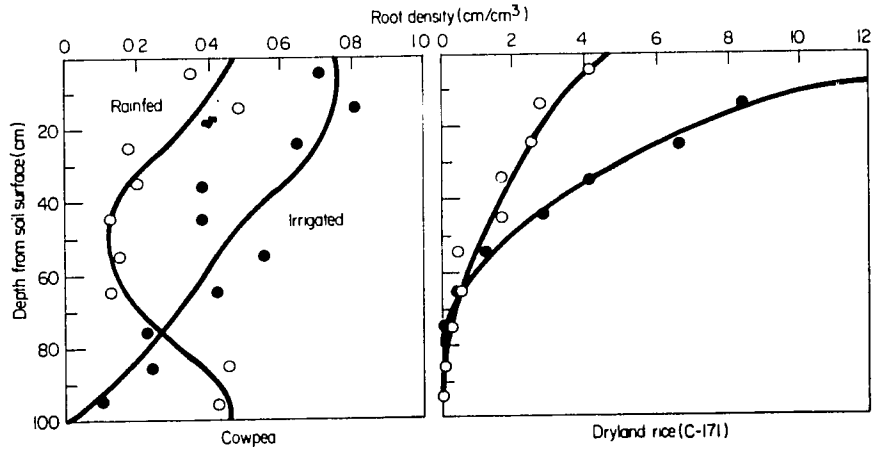
8. Changes in soil water for 8 rainfed crops. IRRI, 1979.



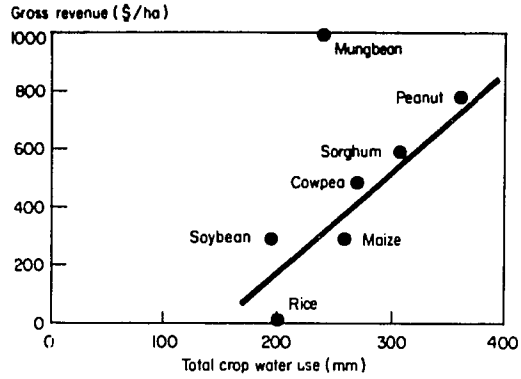
9. Changes in depth of the rooting zone of rainfed dryland crops, determined from water extraction patterns. IRRI, 1979.

penetration, but the two rice cultivars showed slow penetration. For the other crops, rooting depth was related to age. Root distribution was examined more closely by counting root intersections for cowpea and the dryland rice variety. Cowpea roots proliferated at depth in rainfed plots, but in an irrigated control deep roots were few (Fig. 10). In contrast, dryland rice showed no increased root density at depth in dry conditions. Measurements of leaf water potential (Table 43) showed the importance of deep roots — rainfed rice showed greater stress than other crops.

The results suggest that cowpea, peanut, and sorghum have inherent advantages for extracting



10. Root densities of cowpea and dryland rice in rainfed and irrigated plots. (Note the different scales.) IRRI, 1979.



11. Revenue from grain in relation to water lost in evapotranspiration. IRRI, 1979.

water after dryland rice, with cowpea requiring less water because of its brief duration. In economic terms, the crop revenue was closely related to the water lost through evapotranspiration for all crops except mungbean, which was easily the most profitable because of its high unit value (Fig. 11).

Wide row spacing for dryland crops *(Multiple Cropping).* In the dry season, many rice farmers grow dryland crops after rainfed rice, but yields are often limited by drought. Research in semiarid regions has shown dryland crop yields can be increased by planting in wide rows rather than in a conventional narrow row system.

Wide-row technology may be successful because the root system first exploits the soil water directly beneath the row and thereby leaves the subsoil water between the rows for exploitation during flowering and grain filling. With narrow rows, crops exhaust soil water before maturity. Wide row technology appears to be particularly effective when the crop grows mostly on stored soil water;

Table 43. Values of midday leaf water potential for selected crops on 7 February. IRRI, 1979.

Crop	Leaf water potential (bars)	
	Irrigated	Rainfed
Rice, IR36	−10.3	−25.6
Rice, C-171	− 8.3	−22.1
Maize	− 9.5	−12.5
Sorghum	− 8.0	− 7.1
Cowpea	− 8.5	− 8.1

Table 44. Yield for sorghum and peanut (as kernel) planted in wide and narrow rows. IRRI, 1979.

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

rainfall during the growing season encourages surface roots which lead to early exploitation of soil water between the rows.

In many rice-growing areas the weather and soil-water regimes for a dryland 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 on a dryland site at IRRI.

The results (Table 44) show that sorghum yields were depressed at wide spacing, but that peanut yields increased by 33% over yield at narrow spacing. The increase for peanut was associated with larger kernel size, suggesting that soil water was conserved for transpiration during the pod-filling phase. The response of sorghum was due to sufficient soil water even at conventional spacing.

The difference between sorghum and peanut may have been due to poor nitrogen uptake from the dry soil beneath the wide rows; the peanut was nodulated and was adequately supplied with nitrogen.

Soil water redistribution and drainage *(Multiple Cropping).* A study was conducted on dryland soil (tentatively classified as Mollic Tropofluvent) and a wetland soil (tentatively classified as Lithic Vertic Tropaquept) at IRRI to compare water movement differences following infiltration. The dryland soil was selected because its profile was deep and uniform, and moisture movement patterns similar to those described by scientists elsewhere were expected. The wetland soil was selected because its profile was typical of that of many rice soils in the surrounding area. Both soils were on sites where they would be virtually free from the effects of irrigation. The field descriptions in Table 45 and the chemical and physical data in Table 46 indicate the comparative uniformity of the dryland soil relative to the wetland soil. Moisture desorption curves for the uppermost three horizons of the root zone are shown in Figure 12.

Table 45. Profile description of 2 soils, IRRI farm.

Dryland soils: Mollic Tropofluvent (tentative classification)

Landform : Slightly convex slope, close to deeply incised creek, undulating to almost flat.

Slope : 2–3%

Vegetation : Grasses and citrus

Parent material : Recent colluvial deposits. The lower part of the profile (below 4 m) contains tuffaceous material; the upper part has been influenced by ash fall.

Drainage : Moderately well drained.

Depth of ground water : Below 3 m during description.

Erosion : Slight

Horizon	*Depth (cm)*	*Morphological characteristics*
Ap	0–20	Dark reddish brown (5 YR 3/2) clay loam; no mottling; structureless and loose when moist, common fine roots; smooth boundary.
B_1	20–40	Dusky red (2.5 YR 3/2) clay loam; no mottling; poorly formed (grade 1) and very fine (5 mm) subangular blocky; friable; few fine and few medium tubular pores; some roots; gradual, smooth boundary.
B_{21}	40–54	Dark reddish brown (5 YR 3/3) clay loam; no mottling; poor form (grade 1) and very fine to fine (< 5–10 mm) subangular blocky; friable; few fine and few medium irregular pores; few roots; gradual, smooth boundary.
B_{22}	54–74	Reddish brown (5 YR 3/4) clay loam; no mottling; moderate form (grade 2) and very fine to fine (< 5–10 mm) subangular blocky; firm; few fine and few medium irregular pores with clay coating around the pores and peds; few roots; gradual, smooth boundary.
B_{23}	74+	Strong brown (7.5 YR 4/6) clay loam; no mottling; moderate form (grade 2) and fine (5–10 mm) subangular blocky; firm; few fine and few medium irregular pores; few roots; very few Fe and Mn concretions.

Wetland soil: Lithic Vertic Tropaquept (tentative classification)

Landform : Almost flat to slightly concave; undulating to almost flat surrounding land, close to deeply incised creek.

Slope : < 1%

Vegetation : Grasses (formerly wetland rice and other crops).

Parent material : Plio-Pleistocene tuffaceous material in the lower part of profile; the upper part of the profile has been influenced by repeated ash falls.

Drainage : Poorly drained.

Depth of ground water : About 70 cm during description; flooded during heavy rains in the wet season.

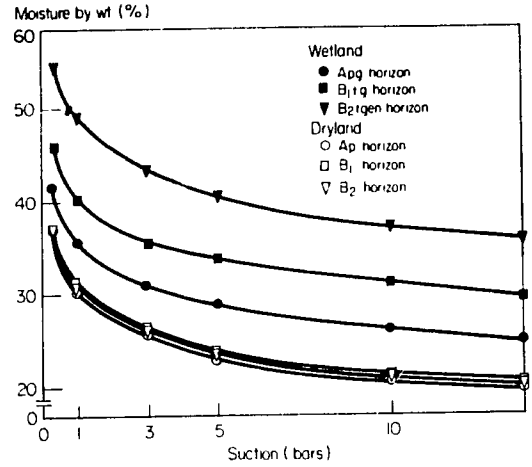
Erosion : None.

Horizon	*Depth (cm)*	*Morphological characteristics*
Apg	0–15	Dark reddish brown (5 YR 3/2) silty clay loam; some yellowish brown mottling; structureless and very friable, common fine roots, very few tubular pores; smooth boundary.
B_{1tg}	15–27	Dark reddish brown (5 YR 3/3) silty clay; some yellowish brown mottling; poorly formed (grade 1) and very fine (< 5 mm) angular blocky; friable; common fine roots; few irregular pores; smooth boundary.
B_{2tgcn}	27–56	Dark reddish brown (5 YR 3/4) clay; concretions of Mn and Fe about 30% of volume; very dark gray (2.5 YR 3/0) for Mn concretions and dark red (2.5 YR 3/6) for Fe concretions, 2–8 mm in size; moderate formed (grade 2) and fine prismatic and block (5–10 mm); friable; very few fine roots; fine pores and peds with clay coats; gradual, smooth boundary.
IIB_{2tgcn}	56–95	Dark brown (7.5 YR 4/4) clay; 50–60% of Mn, Fe and tuffaceous materials, concretions with black (2.5 YR 2.5/0) for Mn, red (2.5 YR 5/8) for Fe, and pale yellow (2.5 YR 8/4) for tuffaceous materials, 2–30 mm in size; moderate formed (grade 2) and fine (5–10 mm) prismatic with some blocky, firm; fine pores and peds with clay coats; wavy boundary.
IIIR	95+	80–90% pale yellow (2.5 YR 8/4) partly weathered horizontally layered tuff, interbedded with 10–15% very dark grayish brown (10 YR 3/2) clay, sometimes along vertical and oblique cracks; structureless, massive; hard; few coarse vesicular pores, partly filled with very dark gray clay.

Table 46. Chemical and physical properties of 2 soil profiles, IRRI farm.

Depth (cm)	pH (1:1 H_2O)	Organic carbon (%)	Total N (%)	Exchangeable cations (meq/100 g soil)				Cation exchange capacity (meq/100 g soil)	Bulk density (g/cc)	Total porosity (%)	Sand (%)	Silt (%)	Clay (%)	Saturated hydraulic conductivity (cm/h)
				Na	K	Mg	Ca							
							Mollic Tropofluvent[a]							
0–20	7.1	1.2	0.11	0.2	1.0	6.8	12.5	24.5	1.29	52	33.4	38.6	28.0	0.12
20–40	7.1	1.0	0.10	0.2	1.0	6.6	12.3	25.1	1.31	52	32.2	38.4	29.4	0.20
40–54	7.2	1.0	0.08	0.2	0.9	6.4	12.6	25.0	1.34	51	34.0	35.7	30.3	0.45
54–74	7.2	0.7	0.07	0.2	1.2	6.6	13.2	26.1	1.32	51	33.0	34.7	32.3	0.30
74 +	7.2	0.5	0.06	0.2	1.8	6.4	13.2	25.5	1.30	53	35.8	31.0	33.2	0.15
							Lithic Vertic Tropaquept[a]							
0–15	6.8	1.6	0.12	0.9	0.4	8.9	17.7	31.7	1.23	53	10.0	50.2	39.8	0.17
15–27	6.6	1.2	0.11	0.9	0.2	9.1	17.7	31.7	1.17	57	7.2	43.4	49.4	0.15
27–56	6.6	0.8	0.09	1.3	0.1	10.2	18.8	36.2	1.14	58	5.1	38.9	56.0	0.15
56–95	6.5	0.4	0.06	1.3	0.1	11.5	19.7	39.1	0.99	60	20.0	30.7	49.3	0.92
95 +	6.9	0.1	0.04	1.3	0.3	9.1	19.3	35.2	0.97	63	63.7	23.5	12.8	5.62

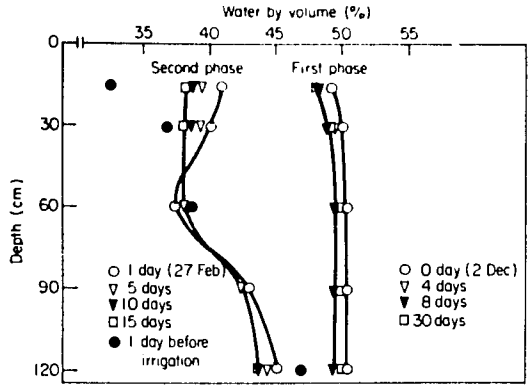
[a]Tentative classification.



12. Moisture retention curves of selected horizons from wetland and dryland soil profiles. IRRI, 1979.

Differences in soil water redistribution patterns and drainage rates were compared following two starting conditions. One started with a fully recharged soil profile and substrata and was regarded as representative of soil water distribution following a wet season rice crop; internal drainage was expected to be slow in both soils. In the other condition, soil profiles had been depleted by crop extraction and deep drainage to a state in which further drainage was minor. The second condition was regarded as representative of soil water distribution midway through the growth of a dryland crop planted after wetland rice harvest. Water behavior patterns and drainage rates following these two starting conditions are important factors in the management of dryland crops planted after wetland rice. The study was in two phases. In the first phase, test plots were heavily irrigated until they were saturated or nearly so. The plots were hydraulically isolated from the surrounding soil and covered with plastic sheet to eliminate surface evaporation. With a neutron probe in an access tube at the plot center, changes in soil water were determined at depths of 15, 30, 60, 90, and 120 cm from the surface. Two sets of tensiometers were installed at depths of 15, 30, 60, 90, and 120 cm, in a circle 1 m from the access tube. Periodic soil water content and matric suction determinations were made over a 30-day period.

After the last soil water determination, the plastic sheeting was removed, and a high-density sorghum-cowpea intercrop was planted to rapidly

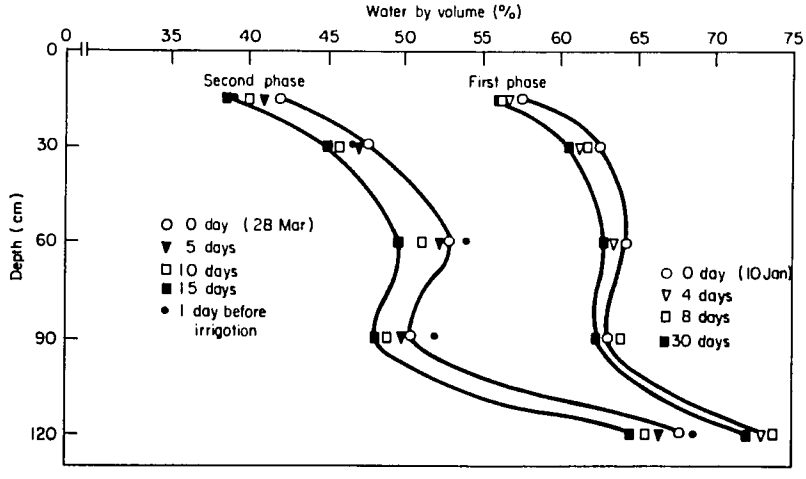


13. Soil water profiles on selected days following infiltration. First and second phases of dryland field study, IRRI, 1978-79.

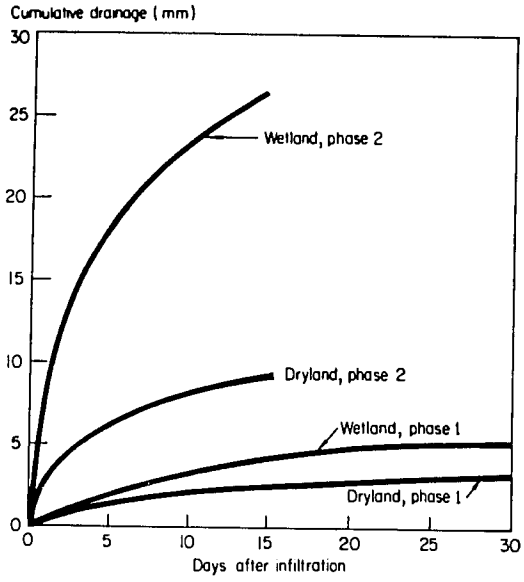
extract moisture from the soil profile. At 28 DE in the dryland condition and 22 DE in the wetland condition, sorghum was cut at ground level to reduce shading on cowpea. The neutron probe monitored profile water changes over a 54-day period in the dryland condition and a 42-day period in the wetland condition. In the second phase, the plots were irrigated with measured quantities of water (44 mm in the dryland and 22 mm in the wetland). Assuming the crop extracted water to at least 3 bars suction, desorption curves showed 40—45 mm water should be stored in the surface 40 cm below $^1/_3$ bar suction. After irrigation, the plot surfaces were again covered and soil water profiles were determined periodically over the next 15 days.

The contrasting soil physical characteristics were reflected in differences in soil moisture profiles during the first phase (Fig. 13, 14). Differences between day 1 and day 30 profiles, although minor within a soil, were different between soils; the dryland moisture profile was relatively uniform with depth, compared to the irregular wetland profile. The dryland profile drained uniformly with depth; in the wetland profile, more water drained from the upper portion. In both profiles, total drainage from the 0—75 layer over 30 days was minor — 3 mm for the dryland soil and 5 mm for the wetland (Fig. 15). Although somewhat higher for the wetland profile, daily loss rates for both profiles were initially low and diminished over the entire first phase (Fig. 16). The slow drainage rates in both profiles are thought to be caused by high subsoil water levels during the first phase. The dryland subsoil was frequently recharged by rains and the wetland subsoil was below a water table. In fact, subsequent to day 12, minor water increases were detected in the dryland profile, especially in the lower two-thirds (Fig. 13).

As expected on the basis of porosity differences, the wetland profile contained more water than the dryland profile. In the wetland soil, however, an abrupt increase was noted at the 120-cm position where the material consisted of horizontally lay-



14. Soil water profiles on selected days following infiltration. First and second phases of wetland field study, IRRI, 1978-79.

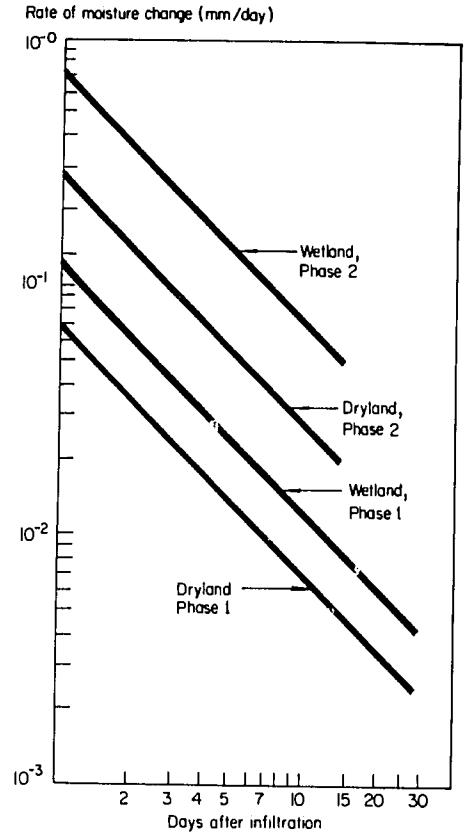


15. Cumulative water loss from 0-75 cm, first and second phases of dryland and wetland studies. IRRI, 1978-79.

ered thixotropic tuff with vertical and oblique cracks. On the basis of a 73% porosity, and a 2.64 g/cm^3 particle density, the bulk density of the material is estimated to be 0.71 g/cm^3, much lower than a determination made on a sample taken at 100-cm depth.

During the moisture extraction period between phases, the water content of the 0—75 cm layer decreased by 92 mm over 54 days in the dryland soil, and 100 mm in 42 days in the wetland soil. Given the slow rates of internal drainage, this depletion was assumed to be mainly due to crop extraction. Much smaller amounts, 14 and 13 mm for the dryland and wetland plots, were depleted from the 75—135 cm depths, the major portion of which was assumed lost by deep drainage. On the basis of matrix suction profiles, estimated mean root extension rates were 24 mm/day in the dryland soil and 30 mm/day in the wetland soil. Part of the difference in these root extension rates may have been due to soil and soil water factors but the major difference was attributed to atmospheric conditions more favorable for growth (warmer temperatures and higher solar radiation), which prevailed during the cropping period on the wetland soil.

Daily water loss rates and cumulative losses in both profiles were greater during the second phase



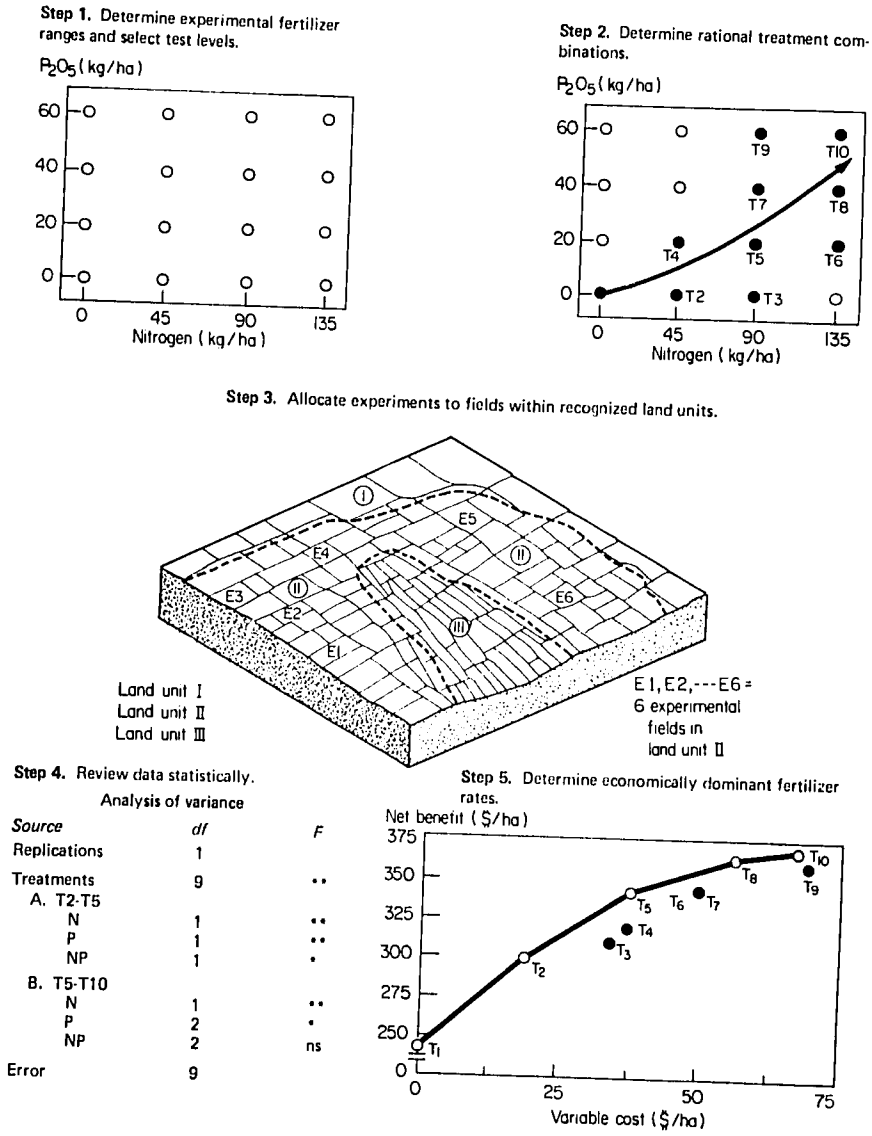
16. Rates of drainage determined for 0-75 cm depths, first and second phases of dryland and wetland studies. IRRI, 1978-79.

(Fig. 16). An estimated 20% of the applied water drained through the 75-cm level of the dryland profile during the second phase, despite a storage capacity between the 0 and 40-cm depth that was estimated adequate to retain the 44 mm applied. Comparisons of moisture profiles on day 1 and day 15 show that a small quantity of water initially stored in the upper 45 cm was redistributed to the 45—75 cm layer. The lower portion of the profile was little affected by the applied water; most of the water released from the top third of the profile drained through the middle and lower thirds of the profile and, together with water remaining in the lower third after crop extraction, drained below 120 cm. An estimated 120% of the applied water drained through the 75-cm level of the wetland profile during the second phase, despite a storage capacity between the 0 and 40-cm depth estimated to be adequate to retain the 22 mm applied. Obviously, water remaining after the crop extract-

ion period continued to drain during the second phase. A comparison of day 1 and day 14 moisture profiles in Figure 14 shows that drainage occurred rather uniformly throughout the depth of the wetland profile. During drainage from the wetland soil, the water table surface was observed to recede rapidly, which increased the hydraulic gradient appreciably, and hastened drainage in the wetland soil.

Besides the obvious and contrasting differences in water behavior patterns in the two profiles, the study showed that within soils, the drainage rates between the first and second phases differed greatly.

Determining fertilizer rates for rice *(Multiple Cropping).* Variable responses to fertilizer applications are frequently observed in multilocational field trials. Although there is a general understanding of the climatic, edaphic, and other factors that are the sources of response variations, these factors are not of immediate interest to a cropping systems agronomist who must determine fertilizer dosages



17. The 5-step approach to determine economical fertilizer rates by field experimentation. IRRI, 1979.

Table 47. Mean chemical and textural components of fields in first and second rice crops, Iloilo, Philippines, 1978–79.

	pH (1:2.5)	CEC[a] (100 meq/100 g)	Exchangeable bases (100 meq/100 g)				Available phosphorus (ppm)		Organic carbon (%)	Total nitrogen (%)	Mechanical analysis		
			Ca	Mg	K	Na	Olsen	Bray 1			Clay (%)	Silt (%)	Sand (%)
First crop	6.9	46.7	22.8	15.8	1.3	1.1	4.3	8.8	1.2	0.10	61	33	6
Second crop	7.0	43.8	22.8	15.8	0.6	0.9	6.0	9.2	1.3	0.14	52	43	5

[a]Cation exchange capacity.

for a cropping pattern designed for a recognized land unit.

In 1979 the five-step approach outlined in Figure 17 was developed for use by cropping systems agronomists to determine an approximate least-cost expansion path for formulating optimal fertilizer dosages at increasing cost levels.

The approach was tested in an irrigated area of Napnapan, Iloilo. Two wet-seeded IR36 rice crops were used, with the first crop broadcast in the first half of June 1978 and harvested in mid-September, and the second crop broadcast in mid-September and harvested in early January. Twenty fields were used for each crop. The gross area from which the 20 fields were selected was limited to about 200 ha in the Sibalom River Irrigation System.

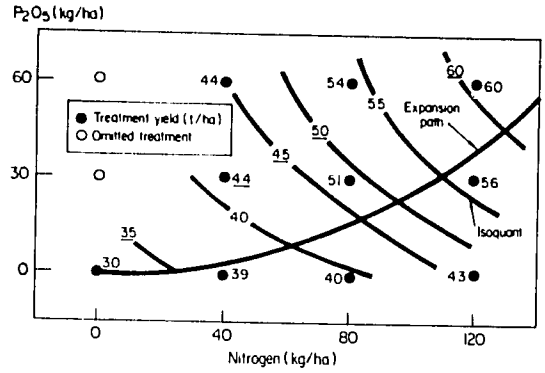
Selection of first-crop fertilizer treatment combinations. Mean chemical and physical data for soils used in the first crop are given in Table 47. From these data and general knowledge of the area, the upper fertilizer limits were set at 120 kg N/ha and 60 kg P_2O_5/ha. An upper limit of 30 kg K_2O/ha was used in 6 treatment combinations despite the argument by some scientists that the exchangeable level of soil potassium was adequate to satisfy crop requirements.

Nitrogen was regarded as the most limiting element for high yielding varieties. The 16 treatments, as nitrogen, P_2O_5, and K_2O, in kg/ha, were:

T1 — 0 — 0 — 0	T9 — 80 — 60 — 0
T2 — 40 — 0 — 0	T10 — 120 — 60 — 0
T3 — 80 — 0 — 0	T11 — 40 — 30 — 30
T4 — 120 — 0 — 0	T12 — 80 — 30 — 30
T5 — 40 — 30 — 0	T13 — 120 — 30 — 30
T6 — 80 — 30 — 0	T14 — 40 — 60 — 30
T7 — 120 — 30 — 0	T15 — 80 — 60 — 30
T8 — 40 — 60 — 0	T16 — 120 — 60 — 30

Analysis of variance. Analysis of variance was applied to the yields of each experiment separately and to those of the experiments combined. Analysis of the combined experiments showed a significant interaction between fields and treatments. The data indicated that yields were comparatively high for all treatments including T1 on five fields, showing that nutrients were not severely limiting in all cases. But because these high yielding fields could not be readily identified *a priori,* they were retained in the overall data analysis.

Analysis of each experiment showed significant treatment effects in each field. A sight-drawn



18. Rice grain yields of first crop and sight-drawn isoquants and expansion path, means of 20 fields, 2 replications/field, Iloilo, Philippines, 1978.

response surface and expansion path, using mean yields from treatments 1 to 10 (i.e. excluding treatments receiving K), conformed to expectations (Fig. 18).

Economic analysis, first crop. As applied to results in the study, net yield was taken as the measured yield per hectare in the field, minus a 5% harvest loss and a one-sixth harvester share. Because it was assumed that the farmer sold his crop immediately after harvest, no storage losses were deducted. Gross field benefit was taken as the net yield times field price. Total variable costs were taken as the sum of fertilizer cost, cost of application of fertilizer for topdressing, and interest on variable costs. Two cases were examined: one with interest at 6.5%/half year and another at 50%/half year. Net benefit was computed as gross field benefit minus total variable cost.

A partial budget analysis, presented in Table 48, shows computations based on mean yields for the 20 experiments. The highest gross field benefit and net benefit were obtained at 120—60—0.

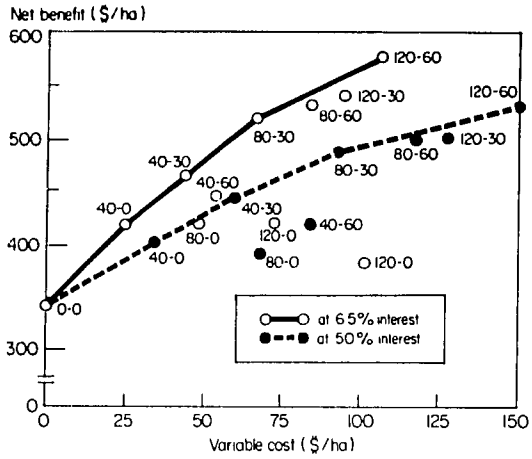
Net benefit curves were constructed by plotting the variable costs of the alternative fertilizer rates (excluding those receiving K) against their net benefits and connecting the most profitable fertilizer rates by a solid line to form the net benefit curve (Fig. 19). The slope of the curve shows the marginal rates of return to investments for the first three rates— T2 (40—0). T5 (40—30), and T6 (80—30—0) — on the curve were higher than the returns to more costly rates: T9 (80—60—0), T7 (120—30—0), and T10 (120—60—0).

Economics studies in Iloilo had shown that

Table 48. Grain yields, variable costs, and net benefits of 16 fertilizer treatments at 2 interest rates for the first crop. Mean of 20 fields, 2 replications/field, Iloilo, Philippines, 1978.

	Treatment															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Fertilizer rates (N-P_2O_5-K_2O)	0-0-0	40-0-0	80-0-0	120-0-0	40-30-0	80-30-0	120-30-0	40-60-0	80-60-0	120-60-0	40-30-30	80-30-30	120-30-30	40-60-30	80-60-30	120-60-30
Av grain yield (t/ha)	3.00	3.87	4.05	4.27	4.44	5.14	5.55	4.42	5.43	6.00	4.30	5.03	5.30	4.52	5.33	5.54
Net yield[a] (t/ha)	2.38	3.06	3.21	3.38	3.52	4.07	4.39	3.50	4.30	4.75	3.40	3.98	4.20	3.59	4.22	4.39
Gross field benefit[b] (S/ha)	342	440	462	486	506	585	632	503	618	683	489	572	604	515	607	632
Fertilizer cash cost[c] (S/ha)	0	22	45	67	40	63	85	56	78	101	49	72	94	65	87	110
Other variable cost and interest @6.5% (S/ha)	0	3	4	6	4	5	6	4	6	7	5	6	7	5	7	8
Other variable cost and interest @50% (S/ha)	0	13	24	35	21	32	44	28	40	51	26	37	49	34	45	56
Net benefit interest @6.5% (S/ha)	342	415	413	413	462	517	541	443	534	575	435	494	503	445	573	574
Net benefit interest @50% (S/ha)	342	405	393	383	445	490	503	419	500	531	414	463	461	416	475	466

[a]Assuming one-sixth share goes to harvester, and additional field losses are 3–4%, for a total reduction of 20%. [b]At $144/t of net yield. [c]At $55/100 kg N and $56/100 kg P_2O_5.



19. Net benefits and variable costs of 10 fertilizer treatment combinations for the first crop, at 2 interest rates. Means of 20 fields, 2 replications field, Iloilo, Philippines, 1978. Numbers joined by a hyphen indicate kilograms N and P per hectare.

farmers were getting 200% returns on cash inputs in their patterns. For both interest rates, all highly profitable fertilizer treatments had average returns exceeding 200%, and rates on the net benefit curve had marginal returns exceeding 200%. The Iloilo economics studies also showed that few farmers exceeded cash expenditures of $50/ha for fertilizer on their main rice crops. Although T5 (40—30) was within this range, Figure 19 shows that the 40—30 nutrient combination was well off the expansion path, and that probably a 50—20 combination, at about the same cost, would be better balanced and still not exceed levels farmers were already using. Expansion to 80—30 and beyond could easily be justified where expenditures are not constrained.

Marginal analysis of highly profitable fertilizer rates using the 6.5% interest rate to compute cost was separately made on each of the 20 experiments. Treatments containing potassium were excluded from the analysis of individual experiments. The distribution showed that generally where little or no nitrogen was required, little or no phosphorus was required; where large amounts of nitrogen were required, large amounts of phosphorus were required, indicating that soils that supplied little nitrogen also supplied little phosphorus. Although the largest marginal frequencies for nitrogen corresponded to 80 kg/ha, the largest frequency for P_2O_5 did not correspond to 30 kg/ha. Furthermore, considerable variation was found between fields.

- Of major concern are fields on which even low rates of fertilizers did not produce profitable returns, although yields were high.
- The recommendation of 30 kg P_2O_5/ha often appeared too low where phosphorus was needed.

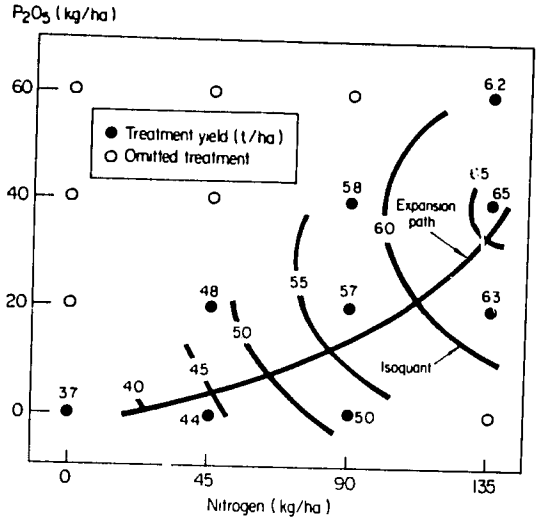
Within the 20 test fields, the chemical soil tests found to most closely correlate with nitrogen and phosphorus uptake across the experiments could not be used to identify fields requiring no fertilizers, or phosphorus rates greater than 30 kg P_2O_5/ha. Factors other than slight differences in chemical constituents of the soil clearly caused the variation in optimal fertilizer dosages for the 20 fields.

Given the obvious differences in natural field fertility in environmental factors (including those which contribute to risk, such as drought, typhoons, insects), in farmers' management abilities, and in farmers' economic positions, rates of 80—30 to 90—40 were suggested as general rates for the first rice crop where there is no cash constraint. Where cash was constrained to $50/ha, rates of 50—20 or 60—20 were suggested. Given the many factors that go into a farmers' final choice, these approximate rates were assumed as adequate for analysis in cropping systems studies.

Selection of second-crop fertilizer treatment combinations. Although the general study area was the same as in the first rice crop, different fields were selected because:

- 20% of the first-crop area had irrigation of questionable reliability for the second crop.
- Potassium treatments were eliminated and an additional phosphorus level was introduced, requiring a different field layout.

Higher nitrogen levels were used on the second crop because the highest nitrogen levels on the first crop appeared limiting in some cases and solar radiation on the second crop was expected to be higher. The highest P_2O_5 level was kept at 60 kg/ha but instead of 2 levels (30 and 60 kg/ha), 3 (20, 40, and 60 kg/ha) were used to examine phosphorus responses. A zinc treatment was also added because soil analysis indicated that zinc was below the critical level and because of the long period of submergence during the first crop. The 10 treatment combinations, as kg N/ha and kg P_2O_5/ha,



20. Rice grain yields and sight-drawn isoquants and expansion path for the second crop. Means of 20 fields, 2 replications/field, Iloilo, Philippines, 1978-79.

were:

T1	0	0	T6	135	20
T2	45	0	T7	90	40
T3	90	0	T8	135	40
T4	45	20	T9	135	60
T5	90	20	T10	135	60 + Zn

Treatment effects were significant in each experiment analyzed separately. Using yield means from treatments 1 to 9, response surface and expansion path was sight-drawn (Fig. 20). The surface conformed with expectations.

Economic analysis. Partial budgets of the 10 treatments, using mean yields for the 20 experiments, are presented in Table 49. Both highest gross field benefit and highest net benefit were obtained in treatment 8 (135—40). Costs and prices assumed in the budgets are listed on the left side of the table.

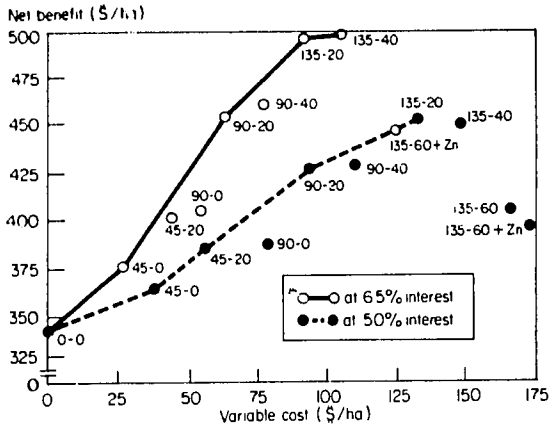
The net benefit curve in Figure 21 shows that the 135—60 and 135—60 + Zn treatments were inferior because for each of them, there was another rate with a higher net benefit but a lower variable cost.

As in the first crop, marginal rates of return were high where fertilizer applications relieved limiting nutrient supplies. Because of the lower rice price, marginal rates were not as high as in the first crop, but the marginal return to 90—20 was about 270% at the 6.5% interest rate and 21% at the 50% inter-

Table 49. Grain yields, variable costs, and net benefits of 10 fertilizer treatments, at 2 interest rates. Second crop, mean of 20 fields, 2 replications/field, Iloilo, Philippines, 1978–79.

	Treatment									
	1	2	3	4	5	6	7	8	9	10
Fertilizer rates (N-P_2O_5)	0-0	45-0	90-0	45-20	90-20	135-20	90-40	135-40	135-60	135-60+Zn
Av grain yield (t/ha)	3.67	4.37	5.03	4.78	5.65	6.33	5.84	6.48	6.16	6.16
Net yield[a] (t/ha)	2.91	3.46	3.98	3.78	4.47	5.01	4.47	5.13	4.87	4.88
Gross field benefit[b] ($/ha)	339	403	463	440	520	583	538	597	568	568
Fertilizer cash cost[c] ($/ha)	0	25	51	36	62	87	73	98	109	114
Other variable cost and interest at 6.5% ($/ha)	0	3	4	4	4	6	5	7	8	8
Other variable cost and interest at 50% ($/ha)	0	14	26	20	32	45	37	50	56	58
Net benefit, 6.5% interest ($/ha)	339	375	408	400	454	490	460	492	451	446
Net benefit, 50% interest ($/ha)	339	364	386	384	426	451	428	449	403	396

[a]Assuming one-sixth share goes to harvester, and additional field losses are 3—4% for a total reduction of 20%. [b]At $116/t of net yield. [c]At $55/100 kg N and $56/100 kg P_2O_5.



21. Net benefits and variable costs of 10 fertilizer treatment combinations for the second crop, at 2 interest rates. Means of 20 fields, 2 replications fields, Iloilo, Philippines, 1978-79. Numbers joined by a hyphen indicate kilograms N and P_2O_5 per hectare.

est rate. Beyond 135—20 (T6), returns decreased rapidly.

Although 90—20 (T5) produced high net benefits, a fertilizer cash cost of $62/ha was required, which appeared slightly high in relation to most farmers' expenditures on fertilizers. A rate of 70—20, determined by interpolating between rates used in the experiments, would provide a high rate of return under a restriction of $50/ha on fertilizer materials.

Marginal analyses of fertilizer rates, using the 6.5% interest rate to compute costs, were separately made on each of the 20 experiments. The distribution of optimum fertilizer combinations using 200% marginal returns to variable costs is shown in Table 50. As in the first crop, differences between fields were great. However, in contrast to the first crop Olsen P determinations were in general agreement with the optimum P_2O_5 rates, but the scatter remained too wide for the soil test to be of use beyond defining the range of experimental levels. Similarly, organic carbon showed much scatter and cannot be considered as a precise test for defining nitrogen rates.

Use of old seedlings to shorten field duration *(Multiple Cropping).* The use of a higher number of rice seedlings per hill to compensate for reduced yields due to the use of old seedlings has potential in increasing crop intensification, particularly in rainfed wetland areas (1978 annual report). Six field trials with old seedlings were completed in 1979.

In the first trial IR36 seedlings at 18, 28, 34, and 48 DS were in main plots and 3, 6, 9, and 12 seedlings per hill were subplot treatments. The 18-day-old seedlings at 3/hill were the check entry.

The second study tested IR36 (maturity of 110 DS), IR38 (125 DS), and IR32 (140 DS) transplanted at 18 and 40 DS at 3 and 9 seedlings per hill to see if varieties of different maturity periods would react differently to the use of old seedlings.

The third trial determined the influence of seedbed and main field nitrogen levels on the yield potential of old seedlings. Two rates of nitrogen in the seedbed stage (100 and 200 kg N/ha each applied in 2 equal splits) and 2 at transplanting (20 and 60 kg N/ha applied basally) were imposed on 40- and 60-day IR36 seedlings transplanted at 3 and 9 seedlings per hill. The 60-day treatment was tested as an extreme to look for ways to reduce

Table 50. The distribution of optimal fertilizer combinations as determined by marginal analyses of individual fields, and mean organic carbon contents and Olsen P values corresponding to N and Olsen P fertilizer levels. Second rice crop, Iloilo, Philippines, 1978–79.

Nitrogen (kg/ha)	Frequency of fields with optimal fertilizer combinations				Total no. of fields	Mean organic carbon (%)
	0 P_2O_5	20 kg P_2O_5/ha	40 kg P_2O_5/ha	60 kg P_2O_5/ha		
0	3	–	–	–	3	1.3
45	2	4	–	–	6	1.5
90	0	4	3	–	7	1.4
135	–	2	2	0	4	1.0
Total no. of fields	5	10	5	0	20	
			Olsen P values (ppm)			
Mean	8.3	5.9	3.8			

Table 51. Effects of seedling age on grain yield and field duration of IR36.[a] Experiment 1, IRRI, Mar–Jun 1978.

Age of seedlings (days)	Grain yield (t/ha)	Field duration (days)	Yield (kg) per day
18	5.82 a	84.0 a	69.3 a
28	5.82 a	82.0 b	70.9 a
34	5.57 a	80.1 c	69.5 a
48	4.60 b	75.1 d	61.3 b

[a]With varietal mixture. Av of 4 replications and 4 numbers of seedlings per hill. In a column, means followed by a common letter are not significantly different at the 5% level.

yield loss in this trial and in others. The 40-day-old seedlings received 100 kg N/ha in the seedbed and 20 or 60 kg N/ha at transplanting at 3 seedlings per hill. All treatments received 30 kg/ha each of K_2O and P_2O_5 at planting time in the seedbed and in the main field and 20 kg N/ha at the panicle initiation (PI) stage. The total nitrogen applied in the field was 40 and 80 kg/ha.

The fourth trial was similar to the second trial except that IR8608-298-3-1 (maturity of 100 DS), IR36 (110 DS), and IR42 (130 DS) were transplanted at 20, 40, and 60 DS using 3 and 9 seedlings per hill.

The fifth trial tested the effects of seedling age (20 and 40 DS) and number per hill (2 and 8) when IR36 and IR42 were planted at spacings of 12.5 × 12.5 cm and 25 × 25 cm.

The sixth experiment determined the effect of low and normal management levels in the seedbed stage on the subsequent yields of the old seedlings — 40- and 60-day-old IR36 and IR42 seedlings planted at 2 and 8 seedlings per hill. The normal management treatment consisted of the application of 50-50-50 kg of N, P_2O_5, and K_2O/ha at sowing and 20 kg N/ha for every 10 days in the seedbed. In addition the seedbeds were kept flooded. The low-management dry seedbeds received 10-50-50 kg of N, P_2O_5, and K_2O/ha as basal and 5 kg N/ha was applied only when the older leaves started to show nitrogen deficiency symptoms. The low-management seedlings received only 17% of the total nitrogen applied in the normal management seedbeds. As a check, 20-day-old seedlings of each variety were raised under normal management level and were transplanted at 2 seedlings/hill. At transplanting all treatments got 50-50-50 kg of N, P_2O_5, and K_2O/ha and 20 kg N/ha at PI.

All experiments were irrigated, with each treatment replicated four times. To minimize damage to the roots when pulling the old seedlings for transplanting, weathered rice hulls were scattered about 1 cm thick on the soil surface at sowing. At transplanting the seedlings were counted to get the correct number per hill. Transplanting was at 25 × 25 cm except in the fifth trial.

Effect of seedling age and number per hill. In the first trial the number of seedlings per hill had no significant effect on yield and field duration (days from transplanting to harvest) of IR36. The yields of IR36, averaged across 4 seedling ages, were stable for seedlings up to 35 days old. Yield was reduced significantly (21% from that of the 18-day-old seedlings) only when 48-day-old seedlings were used (Table 51). Reduction in field durations was significant at all seedling ages, although there was only a 9-day difference between the oldest and youngest seedlings used. The oldest seedlings had the shortest duration but also the lowest yield on a per day basis.

In the second trial, the early-maturing IR36 was more sensitive to the use of old seedlings than IR38 and IR32 at 3 seedlings/hill (Table 52). Increased number of seedlings tended to compensate (not significant at $P = 0.05$) for yield losses incurred with 40-day-old IR36 seedlings. The higher number of seedlings reduced the yields of IR32, particularly when 40-day-old seedlings were used. However, the yields of the later-maturing varieties IR32 and IR38 obtained with 40-day-old seedlings were not significantly lower than those of the 18-day-old

Table 52. Effects of age and number of seedlings (3 and 9) per hill on the grain yields of 3 rice varieties.[a] Experiment 2, IRRI, Mar–Jun 1978.

Age of seedlings (days)	Grain yield[b] (t/ha) 3	9	Difference
	IR36[c]		
18	5.92 a	5.87 a	0.05
40	4.87 b	5.31 abc	−0.44
	IR38		
18	6.00 a	6.04 a	0.04
40	5.93 a	5.48 ab	0.45
	IR32		
18	5.24 ab	4.83 bc	0.41
40	5.45 ab	4.52 c	0.93**

[a]Av of 4 replications. [b]In a column, means followed by a common letter are not significantly different at the 5% level. [c]With varietal mixture.

Table 53. Effects of age and number of seedlings per hill on the field duration of 3 rice varieties.[a] Experiment 2, IRRI, Mar–Jun 1978.

Age of seedlings (days)	Field duration (days)		Total growth duration (DS)[b]
	3 seedlings/ hill	9 seedlings/ hill	
	IR36		
18	87.0	87.0	105.0
40	78.8	78.0	118.4
Difference	8.2**	9.0**	13.4
	IR38		
18	100.0	96.0	116.0
40	93.0	91.0	116.0
Difference	7.0**	5.0**	16.0
	IR32		
18	112.5	115.0	131.8
40	104.5	105.3	144.9
Difference	8.0**	9.7**	13.1

[a]Av of 4 replications. Averaged across seedling number in each seedling age. [b]DS = days after seeding.

seedlings. The varieties showed little difference in their relative time gain from transplanting to maturity (Table 53). Growth duration did not decrease with delayed transplanting as much as was anticipated. Increasing the seedling number did not substantially change the gain in time at all seedling ages. The use of seedlings past the PI stage delayed crop development after transplanting because of the extensive formation of late tillers. This led to delay in maturity and loss in production.

A similar trial (experiment 4) showed that the three varieties tested were sensitive to the use of old seedlings — significant reductions in yield occurred when 40- and 60-day-old seedlings were used at 3/hill (Table 54). However, with 9 seedlings per hill the yields of IR8608-298-3-1 and IR42 were unchanged. In contrast IR36 suffered significant yield loss with 40- and 60-day-old seedlings even with 9 seedlings per hill. Bird and rat damage and typhoons caused lodging in many plots and contributed to the variability in yields. Heavy shattering at the early soft dough stage of IR42 reduced its yield.

The older seedlings tended to mature earlier than the normal 20-day-old seedlings, but the time gain was not as much as expected (Table 54). The 60-day-old seedlings of IR8608-298-3-1 matured later than the 20-day-old ones because of the delayed maturity of many new tillers which formed after the original tillers senesced and deteriorated after transplanting.

In the sixth experiment (Table 55) the yields of IR36 were significantly reduced as seedling age was increased from 40 to 60 DS and seedling number from 2 to 8 seedlings per hill. On the other hand, the later-maturing IR42 showed reduced yield only at the high seedling number as seedling age was increased from 40 to 60 DS, indicating greater stability. Overall, the yield of the 40-day-old seedlings did not significantly differ from the check

Table 54. Effects of age and number of seedlings (3 and 9) per hill on the grain yield and field duration of 3 rice varieties.[a] Experiment 4, IRRI, Aug 1978–Jan 1979.

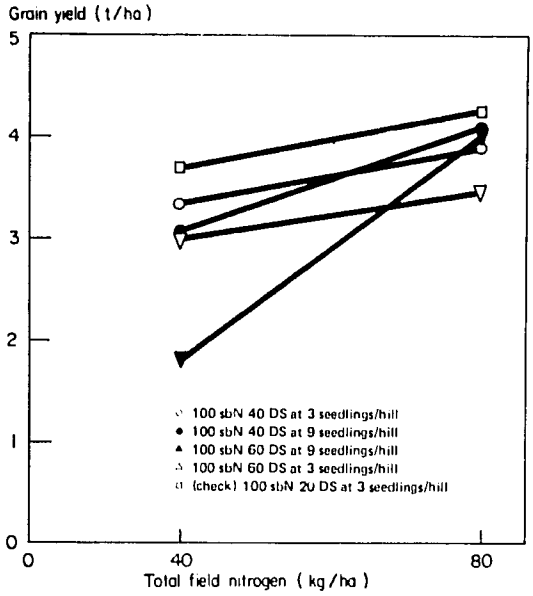
Seedling age (DS)	Grain yield (t/ha)[b]			Field duration (days)		Total growth duration[c] (days)
	3 seedlings/ hill	9 seedlings/ hill	Difference	3 seedlings/ hill	9 seedlings/ hill	
			IR8608-298-3-1			
20	4.18 a	3.26 a[d]	0.92*	84.0	81.0	102.5
40	2.86 b	2.57 a	0.29	83.0	79.3	121.2
60	3.03 b	3.14 a	−0.11	86.0	87.5	146.8
			IR36			
20	4.29 a[e]	4.18 a	0.08	87.0	81.0	104.0
40	3.29 b	2.61 b	0.69	75.8	70.0	112.9
60	2.67 b[d]	2.13 b	0.54	76.3	70.0	133.2
			IR42			
20	4.07 a	3.71 a[e]	0.36	101.8	100.5	121.2
40	3.36 b	3.63 a	−0.27	99.3	96.0	137.6
60	3.78 ab	4.09 a	−0.31	93.0	87.0	150.0

[a]Av of 4 replications. [b]In a column within a variety, means followed by a common letter are not significantly different at the 5% level. DS = days after seeding. [c]Averaged across 2 seedling numbers in each seedling age. [d]Av of 2 replications. [e]Av of 3 replications.

Table 55. Effects of age (40 and 60 days) and number of seedlings per hill on the grain yields of IR36 and IR42.[a] Experiment 6, IRRI, Jul–Nov 1979.

Seedlings (no./hill)	Grain yield[b] (t/ha)					
	IR36			IR42		
	40 d	60 d	Difference	40 d	60 d	Difference
2	3.72	2.99	0.73**	5.41	5.42	0.01
8	3.10	2.60	0.50*	5.63	5.06	0.57**
Difference	0.62**	0.39*		0.22	0.36	

[a]Av of 2 seedbed management levels; 4 replications. [b]Yields of check plots (two 20-day-old seedlings/hill): IR36, 3.48 t/ha; IR42, 5.10 t/ha.



22. Relation between grain yield and field nitrogen as affected by nitrogen in the seedbed, and age and number of IR36 seedlings per hill. Experiment 3, IRRI, Jul–Dec 1978. sbN = seedbed nitrogen, DS = days after seeding.

yields of IR36 (3.48 t/ha) and IR42 (5.10 t/ha).

An observation common to all experiments particularly the second and fourth, was that old seedlings that were close to or past the panicle initiation stage at transplanting produced new tillers in addition to those already formed in the seedbed stage. These new tillers generally caused uneven ripening as the old tillers continued to maturity and senescence, and delayed the harvest period of the plots considerably. Delayed transplanting also delayed panicle initiation time by about a week. For a given age, increasing the number of seedlings per hill tended to hasten the maturity of the crop by 3 or 7 days particularly with the older seedlings.

Effect of nitrogen application. The normal 20-day-old IR36 seedlings planted at 3/hill gave the highest grain yields at both levels of total field nitrogen (40 and 80 kg N/ha) used in the third trial (Fig. 22, Table 56). Both the 40- and 60-day-old seedlings at 3 seedlings/hill showed increased yields due to increased field nitrogen (13.5 and 11.2 kg/kg N, respectively). When the seedling number was 9/hill, the response to nitrogen was even greater (24.8 kg/kg N for the 40-day-old seedlings), especially for the 60-day-old seedlings (55.8 kg/kg N). With 40 kg N/ha, plots with 9 seedlings/hill yielded lower than those with 3 seedlings; at 80 kg/ha, yields were highest with 9 seedlings/hill. A high nitrogen level in the field

Table 56. Effects of seedling age, number per hill (3 and 9), and nitrogen applied in the seedbed[a] and main field on the grain yield of IR36.[b] Experiment 3, IRRI, Jul–Dec 1978.

Total field nitrogen (kg/ha)	Grain yield (t/ha)							
	Seedlings at 40 DS				Seedlings at 60 DS			
	100 kg N/ha		200 kg N/ha		100 kg N/ha		200 kg N/ha	
	3	9	3	9	3	9	3	9
40	3.36	3.07	3.28	2.91	2.98	1.76	2.98	2.43
80	3.90	4.06	3.85	3.51	3.45	3.98	3.22	2.31
Difference	0.54	0.99**	0.56	0.60*	0.47	2.22**	0.24	0.12

[a]Nitrogen was applied to the seedbed at 100 and 200 kg N/ha. DS = days after seeding. [b]Av of 4 replications. Yields of 20-day-old seedlings at 3/hill that received 100 kg N/ha in the seedbed and 40 and 80 kg N/ha in the main field were 3.69 and 4.25 t/ha, respectively.

Table 57. Effects of seedling age, number per hill, and spacing on the grain yield, field duration, and yield per day of IR36 and IR42.[a] Experiment 5, IRRI, Jul–Nov 1979.

Seedlings		Spacing (cm)	IR36			IR42		
No./hill	Age[b] (DS)		Grain yield (t/ha)	Field duration (days)	Yield (kg) per day	Grain yield (t/ha)	Field duration (days)	Yield (kg) per day
2	20	25 x 25	4.68 a[c]	86.5 a	54.5 a[c]	5.53 a	105.5 a	52.5 a
2	40	25 x 25	3.85 a	85.0 a	45.3 ab	5.75 a	104.0 a	55.3 a
2	40	12.5 x 12.5	4.17 a[d]	79.3 b	51.6 a	5.37 a	103.8 a	51.8 ab
8	40	25 x 25	2.85 b	78.0 b	36.5 bc	5.06 ab	103.8 a	48.8 ab
8	40	12.5 x 12.5	2.28 b	78.0 b	29.2 c	4.27 b	104.0 a	41.1 b

[a]Av of 4 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]DS = days after seeding. [c]Av of 3 replications. [d]Av of 2 replications.

and a seedling number greater than 3/hill give better compensation or protection against yield loss resulting from the use of old seedlings, provided there is no lodging.

Observations in this trial also demonstrated that a high nitrogen level (more than 100 kg N/ha) applied to old seedlings in the seedbed produced plants that were lanky, prone to lodging and leaf breakage, and susceptible to bacterial leaf diseases. The use of such seedlings lowered yields, particularly when planted at a high number per hill. Thus, the crop had low yield potential and responses to field nitrogen were low in these plots (Table 56).

Effect of hill spacing. The grain yields of the 40-day-old IR36 and IR42 in the spacing trial were generally lower than those of the 20-day-old seedlings, particularly in treatments with an increased number of seedlings per hill (Table 57). The reduction was significant at 8 seedlings/hill at both hill spacings for IR36, but only at the 12.5 × 12.5 cm spacing for IR42. It was noted that lodging incidence due to a typhoon was highest in the close-spaced treatments.

Increasing the plant density of IR36 by increasing the number of seedlings per hill or by using close spacing hastened maturity and shortened the field duration by about a week (Table 57). The later-maturing IR42 showed no such effect; however, it generally showed little variation in growth duration as an effect of seedling age or number in this trial and in the others.

In terms of grain production per unit field time, the most efficient treatment with 40-day-old seedlings was 2 seedlings in hills at 12.5 × 12.5 cm for IR36 (Table 57) and 2 seedlings in hills at 25 × 25 cm for IR42.

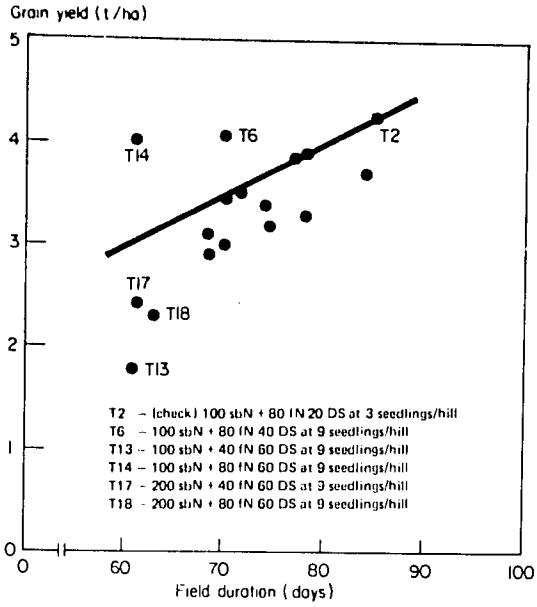
Effect of seedbed management level. The grain yield of IR36 (averaged across 2 seedling numbers — 2 and 8 — per hill) was significantly reduced when the seedling age was increased from 40 to 60 DS for seedlings raised in seedbeds under normal management (Table 58). The nitrogen stress to which the old seedlings were subjected under the low management level enabled them to tolerate the transplanting stresses better, hence no yield loss occurred. The low-management seedlings recovered sooner after transplanting than those under normal management, regardless of variety, age, and seedling number.

Relation of yield to field duration. Figure 23 illustrates the relationship between grain yields and field duration of treatments (experiment 3) as influenced by age, number of seedlings, and applied nitrogen. A line was drawn between the check treatment (20-day-old seedlings, which received 100 and 80 kg N/ha in the seedbed and main field, respectively, and planted at 3 seedlings/hill) and the zero yield-zero duration intercept. Treatments falling on or above the line (i.e. T6 and T14) had efficiencies equal to or better than that of the check (T2) in producing grain yield per day, while those below the line (e.g. T18 and T13) had poor daily

Table 58. Effect of seedbed management level and age of seedlings on the grain yield of IR36.[a] Experiment 6, IRRI, Jul–Nov 1979.

Management level	Grain yield[b] (t/ha)		
	40-day-old seedlings	60-day-old seedlings	Difference
Normal	3.44	2.52	−0.92**
Low	3.38	3.06	−0.32
Difference	0.06	−0.54**	

[a]Av of 2 seedling numbers per hill, 4 replications. [b]Yield of check plot (normal 20-day-old seedlings) = 3.48 t/ha.



23. Relation between grain yield and field duration as influenced by applied nitrogen and age and number of IR36 seedlings per hill. Experiment 3, IRRI, Jul–Dec 1978. sbN = seedbed nitrogen, fN = field nitrogen, DS = days after seeding.

grain production efficiencies (short durations but low yields). Thus T6 had good efficiency because it produced about 4 t/ha in about 70 days after transplanting (or about 58 kg/day). T17 had a shorter field duration (about 63 days), but produced less than 2.5 t/ha for a much smaller daily grain production (about 38 kg/ha).

Other experiments showed only a few treatments with higher yield per day than the check yield. These treatments generally used 40-day-old seedlings and resulted in reduced field durations with little or no yield loss compared to the check. Late-maturing varieties such as IR38 and IR42 were insensitive to changes in seedling age and plant densities. For these varieties all treatment points clustered around the check treatment (see also Tables 51, 54, 57).

The results of the 1979 experiments with old rice seedlings suggest that farmers in the rainfed wetland rice areas can use old seedlings (35—50 DS, depending on the variety) to enable them to adjust their planting time to the variable onset of the monsoon rains. In addition, the use of old seedlings can considerably increase the cropping intensities in the partially and fully irrigated rice areas.

Ratoon cropping of rice *(Multiple Cropping).* Areas with growing season of 160 to 200 days are not suited to double rice cropping patterns (Table 59). Modern varieties of shorter duration result, however, in a wet growing season period after rice harvest during which fields remain at or above saturation. To find ways to utilize the water and land during these periods and to provide more flexibility to farmers in the choice of cropping

Table 59. Approximate growing-season[a] requirements for rice-rice and rice-ratoon cropping patterns. IRRI, 1979.

Cropping pattern[b]	Crop duration (days)	Turn-around time (days)	Growing season[c] offset (days)	Growing season requirement (days)
DSR_s – TPR_s	100 + 80	20	0	200
WSR_s – TPR_s	100 + 80	20	20	220
TPR_s – TPR_s	80 + 80	20	40	220
DSR_s – ratoon	100 + 60	0	0	160
WSR_s – ratoon	100 + 60	0	20	180
TPR_s – ratoon	80 + 60	0	40	180
DSR_m – TPR_s	125 + 80	20	0	225
WSR_m – TPR_s	125 + 80	20	20	245
TPR_m – TPR_s	100 + 80	20	40	240
DSR_m – ratoon	125 + 70	0	0	195
WSR_m – ratoon	125 + 70	0	20	215
TPR_m – ratoon	100 + 70	0	40	210

[a]Growing season is the time between the day on which 75 mm rain is received and the day after which 100 mm rain remains to be received. [b]DSR = rice seeded into dry soil, WSR = rice seeded onto puddled soil, TPR = transplanted rice, s = early-maturing (100 days) variety, m = medium-maturing (125 days) variety. [c]Time between the start of the growing season and planting time.

Table 60. Yield component analyses of ratoon yields from 13 dry-seeded IRRI varieties. IRRI, 1978.

Variable	Average	Standard deviation	Standard partial regression coefficient
Ratoon yield (t/ha)	1.32	0.77	–
Tillers (no./m^2)	423	115	0.32*
Filled grains (no./panicle)	55	16.6	0.42**
1,000-seed wt (g)	19.5	2.50	0.50**
Filled grains (%)	82.5	5.1	0.07
Productive tillers (%)	86.1	4.5	0.13

sequences, ratoon cropping of rice was further tested in 1979.

Ratoon crop yields at IRRI were 2.0 to 3.2 t/ha in 1978 replicated small-plot trials. There was no significant correlation between yields of the plant crop and the ratoon crop of 13 varieties tested under 3 water regimes. Ratoon yields were related to ratoon crop duration ($r = 0.71$), and ratoon crop duration was associated with plant crop duration ($r = 0.65$) so that varieties of intermediate maturity ($\geqslant$ 135 days) produced higher ratoon yields than the early-maturing varieties ($\leqslant$ 115 days). There was a significant correlation between ratoon crop yield and three ratoon yield components: tiller number ($r = 0.74$), particle size ($r = 0.70$), and 1,000-seed weight ($r = 0.79$). These three accounted for 92% of the variation in the ratoon yields.

Seed weight varied from 17 to 25 g/1,000 seeds, and panicles had from 49 to 87 filled grains among the 13 varieties. These two yield components were more or less independent ($r = 0.03$), yet standard partial regression coefficients showed them to be major determinants of ratoon yields (Table 60). Of the 13 varieties, 5 produced more than 400 tillers/m^2 and 3 of those produced sizable panicles (more than 60 grains/panicle) and 4 produced large grains (more than 20 g/1,000). The varieties with high ratoon yields had high tiller numbers and large panicles or grains, or both.

Trials in the 1979 dry season with the same varieties gave disappointing results. High temperatures (35° C daily maximum) and solar radiation around harvest time appeared to cause low yields. The dry-season trials also showed ratooning (tillers/hill) and ratoon yields to be fickle.

To test the effects of temperature, two varieties at the booting stage were placed in three temperature regimes. After the main crop harvest, pots exposed to low temperatures formed twice the number of ratoon tillers of those under normal and high temperatures (Table 61). Ratoon grain yields were low in the 20/20° C regime because of panicle sterility.

Panicle and leaf clipping treatments designed to modify the source-sink ratio of the plant were tested. Tillering increased from 10 to 14 per hill where half of each panicle was removed, and was reduced from 10 to 6 per hill where half of each leaf was removed. These effects were confirmed in a subsequent trial, which also showed that late clipping of the panicles (at soft dough stage) reduced the effect on ratooning (Table 62). The results indicate that ratooning ability may be associated with nonstructural carbohydrates of the rice plant at harvest time.

In collaboration with the Plant Breeding Department, 400 IRRI lines were tested for ratooning ability during the 1979 dry season. Only 19 breeding lines, which showed vigor ratings of 1, 2, or 3, were subjected to tiller counts (Fig. 24). Those lines were also evaluated for dry matter production per day. The best were 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. They had less than 5% missing hills, at least 16 tillers/hill, and excellent vigor.

Continuous cropping of dryland rice and other crops *(Soil Microbiology). Soil sickness in the cropping patterns.* The growth of rice, mungbean, and cowpea remained inhibited after 6 years of continuous cropping. The growth inhibition varied among croppings but was usually 30 to 60%. Cowpea failed in 1978 and 1979 and a resistant sorghum began to show signs of growth reduction.

Mungbean growth following several cowpea

Table 61. Ratoon yields of 2 rice varieties under low temperature.[a] IRRI, 1979.

Temperature regimes (°C)		Ratoon tillers (no./hill)	Ratoon grain yield (g/hill)
Day	Night		
35	27	26.6 b	5.8 a
29	21	22.3 b	5.7 a
20	20	47.5 a	1.9 b

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

Table 62. Clipping half of each panicle substantially increased ratooning, and clipping the leaves resulted in reduced ratooning of IR36 and IR42. IRRI, 1979.

Treatment	Ratoon tillers (no./hill)			
	IR36		IR42	
	Basal	Nodal	Basal	Nodal
1. Clip 50% panicle length just after flowering	2.0 a	40 a	7.5 a	17.3 a
2. As 1, at soft dough stage	1.5 a	23.8 a	7.1 a	10.3 b
3. Clip 50% leaf area just after flowering	1.0 a	4.4 c	3.7 b	5.7 c
4. As 3, at booting stage	0.7 a	7.2 c	3.7 b	8.8 bc
5. Gentle clubbing just after flowering	1.7 a	15.3 b	6.4 a	11.0 b
6. Control	1.0 a	15.0 b	7.6 a	8.8 bc

crops was also greatly inhibited, showing inhibitory effects common in grain legumes. Rotating mungbean with dryland rice for 2 years did not cause growth retardation for either crop, suggesting the absence of soil sickness in certain cropping patterns. Transforming a dryland rice soil to a wetland condition improved growth of the wetland crop but the inhibitory effects remained; the growth of succeeding dryland rice was as inhibited as in continuous dryland cropping (Table 63).

After 6 years of continuous cropping, the nutrient status of the soil was checked. With fertilizer application every cropping, the nutrient levels were maintained in the continuous rice plot, showing that nutrients in soil were not directly related to the appearance of soil sickness. Continuous mungbean cropping improved the nitrogen and phosphorus contents of the soil, and that may have contributed to the improved dryland rice that was rotated with mungbean. The available boron content of the soil was 5 ppm and no symptoms of boron toxicity were observed.

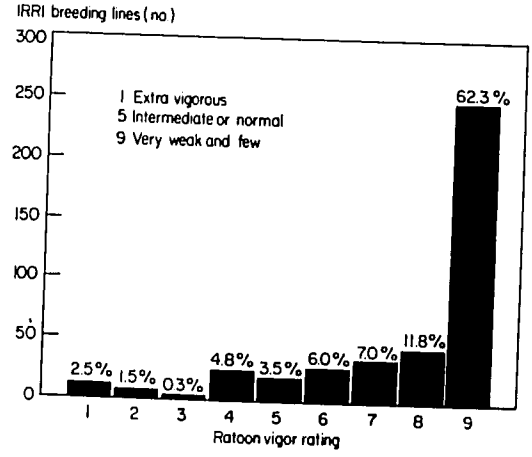
Causal agents of soil sickness. Sterilization of the sick soil and root residues by gamma ray irradiation (5 megarads) significantly improved plant growth, confirming the involvement of microorganisms in soil sickness.

The involvement of nematodes in dryland rice soil sickness was further examined. Few parasitic nematodes were found and they decreased in number with the age of the rice plants, confirming their non-involvement in dryland rice soil sickness.

In 1978 (1978 annual report) *Fusarium* was reported as the most abundant among the fungal genera found in dryland rice soil. Its involvement in dryland rice soil sickness, however, could not be clearly established as the application of benomyl at 10 and 20 kg a.i./ha to the sick soil did not improve plant growth in 1979.

Nematodes, with *Rotylenchulus* as the predominating genus, appeared to be related to mungbean soil sickness (Table 64).

In confirmatory tests in the greenhouse the sick soil was exposed to gamma ray irradiation (5 megarads) or treated with nemacur at 15 kg a.i./ha. These killed all nematodes and removed the inhibi-



24. Out of 400 lines in the irrigated IRRI replicated yield trial only 19 showed vigorous ratooning. More than 80% of the entries produced few and very weak ratoon tillers. IRRI, 1979 dry season.

Table 63. Effect of dryland-wetland farming rotation on dryland rice soil sickness. IRRI greenhouse, 1978 dry season to 1979 dry season.

Previous cropping pattern[a]	Present crop	Plant ht (cm)	Dry matter wt (g/pot)
	1st greenhouse crop		
Continuous dryland rice (8)	Dryland rice	60.0	21.0
Continuous dryland rice (8)	Dryland rice	58.7	21.3
Continuous fallow	Fallow		
	2d greenhouse crop		
Continuous dryland rice (9)	Dryland rice	64.4	9.0
Continuous dryland rice (9)	Wetland rice	90.9	23.9
Continuous fallow	Fallow		
	3d greenhouse crop		
Continuous dryland rice (10)	Dryland rice	63.0	19.8
Dryland rice (9) + 1 wetland rice	Dryland rice	63.0	19.6
Continuous fallow	Dryland rice	69.8	45.1

[a]Soil materials taken from the continuous rice plots and plots kept fallow for the past 4 years. Each pot had 3 kg soil, oven-dry basis, applied with 100-60-60 kg N-P_2O_5-K_2O/ha every cropping.

tory effects. The inoculation of *Rotylenchulus* (77 egg masses/pot) and *Meloidogyne* (1 egg mass/pot) to the irradiated sick soil increased the nematode population and caused a reduction in plant growth and yield as in the untreated sick soil, indicating the involvement of nematodes in mungbean soil sickness. No growth inhibition was found, however, when nematodes were inoculated to the healthy soil, suggesting that a substance produced during continuous mungbean cropping may have caused the inhibitory effect. The growth of mungbean was improved with the addition of benomyl (20 kg a.i./ha) to the sick soil, despite the large number of nematodes in the treatment, indicating further the possible added role of fungi in causing or complicating the soil sickness problem.

VARIETAL TESTING

Multiple Cropping Department

The nonrice crops used in IRRI research on rice-based cropping systems are rice, maize, sorghum,

Table 64. Plant parasitic nematodes in mungbean. IRRI field, 1979 dry season.

Previous crop treatment	Present crop	Nematodes[a] (mean no./300 cc soil + 1 g roots)			Plant population per ha	Grain yield (kg/ha)
		Rotylenchulus	*Meloidogyne*	Total of 5 genera[b]		
		2 weeks old				
Continuous mungbean (15)	Mungbean	73	1	78	221,000	
One-year fallow	Mungbean	3	0	17	364,000	
Mungbean-rice rotation	Mungbean	12	1	22	284,000	
		Flowering stage				
Continuous mungbean (15)	Mungbean	1,250	3	1,255	97,625	
One-year fallow	Mungbean	19	3	40	182,836	
Mungbean-rice rotation	Mungbean	3,320	33	3,369	263,000	
Two-year fallow	Fallow	4	0	17		
		Maturity stage				
Continuous mungbean (15)	Mungbean	603	3	606	63,500	61.5
One-year fallow	Mungbean	440	0	554	158,209	419.6
Mungbean-rice rotation	Mungbean	1,707	48	1,760	228,000	514.7
Two-year fallow	Fallow	2	1	4		

[a]Soil from 20 locations of every plot were pooled and 2 subsamples were taken. Each treatment had 4 replicated plots. Nematodes were extracted from each subsample by the sieving – Baerman funnel technique. [b]*Rotylenchulus, Meloidogyne, Helicotylenchulus, Tylenchorynchus,* and *Criconemoides.*

soybean, mungbean, cowpea, peanut, and sweet potato. Variety tests in 1979 with elite cultivars from the screening program of the Institute of Plant Breeding, University of the Philippines at Los Banos (UPLB), were at IRRI and at cropping systems research sites in Cale, Batangas (dryland); Manaoag, Pangasinan (wetland); and Oton, Iloilo (wetland).

Rice. In the wet season, 9 promising early-maturing and 10 medium-maturing rice selections were dry-seeded in rainfed wetland fields in Iloilo and Pangasinan. The early-maturing selections were also transplanted in Pangasinan and Iloilo. At IRRI, 16 early-maturing selections and 17 medium-maturing selections were dry-seeded in rainfed wetland fields and evaluated for ratooning potential.

IR9703-41-3-3-1 was the highest yielder among the dry-seeded early selections in Iloilo. It yielded 5.1 t/ha but was not significantly better than all other entries except IR8608-167-1-2, which yielded 2.6 t/ha. IR9703-41-3-3-1 matured in 114 days. It had more tillers and panicles per square meter but relatively less percentage of filled grains per panicle than IR36, which yielded 4.1 t/ha and matured in 118 days.

In Pangasinan, the highest yield was obtained from the local check (2.9 t/ha) and IR36 (2.8 t/ha). The local check matured in 180 days; IR36 matured in 123 days. IR9129-209-3-3-3-4 yielded 2.5 t/ha and matured in 108 days. Yields in Pangasinan were lower than in Iloilo because of late seedling emergence and moisture stress at flowering stage.

At IRRI, IR8608-125-3-1 had the highest yield (2.9 t/ha) followed by IR8608-125-3-3 and IR36 with 2.7 t/ha. The low yields at IRRI were due to moisture stress during the flowering stage of the crop. In the ratoon crop, the highest yield (0.8 t/ha) was from IR9729-321-3-1-2, which had lowest yields in the main crop.

For dry-seeded medium-maturing selections, IR3880-10 had the highest yield (4.4 t/ha) in Iloilo, followed by IR1529-430-3 and IR36 (4.3 t/ha). IR36 matured 7 days earlier than the other selections and had the highest percentage of filled grains per panicle.

In Pangasinan, the highest yield was obtained from the local check (4 t/ha); other high-yielding selections were IR2873-399-5-6 (3.4 t/ha) and IR1529-430-3 (3.3 t/ha). The local check significantly outyielded IR36 and C171-136 but matured late (180 days). IR2873-399-5-6 matured in 140 days, IR36 in 127 days, and C171-136 in 125 days. The IRRI trial was abandoned because of drought and sheath rot.

Among the transplanted early-maturing selections, IR13168-14-3-1 was the best entry in Pangasinan. It yielded 4.3 t/ha — significantly better than IR36 (3.6 t/ha). IR13168-14-3-1 matured in 95 days and IR36 in 101 days.

IR9224-22-2-2-2-3 was the best yielder in Iloilo (5.1 t/ha). The check variety, IR36, yielded 4.3 t/ha. Both were significantly better than the local check.

IR4019-77-3-2 had the highest yield (4.5 t/ha) in the transplanted medium-maturing trial in Iloilo but it matured 7 days later than IR36.

Mungbean. Thirteen green-seeded and eight yellow-seeded mungbean varieties were evaluated on zero tillage after lowland rice at IRRI and Iloilo, and on low and high tillage in Pangasinan. Fourteen green-seeded and eight yellow-seeded varieties were tested in an upland field with high tillage in Batangas.

Among the green-seeded varieties, CES U-1, CES 2C, and CES 1T-2 were outstanding at IRRI under zero tillage with yields of 1.2, 1.1, and 1.1 t/ha, respectively. However, those yields did not differ significantly from those of CES 1D-21, the variety used in cropping patterns testing. The same varieties were also promising in Iloilo but with lower yield levels because of moisture stress during flowering.

With low tillage, no significant differences in yield were obtained among entries in Pangasinan. CES U-1 was the most promising (0.8 t/ha). With high tillage, EG-MG 174-3 gave the highest yield (0.7 t/ha) followed by H70-16 (0.7 t/ha). CES 1D-21 ranked 10th (0.5 t/ha).

In an upland field in Batangas, the highest yield was obtained from CES 55 (1.2 t/ha); CES 1D-21 ranked third with 1.1 t/ha.

For the yellow-seeded varieties, no significant differences in yield were obtained among entries at IRRI with zero tillage. Cc gave the highest yield of 0.9 t/ha. Cc was also the highest yielder at Iloilo with 0.9 t/ha. Yield levels at both sites were almost the same. In Pangasinan, Aa had the highest yield (0.8 t/ha) with low tillage and Mg50-10A(Y) (1.0

t/ha) with high tillage.

In Batangas, the most promising yellow-seeded varieties were Aa (1.0 t/ha), Bb (1.0 t/ha), and Mg 50-10A(Y) (1.0 t/ha).

In the wet season, 11 varieties were tested before wetland rice with high tillage. At IRRI, the highest yield was obtained from CES J-2Y and M350 (1.5 t/ha). CES 1D-21 yielded 1.5 t/ha. In Iloilo, CES 1D-21 significantly outyielded all entries (1.6 t/ha). It was also the highest yielder in Pangasinan with 1.1 t/ha.

Soybean. Nine soybean cultivars were tested in lowland fields with zero and low tillage at IRRI, Iloilo, and Pangasinan and in upland fields with high tillage in Batangas in the dry season. With zero tillage, 30290-11-11 was the most promising entry at IRRI (2 t/ha) and significantly outyielded all other entries including UPL-SY2 (1.3 t/ha), the variety used in cropping patterns testing. In Iloilo no entry significantly outyielded UPL-SY2. 30229-8 had the highest yield (0.7 t/ha). With low tillage at Iloilo, Clark 63 (0.8 t/ha) significantly outyielded UPL-SY2 (0.6 t/ha). Yield levels in Iloilo and Pangasinan were low because of the photoperiod sensitivity of the varieties used and the limited moisture at the flowering stage.

In the upland field in Batangas, Orba had the highest yield (1.1 t/ha) followed by UPL-SY2 and Clark 63 (1.0 t/ha).

Cowpea. In the dry season, 13 indeterminate and 11 determinate cowpea cultivars were evaluated in lowland fields with high and low tillage in Iloilo and Pangasinan, with zero tillage in IRRI and Iloilo, and in an upland field with high tillage in Batangas.

Among the indeterminate cultivars in lowland fields with high tillage, E.G. #2 had the highest dry bean (0.7 t/ha) and green pod (2.6 t/ha) yield in Pangasinan, and Vita 4 had the highest dry bean (2.1 t/ha) and fodder (20.0 t/ha) yield after dry bean harvest in Iloilo. Yield levels in Iloilo were higher than in Pangasinan because of the limited moisture at Pangasinan.

With low tillage, PI 221731 was the best yielder of dry beans (0.7 t/ha) and green pods (2.0 t/ha) in Pangasinan. With zero tillage, All Season was the most promising entry at Iloilo (1.2 t dry beans/ha and 3.6 t green pods/ha).TVx-1836-187E had the highest fodder yield (23.6 t/ha) after dry bean harvest.

At IRRI, Vita 4 yielded 1.7 t dry bean/ha, followed by TVx-1836-19E (1.6 t/ha). In Batangas, PI 221731 and TVx-1836-187E were the most promising entries in the upland field with high tillage.

Among the determinate cultivars, Vita 3 and Pelungthay had the highest dry bean and green pod yields at Pangasinan in a lowland field with high tillage. With low tillage, the most promising entries were Pelungthay, TVx-1193-059D, Pelungga, and Vita 3. Pelungthay was the best yielder of dry beans (1.1 t/ha), Pelungga of green pods (3.5 t/ha), and Vita 3 (6.0 t/ha) and TVx-1193-059D (5.7 t/ha) of fodder.

With zero tillage, Vita 3 and Pelungga had the highest dry bean yield in Iloilo. In an upland field with high tillage, TVx-289-4G was an outstanding entry in Batangas with yields of 1.6 t dry beans/ha, 6.2 t green pods/ha, and 11.2 t fodder/ha. TVx-289-4G had more seeds per pod and was more tolerant of insects and diseases than the local check.

Two uniform cowpea cultivar trials from the International Institute of Tropical Agriculture in Nigeria were also tested in IRRI upland fields with high tillage. Trial 1 had 20 indeterminate cultivars and trial 2, 10 determinate cultivars. White Wonder Trailing, TVx-1999-1D, and Vita 3 significantly outyielded E.G. # 2, the check variety in trial 1. In trial 2, TVx-7-5H and TVx-1193-7D were the most promising entries.

Sorghum. Eighteen elite sorghum lines, varieties, and hybrids from UPLB, Kasetsart University, Thailand, and a commercial breeder were evaluated in IRRI, Iloilo, and Pangasinan in lowland fields with zero, low, and high tillage. The same entries were also tested in an upland field with high tillage in Batangas.

The IRRI trial was abandoned because of poor stand. In Iloilo, CS 182 was the most promising entry with zero tillage (3.3 t/ha). It was followed by Pioneer 8417 (3.2 t/ha), CS 137 (3.2 t/ha), and CS 226 (3.0 t/ha). All lines and hybrids significantly outyielded UPLB-SG-5 (2.6 t/ha), the check variety.

With low tillage, UPLB-SG-5 gave the highest yield (2.6 t/ha) in Pangasinan. However, UPLB-SG-5 yields did not differ significantly from those of most of the entries.

With high tillage, the most promising entries in Pangasinan were CS 102 (3.2 t/ha) and CS 124

(3.1 t/ha). The low yields in Pangasinan, for both tillage levels, were due to limited moisture.

In an upland field with high tillage in Batangas, high yields were obtained from all entries. CS 226 and Pioneer Hybrid 8417 gave the highest yield (5.1 t/ha) followed by UPLB-SG-5 (4.9 t/ha) and CS 182 (4.8 t/ha).

Maize. Fourteen field maize and nine green maize (glutinous and sweet maize) varieties were tested with high tillage in Pangasinan before lowland rice.

Among the field maize varieties, Thai Composite 1 Early DMR(S) C_4 with a yield of 3.4 t/ha significantly outyielded all entries and was resistant to downy mildew disease. All entries were tolerant of downy mildew except Macapuno, the local check, which was destroyed.

In the green maize trial, Glutinous DMR Composite Popn 41 was the most promising variety with marketable ears of 4.0 t/ha. It outyielded Macapuno, the local check (2.0 t/ha), but was only fairly resistant to downy mildew.

Sweet potato. Ten sweet potato cultivars were tested after rainfed lowland rice with zero tillage in IRRI, 14 entries after upland rice with high tillage in Batangas, and 15 entries after lowland rice with high tillage in Iloilo. Two dates of harvesting (90 and 100 days after planting) were used at IRRI and Batangas to determine the optimum number of days for best tuber production. The Iloilo trial was harvested 112 days after planting (DP).

In a lowland field with zero tillage, yields at IRRI ranged from 0.3 to 2.0 t/ha. There was an increase from 0.1-0.6 t/ha to 0.3-2.0 t/ha when harvest was delayed from 90 days to 110 DP. Binasayon and Karja 381 had highest yields of 2.0 and 1.8 t/ha. The low yield in IRRI was attributed to compactness of soil, which resulted in production of malformed tubers. With high tillage, Jewel had the highest yield in Iloilo (18.5 t marketable tubers/ha) and significantly outyielded all other varieties.

In an upland field with high tillage, high yields were also obtained when harvesting was 110 DP. (Japan × US-1) and (Japan × US02)5 were the most promising entries with 20.1 and 18.8 t marketable tubers/ha. Both varieties significantly outyielded the check variety BNAS 51 (13.9 t/ha). Both had red skin and white flesh. (Japan × US-1)10 also produced a high vine yield (19 t/ha 90 DP and 15 t/ha 110 DP).

Peanut. Seven peanut varieties were tested at IRRI, 9 varieties in Iloilo and 10 varieties in Pangasinan lowland fields with high tillage. Sixteen varieties were also tested in an upland field with high tillage in Batangas.

In the lowland field with high tillage, the best entries were CES 101 (0.6 t/ha) at IRRI, CES 102 (1.1 t/ha) at Iloilo, and PI 259692 (1.4 t/ha) at Pangasinan. CES 102 and PI 259692 significantly outyielded UPL PN-2, the check variety at all sites. UPL PN-2 yielded 0.6 and 0.7 t/ha at Iloilo and Pangasinan. In Batangas, Accession 12 gave the highest yield (1.2 t/ha) and significantly outyielded UPL PN-2 (0.8 t/ha).

Cropping systems program

Preproduction evaluation

Rice Production Training and Research Office and Cropping Systems Component of the Agricultural Economics Department

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APPLIED RESEARCH AND MULTILOCATION TESTING

Rice Production Training and Research Office and Cropping Systems Component of Agricultural Economics Department

KABSAKA project evaluation. Activities for the Iloilo pilot project code-named *Kabsaka* have been reported since 1975 (1975-78 annual reports). An economic survey of the area, made in 1979, covered nine barrios of Santa Barbara, Iloilo. Twenty-three of 108 bank-financed farmers and 7 self-financed farmers were interviewed.

Socioeconomic, infrastructural, and institutional benefits of the project. Socioeconomic benefits of the project included farm and household assets, house improvements, and education. Institutional benefits consisted primarily of the technical assistance extended by the extension specialist on the use of modern farm technology. Motivation for increased production was attributed largely to the financial assistance extended by the Philippine National Bank and other financial institutions. Financial gains included payment of previous debts.

Household assets and house improvements for the bank-financed farmers included television sets, stereo sets, gas stoves, ovens, motorcycles, living room sets, and wells. Ten farmers were able to renovate their houses (Table 1).

About 30 hand tractors and 25 threshers provided services to the farmers in the study area. Fourteen water pumps for irrigation were added in barrios traversed by creeks (Table 2).

Eight bank-financed farmers and six self-financed farmers sent children to college, vocational school, or high school.

Twenty-two bank-financed farmers attributed the improvements in their living standards to double-cropping of rice.

Level and extent of component technology adopted by farmers. The major cropping patterns used by farmers before *Kabsaka* were rice-dryland crop (60%) and rice-fallow (30%). A rice-rice pattern was used by 10% of the farmers. Of the 30 farmers interviewed in 1979, 47% had completed 2 rice crops and 1 dryland crop in crop year 1978—79. One farmer attempted three rice crops, but the third crop failed. Other respondents (50%) completed only 2 rice crops because of insufficient rainfall in late October—November.

Table 1. Household assets and other improvements acquired by bank-financed farmers and attributed by them to *Kabsaka*, Iloilo, Philippines, 1979.

Assets	Farmers reporting (no.)	Total value ($)[a]
Television set	3	959
Stereo set	3	514
Gas stove	1	7
Oven	1	338
Refrigerator	3	919
Motorcycle	1	1243
Sala set	3	176
House improvement	10	3986
Artesian well drilling	2	81

[a]Philippine peso (₱) converted to US$ at the rate of ₱7.4 = $1.00 and rounded to nearest dollar.

Before *Kabsaka*, 87% of the farmers used traditional rice varieties. In 1979 100% used modern varieties for the first crop and 97% used them for the second crop. There was a 25% increase in the number of fertilizer users over the pre-*Kabsaka* period. For the second rice crop in 1979, 90% of the farmers used fertilizers. The number of fertilizer applications on both rice crops in 1978 was higher than for the first rice crop before *Kabsaka*.

All farmers used insecticides on the first rice crop in 1978, a 30% increase in the number of farmer-users before *Kabsaka*. For the 1978 second crop, 97% of the farmers applied insecticide.

Twenty-five farmers applied herbicides on the first crop (dry-seeded rice [DSR]) in 1978. For the second crop (wet-seeded rice [WSR]), 15 farmers applied herbicides.

Table 2. Farm machinery and power equipment purchased in 9 barrios since the start of the *Kabsaka* project in 1975 in Iloilo, Philippines, 1979.

Barrio	Hand tractors (no.)	Threshers (no.)	Water pumps (no.)
Tigtig	6	5	0
Calaboa Oeste	3	1	1
Calaboa Este	3	3	2
Mangacina	4	6	6
Tuburan	0	0	2
Miraga	3	2	0
Conaynay	3	0	0
Canipayan	4	4	0
Agusipan	4	4	3
Total	30	25	14

Table 3. Total gross and net returns on material costs[a] before and after *Kabsaka* for 30 farmers, Iloilo, Philippines, 1978–79.

Classification of farmers	*Kabsaka* period	
	Before	After
	Total gross return ($/ha)	
Bank-financed	459	1094
Self-financed	394	836
	Net return on material costs ($/ha)	
Bank-financed	397	853
Self-financed	359	659

[a]Philippine peso (₱) converted to US$ at the rate of ₱7.4 = $1.00, and rounded to nearest dollar.

Yield costs and returns. The yield of the first crop (DSR) in 1978 averaged 4 t/ha for bank-financed farmers and 3.1 t/ha for self-financed farmers (av of 3.7 t/ha for all farmers). Thirty percent of the yield were in the 4.0—4.9 t/ha range, and 27% in the 3.0—3.9 t/ha range. A yield range of 5.0 to 5.9 t/ha was attained by 23% of the farmers.

For the second crop (WSR), the yield was 3 t/ha for bank-financed farmers and 2.9 t/ha for the self-financed. Four farmers had no yield (3 bank-financed and 1 self-financed), and 10 farmers had low yields because of drought in October—November. Almost 50% of the farmers had a yield of 3 t/ha or below, and only 10% had a yield between 5 and 6 t/ha.

The increase in yield of the first rice crop over the pre-*Kabsaka* period, regardless of method of rice establishment, was 65% for all farmers. For the second rice crop, the yield increase was 38%.

Mungbean yielded an average of 0.4 t/ha. Other dryland crops planted were cowpea, peanut, sweet potato, maize, sorghum, squash, and watermelon. The gross and net returns for 30 farmers before and after *Kabsaka* are in Table 3. Computation for gross return and cash material items was based on constant prices for crop year 1978—79.

Marketing constraints encountered by farmers. Farmers' constraints were categorized mainly as economic and infrastructural. They were low price (53%), lack of drying facilities (33%), high transport costs (7%), and bad arrangements with buyers (6%) in marketing their product. The low price was primarily due to low quality, especially during the wet months when farmers had to dispose of fermented or water-soaked rice. High transport costs were highly correlated with bad roads and insufficient transport facilities.

Kasa-tinlu. In the second year of the South Cotabato *Kasa-tinlu* pilot project, with a 2-rice crop pattern, results were as good as, or better than, those for *Kabsaka.* The average yields in the project area for the 2 seasons of 1978—79 were 8.6 and 9.4 t/ha for 2 crops.

Pagadian (Zamboanga del Sur), Mindanao. In 1979, yields in Pagadian were 4.3 t/ha for the first crop and 4.3 t/ha for the second. Australian cooperators in that area indicated they would start a pilot production program.

Luzon. *Light soils.* In initial studies in Luzon, rice grown as a second crop on light soils failed most of the time, but dryland crops were successful. A cropping pattern was finalized for Luzon with rice as the first crop and mungbean or peanut as the second crop. The new cropping pattern was evaluated for a pilot program code-named *Manbilayka* to be started 1979. The rice crop produced 5.1 t/ha.

Heavy soils. For 1978—79, 2 rice crops a year, grown on the heavy soils (Bani area) of Luzon, gave yields of 8.6 t/ha. It is proposed that Bani become a part of a pilot area to be established in Pangasinan for 1980.

Cagayan. Knowledge from 5 years of applied research experience was used to reduce the time required to develop a new cropping pattern. In work in the Cagayan Valley in northern Philippines, a preliminary review of the rainfall pattern indicated that the period August through December had monthly rainfall of more than 215 mm; May, June, and July had 111—189 mm. Soils were generally satisfactory for growing dryland crops and rainfed wetland rice. Preliminary trials with a dryland crop as a first crop and wetland rice as a second crop were established. With fertilizer and insecticides on mungbean (CES ID-21), a 1.1 t/ha yield was achieved. Lal-lo mungbean, with insect protection based on recommendations developed in Pangasinan, yielded 0.9 t/ha. The average yield of mungbean in Cagayan is about 0.3 t/ha. Cowpea grown with fertilizer produced 1.3 t/ha. Yields from the second crop (wetland rice) will be reported in 1980.

Cropping systems program

Asian cropping systems network

Multiple Cropping Department

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A cropping systems network of research sites in Asia has been established by IRRI in collaboration with national programs to develop cropping systems technology for different rice environments in the region. The research methodology developed by IRRI is now used by the national programs, with some adjustments to fit their financial and manpower resources and organizational setup.

Twenty-two research sites in the Asian Cropping Systems Network were fully operational in 1979 (Table 1). The sites represented a broad range of climatic zones, soil type, soil texture, and socioeconomic conditions in major rice-growing countries in Asia.

In addition, national programs in Indonesia, Philippines, Thailand, Sri Lanka, and Bangladesh expanded their work and formed national cropping systems networks of their own. In 1979, 23 more national research sites were established, making a total of 55 operational sites (Fig. 1). The major efforts of national programs were concentrated on both rainfed and irrigated wetland rice areas.

TESTING OF CROPPING PATTERNS

The cropping systems research at the Asian network sites concentrated on design and testing of cropping patterns, and on component technology research such as varietal testing, fertilizer studies, and pest control. The number of cropping patterns tested and the research on component technology varied from site to site depending on the need, available funds, and manpower.

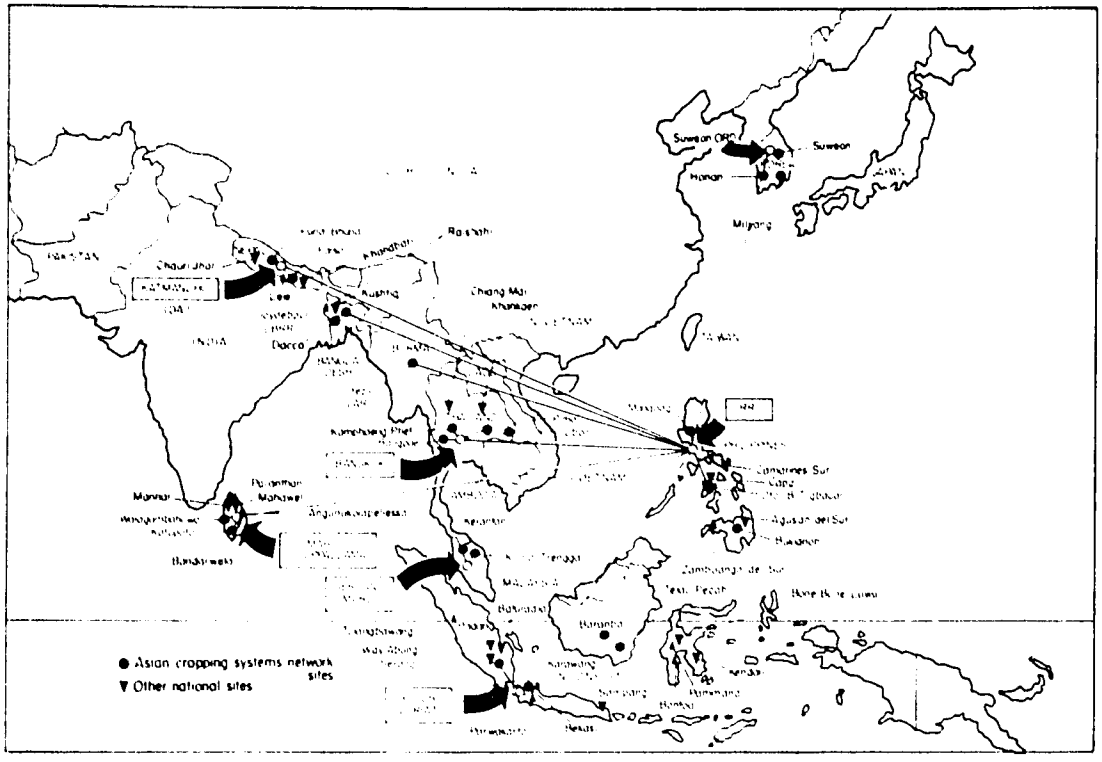
Philippines. There were three research sites in the Philippines. Two were directly managed by IRRI in cooperation with the Philippine Bureau of Plant Industry (BPI) — Oton, Iloilo (rainfed wetland), and Manaoag, Pangasinan (rainfed wetland). The third site (at Bukidnon) represented dryland and was managed by BPI scientists in cooperation with IRRI.

Pangantucan, Bukidnon. The traditional cropping patterns at Pangantucan were maize-maize, rice-maize, and rice-fallow. In 1979, four alternative cropping patterns were tested: rice-maize-mungbean, maize-maize-mungbean, maize-mungbean, coffee/maize-maize. Cropping pattern testing started in March 1979. The yield of dryland rice (C171-136) was 230% more than that of the local variety. The first maize crop (Philippine DMR Comp. #2) was about 400% better than the local variety. The highest gross return was obtained in the rice-maize-mungbean pattern ($890) and the lowest was in maize-mungbean ($337). However, the maize-maize-mungbean pattern showed the highest net returns above variable cost ($524), followed by rice-maize-mungbean ($509). The gross returns and net income from the alternative patterns were higher than those from the farmers'.

Nepal. Network collaboration in Nepal was with the Department of Agriculture and the International Agricultural Development Service. The sites in Nepal represented rice areas where temperature determines cropping systems in the winter months. Cropping intensity is already high in Nepal and major efforts were concentrated on increasing the production of each crop in the patterns by using improved varieties and better management techniques.

Table 1. Number of research sites and kind of rice land involved in the Asian Cropping Systems Network, 1979.

Country	Sites (no.)					
	Total	Rainfed wetland	Partially irrigated	Dryland	Irrigated	Deep water
Philippines	3	2	–	1	–	–
Indonesia	3	2	–	2	–	1
Thailand	4	4	–	–	–	–
Sri Lanka	3	2	1	–	–	–
Bangladesh	2	1	1	–	1	1
Nepal	2	2	1	–	1	–
Malaysia	2	2	–	–	–	–
South Korea	3	–	–	–	3	–
Total	22	15	3	3	5	2



1. The Asian Cropping Systems Network sites, 1979.

Pumdi Bhumdi (rainfed lowland). The Pumdi Bhumdi site is representative of the hills where 60% of the population live and farming activities are at the subsistence level. The elevation ranges from 750 to 1,270 m above sea level. The rice land was classified into wetland with high production potential, and wetland with low production potential.

In wetlands with high potential, the predominant cropping patterns were rice-wheat-maize and rice-wheat. Introduction of improved techniques, including improved varieties, increased the total grain production by 33% in the rice-wheat-maize pattern and by 35% in the rice-wheat. Improved varieties of Taichung 176, IET1444, and CH45 were earlier than most of the local varieties and yields were 30-80% higher. Earliness of the improved varieties allowed more turnaround time in the triple- and double-cropped area. Taichung 176 in wetlands with permanent water supply for supplemental irrigation during the monsoon season produced 3.7 t/ha; the commonly cultivated local varieties produced 2 t/ha. IET1444 in areas with limited supplementary irrigation during the monsoon season produced 3.3 t/ha.

Rice-fallow was the dominant pattern in wetlands with low potential. Rice-lentils and rice-barley increased production over the farmers' pattern by 125% and 168%. Increased net income was highest for rice-lentils. The rice variety CH45, suitable for that area, gave an average yield of 2.3 t/ha. It did not yield much higher than the local varieties, but its early maturity permitted better use of residual soil moisture for a relay crop and indicated potential avoidance of hail damage.

Parsa (irrigated, partially irrigated, and rainfed). The Parsa site represents the plain areas of Nepal, which have maximum potential to supply the internal needs for rice and some for export. In the cropping pattern rice-rice-wheat, the total production on irrigated fields has been increased by 95% since 1978 with the use of improved varieties and improved management. Major increases in pro-

duction were due to improved varieties like CH45, Chandina, and Parwanipur in the first crop. Those varieties produced more than 4 t/ha — double the yield of local varieties — and left more time for the second crop. With improved technology, production of the rice-wheat pattern increased by 78%, rice-potato by 84%, rice-mustard by 41%, and rice-lentils by 54%. The change in net revenue over farmers' practices was highest for rice-potato ($384).

In the rainfed area (Suekhchaina), rice varieties CH45, Masuli, IET1444, and B9C were substituted with advantage over the local varieties. The total grain production of the rice-wheat pattern increased from 2.5 t/ha with local varieties to 4.7 t/ha with improved varieties of rice and wheat. The improved technology in this pattern had a cash cost of $70 and produced a change in net revenue of $168/ha. As in the irrigated area, the maximum potential for increasing production in the rainfed area was in the replacement of the local varieties of rice.

Republic of Korea. The three Korean sites — at the Office of Rural Development Experiment Stations in Suweon, Iri, and Milyang — represent temperate rice environments with good irrigation and drainage facilities.

Suweon (irrigated). Cropping pattern testing at Suweon was by the Rice Production Research group in the Crop Experiment Station. Cropping patterns of barley-rice, wheat-rice, Irish potato-rice, pea-rice, and rye (green fodder)-rice were investigated with two levels of field management: ordinary management, and intensive management with increased fertilizer and crop density.

The most promising patterns were the Irish potato-rice pattern, with average yields of 13.8 t Irish potato/ha and 6.2 t brown rice/ha; and rye-rice with average yields of 35.6 t rye fodder/ha and 6.7 t brown rice/ha under intensive management. Rice yield alone was 7.0 t/ha. Compared with the ordinary rice-fallow, the Irish potato-rice and rye-rice patterns increased net income by 17% and 8%.

Iri (irrigated). The Iri collaborator is the Honan Crop Experiment Station, which represents southwestern Korea. The region has 10 more consecutive frost-free days than Suweon. The cropping patterns tested were pea-rice, barley-rice, wheat-rice, rape-rice, and onion-rice. The most promising pattern was pea-rice, in which the fresh pea yield of 7.8 t/ha was obtained without decreasing the rice yield.

Milyang (irrigated). The Milyang collaborator is the Yeongnam Crop Experiment Station, which represents the southeastern region of South Korea. The site has 204 frost-free days. The most promising cropping pattern for the region was Irish potato-rice with rice yields of 4.6 t/ha and Irish potato yields of 8.3 t/ha. The rice yield was low compared to that at other sites because of typhoon damage at heading stage.

Sri Lanka. Research at the Sri Lankan sites — Walagambahuwa, Katupota, and Paranthan — represents rainfed wetland rice in the dry and intermediate zones and the small tank-irrigated rice lands and is in collaboration with the Department of Agriculture.

Walagambahuwa (partially irrigated). The Walagambahuwa site is a typical cross section of the dry-zone minor-tank-based village. Rice is normally not planted until the tank is full. Dry seeding of rice was introduced for the start of the rainy season with water in the tank used as supplemental irrigation. Advancing the planting dates allowed planting the first rice crop as early as October, and use of a 3- to 3.5-month variety allowed the first crop to mature with the minimum of supplementary irrigation from the tank. This rice-rice pattern gave 350% increase in the rice production, compared to the traditional cropping pattern in the region.

Katupota (rainfed wetland). The cropping systems research activities in Katupota concentrate on two rainfed wetland tracts adjoining the villages of Alankara and Moragana. Research in 1978-79 demonstrated that crest, slope, and valley bottom areas require different cropping patterns. The cropping patterns appropriate in those land elements are:

- rice-dryland crop (cowpea, mungbean, or peanut) on the crest,
- rice-rice on the slope and on the valley bottom.

Cropping pattern trials have shown a potential of BG94-1 to produce yields as high as 6.3 t/ha. Cowpea on the crest position gave yields of 1.1 t/ha with MI 35.

Paranthan (rainfed wetland). Paranthan represents the northeastern coastal belt of Sri Lanka.

The cropping systems activities are mainly to increase the productivity of Manawari rice lands either through intensified agriculture or by increasing the rice yields or both.

Several varieties were tested in different soils. Among the tall varieties, 62-355 and Karuppan were promising on both sandy and clayey soils. BG401-1 yielded 5 t/ha on clay soils. Varieties with medium plant height showed higher yields on sandy soils and short-statured varieties were better on clayey soils. Second crops of sesame, mungbean, cowpea, and peanut ran into severe difficulties because of drought.

Thailand. Cropping systems research in Thailand is conducted in collaboration with the Rice Division, Department of Agriculture, at the Ubon and PiMai sites; with the Technical Division of the Department of Agriculture at the Khompangphet site; and with Kasetsart University at the Bangpae site. The Division of Agricultural Economics collaborates with the Rice and Technical Divisions on the economics component.

Ubon (rainfed wetland). The Ubon site represents the wettest part of northeast Thailand (5 wet months and 7 dry). Two-crop and three-crop patterns such as yardlong bean-rice-peanut, peanut-rice-mungbean, glutinous maize-rice-peanut, mungbean-rice-sweet maize, DSR-rice, and rice-ratoon, were evaluated. The third crops failed because of drought. In 1978-79, rice yields of 3 t/ha were obtained in the glutinous maize-rice pattern. The rice-rice pattern total yield was 3.9 t/ha.

PiMai (rainfed wetland). The PiMai site represents the drier areas of northeast Thailand (1-2 wet months and 7 dry). The patterns tested were sesame-rice, mungbean-rice, peanut-rice, and sweet maize + peanut-rice. Peanut, maize, and mungbean before rice were promising in 1977-78 testing, but in 1978-79 the yields of the dryland crops before rice were low because of flooding. The 1978-79 yield of rice was also lower than in the previous year because of early flooding.

Bangpae (rainfed wetland). Most farms in Bangpae grow only one rice crop of a local variety. A few farmers grow mungbean before and after rice. In 1979 tests mungbean, soybean, sweet maize, glutinous maize, mungbean + sweet maize, and glutinous maize + soybean were grown before rice; mungbean, soybean, sweet maize, and glutinous maize were grown after rice. Two years of tests showed sweet maize and glutinous maize were a suitable first crop before rice, and only mungbean was suitable after rice.

Bangladesh. Cropping systems research in farmers' fields is in three areas near the Bangladesh Rice Research Institute at Joydebpur. Work is in rainfed wetland in Bhogra village, irrigated wetland in the high land and shallow valley land at Laskarchala village, and irrigated wetland in Salna village. The cropping intensity in most of the test areas is already high at 2—3 rice crops. The research concentrated on increasing the production of each crop in the system.

Results of testing 7 cropping patterns in 39 farmers' fields at Salna suggested that with no soil problems, triple rice cropping is most profitable. The 3-rice crop patterns of modern variety aus-pajam transplanted aman-pajam boro, and modern variety aus-pajam transplanted aman-modern variety boro gave a high net income of about $1,324/ha.

On the light-textured upland soils at Laskarchala, 10 cropping patterns were tested. The most profitable were aus rice-wheat ($424/ha), aus rice-chili ($769/ha), and aus rice-blackgram-wheat ($499/ha). On the medium upland areas at Laskarchala the most profitable pattern was modern variety aus-pajam transplanted aman, with a net income of $789.

Among five double rice crop patterns tested at Bhogra in 39 farmers' fields, BR3 aus-BR4 transplanted aman gave high net returns of $767/ha despite low rainfall. In Bhogra a 3-crop pattern of modern variety aus-modern variety transplanted aman-watermelon gave a net return of $1,327/ha with supplemental hand irrigation for the watermelon crop.

Indonesia. Cropping systems research in Indonesia is in collaboration with the Central Research Institute for Agriculture. A site in Madura represents the rainfed wetland areas in northern Java with 5 wet months and 4 dry months, and the Tajau Pecah site represents wetter dryland areas. Barambai is the only site in the network studying tidal swamp rice.

Madura (rainfed wetland and dryland). The Madura site is divided into dryland, rainfed wetland with low elevation, and rainfed wetland with

high elevation. In the dryland category, the farmers' cropping pattern of maize + peanut-maize + peanut-maize + peanut gave the same gross return but higher net return ($593) than the introduced pattern of maize + dryland rice cassava mungbean peanut ($314). In the rainfed wetland with low elevation, wetland rice-maize + peanut, wetland rice-maize + mungbean, and DSR-maize + peanut gave higher yields and net returns than the farmers' cropping pattern of wetland rice-peanut + maize. Yield of dry-seeded rice (3.4 t/ha) was higher than that of transplanted rice (2.2 t/ha). Transplanted rice-maize + peanut showed net returns of $491, 145% better than those for the farmers' cropping pattern.

In the rainfed wetland area with high elevation, wetland rice-maize + peanut and dry-seeded rice-maize + peanut showed higher net returns than the farmers' cropping pattern of wetland rice-mungbean despite low yield of maize. The dry-seeded rice gave higher yields than the transplanted rice. However, the wetland rice-maize + peanut pattern had a higher net return because of lower material cost and lower cost of planting.

Tajau Pecah (dryland rice). The predominant farmers' cropping pattern at the Tajau Pecah site consists of maize + dryland rice-maize. The introduced pattern tested was maize + dryland rice intercrop with cassava relay planted into maize rows 30 days after planting. After harvesting rice, cowpea was planted as an intercrop with cassava. The introduced cropping pattern with high and medium input showed higher productivity and better net returns than the farmers' pattern. The introduced pattern with medium input showed the highest net return, which was 338% better than that for the farmers' pattern. Returns to labor and material inputs were also higher.

Barambai (tidal swamp). At the tidal swamp in Barambai, the hydrology is affected by rainfall and by tides. Most of the area is continually submerged. The farmers' pattern consists of maize-maize grown in raised beds and one local late-maturing variety of wetland rice. The introduced pattern was dryland rice + maize intercrop combination relay planted with cassava in the raised beds and rice-rice in the paddies with a modern variety as the first crop and a local variety as the second crop. The introduced cropping pattern had net returns 93% better than those for the farmers' pattern, but returns to labor and materials were about the same.

CROPPING SYSTEMS WORKING GROUP

The eighth meeting of the Cropping Systems Working Group was in Nepal 28-31 May 1979. Coordinators from 10 countries in Asia and 25 resource persons attended the meeting and reviewed the progress of research at all network sites. The group discussed techniques for on-farm systems research, use of site-related research in multilocation testing, role of component technology research at cropping systems research sites, the cropping systems training program, and rainfall probability analyses for crop scheduling.

TRAINING AND INFORMATION SHARING

Training of scientists in cropping systems intensified in 1979 in support of the cropping systems network and national programs. There were 47 trainees in a 6-month course and 9 on-the-job trainees in cropping systems economics and 2 in entomology.

A cropping systems study tour in October-November 1979 had 17 participants from 6 countries. The group visited research sites in Thailand and Nepal and discussed cropping systems research programs in Thailand, Indonesia, Bangladesh, Philippines, South Korea, Nepal, and Sri Lanka.

Machinery development and testing

Agricultural Engineering and Agricultural Economics Departments

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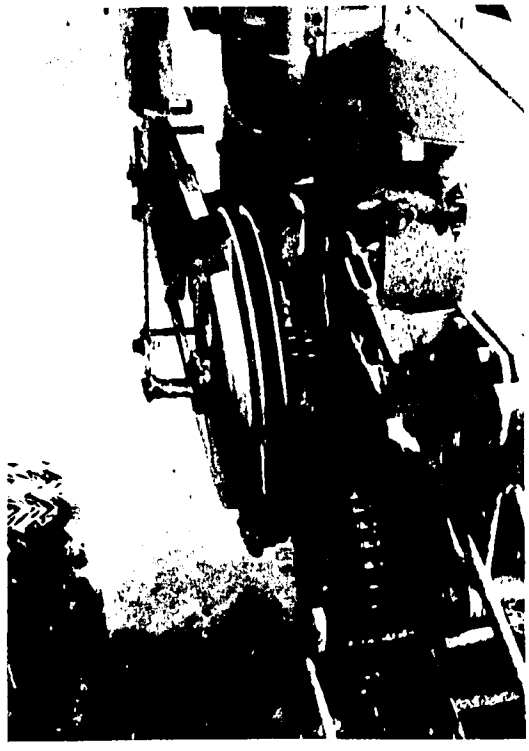
6- to 8-hp tiller with steering clutches. The testing of a four-spring engine mounting on the tiller continued. The mounting was designed to reduce the transfer of vibration from a lightweight air-cooled diesel engine to the operator. Discarded automotive engine valve springs with a 4.5-mm wire diameter and 29-mm coil diameter were used initially in the evaluation. Two springs failed after 110 hours of field operation. New valve springs again failed after about 200 hours of operation. Springs with a 6.5-mm diameter and 37-mm coil diameter completed 800 hours of field operation without a failure and were as effective as the original springs in reducing vibration transfer. This design was added to the power tiller drawings.

Rotary tiller attachment for the 6- to 8-hp tiller. The first prototype of a rotary tiller attachment was field tested and the design revised based on the test results. A pivoted bearing housing and countershaft, which carries the input pulley and the driving sprockets, was added to the four-speed belt and chain drive (Fig. 1). The change provided a variable distance between the engine and countershaft, which eliminated the need for a tension pulley for engaging and disengaging the belt and increased belt life. Clutching is done by swinging the countershaft housing about its pivot point with the clutch lever, which decreases the belt drive center distance and disengages the drive. Four speeds from 2 kph to 12 kph are available. Speed is changed by shifting the belt or the chain, or both. A wooden braking block was added to prevent the belt from jumping off the pulleys during disengagement.



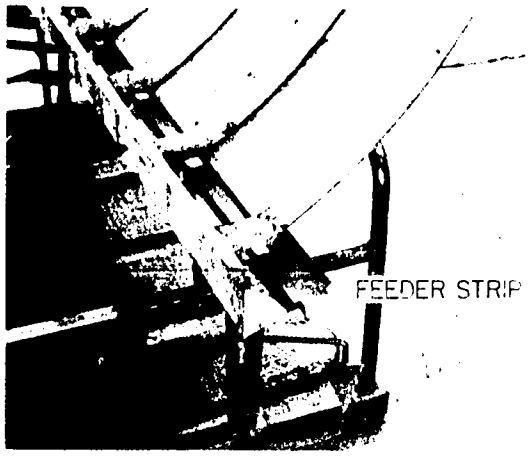
1. Four-speed tiller drive. IRRI, 1979.

The primary chain drive of the first rotary tiller showed excessive wear due to the entry of dust and dirt during dryland tillage. A dust-tight chain shield with provisions for allowing changes in center distance between the driving and driven members was added to eliminate the problem. The number of parts in the rototiller clutch was reduced by using an eccentric shifter instead of the earlier fork type. A new prototype was built and field tested for more than 1,000 hours. Problems encountered during the test were corrected and production drawings were prepared.

Multicrop dryland seeder. Final field calibration and performance trials and initial evaluations in Thailand and Bangladesh resulted in additional improvements of the multicrop dryland seeder. The bearing mount bar of the main frame was lengthened by 5 cm to provide more ground clearance for the tool bar to prevent it from pushing loose soil when the furrowers are set deep. To ensure uniform seed and fertilizer discharge, the loosely fitted pins that connected the plates to the oscillating frame were replaced by bolts. Production drawings were completed and the machine was released.

Rice transplanter. Development of the transplanter continued. The feeder fingers, which enter through slots in the feeding frame, did not effectively push the seedling mat down the tray. To correct this, the lower edge profile of the tray was modified to give a slightly higher entry point for the feeder. A narrow sheet metal strip was attached to the lower end of the tray to form a slot running the entire length of the tray. This slot, which is of the same length as the feeding frame, serves as the entry for a single narrow strip that replaced the feeder fingers (Fig. 2).

The guides that limited the handle to straight



2. Transplanter seedling feeder. IRRI, 1979.

line travel were eliminated. Instead a U-shaped handle that pivots freely when pulled or pushed downward during machine operation was pinned to the pivot arms. The change allowed more flexibility, simplified construction, and reduced weight. The modifications produced a marked improvement in the performance of the transplanter. Missing hills ranged from 2 to 5% depending on the quality of the seedlings, and field capacity was about 0.25 ha/labor-day.

A second prototype incorporated changes in machine geometry to permit transplanting in fields with deeper standing water. The picker holders were lengthened to allow planting in water up to 15 cm deep without immersing the picker frame in water. Adjustable stops, mounted at both sides of the wooden skid, control depth of planting.

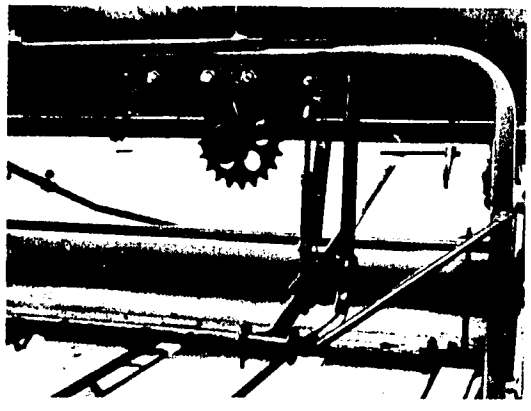
An improved seedling tray indexing system, which uses a pawl and ratchet to rotate a sprocket (Fig. 3), was developed. The sprocket drives a roller chain supported by two rollers on the main frame. The distance between the rollers determines the length of tray travel. A carriage bar, connected by an offset link to the roller chain, slides on a guide secured to the frame. The reciprocating movement of the bar is transmitted to the seedling tray, which is attached to the carriage bar.

A blade-type picker was developed to cut the soil bearing seedlings into blocks, instead of clawing them as with the 3-prong type (Fig. 4). The picker has three blades bolted to a square shank. The two outside blades are sharpened to an S-shape cutting edge for less shearing resistance; the middle blade is shorter and has a dull edge for pushing the block of seedlings that are cut by the two side blades. The blade-type picker reduces the number of seedlings planted per hill and improved seedling release.

An accelerated life test in the laboratory simulated operation of the transplanter in the field. The test was terminated after 650,000 cycles (an equivalent of 13 ha) without any part failures.

Field tests continued at IRRI. Comparative yield trials revealed no significant difference between plots planted with the transplanter and those planted manually. Use of the transplanter in water 10 cm and 4 cm deep, and land preparations of 1 plowing and 1 harrowing and 1 plowing and 3 harrowings showed the transplanter could operate satisfactorily in these conditions. Yield differences among the treatments were not significant.

Wetland seeder. The IRRI multihopper wet-



3. Seedling tray indexing system. IRRI, 1979.

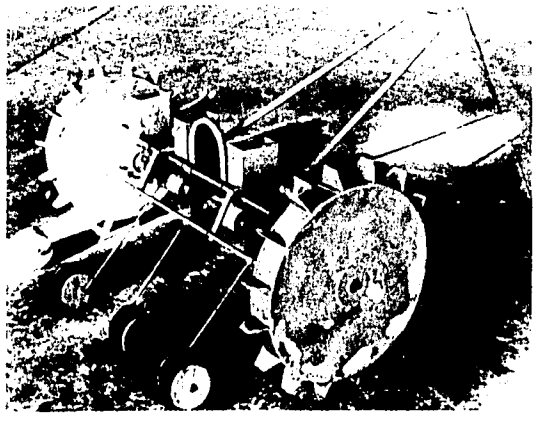
4. [illegible] pickers. IRRI, 1979.

land seeder, developed several years ago, had limited adoption by farmers because it required fields with no standing water. The machine was redesigned to deposit and lightly anchor the seeds on the surface of puddled soil to prevent floating during a heavy rain, reduce the pull requirement, and improve the machine's performance in good-to-moderate soil preparation.

A prototype was constructed in 1979 with improved seed metering and modified drive wheels (Fig. 5). The metering roller with seed pockets was replaced by a roller with spikes made of headless nails located at the middle portion. A groove was added to the hopper so that seeds are scratched out by the spikes. The drive wheels were increased in width and diameter for greater flotation and higher clearance. Preliminary tests showed good seed placement. Maximum penetration of the ground wheel was about 10 cm, which reduced the pulling effort.

Inclined-plate planter. To reduce land preparation time so that a dryland crop can be planted earlier after rainfed wetland rice, a machine that opens a narrow furrow in untilled soil, places the seed in the furrow, closes the furrow, and firms the soil around the seed was developed.

A prototype machine with two planting units mounted on a tool bar was built (Fig. 6). Each planting unit can be moved on the bar to vary row spacing. A metal metering plate gives good metering without seed damage. Single-seed metering with larger seeds is possible. Plant spacing in the row is controlled by the number of seed cells or metering holes in the metering plate. The planter



5. Wetland seeder. IRRI, 1979.

6. Inclined-plate planter. IRRI, 1979.

was put on test by the Multiple Cropping Department.

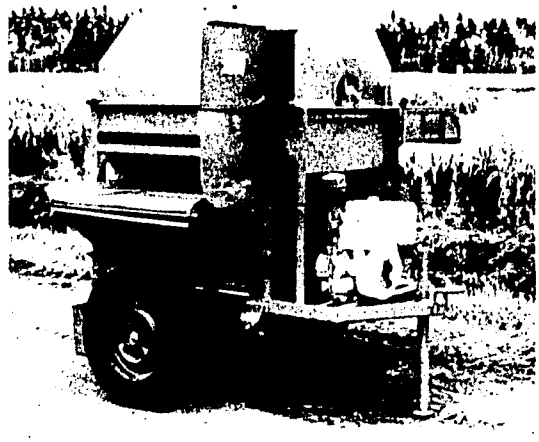
10-row liquid injector. Previous machine developments for the deep placement of chemicals in the soil encountered problems of unstable discharge rate, excessive effort to push the machine in the field, clogging of the discharge nozzles, and high labor requirements per hectare.

To eliminate or reduce these problems, a pull-type, 10-row liquid injector was designed. The machine places either insecticide or fertilizer 5-10 cm below the soil surface by spot injection 5-10 days after transplanting. The applicator can also be used as a row marker for transplanting while injecting chemicals. A peristaltic pump metering assembly attached to a wooden frame pumps the chemicals through 10 discharge nozzles housed in steel tubes that penetrate the soil (Fig. 7). The pump meters the correct amount of chemical and provides sufficient pressure to substantially reduce nozzle clogging. A ratchet secured to the pump shaft is rotated by a pawl attached to a crank. The back-and-forth movement of the hand lever actuates the crank. The length of the hand lever stroke controls the dose of chemical injected into the soil.

Total weight of the machine is 10 kg. The first prototype was calibrated in the laboratory and field tested. It performed well even in poorly prepared soil, although improvements had to be made to prevent occasional clogging of the nozzles and to eliminate dripping in the pump after stopping. Field capacity was about 0.5 ha/day.

Axial-flow thresher. Development of an improved version of the axial-flow thresher con-

7. Liquid injector. IRRI, 1979



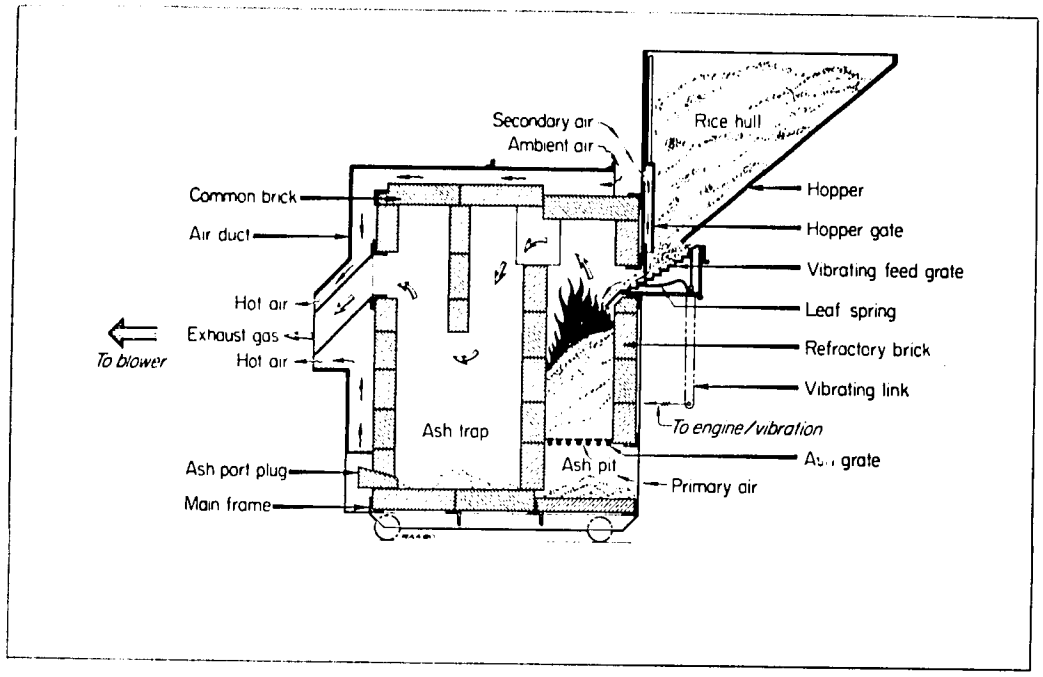
8. Axial-flow thresher. IRRI, 1979.

tinued. The first prototype performed satisfactorily in short tests, but field testing revealed design and endurance problems. It was, therefore, redesigned and individual components and assemblies were analyzed to produce a more efficient and durable machine (Fig. 8). The open threshing cylinder was strengthened and air vanes were added inside the cylinder to assist material movement and suck air through the feed opening to eliminate blowback and dust hazard to operators. The semicircular round bar concave was bolted to the frame for easier removal and repair. The two centrifugal blowers were strengthened and the assembly was repositioned outside the main frame to provide more clearance between the concave and grain chute. The screen frames were redesigned for easier installation and dismantling, and minimum grain spillage. Screen oscillation was reduced to 306 cycles/minute and stroke increased to 31.8 mm. The clean grain auger was repositioned and adjusted to reduce grain damage.

The redesigned machine produced good results in short performance tests. Capacities of 1.2 t/hour were obtained in paddy at 25% moisture content with separation loss, blower loss, and grain damage at less than 1% each. Some problems encountered during the 600-hour durability testing led to the replacement of the rubber bushing with ball bearings at the pivot points between the eccentric arm and bell crank assembly and the bell crank assembly pivot to the frame; installation of a peg-type straw paddle; enlargement of the discharge opening; and addition of a straw discharge guide. The 0.9-mm-thick semihexagonal cover was replaced by a 1.2-mm-thick sheet and a replaceable wear plate was added.

Prototypes were sent to ICRISAT, in India, the IRRI-Pakistan project, and Egypt for field evaluation, and drawings were released to manufacturers.

Rice hull furnace. The rice hull furnace for the 2-t vertical bin dryer was redesigned to make more use of conventional materials such as fire brick and sheet steel and to eliminate the operational problems of the initial design. The combustion chamber of the furnace is made of refractory fire brick, but the ash trap uses common fire brick to reduce cost. A sheet metal envelops the furnace and forms a cooling air duct, which increases thermal efficiency and reduces the temperature near the furnace (Fig. 9). An automatic feeding system for the hulls is activated by vibration from the engine used to drive the dryer blower. The operator can easily maintain a constant drying air temperature.



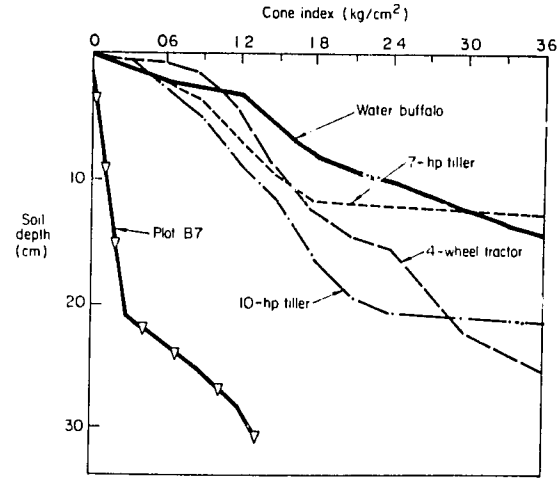
9. Rice hull furnace. IRRI, 1979.

The furnace, which can heat 106 m^3 of air to 45°C in a minute, was test operated for 400 hours, with no major problems or component failures. Average rice hull consumption was 11 kg/hour.

MACHINERY TESTING AND USE

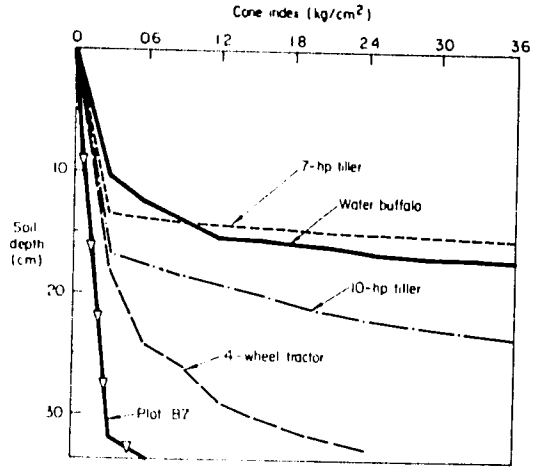
Compacted soils studies. In a continuously cropped soil a cone index versus depth profile was obtained in each plot, before and after tillage for crop 12. The cone penetrometer was mounted on a frame that rested on the soil. Individual weights, calibrated to produce a cone index of 0.6 kg/cm^2, were placed on the penetrometer in succession and the resulting penetration depth at each weight increment was recorded.

The profiles are shown in Figures 10 and 11. The profiles from the tillage plots exhibit a point where a marked change in the slope occurs (Fig. 10). For the 7-hp tiller, this point roughly coincides with the average plowing depth and can be interpreted as the plow pan. These slope changes do not appear in the profiles for the water buffalo and 4-wheel tractor plots. This lack of an abrupt slope change and the less pronounced slope change in the water buffalo profile (Fig. 11) could have been caused by the tillage action of the animal's hooves.



10. Cone index profile: before tillage for crop 12, and before tillage for crop 51 in plot B7. IRRI, 1979.

Similar profiles were obtained in plot B7 of the Institute's continuous cropping plots during land preparation for crop 51. Compared to the plot



11. Cone index profile: after tillage for crop 12, and after tillage for crop 51 in plot B7. IRRI, 1979.

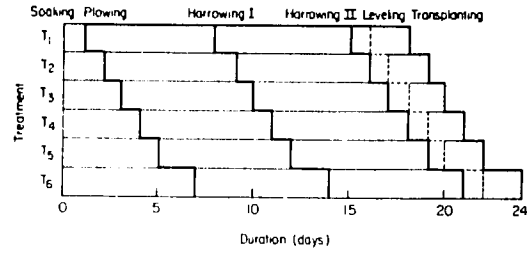
profiles in the tillage trials, the profiles of plot B7 showed substantially deeper soil with little indication of a hardpan layer in the first 30 cm, even though lightweight power tillers have tilled the plots for a number of crops.

Water-use efficiency and energy requirements for wetland tillage. A study was conducted to determine the most efficient tillage procedure for the wet and dry seasons with respect to water use, energy, and time requirements, while maintaining tillage quality and weed control.

A 0.25-ha field at IRRI was divided into 6 plots. Evaporation, rainfall, piezometer water level, and sloping gauge readings were recorded daily. A power tiller, with a moldboard plow, and a comb harrow were used for all tillage.

For the dry-season trials the field was allowed to dry before water was applied. Change of soil moisture content, cone index, and soil shearing force were recorded daily on all plots during the plowing period, just before irrigation. Harrowing followed plowing according to the schedule shown in Figure 12.

Soil moisture content increased during the first 1 or 2 days of irrigation, and soil resistance decreased rapidly. Irrigation after the second day resulted in slow changes in soil resistance, but after 3 days no additional change was detected; therefore, differences in fuel consumption and

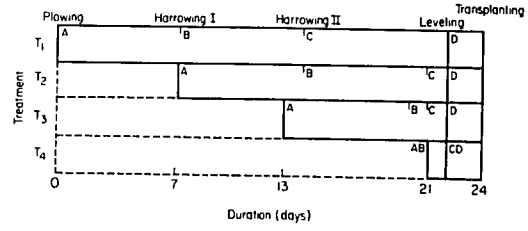


12. Duration of land preparation. IRRI, 1979 dry season.

machine field capacity were similar in the treatments tilled after 3 days of soaking. No significant differences in weed and plant growth were found between treatments.

Because the soil was fully saturated before the wet-season trials started, soil characteristics did not change with the application of more water. Only the duration of the tillage period was varied (Fig. 13). The 6 plots were divided and the resulting 12 plots allowed a test of 4 treatments and 3 replications.

No positive relationships were found between fuel consumption, machine field capacity, and water applied, primarily because the soil was saturated before the start of land preparation. Soil shearing force and fuel consumption were a little higher in the tillage treatment of shortest duration than in the other plots. Weed dry matter weight was also higher. Treatment 3, which involved 11 days of land preparation (day 13 to day 24), was the most efficient tillage procedure. No advantage was apparent in land preparation of longer duration.



13. Duration of land preparation. IRRI, 1979 wet season.

Horizontal oscillating screen performance. IRRI threshers use horizontal oscillating screens for grain cleaning. These screens are expected to perform satisfactorily over a wide range of grain moisture content. A project was initiated to study the effects and relationships of the primary design parameters of an oscillating screen: the hanger angle, crank radius (throw), and oscillation frequency.

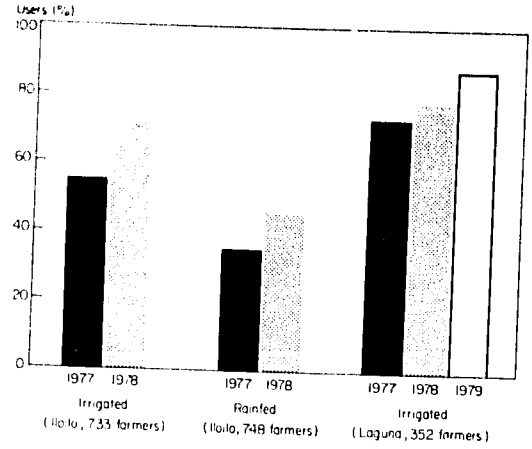
A laboratory machine was built to provide for easily adjustable hanger angle, crank radius, oscillation frequency, screen hole size, and material feed rate.

Initial tests were conducted to develop a method for obtaining grain samples with reproducible moisture and foreign matter contents. Determining an optimum combination of parameters for cleaning wet paddy (27% M.C.) is the first objective. A series of runs were conducted at the ends of the parameter ranges to reduce those ranges and to permit a manageable number of test runs. Crank angle had the greatest effect on screen loss and accumulation of wet material on the screen. In all cases, losses were high because the screen holes were clogged by wet material when the test ran longer than 2 minutes.

Engineering economic systems. *Thresher adoption and use.* Figure 14 illustrates the degree of adoption of the IRRI-designed threshers by farmers in two areas of the Philippines. Figure 15 portrays the rate of adoption by farmers currently using the machine. Use for custom services is common in both areas and is highly profitable (Table 1). Introduction of the thresher has reduced labor requirements and created pressures for adjustments in traditional sharing arrangements (Table 2). Introduction of the machine in Iloilo appears to have closely followed the introduction of irrigation and modern varieties, which increased both cropping intensity and yields (Fig. 16).

Energy and tropical rice production. To evaluate energy use patterns in rice production, three alternative systems were synthesized using data reported in studies by IRRI and other organizations. The systems differed primarily in the degree to which they used machines.

Assumed levels of chemical inputs and rice yields approximate those of Filipino farmers and were held constant for the three systems. The greatest concentration of commercial energy in all



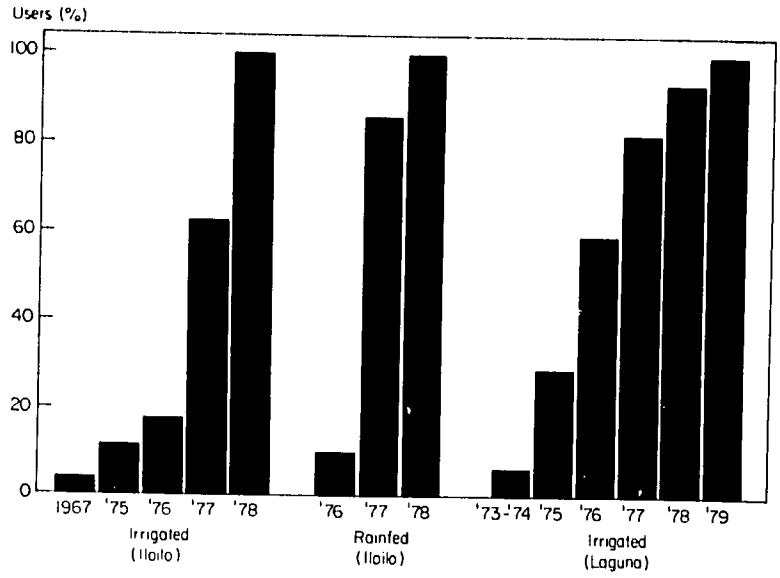
14. Thresher adoption and use in 3 irrigated and 3 rainfed villages of Iloilo and 6 irrigated villages of Laguna, Philippines, 1978-79.

systems is due to seed and chemical inputs (Fig. 17). In the systems that used machines, fuel and oil ranked next to chemicals. Crop care, which includes fertilization, weed control, and pest management, ranked ahead of all other tasks in the production systems (Fig. 18).

Considering only gross energy use, more efficient use of chemical fertilizers, insecticides, and herbicides represents a potential source of significant savings. Expressed in current market values, human and animal inputs ranked as high-cost energy inputs compared to fuel and chemicals (Table 3). The mechanical system, which consumed the most energy, also had the lowest cost per hectare. One implication of the analysis is that the choice between animal and mechanical power is not sensitive to fuel price increases, particularly for operations such as land preparation and threshing. The opposite is true for mechanical drying, which consumes 60% of the total fuel energy in the mechanical system.

INDUSTRIAL EXTENSION

Thailand. The IRRI-designed axial-flow thresher continued to gain popularity and has spread from the southern part of the Central Plain into the northern Thailand provinces. About 2,160 units



15. Thresher adoption patterns by farmer users in Iloilo and Laguna, Philippines, 1967-79.

Table 1. Thresher cost and use patterns in Iloilo and Laguna, Philippines, 1978–79.

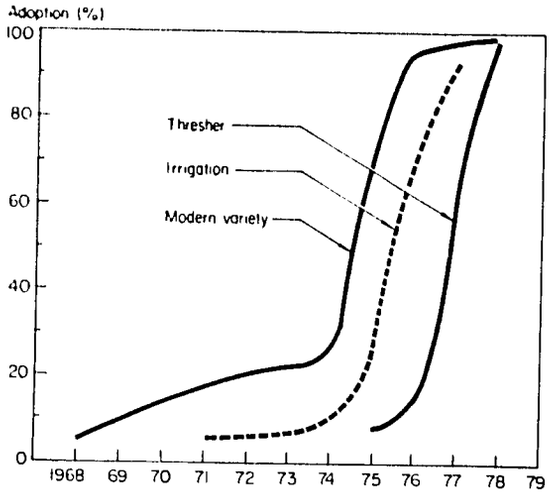
Area	Initial cost (S)	Annual use (h)	Output (t/yr)	Gross income (S/yr)	Net income (S/yr)	Payback period (yr)
Iloilo (irrigated)	738	214	120	965	837	0.9
Iloilo (rainfed)	775	116	72	510	383	2.0
Laguna (irrigated)	1243	153	98	827	666	1.9

Table 2. Rates of payment for harvesting (H), threshing (T), and cleaning (C) in Iloilo, Philippines, 1979.

HTC = 16.6% of gross	H = 11.1% of gross		Portable thresher, 2 operators or helpers in Oton and Tigbauan, Iloilo
	TC = 5.5% of gross	3.7% of gross to machine owner	
		1.8% of gross to 2 operators	
	or sometimes		
	TC = 5.5% of gross	4.1% of gross to machine owner	
		1.4% of gross to 2 operators	

were manufactured, a 37% increase over that in 1978.

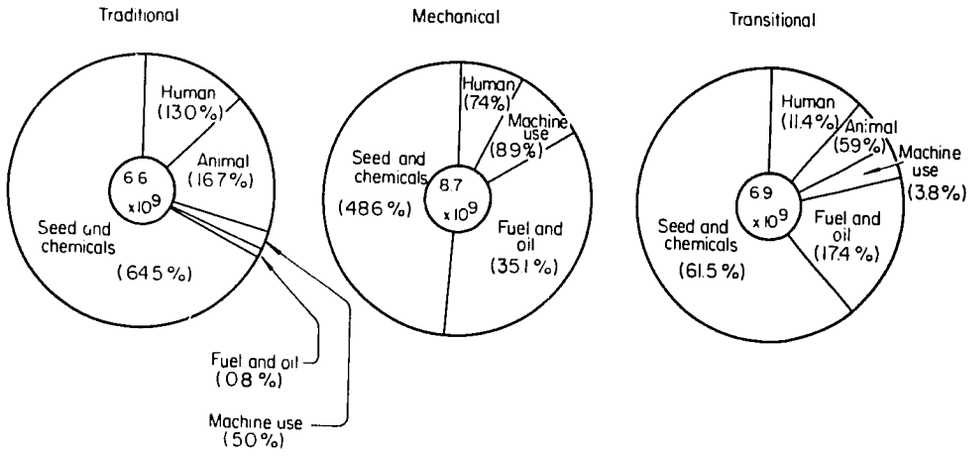
Although there is a good chance for increasing cropping intensity in northeast Thailand, low power availability is a major constraint. Farmers in northeast Thailand still rely heavily on buffalo for draft



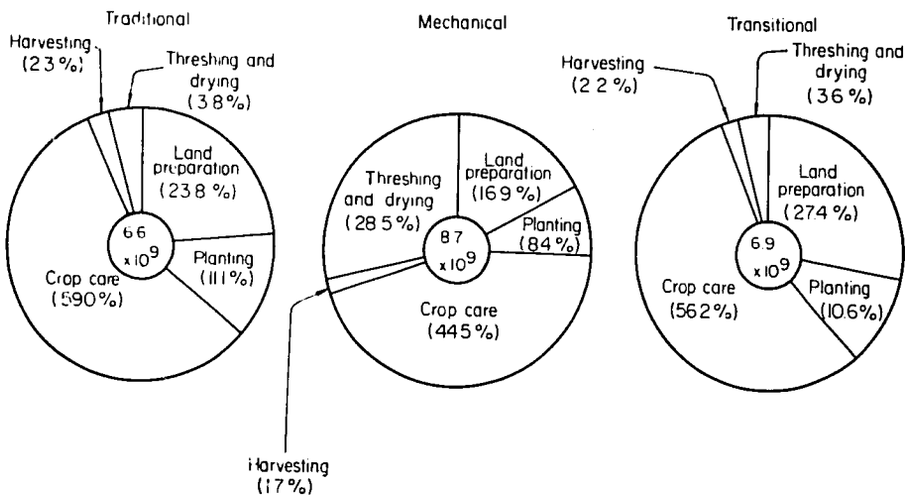
16. Adoption of 3 rice production technologies in sample irrigated villages, Iloilo, Philippines, 1979.

power. To increase the efficiency of plowing with animals, the project staff, conducted a series of experiments with modified moldboard plow shapes. Preliminary tests in one soil type showed the draft could be reduced by modifying the traditional plow shape used in the area.

Pakistan. The industrial extension project staff in Pakistan assisted the Pakistan Agricultural Research Council (the project's host organization) in establishing a new division named the National Institute of Agricultural Mechanization (NIAM). NIAM will develop a wide range of farm machines for Pakistani farmers and will test and issue reports



17. Energy (joules) inputs by source, IRRI, 1979.



18. Energy (joules) by major tasks, IRRI, 1979.

Table 3. Cost of inputs at market prices for alternative rice production systems.[a] IRRI, 1979.

Item	Unit cost ($)	Cost ($/ha) of inputs		
		Traditional system	Transitional system	Mechanical system
Seed	0.16/kg	8.00	8.00	8.00
Fertilizer	0.58/kg N	23.20	23.20	23.20
Insecticide	36/kg a.i.	27.00	27.00	27.00
Herbicide	38/kg a.i.	26.60	26.60	26.60
Fuel[b]	0.193/liter	0.38	6.04	15.42
Machinery[c]	–	10.00	24.00	29.34
Animal power[d]	0.65/hour	68.25	25.35	0
Human labor	0.17/hour	125.00	114.46	92.68
Total		288.43	254.65	222.24

[a]Input prices are averages prevailing in rural areas of the Philippines. US$1 = ₱7.35. a.i. = active ingredient. [b]Fuel costs are valued in terms of diesel fuel equivalents. [c]Includes only fixed-cost component. [d]Based on daily rental rate without operator.

on the performance of commercially available farm machinery.

The project staff is developing a *single-shaft axial-flow thresher* with a large aspirator fan mounted on the same shaft as the threshing drum. The thresher uses the axial-flow principle combined with the aspiration cleaning system used on wheat threshers popular on the Indian subcontinent. Two versions were developed: one powered by a 16-hp engine and the other by the power takeoff of a 4-wheel tractor.

Indonesia. The new project in Indonesia assisted several manufacturers in starting production of the IRRI thresher, power tiller, and axial-flow pump. In West Sumatra, a pilot project, which will serve to demonstrate IRRI-type farm machinery to farmers in the area, was established.

Philippines. The IRRI axial-flow thresher continued to dominate the market in the Philippines. Good progress was also made in introducing the new axial-flow water pump and IRRI power tiller.

A survey of all cooperating manufacturers in the Philippines resulted in intensified technical assistance in manufacturing and product development to a selected group of cooperating firms.

Associated formal training

IRRI's training programs deal primarily with the practical aspects of rice production. Trainees in research-oriented programs are classified as research scholars if they have a BS degree, or research fellows if they have MS or Ph D degrees.

A total of 219 persons were in the research-oriented training program in 1979 (Table 1, 2). The number included 32 postdoctoral research fellows, 47 students working for the Ph D, 82 working for the MS degree, and 58 on special short-term non-degree programs. Besides the degree scholars, four graduate students were sent to Australia, the Netherlands, and the United States on specialized projects.

SPECIAL TRAINING COURSES

Participation in formal training courses is summarized in Table 3. The INSFFER course was initiated in 1979.

Besides the training listed in Table 3 several other special short-term training programs were offered: a 1-week course to prepare 25 Filipino technicians of the Cagayan Integrated Agricultural Development Project on the conduct of applied researches in cooperation with NFAC-IRRI-PCARR; a 1-month familiarization course on rainfed-wetland rice technology for 7 extension workers from Thailand; a 1-month observation by two extension workers from Sri Lanka of established applied research in different parts of the Philippines; and a 2-week course on the continuous rice production system for 6 extension workers of Indonesia.

In all training the trainees spent about 50% of their time working in the field, greenhouses, and laboratories. All trainees returned to their respective countries after completion of their programs.

TRAINING PROGRAM PARTICIPANTS

A list of individuals who completed their programs in 1979, including their countries and research project areas, follows. An asterisk (*) indicates completion of the MS degree; two asterisks (**) denote completion of the Ph D degree during the year.

Table 1. Distribution by department of IRRI research fellows and scholars, 1979.[a]

Department	Postdoctoral fellows	Research fellows			Research scholars		Total
		Ph D	MS	N.D.	MS	N.D.	
Agricultural Economics	5	8	3	3	8	11	38
Agricultural Engineering	1	2	–	1	9	3	16
Agronomy	5	8	2	–	4	–	19
Chemistry	1	2	–	1	–	2	6
Entomology	5	4	2	2	4	5	22
Experimental Farm	–	–	–	–	–	1	1
International Rice Testing Program	–	2	–	–	–	–	2
Multiple Cropping	1	4	5	–	5	1	16
Plant Breeding	3	9	–	–	3	8	23
Plant Pathology	2	1	–	1	8	6	18
Plant Physiology	3	1	1	2	2	2	11
Rice Production Training and Research	–	–	2	–	–	7	9
Soil Chemistry	5	–	3	–	1	1	10
Soil Microbiology	2	–	2	1	1	1	7
Statistics	–	–	1	–	1	–	3
Training Office	1	–	–	–	–	–	1
Water management	1	3	–	–	12	1	17
Total	35	44	21	11	58	50	219

[a]N.D. = nondegree.

Table 2. Distribution by country of IRRI research fellows and scholars, 1979.[a]

Country	Postdoctoral fellows	Research fellows			Research scholars		Total
		Ph D	MS	N.D.	MS	N.D.	
Australia	–	1	–	–	–	–	1
Bangladesh	2	3	21	1	3	–	30
Brazil	–	1	–	–	–	–	1
Burma	–	–	–	1	2	–	3
Canada	–	1	–	–	–	–	1
China	–	–	1	–	3	4	8
Colombia	–	–	–	–	1	–	1
Costa Rica	–	–	–	–	–	1	1
Cuba	–	–	–	–	–	3	3
Dominican Republic	–	1	–	–	–	–	1
Germany, Federal Republic of	3	2	–	–	–	–	5
India	13	4	–	1	–	–	18
Indonesia	1	5	–	–	8	9	23
Japan	4	1	–	2	–	3	10
Kenya	–	–	–	–	1	1	2
Korea	1	1	–	2	3	6	13
Malaysia	–	–	–	–	–	4	4
Mexico	–	1	–	–	1	–	2
Nepal	–	1	–	–	1	–	2
Netherlands	–	1	–	–	1	1	3
Pakistan	1	3	–	–	1	2	7
Philippines	1	6	–	1	18	3	29
Sri Lanka	5	1	–	1	5	1	13
Thailand	–	5	–	–	12	8	25
United Kingdom	–	1	–	1	–	2	4
United States	1	6	–	–	–	–	7
Vietnam	–	2	–	–	–	–	2
Total	32	47	22	10	60	48	219

[a]N.D. = nondegree.

Table 3. Distribution by country of participants in IRRI training courses,[a] 1979.

Country	CSTP	GEU	RPTP	INSFFER	IWMT	AET	Total[b]
Bangladesh	10	10	4	2	5	2	33
Burma	3	–	–	–	–	1	4
China	–	8	–	–	–	2	10
Cuba	–	2	–	–	–	–	2
Egypt	–	–	–	1	–	–	1
India	–	6	19	6	0	6	37
Indonesia	12	8	4	4	6	3	37
Korea	1	–	–	1	–	1	3
Malaysia	3	3	4	–	2	1	13
Nepal	3	2	–	1	–	–	6
Nigeria	–	–	1	–	–	–	1
Pakistan	–	2	–	–	–	2	4
Papua New Guinea	–	–	1	–	–	–	1
Philippines	5	2	1	2	6	1	17
Sri Lanka	2	5	3	1	2	–	13
Tanzania	–	1	–	–	–	–	1
Thailand	8	5	–	4	3	2	22
Turkey	–	1	1	–	–	–	2
Total	47	55	38	22	24	21	207

[a]CSTP = Cropping Systems Training Program, GEU = Genetic Evaluation and Utilization Program, RPTP = Rice Production Training Program, INSFFER = International Network on Soil Fertility and Fertilizer Evaluation for Rice, IWMT = Irrigation Water Management Training, AET = Agricultural Engineering Training. [b]Does not include a group of 75 participants in the 2-week rice production course offered at 6 different times during 1979.

RESEARCH SCHOLARS

Agricultural economics

Linda Castillo.* Philippines. Agricultural extension farmer technical knowledge and its impact on productivity.

Eloisa Labadan.* Philippines. The contribution of schooling to Canadian farm income.

Thelma Paris.* Philippines. A study of determinants of cropping systems in some selected rainfed areas in the Philippines.

Josef Thattil.* Sri Lanka. Criteria for screening hypothetical technologies prior to field testing.

Gloria Umali.* Philippines. Production function analysis of variability in cropping pattern performance.

Agricultural engineering

Nongluck Jongsuwat.* Thailand. A historical study of farm mechanization and rice production in Thailand.

K.S. Lee.* Korea. An evaluation of water use efficiency and energy requirements for wetland tillage.

Renu Pathnopas.* Thailand. The economics of rice threshing machines in Thailand.

Velupillai Premakumar.* Sri Lanka. Yield gap analysis by efficiency function approach — A case study in Sri Lanka.

Jai Singh.* India. Evaluation of selected crop establishment techniques.

Ganesh Thapa.* Nepal. The economics of tractor ownership and use in selected districts of the Nepal Terai.

Agronomy

Soon Chul Kim.* Korea. An ecological approach to controlling weeds in transplanted lowland rice.

Hamdan Pane.* Indonesia. Control of *Cyperus rotundus*.

Chemistry

Yasuo Mano.* Japan. Preparation of lipids from starch granules of tropical rice.

Irrigation water management

Adul Apinantara.* Thailand. Cooperation and conflict in water utilization in land irrigation systems in Northeastern Thailand.

Wiraphol Chatchawalwong.* Thailand. Agronomic factors limiting dry season cropping in tank irrigation systems in Northeast Thailand.

Roberto Clemente.* Philippines. A water balance study of water supply from a small agricultural watershed for lowland rice production in Iloilo, Philippines.

Catalino Collado.* Philippines. Water balance study of water movement within a toposequence of rainfed lowland rice paddies in Iloilo, Philippines.

Nurul Haque.* Bangladesh. Measurement of water movement through soils on a rainfed toposequence.

Tolentino Moya.* Philippines. Factors affecting water distribution within the tertiaries of a gravity irrigation system.

Surasuk Sritunya.* Thailand. A study of factors limiting dry season cropping intensity and rice yield in the Nam Phong-Nong Wai Irrigation Project of Northeast Thailand.

Multiple cropping

Thanom Klodpeng.* Thailand. A comparison of water redistribution in an upland tropofluvent and on lowland tropaquept.

Piroge Suvajinda.* Thailand. The effects of rates and times of nitrogen application on dry seeded rice.

Plant breeding

Sugiono Moeljopawiro.* Indonesia. Inheritance of salt tolerance in rice.

R. V. Nair.* India. Inheritance and allelic relationship of genes governing resistance to the whitebacked planthopper, *Sogatella furcifera*, in some rice varieties.

Plant pathology

Andi Hasanuddin.* Indonesia. Effect of tungro virus source on the infectivity of *Nephotettix virescens* (Distant).

Sunendar Kartaatmadja.* Indonesia. Efficiency of *Nilaparvata lugens* (Stal) to transmit rice ragged stunt virus.

RESEARCH FELLOWS

Agricultural economics

Gordon Banta.** Canada. Methods of economic testing of new cropping systems technology.

Dennis O'Brien.** Australia. An empirical analysis of existing and alternative weed management practices in rice and corn in Cale, Batangas, Philippines.

James Chapman.** USA. The potential of

mechanization for crop intensification in a rainfed lowland area — Iloilo, Philippines.

Bouis Howard.** USA. Rice policy in the Philippines.

Donald Sillers.** USA. Income risk and fertilizer use among peasant cultivators: A mean-variance approach.

Joyotee Smith.** India. The effect of the new rice technology on labor utilization in Laguna.

Chemistry

Chandra Breckenridge.** Sri Lanka. Quality characteristics of raw and parboiled rices in Sri Lanka.

POSTDOCTORAL FELLOWS

Agricultural economics

Sisira Jayasuriya. Sri Lanka. Whole farm budgeting project.

Chemistry

Teruhiko Yoshihara. Japan. Biochemical basis of varietal resistance of rice plants to brown planthopper (cooperative work with entomology department).

Plant breeding

M. Eunus. India. Feasibility of rapid generation advance.

Plant pathology

S. Suryanarayanan. India. Studies on the mechanisms of "Stable resistance" to rice blast.

Soil chemistry

Chr. Haupenthal. West Germany. Studies on environmental factors influencing rice yields: Relief-soil-drainage-rice yield interrelationship of reported problem soils in the Philippines.

Soil microbiology

Osamu Ito. Japan. N_2 fixation in paddy soil studied by labelled dinitrogen.

S. A. Kulasooriya. Sri Lanka. Ecological aspects of blue green algae in paddy field.

OTHERS

Agricultural economics

Adi Mesra Djulin. Indonesia. Trainee. Cropping systems.

Nik Fuad. Malaysia. Trainee. Cropping systems.

Raymundo Gonzaga. Philippines. Trainee. Cropping systems.

Herianto. Indonesia. Trainee. Cropping systems.

Tuan Rosdi Ibrahim. Malaysia. Trainee. Cropping systems.

Jamaluddin. Indonesia. Trainee. Cropping systems.

Wilfreda Manos. Philippines. Trainee. Cropping systems.

Yoshinori Morooka. Japan. (a) Aliwalas to rice garden: A case study of the intensification of rice farming in Camarines Sur, Philippines; (b) An analysis of the labor-intensive continuous rice production system at IRRI.

Gazali Muchtar. Indonesia. Trainee. Cropping systems.

U Nyi Nyi. Burma. Rice cropping systems of Burma and the impact of the high yielding rice program.

Glenn Paraico. Philippines. Trainee. Cropping systems.

Suharyadi. Indonesia. Trainee. Cropping systems.

Karsidi Sukamandi. Indonesia. Trainee. Cropping systems.

N. Weeralugolla. Sri Lanka. Trainee. Cropping systems.

Chemistry

Damaso Castillo Toro. Cuba. Quality evaluation application to Cuban rices.

Plant breeding

Somkid Virigool. Thailand. Inheritance of elongation ability in rice.

Plant physiology

Ricardo Canet. Cuba. Diagnosis of healthy rice roots.

Soil chemistry

Kamal Uddin Ahmed. Bangladesh. Greenhouse screening of 9 rice varieties/lines for salinity at seedling stage.

Amir Basyir. Indonesia. Screening for salinity/alkalinity.

Polwatta Hemadasa. Sri Lanka. Adverse soils/iron toxicity.

D. Janzibar. Indonesia. Iron toxicity greenhouse screening.

B. N. Nizar. Sri Lanka. Effect of two levels of zinc on the growth and yield of rice on four zinc-deficient soils.

M.F.R. Sanzo. Cuba. Tolerance of 3 semi-dwarf rice varieties to salinity at seedling stage under direct seeding conditions.

INTERNATIONAL NETWORK ON SOIL FERTILITY AND FERTILIZER EVALUATION FOR RICE (INSFFER)

1 February–31 May 1979

Murshidul Md. Kabir, Scientific Officer, Soil Chem Div., Bangladesh, Rice Research Inst., (BRRI), Joydebpur, Bangladesh

Murshidur Rahman, Scientific Officer, Agronomy Division, BRRI, Bangladesh

Sobhy Abd El-Halim Ghanem, Research Assistant, Rice Section, Sakha Agricultural Research Station, Kaffer El-Shiekh, Egypt

D. B. B. Choudhary, All-India Coordinated Rice Improvement Project (AICRIP), Hyderabad, India

R. C. Gautam, G. B. Pant University, India

P. K. Nayar, CRRI, Cuttack, India

C.R. Padalia, CRRI, Cuttack, India

S. S. R. K. Raju, Business Executive, Fertilizer Department, E.I.D. Parry (India) Ltd., Secunderabad, India

C. H. Dayakara Reddy, Agronomy Development Officer, Coromandel Fertilizer Ltd., Secunderabad, India

Harmastini Sukiman, Research Assistant, National Biological Institute, Bogor, Indonesia

Akhmad Hidayat, Chemical Analyst, Soil, Plant, Water and Fertilizer Laboratory, Physiology Division, CRIA, Bogor, Indonesia

Hendrick Virgilius, Agronomy Division, Central Research Institute for Agriculture, Indonesia

Tadjudin Surawinata, Faculty of Agriculture, Padjadjaran University, Jalan Bykit Dago Selatan, Bandung, Indonesia

Myeong Gu Lee, Junior Researcher, Soil Chem Dept., Institute of Agricultural Sciences, Office of Rural Development, Suweon, Korea

Shanti Bhattarai, Asst. Soil Scientist, Division of Soil Science and Agricultural Chemistry, Khumaltar, Kathmandu, Nepal

Norma S. Gonzaga, Soil Technologist II, Bureau of Soils, Butuan City, Philippines

Sonia Salguero, Soil Technologist II, Bureau of Soils, Manila, Philippines

Nirmala Gunapala, Experimental Officer, Central Agricultural Research Institute, Gannoruwa, Peradeniya, Sri Lanka

Hansa Khunathai, Agricultural Technologist, Rice Division, Dept. of Agriculture, Bangkhen, Bangkok, Thailand

Somjit Khothasuvon, Agricultural Technologist, Khon Kaen Experiment Station, Khon Kaen, Thailand

Nipansri Komthong, Agricultural Technologist, Rangsit Rice Experiment Station, Prathumthani, Thailand

Ksemsri Subsorn, Soil Chemist, Agricultural Chemistry Division, Dept. of Agriculture, Bangkhen, Bangkok, Thailand

6-MONTH RICE PRODUCTION TRAINING PROGRAM

5 March–20 August 1979

S. B. Naseem, Scientific Officer (Applied Research), Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh

Md. Abdul A. Parvez, Scientific Officer (Training), BRRI, Bangladesh

Abdur Razzaque, Scientific Officer (CTARD), BRRI, Bangladesh

Md. Abdur Salam, Scientific Officer, Breeding Div., BRRI, Bangladesh

Chandan Chandra Barroah, Asst. Agronomist, Dept. of Agriculture, Tezpaur, Assam, India

N. C. Basu Raychaudhuri, Research Officer, Rice Research Station, Bankura, West Bengal, India

Manmehan Bhatnagar, District Extension Officer, Dept. of Agriculture, Bundi, Rajasthan, India

Chandra Kanta Bora, Subject Matter Specialist, Sub Divisional Agricultural Office, Marigaon, Nowgong, India

Banabahari Chakrabarty, District Agricultural Information Officer, Gov't. of West Bengal, Calcutta-70035, India

Kashinath N. Kharnal, Subject Matter Specialist (Extension/Research), Rice Research Station, Bankura, West Bengal, India

Arun Kumar Mitra, Subdivisional Agricultural Officer, Dept. of Agriculture, Alupurduar, West Bengal, India

Dinesh Chandra Ojah, Asst. Agronomist, Crauhati-9, Assam, India

Baikunth Nath Panda, Agronomist, Office of Deputy Director (Agriculture), Bolangir, Orissa, India

Samarenda Pattnaik, Agronomist, Office of

Deputy Director, Baripada, Orissa, India
Gouri Shanker Persai, Instructor in Agriculture, Grám Sewek Training Center, Madhya Pradesh, India
Potnoru Sankaram Patro, Dist. Agricultural Officer. Rayagada, Dist. Oraput, Orissa, India
Magat Ram Rathee, Asst. Director (Agriculture), Panimat Rohtak, Haryana, India
Amarnath Ray, Agronomist, Directorate of Agriculture, Burdwan, West Bengal, India
Sashi Mohan Sarmah, Asst. Agronomist, Dept. of Agriculture, Nowgong, India
Surinder Singh Sidhu, District Agricultural Officer, Rajasthan, India
Shreesh Kishore Sinha, Add'l. District Agriculture Officer, Dept. of Agriculture, Bihar, India
Golar Bihari Sahoo, Water Management Specialist, State Government of Agriculture, Bhadrak, Orissa, India
Gurbachan Singh Virk, Deputy Director (Agriculture), Dept. of Agriculture, Haryana, India
Djunnainah Arifin, Research Dissemination Office, Central Research Institute of Agriculture, Bogor, Indonesia
Ekó Ananto, Agricultural Engineer, Agronomy Department, CRIA, Indonesia
Abdul Rachim, Agricultural Economist, Agronomy Department, CRIA, Indonesia
M. Sirod, Subject Matter Specialist, National Food Crop Extension Project, Ciamis, Indonesia
Mat Salim Bin Abdullah, Agricultural Assistant, c/o National Extension Project, Extension Branch, Dept. of Agriculture, Kuala Lumpur, Malaysia
Baharom bin Safie, Agriculture Officer (Rice), c/o National Extension Project, Malaysia
Zainal Abidin Said, Agricultural Assitant, (Subject Matter Section), Dept. of Agriculture, Kuala Lumpur, Malaysia
Mohd. Zain bin Yusof, Manager, FELCRA Land Dev. Project, FELCRA, Seberang Perak, J.P.T. Telok Sena, Parit, Berak, Malaysia
Jenkins A. Ifiouno, Agronomist, Ananbra/Imo State (World Bank) Rice Project, Ministry of Agric. and Natural Resources, P.M.B. 1003, Enugu, Nigeria
Joseph Wohuinangu, Rice Agronomist, Agriculture Research Centre, Bubia-Box 348-LAE, Papua New Guinea
Ned Jaictin, Soil Technologist II, Bureau of Soils, Agusan del Norte, Philippines
K. A. J. M. Fernando, Field Trials Division, Dept. of Agriculture, Kegalle, Sri Lanka
S. K. Seneviratne, Field Trials Division, Dept. of Agriculture, Irranavillu Scheme, Sri Lanka
Ananda Wickramansinghe, Lab. Assistant, Paddy Research Station, Ambalantola, Sri Lanka
Mehmet Teceren, Research Assistant, Director of Regional Variety Testing and Adaptation, Ankara, Turkey

IRRIGATION WATER MANAGEMENT TRAINING

20 August–28 September 1979

Mesbauddin Ahmed, Assitant Professor, Bangladesh Agri-Varsity, Mymensingh, Bangladesh
Md. Jahirul Islam, Scientific Officer, Bangladesh Rice Research Institute, Dacca, Bangladesh
Wais Kabir, Scientific Officer, Bangladesh Agricultural Research Council, Dacca, Bangladesh
Miah Md. Mirjahan, Lecturer, Dept. of Water Resources Engineering, BUET, Dacca, Bangladesh
Md. Abdus Sattar, Scientific Officer, Agricultural Engineering Div., Bangladesh Rice Research Institute, Dacca, Bangladesh
Bayudono, Chief of Tertiary Development Program, Way Seputin Way, Sekampung Irrigation Project, Ministry of Public Works, Directorate of General Water Resources, Indonesia
Moetjahjo Kartodirdjo, Staff, Irrigation Project for Operation and Maintenance, Sub-project Madiun, Department of Public Works, Indonesia
Kaman Mochamad Ma'mun, Staff, Directorate of Irrigation, Jakarta, Indonesia
Muchtadi, Subject Matter Specialist, Agricultural Department of Nusa Tenggara, Barat Province, Indonesia
Eman Reyman, Agricultural Counterpart of Jratunseluna Project, Directorate General of Water Resources Development, Ministry of Public Works, Indonesia
Boy Sarwono Soepardi, Staff, Rice Agronomy, CRIA, Bogor, Indonesia
Mohd. Sharin Bin Mohd Yob, Research Officer,

MARDI, P.P. 105, Alor Star, Kedah, Malaysia

Sulaiman Bin Md. Zain, Agriculture Officer/Engineer, Department of Agriculture, Alor Star, Kedah, Malaysia

Voltaire R. Barlis, Agricultural Engineer, National Irrigation Administration, Quezon City

Rodolfo Belmonte, Agriculturist, NIA-LCIADP, Libmanan, Camarines Sur, Philippines

Florentino Cortez, Agricultural Engineer Trainee, OFFS, RDD-NIA, CLSU, Muñoz, Nueva Ecija, Philippines

Eleno B. Raful, Jr., Training Coordinator, Water Management Training Center, NIA, CLSU, Mũnoz, Nueva Ecija, Philippines

Danilo M. Santiago, Irrigation Engineer, NIA-UPRIIS, Talavera, Nueva Ecija, Philippines

Reynaldo V. Sarmiento, Farmers Organization Specialist, OIC, Small Systems Section, O&M Div., Systems Management Dept., Office of Operations, NIA, Quezon City, Philippines

Madawita Patabendige Dayananda, Research Officer, Department of Agriculture, Angunukdapelessa, Sri Lanka

Gardiyawasam Balage Keerthiratna, Research Officer, Agricultural Research Station, Maha Illupallama, Sri Lanka

Kittichai Krataithong, Irrigation Agronomist, Royal Irrigation Department, Kalasin, Thailand

Samran Thammultree, Civil Engineer 5, Royal Irrigation Department, Bangkok, Thailand

Visuth Whytongcome, Irrigation Engineer, Mongwai Irrigation Project, Khonkaen, Thailand

6-MONTH CROPPING SYSTEMS TRAINING PROGRAM

10 September 1979 – 29 February 1980

Md. Abul Kalam Azad, Scientific Officer, Jute Research Institute (Agriculture), Sher-e Bangla Nagar, Dacca-7, Bangladesh

A. B. M. Khaled Haidar, Extension Officer, Directorate of Land & Water Use, Bangladesh Water Development Board, 147, Sultan Building, Motijheel Com. Area, Dacca-2, Bangladesh

Mainul Haq, Scientific Officer, Entomology Division, Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh

A.M.M. Mosiul Haque, Scientific Officer (Farm Mgt.) Central Agr'l. Research Station, Bangladesh Agricultural Research Institute (BARI), P.O. Chandna, Joydebpur, Dacca, Bangladesh

Mohammed Mominul Hoque, Scientific Officer, Bangladesh Jute Research Institute (Agric.). Sher-e Bangla Nagar, Dacca-7, Bangladesh

Md. Azizur Rahman, Senior Scientific Officer (Agronomy), Bangladesh Agricultural Research Institute (BARI), Dacca, Bangladesh

Md. Azizur Rahman (Nimu), Scientific Officer, RCS Division, Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh

Md. Montezar Rahman, Scientific Officer, Pathology, Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh

Syed Manzoor Towheed, Extension Officer, Directorate of Land and Water Use, Bangladesh Water Development Board, 147, Sultan Building, Motijheel Com Area, Dacca-2, Bangladesh

Daw Myint Myint Cho, Deputy Asst. General Manager, Agricultural Research Institute, Yezin, Burma

U Kan Nyunt, Extension Township Manager, Agricultural Corporation, Kyaukpadaung, Burma

U Kyaw, Farm Manager, Agricultural Corporation, Heho Seed Farm, Kalaw, Burma

Saeful Bachrein, Agronomy/Physiology Staff, Maros Research Institute for Agriculture, P.O. Box. 173, Ujung Pandang, South Sulawesi, Indonesia

Unang Gunara Kartasasmita, Staff, Cropping Systems Sub-dept., Agronomy Department, CRIA, Jalan Merdeka 99, Bogor, Indonesia

Husni Malian, Staff, Cropping Systems Sub-dept., Agronomy Department, CRIA, Jalan Merdeka 99, Bogor, Indonesia

Mangarerak Manurung, Extension Worker, Dinas Pertanian Rakyat, TK II Gowa, Sulawesi, Selatan, Indonesia

Moegono, Extension Worker, Agriculture Extension Services, KBS Tegalgondo, Kartosuro Surakarta, Central Java, Indonesia

Imam Prasadja, Staff, Entomology Department, CRIA, Jalan Merdeka 99, Bogor, Indonesia

Widodo Purwosubagyo, Extension Worker, Agriculture Extension Services, Jl. Sagan III/IV, Yogyakarta, Indonesia

Bonar Simbolon, Extension Worker, Agriculture Extension Services, Jl. Pejanggik 40, Mataram, Indonesia

Soeharmadi, Staff, Post-Harvest Department, CRIA, Jalan Merdeka 99, Bogor, Indonesia

Nyoman Sudiska, Extension Worker, Agriculture Extension Services, Jl. Gianyar, P.O. Box 38, Denpasar, Bali, Indonesia

Herman Supriadi, Staff, Agronomy Department, CRIA, Jalan Merdeka 99, Bogor, Indonesia

Abdul Jalil Zakaria, Extension Worker, Agriculture Extension Services, Jln. A. Yani No. 19, Banda Aceh, Indonesia

Razali Bin A. Rahman, Research Assistant, Malaysian Agriculture Research and Development Institute, Batu Berendam, Malacca, West Malaysia

Ibrahim Bin Omar, Research Assistant, Malaysian Agriculture Research and Development Institute, Bumbong Lina, Kelapa Batas, Malaysia

Ahmad Azamir Bin Abdul Wahab, Malaysian Agriculture Research and Development Institute, Hilir Perak, Hutan Melintang, Perak, Malaysia

Dil Bahadur Chand, Asst. Agriculture Dev. Officer, Agriculture Development Office, Mahendra Nagar, Kanchanpur, Nepal

Hem Sagar Gautam, Asst. Agriculture Dev. Officer, Regional Directorate of Agriculture, Nepalgunj, Nepal

Ramesh Lal Karna, Asst. Agriculture Dev. Officer, Agriculture Development Office, Dhulikhel, Kavre, Nepal

Federico F. Bongolan, Agronomist I (Research Team Leader), BPI-PADAP-PCARR Research Farm, Pagadian City, Philippines

Ernesto R. dela Cruz, Agronomist I, BRCES/BPI, San Agustin, Pili, Camarines Sur, Philippines

Hilario C. dela Cruz, Agronomist III, Maligaya Rice Research and Training Center, Muñoz, Nueva Ecija, Philippines

Celso L. dela Cueva, Agricultural Program Coordinator II, National Food and Agriculture Council (NFAC), Ministry of Agriculture, Diliman, Quezon City, Philippines

Ricardo D. Ona, Agronomist I, Bureau of Plant Industry, San Andres, Malate, Manila, Philippines

Namhyun Song, Junior Researcher, Gyeonggi-Provincial Office of Rural Development, Suweon, Korea

Morawakage Saranapala Perera, Research Assistant, Agricultural Research Station, Maha Illupallama, Sri Lanka

Alvainar Selbarajah, Agricultural Experimental Officer, Department of Agriculture, Mannar, Sri Lanka

Sompong Aksornkoae, Provincial Subject Matter Specialist, Office of Provincial Agricultural Officer, Pattani, Thailand

Hatsachai Boonjung, Technical Officer, Rice Division, Department of Agriculture, Bangkhen, Bangkok 9, Thailand

Kanay Boontop, Research Assistant, Faculty of Agriculture, Khonkaen University, Khonkaen, Thailand

Pairat Duangpiboon, Applied Research Assistant, Technical Division, Department of Agriculture, Bangkok, Thailand

Nikom Poputtanachai, Research Assistant, KU-IDRC, Faculty of Agriculture, Kasetsart University, Bangkok, Thailand

Rewat Promla, Provincial Subject Matter Specialist, Office of Provincial Agricultural Officer, Sisaket Province, Thailand

Danai Taipanich, Agricultural Technician, Division of Agricultural Economics, Ministry of Agriculture and Cooperative, Bangkok 2, Thailand

Suthep Wasinarat, Provincial Subject Matter Specialist, Office of Provincial Agricultural Officer, Lopburi, Thailand

GENETIC EVALUATION AND UTILIZATION (GEU) TRAINING

Md. J. U. Chowdhury, Scientific Officer, Breeding Division, BRRI, Sagardi, Barisal, Bangladesh

Md. Mostak Chowdhury, Scientific Officer, Entomology Division, Bangladesh Rice Research Institute, Joydebpur, Dacca, Bangladesh

Md. Anwar Hossain, Scientific Officer, Plant Pathology, BRRI, Joydebpur, Bangladesh

Md. Rafiqul Islam, Scientific Officer, Breeding Division, BRRI, Joydebpur, Bangladesh

A.W. Julfiquar, Scientific Officer, Breeding Division, BRRI, Joydebpur, Bangladesh

Kamal Uddin Ahmed, Scientific Officer, Breeding

Division, BRRI, Sonagazi Sub-station, Noakhali, Bangladesh

Habib Abul Quayyum, Scientific Officer, Plant Physiology Division, BRRI, Joydebpur, Bangladesh

Arun Saha Kumar, Scientific Officer, BRRI, Joydebpur, Bangladesh

Nitya Ranjan Sharma, Scientific Officer, Plant Pathology Division, BRRI, Dacca, Bangladesh

Usman Ghani, Scientific Officer, Breeding Division, BRRI, Sub-station, Kazla, Rajshahi, Bangladesh

Ramesh Chandra Dani, Scientist S_1 (Entomology), CRRI, Cuttack, Orissa, India

Amulya Kumar Ghosh, Scientist S_2 (Plant Breeding), ICAR Research Complex for NEH Region, Tripura Centre, P.O. Lembucherra, Tripura, PIN-799210, India

Rajendra K. Nigam, Scientist S_1 (Agronomy), CRRI, Cuttack -6, Orrisa, India

Balabhadra Padi, Scientist S_1 (Pathology), CRRI, Cuttack -6, Orissa, India

Kameshwari Prasad, Scientist S_1, CRRI, Cuttack 75300, Orissa, India

Rabindra Nath Verma, Scientist S_2 (Plant Pathology), ICAR Res. Complex for NEH Region, Manipur Centre, Imphal, Manipur, India

M. Anwari, Technical Staff, CRIA, East Java, Indonesia

Amir Basyir, P.O. Box 66, Kendalpayak, Malang, Indonesia

Zandry Hamzah, Breeding Department, CRIA, Padang, Indonesia

M. Zain Hamijaya, Staff Member (Pest and Diseases Division), CRIA, Banjarmasin, South Kalimantan, Indonesia

Djanalus Janzibar, Staff Member, Plant Agronomy Division, CRIA, Banjarmasin, South Kalimantan, Indonesia

Bambang Kustianto, Assistant Breeder, CRIA, Bogor, Indonesia

Farid Nocktah, Staff Member (Plant Breeding Division), CRIA, Banjarmasin, South Kalimantan, Indonesia

Peonarto Slamet, Technical Staff, CRIA, East Java, Indonesia

Dominguez O. Morales, Agricultural Engineer (Agro-Chemist), Edificio No. 23, Apto. D-7, Vado del Yeso, Bayamo, Cuba

Mancebo F.R. Sanzo, Agricultural Engineer (Agro-Chemist), Edificio No. 3, Apartamento No. 3, Apto. Roman, S. Stus., Cuba

Latifah Ahmad, Research Officer (Breeding Section), MARDI, Bumbong Lima, Kepala Batas, Seberang, Prai, West Malaysia, Malaysia

Hadzim Khalid, Research Asst. (Breeding Section), Rice Research Centre, MARDI, Bumbong Lima, Kepala Batas, Penang, Malaysia

Mohd. Noor Nik Salleh, Research Officer (Rice Entomology), MARDI, Kubang Keranti, P.O. Box 154, Kota Bharu, Kelantan, Malaysia

Rishi R. Sharma, Assistant Plant Pathologist, NRIP, Parwanipur, Nepal

Krishna Prasad Dhungana, Agronomist (Kankai Agric. Station), Shivganj, Jhapa, Nepal

Malik Fazal Ilahi, Rice Botanist, Department of Agriculture (Research Wing), Pakistan

Mohammad Hashim Khan, Asst. Agronomist, Rice, Dept. of Agriculture (Research Wing), Pakistan

Rufino T. Dumlan, Agronomist I/Research Asst., Banaue, Ifugao, Philippines

Raul J. Lara, Agronomist, Ilagan Experiment Station, Ilagan, Isabela, Philippines

Fei Hwai-Lin, Agronomist, Specialist, Academy of Agric. Sciences, Chekiang Province, People's Republic of China

Chang Hsu, Entomologist, Dean of Entomological Research Room, Academy of Agricultural Sciences, Chekiang Province, People's Republic of China

Chuke Ken-chang, Plant Pathologist, Specialist, Plant Protection Research Institute, Academy of Agricultural Sciences, Chekiang Province, People's Republic of China

Li Tai-Qui, Research Officer, Rice Physiology, Chinese Academy of Agricultural Sciences, Peking, People's Republic of China

Liu Jin-Ming, Research Officer (Rice Breeder) Hunan Academy of Agric. Sciences, Changsha, People's Republic of China

Li Xuan-Keng, Research Officer (Rice Pathologist), Hunan Academy of Agricultural Science, Changsha, People's Republic of China

Min Shao-kai, Rice Breeder, Vice Director, Rice Research Institute and Dean of Rice Breeding Research Room, Academy of Agricultural Sciences, Chekiang Province, People's Republic of China

Xiao He-Sheng, Research Officer (Rice Gene-

tics), Chinese Academy of Agricultural Sciences, Peking, People's Republic of China

Polwattedurage Hemadasa, Laboratory Assistant, Paddy Research Station, Bombuwela, Kalutara, Sri Lanka

K.D.S.M. Joseph, Research Officer (Agronomy), Department of Agriculture, Field Trial Division, Botanic Gardens, Peradeniya, Sri Lanka

Keelitha Jayaweera, Experimental Officer (Agronomy), Department of Agriculture, Rice Research Station, Bentoia, Sri Lanka

J. R. Pooramanipillai, Research Officer (Agronomy), Department of Agriculture, Experimental Station, Mabalana Govt. Farm, Kamburubitiya, Sri Lanka

F. M. G. Raphael, Field Trials Division, Botanical Gardens, Peradeniya, Sri Lanka

Rajeswary Srilingam, Agricultural Experimental Officer, Paddy Research Station, Paranthan, Sri Lanka

A.D.S. De Zoysa, Research Officer (Plant Breeding), Department of Agriculture, Rice Research Station, Bombuwela, Kalutara, Sri Lanka

Wichai Khumlekhasing, Second Grade Officer (Rice Breeder), Klong Luang Rice Experiment Station, Patumthani, Thailand

Pisarn Konghakote, Junior Researcher (Rice Breeding), Khonkaen Rice Experiment Station, Khonkaen, Thailand

Somnuk Noonim, Rice Breeder, Kuan Gut Rice Experiment Station, Phattalung, Thailand

Banloo Ruangsook, First Grade Officer (Rice Breeder), Sakonnakorn Rice Experiment Station, Sakonnakorn, Thailand

Supachai Tangchoopong, Junior Researcher (Rice Breeding), Khonkaen Rice Experiment Station, Khonkaen, Thailand

Ashura N. Kihupi, Rice Breeder, Faculty of Agriculture, Forestry and Veterinary Science, P.O. Box 643, Morogoro, Tanzania

Muzafer Kiziltan, Agricultural Research Institute, Edirne, Turkey

TWO-WEEK AGRICULTURAL ENGINEERING TRAINING COURSE

Saba Aba Noor Mohd. Akhtarus, Engineer, Bengal River Service Bhd. Ltd., 72, Serajuddowlla Road, Narayanganj Dist., Dacca, Bangladesh

John Kennan, Agricultural Engineer, Lutherman World Federation, Rangpur-Dinajpur Rehabilitation Service, Dacca, Bangladesh

Gnanendar Baggu, Manufacturing Superintendent, Water Development Society, Hyderabad, India

Neeraj Bhatnagar, Development Engineer, Suri Research Foundation, New Delhi, India

Ravish Chandra Maheshwari, Process Engineer, Implements Testing and Improvement Centre, Government of West Bengal, Directorate of Agriculture, Kalna Road, Budwar, India

Kumar Dutta Rajinder, Manager, Union Tractor Workshop, New Delhi, India

Vinod Kumar Sharma, Research Engineer, Dept. of Farm Power and Machinery, Punjab Agricultural University, Ludhiana, Punjab, India

Om Prakasah Singhal, Agricultural Engineer, ICRISAT, Hyderabad, India

Handaka, Staff Member, Directorate of Food Crop Production Development, Pasarminggu, Jakarta, Indonesia

Bob Syakrani, Head, Mechanizations Sections, Agricultural Extension Service, Padang, Indonesia

Wiyanto, Staff, Farm Machinery, Directorate of Food Crop Production Development, Jl. Ragunan Pasarminggu, Jakarta Selatan, Indonesia

Moon Gyeh-Song, Engineer, Dae Dong Industrial Co., Jinju Korea

Mohd. Dan bin Mat Palii, Malaysian Agricultural Research and Development Institute, Bag Berkunci No. 202, Universiti Pertanian Pos, Serdang, Selangor, Malaysia

Khalid Hussain Uqaili, Research Assistant, IRRI-PAK Agr Machinery Program, Islamabad, Pakistan

Saleem Haider Zaidi, Agricultural Engineer, IRRI-PAK Agr. Machinery Program, Rawalpindi, Pakistan

Guan Shij, c/o Foreign Affairs Bureau, Ministry of Agricultural Machinery, Peking, People's Republic of China

Chen Shuguang, c/o Foreign Affairs Bureau, Ministry of Agricultural Machinery, Peking, People's Republic of China

Ernesto Colmenares, Jr., Plant Manager, Springfield Industries, Davao, Philippines

Kriengsak Sirichaimanus, Senior Research Assistant, IRRI-Thai Small Farm Machinery Project,

Bangkok, Thailand
Long Srichan, Manager, J. Jaidee Panich, 217 Mahajak Road, Chachoengsao, Thailand

U Mya Than, Agricultural Mechanization Department, Ministry of Agriculture and Forest, Rangoon, Burma

International activities

INTERNATIONAL PROGRAMS

Outreach activities in 1979 covered Asia, Africa, and South America. More than 600 persons participated in international meetings sponsored or co-sponsored by IRRI.

Africa. An IRRI liaison scientist for the African region, appointed late in 1978, moved to his headquarters at the International Institute of Tropical Agriculture (IITA) in Nigeria in July 1979.

In 1979, 98 International Rice Testing Program (IRTP) nurseries were dispatched to the West African Rice Development Association (WARDA), IITA, and the National Cereals Research Institute in Nigeria for distribution and testing in West Africa. However, only 17 nurseries could be planted during the off-season (October 1979).

Bangladesh. A six-man team of IRRI scientists worked with various Bangladesh Rice Research Institute (BRRI) programs in 1979.

Deepwater rice. Nearly all breeding nurseries and trials were direct-seeded (transplanting was done in previous years) so that the materials grew under stresses and cultivation practices comparable to farmers' conditions. In cooperation with scientists from other BRRI research divisions, the breeding materials were screened for specific stresses.

- Plant physiologists screened 90 breeding lines for drought resistance. Preliminary results indicated that BKN6986-81-5, BKN6986-147-2, CNL-319, Jalay, Begumkorpi, BR306-B-3-1, BR311-B-5-4, and BR232-2B-3-5 were most resistant.
- Entomologists screened deepwater rices for stem borer resistance but failed to identify any resistant material.
- Ninety-three breeding lines were screened for resistance to the ufra nematode but little resistance was observed.
- The rice technology division evaluated 70 advanced lines and varieties for 16 grain quality characters.

Varieties for tidal submergence. Fourteen advanced lines were selected from 80 crosses between local photoperiod-sensitive varieties tolerant of tidal submergence and varieties with modern plant type and high yield potential. The selections were grown in low-level lands during late aman. BR11-461-1, which yielded about 3.7 t/ha, was most promising.

Work was done on rices for use during boro in places where flash floods often combine with tidal submergence. Chaita Boro was used as the local parent in crosses with improved varieties suitable for the region.

Farmers' varietal observational trials. BRRI researchers joined extension workers in developing plans for a variety trial program for the 1979-80 winter. Kits with seeds of six recommended varieties, a detailed plan for the trial, and a suggested trial management system were prepared.

Seed kits of BR8 and BR9, new boro-aus varieties released in 1978, were distributed to all district extension officers and interested volunteer agencies for distribution to farmers willing to produce seeds for local sale.

Sulfur and zinc deficiency investigations. Although yield increases from the addition of gypsum to soils were obtained in 1978 on research stations and in farmers' fields, relatively few plant samples were found deficient in sulfur in 1979 and responses to gypsum were not uniformly positive. During several field tours, BRRI scientists observed zinc-deficiency symptoms on rice plants at many places. A survey was started to determine the extent of the problem, and authorities concerned with fertilizer imports were alerted to secure supplies of zinc.

Crop management. Where the weed population is minimal in a harvested crop, no yield benefit is obtained from tillage between aus and transplanted aman or the boro and aus crops. Studies in 1979 show that cutting the crop near the ground and keeping the soil moist allowed transplanting on harvest day. This avoided land preparation costs and delays in establishing the crop.

Machinery development. IRRI-designed threshers were produced by Comilla Cooperative Karkhana Ltd. and Kumudini Welfare Trust. The Bangladesh Machinery Tools Factory produced and tested an IRRI-designed power tiller with steering clutches.

Irrigation water management. Benefits from supplemental irrigation in transplanted aman after the monsoon rains have stopped were studied. Dur-

ing 1979, 99 mm of supplemental irrigation produced a 43% increase in yield and continuous flooding required 335 mm of supplemental irrigation to produce a 52% increase above yields from rainfed plots.

Data collected in tube well studies outside BRRI show average conveyance losses of 18% for a 60-m section of earthen channel and as much as 37% for a 120-m-long channel.

Cropping systems. Cropping systems work in 1979 was concentrated at Bogra, Laskarchala, and Salna, and at BRRI. Attention was also given to the development of methodology for use in the network involving other agencies.The premonsoon drought reduced cropping intensity from 185 to 172% in the rainfed site at Bogra. The study of 10 whole farms at Bogra highlighted the fragmentation of landholdings.

Cropping intensity was less affected at the Laskarchala and Salna sites where irrigation was available. Yields in 1979 were similar to those in 1978, but cash returns were greater because of higher market prices.

Burma. A cooperative project in Burma provided for a plant breeder, an agricultural engineer, and a cropping systems agronomist. Only the plant breeder was on duty for all of 1979, the engineer joined September 1979, and the cropping systems agronomist will come in early 1980. Work to date has entirely been on varietal improvement.

From the dry-season observational nursery of more than 200 entries, more than 50% were selected for further observation or performance testing. From about 100 entries in the performance test, 40 entries were selected for further tests. Six of the most promising early-maturing lines yielded 10-80% higher than the check (C4-63).

About 80 entries from the wet-season observational nursery were selected for further observation or performance tests.

India. Major collaborative activities between India and IRRI continued in 1979.

Collection and preservation of germplasm. The National Bureau of Plant Genetic Resources made funds available for a coordinated collection of rice varieties in several parts of India in accordance with the pattern of geographic priorities agreed upon with IRRI. The following collections were sent to IRRI:

- 773 samples from the Central Rice Research Institute, Cuttack;
- 226 samples from the Rice Research Station, Faizabad, Uttar Pradesh;
- 24 samples from the Rice Research Station, Moncompu, Kerala;
- 497 samples from the University of Udaipur, Rajasthan; and
- 15 samples from the Rice Research Station, Nawagam.

Collaborative research. Collaborative research on resistance to gall midge, brown planthopper, viruses; drought resistance; high and low temperature tolerance; and adverse soils continued. A new project on resistance to blast was initiated.

Industrial extension. Extensive help to small industrialists to produce IRRI-designed machines continued. Brief visits were made by IRRI staff and on-the-spot assistance came from groups in India including the Suri Research Foundation; G.B. Pant Agricultural University; Indian Institute of Technology, Kharagpur; and Tamil Nadu Agricultural University, Coimbatore.

Exchange of scientists. Twenty-two IRRI scientists made a total of 31 visits to India. The IRRI scientists participated in the annual All India Rice Research Workshop at Tamil Nadu Agricultural University and the Indian Council of Agricultural Research jubilee celebration at Delhi. Sixty-seven scientists from India visited IRRI during 1979 to participate in IRRI-sponsored conferences, workshops, and symposia or in training activities.

Indonesia. An 11-man team of IRRI scientists worked in various programs with the Central Research Institute for Agriculture during 1979.

Genetic evaluation and utilization. Significant progress was made in 1979 toward the development of new rice varieties with eating qualities preferred by Indonesians plus resistance to biotype 2 of the brown planthopper. At least two lines appeared to be potential varieties.

Field screening for brown planthopper resistance successfully carried out at Mojosari (East Java) during the 1978-79 wet season strengthened the BPH screening program.

Other screening techniques were also strengthened. They included those for brown planthopper biotype 2, green leafhopper, and gall midge. Improvement of the rice grain quality laboratory was started.

The acceptance of early-maturing rice varieties

was clearly demonstrated in 1979 as the use of IR36 spread rapidly throughout Indonesia. In many instances an extra rice crop was produced by using IR36.

The tungro screening nursery at Lanrang, South Sulawesi, continued to be an important field laboratory. An increased effort was made to utilize the ragged stunt-resistant lines identified at Lanrang. The possibility of better neck blast control for dryland rice in the transmigration areas of Sumatra and elsewhere was given added attention. The South Korean blast research program was monitored closely for information on principles of control that could be of practical use in Indonesia.

Cropping systems. Cropping systems research in Bogor has scientists doing research in West Java, Lampung, South Sumatra, Kalimantan, Madura, and Timor. Research in Maros, South Sulawesi, is primarily on the island of Sulawesi.

The significant accomplishments of the Bogor-based program follow:

- Technology and cropping patterns for dryland agriculture developed on Ultisols were extensively tested in southern Sumatra. The technology tested in South Kalimantan, Southeast Sulawesi, and Java was found applicable.
- Intensification of crop production on irrigated and partially irrigated land was successfully demonstrated in Indramayu, West Java. Intensification was through the introduction of an extra crop into the farmers' existing cropping pattern.

Most of the research done by the Maros group related to intercropping studies to explore the possibility of increasing cropping intensity in irrigated or rainfed wetland areas. The studies established that increased crop production was possible through increasing cropping intensity

Adverse soils. The soils research program, based in Maros, worked on identification of limiting elements in major soil classes in South Sulawesi and other parts of East Indonesia. Five of 12 sites showed both nitrogen and phosphorus deficiencies; in the rest, only nitrogen was the limiting factor. Of the five sites deficient in phosphorus, two were so deficient that there was practically no yield when phosphorus was not applied. One site appeared to be slightly deficient in zinc and sulfur.

Economics. The economics research program consisted of:

- Evaluation of the socioeconomic potential of technology before release to farmers. Work was done on demonstrating a methodology for economic evaluation of experimental results that is particularly applicable to component technology trials.
- Evaluation of the constraints to the successful adoption of technology that has been released.
- Evaluation of the socioeconomic consequences of a technology.
- Development of survey research techniques. Progress was made in developing and implementing data collection techniques and an analytical framework compatible with existing computational and staff resources.

Diseases and insects. One of the most significant contributions of the pathology program at Maros was the development of an exceptionally good field laboratory at Lanrang, South Sulawesi.

Gall midge is an important rice insect pest in Java. About 60 ha for seed production of 4 new varieties was almost totally destroyed by gall midge at Sukamandi in early 1979. In screening tests, CR189-4, Obs. 677, 75-159, Leasung 152, ETB 10, and CR95-jr-46-1 were highly resistant.

The population dynamics of the brown planthopper was studied using several methods of determining population density.

Agricultural engineering. During the year an existing building was renovated to provide offices, a drafting room, and a shop for the engineering project. These were used in modifying prototypes from IRRI to suit local conditions.

Extensive field extension in cooperation with agencies of the provincial government continued in West Sumatra. Two local companies manufactured one power tiller and six portable threshers. Kalimantan and Sulawesi indicated interest in participating in a similar program.

Communication. Short-term communication consultancies assisted in the development of the CRIA Office of Research Information Dissemination. A detailed proposal for the establishment of a CRIA dissemination office was submitted to the CRIA administration and presented to the entire CRIA staff through a formal seminar. A CRIA brochure was developed by the staff.

Latin America. The main program for the Latin American region is the International Rice Testing Program (IRTP). In Cuba IR1529-430-3, included in the Upland Yield Nursery for Latin America, was released to farmers as IR1529. The same line was in regional trials and seed multiplications in Santa Cruz, Bolivia, as Saavedra V-5.

Twelve 1979 IRRI nurseries were planted at Centro Internacional de Agricultura Tropical (CIAT) for evaluation, selection, and seed increase.

A monitoring tour to northern South America covered rice research activities of national programs and evaluated entries in IRTP nurseries in Ecuador, Colombia, Venezuela, Guyana, and Surinam.

A third conference of the IRTP for Latin America, with emphasis on a blast workshop, was organized at CIAT 30 May-2 June 1979. Fifty-nine scientists from national programs and 14 from national and international institutions participated.

Malaysia. Discussions with top-level administrators of the Malaysian Agricultural Research and Development Institute (MARDI) and other agencies related to Malaysia's participation in IRRI's training programs.

Pakistan. Three IRRI scientists worked in Pakistan during 1979.

Sarian Jo 77 program (Sind). The Sarian Jo 77 program is the second phase of the collaborative rice research project between the Pakistan Agricultural Research Council and IRRI. The program was designed to demonstrate, on a whole-farm basis, the new package of technology developed from applied research trials during the first phase.

Sarian Jo 77 was implemented through the cooperative efforts of different government agencies. The goal was to increase rice yields in the project area to 7 t/ha.

The farmers in the program area responded well; many adopted in full or in part the major components of the package of technology. The extension workers demonstrated they can be effective change agents when given adequate support and encouragement.

The yield of 12 participating villages doubled to an average 6.5 t/ha. Most of the farmers who used the full package of technology obtained yields higher than 7 t/ha.

Agricultural machinery program. The Pakistan agricultural machinery program started with the premise that small machines would be more desirable for Pakistan. Three years of experience, however, have indicated that relatively larger and more powerful equipment is in greater demand.

Philippines. Since 1972 an IRRI crop production specialist has worked with the Philippine Masagana 99 rice production program. During 1979 the transfer of modern production technology through agricultural extension was emphasized.

- The use of 5 kg zinc sulfate/ha on irrigated rice fields increased from 50,000 ha in 1978 to 200,000 ha in 1979.
- With results from 47 farm trials in 22 provinces, the Masagana 99 management committee recommended the use of soil-incorporated granular carbofuran at 5.5 kg active ingredient/ha before transplanting to control insects, especially rice whorl maggots and stem borers.
- Shortening the time the rice crop is in the field by transplanting older seedlings was successfully evaluated on irrigated and on rainfed wetland rice farms.
- The Bureau of Soils implemented 100 sulfur-screening, applied-research farm trials using IR26 on irrigated lands.
- Seven hundred and fifty extension farm trials of an innovative method of partially soil-incorporating broadcast topdressed nitrogen and a second application of granular carbofuran were started during the 1979 dry season. Nitrogen was incorporated by passing a rotary weeder in a paddy with water impounded.
- The Bureau of Agricultural Extension started a semimonthly 4-page subject matter newsletter entitled *The rice specialist*. Thirteen issues in 1979 went to 180 extension rice specialists working with 6,000 rice technologists in 72 provinces.

Sri Lanka. Four IRRI scientists worked in the Government of Sri Lanka/IRRI cooperative rice project during 1979.

Rice breeding. About 80% of the rice area in Sri Lanka is planted to improved varieties. In 1979 the government released three varieties — Bg 276-5, a 90-day variety highly resistant to gall midge, blast, and iron toxicity; Bg 400-1, a 135-day variety with gall midge resistance; and Bw100, a 120-day variety with moderate levels of

resistance to blast, gall midge, and bronzing.

Brown planthopper-resistant breeding materials were tested in the national coordinated rice variety trials. These materials had Ptb 33 as their source of resistance. Selections with Suduru Samba, Sudu Heenati, and ARC 6650 were also evaluated at Batalagoda.

Crosses that showed submergence tolerance (8 days) included Karamana/Bg276-3; Deverederri/Bg276-3, and Molligoda/Bg400-1.

Fifteen photoperiod-sensitive varieties were sent to IRRI for processing in the rapid generation advance system.

A rice consumer preference survey was organized for Sri Lanka to clarify preference for rice pericarp color and parboiled or raw rice.

Cropping systems. Cropping systems research was at:

- Walagambahuwa — dry zone, minor tank-based agriculture;
- Mahaweli — dry zone, fully irrigated agriculture;
- Paranthan — dry zone, rainfed agriculture;
- Katupota — intermediate zone, rainfed agriculture; and
- Bandarawela — intermediate zone, rainfed or stream-fed irrigated agriculture.

In Walagambahuwa the cropping pattern developed provides for early tillage after the first rains so that a 90- to 105-day rice variety could be planted in October with limited supplemental irrigation from a tank. The tank water was used to grow a crop of dry-season rice or a vegetable crop depending on the amount of stored water. Extension of results from Walagambahuwa to farmers started.

Cropping systems work in Mahaweli was with the Mahaweli River project and an extensive water distribution system. Benchmark data in resource use and infrastructure patterns were obtained.

In Paranthan, work concentrated on increasing yields of the maha crop (rainy season, October-December) through better-adapted varieties, improved weed control, and adequate and timely use of fertilizers. Possibilities of a yala crop (dry season) grown on the residual moisture plus the limited yala rainfall were tested.

At the Katupota site rice and coconut are the main crops, with the rice lands between the higher coconut lands. The paddy tract consists of three land elements — a crest (adjacent to the coconut lands), a slope, and a valley bottom. Cropping patterns tested were rice-upland crop on the crest, and rice-rice on the slope and valley bottom.

The cropping systems activities at Bandarawela investigated ways of increasing cropping intensity to a three-crop sequence, such as rice-vegetable-vegetable on irrigated lands.

Resource capability survey. A resource capability survey, designed to classify the rice lands of the wet and intermediate zones into land systems and land elements having significance for rice production, was completed in Kandy, Kegalla, Matale, Kalutara, and Kurunegala districts. Work was in progress in Colombo district.

Thailand. Thailand began the 1979 dry-season crop with sufficient water to plant almost 500,000 ha of irrigated rice completely devoted to the semidwarf varieties.

Deepwater rice research. The government released two semidwarf lines — RD17 and RD19 — tolerant of water depths up to 1 m. RD17 is photoperiod insensitive; RD19 is photoperiod-sensitive and flowers in mid-November in the Bangkok area.

Small farm machinery program. Commercial production of the IRRI-designed axial-flow thresher exceeded 4,000 units. As a result of requests from various countries for information on a small locally made 4-wheel tractor, a unit was purchased from the assembly line of a dealer and tested with moldboard and disk plows. The improved buffalo plow, dryland seeder, manual transplanter, and paddy seeder received attention.

Other collaborative projects. Thai scientists continued to cooperate with IRRI scientists in implementing IRTP nurseries; International Network on Soil Fertility and Fertilizer Evaluation for Rice trials; and studies on azolla, grain quality of glutinous rice varieties, bacterial blight, brown planthopper, and gall midge biotypes. Continuous-rice-cropping experiments were established at Ubon, Rangsit, and Kuan Gut Rice Experiment Stations based on concepts developed at IRRI.

Table 1. Conferences, workshops, and symposia sponsored or cosponsored by IRRI in 1979.

	Date	Participants (no.)
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 Jan	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

Cooperation in cropping systems research and development of rice varieties for rainfed areas also continued.

INTERNATIONAL MEETINGS

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

Information resources, experimental farm, and service laboratories

LIBRARY AND DOCUMENTATION CENTER

Bibliographies. The 1978 Supplement to the *International Bibliography of Rice Research* was published in 1979. It contains 5,684 references to scientific rice literature, most of which appeared in journals in 1978. Its coverage is worldwide and the items of reference are classified according to subject matter. The supplement includes literature written in 24 languages and a list of 44 rice literature translations, mostly from Japanese to English. It has an author index and a manually produced keyword index.

Supplement 1977 to the *International Bibliography on Cropping Systems* was also published in 1979. It embraces worldwide published and unpublished technical reports produced in 1977 and deals with all aspects of cropping systems for food crops. The entries are classified according to subject; items within each subject category are arranged alphabetically. An author index and a manually produced keyword index are provided.

The 1979 supplement to *Theses and Dissertations on Rice Available in the Library of the International Rice Research Institute* was also produced in 1979. The supplement lists 104 titles, bringing the overall collection of theses and dissertations to a total of 887.

The International Bibliography on Azolla was also published. It consists of 671 classified items and has an author index and a keyword index.

All new bibliographies were sent to agricultural libraries and documentation centers of the rice-producing regions. Essentially, all the citations included are available at IRRI.

Reference and circulation. Within IRRI, the number of books and journals and other library materials borrowed during 1979 increased markedly. As in previous years, requests for copies of Japanese literature on genetics and breeding exceeded those for literature on all other aspects of rice culture. Requests for photocopies of papers on water management and irrigation were also received. Assistance in library organization and management, and in the selection and acquisition of agricultural materials was also sought. Requests for short specific-subject bibliographies, mostly from Bangladesh, India, Thailand, Indonesia, and Malaysia, increased notably.

Library holdings. The additional 3,365 monographs (books, pamphlets, and reprints) increased the overall monographic collection to 52,045. A total of 161 serial titles were added through subscriptions, exchanges, and some donations. Maps, translations, and microfilms were also added.

Other library activities. To keep the scientists informed of the latest publications on rice, routing of tables of contents of newly received journals was continued within IRRI and extended to the Bangladesh Rice Research Institute; the Lembaga Penelitian Pertanian Maros, Indonesia; the Central Research Institute for Agriculture, Sukamandi Branch, Indonesia; IRRI, Sri Lanka; and the West Africa Rice Development Association, Liberia.

The Library continued to purchase books for IRRI research scholars and other training participants.

OFFICE OF INFORMATION SERVICES

The Office of Information Services distributed about 36,000 copies of major publications during 1979, with 96% sent to addresses in developing nations. About 15,000 publications were distributed free, mostly to libraries.

Ten years after its release, *Field Problems of Tropical Rice* remains the most widely distributed IRRI publication. The second and the third most widely distributed in 1979 were *Rice: Soils, Water, Land and Statistical Procedures for Agricultural Research.*

Major publications. Major publications released in 1979 were:

- Report of a Rice Cold Tolerance Workshop
- Proceedings of the 1978 International Deepwater Rice Workshop
- Proceedings of the Rice Blast Workshop
- Interfaces between Agriculture, Nutrition, and Food Science

- A Farmer's Primer on Growing Rice
- Rainfed Lowland Rice
- Rice Improvement
- Proceedings of the Workshop on Chemical Aspects of Rice Grain Quality
- Brown Planthopper: Threat to Rice Production in Asia
- Farm-level Constraints to High Rice Yields in Asia: 1974-77
- Nitrogen and Rice
- Annual Report for 1978
- Research Highlights for 1978

Series publications. The *IRRI Reporter*, a quarterly newsletter describing IRRI's activities, was distributed to about 11,000 rice workers. Six issues of the *International Rice Research Newsletter* were published, plus the *Subject Index 1976-1978*.

Twenty-three titles in the IRRI Research Paper Series were published:

No. 23 Genetic interrelationships of improved rice varieties in Asia

No. 24 Barriers to efficient capital investment in Asian agriculture

No. 25 Barriers to increased rice production in eastern India

No. 26 Rainfed lowland rice as a research priority — an economist's view

No. 27 Rice leaf folder: Mass rearing and a proposal for screening for varietal resistance in the greenhouse

No. 28 Measuring the economic benefits of new technologies to small rice farmers

No. 29 An analysis of the labor-intensive continuous rice production systems at IRRI

No. 30 Biological constraints to farmers' rice yields in three Philippine provinces

No. 31 Changes in rice harvesting systems in Central Luzon and Laguna

No. 32 Variation in varietal reaction to rice tungro disease: Possible causes

No. 33 Determining superior cropping patterns for small farms in a dryland rice environment: Test of a methodology

No. 34 Evapotranspiration from rice fields

No. 35 Genetic analysis of traits related to grain characteristics and quality in two crosses of rice

No. 36 Aliwalas to rice garden: A case study of the intensification of rice farming in Camarines Sur, Philippines

No. 37 Denitrification loss of fertilizer nitrogen in paddy soils — its recognition and impact

No. 38 Farm mechanization, employment, and income in Nepal: Traditional and mechanized farming in Bara District

No. 39 Study on kresek (wilt) of the rice bacterial blight syndrome

No. 40 Implication of the international rice blast nursery data to the genetics of resistance

No. 41 Weather and climate data for Philippine rice research

No. 42. The effect of the new rice technology on family labor utilization in Laguna

No. 43 The contribution of varietal tolerance for problem soils to yield stability in rice

No. 44 IR42: A rice type for small farmers of South and Southeast Asia

No. 45 Germplasm bank information retrieval system

Research and training support. The Rice Production Training and Research Department and the Office of Information Services continued a program to develop a series of self-instructional slide-tape units on specific rice production problems and their solution. Each unit consists of a set of 60 to 80 colorslides on the problem, a prerecorded cassette tape, and a booklet.

Of the 62 units planned, 25 were completed in 1979. Sale of the units to national rice improvement training programs was initiated.

Computerization of the IRRI mailing system. A program to computerize the IRRI mailing system to allow specific publications to be directed to the users that most need that information was initiated.

Release of printing negatives. A procedure for providing duplicate printing negatives of selected IRRI publications to agricultural development

organizations or publishing companies in developing nations was developed.

Communication conference. The Conference on the *Communication responsibilities of the international agricultural research centers*, jointly sponsored by IRRI and the Agricultural Development Council, Inc., was held at IRRI 14-19 May 1979. The purpose of the conference was to review in detail the organization, purpose, and effectiveness of international center communication activities and, more important, to recommend what the centers could do to make their information programs more effective. A set of conference recommendations was published.

Training. OIS provided training for one information specialist from Indonesia in 1979 — IRRI's first venture into communication training. An IRRI senior editor spent 3 weeks working with the Research Dissemination Group, Central Research Institute of Agriculture, Indonesia — a follow-up to 2 previous IRRI consultancies. His purpose was to provide practical communication training to information staff and to identify personnel who could benefit from extended on-the-job training in OIS.

EXPERIMENTAL FARM

The Experimental Farm continued to supply all the labor needed by the research departments for land preparation, planting, weed and insect control, harvesting, and drying.

Relocation of people living on the new farm area started in 1979 and the areas vacated were converted to wetland rice fields, most of which were planted to rice. In 1979 the reservoirs in five research blocks were connected to the new lowland farm reservoir to allow the continuous supply of irrigation water from deep wells. Initial filling of the new site for the farm machinery shed was started.

A 162.4-ha area was prepared and planted to lowland rice. The main clients were Plant Breeding (69.74 ha), Agronomy (22.24 ha), and Entomology (20.17 ha). A total of 133.7 ha was plowed and harrowed, or rototilled, for upland crops. The main clients were Agronomy (32.2 ha), Multiple Cropping (31.8 ha), and Plant Breeding (23.58 ha).

Seed multiplication was a major function in 1979. Seven varieties or selections — C171-38, IR833-118-3, IR29, IR36, IR4570-83-3-3, IR13168-143-1, and IR9224-117-2-3-3-2 — were grown on 11.66 ha during the wet season. During the dry season, 8 varieties or selections — C171-36, UPLB Ri-2, BPI Ri-4, IR2863-38-1, IR36, MR6438, IR841, and C463G — were grown on 7.63 ha. IR2863-18-1 and IR36 were grown on 3 ha in a nearby barrio.

Fertilizer expenditure (159.8 t) was 2.5% higher than for 1978. The expenditure for insecticides was 20.8% lower than for 1978. There was no serious outbreak of tungro and other diseases on the farm. There was a slight decrease in the amount spent for herbicides.

Expenditures for contract labor were much higher than those for 1978. The amount paid to bird boys, contract operators, and contract laborers increased.

The sale of farm produce increased 120.8%. About US$27,000 was derived from the sale of rice seeds, milled rice, rice for milling, glutinous rice, and other crops. Nearly half of the farm income came from the sale of rice seeds.

Rat damage to rice plants and other crops was a big problem throughout 1979. Rat holes were dug out instead of being dusted with cyanogas, the manufacture of which has been banned. The digging killed a total of 31,305 rats; the electric fence, 46,653.

ANALYTICAL SERVICE LABORATORY AND PESTICIDE RESIDUE LABORATORY

Analytical Service Laboratory. The transfer of the Analytical Service Laboratory (ASL) to the former Chemical Storage Building in 1979 consolidated all analytical facilities in one building. The ASL assumed administration of the sample-preparation rooms and started accepting fresh samples for drying and grinding. A refresher course on sampling was conducted by the Principal Soil Chemist and a visiting agronomist. Analyses for 1979 are summarized in Table 1. The colorimetric ammonia and urea determinations in floodwater were automated, and more than 2,000 analyses for each compound were made.

Pesticide Residue Laboratory. New quarters for the Pesticide Residue Laboratory (PRL) were constructed in the F.F. Hill Laboratory Building and will be occupied early in 1980. A pesticide specialist from the Tropical Products Institute,

Table 1. Summary of analyses rendered by the Analytical Service Laboratory (ASL), IRRI, 1979.

Property analyzed	Determinations (no.)	
	Plant	Soil
Total nitrogen or crude protein	19,729	5,665
Total elements		
Phosphorus	4,029	1,536
Potassium	3,016	1,151
Zinc	3,040	1,445
Iron	1,523	346
Manganese	955	61
Magnesium	607	180
Calcium	639	10
Copper	345	48
Sodium	5	–
Cadmium	–	2
Lead	–	2
pH	–	4,458
Electrical conductivity	–	1,671
Exchangeable cations		
Sodium	–	1,994
Potassium	–	3,783
Magnesium	–	2,104
Calcium	–	2,213
Cation exchange capacity	–	3,014
Available phosphorus	–	4,935
Available zinc	–	1,854
Available potassium	–	1,747
Organic carbon	–	3,464
Particle size	–	1,057
Moisture	294	67
Urea N	–	2,024
NH_3 N	–	2,024
Total solids	–	14
Total	34,182	46,869
Total	81,051	
Samples (no.)	23,121	9,310
Sample preparation done by ASL	3,587	989

Table 2. Summary of complete and gas-liquid chromatographic (GLC) determinations by the Pesticide Residue Laboratory, IRRI, 1979.

Constituent analyzed	Determinations (no.)	
	Complete	GLC only
Carbofuran and its metabolites	958	–
Orthene	70	–
Lindane	12	–
Others	6[a]	436[a]
Total	1,046	436

[a]Dicarboxylic-acid and fatty-acid methyl esters (Chemistry), pheromones (Entomology), and formulations (Agricultural Economics and Experimental Farm).

London, advised on the organization of the PRL and trained PRL personnel. A full-time person in charge of PRL was assigned in July 1979. That development plus excellent maintenance of the gas chromatographs by the person-in-charge of the ASL during the first half of the year contributed to an increased output of the PRL in 1979 (Table 2).

Publications and seminars

PUBLICATIONS

Agricultural Economics

Barlow, C., S. Jayasuriya, V. Cordova, N. Roxas, L. Yambao, C. Bantilan, and C. Maranan. 1979. Measuring the economic benefits of new technologies to small rice farmers. IRRI Res. Pap. Ser. 28. 21 p.

Barker, R., and R. W. Herdt. 1979. Rainfed lowland rice as a research priority - an economist's view. IRRI Res. Pap. Ser. 26. 50 p.

Flinn, J. C. 1979. Agro-economic considerations in cassava intercropping research. Pages 87-101 *in* E. Weber, B. Nestel, and M. Campbell, eds. Intercropping with cassava. International Development Research Centre, Canada.

Garrity, D., H. G. Zandstra, and E. C. Price. 1979. Determining superior cropping patterns for small farms in a dryland environment: test of a methodology. IRRI Res. Pap. Ser. 33. 11 p.

Hayami,. Y., P. F. Moya, and L. M. Bambo. 1978. Labor utilization in a rice village. Philipp. Econ. J. 17(1)(2):244-258.

Hayami, Y., and A. Hafid. 1979. Rice harvesting and welfare in rural Java. Bull. Indones. Econ. Stud. 15(2):94-112.

Herdt, R. W. 1979. An overview of the constraints project results. Pages 395-411 *in* International Rice Research Institute. Farm-level constraints to high rice yields in Asia: 1974-77. Los Banos, Philippines.

Herdt, R. W. 1979. Rice and agriculture in the Philippines. Pages 163-171 *in* International Rice Research Institute. Farm-level constraints to high rice yields in Asia: 1974-77. Los Banos, Philippines.

Herdt, R. W., and Michael Dehn. 1978. Insurance for small farmers to encourage innovation. Bangladesh Inst. Dev. Stud. 6(2):191-200.

Huke, R. E. 1979. San Bartolome and the Green Revolution. Papers in Anthropology, University of Oklahoma, 19(2):39-58.

Kikuchi, M., V. Cordova, E. B. Marciano, and Y. Hayami. 1979. Changes in rice harvesting systems in Central Luzon and Laguna. IRRI Res. Pap. Ser. 31. 24 p.

Morooka, Y., P. Masicat, V. Cordova, and R. W. Herdt. 1979. Aliwalas to rice garden: a case study of the intensification of rice farming in Camarines Sur, Philippines. IRRI Res. Pap. Ser. 28. 23 p.

Morooka, Y., R. W. Herdt, and L. D. Haws. 1979. An analysis of the labor-intensive continuous rice production system at IRRI. IRRI Res. Pap. Ser. 29. 41 p.

Nangju, D., J. C. Flinn, and S. R. Singh. 1979. Use of host plant resistance and minimum insecticide application in cowpea insect control. Field Crops Netherlands 2(4).

Northcraft, C. A., and L. E. Small. 1979. Factors affecting land prices in a rural New Jersey county. J. Northeastern Agric. Econ. Counc. 8(2).

Price, E. C., and R. Barker. 1978. Time distribution of crop labor. Philipp. J. Econ. 17(1)(2): 224-243.

Smith, J., and F. Gascon. 1979. The effect of the new rice technology on family labor utilization in Laguna. IRRI Res. Pap. Ser. 42. 17 p.

Agricultural Engineering

Camacho, L., R. Manalabe, and B. Duff. 1979. Empirical and laboratory evaluation of village level rice milling systems. Pages 242-266 *in* Proceedings of workshop on grain postharvest technology. Jakarta, Indonesia.

Duff, B. 1979. Assessing the economic impact of agricultural mechanization and other engineering technologies. Philipp. Agric. Eng. J. 10(4): 21-27.

Duff, B. 1979. Evaluating the quantitative and qualitative employment effects of technological change in rice production. Pages 73-97 *in* International Labor Organization. Technology to improve working conditions in Asia. Geneva, Switzerland.

Duff, B. 1979. The potential for mechanization in small farm production systems. *In* Integrating crop and animal production to optimize resource utilization on small farms in developing countries. Rockefeller Foundation, New York.

Ebron, L., H. Takai, and B. Duff. 1979. Farm level paddy storage practices in the Philippines. Pages 365-400 *in* Proceedings of workshop on grain postharvest technology. Jakarta, Indonesia.

Habito, C., and B. Duff. 1979. A systems analysis of mechanized versus non-mechanized rice harvesting in the Philippines. Pages 60-91 *in* Proceedings of workshop on grain postharvest technology. Jakarta, Indonesia.

Kiamco, L., and J.A. McMennamy. 1979. Reflection of the energy requirements of small rice farmers. Agric. Mechanization Asia 10(2): 11-16.

Kuether, D.C., and B. Duff. 1977. Energy requirements for alternative rice production systems in the tropics. Tech. Pap. Ser. Society of Automotive Engineers, Warrendale, Pennsylvania.

McMennamy, J. A. 1979. Considerations for designing and developing agricultural machinery. Philipp.

Agric. Eng. J. 10(4):2-4.

McMennamy, J.A., and J.S. Policarpio. 1978. Development of a portable axial-flow thresher. Pages 170-173 *in* Proceedings of the International Grain and Forage Harvesting Conference by the American Society of Agricultural Engineers. Ames, Iowa.

Moss, C. J. 1979. Engineering design and development challenge for the benefit of small farmers. Paper presented at the Annual Convention of the Philippine Society of Agricultural Engineers. Ramada Hotel, Manila, Philippines. April 27.

Agronomy

Ahmed, Nizam U., and K. Moody. 1979. Tolerance of crops to butachlor and pendimethalin applied at different growth stages. Philipp. J. Weed Sci. 6:10-22.

Bolton, F. R., and S. K. De Datta. 1979. Dry soil mulching in tropical rice. Soil Sci. Plant Nutr. 25(2):173-181.

Chang, T. T., B. Somrith, and J. C. O'Toole. 1979. Potential for improving drought resistance in rainfed lowland rice. Pages 149-164 *in* International Rice Research Institute. Rainfed lowland rice: selected papers from the 1978 International Rice Research Conference. Los Banos, Philippines.

Civico, R. S. A., and K. Moody. 1979. The effect of the time and depth of submergence on growth and development of some weed species. Philipp. J. Weed Sci. 6:41-49.

De Datta, S. K., F. V. Garcia, A. K. Chatterjee, W. P. Abilay, Jr., J. M. Alcantara, B. S. Cia, and H. C. Jereza. 1979. Biological constraints to farmers' rice yields in three Philippine provinces. IRRI Res. Pap. Ser. 30. 69 p.

De Datta, S. K., A. K. Chatterjee, B. S. Cia, and P. B. Masicat. 1979. Constraints to high rice yields, Bicol, Philippines. Pages 235-263 *in* International Rice Research Institute. Farm-level constraints to high rice yields in Asia: 1974-77. Los Banos, Philippines.

De Datta, S. K., B. S. Cia, H. C. Jereza, and P. B. Masicat. 1979. Constraints to high rice yields, Iloilo, Philippines. Pages 265-286 *in* International Rice Research Institute. Constraints to high rice yields in Asia: 1974-77. Los Banos, Philippines.

De Datta, S. K., F. V. Garcia, W. P. Abilay, Jr., J. M. Alcantara, A. Mandac, and V. P. Marcia. 1979. Constraints to high rice yields, Nueva Ecija, Philippines. Pages 191-234 *in* International Rice Research Institute. Farm-level constraints to high rice yields in Asia: 1974-77. Los Banos, Philippines.

De Datta, S. K., R. A. Morris, and R. Barker. 1979. Land preparation and crop establishment for rainfed lowland rice. IRRI Res. Pap. Ser. 22. 34 p.

De Datta, S. K., and R. Barker. 1978. Land preparation of rice soils. Pages 623-648 *in* International Rice Research Institute. Soils and rice. Los Banos, Philippines.

De Datta, S. K., F. R. Bolton, and W. L. Lin. 1979. Prospects for using minimum zero tillage in tropical lowland rice. Weed Res. 19:9-15.

Evans, L. T., and S. K. De Datta. 1979. The relation between irradiance and grain yield of irrigated rice in the tropics, as influenced by cultivar, nitrogen fertilizer application and month of planting. Field Crops Res. 2(1):1-17.

Garcia, F. V., W. P. Abilay, Jr., J. M. Alcantara, and S. K. De Datta. 1978. Biological constraints to high rice yields in selected farmers' fields in Nueva Ecija, Philippines. Philipp. J. Crop. Sci. 3(4):207-214.

Gomez, K. A., R. W. Herdt, R. Barker, and S. K. De Datta. 1979. A methodology for identifying constraints to high rice yields on farmers' fields. Pages 27-47 *in* International Rice Research Institute. Farm-level constraints to high rice yields in Asia: 1974-77. Los Banos, Philippines.

Gotoh, K., T. T. Chang, J. C. O'Toole, R. Riley, and B. R. Murty. 1979. Crop adaptation. Pages 234-261 *in* J. Sneep and A. J. T. Hendriksen, eds. Plant breeding in perspective. Pudoc, Wageningen.

Mikkelsen, D. S., and S. K. De Datta. 1979. Ammonia volatilization from wetland rice soils. Pages 135-156 *in* International Rice Research Institute. Nitrogen and rice. Los Banos, Philippines.

Moody, K. 1979. Weed control in root crops in the tropics. Philipp. J. Weed Sci. 6:81-101.

Navarez, D. C., and K. Moody. 1979. Farmers' weed control practices in rainfed lowland rice growing areas in Manaoag, Pangasinan, Philippines. Philipp. J. Weed Sci. 6:55-68.

Navarez, D. C., L. L. Roa, and K. Moody. 1979. Weed control in wet-seeded rice grown under different moisture regimes. Philipp. J. Weed Sci. 6:23-31.

Nguu, N. V., and S. K. De Datta. 1979. Increasing efficiency of fertilizer nitrogen in wetland rice by manipulation of plant density and plant geometry. Field Crops Res. 2(1):19-34.

O'Toole, J. C., and T. T. Chang. 1979. Drought resistance in cereals: rice - a case study. Pages 373-406 *in* H. Mussell and R. C. Staples, eds. Stress physiology in crop plants. Wiley, New York.

O'Toole, J. C., R. T. Cruz, and J. N. Seiber. 1979. Epicuticular wax and cuticular resistance in rice. Physiol. Plant. 47:239-244.

O'Toole, J. C., R. T. Cruz, and T. N. Singh. 1979. Leaf rolling and transpiration. Plant Sci. Lett. 16:111-114.

Prasad, R., and S. K. De Datta. 1979. Increasing fertilizer nitrogen efficiency in wetland rice. Pages 465-484 *in* International Rice Research Institute.

Nitrogen and rice. Los Banos, Philippines.
Savant, N. K., and S. K. De Datta. 1979. An undisturbed core sampling and sectioning technique for wetland rice soil. Commun. Soil. Sci. Plant Anal. 10(4):775-783.
Savant, N. K., and S. K. De Datta. 1979. Nitrogen release patterns from deep placement sites of urea in a wetland rice soil. Soil Sci. Soc. Am. J. 43(1):-131-134.
Tomar, V. S., and J. C. O'Toole. 1979. Evapotranspiration from rice fields. IRRI Res. Pap. Ser. 34. 15 p.

Chemistry

Coffman, W. R., and B. O. Juliano. 1979. Seed protein improvement in rice. Pages 271-277 *in* International Atomic Energy Agency. Seed protein improvement in cereals and grain legumes, vol. II. Vienna.
Juliano, B. O. 1979. Amylose content in rice - a review. Pages 251-260 *in* International Rice Research Institute. Chemical aspects of rice grain quality. Los Banos, Philippines.
Juliano, B. O. 1979. The chemical basis of rice grain quality. Pages 69-90 *in* International Rice Research Institute. Chemical aspects of rice grain quality. Los Banos, Philippines.
Juliano, B. O. 1979. Starch and protein and eating quality of milled rice. NSDB (Natl. Sci. Dev. Board) Technol. J. 4(3):62-72.
Maningat, C. C., and B. O. Juliano. 1979. Properties of lintnerized starch granules from rices differing in amylose content and gelatinization temperature. Starke 31:5-10.
Paule, C. M., K. A. Gomez, B. O. Juliano, and W. R. Coffman. 1979. Variability in amylose content of rice. Il Riso 28:15-22.
Perez, C. M. 1979. Gel consistency and viscosity of rice. Pages 293-302 *in* International Rice Research Institute. Chemical aspects of rice grain quality. Los Banos, Philippines.
Perez, C. M., and B. O. Juliano. 1979. Indicators of eating quality for non-waxy rices. Food Chem. 4:185-195.
Perez, C. M., C. G. Pascual, and B. O. Juliano. 1979. Eating quality indicators for waxy rices. Food Chem. 4:179-184.
Resurreccion, A. P., B. O. Juliano, and Y. Tanaka. 1979. Nutrient content and distribution in milling fractions of rice grain. J. Sci. Food Agric. 30:475-481.
Roxas, B. V., C. Ll. Intengan, and B. O. Juliano. 1979. Protein quality of high-protein and low-protein milled rices in preschool children. J. Nutr. 109:832-839.
Yoshihara, T., K. Sogawa, M. D. Pathak, B. O. Juliano, and S. Sakamura. 1979. Soluble silicic acid as a sucking inhibitory substance in rice against the brown planthopper (Delphacidae, Homoptera). Entom. Exp. Appl. 26:314-322.

Entomology

Chapman, R. F., W. W. Page, and A. G. Cook. 1979. A study of population changes in the grasshopper *Zonocerus variegatus*, in Southern Nigeria. J. Anim. Ecol. 48:247-270.
Chapman, R. F., A. G. Cook, G. A. Mitchell, and W. W. Page. 1978. Wing dimorphism and flight in *Zonocerus variegatus* (L.) (Orthoptera: Pyrgomorphidae). Bull. Entomol. Res. 68:229-242.
Cook, A. G. 1979. The ultrastructure of some sensilla on the clypeolabrum of *Locusta migratoria* (L.) (Orthoptera: Acrididae). Acrida 8:47-62.
Cook, A. G., B. R. Critchley, U. Critchley, T. J. Perfect, A. Smith-Russell, and R. Yeadon. 1979. The effects of soil treatment with DDT on the biology of a cultivated forest soil in the sub-humid tropics. Pedobiologia 19:279-292.
Dyck, V. A., B. C. Misra, S. Alam, C. N. Chen, C. Y. Hsieh, and R. S. Rejesus. 1979. Ecology of the brown planthopper in the tropics. Pages 61-98 *in* International Rice Research Institute. Brown planthopper: threat to rice production in Asia. Los Banos, Philippines.
Dyck, V. A., and B. Thomas. 1979. The brown planthopper problem. Pages 3-17 *in* International Rice Research Institute. Brown planthopper: threat to rice production in Asia. Los Banos, Philippines.
Galileo, M. H. M., and E. A. Heinrichs. 1978. Avaliação dos danos causados as sementes da soja *(Glycine max* (L.) Merrill) por *Piezodorus guildinii* (Westwood, 1837) (Hemiptera: Pentatomidae) em diferentes niveis e epocas de infestação. An Soc. Entomol. Bras. 7:40-46.
Galileo, M. H. M., and E. A. Heinrichs. 1978. Avaliação dos danos causados aos legumes da soja *(Glycine max* (L.) (Merrill) por *Peizodorus guildinii* (Westwood, 1837) (Hemiptera: Pentatomidae), em diferentes niveis e epocas de infestação. An Soc. Entomol. Bras. 7:33-39.
Galileo, M. H. M., and E. A. Heinrichs. 1978. Avaliação dos danos causados por *Piezodorus guildinii* (Westwood, 1837) (Hemiptera: Pentatomidae), em diferentes niveis e epocas de infestação, na qualidade da semente da soja *(Glycine max* (L.) (Merrill). An. Soc. Entomol. Bras. 7:89-98.
Galileo, M. H. M, and E. A. Heinrichs. 1979. Danos causados a soja em diferentes niveis e epocas de infestação durante o crescimento. Pesqui. Agropecu. Bras., Brasilia 14:279-282.
Galileo, M. H. M., and E. A. Heinrichs. 1978. Efeito dos

danos causados por *Piezodorus guildinii* (Westwood, 1837) (Hemiptera: Pentatomidae), em diferentes niveis e epocas de infestação, no rendimento de graos de soja (*Glycine max* (L.) Merrill). An. Soc. Entomol. Bras. 7:20-25.

Galileo, M. H. M, and E. A. Heinrichs. 1978. Retenção foliar em plantas de soja (*Glycine max* (L.) Merrill) por efeito da acao de *Piezodorus guildinii* (Westwood, 1837) (Hemiptera: Pentatomidae), em diferentes niveis e epocas de infestação. An. Soc. Entomol. Bras. 7:75-88.

Heinrichs, E. A. 1978. Control of leafhopper and planthopper vectors of rice viruses. Pages 529-560 *in* K. Maramorosch and K. F. Harris, eds. Leafhopper vectors of plant disease agents. Academic Press, New York.

Heinrichs, E. A. 1978. The brown planthopper threat to rice production in Asia. Pages 45-66 *in* The brown planthopper. Proceedings of a symposium on the brown planthopper. Third Inter-Congress of the Pacific Science Association, Bali, Indonesia, July 22-23, 1977. Indonesia Institute of Sciences, Jakarta.

Heinrichs, E. A. 1979. Chemical control of the brown planthopper. Pages 145-167 *in* International Rice Research Institute. Brown planthopper: threat to rice production in Asia. Los Banos, Philippines.

Heinrichs, E. A., and R. F. P. Da Silva. 1978. Controle de *Anticarsia gemmatalis* Hubner, 1818 (Lepidoptera-Noctuidae) con pH 6040 em baixas dosagens. Agron. Sulriograndense, Porte Alegre, 14:261-267.

Heinrichs, E. A., R. C. Saxena, and S. Chelliah. 1979. Development and implementation of insect pest management systems for rice in tropical Asia. ASPAC Food Fert. Technol. Cent. Ext. Bull. 127. Taipei, Taiwan. 38 p.

Heinrichs, E. A., V. A. Dyck, R. C. Saxena, and J. A. Litsinger. 1979. Development of rice insect pest management systems for the tropics. Page 86 *in* Proc. IX International Plant Protection Congress, Washington, D. C., USA.

Heinrichs, E. A., P. K. Pathak, V. A. Dyck, S. Chelliah, R. C. Saxena, and J. A. Litsinger. 1979. Guide to the management of insect pests of lowland rice in Tropical Asia. IPC SP 65 *in* Bureau of Plant Industry. Short course in integrated pest control for irrigated rice in South and Southeast Asia. Manila, Philippines.

Heinrichs, E. A., H. A. de O. Gastal, and M. H. M. Galileo. 1979. Incidence of natural control agents of the velvetbean caterpillar and response of predators to insecticide treatments in Brasilian soybean fields. Pesqui. Agropecu. Bras., Brasilia 14:79-87.

Litsinger, J. A., E. A. Price, R. T. Herrera, J. P. Bandong, M. D. Lumaban, C. B. Quirino, and M. D. Castillo. 1977. Introducing pest control technology to a low management crop: the mungbean example in the Philippines. Pages 183-191 *in* Asian Vegetable Research and Development Center. Proceedings of the first international symposium on mungbean, August 16-19, 1977, Los Banos, Philippines. Taiwan. 262 p.

Litsinger, J. A., P. E. Kenmore, and R. C. Saxena. 1978. Cultural control of rice insect pests. *In* Proc. Regional Training Seminar on Integrated Pest Control for Irrigated Rice in South and Southeast Asia, October 16-November 18, 1978. Sponsored by FAO, USAID, and Philippine Bureau of Plant Industry. 15 p.

Litsinger, J. A., C. B. Quirino, M. D. Lumaban, and J. P. Bandong. 1979. The grain legume complex of rice-based cropping systems at three locations in the Philippines. Pages 309-320 *in* S. R. Singh, H. F. van Emden, and R. A. Taylor, eds. Pests of grain legumes: ecology and control. Academic Press, London. 454 p.

McCaffery, A. R., A. G. Cook, W. W. Page, and T. J. Perfect. 1978. Utilization of food by *Zonocerus variegatus* (L.) (Orthoptera: Pyrgomorphidae). Bull. Entomol. Res. 68:589-606.

Pathak, M. D., and R. C. Saxena. 1979. Breeding approaches in rice. Pages 565 *in* F. G. Maxwell and P. R. Jennings, eds. Breeding plants resistant to insects. J. Wiley and Sons, Inc., New York.

Pathak, M. D., and R. C. Saxena. 1979. Insect resistance. Pages 270-284 *in* J. Sneep and A. J. T. Hendriksen, eds. Plant breeding perspectives. Centre for Agricultural Publications and Documentation, Wageningen.

Saxena, R. C., and B. Puma. 1979. Effect of trans-aconitic acid, a barnyard grass allelochemic, on hatching of eggs of brown planthopper and green leafhopper. Pages 84-85 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines.

Saxena, R. C., and M. D. Pathak. 1979. Factors governing susceptibility and resistance of certain rice varieties to the brown planthopper. Pages 303-317 *in* International Rice Research Institute. Brown planthopper: threat to rice production in Asia. Los Banos, Philippines.

Saxena, R. C., N. J. Liquido, and H. D. Justo. 1979. Neem seed oil, an anti-feedant for brown planthopper control. Pages 86-87 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines.

Waldbauer, G. P., and A. P. Marciano. 1979. Rice leaf folder: mass rearing and a proposal for screening for

varietal resistance in the greenhouse. IRRI Res. Pap. Ser. 27. 17 p.

Office of Information Services

Hargrove, T. R. 1979. The diffusion and adoption of semidwarf rice cultivars as parents in Asian rice breeding programs. Crop. Sci. 19(5):571-574.

Hargrove, T. R. and V. L. Cabanilla. 1979. The impact of semidwarf rice varieties on Asian rice breeding programs. BioScience 29(12):731-735.

Hargrove, T. R., W. R. Coffman, and V. L. Cabanilla. 1979. Genetic interrelationships of improved rice varieties in Asia. IRRI Res. Pap. Ser. 23. 34 p.

International Rice Testing Program

Khush, G. S., and D. V. Seshu. 1978. Rice varietal improvement for tropical and sub-tropical Asia. Pages 131-143 *in* International Commission on Irrigation and Drainage, Philippine National Committee. ICID 2nd regional Afro-Asian conference. Technical papers for Session III "Rice varieties cultivation and fertilization." Manila.

Nanda, J. S., and D. V. Seshu. 1979. Breeding strategy for cold-tolerant rices. Pages 91-99 *in* International Rice Research Institute. Report of a rice cold tolerance workshop. Los Banos, Philippines.

Rao, U. Prasada, M. B. Kalode, T. E. Srinivasan, and D. V. Seshu. 1977. Resistance to brown planthopper in rice. Indian J. Genet. Plant. Breed. 37(3):453-456.

Sarma, Y. R. B., A. V. Rao, D. V. Seshu, and T. E. Srinivasan. 1978. Sampling in rice field experiments. Indian J. Agric. Sci. 48(9):505-509.

Seshu, D. V., and H. E. Kauffman. 1979. Preliminary findings from the first International Rainfed Lowland Rice Observational Nursery. Pages 335-341 *in* International Rice Research Institute. Rain fed lowland rice: selected papers from the 1978 International Rice Research Conference. Los Banos, Philippines.

Srinivasan, T. E., U. Prasada Rao, and D. V. Seshu. 1978. Rasi, an early high yielding rice variety. Seeds Farms 4(5-6):25-26.

Irrigation Water Management

Bhuiyan, S. I., T. H. Wickham, L. N. Sen, and D. Cablayan. 1979. The influence of water-related factors on land preparation, cropping intensity, and yield of rainfed lowland rice in Central Luzon, Philippines. Pages 215-234 *in* International Rice Research Institute. Rainfed lowland rice: selected papers from the 1978 International Rice Research Conference. Los Banos, Laguna, Philippines.

Early, A., M. Alagcan, N. Tapay, L. Evangelista, T. Wickham, R. Bautista, and M. Vallarta. 1978. An innovative method of irrigation system management in the Philippines. *In* International Commission on Irrigation and Drainage, Philippine National Committee. ICID 2nd regional Afro-Asian conference. Manila. 34 p.

Early, A. C., V. P. Singh, D. F. Tabbal, and T. H. Wickham. 1979. Land evaluation criteria for irrigated lowland rice. Pap. 14 *in* Land evaluation criteria for irrigation, FAO World Soil Resour. Rep. 50.

Singh, V. P., T. H. Wickham, I. T. Corpuz, and A. C. Early. 1979. Nitrogen losses in runoff from irrigated rice fields. *In* Progress in water technology. Pergamon Press, Ltd., Hamilton, New Zealand.

Singh, V. P., A. C. Early, and T. H. Wickham. 1979. Rice agronomy in relation to rice-fish culture. *In* Proceedings of the ICLARM-SEARCA conference on integrated agriculture-aquaculture farming systems, Manila, 6-9 August 1979.

Sumayao, A., D. Tabbal, T. Wickham, and S. I. Bhuiyan. 1979. Management of irrigation water in a communal irrigation system. Philipp. Agric. Eng. J. 10(2):19-27.

Sumayao, A. R., and S. I. Bhuiyan. 1978. Quantification of rice yield benefits attributable to irrigation water. Pages 11-12 *in* International Commission on Irrigation and Drainage, Philippine National Committee. ICID 2nd regional Afro-Asian conference. Summaries of technical papers for sessions I-IV. Manila.

Multiple Cropping

Angus, J. F., and E. B. Manalo. 1979. Weather and climate data for Philippine rice research. IRRI Res. Pap. Ser. 41. 14 p.

Angus, J. F., S. P. Liboon, T. C. Hsiao, and S. Hasegawa. 1979. Yield, growth, and root development in relation to water stress and water use for six upland crops and rice. *In* Crop Science Society of the Philippines. Annual scientific meeting, 10th, Los Banos, Laguna, 1979. Pap. 3.

De Datta, S. K., R. A. Morris, and R. Barker. 1979. Land preparation and crop establishment for rainfed lowland rice. Pages 189-214 *in* International Rice Research Institute. Rainfed lowland rice: selected papers from the 1978 international rice research conference. Los Banos, Philippines.

Furoc, R. E., G. O. Turija, and R. A. Morris. 1979. Comparative performance of photosensitive and non-photosensitive rice cultivars in cropping pattern trials. *In* Crop Science Society of the Philippines. Annual scientific meeting, 10th, Los Banos, Laguna, 1979 Pap. 9.

Furoc, R. E., G. O. Turija, and R. A. Morris. 1979. Fertilizer nitrogen requirement of dry-seeded rice following sorghum and soybean. *In* Crop Science Society of the Philippines. Annual scientific meeting,

10th, Los Banos, Laguna, 1979. Pap. 10.
Garrity, D. P., R. R. Harwood, H. G. Zandstra, and E. C. Price. 1979. Determining superior cropping patterns for small farms in a dryland rice environment: test of a methodology. IRRI Res. Pap. Ser. 33. 11 p.
Godilano, E. C., S. P. Liboon, P. M. Molinawe, G. M. Huelgas, and V. R. Carangal. 1979. *In* Crop Science Society of the Philippines. Annual scientific meeting, 10th, Los Banos, Laguna, 1979. Pap. 11.
Herrera, W. A. T., and H. G. Zandstra. 1979. The response of some major upland crops to excessive soil moisture. *In* Crop Science Society of the Philippines. Annual scientific meeting, 10th, Los Banos, Laguna, 1979. Pap. 13.
Morris, R. A., and H. G. Zandstra. 1979. Land and climate in relation to cropping patterns. Pages 255-274 *in* International Rice Research Institute. Rainfed lowland rice: selected papers from the 1978 international rice research conference. Los Banos, Philippines.
Nadal, A. M., and V. R. Carangal. 1979. Performance of the main and ratoon crops of 13 advanced rice selections under dry-seeded rainfed bunded conditions. *In* Crop Science Society of the Philippines. Annual scientific meeting, 10th, Los Banos, Laguna, 1979. Pap. 15.
Zandstra, H. G. 1978. Soil management for rice-based cropping systems. Pages 703-715 *in* International Rice Research Institute. Soils and rice. Los Banos, Philippines.
Zandstra, H. G. 1979. A cropping systems research methodology for agricultural development project. Pages 496-521 *in* Proceedings of the agricultural sector symposia. World Bank, Washington, D.C.
Zandstra, H. G. 1979. Cassava intercropping research: agroclimatic and biological interactions. Pages 67-75 *in* E. Weber, B. Nestel, and M. Campbell, eds. Intercropping with cassava. International Development Research Center.
Zandstra, H. G. 1979. Cropping systems research for the Asian rice farmer. Agric. Systems (4):136-153.

Plant Breeding

Chang, T. T. 1979. Deepwater rice germplasm. Pages 35-37 *in* International Rice Research Institute. Proceedings of the 1978 international deepwater rice workshop. Los Banos, Philippines.
Chang, T. T. 1979. Genetics and evolution of the Green Revolution. Pages 187-209 *in* R. de Vicente, ed. Replies from biological research (Proc. UNESCO-CSIC Symp. on Biology and Ethics). Consejo Superior de Investigaciones Cientificas, Madrid.
Chang, T. T. 1979. History of the early rice crop [in Chinese]. Pages 49-68 *in* T. H. Shen and Y. S. Chao, eds. Chinese agricultural history - collection of essays, vol. 1. Commercial Press, Taipei.
Chang, T. T. 1979. Hybrid rice. Pages 173-174 *in* J. Sneep, A. J. T. Hendriksen, and O. Holbek, eds. Plant breeding perspectives. PUDOC, Wageningen.
Chang, T. T. 1979. The green revolution's second decade. SPAN 22(1):2-3.
Chang, T. T. 1978-79. The origins and early cultures of the cereal grains and food legumes. Early China (Berkeley) 4:90-91.
Chang, T. T., and B. Somrith. 1979. Genetic studies on the grain quality of rice. Pages 49-58 *in* International Rice Research Institute. Proceedings of the workshop on chemical aspects of rice grain quality. Los Banos, Philippines.
Chang, T. T., W. L. Brown, J. G. Boonman, J. Sneep, and H. Lamberts. 1979. Crop genetic resources. Pages 83-103 *in* J. Sneep, A. J. T. Hendriksen, and O. Holbek, eds. Plant breeding perspectives. PUDOC, Wageningen.
Chang, T. T., B. Somrith, and J. C. O'Toole. 1979. Potential for improving drought resistance in rainfed lowland rice. Pages 149-164 *in* International Rice Research Institute. Rainfed lowland rice: selected papers from the 1978 international rice research conference. Los Banos, Philippines.
Crill, J. P., and G. S. Khush. 1979. Effective and stable control of rice blast with monogenic resistance. Food Fert. Technol. Cent. Ext. Bull. 128. Taipei, Taiwan. 13 p.
Dwivedi, J.L., and J. S. Nanda. 1979. Inheritance of amylose content in three crosses of rice. Indian J. Agric. Soc. 49(10):753-755.
Gotoh, K., T. T. Chang, J. C. O'Toole, R. Riley, and B. R. Murthy. 1979. Crop adaptation. Pages 234-261 *in* J. Sneep, A. J. T. Hendriksen, and O. Holbek, eds. Plant Breeding perspectives. PUDOC, Wageningen.
Hargrove, T. R., W. R. Coffman, and V. L. Cabanilla. 1979. Genetic interrelationships of improved rice varieties in Asia. IRRI Res. Pap. Ser. 23. 34 p.
Hendriksen, A. J. T., J. Sneep, D. J. Glas, M. E. Roothaan, F. de Wolff, W. L. Brown, and T. T. Chang. 1979. Seed production and distribution. Pages 370-395 *in* J. Sneep, A. J. T. Hendriksen, and O. Holbek, eds. Plant breeding perspectives. PUDOC, Wageningen.
Ikehashi, H., and G. S. Khush. 1979. Methodology of assessing appearance of the rice grain including chalkiness and whiteness. Pages 223-229 *in* International Rice Research Institute. Proceedings of the workshop on chemical aspects of rice grain quality. Los Banos, Philippines.
Jennings, P. R., W. R. Coffman, and H. E. Kauffman. 1979. Rice improvement. International Rice Research

Institute, Los Banos, Philippines.

Khush, G. S. 1979. GEU, an international rice improvement program. Grains J. 4:9-14.

Khush, G. S. 1979. Genetics of and breeding for resistance to the brown planthopper. Pages 321-332 *in* International Rice Research Institute. Brown planthopper: threat to rice production in Asia. Los Banos, Philippines.

Khush, G.S., G.S. Sidhu, and T.W. Mew. 1978. Genetics of resistance to bacterial blight in rice. Page 92 *in* Abstract of contributed papers. Part II. 14th International Congress of Genetics. Moscow, USSR.

Khush, G. S., and S. H. Ou. 1978. Genetics of resistance to diseases of rice. Page 288 *in* Abstracts of papers. 3rd International Congress of Plant Pathology, Munchen, Germany.

Khush, G. S., C. M. Paule, and N. M. dela Cruz. 1979. Rice grain quality evaluation and improvement at IRRI. Pages 21-31 *in* International Rice Research Institute. Proceedings of the workshop on chemical aspects of rice grain quality. Los Banos, Philippines.

Khush, G. S., and D. V. Seshu. 1978. Rice varietal improvement for tropical and subtropical Asia. Pages 131-143 *in* International Commission on Irrigation and Drainage ICID Second Regional Afro-Asian Conference. Technical papers for Session III. Tech. Pap. 10.

Nanda, J. S., and W. R. Coffman. 1979. Alternative plant types and other agronomic characteristics for rainfed lowland rice. Pages 123-133 *in* International Rice Research Institute. Rainfed lowland rice: selected papers from the 1978 international rice research conference. Los Banos, Philippines.

Nanda, J. S., and V. S. Seshu. 1979. Breeding strategy for cold tolerant rices. Pages 91-99 *in* International Rice Research Institute. Report of a rice cold tolerance workshop. Los Banos, Philippines.

Nanda, J. S., and W. R. Coffman. 1979. IRRI's efforts to improve the protein content of rice. Pages 33-47 *in* International Rice Research Institute. Proceedings of the workshop on chemical aspects of rice grain quality. Los Banos, Philippines.

O'Toole, J. C., and T. T. Chang. 1979. Drought resistance in cereals - rice: a case study. Pages 374-405 *in* H. Mussell and R. Staples, eds. Stress physiology in crop plants. Wiley, New York.

Pathak, M. D., and G. S. Khush. 1979. Studies on varietal resistance in rice to the brown planthopper at the International Rice Research Institute. Pages 285-301 *in* International Rice Research Institute. Brown planthopper: threat to rice production in Asia. Los Banos, Philippines.

Paule, C. M., K. A. Gomez, B. O. Juliano, and W. R. Coffman. 1979. Variability in amylose content of rice. Il Riso 28(1):15-22.

Sidhu, G. S., G. S. Khush, and F. G. Medrano. 1979. A dominant gene in rice for resistance to whitebacked planthopper and its relationship to other plant characteristics. Euphytica 28:227-232.

Sidhu, G. S., and G. S. Khush. 1979. Linkage relationships of some genes for resistance and semidwarf stature in rice. Euphytica 28:233-237.

Somrith, G., T. T. Chang, and B. R. Jackson. 1979. Genetic analysis of traits related to grain characteristics and quality in two crosses of rice. IRRI Res. Pap. Ser. 35. 14 p.

Swaminathan, M. S., J. Sneep, A. J. T. Hendriksen, W. L. Brown, T. T. Chang, and R. Riley. 1979. Perspectives. Pages 396-429 *in* J. Sneep, A. J. T. Hendriksen, and O. Holbek, eds. Plant breeding perspectives. PUDOC, Wageningen.

Zadoks, J. C., T. T. Chang, and C. F. Konzak. 1978. Decimal code for the growth stages of cereals [in English, French, and German]. European and Mediterranean Plant Protection Organization, Paris. 5 p.

Plant Pathology

Bandong, J. M., S. H. Ou, S. P. Ebron, F. L. Nuque, and J. P. Crill. 1979. An unusual *Helminthosporium* leaf spot on the rice variety Sekiguchi Asahi. Pages 53-54 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Bandong, J. M., B. A. Estrada, L. M. Sanchez, and J. P., Crill. 1979. Chemical control of sheath blight disease of rice. Pages 52-53 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Bandong, J. M., C. Q. Torres, and J. P. Crill. 1979. Fungicide foliar sprays for leaf blast control on rice. Pages 50-51 *in* Pest Contol Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Bandong, J. M., T. V. de Dios, B. Arce, and J. P. Crill. 1979. Laboratory bioassay of fungicides against rice fungus pathogens. Page 49 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Bandong, J. M., C. Q. Torres, L. M. Sanchez, F. L. Nuque, and J. P. Crill. 1979. Seed treatment with systemic fungicides for leaf blast control. Page 50 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Chou, L. K., F. L. Nuque, and J. P. Crill. 1979. A study of some components of resistance to rice blast. Page 68 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philip-

pines. (abstr.)

Crill, J. P., and G. S. Khush. 1979. Effective and stable control of rice blast with monogenic resistance. ASPAC Food Fert. Technol. Cent. Ext. Bull. 128. Taipei, Taiwan. 13 p.

Crill, J. P., F. L. Nuque, T. V. de Dios, and S. P. Ebron. 1979. Production of the perfect stage of *Rhynchosporium oryzae* in culture. Pages 59-60 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Estrada, B. A., L. M. Sanchez, and J. P. Crill. 1979. Evaluation of screening methods for sheath rot resistance of rice. Plant Dis. Rep. 63(11):908-911.

Estrada, B. A., L. M. Sanchez, and J. P. Crill. 1979. Screening methods for sheath rot of rice. Pages 64-65 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Lee, Y. H., J. M. Bandong, and J. P. Crill. 1979. Effect of chemicals against leaf blast of rice in the greenhouse and upland blast nursery. Pages 51-52 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines (abstr.)

Lee, Y. H., F. L. Nuque, J. P. Crill, and S. P. Ebron. 1979. Pathogenic races of *Pyricularia oryzae* in the Philippines. Page 60 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Ling, K. C. 1979. Rice virus and virus-like diseases. International Rice Research Institute, Los Banos, Philippines.

Ling, K. C., and E. R. Tiongco. 1979. Rice virus diseases in the Philippines. International Rice Research Institute, Los Banos, Philippines.

Mew, T. W., M. B. Rosario, and K. Tsuchiya. 1979. Etiology of a bacterial stalk rot of rice. Pages 57-58 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Mew, T. W., C. M. Vera Cruz, and R. C. Reyes. 1979. Evaluation of different resistance to bacterial blight of rice. Pages 66-67 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines.

Mew, T. W., C. M. Vera Cruz, R. C. Reyes, and B. A. Zaragoza. 1979. Study on kresek (wilt) of the rice bacterial blight syndrome. IRRI Res. Pap. Ser. 39. 8 p.

Mew, T. W., and C. M. Vera Cruz. 1979. Variability of *Xanthomonas oryzae:* specificity in infection of rice differentials. Phytopathology 69(2):152-155.

Mew, T. W., M. Machmud, and C. M. Vera Cruz. 1979. Variability of *Xanthomonas oryzae:* variation in virulence. Pages 62-63 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Miah, S. A., and T. W. Mew. 1979. Diseases of lowland rainfed rice. Pages 247-251 *in* International Rice Research Institute. Rainfed lowland rice: selected papers from the 1978 international rice research conference. Los Banos, Philippines.

Milne, R. G., E. Luisoni, and K. C. Ling. 1979. Preparation and use of an antiserum to rice ragged stunt virus subviral particles. Plant Dis. Rep. 63:445-448.

Nuque, F. L., S. H. Ou, J. P. Crill, J. M. Bandong, and S. P. Ebron. 1979. Standardization of Philippine race numbers of *Pyricularia oryzae.* Pages 54-55 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Nuque, F. L., and D. B. Lapis. 1979. Rice blast. Pages 10-19 *in* Plant Pest Control Council. Tenth anniversary publication.

Sanchez, L. M., B. A. Estrada, F. L. Nuque, and J. P. Crill. 1979. Survival of sheath rot and leaf scald pathogens in rice seeds. *In* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Suryanarayanan, S., and J. P. Crill. 1979. Leaf wettability and stable resistance to rice blast. Pages 68-69 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Torres, C. Q., F. L. Nuque, S. H. Ou, T. T. Ebron, Jr., and J. P. Crill. 1979. Race patterns of *Pyricularia oryzae* in the different rice geographical regions of the world. Page 61 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Tsuchiya, K., T. W. Mew, and S. Wakimoto. 1979. Induced mutation of *Xanthomonas oryzae* for virulence and avirulence. Pages 61-62 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Wakimoto, S., and T. W. Mew. 1979. Prospects of prediction for the outbreak of rice bacterial blight by the bacteriophage method in the tropics. Philipp. Phytopathol. 15(1):81-85.

Zaragoza, B. A., and T. W. Mew. 1979. Relationship of root injury to the "kresek" phase of bacterial blight of rice. Plant Dis. Rep. 63(12):1007-1011.

Zaragoza, B. A., and T. W. Mew. 1979. Relationship of root injury to the "kresek" phase (wilt) of the rice bacterial blight syndrome. Page 58 *in* Pest Control Council of the Philippines. Proceedings, tenth national conference. Manila, Philippines. (abstr.)

Plant Physiology

Bhattacharya, S. N., and B. S. Vergara. Importance of seedling age in transplanted rice. Pages 173-183 *in* International Rice Research Institute. Proceedings of the 1978 international deepwater rice workshop. Los Banos, Philippines.

Jackson, B. R., and B. S. Vergara. 1979. Progress in deepwater rice research. Pages 3-12 *in* International Rice Research Institute. Proceedings of the 1978 international deepwater rice workshop. Los Banos, Philippines.

Mazaredo, A. M., and B. S. Vergara. 1979. Screening for ability to elongate at an early stage of growth. Pages 143-144 *in* International Rice Research Institute. Proceedings of the 1978 international deepwater rice workshop. Los Banos, Philippines.

Seshu, D. V., and B. S. Vergara. 1979. The International Rice Deepwater Observational Nursery - a summary of results and suggestions for the future. Pages 93-101 *in* International Rice Research Institute. Proceedings of the 1978 international deepwater rice workshop. Los Banos, Philippines.

Setabutara, C., B. S. Vergara, and R. M. Visperas. 1979. Flowering response of deepwater rice varieties to photoperiod. Pages 55-61 *in* International Rice Research Institute. Proceedings of the 1978 international deepwater rice workshop. Los Banos, Philippines.

Setabutara, C., and B. S. Vergara. 1979. Morphology of nodal tillers in deepwater rice. Pages 45-54 *in* International Rice Research Institute. Proceedings of the 1978 international deepwater rice workshop. Los Banos, Philippines.

Setabutara, C., and B. S. Vergara. 1979. Screening deepwater rice varieties for ability to produce nodal tillers. Pages 151-154 *in* International Rice Research Institute. Proceedings of the 1978 international deepwater rice workshop. Los Banos, Philippines.

Vergara, B. S. 1978. Measurement of crop development in rice. *In* FAO/USAID/BPI, in cooperation with IRRI, NCPC/UPLB, and PGCPP. Regional training seminar on integrated pest control for irrigated rice in South and Southeast Asia. IPC/SP/21.

Vergara, B. S. 1978. Measurement of crop development in rice. Pages 183-204 *in* Regional seminar-workshop on prognosis and warning in plant protection. Feb 27-March 18, 1978, Manila and Maligaya, German Foundation for International Development.

Vergara, B. S. 1979. A farmer's primer on growing rice. International Rice Research Institute, Los Banos, Philippines. 221 p.

Vergara, B. S., and R. M. Visperas. 1979. Bibliography of the effect of low temperature on rice. International Rice Research Institute, Los Banos, Philippines. 117 p.

Vergara, B. S., and A. M. Mazaredo. 1979. Effect of presubmergence drought on internode elongation of deepwater rice. Pages 41-44 *in* International Rice Research institute. Proceedings of the 1978 international deepwater rice workshop. Los Banos, Philippines.

Vergara, B. S., D. HilleRisLambers, N. Supapoj, B. R. Jackson, C. Prechachart, C. Boonwite, and S. Karin. 1979. International collaborative program on methods of screening for flood tolerance. Pages 249-260 *in* International Rice Research Institute. Proceedings of the 1978 international deepwater rice workshop. Los Banos, Philippines.

Vegara, B. S., and A. M. Mazaredo. 1979. Using the new standard evaluation system to measure elongation ability. Pages 139-142 *in* International Rice Research Institute. Proceedings of the 1978 international deepwater rice workshop. Los Banos, Philippines.

Yoshida, S. 1979. A simple evapotranspiration model of a paddy field in tropical Asia. Soil Sci. Plant Nutr. 25:81-91.

Yoshida, S., and M. R. Chaudhry. 1979. Sulfur nutrition of rice. Soil Sci. Plant Nutr. 25:121-134.

Soil Chemistry

Castro, R. U., A. B. Capati, and F. N. Ponnamperuma. 1979. Rice straw as a natural source of plant nutrients. *In* Crop Science Society of the Philippines. Annual scientific meeting, 10th, Los Banos, Laguna, Philippines, 1979. Pap. 7.

Craswell, E. T., and P. L. G. Vlek. 1979. Fate of fertilizer nitrogen applied to wetland rice. Pages 175-192 *in* International Rice Research Institute. Nitrogen and rice. Los Banos, Philippines.

Lantin, R. S., M. T. C. Cayton, and F. N. Ponnamperuma. 1979. A simple test for available zinc and copper in wetland rice soils. Pages 174-175 *in* Agronomy Abstracts, 1979 ASA meetings, Fort Collins, Colorado, Aug. 5-10, 1979.

Mahadevappa. M., H. Ikehashi, and F. N. Ponnamperuma. 1979. Contribution of varietal tolerance for problem soils to yield stability in rice. IRRI Res. Pap. Ser. 43. 15 p.

Ponnamperuma, F. N. 1979. IR42: A rice type for small farmers of South and Southeast Asia. IRRI Res. Pap. Ser. 44. 10 p.

Ponnamperuma, F. N. 1979. IR42: The answer to the small farmers' prayer. *In* Crop Science Society of the Philippines. Annual scientific meeting, 10th, Laguna, 1979. Pap. 18. Also *in* Greenfields 9(12):80-86.

Ponnamperuma, F. N. 1979. IR42: a rice variety for

small farmers of South and Southeast Asia. Page 48 *in* Agronomy Abstracts, 1979 ASA meetings, Fort Collins, Colorado, Aug. 5-10, 1979.

Vlek, P. L. G., and E. T. Craswell. 1979. Effect of nitrogen source and management on ammonia volatilization losses from flooded rice-soil systems. Soil Sci. Soc. Am. J. 43:352-357.

Soil Microbiology

Espinas, C. R., N. S. Berja, D. C. Del Rosario, and I. Watanabe. 1979. Environmental conditions affecting azolla growth. Greenfields 9(8):14-19.

Siddaramappa, Ramappa, and I. Watanabe. 1979. Evidence for vapor loss of ^{14}C-carbofuran from rice plants. Bull. Environ. Contam. Toxicol. 23(45):544-551.

Sidddaramappa, Ramappa, A. Tirol, and I. Watanabe. 1979. Persistence in soil and absorption and movement of carbofuran in rice plants. J. Pesticide Sci. 4(4):473-479.

Subudhi, B. P. R., and I. Watanabe. 1979. Minimum level of phosphate in water for growth of azolla determined by continuous flow culture. Curr. Sci. 48(24):1065-1066.

Watanabe, I. 1978. Biological nitrogen fixation in rice soils. Pages 465-477 *in* International Rice Research Institute. Soils and rice. Los Banos, Philippines.

Watanabe, I., and S. Mitsui. 1979. Denitrification loss of fertilizer-nitrogen in paddy soils - its recognition and impact. IRRI Res. Pap. Ser. 37. 10 p.

Watanabe, I., and W. Cholitkul. 1979. Field studies of N_2-fixation in paddy soils. Pages 223-239 *in* International Rice Research Institute. Nitrogen and rice. Los Banos, Philippines.

Watanabe, I., and W. L. Barraquio. 1979. Low levels of fixed nitrogen required for isolation of free-living N_2-fixing organisms from rice roots. Nature 277:565-566.

Watanabe, I., O. Ito, and A. App. 1979. Nitrogen fixation associated with Graminaceae-associative N_2 fixation by heterotrophic bacteria [in Japanese]. Kagaku To Seibutsu 17(4):221-223.

Watanabe, I., and D. A. Cabrera. 1979. Nitrogen fixation associated with the rice plant grown in water culture. Appl. Environ. Microbiol. 37:373-378.

Watanabe, I., and W. L. Barraquio. 1979. Nitrogen-fixing (acetylene reduction) activity and population of aerobic heterotrophic nitrogen-fixing bacteria associated with wetland rice. Appl. Environ. Microbiol. 37(5):813-819.

Watanabe, I., and A. App. 1979. Research needs for nitrogen fixation in flooded rice crop systems. Pages 485-490 *in* International Rice Research Institute. Nitrogen and rice. Los Banos, Philippines.

Statistics

Gomez, K. A., R. W. Herdt, R. Barker, and S. K. De Datta. 1979. A methodology for identifying constraints to high rice yields on farmers' fields. Pages 27-47 *in* International Rice Research Institute. Farm-level constraints to high rice yields in Asia: 1974-77. Los Banos, Philippines.

Gomez, K. A., L. Lopez, M. J. Novenario, R. W. Herdt, and V. P. Marciano. 1979. Constraints to high rice yields, Laguna, Philippines. Pages 173-190 *in* International Rice Research Institute. Farm-level constraints to high rice yields in Asia: 1974-77. Los Banos, Philippines.

SEMINARS

The seminars held at IRRI during 1979 are grouped as Saturday seminars, general seminars, and special seminars. The Saturday seminars report ongoing IRRI researches. Unless otherwise stated the speakers were staff members.

Saturday Seminars

Genetic interrelationships of improved rice varieties. Dr. T. R. Hargrove.

Approaches to control of sheath blight disease of rice. Mr. B. A. Estrada.

Mechanism of sterility caused by cool temperature at the booting stage in rice plants. Dr. I. Nishiyama, visiting scientist, Plant Physiology Department.

Recent developments in chemical control of the brown planthopper *Nilaparvata lugens*. Mr. G. B. Aquino.

Ecological techniques for insect pest management. Mr. F. O. Carino, Mr. P. E. Kenmore, and Dr. V. A. Dyck.

Root development and water uptake under field condition. Dr. S. Hasegawa.

Korea-IRRI collaborative experiments on rice cold tolerance. Dr. B. S. Vergara.

Zinc deficiency: a widespread nutritional disorder of rice in the Philippines. Ms. Myrna Orticio.

Studies of alkali tolerance of rice varieties. Dr. M.S. Bajwa.

Review of soil nitrogen research in the IRRI Soil Chemistry Department. Ms. Ruby U. Castro.

N_2 fixation in wetland rice soils. Dr. O. Ito.

New type of N_2-fixing bacteria and their distribution. Mr. W. Barraquio.

Chemical properties of lipids in developing and mature brown rice. Mr. Md. N. Choudhury.

An agriculturist looks at aid. Dr. David Hopper, vice president, World Bank, Washington, D. C., USA.

Pitfalls in the application of statistical methods in agricultural research. Ms. Grace L. Reyes.

Computer-aided research in crop improvement. Mr. Roberto Cembrano.

The genetic resources program of IRRI. Dr. T. T. Chang and Mr. Duncan Vaughn.

Primary trisomics of rice and their use in genetics and breeding. Dr. R. J. Singh.

Induced-mutant genes in rice. Mr. David McKill and J. N. Rutger.

Environmental conditions affecting *Azolla* growth. Ms. Corazon Espinas.

Increasing cropping intensity of rainfed rice lands by soil management and moisture conservation techniques. Mr. M. P. Singh and Dr. S. K. de Datta.

The limits of the brown planthopper problem: implications for integrated pest management. Mr. Peter Kenmore.

New cropping patterns for Iloilo and Pangasinan farmers: a whole farm analysis. Dr. S. Jayasuria.

Evaluation of selected upland crop establishment techniques. Mr. J. Singh and Mr. J.A. McMennamy.

Contribution of varietal tolerance in stabilizing rice yields in problem soils. Drs. M. Mahadevappa, H. Ikehashi, and F. N. Ponnamperuma.

The effect of the new rice technology on family labor utilization in Laguna. Ms. Joyotec Smith.

Dry matter and grain production of rice with respect to drought screening using a line-source sprinkler to vary water supply. Dr. D. W. Puckridge, visiting scientist, Agronomy Department.; Dr. J. C. O'Toole, and P. T. Vizmonte, Jr.

Evaluating yield variability in Bulacan using crop cut and survey techniques. Mr. Policarpio Masicat.

The water constraints loop survey. Mr. Policarpio Masic.. .

Changes in cropping systems: Cale, Tanauan, Batangas. Ms. Anita Frio.

Environmental and management constraints to high rice yields in Nueva Ecija, Philippines. Mr. Abraham Mandac.

Cross-site comparison of rainfed rice based on cropping systems. Ms. Thelma Paris.

The economic and institutional impact of adopting mechanical threshing methods in Iloilo and Laguna provinces in the Philippines. Ms. Fleurdeliz Juarez.

An overview of water pumping equipment available to small farmers. Mr. Godofredo Salazar and Mr. C. J. Moss.

Modeling of potential evapotranspiration and solar radiation for different regions of the Philippines. Messrs. M. Tamisin, D. T. Franco, E. B. Manalo, and Dr. H. G. Zandstra.

Soil compaction in wetland tillage. Mr. F. Cabrales.

Effect of tungro virus on the infectivity of *Nephotettix virescens*. Mr. M. A. Hasanuddin.

Integrated management and control of rice diseases. Dr. M. C. Rush, visiting scientist, Plant Pathology Department.

Herbicide antidotes and environmental factors that affect rice cultivar tolerance to herbicides. Dr. A. Ruscoe, M. T. Madrid, Jr., and Dr. K. Moody.

Physicochemical properties of rainfed rice soils as affected by cropping systems and crop residue management. Mr. Achmad Mudzzakir Fagi and Dr. S. K. de Datta.

The role of slide-tape presentations in the rice production training program. Dr. Robert Hurst, visiting scientist, Office of Rice Production Training and Research.

Quantitative study on the transmission of rice ragged stunt disease by *Nilaparvata lugens* (Stal). Mr. Sunendar Kartaatmadja.

Cytological studies of the blast fungus. Dr. K. V. S. R. Kameswar Row.

Response of rice crop to soil moisture availability during drought stresses. Dr. V. S. Tomar.

Lower limit of available water and rice response to soil moisture during drought stress. Dr. V. S. Tomar and Dr. J. C. O'Toole.

Rice cultivar tolerance to herbicides. Mr. Modesto T. Madrid, Jr., Dr. A. W. Ruscoe, and Dr. K. Moody.

Some effects of tillage systems on a wetland rice soil. Messrs. F. Cabrales and D. O. Kuether.

General Seminars

The brown planthopper: resistance of the rice plant and biotic variations of the insect. Dr. K. Sogawa.

Rice entomology in the People's Republic of China. Dr. E. A. Heinrichs.

A renewed emphasis on dryland crops breeding at UPLB. Dr. Ricardo M. Lantican, director, Institute of Plant Breeding, UPLB, College, Laguna.

Natural enemies of rice insect pests: their biology and value in pest control. Dr. V. A. Dyck.

Paddy culture of fishes and invertebrates. Dean Rafael D. Guerrero, III, College of Inland Fisheries, Central Luzon State University, Munoz, Nueva Ecija.

Fertility management of flooded rice soil: a proposal to minimize the biological production potential-performance gap of high yielding varieties. Dr. C. S. Park, visiting scientist, Agronomy Department.

Altitude limits and geoecological differentiation of rice cultivation in the Himalayas and Southeast Asian Mountain Regions. Dr. Harold Uhlig, director, Geographisches Institut, Federal Republic of Germany.

Rice cropping systems of Burma and the impact of the high yielding rice program. U. Nyi Nyi, assistant deputy general manager, Agricultural Corporation, Ministry of Agriculture, Burma.

Agrarian reform program of the Philippines. Mr. Jose Medina, assistant minister, Ministry of Agrarian Reform, Quezon City.

Wheat breeding in the Philippines: problems and prospects. Dr. Thomas Masajo, assistant professor, Department of Agronomy, UPLB, College, Laguna.

The University's research and development thrusts for the 1980s. Dr. Emil Q. Javier, Chancellor, UPLB, College, Laguna.

A modern alchemist *Azolla-Anabaena* symbiosis and its use in rice production. Dr. I. Watanabe.

Research thrust in crops for the 1980s. Dr. E. B. Pantastico, director, Crops Research Division, Philippine Council for Agriculture and Resources Research (PCARR), Los Banos, Laguna.

Data analysis and research methodology. Mr. K. P. Haydock, visiting scientist, Statistics Department, IRRI.

An evaluation of the Masagana 99 Program (Phases I-VIII). Dr. Edgardo C. Quisumbing, deputy executive director, National Food and Agriculture Council, Quezon City.

An environmental impact study of DDT on a tropical agroecosystem. Dr. John Perfect, visiting scientist, Entomology Department.

Farm trials in support of the Masagana 99 rice production program. Dr. Reeshon Feuer, crop production specialist, Philippine Outreach Program.

The control mechanisms of grain-filling in wheat, rice, and millet a structural analysis. Dr. S. Y. Zee, visiting scientist, Plant Physiology Department.

Philippine medicinal plants. Ms. Ludivina de Padua, assistant professor, Department of Botany, College of Arts and Sciences, UPLB, College, Laguna.

Recent development in crop spraying technology. Dr. J. Spillman, reader in Aerodynamics, Cranfield College of Technology, United Kingdom.

Interaction between root growth and soil and plant water status. Dr. T. C. Hsiao, visiting scientist, Agronomy Department.

Sex life of the blast fungus. Dr. J. P. Crill.

Soil testing as a basis for fertilizer recommendations. Dr. J. T. Cope, Jr., visiting scientist, Agronomy Department.

Crop-pest systems models for optimizing integrated pest management. Dr. A. P. Gutierrez, professor of Entomology, University of California, Berkeley, California, USA.

Rices in saline and alkaline areas -- observations and strategies for their improvement. Dr. H. Ikehashi.

The Danish fertilization system transferred to paddy cultivation in Southeast Asia. Dr. Jens Moeller Nielsen, professor of Soil Science, Royal Veterinary and Agriculture College, Copenhagen, Denmark.

Cotton growing in the Philippines. Dr. Rodolfo P. Cabangbang, assistant professor, Department of Agronomy, UPLB, College, Laguna.

Vertebrate pest control in the Philippines. Dr. Lynwood Fiedler, vertebrate biologist, National Crop Protection Center, UPLB, College, Laguna.

Some aspects of water and nitrogen in rainfed agriculture of Southern Australia. Dr. Donald W. Puckridge, visiting scientist, Agronomy Department, IRRI.

Soil problems in the IRRI farm. Dr. F. N. Ponnamperuma.

Integrated disease management and control in rice. Dr. Milton C. Rush, visiting scientist, Plant Pathology Department.

An evaluation of water use efficiency and energy requirements for wetland tillage. K. S. Lee.

Special Seminars

The spatial approach to rural development. Dr. R. O. Whyte, research associate, Institute of Southeast Asian Studies, Republic of Singapore.

Some aspects of recycling of straw in rice cropping systems. Dr. S. C. Modgal.

China's farm mechanization. Mr. Xiang Nan, vice minister, Ministry of Agricultural Machinery, People's Republic of China.

Degradation of carbaryl and carbofuran in paddy field ecosystem in West Malaysia. Dr. Sarjeet Singh Gill, School of Biological Sciences, University Sains Malaysia, Penang, Malaysia.

AVRDC, the vegetable center -- perspective after half a decade. Dr. James Riley, acting director, Asian Vegetable Research and Development Center, Shanhua, Taiwan.

Resistance and recognition in host-parasite interactions. Dr. J. A. Callow, Department of Plant Sciences, University of Leeds, Leeds, United Kingdom.

Phosphorus nutrition of crop plants. Dr. D. G. Edwards, senior lecturer in plant nutrition, University of Queensland, Australia.

Mutations in plant breeding. Professor Horst Gaul, plant breeder, International Atomic Energy Agency, Vienna.

Tissue culture in rice improvement. Dr. Liddia Kucherenko, head, Tissue Culture Laboratory, All Union Institute of Rice Research, Krasnodar, USSR.

Simulating production of rainfed rice. Dr. J. F. Angus, visiting agronomist, Multiple Cropping Department.

Photosynthesis, water use, and crop modelling of wheat grown in a rainfed environment. Dr. Donald W. Puckridge, visiting scientist, Agronomy Department, IRRI.

Solar energy for food production in Vermont, USA. Dr. Robert E. Huke, visiting scientist, Agricultural Economics Department.

The planning of sampling for population forecasting and control of insect pests. Dr. E. Kuno, associate professor, Entomological Laboratory, College of Agriculture, Kyoto University, Japan.

Entomopathogenic microorganisms as potentially useful pest management tools in rice. Dr. D. W. Roberts, insect pathologist, Boyce Thompson Institute for Plant Research, Cornell University.

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 6 continuing contracts:

- $839,949 for a five-year contract signed in May 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 with a dollar budget of $3,125,130 plus Rp 2,006,560 managed by the USAID in Colombo.
- $335,140 for a contract, signed in October 1977 between IRRI and USAID, supporting a 2 1/2-year project for accelerated development and utilization of improved rice technology in Indonesia with a total budget of $860,000.
- $86,442, for a contract, signed in February 1977, for a 2-year project on collaborative rice research in Pakistan with a budget of $258,000 plus Rp 1,110,000 managed by USAID in Pakistan.
- $71,428 for a contract, signed in September 1977, for a project on the consequences of mechanization on small rice farms.
- $49,605 for a contract, signed in March 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 September 1977, between IRRI-FNRI and USAID for supporting a project entitled *Protein quality of milled rice in preschool children*, with a budget of $17,705.

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 cropping program, varietal screening for maize, sorghum,

mungbean, 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 of the $1,070,000 grant 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 $260,598 as 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, $34,362 was released to the Institute.

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, the areas they supported, and the amount they contributed are as follows:

- Philippine Council for Agriculture and Resources Research:
  - (a) cooperative applied research project 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 rainfed and irrigated 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 International Network on Soil Fertility and Fertilizer Evaluation for Rice .. 4,000
- Stauffer Chemical Company, weed control 3,000
- Ciba Geigy, agrochemical research 2,000
- Monsanto, herbicide research 2,000

Staff changes

January

Dr. Dennis Greenland joined IRRI as deputy director general.

Dr. Pierre A. Roger joined the Soil Microbiology Department as visiting scientist.

February

Mr. Ildefonso Guinoo, assistant to the director general, resigned.

Dr. Hiroshi Ikehashi, plant breeder, Plant Breeding Department, resigned.

March

Mr. Raymond C. Fischer joined IRRI as associate agricultural engineer assigned to the collaborative project in Thailand.

Dr. Bruce Stone of La Trobe University completed his sabbatical leave as visiting scientist, Chemistry Department.

April

Dr. Chon Suh Park joined the Agronomy Department as visiting scientist.

Dr. John Wicks joined the Agricultural Engineering Department as associate agricultural engineer.

May

Mr. William H. Smith joined the Office of Information Services as editor.

Mr.Robert L. Cowell joined the Office of Information Services as visiting associate editor.

Dr. John Thomas Cope, Jr. of Auburn University completed his sabbatical leave as visiting scientist, Agronomy Department.

Dr. John Angus of the Division of Land Use, CSIRO, completed his sabbatical leave as associate visiting scientist, Multiple Cropping Department.

June

Dr. Walter Griffeth joined IRRI as crop production specialist/team leader, Sri Lanka Collaborative Project.

July

Mr. Alan M. Fletcher of Cornell University completed his sabbatical leave as visiting editor, Office of Information Services.

Dr. Milton C. Rush of Louisiana State University joined the Plant Pathology Department as visiting plant pathologist.

Dr. Leslie E. Small of Rutgers University joined the Agricultural Economics Department as visiting agricultural economist.

Dr. John Leece of the University of Newcastle completed his sabbatical leave as visiting associate statistician, Statistics Department.

Dr. Robert N. Hurst of Purdue University completed his sabbatical leave as visiting communications scientist, Office of Information Services and Rice Production Training and Research Department.

Dr. Paidipelly S. Rao, associate plant pathologist assigned in Indonesia, resigned.

Mr. James E. Wimberly completed his assignment as acting team leader of the IRRI-Sri Lanka Project.

Dr. Theodore C. Hsiao of the University of California Davis completed his sabbatical leave as visiting scientist, Agronomy Department.

August

Dr. Lyle Nelson of the Mississippi State University completed his sabbatical leave as visiting scientist, Soil Chemistry Department.

Dr. James S. Townsend of the University of Manitoba joined IRRI as agricultural engineer assigned in Burma.

Dr. Satoshi Wakimoto of Kyushu University completed his sabbatical leave as visiting scientist, Plant Pathology Department.

Dr. Gilbert Waldbauer of the University of Illinois completed his sabbatical leave as visiting scientist, Entomology Department.

Dr. S.Y. Zee of Hongkong University completed his sabbatical leave as visiting scientist, Plant Physiology Department.

Dr. Donald W. Puckridge of the University of

Adelaide completed his sabbatical leave as visiting scientist, Agronomy Department.

Mr. Gemelo S. Alvez joined IRRI as assistant to the director general.

Dr. Louis T. Palmer, plant pathologist in IRRI's project in Indonesia, resigned.

Mr. Kenneth Paul Haydock of the CSIRO completed his sabbatical leave as visiting statistician, Statistics Department.

Dr. Ulysses S. Jones of Clemson University joined the Agronomy Department as visiting agronomist.

Dr. W. Harvey Reissig of the New York State Agricultural Experiment Station joined the Entomology Department as visiting scientist.

September

Mr. Carlos Garces, IRRI farm development engineer assigned in Indonesia, resigned.

Dr. Robert Brinkman of the Agricultural University, The Netherlands, joined the Soil Chemistry Department as visiting scientist.

Dr. Robert E. Huke of Dartmouth College joined the Agricultural Economics Department as visiting economist.

Dr. S. S. Virmani of the International Institute of Tropical Agriculture joined the Plant Breeding Department as plant breeder.

October

Dr. Hiroshi Sakai, agronomist of the IRRI project in Bangladesh, resigned.

November

Dr. Richard L. Tinsley, IRRI associate agronomist in the Sri Lanka project, resigned.

Dr. Sisira Jayasuriya joined the Agricultural Economics Department as associate agricultural economist.

December

Mr. Inocencio C. Bolo completed his assignment as consultant at IRRI's project in Pakistan.

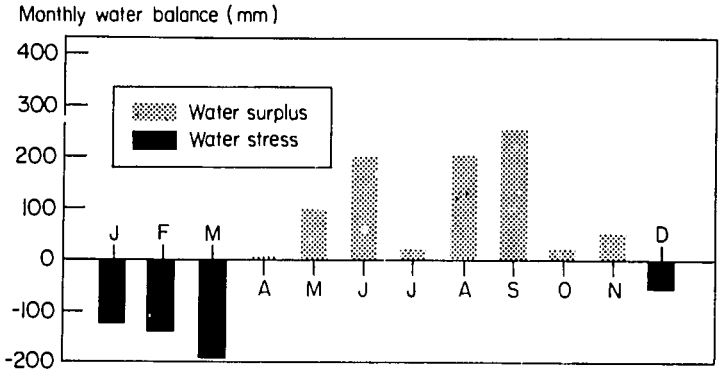
Dr. Kazushige Sogawa of the Tropical Agriculture Research Center of Japan completed his 2-year stay as visiting scientist, Entomology Department.

Dr. Donald W. Barton of the New York Agricultural Experiment Station, Cornell University, joined IRRI as visiting director for research management.

Crop weather

The 1979 total rainfall at IRRI was 1,889 mm. It was 754 mm less than that for 1978. The evaporation total was 1,605 mm for 1979 and 1,611 mm for 1978.

Table 1 presents IRRI climatic data for 1978-79. Rainfall for 1979 was far above the normal amount for April, continued above normal for May and June, but was substantially below average in July. Tropical disturbances from August to November influenced rain during those months. Rainfall in October and November was below normal but showed a positive water balance bacause of lower evaporation (Fig. 1). Because of lower than average rainfall at IRRI, solar radiation increased in July. In August and September solar radiation was above average, but in the remaining months of the year it approached normal values.



1. Water balance at IRRI, 1979.

Table 1. The climatic environment at IRRI for 1978–79.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					Rainfall (mm)							
1979	6.8	7.1	2.4	173.0	245.1	312.8	112.3	328.7	371.4	126.8	151.8	50.7
1978	21.5	8.9	6.4	28.7	210.8	76.7	239.6	535.3	495.0	714.6	220.9	84.2
Normal for 1966–75	49.9	14.0	33.0	27.6	135.7	229.3	279.5	249.0	208.3	248.5	314.7	258.6
					Evaporation (mm)							
1979	131.9	148.6	192.4	171.3	147.7	112.6	130.8	125.5	123.4	111.5	102.6	106.3
1978	121.3	127.2	197.3	194.8	190.7	130.2	133.3	78.3	99.5	116.5	109.7	111.8
Normal for 1971–75	126.6	124.7	161.6	181.8	175.5	193.3	136.4	129.0	131.2	111.9	115.2	95.9
					Solar radiation (g cal/cm²)							
1979	12,937	13,896	17,467	16,435	15,[illegible]28	13,988	14,901	13,910	13,937	12,252	11,395	11,984
1978	12,457	12,884	17,115	16,291	15,596	13,917	13,987	10,862	11,361	11,934	11,879	11,056
Normal for 1966–75	11,186	12,657	15,846	17,598	15,890	13,645	12,406	11,566	11,755	11,460	10,256	9,138
					Bright sunshine (h)							
1979	227.2	248.8	305.1	271.1	217.1	169.5	179.0	169.2	179.6	157.6	159.0	185.6
1978	205.9	205.2	304.6	277.0	242.9	166.4	182.3	91.3	129.1	139.9	182.4	143.3
					Maximum temperature (°C)							
1979	28.7	30.3	31.1	32.4	32.0	31.8	31.4	31.0	31.6	30.0	29.9	28.3
1978	25.0	24.4	30.6	32.0	32.4	31.5	31.4	27.8	30.9	30.7	29.8	28.6
Normal for 1966–75	27.8	28.8	29.8	31.8	32.8	32.1	31.4	30.2	30.8	29.9	29.3	28.4
					Minimum temperature (°C)							
1979	21.2	21.9	21.8	23.6	23.8	23.8	23.8	23.0	23.3	22.9	22.4	20.8
1978	18.2	17.3	2.4	23.6	24.7	24.4	23.6	23.2	23.4	23.0	22.7	22.8
Normal for 1966–75	22.3	22.4	23.0	24.5	25.1	24.8	25.0	24.4	24.7	24.4	24.3	23.9
					Relative humidity (%)							
1979	85	83	77	81	84	86	85	88	87	85	86	92
1978	79	79	76	74	75	80	85	91	93	94	93	92
Normal for 1966–75	81	80	76	77	79	78	79	82	82	82	81	81

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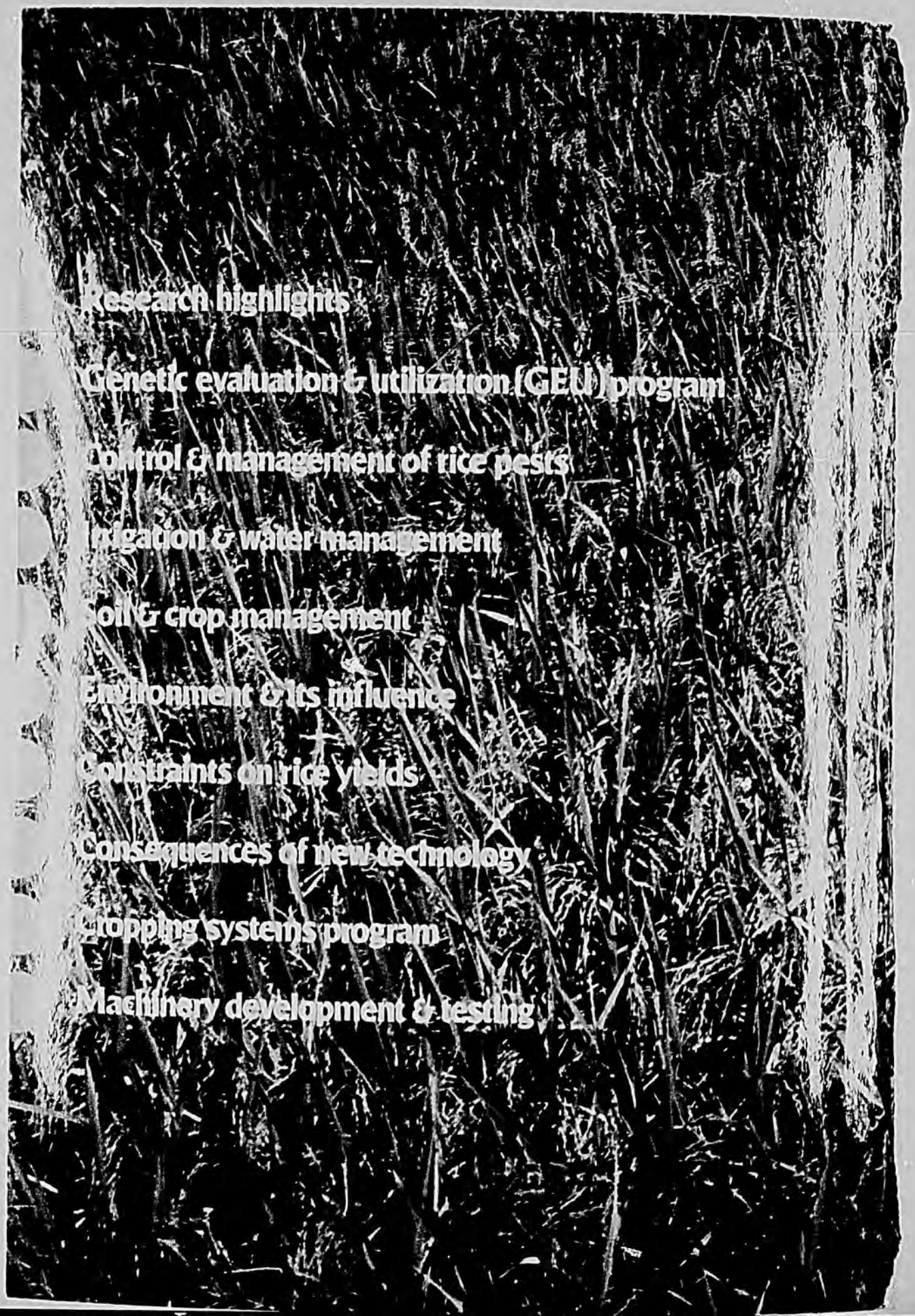

Research highlights

Genetic evaluation & utilization (GEU) program

Control & management of rice pests

Irrigation & water management

Soil & crop management

Environment & its influence

Constraints on rice yields

Consequences of new technology

Cropping systems program

Machinery development & testing