RICE RESEARCH STRATEGIES FOR THE FUTURE

INTERNATIONAL RICE RESEARCH INSTITUTE

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1982
INTERNATIONAL RICE RESEARCH INSTITUTE
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The responsibility for this publication rests with the International Rice Research Institute.

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FOREWORD

As the International Rice Research Institute starts its third decade it is fitting that we take a look at research strategies for the future. The Institute's first decade was clearly the decade of IR8, the first of the semidwarf modern rice that helped start the so-called green revolution in Asia. The second decade was one of broadened research and training activities as IRRI's program focused on the less advantaged farmers — those with rainfed crops, deep water, adverse soils, etc — and on assisting development of national rice improvement programs. Insect and disease resistance was bred into the high yielding modern varieties and rices with tolerance for drought, adverse soils, and deep water were in advanced stages of testing.

At the start of IRRI's third decade, the strategy papers, which we include here, and the discussions during this symposium have helped to again sharpen our research focus. IRRI's latest long-range plan reflects that sharper focus.

Thus, we start IRRI's third decade with a research *pipeline* filled with technology that will soon serve rice farmers and farmers who grow crops other than rice in rice-based cropping systems. Training of rice scientists and rice production specialists will increase and close cooperation with national rice production programs will continue. Several of those programs are at the point of takeoff in several countries of Asia.

This symposium on *Rice Research Strategies for the Future* (21-23 April 1980) was part of the annual International Rice Research Conference. The symposium planning committee was composed of M. D. Pathak as chairman and R. W. Herdt, J. C. Flinn, W. R. Coffman, T. T. Chang, V. R. Carangal, K. Moody, F. N. Ponnamperuma, I. Watanabe, and G. S. Alvez as members. Walter G. Rockwood, editor, and Corazon Mendoza, assistant editor, edited these proceedings.

M. R. Vega
Acting Director General

THE INTERNATIONAL RICE RESEARCH INSTITUTE AT TWENTY

C. C. GRAY III

Distinguished guest Dr. Harrar, other distinguished guests, trustees past and present, Dr. Chandler, Dr. Cummings, Director General Brady, members of the IRRI staff, ladies and gentlemen. It is my great pleasure to welcome all of you to IRRI on this, our Twentieth Anniversary celebration.

Lest we forget the foresightedness of those agricultural statesmen who brought IRRI into being, let me read to you a short passage from the Preamble to the Memorandum of Understanding between the Ford and Rockefeller Foundations and the Government of the Philippines regarding the proposal to establish IRRI:

> In view of the importance of rice as a human food and the interest of the Ford and Rockefeller Foundations in contributing to increasing the quantity and quality of available food crops for peoples of the world, these two foundations and the Government of the Philippines have during the past six months been discussing the desirability of establishing an international rice research institute at an appropriate location. It has now been decided that there is great need for a research institution of that character; that it should be located in Southeast Asia; and that the Philippine Islands could provide an ideal site for its establishment.

Before I identify those pioneering agricultural statesmen who responded to an urgent need by creating an appropriate institution in a favorable environment, let me complete some of the history. The proposal was approved by the Cabinet of the Republic of the Philippines on 6 September 1959. All the enabling conditions and requirements for the establishment of IRRI, which had been approved by the Cabinet, were later embodied in Republic Act 2707, passed by the Third Session of the Fourth Congress of the Philippines in May 1960. However, before this official approval and sanction, the Articles of Incorporation of IRRI had been filed with the Securities and Exchange Commission of the Philippines on 8 March 1960, and the Bylaws had been adopted and approved by the Members of the Corporation at a meeting in Manila on 14 April 1960.

Chairman, Board of Trustees, IRRI.

Now, who organized IRRI and secured its establishment? The record shows that there were five incorporators:

From the Philippine Government:

- Honorable Juan de G. Rodriquez
- Dr. Vicente G. Sinco
- Dr. Paulino Garcia

From the Rockefeller Foundation:

- Dr. J. George Harrar

From the Ford Foundation:

- Dr. Forrest F. Hill

Of those five incorporators and founders of IRRI, only one can be with us today. Mr. Rodriquez and Drs. Sinco and Garcia are deceased. Dr. Hill couldn't be here because of illness. We are pleased that you, Dr. Harrar, can be here on this special occasion.

After the incorporation and adoption of the Bylaws to govern the Institute, the members of the Corporation elected a self-perpetuating Board of Trustees. All of the original corporate members were elected Trustees and they elected five others, including the Director, Dr. Robert F. Chandler, Jr. Thus, the members of the First Board of Trustees (Charter Members) of IRRI were:

Dr. J. George Harrar, Chairman	United States
Dr. Forrest F. Hill	United States
Hon. Juan de G. Rodriguez	Philippines
Dr. Vicente G. Sinco	Philippines
Dr. Paulino Garcia	Philippines
Dr. Robert F. Chandler, Jr., Director	United States
Dr. K. R. Damle	India
Dr. Hitoshi Kihara	Japan
Dr. P. C. Ma	Taiwan
Prince M. C. Chakrabandhu	Thailand

These and other Trustees will be specially honored during this celebration; but we should recognize those members of the First Trustee Board who are here today —Prince Chakrabandhu, Dr. Kihara, and Dr. Ma.

In addition to the members of our first Board and our present Board, 32 others have served as trustees — all distinguished individuals from countries in Asia, Africa, and South America. The list of names reads like *Who's Who in the World.* Some of those trustees are with us:

Dr. Ralph Cummings (Former Director)	United States
Dr. Tojib	Indonesia
Dr. Salvador Lopez	Philippines
Dr. Sukhdev Singh	India
Dr. Kaung Zan	Burma
Dr. Parthasarathy	India
The Hon. C. Subramaniam	India
Dr. Ishizuka	Japan

Dr. Sala Dasananda	Thailand
Dr. Bhakdi	Thailand
Dr. Moseman	United States
Dr. M. O. Ghani	Pakistan
Dr. G. P. Viegas	Brazil
Dr. G. Satari	Indonesia
Dr. Shastry	India
Mr. Ahsan-Ud-Din	Pakistan

Since the establishment of IRRI, there has been a policy of electing Trustees from various parts of the world where rice is important. In keeping with that tradition, our present Board of Trustees is composed of distinguished individuals from 12 countries of Asia, Africa, North America, and Central America. They are:

Dr. Clarence C. Gray III, Chairman	United States
Min. Arturo R. Tanco, Jr.	Philippines
Dr. Nyle C. Brady	United States
Dr. Norman R. Collins	United States
Dr. Emmanuel V. Soriano	Philippines
Mr. Alban Gurnett-Smith	Australia
Dr. M. Amirul Islam	Bangladesh
Mr. Lin Shih-Cheng	People's Republic of China
Mr. S. W. Sadikin	Indonesia
Dr. Hans W. Scharpenseel	Germany
Dr. Mustafa M. Elgabaly	Egypt
Dr. H. K. Pande	India
Dr. In Hwan Kim	Korea
Dr. Francisco de Sola	Guatemala
Dr. Tomoji Egawa	Japan

With a Director and Trustees, and approval and support of the Government of the Philippines and the University of the Philippines, the Institute was ready to begin in 1966. But it couldn't begin without a staff. The Director systematically recruited a remarkable international scientific staff, adroitly balanced between seasoned scientists of demonstrated ability and brilliant young people with great potential. It is not possible to mention all who were here in those days and months in establishing the Institute, but there is a special group that deserves special recognition. It has been said, "that the race is not to the swift or to the strong, but to he who proves faithful to the end." IRRI has been blessed with just such a group of faithful people. In reviewing the staff listed in IRRI's first and last annual reports, I found the following names. I have listed them in alphabetical order:

T. T. Chang
B. O. Juliano
Lina Manalo-Vergara
Rebecca Pascual
Mano D. Pathak
Z. Q. Pizarro

Felix N. Ponnamperuma
Federico V. Ramos
Faustino Salacup
Orlando Santos
B. S. Vergara

To this list I also add Henry "Hank" Beachell, who headed the breeding program for so many years and is still on the job. And there are two others here that I cannot overlook: Dr. D. S. Athwal and Dr. Colin McClung.

These are loyal and faithful staff who have devoted a major portion of their lives to making IRRI what it is today. We and many others throughout the rice-producing world are indebted to them for their many and varied contributions.

An anniversary is more than a time for celebration. It is a time for assessing accomplishments and anticipating the challenges ahead. But it is also a time for recognition — recognition of those that have made a Twentieth Anniversary possible. Very little of what has happened would have been possible without the necessary funding. In the beginning it was the Ford and Rockefeller Foundations that provided the funds. And of course, the University of the Philippines provided the land — which was really better than money. But, it soon became necessary to secure greater funding if the Institute was to accomplish its mission. Over the years, individual country donors, multilateral assistance agencies, development banks, and private donors have responded generously to IRRI's needs for core support and special-project funding. At last count, there were more than 20 donors contributing roughly $20 million annually to IRRI's operations, and IRRI had a headquarters facility valued at close to $25 million. This has all been possible through a diverse group of donors that has given generously over the years. In recent years, the FAO, the UNDP, and the World Bank have sponsored the Consultative Group for International Agricultural Research. This consortium of public and private donors now provides financing for the approved basic operations on an annual basis. This arrangement has provided the assured funding and financial stability required to undertake enduring programs. Many representatives of the Consultative Group and individual donors are with us today. IRRI, its Trustees, and staff, are indeed grateful and appreciative of the generosity of the donors. We will continue to express our thanks in words and in deeds that contribute directly to rice improvement in rice-producing nations and indirectly to improvement in the lives of the millions who depend upon rice for food and income.

A successful international center must have, aside from founders, Trustees, staff, and donors, a loyal group of allies — collaborators and cooperators — both in the countries where the rice problems exist and in other countries where special expertise and resources reside. If IRRI had not been able to secure the interest and help of a host of scientists, educators, administrators, and government officials in rice-producing nations, it would have been just another sterile, ineffective research enclave working in splendid isolation from the world. The goodwill, entré, knowledge, assistance, and cooperation from the rice-growing nations afforded IRRI

from its beginning contributed greatly to making it what it is today. It is doubtful if very much would have been accomplished without such nations' free and gracious sharing of rice germplasm, research results, experience and know-how, and, above all, their scientists to help staff and work with IRRI.

Other important allies of IRRI reside in institutions, laboratories, agencies, and experiment stations where expertise, technology, and research capacity of current or potential value to the improvement of rice and its production exist. Over the years, IRRI has drawn heavily on and benefited enormously from such expertise from countries throughout the world. For example, from the beginning, Japan has provided outstanding scientists to conceptualize and lead important lines of research. Australia gave and constructed our phytotron. One of our Trustees, Hans Scharpenseel, left his laboratory in Germany and came out to help with the soils program in the early days. And there was Prof. Frans Moormann from the Netherlands, a world authority on soils, who helped us by writing a definitive text on rice soils. I mention these as examples to make the point that a stream of distinguished scientists has provided great support to IRRI and the nations it serves. To the many invited guests from the countries, institutions, and agencies that have provided support, we express our gratitude for their help as allies and cooperators. We would like to thank all of our allies individually, but unfortunately I don't have all of their names; thus, I would risk an unfortunate slight. Under the circumstances, I express our thanks to them collectively!

I have stressed the importance of various groups that have contributed importantly to making IRRI what it is on this Twentieth Anniversary — the founders, the Trustees, the staff, the donors, and our allies. I have saved for last, recognition and everlasting thanks and appreciation to our hosts, the people of the Philippines, who provided us with a home and all that goes with home, such as friendship, care, and attention, understanding and forebearance when we made mistakes, counsel, direction, land, privileges and special dispensations, and security. Our benevolent hosts, the Government of the Philippines and the University of the Philippines, particularly the Los Baños unit, made it possible to use the inputs of all the others. One could spend most of the anniversary days recounting and citing the many Philippine institutions, agencies, and individuals who have contributed in manifold ways to the birth, growth, and development of IRRI. It is not possible at this time to mention each and every one. In the last decade, two persons stand out in every respect in their support for IRRI.

One is Minister of Agriculture Arturo Tanco, who has been a Trustee for 10 years. Bong, as we affectionately call him, has been a dedicated Trustee and a friend of IRRI all the way. IRRI has been fortunate to have such a Trustee.

The other person is President Ferdinand Marcos. The first time I met President Marcos was at the Presidential Palace in 1972, when he hosted a reception in honor of IRRI and feted Drs. Harrar, Hill, and Chandler. Over the years, he has provided tremendous goodwill and support for IRRI. No international center has had such support from a Chief of State as IRRI has had from President Marcos. Through his support, the Government of the Philippines has afforded the Institute official

recognition as an "international organization." On behalf of our Trustees, staff, donors, and friends, I say to the people of the Philippines, "Thank you!"

Thus, good friends, allies, and colleagues, we have gathered here today to celebrate our Twentieth Anniversary, to give thanks, to take note of progress, and to prepare for the future.

With regard to progress, the many physical changes and improvements that have been effected are quite apparent and discernible to all and appreciated. But there are many more profound and far-reaching changes and improvements, here and elsewhere, that are not readily apparent. Dr. Brady, our Director General, will detail these for you.

Speaking of Dr. Brady, let me say that we have had great fortune indeed in getting this remarkable scientist-administrator and keeping him. During the past several months, it has been touch-and-go as to whether he would be with us. In fact, we gave him a leave of absence last December, but he's still on the job and we consider ourselves fortunate, indeed.

I recall vividly the first Trustee meeting after Dr. Brady became Director General. At that meeting, although he praised the achievements of IRRI profusely, he said that there was a need to shift the thrust of research from the Los Baños headquarters — "from the world of IRRI" — more to "the world of the rice farmer." That is exactly what he has done.

He also let it be known that although IRRI had made considerable progress in assisting nations to increase rice production, he did not believe the magnitude of the effort was commensurate with the problem. Largely because of his vision, capacity, and untiring — almost relentless — efforts and his special ability to convince staff, Trustees, and donors, IRRI now has a capacity to serve that is more equal to the task — both present and future.

Prime Minister of England Margaret Thatcher has called the 1980s the "Dangerous Decade." For those of us who work in agriculture, particularly in Asia where the press of burgeoning populations on the food supply is greatest, the 1980s are indeed a dangerous decade. Although we have had a measure of relief in the past several years due to generally favorable weather, the next food crisis is predictably right around the corner. It is imperative, therefore, for all of us to strengthen our resolve and determination in a manner exemplified by Dr. Brady, and redouble our efforts, individually and collectively.

On behalf of our Trustees and staff, we thank you for your support and for taking time out to be here on this auspicious occasion. We sincerely hope your stay with us during the commemoration of this important milestone in IRRI's existence will be pleasant and rewarding.

A SALUTE TO THE INTERNATIONAL RICE RESEARCH INSTITUTE

F. E MARCOS

Twenty years ago today, the International Rice Research Institute, the first truly International Research Organization for a Tropical Food Crop, was established in Los Baños.

IRRI was built on the vision of scientists who believed that with determination, dedication, and funding, science could contribute immeasurably in the task of feeding a hungry world. The dedicated men and women of IRRI have shown how this combination can work. Within 6 years of its founding, IRRI produced the high-yielding varieties that brought about the major breakthrough in food production in Asia, widely characterized as the green revolution. Today, with 20 years of distinguished studies benefiting the rice-growing and rice-consuming world, IRRI stands as a shining example of humanitarian service. I stand along with the 1.5 billion rice-eating peoples of this earth to salute the men and women of this Institute on your 20th anniversary celebration.

By your pioneering and excellent work on tropical agriculture, you have shown the way to other research entities. Today, over 20 international research organizations worldwide are dedicated to evolving new and improved agricultural techniques for the tropics, focusing at last on the needs of the developing world.

As a Filipino, I am proud of the role that the Philippines has played in making IRRI a living reality. In 1960, the Philippine Government made available to IRRI 80 ha of land on which to build its offices, laboratories, and experimental fields. In 1975, when IRRI needed more land, we made available another 185 ha.

You will agree that our relationship has not only been long, it has also been fruitful. We have not been merely a host country, but a partner in cooperative research. IRRI scientists have joined our Filipino scientists from the Bureau of Plant Industry and various branches of the University of the Philippines and other universities, as well as other government agencies in joint programs to alleviate hunger and poverty.

Perhaps the best example of cooperative action between IRRI and the Philippine Government is the Masagana 99 Rice Program. In the 1960s, the Philippines

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Address of President Ferdinand E. Marcos, Republic of the Philippines. An address read by Minister of Agriculture Arturo R. Tanco, Jr.

chronically suffered from a shortage of rice, our staple food. Runaway population growth made it difficult for an agricultural society using age-old cultural practices and inferior seed varieties to meet the most basic food requirements.

But when the first high-yielding varieties came out of IRRI in 1966, the situation began to change quickly. By 1969, the new rices had spread to cover over 50% of our total hectarage, and our rice production rose, this time more rapidly than our population.

Record floods and droughts hit us in 1971 and 1972, however. Production slumped, and by 1973, we were again importing hundreds of thousands of tons of rice annually to meet our needs.

In 1973, we undertook the large-scale application of a technology for increased rice production developed jointly by IRRl and our government scientists at BPI and UP at Los Baños. We called it Masagana 99 and it involved the use of high-yielding varieties along with improved cultural practices developed by IRRI and the BPI. We removed the financial constraints on the farmer by providing him with noncollateral credit and subsidizing his supply of fertilizers and other chemicals. We established a price–support scheme to ensure the farmer a profitable price in case market prices fell at harvest time.

Masagana 99 was a resounding success. Within 3 years, we stopped importing rice. By the fifth year, we had enough surplus for export.

Even with a program for expanded grain storage, however, our facilities proved inadequate for the expanded production. Our problems now have to do with storage and keeping farm prices high enough for farmers to find it profitable to continue planting.

But we are pleased to be able to provide rice for others. We are pleased with our new status of rice exporter. At the same time, we intend to keep significant quantities of our rice production in storage as a hedge against destructive typhoons and droughts that could again tax our ability to provide rice for our people.

Other examples of successful cooperation between the IRRI and the Philippine Government are projects to increase production by farmers who grow rice in rainfed areas — KABSAKA in Iloilo and KASATINLU in South Cotabato. From one crop a year averaging 1.2 t/ ha, which was all we got out of nonirrigated land, these rainfed areas now average two crops yearly, yielding 9 t/ha. Annually, the multi-cropping technology applied in the KABSAKA and KASATINLU projects could be used in our vast rainfed areas, which total 1.9 million ha.

The Philippines is by no means the only country benefiting from IRRI's research. The Institute's responsibilities and goals extend beyond the Philippines — to at least 1.5 billion of the earth's 4.5 billion population who depend on rice for more than half of their total nutrition. For these people, the word *rice* is synonymous with *food* and it is IRRI’s responsibility to see to it that these people — most of whom are the poorest of the world's poor — get the necessary varieties and technology to produce the rice they need.

IRRI is not alone in this task. Throughout the developing world, a scientific revolution has been taking place in agriculture. India, Pakistan, Korea, and the

Philippines in Asia, Kenya and the Ivory Coast in Africa, and Colombia and Cuba in Latin America are shining examples of how the proper use of science and technology can reverse a food crisis. Onnly 2 decades ago, this could not have been possible.

Understandably, before the 1960s, most research was centered on the needs of the richer and more developed part of the world that produced temperate crops. Today, there are high-yielding disease-resistant varieties available to the tropics, where most of the developing world lies, due mainly to the advent of these institutes.

The experience of the Philippines in the last decade is an example of the kind of problems a developing country has to meet in attempting to improve its level of food production, and the kind of achievement possible with the use of research in science and technology. In 1973, we created the Philippine Council for Agriculture and Resources Research (PCARR) to coordinate, integrate, and monitor all agricultural research activities. PCARR established a listing of research priorities, eliminated overlapping projects, and launched new ones to fill in the gaps that had been overlooked. With PCARR overseeing our research efforts, I am confident that we are on the right track, that all our efforts and resources are going into studies that are relevant to our needs, and in accordance with our priorities.

The next thing we did was to elevate the University of the Philippines at Los Baños (UPLB) into an autonomous university within the University of the Philippines system. The results of this are obvious in the new initiatives and fresh vigor evident on the campus, the realignment of research and education to meet the needs of the rural poor, and the training of young people to be qualified field technicians. UPLB is, at present, involved in the upgrading of other agricultural colleges and universities in the country, shaping them into specialized institutions worthy of the name and staffed with qualified scientists and educators.

Today, the Central Luzon State University (CLSU) in Nueva Ecija specializes in grains research. The Visayas State College of Agriculture in Leyte is a center for research on root crops. The University of Southern Mindanao is involved in research on horticultural crops such as rubber, palm oil, and fruits. The Central Mindanao University focuses on research in cattle, pastures, and feedgrains like corn and sorghum.

We have established new research institutions to complement existing ones. In Los Baños, we set up in 1975 the Institute of Plant Breeding for research in corn, sorghum, wheat, root crops, forage crops, vegetables, legumes, abaca, cotton, and fruits. Also in UPLB the National Crop Protection Center was set up in 1976. We are now in the process of establishing an institute of microbiology.

For fisheries, we have the Southeast Asian Fisheries Development Center (SEAFDEC) in Iloilo, a foreign-assisted ASEAN project for the development of technology in prawn and shrimp production. We have a brackish-water aquaculture station, also in Iloilo, and a fresh-water aquaculture center in CLSU. At CLSU, we have developed technology for the culture of fish in rice paddies.

Research in cotton and tobacco are centered at the Mariano Marcos State University in Batac, Ilocos Norte, where we have established the Cotton Research

and Development Institute and the Tobacco Research Center.

All of this progress has of course been accompanied by vastly increased funding by the national government for research, from a little less than ₱10 million to ₱120 million last year. This has been supplemented by foreign loans and grants totalling $25 million in the last few years alone.

Our programs in agricultural production, which are all research-based, using better varieties and improved cultural practices, have increased production and, as a result, rural incomes. The Masagana 99 farmer, for example, with an average farm size of 2.3 ha, nets ₱3,l00 per crop, an increase of 280% over the pre-Masagana earning of ₱815 per crop, in spite of the higher costs of inputs at present.

The quantum leap in agricultural research by international organizations has occurred only in the last two decades. IRRI, the oldest international research institute in the world, is only 20 years old. This means that it has only been 20 years since the world first took a firm step toward combatting the problem of food shortage.

Obviously, the world reacted too late. Today, food production, though significantly increased, can hardly keep up with increases in population so that, in effect, we are only marking time.

According to a United Nations report, substantial gains have been made in Asian agriculture. From 1969 to 1978, Asian countries registered agricultural growth rates ranging from 8.3% in Bangladesh to 41.6% in the Philippines. While the numbers sound impressive, the picture changes when population growth is taken into consideration. Four countries — Bangladesh, Burma, Pakistan, and Vietnam — though registering significant increases in production, actually produced less per person due to the high rate of population growth. For these countries, it is not even a case of marking time.

The Philippines has fared better in this regard. Improved methods have increased per capita food production by 16.12% in 8 years so that we are one of the few real gainers in Asian agriculture in the past decade.

Having looked into the problem of hunger rather belatedly, mankind's present efforts in food production are in the nature of trying to catch up with a moving target. We have to maximize production efforts to produce the largest amount of food possible to keep abreast of galloping population growth. This can only be done through scientific and technological research.

To illustrate, according to the International Food Policy Research Institute, our present population growth rate and rate of increase in rice production could mean that the Philippines must import rice again by 1990.

This prediction, however, is valid only if present trends continue. But man has the power to alter his environment and shape his future. That is why research is so important. It is man's way of controlling his environment, his future, his destiny.

The world today is faced with two pressing problems: the matter of food and the matter of energy. Both are expensive and essential. And both are within our power, as scientists and policy makers, to control and shape to help mankind.

I, therefore, enjoin you, in your work, to take into account the energy crisis and

increase your efforts at improving efficiency in food production.

Most ASEAN countries must import costly petroleum and petroleum-based fertilizers and pesticides to keep production at desired levels. It is critical therefore that you continue with the development of nitrogen-fixing technology which will lessen our dependence on nitrogen fertilizers. We also continue to need more varieties with built-in resistance to diseases and insects — to decrease the farmers' overdependence on expensive and sometimes toxic pesticides. Accelerated research on the efficiency of fertilizer and pesticide use is vital if we are to save on foreign exchange, which is a concern of all developing nations.

We also continue to need research on varieties that can resist periodic droughts in order to increase production in rainfed areas. At the same time, we need varieties that can withstand the cold temperatures of the Mountain Province in the Philippines and the highlands of Indonesia, India, and Nepal. Success in research on such varieties would vastly improve the living standards of the thousands of poor farmers in these areas.

Future technology in rice and other crops must take into account the fact that the farmer in the developing world is poor and that he cannot afford the technological resources that his western counterpart puts into his crops. Furthermore, the consumer is poor and he cannot afford to purchase expensively produced food crops. There cannot be much point in inventing new methods or innovations if the ordinary resources cannot put them to good use. We must take care that the introduction of these improved methods does not widen already existing social inequalities in the rural areas. Development must not result in rich farmers growing richer and poor ones poorer. Those who are in most need of food must be given the opportunity to buy it.

The problem of hunger and want will continue to be a burden and a challenge to governments everywhere but I am confident that we who meet here today, the scientists and technicians of IRRI, have the capacity to help win this struggle. We have demonstrated this in the last 20 years. God willing, we will continue to demonstrate this for the benefit of mankind in the years to come.

Thank you and congratulations again on this your twentieth year of success. Good day.

IRRI'S SECOND DECADE

N. C. BRADY

IRRI and associated national rice improvement programs made remarkable progress during IRRI's first decade. Conceived by a group of visionary planners, IRRI helped initiate a new era for agricultural research, and international cooperation. Harrar, Hill, Umali, Kihara, Cinco, Rodriquez, Bradfield, and Chandler formed the core of that visionary group. As we enter the second decade of IRRI, full tribute must be paid to these great men.

Special recognition should be given to Dr. Robert F. Chandler, Jr., the first director of IRRI. He helped develop the blueprint for IRRI and gave it aggressive leadership for its first 12 years. He was a director and an intellectual leader; he was also a keen scientist. He was a good judge of programs and people; he gathered the foremost scientists from major rice-growing countries around the world; he put together one of the most innovative scientific groups in the history of world agriculture. From the start, the importance of collaboration with scientists from other countries characterized IRRI's programs.

IR8 AND THE GREEN REVOLUTION

The release of IR8 in 1966, only 4 years after IRRI's primary buildings were dedicated, electrified the rice-growing world. IR8 and associated rices and wheats in national programs initiated what became commonly termed the *green revolution.* The new varieties revolutionized the scientists, giving them a role and respect they had not enjoyed before. They revolutionized the attitude of national leaders from both the developing and the more developed countries who suddenly recognized that science had a role to play in helping to meet the world's food requirements. And, of course, the new varieties revolutionized farmers who heretofore had been dependent entirely on traditional varieties that gave low yields — and took 160-180 days to produce those yields.

But the early successes of IRRI and its partners in national programs brought about great expectations, not only from the leaders in the rice-growing countries but

Director general, IRRI.

from their counterparts in the more developed areas who were equally concerned about the world's food and population problems. The direct extrapolation from yields obtained in the researchers' fields to those which farmers were expected to obtain suggested that production could soon outstrip the world's food needs. Attention began to be focused on the so-called second-generation problems, including marketing, income distribution, and the problems of food surpluses. Those who took a simplistic view reasoned that with the new rices and wheats, much of the food production battle had been won. They began to be concerned more with surpluses than with food shortages.

We now know that expectations and reality did not coincide. Food production remained far below the levels predicted. Even with the new cereal varieties, production per capita in the developing countries remained essentially unchanged. During the decade that followed the release of IR8, rice yields increased significantly only in the irrigated areas. During 1972-74 droughts and floods were responsible for an actual reduction in the food production per season in the developing countries. Worldwide food shortages resulted.

The enormity of these problems forced the realization that simplistic solutions were not the answer to the world's food production problems. It became clear that new cereal varieties alone were not the answer to the world's food problem. Casual observers said that the green revolution had turned brown. The situation was well described by Dr. Chandler at the Third World Food Conference of 1976 at Iowa State University:

> "Many of us who were directly involved in improving the productivity of the rice plant and its management expected that by 1976, a decade after IRRI developed its first-named, widely distributed variety, IR8, rice production in Asia would have *increased by at least 50 percent.* Obviously, we were wrong. The best that we can do now is to examine more carefully the constraints to production on farmer's fields in an attempt to find out why average yields are so far below those consistently being obtained on experimental fields or in carefully supervised on-farm trials."

The situation in 1973 can be summarized:

- IRRI and its associates in national programs had been successful in scientific accomplishments. They had successfully demonstrated higher yield potentials;
- The confidence of scientists and national leaders had been successfully gained;
- There was less success in increasing rice production.

Three approaches were taken in 1973:

1. Find out why farmers were not producing more food. *What were their constraints?*
2. Orient internal research to the removal of those constraints.
3. Build on the successes of earlier years to organize and implement international cooperation through formal research networks.

In the comments that follow, keep in mind that the international networks have been the primary mechanism through which IRRI cooperates with counterparts in

the national programs. These networks not only have helped achieve goals but also have been responsible for greater cooperation among scientists in the national programs. They include the International Rice Testing Program, the International Rice Agroeconomic Network, the Cropping Systems Network, the International Network on Soil Fertility and Fertilizer Evaluation for Rice, and the Farm Machinery Network.

PROGRAM AT IRRI

Programs implemented at IRRI headquarters were primarily in four major research areas:

1. The genetic evaluation and utilization, or GEU approach, an interdisciplinary effort to produce rices suitable for the major ecological situations in the world, was developed.
2. A greatly expanded program on rice-based cropping systems aimed at increasing crop intensification by growing more crops per year was initiated.
3. Component technology that would permit the new rice and cropping systems to produce most in field conditions was developed.
4. An attempt was made to determine the effectiveness and consequences of the new technology through socioeconomic research.

Genetic evaluation and utilization

Perhaps the most significant change in IRRI's research approach is that relating to GEU, an interdisciplinary and international attempt to develop and test rices that will perform well in the face of high pest infestation, excess or deficient water supply, high or low temperature, and adverse soil conditions. Teams of problem-area scientists and plant breeders work together in each problem area to develop more effective and responsive rice varieties.

The GEU program has genetic resource conservation as its basis and includes collection of rice genetic resources from around the world and its conservation in one of the world's most modern seed handling and storage facilities. The collection now has more than 50,000 varieties and lines of rice. It is a seed bank, into which varieties are placed but from which they are also removed for scientific purposes. Seed samples from the world collection are used extensively by scientists at the IRRI headquarters and by cooperators in the national research programs.

For GEU research, IRRI has developed strong teams of scientists for several research areas:

- *Agronomic characteristics.* IRRI seeks improvement of the agronomic characteristics of new rices. Progress in reducing the growing period of high yielding rices has been continuous. Most traditional rice varieties need at least 160 days to mature. This period has been reduced to 100-110 days for modern varieties. The difference in the average growth period required between varieties under test in 1969 and in 1978 was nearly a month. Some of IRRI's promising

high-yielding breeding lines mature in 90-100 days and have yield levels similar to those of IR36, probably the world's most widely grown variety of IRRI origin.

- *Pest resistance.* Progress made in the last 10 years to develop plant resistance to diseases and insects has been significant. The devastating tungro virus that struck the Philippines in the early 1970s gave IRRI an opportunity to fully evaluate the disease resistance of some of the new varieties. IR20, because it is resistant to the green leafhopper, which transmits the tungro virus, helped prevent a serious tungro virus outbreak.

But it was the brown planthopper that gave the greatest challenge to scientists throughout the rice-growing world in the past decade. This insect remains a serious problem from the equator to as far north as Japan and northeast China. IRRI GEU scientists initiated a program to control this pest by screening tens of thousands of rice varieties and lines to determine their resistance to it. Soon after I joined IRRI in 1973, the release of IR26 provided rice farmers with a rice resistant to brown planthopper and quickly brought the pest under control in central Philippines.

Scientists at IRRI and their colleagues in national research programs soon learned, however, that the brown planthopper was a more persistent enemy than they had originally anticipated. Several biotypes of the pest existed and each of them was able to attack different rice varieties. That made it necessary to treat each biotype as a separate insect pest. At IRRI a plant breeding and entomology team immediately screened thousands of rices for resistance to the different biotypes found in the Philippines. Genetic resources were exchanged with scientists in India, Thailand, Sri Lanka, Indonesia, and elsewhere to gain more information on the possible biotypes present in those areas. Of the nearly 6,000 rice varieties tested by 1976, only 48 had resistance to the 3 biotypes common in the Philippines, and even those resistant rices were not resistant to some of the biotypes found in India and other Asian countries. Nevertheless, by joining forces in an international network of cooperators, it was possible to bring the brown planthopper under reasonable control.

Work on the brown planthopper is continuing. During the past 10 years, IRRI and its cooperators have tried to determine why one variety resists a given pest and another is susceptible. An approach used is to determine the biochemical basis for insect resistance. It is definitely known that in some cases chemicals contained in resistant plants are responsible for the resistance.

- *Drought resistance.* GEU efforts to find rice varieties that will resist drought have been accelerated. A team of scientists working on this problem identified wide differences in the root distribution of plants resistant or susceptible to drought. In greenhouse and field tests, remarkable differences have been found in the ability of rice varieties to recover quickly after long periods of drought. Likewise, varietal differences were found in the ability to tolerate high levels of aluminum, which are common in very acid soils. Some of the original IRRI varieties such as IR8 were not tolerant of these acid conditions.

- *Deepwater and flood tolerance.* IRRI scientists cooperated with GEU colleagues in South and Southeast Asia to develop rices that would tolerate deep flooding. Some varieties are tested by submerging them in water in IRRI greenhouses and fields but it is in Thailand that the primary research effort is under way. There, in cooperation with scientists in the Ministry of Agriculture, an impressive joint research facility was developed, and outstanding modern rices have already been released for use by the deepwater rice farmer.
- *Adverse soils tolerance.* About 100 million hectares of otherwise good rice lands have soil deficiencies or toxicities that provide a challenge to rice researchers. There being varietal differences in the ability to tolerate an adverse soil condition, thousands of varieties from the germplasm bank and elite lines from the IRRI breeding program are screened to ascertain resistance to salinity, alkalinity, acidity, iron toxicity, and zinc and phosphorus deficiencies.
- *Temperature tolerance.* Rice grows in a wide range of temperatures. Field testing sites have been created to evaluate the tolerance of rices for temperature extremes. Such research ranges from experiments in the Mountain provinces of the Philippines to cooperative work with scientists at sites in India, Nepal, and Korea. The Office of Rural Development in Korea has provided a modern facility for joint testing of low-temperature tolerance of rices. This truly cooperative program will serve not only for the Korean farmer but for farmers in all areas where low temperatures prevail at some time during the growing season.

  The expanding interest in evaluating rices from the germplasm bank and from the IRRI breeding programs, which I have touched on so far, has greatly increased the volume of genetic materials handled in the GEU program. Each year, about 500,000 varieties and lines are evaluated in the GEU program. In addition, about 5,000 crosses are made, more than 1,000 F_2 combinations are grown, and more than 1,000 pedigree lines are tested.
- *Genetic background of modern rices.* A comprehensive study of the genetic background of the modern rice varieties was made in cooperation with rice scientists in Asia. The study showed a narrowing of the genetic background of rices used by farmers. Most IRRI varieties trace to a few common parents. Already steps have been taken to broaden this genetic base.
- *Worldwide rice testing.* The International Rice Testing Program (IRTP) provides a worldwide framework for the testing and evaluation of rices from throughout the world — 250 research stations in 75 rice-growing countries on 5 continents cooperate in the IRTP network. The results from worldwide tests are forwarded to IRRI where computers make reports for quick return to cooperators.

  The IRTP has had a significant effect on national rice production efforts. Rices from one country are released for farmers in other countries after evaluation through IRTP. This truly emphasizes international cooperation.

  An important feature of IRTP is a system of monitoring tours. Scientists from rice-growing countries visit each other's field trials to observe IRTP results. Through these tours, 187 active scientists from 35 countries have visited

126 different rice research stations, institutes, or universities in 32 countries of Asia, Africa, and Latin America.

- *Computerization of data handling.* The large number of rices in the germplasm bank, in the crossing and pedigree program, and in IRTP makes computerization of data handling essential. The GEU programs make effective use of the computer to store millions of bits of information on more than 100,000 lines and varieties of rice. Information from that data bank can be quickly printed to provide researchers anywhere with valuable data on rices in almost any combination desired. The computer is also used extensively to handle the voluminous data coming from on-farm record-keeping used in the IRRI cropping systems and constraints programs.
- *Innovative breeding.* To complement the GEU programs. IRRI cooperates with scientists in other countries to develop and use innovative breeding techniques. For example, colleagues in China have made considerable progress in the development and production of hybrid rice varieties using IRRI lines as one of the parents. IRRI breeders have used the Chinese techniques to produce hybrids at IRRI headquarters and in 1980 developed a joint training program with China's Hunan Academy of Agricultural Sciences to allow scientists from other Asian countries to study the hybridization techniques.
- *Rapid generation advance.* IRRI has helped scientists in national programs reduce the time between an initial cross and the release of a variety through rapid generation advance. A special greenhouse-dark room combination at IRRI makes it possible to artificially adjust day length and encourage the flowering of photoperiod-sensitive rices. That makes growing of three crops a year possible for the scientists in the national programs, who could get only one crop in his field plots. As a consequence, the time taken to fully evaluate a given photoperiod-sensitive variety is shortened from 7 to 5 years.

  In 1979 IRRI started cooperating with scientists from China, India, Japan, Australia, United Kingdom, and the United States on tissue culture techniques to improve rice varieties. Rice plants are being regenerated through anther culture, a technique that should make it possible to greatly increase the eff-ciency of screening rices for resistance to diseases and tolerance for salts, alkalinity, and drought.
- *Pest control and management.* The control and management of rice pests by other than host resistance is a major research problem area at IRRI. The interaction between certain diseases and the insect pests that transmit them has been studied. For example, there is a good relationship between the green leafhopper level in the field from April to June and the incidence of the tungro virus, which the insect transmits, from June to October. That suggests that the early measurement of the vector population can predict a tungro virus infestation.

  Several chemicals have been found effective in the control of rice diseases, especially in the seedbed.

  Chemical methods of controlling insects have also been developed and tested.

For example, pesticides placed in the soil were remarkably successful in controlling the brown planthopper. The plant's absorption of the chemical prevents insect damage.

IRRI cooperates with scientists from the International Centre of lnsect Physiology and Ecology, Japan, the United Kingdom, and the United States, in testing the techniques for controlling insects by nonchemical means. For example, various predators and pathogens have been found to keep certain insect pests in check. In the People's Republic of China, young ducklings in the rice field thrive on brown planthoppers and keep their infestation at a reasonable level.

Unfortunately, certain pesticides have caused a resurgence of the brown planthopper. After frequent sprayings of such chemicals, the brown planthopper tends to build up to levels far higher than when no insecticide is used. Such resurgence does not occur with all pesticides. One reason for the resurgence may be the adverse effects of the pesticide on predators of the insect pests.

Certain naturally occurring chemicals have been found to have pesticidal properties. For example, trans aconitic acid extracted from ordinary barnyardgrass definitely inhibits the hatching of the brown planthopper eggs.

In weed pest research, a low-cost herbicide treatment for controlling certain grasses and broadleaved weeds was developed. Excellent control results from the application of a chemical, 2,4-D, before the emergence of the weeds.

- *Irrigation and water management.* Water management research has concentrated on identifying factors influencing on-farm irrigation water distribution. For example a study in Central Luzon, Philippines, showed wasteful use of water for land preparation. While much of the high water requirement could be justified to meet leaching, soil wetting, and evaporation, much of the water added was not needed. Poor distribution of water among farmers was also found in a given irrigation scheme. On those farms in the first segment of the system, which were near the irrigation canal and where excessive water was used, the rice plants had little moisture stress. Because of such excessive use, however, the efficiency of the water used was much lower than on farms farther down the distribution channel, where farmers suffered from lack of water.
- *Soil and crop management.* Work of IRRI scientists on the reaction of fertilizers when placed in the soil is highly significant. The root-zone placement of urea was found as effective in the tropics as in experiments in Japan. By placing fertilizer in the root zone rather than splitting the application and placing part of it on the surface, the efficiency of the fertilizer applied was essentially doubled.

  In subsequent experiments, some of the reasons for the efficiency difference were discovered. Placement of the urea in the root zone markedly reduced the loss of nitrogen through ammonia and through other gaseous forms such as nitrous oxide. This research work is done in cooperation with the International Fertilizer Development Center (IFDC) and with scientists from South and Southeast Asia and Australia.

  The root-zone treatment was compared with other means of applying nitro-

gen by scientists from 9 Asian countries through what is now termed the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER). These cooperating researchers showed an added value of rice output of US$30–60/ha merely by placing the fertilizer in the root zone. The implications of these findings are obvious in view of the rising energy and fertilizer costs.

Different means of biologically fixing nitrogen for a rice crop — by blue-green algae found in the paddy water, by the azolla-anabaena algae complex, and by the heterotrophic bacteria associated with rice roots and stems — were also intensively studied. Direct proof of nitrogen fixation in the rice root zones was obtained in cooperation with scientists from the Boyce Thompson Institute in the U.S.

Strains of the aquatic fern Azolla have been gathered from various parts of the world and evaluated at Los Baños. Azolla can fix as much as 400 kg nitrogen/ha annually. This agrees with findings in China, India, and Vietnam.

The environment for rice

Research on the influence of the environment on rice growth and development was expanded. With the IRRI phytotron, a gift of the Australian Government in 1972, different climatic conditions were simulated and the work of scientists in Japan and other countries on the effect of temperature and solar radiation on rice yields was confirmed in the tropics. Studies also included the effect of solar radiation on photosynthesis on cloudy and sunny days and with and without moisture stress.

Constraints to rice production

An interdisciplinary team started studies in 1974 to determine the biological and socioeconomic constraints limiting rice yields on farmers' fields. Based on earlier work by a group of economists in various South and Southeast Asian countries, an agroeconomic network of cooperating biological scientists and economists was created.

From IRRI experiments, it was found that insect and disease infestations were of primary importance in constraining rice yields in the Philippines. But it was also found that inadequate nitrogen fertilizer was a prime factor especially during the dry season. Similar results were obtained by scientists in countries in the agroeconomic network. Both fertilizers and insecticides were effective in increasing the gross returns from the rice produced. However, the net returns on the use of insecticides were not so favorable especially during the wet season. The cost of the chemicals was sufficiently high as to make their use less than economical under many of the experimental conditions. In contrast, the fertilizer was a good investment in both the wet and dry seasons.

In studying reasons for the gap between yields obtained by the experimenters and those by the farmers, two important inefficiencies were found. An allocative ineffi-

ciency indicated that the farmers were simply not adding the amount of fertilizers and other inputs that should have been applied. But, at the same time, a technical inefficiency was suggested because even when farmers added fertilizer, they did not get as good yields as the researchers. Both types of inefficiency may help account for the inability of farmers to obtain the same yield response obtained by the researchers.

IRRI scientists have also studied the consequences of using the new rice varieties and their associated technology. The total labor required to produce 1 ha of rice was greater for the new technology than for the traditional varieties. However, on the basis of labor inputs per ton of rice produced, there was a reduction in labor associated with the modern technologies. Studies done in the Philippines suggest that between 1966 and 1974 there was a definite relationship between the percentage of adoption of the new varieties and the total input in labor per hectare. The increase in hired labor was most notable.

Rice-based cropping systems

During the past decade, the amount of research on rice-based cropping systems increased significantly. The objective of the cropping systems program is to develop and test rice-based cropping systems that will result in intensified cropping — more crops per year.

Perhaps the greatest contribution of IRRI cropping systems scientists and their cooperators in national programs has been the development and evaluation of a research methodology to design, improve, and test rice-based cropping systems. First, the physical, biological, and socioeconomic environments of a given area are characterized and field sites with potential for improved cropping systems selected. Improved cropping systems are then designed and tested while improved component technology is developed and tested by the biological scientist. Socioeconomic monitoring and analysis take place simultaneously. The cropping systems with greatest potential are evaluated in pilot trials carried on in cooperation with crop production specialists in the national programs. This methodology is being used successfully by cooperators in six countries in the Asian Cropping Systems Network.

Farmers in Iloilo Province have made significant progress after the 1976 testing of a new cropping pattern in that region by IRRI scientists. The proportion of the farmers using a double cropping system increased from about 5% to about 45% in 3 years. This double cropping was associated with farmer adoption of early maturing rices for the first crop, which left sufficient time for a second crop during the growing season.

Another significant cropping system tested at IRRI is one for continuous rice production. A system used by a farmer in Central Luzon was modified to produce 4 crops a year with annual yields well above 20 t/ha. Economists who evaluated the labor input for this intensive cropping system found that the farmer and his family had ample labor throughout the year to run the system. Furthermore, the return to

the family for labor input was more than twice that for the farmer growing the two-crop rice system in the nearby community. Already this system is being used by small and large farmers in several places in the Philippines.

IRRI has also borrowed and tested a cropping system used by farmers in Indonesia. By reshaping their land, they provide an environment that is well enough drained for upland crops even during the monsoon season. That makes possible the side-by-side production of wetland rice and dryland crop. This innovation is still under test but results during 1979 were promising.

Machinery development

Early in the history of IRRI, it was recognized that some form of mechanization would be useful in helping to put new rice technologies into farm use. The most significant contribution has been the development of a small power tiller for land preparation. Several small threshers, including one that can be moved easily from place to place, were also developed. IRRI engineers work closely with local machinery manufacturers who use IRRI designs to produce equipment for small farmers. In 1980, five IRRI engineers were working with local industry in five Asian countries to expedite the testing and use of small-scale equipment.

The most recent development is a hand-operated transplanter and an associated seedbed technology. With it, one laborer can transplant as much rice as five transplanters can by traditional means.

Information flow and training

From the beginning, IRRI has had training and dissemination of information as prime objectives. During the past 10 years, the size and scope of its training program was greatly increased. Trainees from nearly 56 countries have participated in IRRI training. In some cases, trainees are given practical training in the production of rice and associated crops. But in recent years, training programs aimed specifically at improving the competence of cooperating scientists working in one or more of the international networks were added. A 6-month cropping systems training course was initiated; likewise, two 4-month courses were initiated to improve the capabilities of scientists working in national genetic evaluation and utilization (GEU) programs; and a 4-month course was initiated to improve the capabilities of scientists working in the INSFFER. Training for scientists and engineers working in irrigation water management was established in 1979.

There has been a steady increase in the number of fellows, scholars, and trainees at IRRI. In 1979, 426 persons — 3 times the number who underwent training in 1970 and double that in 1975 — participated in IRRI's training programs. Two hundred and nineteen research fellows and scholars participated in training programs in 1979, and 207 were involved in the formalized short courses, mostly in support of the international research networks.

The number of postdoctoral fellows at the Institute has markedly increased. In 1979, 35 of these highly trained specialists — about triple the number for 1973 —worked with us.

To supplement the formal training program, IRRI sponsors conferences, workshops, and symposia, which give rice scientists from around the world an opportunity to communicate personally with each other.

The IRRI library has the largest accumulation of rice literature in the world. It has also greatly increased information dissemination through publications. An annual *Research Highlights* summarizes, for the nonspecialists, accomplishments of the previous year. *The International Rice Research Newsletter* gives scientists throughout the rice-growing world an opportunity to publish recent research developments. Likewise, the *IRRI Research Paper Series* provides a ready outlet for publication of research findings of IRRI scientists. The proceedings of each workshop, conference, and symposium held at IRRI are also published.

About 15,000 visitors come to IRRI each year. Most of them are farmers, students, and leaders from various parts of the world; many are teachers and scientists.

Expansion of facilities

To accommodate the expansion of IRRI's program, new facilities have been added. Two major buildings were added to complement the primary facilities dedicated in 1962. A Laboratory Training and Conference Center was added in 1976 and construction was started on a Rice Genetic Resources Laboratory nearby, which was inaugurated in 1977. Additional housing for scholars, fellows. and senior staff members was also constructed.

Long-range plans

During the past 10 years, considerable staff time was spent on planning. A preliminary long-range planning report was made by a senior staff committee and presented to the IRRI Board of Trustees. One step was to identify where the additional Asian rice production would come from during the next 20-25 years. The increased production from higher yields and irrigation of existing lands will be about equalled by the increased production from crop intensification through new and improved cropping systems. But the IRRI planners further evaluated the potential for the future in terms of the environmental complex in which rice is grown. Assuming that about half the future production increases will come from higher yields and about half from increased cropping intensification, it is suggested that most of that increase would come from irrigated lands and from rainfed lands where the water is not too deep. Where the water is not under control because of either flooding or drought, no large yield production increases are anticipated. At the same time, however, research must be done for these disadvantaged environmental complexes to determine whatever increases research might be able to bring about.

In lookingat IRRI's future, some changes will be made in the next few years. The proportion of work that is somewhat more basically oriented will increase. The percentage of research done in cooperation with scientists from both the rice-producing developing countries in the tropics or from the more developed countries in temperate zones will definitely increase. IRRI will continue to serve a catalytic role

through network coordination. Efforts will continue to help improve the capabilities of cooperating scientists through training and through shifts in emphasis of work in the networks described. It is fully expected that the IRRI Board of Trustees, who are chosen from rice-growing countries around the world, would take a more vigorous role in determining IRRI's future.

I am proud of the progress made during the past decade by scientists at IRRI and their cooperators in the national programs as they worked together to better identify the constraints on rice yields, and of the research findings needed to help farmers remove some of these constraints. But the job has just started. Research must be done with an international focus. Research in India has a real meaning not only in nearby Bangladesh and Pakistan but in other South and Southeast Asian countries as well. Likewise, the expertise in one country can help solve the problems in another.

The past decade has further convinced those at IRRI of the essentiality of a science-based technology as one of the elements of a stable and economically sound food production system. IRRI intends to carry out the responsibility for helping to feed a hungry world.

RICE RESEARCH NEEDS

THE ROLE OF RICE IN MEETING FUTURE NEEDS

S. C. HSIEH, J. C. FLINN, and N. AMERASINGHE

The International Rice Research Institute enters its third decade as the developing world, in particular, faces the ramifications of four interrelated problems — the energy crisis, food shortage, poverty, and unemployment. Most participants in this conference feel the impact of the energy crisis. However, few personally experience the effects of being poor, malnourished or unemployed, as do some 460 million of the world's population.

A substantial portion of those disadvantaged by the energy crisis are articulate in influencing policies and research leading to new technology and operating rules to reduce this constraint. However, the poor, the malnourished, and the unemployed rarely have a similar capacity to stimulate research or induce change designed to alleviate their deteriorating situation. Thus, national and international agencies concerned with the development of food crop technology in developing countries face particular challenges. They must design technology that is consistent with the needs and means of farmers with limited resources and that will provide such farmers with adequate food, employment, and income. The technology must also be socially acceptable and institutionally realistic for the nation or region concerned. This conference will explore ways and means by which rice research may contribute to the technology that can increase rice yields on farmers' fields. Because most of the papers are technical, it should be useful as a point of departure to examine the current place of rice and its role in meeting future needs. Because of the importance of rice in production and consumption in Asia, it is useful to examine its role in the broader context of its contributions to national and regional problems. In this regard, the work ofthe Asian Development Bank and other organizations indicates some of the most important concerns of the future:

- the capacity of agriculture to provide food relative to consumption needs and demands;
- the ability of agriculture to productively absorb labor relative to the work force available for rural employment;

Director, Agriculture and Rural Development Department (ARDD) of the Asian Development Bank (ADB): agriculture economist, IRRI; and project economist, ARDD, ADB. The views expressed in this paper do not necessarily reflect the opinions of the institutions with which the authors are 0attached.

- the ability of the agricultural sector to earn foreign exchange or to reduce import requirements; and
- the need for a highly productive rice and agricultural sector to achieve an accelerated overall economic growth.

At least the first two concerns similarly reflect the wants and needs of individuals, that is, the provision of adequate diets and, through employment, adequate returns to labor to enable a family to enjoy an acceptable standard of living. In this paper we shall focus on the role of rice in meeting those needs.

THE WORLD FOOD SITUATION AND THE ASIAN SCENARIO

Cereal grains provide about 75% of all the crop energy consumed by mankind. Rice, wheat, and maize are the most important cereals and directly supply more than half of all calories consumed by the entire human population. In a global context, rice ranks second to wheat in area harvested, and second to maize in yield per hectare (Table 1). Rice currently accounts for as much as 75% of the caloric intake of the 2 billion people living in Asia, and as much as 33% of the caloric intake of nearly 1 billion people living in Africa and Latin America.

Rice is more important than that. First, it is the most important food in that part of the world where population densities are highest and overall dietary levels are least adequate. Second, in the highly populated, vast monsoonal areas of tropical Asia, rice offers the highest food-staple cereal yield from a fixed area of arable land. Third, the world's production of rice is concentrated in the hands of small farmers using labor-intensive methods of production. The rice crop provides their main source of income, their staple diet, and employment for large numbers of rural landless workers.

Perspectives of the world food situation

The problems of increasing the supply of foodstuffs to reduce, if not eliminate, malnutrition and hunger have been identified by the Committee on World Food Security (UN 1975) as being among the most urgent global problems of the coming decade. The need to raise food production to bring it in line with projected basic food

Table 1. World cereal production, 1978 and 1979. [a]

	Area (million ha)		Yield (t/ha)		Production (million t)	
	1978	1979	1978	1979	1978	1979
Rice	144.88	139.30	2.6	2.7	385.45	368.56
Wheat	226.23	226.01	1.9	1.8	438.90	402.93
Barley	85.03	89.42	2.2	1.8	184.27	163.46
Maize	124.97	127.18	3.1	3.2	383.18	405.79
Rye	14.93	13.28	1.8	2.1	30.53	21.39
Oats	28.34	27.42	1.8	1.6	51.12	44.65
Millet	45.53	44.46	0.7	0.7	30.63	29.01
Sorghum	46.08	45.85	1.5	1.5	66.93	67.29

[a] Source: Palacpac (1980).

requirements in South and Southeast Asia has also been stressed by the Food and Agriculture Organization (FAO) of the United nations (UN 1974), the International Food Policy Research Institute (IFPRI 1977), by a special task force of the Trilatera1 Commission (Colombo et a1 1977), and most recently by a U.S. Presidential Commission on World Hunger (1979).

The general consensus is that, despite present local surpluses, food supplies in developing countries will remain fragile in the foreseable future. According to the assessment document for the 1974 World Food Conference (UN 1974), at least 460 million persons in developing market economies are malnourished; nearly 66% of these individuals live in South and Southeast Asia. Furthermore, the difference between adequate food and a world food crisis is only 4-5% of the world's food grain production (Drosdoff 1979). As demonstrated by the drought in the Indian subcontinent last year, variation in the year-to-year production, which is caused by climate or pest epidemics and appears not yet broken, can more than account for such swings in supplies; the balance between abundance and hunger is precarious.

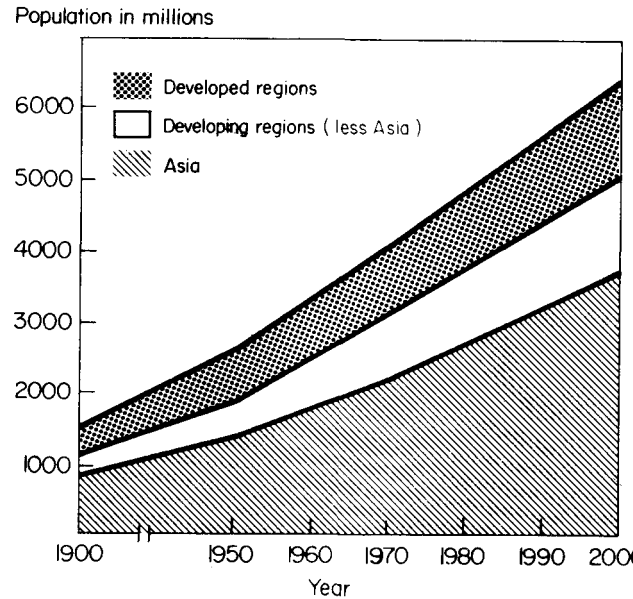
The main problem of food security is in developing countries where the demand for grains is projected to increase more rapidly than local output. Unless food policies and supply and demand situation change by 1985, developing countries, as a whole, could be confronted with the need to import between 80 and 100 million tons of grain annually (Colombo et al 1977, IFPRI 1977). It is doubtful that imports of this magnitude could be managed physically or financially.

The principal factors that influence the level and rate of increase in the demand for cereals are the base population and its rate of growth and the level and distribution of personal incomes. The world's major population problems are concentrated in Asia, Latin America, and Africa, where nearly 85% of the world's births occur. Combined, these continents have 75% of the world's population today and are expected to have 80% by the year 2000 (Fig. 1). Of these regions, Asia dominates. Its population is concentrated in India and China where 1.5 billion people make up 33% of the total world's population.

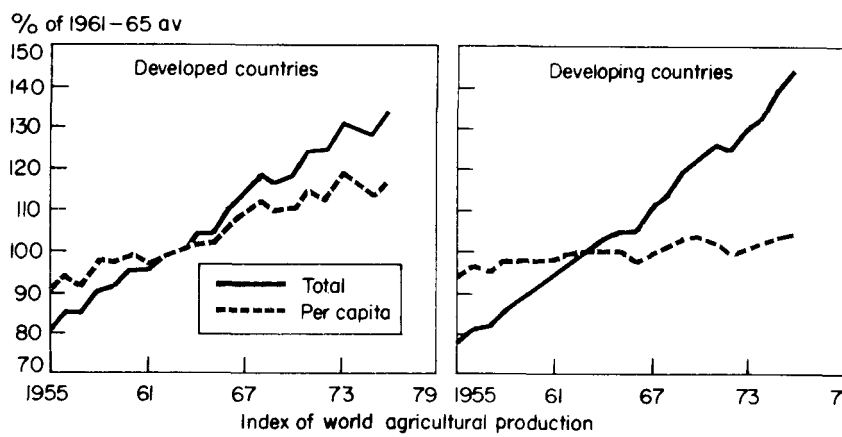
Changes in per capita food availability is determined by the relative rates of growth in food production and population. The differential rates of population growth between the developed (about 1.2% annually) and developing market economies (between 2 and 3% annually) have resulted in substantial improvement in per capita food production in developed countries, but in virtual stagnation in develop ing countries (Fig. 2). Clearly, reducing population growth rates can contribute to reducing the food problem in developing countries.

The projections for commercial demand for food and food production indicate that in the developing countries, demand is expected to increase more rapidly than production — 3.6% for demand and 2.6% for supply (Table 2). To meet the projected commercial demand[1] through 1985, these countries will require an

[1] Meeting commercial demand will not solve the problem of malnutrition because many of the malnourished do not have sufficient income to purchase enough food to meet nutritional requirements.



1. World population growth rates, 1900-2000 (source: Willet 1976).



2. Index of world agricultural production (source: Palacpac 1980).

increased rate of growth in food production or increased imports, or both. In many developing countries the ability to buy food to supplement local production will lag behind nutritional requirements, thus increasing the need for special assistance from the developed world.

Table 2. Projections of food demand [a] and extrapolations of food production to 1985.

	Volume growth rate (%/year)		Overall volume increases (1969-71 = 100)	
	Demand	Production	Demand	Production
World	2.4	2.7	144	150
Developed countries	1.5	2.8	126	151
Market economies	1.4	2.4	124	143
Eastern Europe and USSR	1.7	3.5	130	168
Developing market economies	3.6	2.6	170	146
Africa	3.8	2.5	176	145
South and Southeast Asia	3.4	2.4	166	143
Latin America	3.6	2.9	170	152
Near East	4.0	3.1	180	157
Asian Centrally planned economies	3.1	2.6	158	146
All developing countries	3.4	2.6	166	146

[a] All food, including fish. The base period of extrapolation of food production was 1961-1973. A full description of the methodology of demand projections is given in FAO (1971).
Source: UN 1974.

A problem closely related to the effective demand for food and other goods is the income of poor people. Incomes are being severely eroded by escalating costs of food and other market goods. Clearly the ability of many people in low-income countries to purchase food will remain depressed, and the poorest sections of the community will continue to have the least adequate diets. Similarly, because poor people spend a large proportion of their incomes on food (often more than 60%), they are extremely vulnerable to price fluctuations of basic foodstuffs. Small decreases in the supply of such basic commodities as rice can cause substantial increase in its price. Thus in a tight supply situation, the low-income groups must increase their expenditure and so allocate more of their income on food, or reduce consumption and increase nutritional stresses, or both.

The Asian food scenario

Optimism regarding future adequate food production and consumption in Asia was reflected by scientists and policy makers in the late 1960s (ADB 1969). That optimism was based on the adoption of modern varieties of rice (and wheat) and associated use of fertilizer and agricultural chemicals and water management techniques, which had substantially increased Asian rice yields and production. The added output had also affected price increases in rice. Although weather in the early 1970s adversely affected food production and grain reserves. it did not create widespread suffering among the poor as it did in the 1960s (Sadikin 1981).

Although the new cereal technology provided breakthroughs in food crop production, the aggregate impact was for agricultural production to keep pace with rising population. Dietary levels did not improve. For several reasons the rate of increase in food crop production was less than that anticipated. First, large areas of

Asia, particularly the nonirrigated rice lands, continue to be planted to indigenous varieties, and the yields realized by farmers growing modern varieties are less than those anticipated (Chandler 1975). Second, adverse conditions in the early 1970s and eastern Europe's large purchases of grains in the international markets, coupled with the first energy crisis, caused shortages in food supplies — particularly in the developing countries of Asia.

An assumption supporting the generally optimistic view of the late 1960s — that market demand would not be an obstacle to growth in farm output — proved to be too simplistic. Inadequate purchasing power among larger portions of Asia's rural population coupled with high-cost imports led to tragically paradoxical situations in some areas where foodstocks existed together with widespread malnutrition of poor people.

Special concern for the welfare of disadvantaged groups is evidenced by much of the current concern for food security. However, the international community has been slow in evolving a dependable system of global food resources that would underwrite national food security programs. The food problem has taken on a new significance and risen to critical dimensions in the developing market countries of Asia. To reduce dependence on food-surplus countries, increasing food production by using domestic resources has become as much a political imperative as an economic necessity. In any event, the option of importing food to supply Asian requirements has become increasingly difficult to exercise during the past decade because of the costs of procuring and transporting food grains, and the alternative demands for scarce foreign reserves.

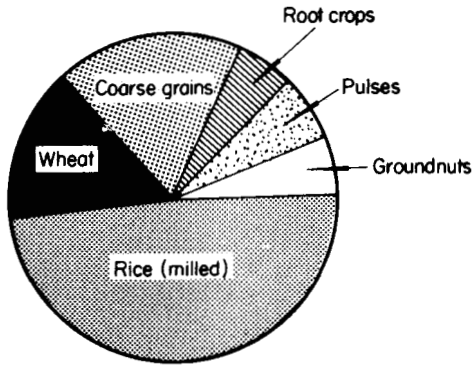
The net effect of food grain and population increases in Asia over the past decade has resulted in per capita production remaining virtually static. The main cause of stagnation in consumption has been the slower 2.2-2.4% year growth in regional grain production compared with a population growth rate of more than 2.5%/year during the period. Therefore, unless the rates of growth in food grain supply —particularly rice — can increase above the rates realized in the past, the diets of large populations in Asia will deteriorate. Indeed, the shortfall in cereal production —essentially rice in Asia — is projected at 39 million tons by 1985 (Table 3).

Rice in Asia. Rice accounts for more than 50% of major staples consumed in Asia where more than 90% of the world's rice is grown (Fig. 3). China (33%) and India

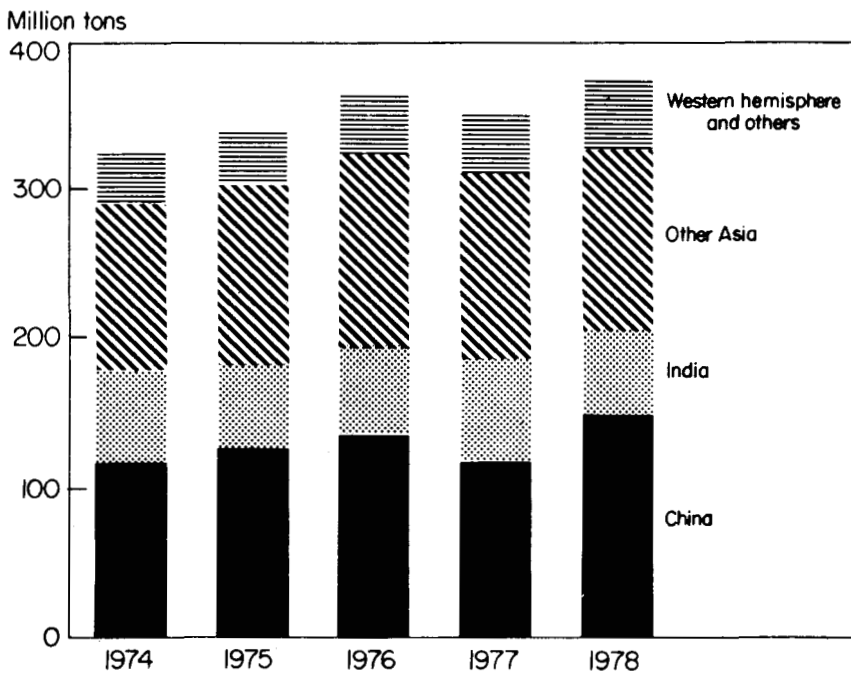
Table 3. Cereals deficit in developing market economies, 1969-71, and projection to 1985.

Developing market economy regions	Shortfall (million t)							
	Wheat		Rice		Coarse grains		Total	
	1969-71	1985	1969-71	1985	1969-71	1985	1969-71	1985
Africa	-2	-3	-1	-1	-1	-17	-4	-21
Latin America	-4	-13	0	+1	+8	+17	+4	+5
Near East	-6	-6	0	0	0	-14	-6	-20
Asia and Far East	-8	+3	-2	-39	0	-13	-10	-49
Total	-20	-19	-3	-39	+7	-27	-16	-85

Source: UN 1974.



3. Distribution of the production of major staples in Asia (1975-76) (source: lFPRl 1977, p. 31).



4. World rice production, 1974-78 (source: IRRl 1979e).

(21%) produce and consume more than half of the world's rice (Fig. 4). Yields and the percentage of the crop grown under irrigation vary markedly in the region (Fig. 4).

The performance of Asian nations in adopting new technology to keep rice production ahead of population has been variable. A simplified impression of percentage changes in food production, population, and domestic demand for food is shown in Table 4. Of course, food refers to more than rice; nonetheless, it does

Table 4. Annual growth[a] in food production, population, and domestic demand in selected Asian countries, 1952-76.[b]

Country	Annual growth (%)		
	Food production	Population	Domestic demand[c]
	Production failed to equal population growth		
Nepal	0.1	1.8	2.1
Bangladesh	1.6	3.5	n.a.
Afghanistan[d]	1.7	1.9	2.2
Indonesia	2.0	2.5	2.6
	Production failed to equal growth in domestic demand		
Burma	2.4	2.2	3.3
India	2.4	2.1	3.0
Pakistan	3.0	3.0	4.2
Philippines	3.2	3.2	4.2
	Production exceeded growth in domestic demand		
Sri Lanka	3.6	2.5	3.1
Korea	4.8	2.7	4.7
Malaysia	5.2	3.0	4.3
Thailand	5.3	3.1	4.6

[a] Exponential trend, 1952-76. [b] Source: ADB 1978. [c] Calculated on basis of population growth and per capita income and estimates of income elasticity of farm value of demand in FAO (1971); n.a. = data not available. [d] 1962-1972.

provide a fairly accurate reflection of trends in rice production and demand.

The nations included in Table 4 fall into three categories:

- those whose food production did not keep pace with population increases;
- those whose growth rate in food production exceeded population increases but did not keep up with the demand; and
- those whose food production expanded more rapidly than both population and demand.

Food production increased rapidly enough to keep up with demand in 4 of the 11 countries examined — the Philippines now joins this group — resulting, in some cases (Thailand and Philippines), in increased export potential, and, for the others in the group, decreased dependence on imports.[2] In the remaining countries, there has

[2] About 7 million tons of wheat and 3 million tons of rice were imported into South and Southeast Asia in 1978. More wheat than rice is imported basically because it is more readily available outside the region at lower prices and on easier terms. Also, as incomes increase, there is a relative increase in the demand for wheat over rice (Barker and Gavan 1978).

been an increased dependence on imports, a decrease in exports of food, or upward pressures on domestic prices.

INCREASING RICE SUPPLIES TO MEET FUTURE FOOD NEEDS

FAO (1979a) projections suggest that the economic demand for rice (at constant prices) in Asia will grow by 4.8-5.3 million t/ year over the next 10 years. In contrast, if the historic long-term production growth rate in rice of 2.2-2.396 continues, paddy production will rise by only 3.7 million t/year in the period. What, then, are the options open to achieve and sustain the 3% growth rate in rice supplies necessary for Asia to gain self-sufficiency in its staple food crop?

Irrigation development

Many analysts (for example, ADB 1977, Colombo et al 1977) have identified water management — an assured supply of water, coupled with drainage and flood protection — as the major investment requirement for increased rice production in Asia.

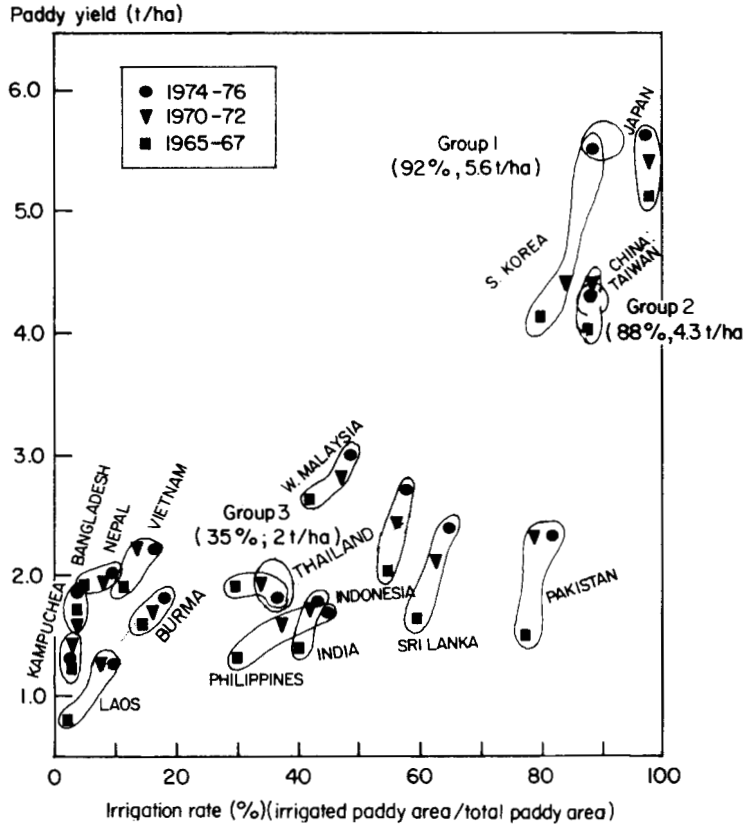
Currently some 40% of the world's rice lands are irrigated. However, in South and Southeast Asia, the irrigated rice area forms 23% of the total (Table 5) and varies significantly between countries (Fig. 5). Increasing the area of irrigated rice will be partly met through upgrading existing systems, and partly by extending the margin of irrigation. These new irrigation projects will generally be on sites less favorable than existing ones, and thus more costly, which raises questions of availability of investment funds as well as economic feasibility.

It is hazardous to generalize on the cost per hectare of irrigation development and operation. Nonetheless, the Trilateral Commission (Colombo et al 1977) provided useful guidelines when debating this issue (Table 6). Their calculations show that the least costly way of increasing paddy production is through the rehabilitation of existing systems. Developing new lands for rice production is the most expensive alternative.

Table 5. Proportion of rice of various regions by type of culture.[a]

Region	Rice area (%)							
	Total[b] area	Irri-gated	Rainfed		Deep water	UP-land	Arid high temp.[c]	Long days, low temp.[c]
			Shallow	Inter-mediate				
India	28	33	33	16	6	6	5	1
Other S & SE Asia	33	23	34	15	10	13	4	1
China	25	90	8	0	0	2	n.a.	n.a.
Other developing	3	13	4	10	0	46	4	23
USA, Japan, USSR	3	98	0	0	0	2	n.a.	n.a.
Total classified[d]	96	42	24	10	5	10	3	3

[a] Source: IRRI 1979a. [b] Values in this column refer to % of world's total area. Those in other columns refer to % of region in culture. [c] n.a. = data not available. [d] Refers to 96% of total world area classified in Table 1.



5. Relation between irrigation rate and paddy yield (source: Colombo et al 1977).

Irrigation systems, whether existing, improved, or new, frequently operate below their designed potential in water efficiency and rice production. The major constraint in effective systems operation is the lack of management capacity, coupled with a lack of communication between irrigation managers and farmer users. Thus, even though water management problems may be ameliorated through redesign of systems, the administrative, organizational, and institutional management of systems also need similar improvement and rehabilitation (Takase and Wickham 1978).

The Trilateral Commission (Colombo et al 1977) calculated that the expansion in irrigation necessary to increase rice supplies by a target in excess of 3%/year would require an annual investment in irrigation in Asia of about $3.5 billion (1975 prices). Other opinions imply that this massive level of investment is unlikely (FAO 1980). Hence, while expansions in irrigated land will undoubtedly account for substantial increases in paddy production over the next decade, significant productivity in-

Table 6. Illustrative model indicating capital investment for 6 alternatives to increase production of paddy by 1 t/ha per year [a] (Colombo et al 1978).

Season	Paddy yield (t/ha): Virgin land (uncultivated)	Rainfed paddies (no irrigation)	Inadequate irrigation (canals less than 50 m/ha)	Adequate irrigation (canals more than 50 m/ha)	Cost per hec-tare	Rise in annual paddy yield (t/ha)	Cost per ton	Investment priority (ranking of costs/ton)
Wet	0	1.0	3.0	3.5				
Dry	0	0	1.0 [b]	2.5 [c]				
Annual total	0	1.0	4.0	6.0				
Alternative A					$3,000	÷ 6.0	= $ 500	(4)
Alternative B					$1,500	÷ 5.0	= $ 300	(2)
Alternative C					$ 400	÷ 2.0	= $ 200	(1)
Alternatlve D					$2,600	÷ 4.0	= $ 650	(5)
Alternative E					$1,100	÷ 3.0	= $ 367	(3)
Alternatlve F					$1,500	÷ 1.0	= $1,500	(6)

[a] Obtained from 10 irrigation projects financed by the Asian Development Bank durlng 1968-72, modified for inflation. [b] Assuming that only 1/3 of the area planted during the wet season can be planted in the dry, the yield during the dry season for the total area is 1/3 of the wet. [c] Assuming that only 2/3 of the area planted during the wet season can be planted in the dry, the yield during the dry season for the total area is 2/3 that of the wet.

creases must also come from nonirrigated rice lands — which will continue to represent more than half the land committed to rice production in Asia.

The emerging focus on nonirrigated agriculture has the advantage of being less capital intensive than the irrigation strategy. Also, from an institutional viewpoint, this approach is less management intensive — a commodity, that is also scarce in most developing countries. Because the poorest rice farmers live on nonirrigated rice lands, increasing their productivity has implications for the distributional impact of research investment as well.

Varieties

The semidwarf high-yielding rice varieties developed by the International Rice Research Institute and by national rice improvement programs are the foundation of much of Asia's modem rice technology. The greatest impact of modern varieties has been in irrigated environments, while on the remaining 60-70% of Asian rice lands, indigenous varieties with low yield potential remain dominant. The judgment of the Trilateral Commission and of rice scientists (IRRI 1979a) is that over the next decade, at least, the greatest increments in rice yields and benefits from rice research will continue to accrue from varietal improvement and the associated management of irrigated rice. Nonetheless, there has been a considerable increase in investment in breeding rices for nonirrigated (e.g. rainfed wetland, dryland, deepwater) and adverse soil conditions. The latter environment (problem soils) has, by comparison, been little researched. They occupy vast areas of Asia, which, through directed efforts in rice breeding and soils research, offer potential to substantially increase rice supplies in Asia. Indeed, the high yield potential of selections adapted to these more difficult environments has been demonstrated and offers clear opportunities of increasing rice production in these situations (IRRI 1979b).

Production technology

Modem seed-fertilizer and pest-control technology has enabled farmers on irrigated lands to increase yield substantially. However, as demonstrated by IRRI research on constraints to increased rice production, there remains considerable scope for increasing the yields on farms using existing modern varieties through the application of known methods of crop and water management (Herdt and Wickham 1975, IRRI 1979c).

It is becoming increasingly urgent to identify and adapt methods that will result in more efficient and economic application of agrochemicals (particularly fertilizers and insecticides) — or to identify lower cost alternatives — as the costs of these inputs increase. At the same time, there is more concern expressed over the environmental impact of agrochemicals. For example, it has been clearly demonstrated that with the correct timing and placement of nitrogenous fertilizers, their efficiency can be doubled and nitrogen losses through drainage outflows reduced (IRRI 1979d). Other options to increase the efficiency of fertilizer use are the screening of rices for good performance in low-input situations, alternative ways and forms of applying fertilizers, and biological fixation of nitrogen.

Research into, and extension of, varieties and agronomic practices have historically tended to focus on irrigated as opposed to rainfed rice. However, research into crop and land management of nonirrigated rice-based cropping systems has made progress (Zandstra 1979).

One component of modern rice technology that has led to heated debate is mechanization. The evidence of the impact of mechanization on rice yields and that of employment are mixed (Binswanger 1978). There are situations where man or animal power is not able to execute farm operations well or on time. Under such circumstances, engineering solutions (designed with a concern for the needs and means of the farmer) to ameliorate these constraints should be sought. To this extent, engineering for irrigated rice production is more advanced than that for nonirrigated environments. In particular, mechanical devices and associated technology to facilitate the management of upland tropical soils offer particular challenges.

Social infrastructure

Modern farming systems that can lead to substantial increases in rice production will be more complex than traditional ones. This complexity includes use of new inputs and techniques; operation in conditions of changing markets, credit, and organizational situations; and gaining access to the findings of contemporary agricultural research.

In the process of economic growth, farmers are forced to become more dependent on the external market in purchasing inputs, acquiring information, and disposing of their rice crop. Indeed, this increased dependence on the market may well constitute one of the major risks faced by farmers when adopting new technology. Thus, in addition to the production technology discussed, input delivery systems (physical inputs — seed, agrochemicals, tools — credit, labor, and knowledge transfer) must be structured to ensure their responsiveness to the needs and means of the small farmers, and bring within his reach the type of technology that will increase rice supplies. Similarly, improved procurement, drying, storage, and distribution systems and facilities are necessary if increased production is to reach urban centers without losses — currently estimated at 20-25% of the crop.

Agrarian structure (tenure, sharing arrangements, political power) has frequently been cited as an obstruction to the small farmer's benefiting from modern technology (Wortman and Cummings 1978). Hence, agrarian reform and tenancy improvements — coupled with improved input delivery — will usually be important components of government policies to attain rice self-sufficiency.

While rice research and social infrastructure must be strengthened, so must the mechanisms to ensure that farmers are informed and trained in the use of new methods of rice culture. Thus, the adaption of research results and their dissemination to farmers also have a critical role in increasing rice production. This interface between researchers and farmers must not be a one-way process because effective communication involves getting information to those in authority, to the market, and to researchers, as well as getting information from them.

Incentives to increase rice production

Rice is clearly one of the most political commodities in Asia. Governments intervene in setting prices (notably for rice and fertilizer), and are major participants in developing rice infrastructure (irrigation, input supplies, credit, marketing). They often legislate agrarian reform (right to land use, land rents, wages), and subsidize or tax production. As a result, government policies can have a major bearing on the incentives an individual farmer has for increasing his rice production.

Most Asian countries aim at attaining self-sufficiency in rice. This objective can be encouraged by ensuring the farmer economic returns that attract him to undertake the necessary investment and accept the risks of adopting the new technology. However, because rice is an important wage good in most Asian countries, low and stable rice prices are also important goals of government. Also, where rice is an important export, it may be taxed or internal prices may be manipulated in such a way that the prices received by farmers are below what they could be without government intervention. Thus, national rice policies and strategies may be contradictory and discourage farmers from increasing rice production (Saleh 1977).

National fertilizer pricing and distributional policies and the relationship between fertilizer and rice prices also have a major impact on the quantity of fertilizer used by farmers and, thus, on rice yields (David and Barker 1978). In countries in Asia where fertilizer is cheap relative to rice or where the technology and management level is high, fertilizer use is high (such as in Japan and Korea, where farmers use more than 300 kg/ ha), and where it is expensive (such as Thailand, Pakistan, and Philippines, where farmers apply less than 100 kg/ ha), it is low. The increases in fertilizer prices resulting from increasing energy and transportation costs, if passed onto the farmers, will obviously provide a disincentive to maintain or increase fertilizer use. One alternative is for governments to continue to subsidize production inputs. However, the financial capacity of many developing countries to maintain subsidies is limited. Thus, as previously discussed, there is urgent need to develop relevant ways of increasing the efficiency of use of inputs, particularly fertilizer.

A cost-price squeeze on modern rice technology

Because of the inelastic demand for rice in local markets, and the thin world market for the crop (normally less than 5% of total world production is traded internationally), a modest decline in production usually causes a large price rise and vice versa. Thus, during periods of shortage due to adverse climatic conditions such as the late 1950s, early 1970s, 1978, and, more recently, late last year, importers bid rice prices to high levels. Also, increasing energy prices are reducing the ability of many developing countries in the region to buy rice and other food commodities on the world market. By implication, if rice production increases more rapidly in the short run than effective demand, then rice prices received by the producer normally fall, or at least stagnate relative to general inflationary trends.

However, increasing costs of inputs are likely to dominate the value of the crop produced when the farmer assesses the relevance of improved rice technology. To

this extent, the dimensions of the energy crises have particular implications. It is reasonable to anticipate that the cost of energy-based inputs (agrochemicals, fuels) will continue to escalate — and their physical availability deteriorate — in the foreseeable future. Thus, the rice farmer adopting modern rice technology is being placed in a particularly vicious cost-price squeeze. Inputs such as labor cannot readily be substituted — land must still be prepared and the crop transplanted, weeded, and harvested — so the farmer's major flexibility in reducing production costs is by using less purchased inputs — notably agrochemicals, fuels for machinery — and to a lesser extent, by reducing labor inputs by direct seeding and reduced weeding. Under such circumstances, modern varieties may lose their management advantage over traditional varieties and there may be a tendency to revert to lower cost, lower productivity technology, as in some parts of India (Lin 1980).

Thus, the spiraling costs of inputs — and the uncertainty of their availability at critical times — may decrease the attractiveness of high-input technology to the farmers with limited resources. While opportunities to increase input efficiency obviously exist, technology specifically designed for low-to-modest cash-input situations must be afforded greater priority than was frequently the case in the past. Herein lies the dilemma — cutbacks in agricultural technology, including fertilizer and pesticides. could lower expansion rates of food output below population growth rates, preventing the long-term demands for rice in the region from being met. Scientists recognize this dilemma and are now selecting for improved varieties better suited to the low-input situation (Ponnamperuma 1979).

RICE AND EMPLOYMENT

The problems of underemployment and unemployment in Asia are as significant as the problems of human nutrition. Indeed, because people are not productively employed, they are poor, and because they are poor, they are hungry.

Agriculture is the predominant source of employment in most Asian countries and its share of the labor force is expected to decline during development (Table 7). Yet, while agriculture's share of the total labor force is expected to decline, the total number of persons seeking to gain a livelihood in this sector continues to increase. The impact of this expanding rural population in Asia is an increase in agricultural workers per unit of a relatively fixed land base and an associated increase in the landless labor force. As the availability of land per worker declines, the share of total output paid to the land owners increases, and the payments to the relatively plentiful labor tend to diminish.

What then is the scope for modern rice technology in alleviating the employment problem, and in increasing labor incomes in the typical Asian situation? In this environment, labor is becoming relatively more plentiful and land relatively less so.

Many studies have shown that the adoption of modern varieties has increased the use of labor per unit of cultivated land by between 20 and 30% (Table 8) mainly because of increased labor use for weeding and harvest and postharvest operations. Generally the use of hired labor has expanded more rapidly than the use of family

Table 7. The labor force's growth rates and agriculture's share in selected countries, 1965-75.

Country	Compounded growth rate of labor force (%/year)			Agriculture's share of labor force (%)	
	Total	Agri-culture	Nonagri-culture	1965	1975
Afghanistan	1.9	1.3	4.7	84	79
Bangladesh	2.8	1.9	4.9	73	67
Burma	1.5	1.8	1.0	67	69
Cambodia	2.6	1.6	5.6	80	73
Taiwan, China	4.4	0.2	6.8	42	29
India	1.5	1.4	1.9	73	72
Indonesia	2.1	1.3	3.9	72	67
Korea	2.9	1.2	5.0	62	54
Laos	2.1	1.2	5.2	81	74
Malaysia	3.2	1.7	5.0	60	52
Nepal	1.7	1.1	7.4	94	89
Pakistan	2.4	1.5	4.5	73	67
Philippines	2.9	2.0	4.0	59	54
Sri Lanka	2.2	1.3	3.2	54	50
Thailand	2.7	1.5	6.9	81	72

[a]Source: ADB 1977.

labor. There are cases in which tractorization has displaced labor, especially for land preparation (Binswanger 1978) and where new harvesting devices have reduced harvest labor (Collier 1979). However, the reduction in labor use for land preparation is often compensated for by increases in labor use for other tasks, such as weeding, with the net effect of more intensive labor use per hectare.

Because the adoption of modem rices and associated technology is largely confined to irrigated areas (which also offers opportunities for increased employment through increasing cropping intensities), the labor-absorbing capacity of new rice technology in this instance must be regarded as the result of the interaction of variety and irrigation. Indeed, it has been argued that irrigation deserves more emphasis than any other single investment activity as a means of alleviating the rural employment problem.

Table 8. Labor requirements for rice.

Country	Traditional variety (days/ha)	Modern variety (days/ha)	Change due to modern variety (%)
Bangladesh	137	194	42
India (Orissa)	145	169	17
Indonesia (Central Java)	234	197	–16
(East Java)	253	287	13
Korea (Hwasunggung)	126	139	10
Philippines (Laguna)	86	110	28
Thailand (Suphanburi)	86	120	40
Sri Lanka (Minipe)	128	171	33
Nepal (Kosi Zone)	96	126	30

Sources: Barker and Cordova 1976, Pal 1975, Amerasinghe 1972, Flinn et al 1980.

From an aggregate viewpoint, the employment benefits from modern rice listed in Table 8 provide an optimistic impression because they relate to irrigated rice, which occupies less than a third of the region's rice lands. However, the demand for labor in rainfed areas is also increasing with the expansion of double-cropping in nonirrigated rice areas (Lee 1975, Price and Barker 1978, Sadikin 1980).

The characteristics of modern rice varieties are expected to continue to contribute to the growth in the demand for rural labor. From an employment viewpoint, policies and rice technologies can be designed to encourage and maintain a high level of employment in the rice sector, and thus increase the productivity and the shares of output accruing to labor. The increased production of rice emanating from modern rice technology also contributes to the welfare of low-income groups in the sense that rice prices, and, thus, food expenditure, are less than they would be in the absence of high-yielding technology (Hayami and Herdt 1977).

However, the expanding rural population, with few alternative opportunities for gainful employment, will continue to create a pressure leading to declining real labor wage rates in many Asian countries (Ruttan 1978, Hayami 1979). Thus, it is unrealistic to expect that rice technology by itself will resolve a problem caused by the more rapid rate of increase of the labor force than of job opportunities.

RICE AND FOREIGN EXCHANGE

Food grains are major import or export commodities for most countries in Asia. Thus, changes in rice production and trade policies in the region have implications through either increasing foreign exchange earnings from increased exports, or reducing foreign exchange expenditures by substituting locally grown rice for imported cereals.

Within Asia, Thailand, Pakistan, China, and Burma now dominate rice exports while Bangladesh, Indonesia, Malaysia, and Sri Lanka dominate imports (Table 9). Asia accounts for nearly half of the world rice trade. However, because of unfavorable price trends, the value of rice exports in Asia has tended to decline in the past decade, except for Pakistan (ADB 1977).

The Second Asian Agricultural Surveys (ADB 1978) attempted to determine the relationship between overall export performance, and overall agricultural performance. The study showed that those countries with high growth rates in agricultural productivity (Indonesia, Peninsula Malaysia, Pakistan, Philippines, and Thailand) also had a positive growth in total agricultural exports as well as a rapid growth in cereal production. Asian Development Bank projections predict the decline of the real (export) price of rice and the total value of agricultural exports from developing countries in Asia (except rubber and coffee) (ADB 1977). The study concluded that because of the unfavorable terms of trade of the agricultural exports subsector for some countries in the region, agricultural exports will only be able to finance a decreasing part of anticipated cereal imports. On the other hand, for the traditional rice-exporting countries, because of unfavorable price relationships, there will be a need for export diversification if foreign exchange earnings are to increase in real

Table 9. Average (1976-1978) imports and exports of milled rice in South and Southeast Asia.[a]

Country	Trade in rice (000 t)	
	Imports	Exports
South Asia	840	1014
India	198	53
Bangladesh	280	0
Nepal	0	117
Pakistan	0	844
Sri Lanka	362	0
Southeast Asia	2132	2713
Burma	0	549
Indonesia	1705	0
Cambodia	0	0
Laos	105	0
Malaysia	293	0
Philippines	29	21
Thailand	0	2143
East Asia	169	1459[b]
Total Asia	3141	5186

[a] Source: FAO 1978, 1979b. [b] Mainly China.

terms. For countries that will probably continue to impart substantial quantities of rice over the next decade (Bangladesh and Indonesia), cereal import requirements are likely to increasingly preempt foreign exchange earnings from agricultural exports. Clearly, in those countries, greater reliance will have to be placed on industrial and other exports to provide the means to procure food from overseas sources.

BEYOND PRODUCTION AND NUTRITION

The ultimate goal is to build a world without hunger by eliminating the poverty of individuals and nations. The short-term goal is to assure that millions of people do not suffer from hunger simply because they are poor. Lasting solutions to world hunger can only result from rapid, equitable, and self-reliant economic growth. While industrialized nations can help to some extent through food aid and technical assistance programs, equitable economic growth cannot be achieved by development assistance alone.

Unemployment, hunger, and poverty are deeply rooted in political and economic relations among and within nations. Hence, fundamental changes in patterns of resource ownership, food production, trade, and finance are needed so that the developing countries can break the cycle of hunger, poverty, stagnant agricultural productivity, unemployment, high birth rates, and mortality. Thus, food production per se is only one component of the complex necessary to alleviate world hunger.

Rice and economic development

As a dominant agricultural product, foodstuff, source of employment, and, in the

early stages of development at least, foreign exchange earner or user, rice has and will continue to contribute to the rate of economic development of the region. Rice mainly contributes to development by:

- supplying the major staple food of people;
- providing the major source of income to enable rural people to effectively demand goods produced in other sectors of the economy;
- providing an investible surplus of savings and taxes to support investment in other expanding sectors; and
- reducing foreign exchange constraints by increasing exports or by saving foreign exchange through import substitution.

Japan and Taiwan, China, are classical examples of places where the widespread adoption of highly productive rice technology provides the surplus to finance rapid industrial expansion. During development, this traditional role of rice will normally decline — except where the country's resource base, compared with that of other nations, provides it a comparative advantage as an export crop (as in Thailand).

While the traditional role of rice may decline with economic development, it tends to represent a shift in emphasis, as opposed to a decline in importance in an aggregate sense. The productivity of the rice sector will continue to influence the distribution of income between urban and rural areas, and influence a country's foreign exchange balances (e.g. as earner of foreign exchange through exports, or as drain of foreign exchange if this basic foodstuff must be imported). For example, the foreign exchange earnings of Burma and Thailand are primarily dependent on rice exports; on the other hand, Bangladesh and Indonesia could reduce their foreign exchange problems if they could reduce dependence on rice imports.

A continuing and abundant supply of basic foodstuff is clearly an important determinant of the welfare of Asian rice consumers. Prices of food, particularly rice, are an important part of labor costs. Low and stable rice prices also help dampen fluctuations and escalating real wage rates, which disrupt economic development in general.

Economic growth, poverty, and nutrition

Recent projections of growth for the next decade indicate that nearly 500 million of the world's poor will still be living in absolute poverty in the year 2000 — 340 million of them in the low-income countries (US Presidential Commission on World Hunger 1979). Experience has shown that the ways in which economic growth is achieved — and especially who benefits from it — will to a large extent determine whether that growth reduces the ranks of the poor. Where governments have lacked a strong commitment to equity, steadily rising gross national products have existed side by side with desperate poverty in large sectors of developing societies. Thus, if poverty is to be reduced, if not eliminated, development policies must be designed to ensure that the poor benefit from economic growth.

The trickle-down strategy and fiscal reforms have often failed to achieve their objectives and hence alternative policies for attacking poverty and malnutrition —

collectively referred to as the basic human needs approach — are being tried (Ahluwalia 1974). This approach focuses special attention on programs in the agricultural sector, which is the major locale of absolute poverty in most developing nations.

It is easier to promote a more equitable distribution of new growth than to reallocate existing income and assets (Chenery and Syraquin 1975). However, the distribution of a nation's income-producing assets (land, in the case of agriculture) have been shown to have a decisive influence on the character of future economic growth. Indeed, those countries that have actively promoted an equitable distribution of assets early in their development efforts (Taiwan, China, and Republic of Korea) demonstrate that such distributive measures can be at least as important as economic growth in reducing poverty.

Historically, the most successful national campaigns against poverty and hunger have involved fundamental, relatively abrupt changes in long-standing economic and political systems. Land and other forms of wealth have been redistributed; new jobs have been created by expanding public services in education, health, and agriculture. These changes have come about through both revolution and evolution. However, structural changes always require an extraordinary degree of political commitment because highly complex social, political, and economic problems must be solved. Determined measures are required to meet the basic needs of the poor, and sometimes these clash with individual political freedoms. In this regard, financial and technical support from the outside, as well as supportive trade and investment policy, can often augment local resolve and help in implementation.

Establishing a system of world food security. A world without hunger will require built-in protection against the inevitable fluctuations in yearly output caused by natural or man-made events. Famine can wipe out the food supplies of an entire area or force up the prices of basic foods beyond the reach of the poor.

Bad weather and natural disasters are nothing new in the history of mankind. Until recently, most of these natural calamities were local disasters with local consequences. Today, however, such events have global implications. Global interdependence means that food production problems, as well as food supplies, are shared by all nations of the world. Because only about l0-15% of total grain output enters world trade, a decline of 5% in global production can radically change the international supply-demand equation. Without alternative sources of food, even minor disruptions can cause a drastic climb in world prices, such as that which occurred in the mid-1970s. A key way to prevent the hunger that higher prices will cause among the poor is to establish grain reserves that can be put on the market in periods of scarcity to redress the demand-supply situation and keep prices at reasonable levels.

As the World Food Conference (UN 1975) recommended, an international grain reserves system should be established, contributed to, and financed by the major grain importing and exporting nations. Financial arrangements to ensure the importation of foodstuffs by food-deficit nations also deserve increasing attention as another means of assuring food security. Several international food insurance

schemes have been proposed, all offering some combination of cash or credit, as well as food, to nations suffering food deficits. Even though such systems are not capable of dealing with a world food crisis, they can, in the absence of international reserves, assist individual nations that are attempting to cope with immediate production shortfalls.

AGRICULTURAL DEVELOPMENT IN THE 1980s

The dramatic increase in the cost of energy, escalating interest rates, and inflation over the past decade have caused dramatic changes in the international economic environment. Many developing countries in Asia faced with unprecedented increases in the prices of energy and capital imports have no alternative but to adjust to higher price levels for petroleum-based products and public utilities such as power and transportation. Furthermore, the anticipated worldwide recession in the advanced countries will make it more difficult for developing countries to expand their economies and trade. These events will also make it more difficult for these countries — and international development agencies — to obtain additional flows of foreign aid.

For political and social reasons, most developing countries have tried to contain the prices of such daily necessities as rice and other food items. Therefore, the terms of trade of agricultural commodities, particularly rice in Asia, are becoming less favorable. The situation is further aggravated by the increased cost of purchased inputs (agrochemicals, machinery) on which modern technology is largely based.

When these situations are considered together, serious thought must be given to whether the development approaches and philosophies of the 1960s and 1970s need rethinking and reorientation. The outcome of such deliberations may have important implications for food production and agricultural development policies. It may have particular relevance for identifying, for agencies such as IRRI, research strategies that will undoubtedly continue to play a vital role in the development of food crop technology in the developing world.

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FACTORS INFLUENCING RICE YIELD, PRODUCTION POTENTIAL, AND STABILITY

S. YOSHIDA and I. N. OKA

Before IR8 was released, rice yields were low, even in experimental fields. IR8 and subsequent modern high yielding varieties produce about 6 t/ha in the wet season and about 9 t/ha in the dry in experimental plots, but national rice yields of Asian countries remain at about 2 t/ha. Investigations into why the yield gap between the experimental and farmers' fields is large have been in progress since 1974 (IRRI 1979). Rice yield under experimental conditions is the maximum and reproducible yield that can be achieved with currently available technology. In farmers' fields, however, there are many constraints to high rice yields. The biological and environmental factors that affect rice yield in experiments and in farmers' fields are mainly discussed in this paper.

RICE YIELD, RICE LAND AREA, AND RICE PRODUCTION

From the biologist's point of view, rice production is formulated as:

$$\text{Rice production (t/year)} = \begin{array}{c}\text{rice land area (ha)} \times \text{number of rice crops} \\ \text{per year (crop/year)} \times \text{yield} \\ \text{(t/crop per ha)}\end{array}$$

The equation implies that rice production can be increased by increasing rice land area, crop intensity, and yield per crop. Increasing rice land area involves the amount of land resources left for reclamation and the economic feasibility of reclaiming virgin land.

Not much land is left for reclamation in South Asia and China (Table 1). However, a fairly sizable increase in cultivable land may be possible in Mindanao, Philippines; and in Sumatra, Sulawesi, South Kalimantan, the Moluccas, the lesser Sunda Island, and Irian Jaya, Indonesia. Most of the lands left for reclamation today, however, are marginal in soil and climatic productivity. In Sumatra and South Kalimantan, Indonesia, for example, a vast area is covered by peat soils (Driessen 1978). These soils require study of how to improve their productivity. The

IRRI, Philippines; Plant Protection of Food Crops, Indonesia.

Table 1. Potential cultivable land compared with present cultivated land.[a]

Region	Population (10^6)	Cultivated land[b] 1970 (10^6 ha)	Cultivable land (10^6 ha)	Percentage cultivated	Cultivated land per capita (ha)	Cultivable land per capita (ha)
South Asia	716	197	195	101.0[c]	0.27	0.27
East and Southeast Asia	317	72	115	62.6	0.22	0.36
China (PRC)	760	111	113	98.2	0.15	0.15
Other Asian centrally planned countries	36	5	11	45.4	0.13	0.30
Near East	171	85	88	96.6	0.49	0.51
North Africa	36	19	39	48.7	0.53	1.08
East and West Africa	199	135	228	59.2	0.68	1.15
Central Africa	36	29	169	17.1	0.80	4.69
South America	190	87	540	16.1	0.45	2.84
Central America and Carribbean	93	38	52	73.0	0.40	0.55
North America	227	236	274	86.1	1.03	1.20
Europe	462	144	180	80.0	0.31	0.39
Oceania	15	45	70	64.3	3.00	4.66
Other developed market economies	127	18	28	64.3	0.14	0.22
USSR	243	233	352	66.1	0.95	1.45
Total	3628	1454	2454	59.2	0.40	0.68

[a]Colombo et al (1978). Sources: FAO, figures for cultivable land in Europe and USSR are from World Food Problems. Report of the Panel of the World Food Supply, a report of the President's Science Advisory Committee (Washington, The White House, 1967). This table first appeared in Ceres, FAO Review on Development (November-December 1974), pp. 6-7. [b]Measured in terms of crop area, and may exceed the physical area in cases of multiple cropping. [c]South Asia is an area of extensive multiple cropping, and the ratio of cultivated to cultivable land exceeds.

nature of the problems in these marginal lands varies with location, and much research is needed to overcome the adverse effects of soil and climate.

Alternatives may be considered in land reclamation and land improvement (Table 2). The cost per ton of rough rice to be produced by the capital investment varies from US$200 for alternative *C* to US$1,500 for alternative *F*. These figures can be modified according to assumptions. The relative order of reclamation costs, however, may be used as the first approximation of economic feasibility. The most economical means is providing irrigation to already cultivated but inadequately irrigated fields; the second is providing irrigation to rainfed paddies. The most expensive is reclaiming virgin land into rainfed paddies. Thus, both the nature of the problem and the economic feasibility of reclamation of virgin land must be carefully examined.

Increasing rice crop intensity basically requires irrigation. In Kwangchow Province in China, two rice crops and one winter crop are normally grown in a year. Experiments on 3 rice crops and 1 winter crop have produced about 18 t rough

Table 2. Illustrative model indicating capital investment for 6 alternatives to increase production of paddy by 1 t/ha per year [a] (Colombo et al 1978).

Season	Paddy yield (t/ha): Virgin land (uncultivated)	Rainfed paddies (no irrigation)	Inadequate Irrigation (canals less than 50 m/ha)	Adequate irrigation (canals more than 50 m/ha)	Cost per hec-tare	Rise in annual paddy yield (t/ha)	Cost per ton	Investment priority (ranking of costs/ton)
Wet	0	1.0	3.0	3.5				
Dry	0	0	1.0[b]	2.5[c]				
Annual total	0	1.0	4.0	6.0				
Alternative A					$3,000	÷ 6.0	= $ 500	(4)
Alternative B					$1,500	÷ 5.0	= $ 300	(2)
Alternatlve C					$ 400	÷ 2.0	= $ 200	(1)
Alternatlve D					$2,600	÷ 4.0	= $ 650	(5)
Alternatlve E					$1,100	÷ 3.0	= $ 367	(3)
Alternatlve F					$1,500	÷ 1.0	= $1,500	(6)

[a] Obtained from 10 irrigation projects financed by the Asian Development Bank during 1968-72, modifted for inflation. [b] Assuming that only 1/3 of the area planted during the wet season can be planted in the dry, the yield during the dry season for the total area is 1/3 of the wet. [c] Assuming that only 2/3 of the area planted during the wet season can be planted in the dry, the yield during the dry season for the total area is 2/3 that of the wet.

rice/ha in 3 crops. Such yields have been made possible by subtropical climate, supply of irrigation water, and very intensive management (IRRI 1978b). Under certain types of rainfall distribution, however, it is possible to grow two or three rice crops a year without irrigation (IRRI 1978a). In Iloilo and South Cotabato, Philippines, two rainfed rice crops a year are grown in pilot experiments called KABSAKA and KASATINLU. Through direct seeding into dry soil, use of an early-maturing variety and herbicide application — the basic components of the technology for double rice cropping — rice yield per year can be doubled.

Rice yield is closely related to type of rice cultivation. It is largely affected by water regimes (Table 3). It can be modified greatly by improved cultural practices but may vary under different water regimes. The yields of dryland rice, deepwater rice, and

Table 3. Average maximum yields for 4 major types of rice cultivation in 11 Asian countries.[a]

Country	Maximum yield (t/ha)				Natl av yield (t/ha) for 1976
	Irrigated dry-season crop	Irrigated wet-season crop	Dryland and deepwater rice	Rainfed paddy	
Philippines	5.9	4.6	2.0	3.5	1.8
India	6.8	5.4	2.0	4.0	1.8
Indonesia	5.9	4.8	2.0	3.6	2.6
Thailand	4.4	3.7	2.0	2.5	1.8
Bangladesh	6.6	4.9	2.0	3.7	1.8
Vietnam	5.8	4.1	2.0	3.1	2.0
Sri Lanka	5.7	5.3	2.0	4.0	2.0
Burma	6.0	4.8	2.0	3.6	1.9
Pakistan	6.0	–	–	–	2.2
Nepal	–	4.8	2.0	3.6	2.1
Malaysia	6.0	4.8	2.0	3.6	3.2

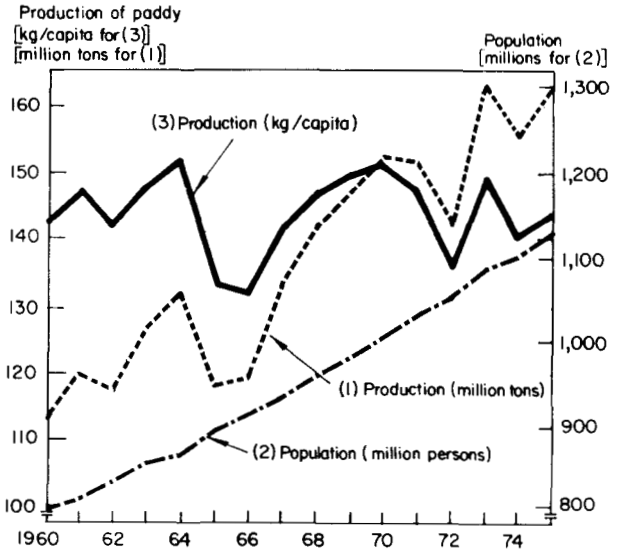
[a]Adapted from Chandler (1979). [b]Av maximum yields obtained in farmers' field trials in the Philippines, India, Indonesia, Thailand, Bangladesh, Vietnam, and Sri Lanka. For the other 4 countries, maximum possible yields were taken as the av of the other 7 countries.

rainfed rice are low. Those of irrigated rice are higher, particularly in the dry season, In many Asian countries, the national average rice yields are even lower than the average maximum yields for dryland and deepwater rice.

STABILITY OF RICE PRODUCTION

Instability of rice production is one of the most serious problems in developing Asian countries. In South and Southeast Asian countries, rice production has increased at about the same rate as population but there have been considerable year-to-year fluctuations (Fig. 1). As a consequence, production per capita also fluctuates greatly, causing food shortage.

Variability in amount and distribution of rainfall, and epidemic outbreaks of insects and diseases are two major factors responsible for such fluctuations. In



1. Paddy production and population for 16 Asian countries with developing market economies. 1960-75 (Colombo et al 1978).

Indonesia, for example, rice production increased quite substantially from 13.7 million tons in 1966 to 26.3 million tons in 1979 (Table 4). However, rice crops suffered severe droughts in 1967 and 1972 and consequently produced significantly less than in the preceding year. Rice production also suffered severe brown planthopper damage from 1975 to 1977. In the Philippines, epidemics of tungro virus disease almost wiped out rice harvests in Central Luzon in 1971.

Table 4. Production of paddy (rough rice) in Indonesia[a].

Year	Production (10^6 t)	Cause of damage[b]
1966	13.73	
1967	13.30	Drought (severe)
1968	17.16	NA
1969	18.61	NA
1970	19.32	NA
1971	20.18	NA
1972	19.39	Drought (severe)
1973	21.48	BPH
1974	22.72	BPH
1975	22.56	BPH (severe)
1976	23.30	BPH (severe)
1977	22.35	BPH (severe)
1978	25.88	BPH (moderate)
1979	26.32	BPH (light)

[a]Adapted from Palacpac (1978) and Biro Pusat Statistik (BPS), Jakarta, 1979 (unpubl.). [b]NA = not applicable, BPH = brown planthopper.

One way to quantify fluctuation in rice production is to compute the stability index, which is defined as:

$$\text{Stability index} = \frac{\text{Minimum yearly production per capita}}{\text{Maximum yearly production per capita}}$$

The stability index of total paddy production per capita in the 16 Asian countries between 1960 and 1975 was 0.74, which means that the lowest paddy production per capita in that period was 74% of the highest paddy production per capita. In Japan, where adequate irrigation facilities minimized the adverse effects of weather, the stability index for the same period was 0.87 (Colombo et al 1978).

Drought and flood

In the temperate region where irrigation is provided for rice cultivation, fluctuation in temperature is the major cause of fluctuation in rice production. In the tropics, where temperature is adequate throughout the year but irrigation is not available, shortages and excesses of water cause droughts and floods.

Among the three major weather components — rainfall. temperature, and solar radiation — rainfall fluctuates greatly from year to year while temperature and solar radiation are fairly stable in the tropics. In Los Baños, for example, during the 10-year period from 1967 to 1976, annual rainfall fluctuated from 1,244 mm in 1968 to 2,492 mm in 1974; annual solar radiation fluctuated from 129 kcal in 1975 to 159 kcal in 1968; and annual mean temperature ranged from 26.4° C in 1971 to 27.6° C in 1976. The ratios of minimum to maximum values (similar to stability index for food production) were 0.50 for rainfall, 0.81 for solar radiation. and 0.96 for temperature.

Rice crops suffer drought caused by late rains, dry rainy season, and dry spells during the rainy season. Dry spells occur unpredictably during the rainy season. Prolonged dry spells from the reduction division stage to flowering, when the rice plant is sensitive to drought, cause partial or total crop failure.

Excess water (floods) is another serious hazard to the rice crop. Its occurrence is largely related to excessive rainfall, topography, and inadequate coverage of forests. Large areas of rice in Java, Indonesia, are flooded almost regularly during heavy rainy seasons. For example, the Lamongan low-lying rainfed area of about 80,000 ha in East Java has 14,000 ha of deep water. The wettest months are December through March, with a monthly rainfall of more than 200 mm. During that period, floods occur frequently in that region. Inadequate forest land coverage should in part be responsible for the occurrence of floods. Jogjakarta has 5% forest land and Central Java 18% — not enough to prevent floods.

Floods cause erosion of the surface fertile soil besides reducing rice yield. In low-lying areas, the silting of rivers, canals, and reservoirs reduces the irrigation capacity for the next rice season.

Droughts and floods cause enormous economic losses. In 6 selected provinces of Indonesia, for example, severe drought struck more than 122,000 ha in 1977 and caused an estimated yield loss of more than 300,000 t milled rice. During the

1977-78 wet season, floods destroyed more than 99,000 ha and caused a yield loss of about 268,000 t milled rice (Table 5).

Drought and flood problems can best be solved by irrigation and drainage facilities. Supplemental irrigation may be the most effective means to overcome drought in the wet season. Several agronomic measures may alleviate the damage of drought and flood, depending on the local conditions:

- planting and harvesting a rice crop at times when the probability of rainfall is statistically highest,
- using photoperiod-sensitive varieties,
- using early-maturing varieties, and
- improving varietal resistance to drought and to partial or total submergence.

Table 5. Damage to rice fields caused by either drought or flood and the estimated yield losses in 6 selected provinces of Indonesia[a] in 1977-79 rice crops.

Rice season	Damaged area		Cause of damage	Estimated yield loss[b] (t milled rice)
	ha	%		
1977 dry	122,215	10.9	Drought	329,981
1977-78 wet	99,494	4.3	Flood	268,634
1978 dry	30,637	2.7	Drought	82,720
1978-79 wet	14,554	0.6	Flood	39,026

[a]Provinces of North Sumatra, West Java, Central Java, East Java, South Sulawesi, and West Nusa Tenggara. [b]Approximate yield of 1 ha = 2.7 t milled rice.

Forest conservation may also be another measure. Since ancient times, the conservation of forest lands has been one of the most effective ways to control floods. For example, a hardwood forest can hold about 200 mm water/150 cm soil. That is 60% greater than the water-holding capacity (120 mm) of a field soil of a similar texture. In the Tone River watershed region in central Japan, annual rainfall amounts to 9.4 billion m^3, of which 4.2 billion m^3 is stored in forests and 0.3 billion m^3 by dams.

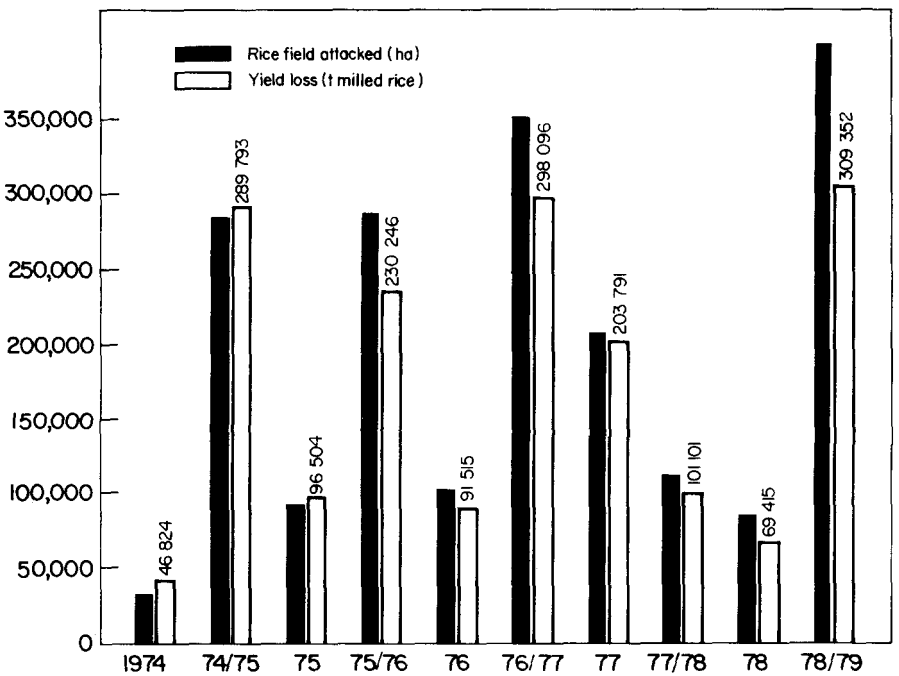
A well-balanced integrated forest and agricultural development plan may be the long-term solution to flood and drought problems. An intensive reforestation project is now under way in Java and Bali, Indonesia.

Pests

On large-scale intensified areas, increasing pest problems add to production instability. The tungro virus disease, transmitted by the green leafhopper species *Nephotettix malayanus, N. nigropictus, N. virescens,* and *Recilia dorsalis* (Ling 1976), is found in South and Southeast Asia. During the last decade, the disease has become epidemic, destroying large rice areas. A severe outbreak of the disease was reported from Thailand in 1966, Bangladesh and India in 1969, Malaysia in 1969 (Ling 1976), Indonesia in 1969 and 1972 (Oka 1971, Tantera 1973), and the Philippines in 1970 and 1971 (Ling 1976). The disease breaks out irregularly. The irregularity may be related to changes in weather and biological factors (Ling 1976). Recently the whitebacked planthopper *Sogatella furcifera,* has also caused increasing damage in

parts of Central Java and South Sulawesi, Indonesia (Oka 1979b). Both the white rice stem borer *Tryporyza innotata* and the yellow rice stem borer *Tryporyza incertulas* remain endemic rice pests.

The brown planthopper (BPH) *Nilaparvata lugens* and the two virus diseases (grassy stunt virus and ragged stunt virus) transmitted by it are perhaps the greatest challenge to plant protectionists in developing countries. The insect has caused significant losses to the rice crops in the Philippines, India, Sri Lanka, Malaysia, Bangladesh, Thailand, the Solomon Islands, Fiji, Japan, Korea, Taiwan, and Vietnam (Dyck and Thomas 1979). But perhaps the losses were greatest in Indonesia, where the BPH infected from 260,000 ha in 1960 to 500,000 ha in 1973 and was responsible for an annual yield reduction of about 21% (Soenardi 1978). Since 1969, the insect's status has changed from a minor rice pest to the most important insect responsible for increased yield losses. In 1971-72 only about 4,000 ha was attacked by BPH, grassy stunt, and ragged stunt. But during the following rice seasons, the area attacked increased drastically. The pests attacked both the wet- and the dry-season rice crops, but the extent of damage on the wet-season crops was much greater (Fig. 2). In the 1976 and 1976-77 rice crops, they attacked more than 450,000 ha (Soenardi 1978), totally damaging 30% of the area. Rice yields averaged 2.7 t/ha



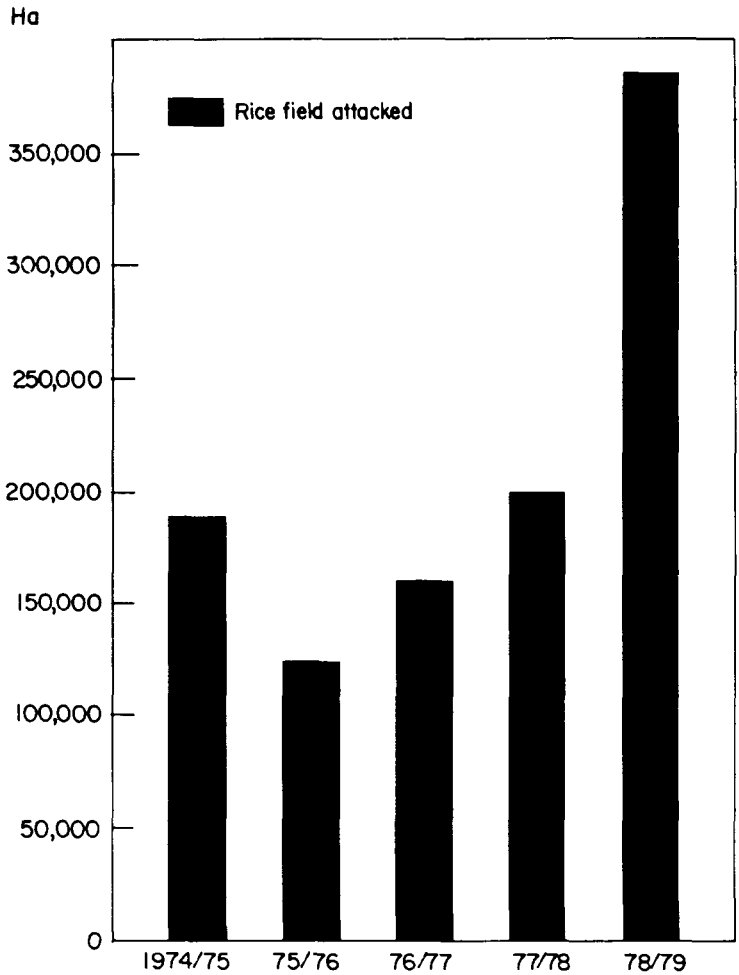
2. Total areas damaged and yield losses due to brown planthopper, ragged stunt virus, and grassy stunt virus, 1974-79.

during the 2 seasons (Palacpac 1978) and the total loss due to the pests was about 350,000 t milled rice, valued at more than US$100 million. Assuming that the per capita consumption is 120 kg rice/year, the total loss represents enough rice to feed more than 3 million people for the whole year.

A number of rat species continuously threaten rice production and cause unstable yields (Fig. 3). They attack both the dry- and the wet-season rice, but the damage to the wet-season rice is more extensive than that to the dry-season rice. No quantitative data on yield losses due to rat damage are available.

Several bioecological changes are suspected to cause increasing pest problems, which add to yield instability:

1. Planting a few modern varieties over wide areas reduced the varietal diversity



3. Total area damaged due to rats 1974-75 to 1978-79.

and increased the instability of community association in favor of the pests. For example, BPH epidemics took place after wide-scale planting of the modern varieties Pelita, C4-63, and IR5, which are susceptible to both the insect and the viruses.

2. Increasing pest problems have occurred on well-irrigated areas on which two or three continuous and staggered rice croppings had long turnaround times, and ratoons remained in the field. This condition provides the pests with year-round food and shelter. For example, the BPH epidemics and rice tungro and grassy stunt diseases occurred on the field cropped continuously rather than on fields with definite rice seasons. The yellow rice stem borer with overlapping generations gradually built up under the staggered-planting system. Under these situations, rats are also much more difficult to control because they prefer rice plants to baits. In developing nations, the construction of irrigation systems will be continued to increase both the per-hectare yield and crop intensity. To prevent increasing pest problems in well-irrigated areas, water should be managed properly, making synchronous planting and crop rotation possible over wide areas. During the nonrice crop period, further pest buildup can be prevented (Oka 1979a, Litsinger et al 1978).
3. Increased application of nitrogen fertilizer favors the development of the BPH (Dyck 1974).
4. Large-scale planting of modern rice varieties with a narrow genetic base for resistance such as IR26, IR28, IR30, and IR34 easily shifts the original BPH population to the BPH biotype 2, which can damage the varieties.
5. The ad hoc or simplistic approach to insect pest control such as intensive and indiscriminate application of pesticides easily shifts the delicate biological balance to instability in favor of the pests, evolving resistance of insect pests to pesticides, as in the case of BPH to gamma-BHC in Japan (Nagata and Moriya 1974, Heinrichs 1979). BPH resurgence has occurred at IRRI after foliar sprayings with carbofuran, methyl parathion, NRDC 161 (Decis), and diazinon (Heinrichs 1979). In Indonesia, it occurred after sprayings with surecide and Ofunax (Dandi 1978). The spraying program against BPH has become complicated because BPH react differently to insecticides, depending on their stage of development, sex, and biotype (Heinrichs 1979). Too frequent spraying with broad-spectrum insecticides destroys effective BPH biological control agents (Chiu 1979) and increases the risks of environmental pollution and hazards to men.

Manipulation of the agroecosystem contributes to the increase in pest problems, particularly the BPH and the viruses. Understanding of the intricate and complex interactions between the rice plant and pests and natural enemies under tropical environments is inadequate. A better understanding of the natural forces can be gained only through comprehensive research. A sound ecological approach to pest control may then be devised to achieve *a stabilized high yield ecosystem, a healthy environment,* and *economical measures for the farmers.*

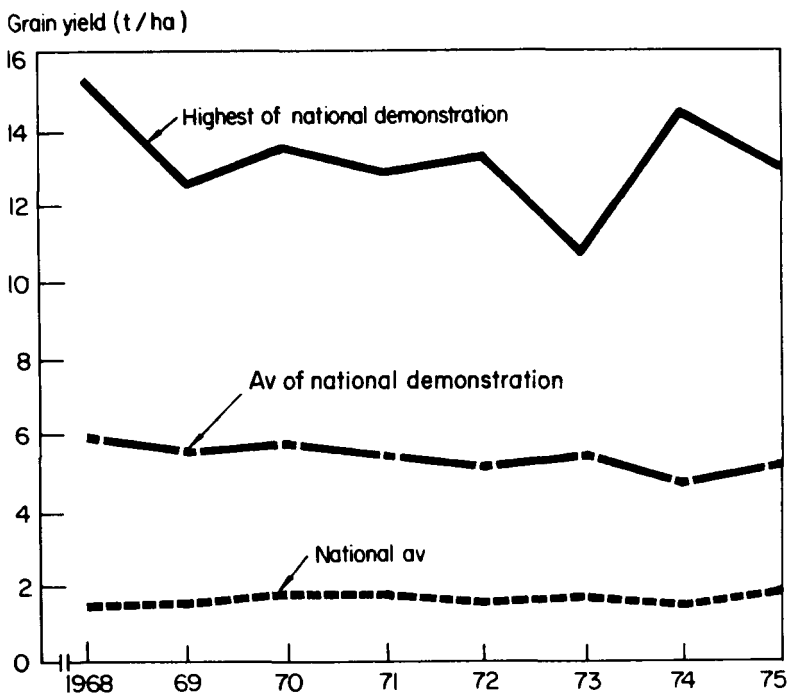
RICE YIELD AND PRODUCTION POTENTIAL

Current rice yields and potential yields

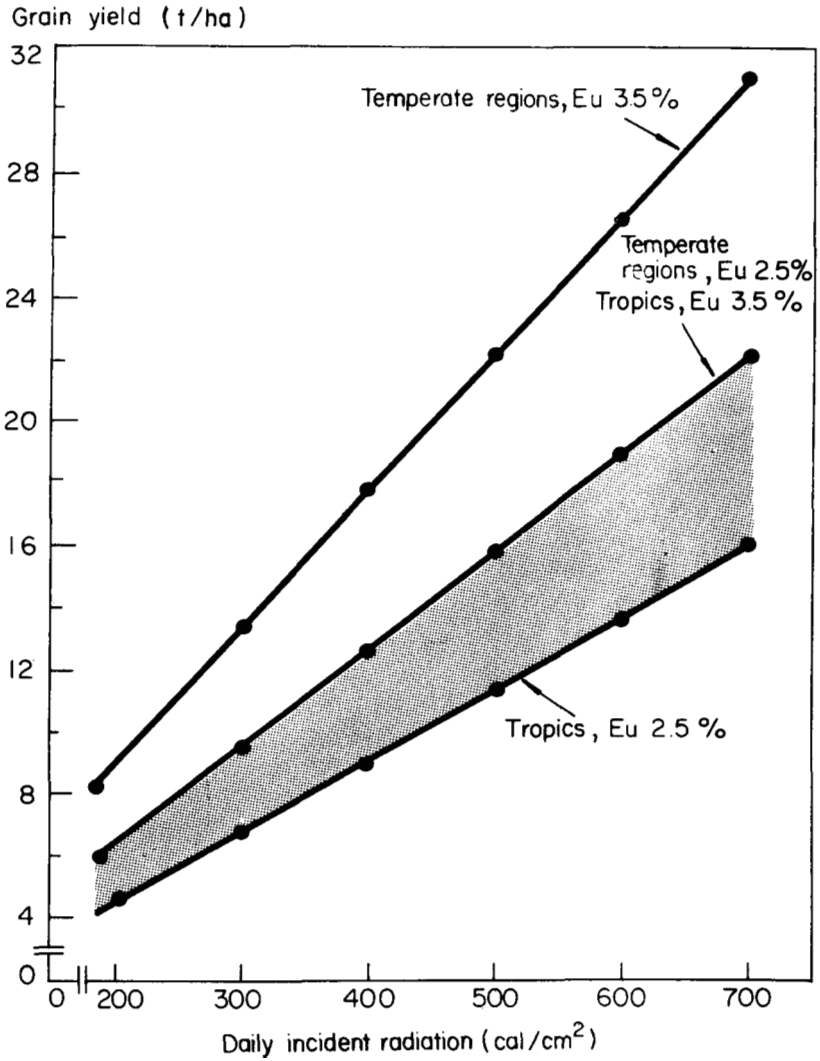
How far rice yield can be increased may be examined: 1) by estimating the maximum yield on the basis of the rice plant's physiological efficiency, and 2) by comparing the recorded maximum yield and the commonly achieved yield, and then studying how the recorded maximum yield can be approached. The physiological potential yield suggests the limit beyond which rice yield cannot be increased with further increase in input.

The maximum rice yield recorded in Japan is 13.2 t/ha (Agricultural Policy Study Commission 1971). In the tropics, IR24 produced 11.0 t/ha at IRRI in the dry season (IRRI 1973), and IR8 yielded 10.7 t/ha at Battambang, Cambodia (Hirano et al 1968). In India, the maximum recorded yield was 17.8 t/ha in Maharashtra State (Suetsugu 1975). A comparison of the maximum recorded yields of experimental fields and national average yields in India is shown in Figure 4.

The average yield of about 6 t/ha from national demonstration trials may represent a reproducible rice yield achieved with available technology. It is almost comparable to the national average in Japan, Korea, and Australia. The highest



4. Changes in rice yields of national average, average of national demonstrations, and the highest of national demonstrations in India during the period 1968-69 to 1975-76 (source: ICAR 1978).



5. Relation between potential yield and incident radiation during the grain-filling period of rice (IRRI 1977).

yield in national demonstration trials (from 11 to more than 15 t/ha) may indicate the maximum yield obtainable with high inputs and in favorable environments. Physiological potential yields depend on the level of solar radiation (Fig. 5). Figure 5 shows a linear relationship between incident solar radiation and potential yield. This is because the same *Eu* value is used at all levels of incident solar radiation. However, *Eu* value is expected to decrease with increasing level of incident solar radiation. As a consequence, the relationship between incident solar radiation and potential yield

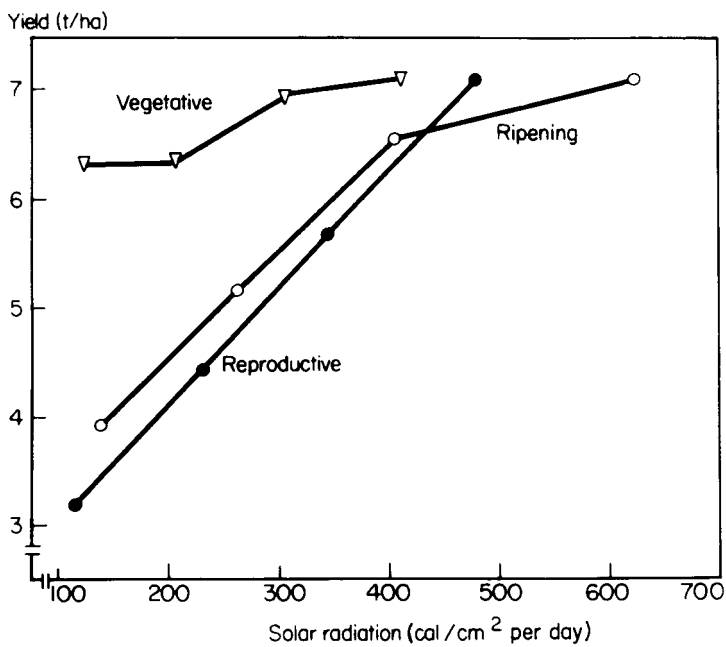
would likely be curvilinear but not linear. At present, however, information is lacking as to how *Eu* relates to incident solar radiation in rice. Considering the preceding information, the potential yields shown in Figure 5 are likely to be overestimates at high levels of incident solar radiation. Under an estimated solar radiation of 300 cal/cm^2 per day for the wet season and 500 cal/cm^2 per day for the dry in the tropics, the maximum potential yield would be 9.5 t/ha for the wet season and 15.9 t/ha for the dry.

Factors affecting rice yield

In principle, a high yield can be achieved only with the proper combination of variety, environment, agronomic practices, and plant protection measures. No single combination of these four factors, however, is applicable to all situations.

It is convenient to consider the interactions of the above four factors under 1) dependable water supply with good management, and 2) less dependable water control with subnormal management.

With good management, variety and environment determine rice yield. IR8 was the first to demonstrate the importance of variety in achieving high yields in the tropics. It has short, stiff culms and erect leaves, and is high tillering, photoperiod insensitive, and of adequate growth duration. With a good variety and proper management, solar radiation is the major determinant of rice yield (Fig. 6). Rice



6. Effect of solar radiation at different growth stages on grain yield of IR747B2-6 (Yoshida and Parao 1976).

yield increases almost proportionately with increase in solar radiation during the reproductive and ripening period. During the vegetative growth stage, solar radiation is not as important because it is normally more than sufficient for young rice plants in most rice–growing regions.

With undependable water control with subnormal management, IR8-type high yielding varieties may not produce good yields because of variety-environment interactions. An obvious example is deepwater rice. Deepwater areas require a special type of variety. When a rice crop is partially submerged, the grain yield decreases as water depth increases (Pande 1976). The yield-decreasing effect of partial submergence may be attributed to impaired tillering and decreased photosynthetic leaf surface. The increase in plant height should counteract the effect of partial submergence. Thus, a variety of intermediate plant height may be preferred to a short variety when water control is somewhat undependable. Under subnormal management where weeds are a problem, intermediate or tall varieties would perform better than short ones because they efficiently suppress weed growth (Moody 1977).

In summary, the following factors are always essential in achieving high yields:

- high yielding variety,
- adequate supply of water,
- fertilizer,
- adequate planting density, and
- high solar radiation.

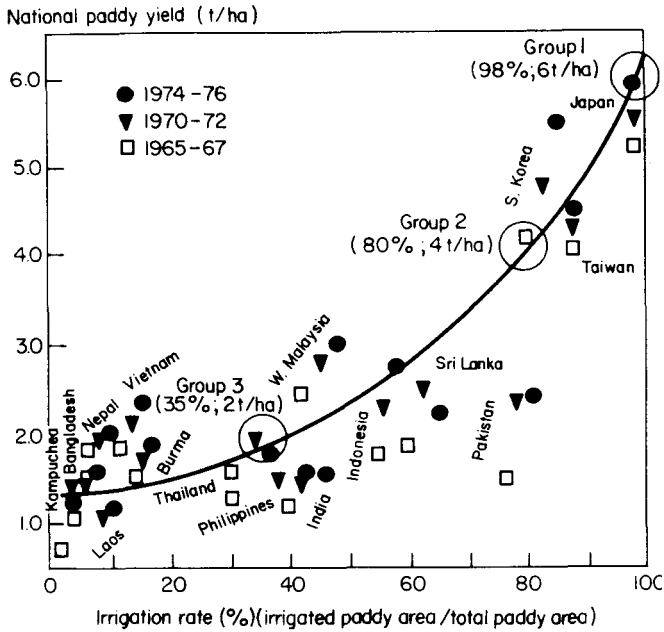
The factors that prevent yield increase are:

- insects and diseases,
- rats,
- weeds,
- water shortage and excess,
- adverse soils, and
- extreme temperatures.

Irrigation and rice yield

Water is the single most limiting factor in rice production. Increases in rice yield, yield stability, and production potential depend largely on the availability of irrigation and drainage for rice cultivation.

Irrigation rate and national average rice yield are closely correlated (Fig. 7). Japan, South Korea, and Taiwan, which have high irrigation rates, have the highest national average yields in Asia. In 1977, South Korea achieved the world's highest national average rice yield. The close correlation between irrigation and national average yield does not mean that irrigation alone can increase rice yield. Irrigation is a fundamental prerequisite for the full exploitation of modern rice production practices. Because it stabilizes rice yield, it increases the farmers' incentive to adopt modern high yielding varieties and to use more fertilizer. The close association between irrigation rate and national average yield brings two challenges. The challenge to national and international administrators is to increase irrigation rate.

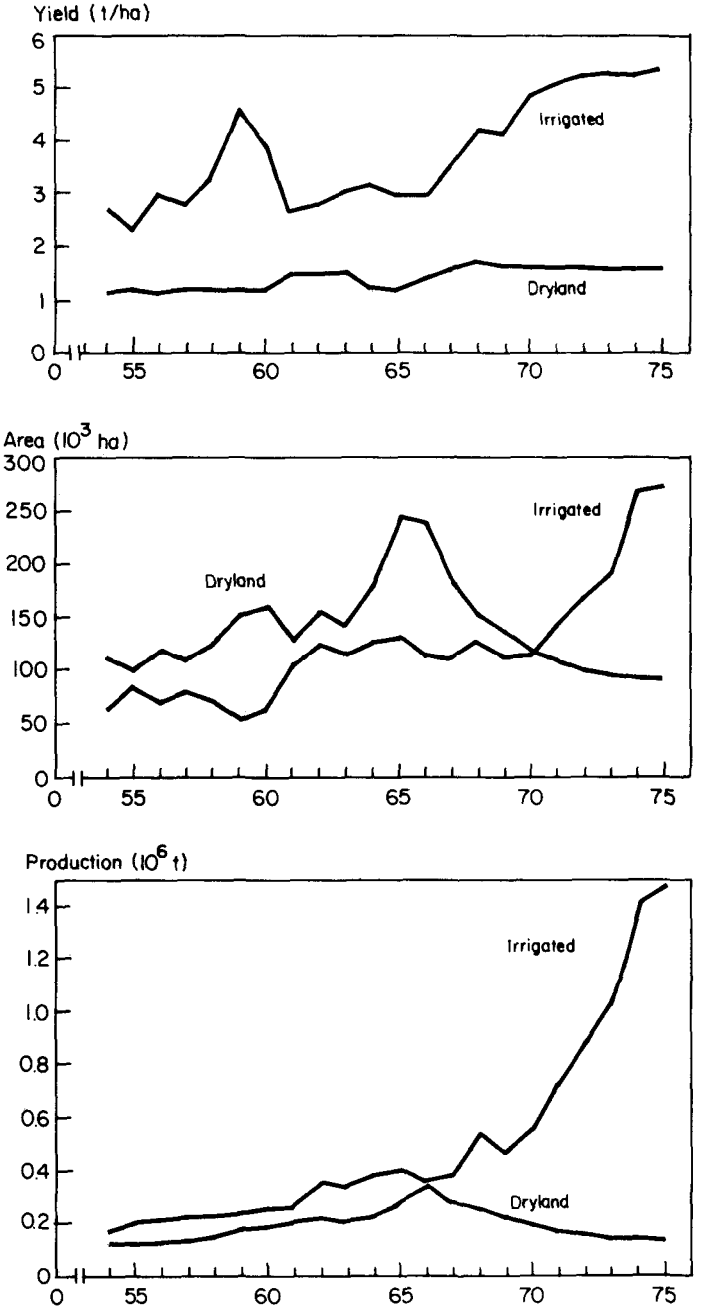


7. Relationship between irrigation rate and paddy yield (Colombo et al 1978).

The challenge to research scientists is to break the above association. Intensive research under way at IRRI and elsewhere has been aimed at increasing the resistance of rice varieties to drought. However, it must be understood that increased resistance helps only in a temporary drought. A basic rule in rice growth is that the amount of growth should be proportional to the amount of water absorbed by the plant. The rice plant must absorb about 300 g water to produce 1 g dry matter. There is, however, a good chance of success in modifying the rice plant to make it more resistant to a temporary drought in the rainy season. Under a long drought, there is no way to prevent yield from decreasing.

Another excellent example to illustrate how irrigation affects rice yield and rice production comes from Colombia (Scobie and Posada 1977). In 21 years, from 1954 to 1975, the rice yield of irrigated land increased from 2.7 t/ha to 5.4 t/ha whereas that of dryland land increased from 1.1 t/ha to 1.6 t/ha (Fig. 8). The land area of irrigated rice increased from 63,000 ha in 1954 to 274,000 ha in 1975. During the same period, the land area of dryland rice increased from 112,000 ha in 1954 to 245,000 ha in 1965 and then declined to 95,000 ha in 1975. As a consequence, irrigated rice accounted for 58% of the total rice production in 1954 and for 91% in 1975.

The water requirement of a rice crop is greater than that of many other crops. One rice crop requires 1,300 mm water whereas 1 wheat crop requires only 430 mm. Thus, rice is considered a water-consuming crop. However, the major rice-growing



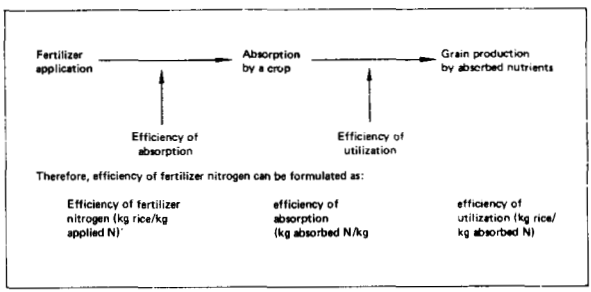
8. Area, production, and yield of paddy rice by sector in Colombia (1954-75) (Scobie and Posada 1977).

area is in monsoon Asia, and hence only supplemental irrigation is needed for the main rice crop in the wet season.

Nitrogen fertilizer and rice yield

Under a very optimistic outlook, resistant varieties may require minimal use of pesticides but a supply of basic nutrients is indispensable to increase yields.

Nitrogen is the first limiting nutrient under most conditions. When fertilizer nitrogen is applied to soil, the crop absorbs it and uses it for grain production. Therefore, efficiency of fertilizer nitrogen can be formulated as:



Available data indicate that the efficiency of nitrogen utilization for grain production in the tropics is about 50 kg rough rice/kg N absorbed, and this efficiency is almost constant regardless of the rice yields (Yoshida, unpubl.). In other words, rice yield is proportional to the amount of nitrogen absorbed by the crop.

On the other hand, efficiency of absorption, which is normally referred to as percentage of nitrogen recovered, can be changed to a much greater extent, depending on soil properties, methods, amounts, and timing of application, and other management practices. Recovery of the applied nitrogen varies from 30 to 50% in the tropics (Prasad and De Datta 1979). The percentage of nitrogen recovered tends to be high at low nitrogen levels and when the nitrogen is topdressed at later stages of growth. Using values for efficiency of absorption and efficiency of utilization, we get

$$\begin{aligned}\text{Efficiency of fertilizer nitrogen} &= 0.3\sim0.5 \times 50 \text{ kg rice/kg absorbed N} \\ &= 15\sim25 \text{ kg rice/kg applied N}\end{aligned} \tag{2}$$

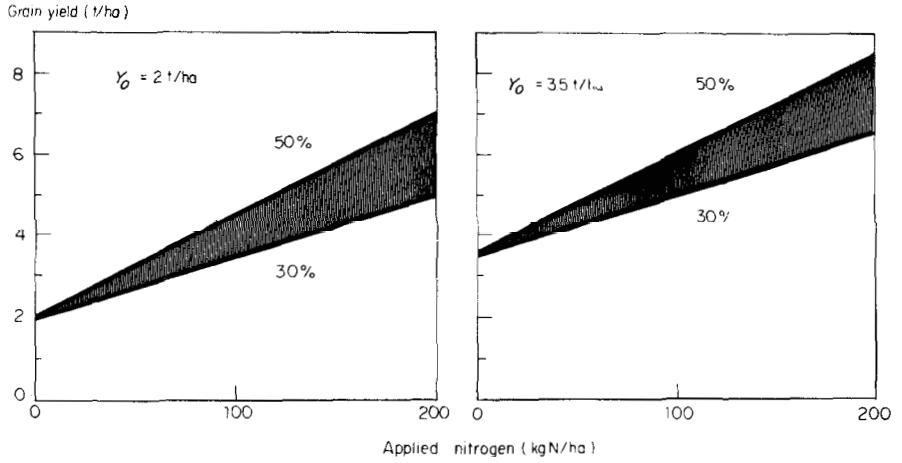
These values of efficiency of fertilizer nitrogen are commonly found in agronomic experiments (Prasad and De Datta 1979).

Grain yield (Y) can be analyzed into two parts: yield obtained without fertilizer nitrogen (Y_o) and yield increase obtained by fertilizer application (DY_F).

$$\begin{aligned}Y &= Y_o + DY_F \\ Y &= Y_o + (\text{fertilizer efficiency}) \times N_F\end{aligned} \tag{3}$$

where N_F is amount of nitrogen applied (kg/ha), and Y_o represents the soil's nitrogen fertility level. The source of nitrogen for Y_o can be either soil organic

nitrogen or biologically fixed nitrogen. Y_o varies with soil and perhaps with variety. To simplify the problem, we shall assign to Y_o 2 values — 2 and 3.5 t/ ha. Y_o = 2 t/ ha perhaps represents the average nitrogen fertility level of paddy fields and Y_o = 3.5 t/ha, a high fertility level. Yield increase obtained by fertilizer application can be computed from equation 3.



9. Simplified models for relationship between fertilizer nitrogen and rice yield. 30% and 50% are minimum and maximum values for nitrogen recovered.

As shown in Figure 9, grain yield is determined by 1) soil fertility level, 2) amount of nitrogen applied, and 3) percentage of nitrogen recovered. At Y_o = 2 t/ ha, 50 kg fertilizer nitrogen can produce a yield of 2.7 to 3.2 t/ ha. To produce 6 t rice/ha, a minimum of 160 kg N is needed at Y_o = 2 t/ ha. These computations illustrate the relationship between the target yield and minimum fertilizer requirement. Long-term fertility experiments appear to indicate that the average amount of biologically fixed nitrogen is about 50 kg N/ha per crop (Watanabe et a1 1979). This amount corresponds to a rice yield of 2.5 t/ ha.

In the Philippines, Tanco (1976) hopes that rice yield will be increased to 7-9 t/ ha by the year 2000. To produce 7 t yield by growing 1 rice crop a year, 200 kg N/ha must be applied when Y_o = 2 t/ ha and nitrogen recovery is 50%. If the same yield is produced by growing 2 crops/ year, 120 kg N/ ha is needed under the same assumption In any case, attempts to increase rice yields in the near future largely depend on fertilizer supply.

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RICE RESEARCH NEEDS FOR THE FUTURE

R. W. CUMMINGS

Rice is the main staple in the diets of the vast populations of South and Southeast Asia, where about 90% of the world's rice is grown. It is dominant among the cereal crops, which provide more than 60% of the people's food calories. Its production in South and Southeast Asia, even under traditional methods of cultivation, used to be adequate to mainly support the growth and survival of the world's densest populations. By the middle of this century, however, the food supply outlook for the region became increasingly precarious.

Rice, indigenous to South and Southeast Asia, has spread to all continents on the globe. The people of Africa, the Middle East, and Latin America have not been heavily dependent on rice as their major staple food. But as urbanization has increased in those regions, the market demand for rice has grown rapidly and, especially in Africa, has put increasing strains on foreign exchange budgets. This, in turn, has led national governments to give increasing attention to measures that could increase their production of rice, and to set goals to attain national self-sufficiency in food (and rice) production.

For South and Southeast Asia, IRRI has estimated that about 28% of the rice area is under controlled irrigation, about 48% bunded rainfed, about 8% deepwater, and about 14% dryland (unbunded rainfed, including arid high temperature). In Africa, more than 60% of the rice area is dryland, with smaller proportions in hydromorphic, deepwater, and mangrove swamp areas, and under controlled irrigation.

In Latin America, which accounts for 4% of world rice production, the major area of rice production is as dryland, but with a substantial and growing proportion being grown under controlled irrigation.

Rice is grown in the United States in two major regions, which are completely under controlled irrigation and use capital-intensive, highly mechanized techniques. Because rice is a minor component of the American diet, the United States is the world's leading exporter of rice.

International trade in rice involves only about 2-3% of the total world's rice

Chairman, Technical Advisory Committee, Consultative Group on International Agricultural Research.

production, but the international market for rice is a highly volatile one. Deficits or surpluses in major rice-consuming countries can have a very major effect on international prices.

The demand for increased rice supplies will continue to grow during the next decade. With populations increasing at a compound rate of 2% or more a year in rice-consuming developing countries around the world, the demand for rice can be expected to rise even faster.

As we pause at the end of IRRI's second decade, we can take much satisfaction in the progress achieved to date. At the same time, we can see even greater challenges ahead.

When IRRI was chartered, it appeared that potential rice yields under the best of conditions in the tropics had reached a ceiling of 3.5-4.0 t/ha. Attempts to push yields higher by closer spacing, choosing varieties that tillered more profusely, and applying higher rates of fertilizer were thwarted by the inability of the available plant varieties to support the heavier grain loads against wind and rain. Higher rates of nitrogen fertilizer usually resulted in increased lodging and often decreased rather than increased yields of grain.

The introduction of the dwarfing characteristics with profuse tillering and strong stalk from the Chinese variety Dee-geo-woo-gen and its incorporation with the grain quality and partial disease resistance of the Indonesian variety Peta in the cross that produced IR8 provided the breakthrough on which major advances were made during IRRI's first decade. This breakthrough on plant type made possible the application of production practices, including improved soil fertility and higher rates of fertilizer application, which helped raise the potential yield ceiling to 8-10 t/ha — more than double the previous levels.

Subsequent genetic improvements — from IRRI, from selection out of genetic combinations put together and distributed by IRRI, from reinvigorated national programs using wider ranges of genetic source materials, and from networks of cooperating scientists — have incorporated an increasing number of desirable characters into present-day rice varieties. These have provided a range of desired grain qualities to meet preferences in different cultures, a wider range of disease and insect resistance and tolerance, greater cold tolerance, tolerance for less favorable soil conditions, etc.

THE IRRI PROGRAM TO DATE

Although IRRI's initial primary focus was on rice production under controlled irrigation in South and Southeast Asia, its mandate was much broader. The gains already achieved in rice production science and technology and the knowledge necessary to support the further production levels have been increasingly shared by a large number of national research establishments in rice-growing countries and by regional and international organizations. IRRI is now recognized as a world center of excellence and must remain prepared to provide back-up support to and collaboration with these groups. I have no doubt that it will do so. Its comprehensive

program of germplasm collection, characterization, and preservation, and its generous sharing of this material on a worldwide basis demonstrate IRRI's resolve in this direction. Its various training and conference programs, its extensive and widely distributed publications, itsannual internal program reviews, and its regular series of program reviews and planning conferences with its collaborators in rice-growing countries give further assurance. The recent posting of liaison scientists in Africa and Latin America indicates IRRI's recognition of limitations that distance and communication problems may place on the discharge of its responsibilities in distant areas. At the same time, it gives evidence of IRRI's readiness to provide support and professional experience to assist programs of rice production research for these regions.

Near the end of its first decade, IRRI convened a conference to review its experience and to project the problems for the second decade. *Rice Research and Training in the 70's* reported the conclusions of that conference. The conference reiterated IRRI's initial goals at the time of its establishment, namely:

- to help increase national average yields of rice, especially in the nations of the tropical Asian rice bowl;
- to help develop strong national technical and related capabilities in interested rice-growing nations; and
- to stimulate international cooperation on important regional or worldwide problems.

While the focus of IRRI's work, and indeed that of most rice research in Asia, was still on the improvement of production in favorable soil and climatic situations, considerable thought and attention was being given to broadening this outlook. The spectacular gains already set in motion on irrigated rice would require much continuing research to protect and extend them, but bunded rainfed, unbunded dryland, deepwater rice production occupied vast areas and presented additional problems. Different soil conditions brought about specific problems that would limit rice yields; rice production on other continents would need attention. The conference deliberation suggested that:

- research directed toward raising average yields be given increased depth;
- economic research and training capability be expanded;
- promising agricultural engineering research and development efforts be encouraged;
- the training of technicians and scientists be continued but gradually shifted toward developing a higher level of competence while retaining field experience in actual rice production;
- innovative ideas and programs for international cooperative attacks on regional and worldwide problems be developed; and
- the present and potential importance of ecologically different rice-producing areas be studied more closely.

The papers presented at the 10th anniversary celebration of IRRI in 1972 emphasized the achievements in rice production technology and the impact of its application, the growing strengths of cooperating national programs, and the social and

economic implications thereof during IRRI's first decade. The papers prepared for that meeting provided a very useful reference point in the progress in rice research and the results of the application of science to rice production.

CHARACTER OF INTERNATIONAL CENTER PROGRAMS

Strong national agricultural extension programs have been recognized as essential to the effectiveness and usefulness of the programs of the international centers. National and international efforts in these fields must complement one another. The last two decades have witnessed a very substantial strengthening of research establishments in a number of developing nations and the emergence of several national programs that can take their place alongside those of many of the more highly industrialized countries. As the national agricultural research programs gain strength and effectiveness, the character of the programs of the international centers must necessarily evolve to maintain their appropriate complementarity. The International Federation of Agricultural Research Directors at its first meeting reiterated the continuing need for international agricultural research centers as complementary to and supportive of national research programs of the developing countries. As the national programs gain strength, the international centers may have a diminishing role in the frontline of applied research but a growing role in background and supporting activities. The research directors foresaw, among the continuing long-term functions of the international centers, the following:

- collection, conservation, cataloging, and distribution of germplasm;
- organization of path-breaking research designed to raise the ceiling of yield and to impart greater stability to yield, for example, research that can lead to high-yield and high-stability varieties with desired quality;
- development of improved research techniques;
- organization and conduct of relevant training programs;
- organization of information and bibliographic services; and
- organization of symposia, seminars, and monitoring tours.

The Technical Advisory Committee (TAC) agrees with this concept, recognizing that its precise application will vary considerably with the varying stages of development of strength in the respective national programs.

IRRI's long-range planning report, released in 1979, and its recent program and budget documents reflect a wholesome recognition of its evolving role. Time does not permit a full review of this document, but it can be highly commended and can serve as an excellent guideline for the deliberations of the conference on Rice Research Strategies in Selected Areas, which follows. It is reflected in IRRI's program and budget document for 1980-81, from which I quote:

> "IRRI's current strategy which will likely be pursued during the next few years is to give greater attention to production problems as found in the major rice producing areas of the world. This requires research to ascertain major production constraints and to find means of removing those constraints. Increased attention will be given to rainfed agriculture and to

constraints such as pests, and soil and climate deficiencies."

These changes in focus make it necessary for IRRI to give greater emphasis to collaboration with and support of national research programs. Concomitantly, there wil be some deemphasis of IRRI's role as an independent research organization.

IRRI's strategy for the next few years will require sharper focus on several types of activity. First, we will give greater attention to basically oriented research to obtain a better understanding of subjects such as the genetic basis of resistance or tolerance to rice pests, the ecology and physiology of insects, biological fixation of nitrogen, and the physiological factors influencing rice yield potentials. Such investigations will be very supportive of applied research programs in national agencies. It is the type of research which, in the interest of efficiency, need not be done in each national research organization. Furthermore, limited human and financial resources make it unlikely that any but the more affluent and the larger of the developing nations can do this type of research.

Second, a significant proportion of IRRI's applied research will be done in collaboration with scientists in national programs. This type of collaboration is essential since IRRI has broadened its focus from the relatively controlled environment of highly productive irrigated farms to the less controlled but more extensive environment of rainfed agriculture. Technology must be developed to fit the soil and climate conditions in the major rice-growing regions of the world. Furthermore, the discovery of different strains of viruses attacking rice makes it essential that these pests be studied in the localities in which they are found. This requirement can be met only by formal collaboration of IRRI scientists with their counterparts at selected locations in national programs. Likewise, the availability to national researchers of early generation breeding materials from the IRRI GEU program can greatly accelerate the evaluation and utilization of valuable genetic resources.

Third, IRRI will continue to play a key role as a catalyst for international cooperation among rice researchers. Through networks such as the International Rice Testing Program (IRTP), the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), the International Rice Agroeconomic Network (IRAEN) (for research on constraints), and the Cropping Systems Network, IRRI scientists can encourage joint research planning and implementation as well as the free interchange of genetic materials and of research methodologies useful in the implementation of the network activities.

Fourth, IRRI will continue its effort to increase the capability of national research organizations. Emphasis will be placed upon training, both formal and informal. Most of the training will be accomplished through participation at IRRI headquarters of trainees, scholars, and fellows in organized research and training programs. Other training opportunities will be given

to national researchers working with IRRI scientists assigned to outreach projects.

"The challenge of the next decade is to maintain the research quality and spirit of inquiry which characterized IRRI's first decade while simultaneously forging more effective linkage with scientists in national programs. IRRI's strategy is based upon the assumption that its ultimate success will be determined by the success of the national programs with which we are associated."

These documents appear to show a very strong focus on South and Southeast Asia — which is understandable because that is where almost 90% of the world's rice is produced. It appears that IRRI anticipates that other organizations would take major direct responsibility for rice research in Africa and Latin America. IRRI has placed in each of these two regions a liaison scientist, through whom contacts with the IRRI research and training and information programs can be maintained, genetic resources exchanged and evaluated, and arrangements for training and participation in conferences or visits of IRRI scientists can be worked out. I will not attempt to comment on this arrangement. With the distances involved and the cost and difficulties of travel and communication, the arrangement may well prove to be most satisfactory. However, because IRRI will be the major repository of the world's genetic resources collections, it may have to assume a larger responsibility in that function.

Recently TAC has examined the question of dryland rice research on a global basis and the respective roles of the different organizations involved. The tentative conclusion of the working group it organized was that IRRI should assume a global coordinating role on dryland rice research and more clearly identify that phase of rice research in its personnel and organizational pattern. IRRI should also take the lead in working out specifications for the dryland rice ideotype and provide from its genetic collection and derivatives therefrom the genetic combinations and crosses among which more suitable and dependably productive and disease-resistant dryland rice varieties could be selected. I trust that IRRI would take these suggestions seriously.

RICE RESEARCH NEEDS

I find it difficult to make many suggestions with respect to rice research needs for the future that have not already been addressed in IRRI's long-range plan, or in the TAC study on dryland rice research. You will be considering strategies for implementing parts of the long-range plan during the next several days. Substantially more rice will be needed to meet the nutritional needs of growing populations throughout the developing world.

Experience with higher yielding varieties and more intensive culture have clearly demonstrated that a great deal of research will be needed simply to protect and stabilize the gains in genetic improvement and production technology that have already been achieved.

Intensification of rice culture, which results in closer spacing of plants and more complete shading, changes the microenvironment within the plant canopy and affects the pest-pathogen-host relationships substantially. Development and widespread use of genetic lines that are resistant to the prevailing strains or biotypes of specific pests and disease organisms place new selection pressure on these populations. Variants within such populations, which may be able to override such resistance, no longer have the same competition and may multiply and become dominant. Thus a line initially showing a high degree of resistance to a given pest or disease may no longer show such resistance. The biotype variants of the brown planthoppers and the necessity to develop strains resistant to each, or a broad-based resistance to all biotypes is a good case in point.

Intensification of rice culture on another basis — two or three successive crops per year on the same land, and timewise overlapping of successive rice crops within the same farming community — can profoundly affect the dynamics of disease organisms and pest populations. If rice is grown continuously throughout the year in a given farming community, there is always a relatively heavy source of inoculum for diseases to which the crop is susceptible or of insects that may destroy the crop. With intensive year-round culture of rice at IRRI headquarters, the pest population pressure is no doubt heavier than in much of the Philippines and other parts of South and Southeast Asia away from IRRI.

Crop intensification will have to increase in tropical areas in the future to the extent climatic conditions permit. We will have to learn how to cope with the results and still maintain and increase yields of rice grain dependably year after year.

Rice blast still presents many perplexing problems. The causal organism seems to possess a unique capability to produce a large number of mutants, making it especially difficult to identify and stabilize broad-based resistance to the disease. Blast affects rice in various types of culture, but seems to be especially severe in dryland rice. The reason for blast severity in dryland rice fields is not clearly understood but has been attributed by some workers to the fact that the susceptibility may be in part stress induced. This needs to be followed up.

Attempts to apply intensive yield-increasing technology on a broad basis has led to the identification of a number of problem soil conditions under which the practices worked out at IRRI headquarters failed to produce the expected results. The fuller characterization of these various problem-soil and environmental situations and the means of overcoming them will continue to present important challenges.

Fortunately IRRI's initial research was directed to the improvement of levels of production in the areas under controlled irrigation in South and Southeast Asia —within which substantial gains might be possible within a reasonable time frame. The research served to open up visions as to what might be achieved in other sectors of rice production — rainfed, dryland, deepwater, mangrove swamp, etc. — and also on other continents, especially Africa and Latin America. Potential yield ceiling levels may not be as high in some of these other sectors but we do need to identify the nature and magnitude of the constraints and develop the technology that can

maximize or optimize the returns. And we should recognize that there are some situations in which rice is not a viable enterprise. We should ultimately be in a position to identify such situations and suggest alternatives.

The first great breakthrough in modern times on yield ceiling with tropical rice came with the incorporation of the dwarfing gene into useful agronomic varieties. IR8 was the focal point. The series of additional varieties with improved grain quality, wider ranges of disease and insect tolerance or resistance, adaptation to less favorable environments, etc., have been carried forward into research on other types of rice culture. But the yield ceiling found possible with IR8 has not been significantly raised. It still has to be determined whether the recent experience with hybrid rice in China will raise it. We should continue to seek ways by which the yield ceiling achieved with IR8 can be significantly raised. We still have a long way to go in achieving an approach to improved yield on a high proportion of the area in rice, and we should push ahead on this front, but research organizations should still explore vigorously the search for means of achieving still higher potentials.

Thus far I have dwelt especially on the biological and physical aspects of research on rice. These aspects will determine what is physically possible. But we recognize that rice is grown by people and that there are social and economic considerations that materially affect the manner and extent to which known technology is applied and utilized.

IRRI's long-term plan and the recent TAC-sponsored consultation on dryland rice provide worthy guidelines for this conference, to map out the research strategy for the period immediately ahead.

But there will be few easy answers.

GENETIC EVALUATION AND UTILIZATION

GENETIC EVALUATION AND UTILIZATION – A MULTIDISCIPLINARY STRATEGY

Z. HARAHAP, M. D. PATHAK, and H. M. BEACHELL

When the International Rice Research Institute was incorporated, a major constraint to tropical rice production was the lack of rice varieties with high yield potential. Rice production had not been intensified in tropical Asia despite the obvious need for more rice to feed a hungry world. Within 5 years after IRRI began its research activities, scientists had made a dramatic breakthrough in rice varietal plant type for the tropics through the development of the short, stiff-strawed, nitrogen-responsive variety IR8.

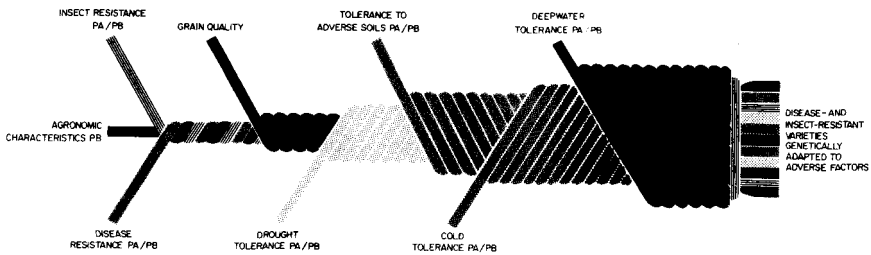
Within the next few years, many new semidwarf and intermediate plant-height Varieties were developed by IRRI and various national rice improvement programs. Among these, IR20 because of its better eating quality and resistance to stem borers, rice tungro virus (RTV), and bacterial blight (BB), became a most widely grown variety in many areas where IR8 generally suffered from these problems. Also, while the semidwarf varieties proved to be ideally adapted to irrigated-rice culture, they were not appropriate for the nonirrigated situations that occur in nearly 70% of the total rice area of the tropics.

THE GENETIC EVALUATION AND UTILIZATION PROGRAM AT IRRI

Thus, there was an urgent need for high yielding varieties suited to different farming conditions: resistant to several species of insects and diseases; tolerant of soil toxicities and deficiencies, temperature, drought, and water submergence; able to elongate through deep water; and photoperiod sensitive in certain areas. Also, the demand for varieties with specific eating qualities to better suit the preferences of different localities became more evident.

Evidently close interdisciplinary teamwork among a larger number of scientists was needed in the work to incorporate the many and diverse traits into new varieties. To organize that teamwork, the Genetic Evaluation and Utilization (GEU) program was formulated in 1973 as a multidisciplinary program in which plant breeders and problem-area scientists would work together as equal partners in developing new

Rice breeder, Central Research Institute for Agriculture, Bogor, Indonesia; director of research coordination and training, IRRI, Los Baños; and rice breeder, Cooperative CRIA-IRRI Program, Bogor, Indonesia, respectively.



1. Plant breeders (PB) and problem-area scientists (PA) together incorporate genetic components.

rice varieties and in perfecting procedures for producing and evaluating breeding material (Fig. 1).

GEU embodies an Institute-wide approach to evaluate and utilize the genetic potential of the rice plant. Each of its problem areas is covered by an interdisciplinary team made up of a plant breeder and one or more problem-area scientists. The plant breeders provide the common linkage for the teams and act as coordinators for the overall effort. A GEU coordinator and a six-member operations committee give GEU its overall coordination and functioning.

The GEU program at IRRI has proved to be an efficient approach to developing and evaluating large numbers of complex and diverse breeding material. The IRRI effort relates specifically to basic international varietal requirements and to the development of diverse germplasm, while national programs relate directly to the varietal needs of their countries. Several national programs have found the GEU organizational setup conducive to meeting their own requirements, and adopted it with appropriate modifications. We review the principles, objectives, and operations of the GEU program at IRRI and in Indonesia, the latter as an example of a national program.

Screening techniques

GEU teams are armed with effective breeding procedures and many reliable techniques for mass screening large numbers of traditional varieties, breeding lines, and bulk hybrid populations. The pedigree and modified bulk-breeding methods that IRRI has used since its beginning and many of the screening techniques are also being used by national programs throughout the tropics. By the mid-l970s, problem-area scientists and breeders had developed and put into operation accurate and reliable mass screening tests for blast (BL), BB, RTV, and grassy stunt (GSV); and milling and eating quality. In the 1970s, screening techniques were developed for tolerance for problem soils, temperature, drought, deepwater submergence, and ability of plants to elongate through deep water. In addition, methodologies for breeding approaches such as rapid generation advance were standardized. The

many screening tests now used at IRRI are the final results of the joint efforts of scientists from IRRI and from many countries throughout the rice-growing world.

The GEU teams at IRRI are screening breeding lines and bulk populations for 40 different genetically inherited characteristics of the rice plant (Table 1). Varietal improvement teams consider, besides these attributes, appropriate site-specific plant types for irrigated wetland, rainfed wetland, dryland, and deepwater growing conditions. This requires selection for growth duration, plant height, tiller number, and other morphological characteristics. The appropriate resistances, tolerances for various physical and biological problems, and other desirable attributes such as eating quality preferences must be incorporated into varieties for each of those farming conditions.

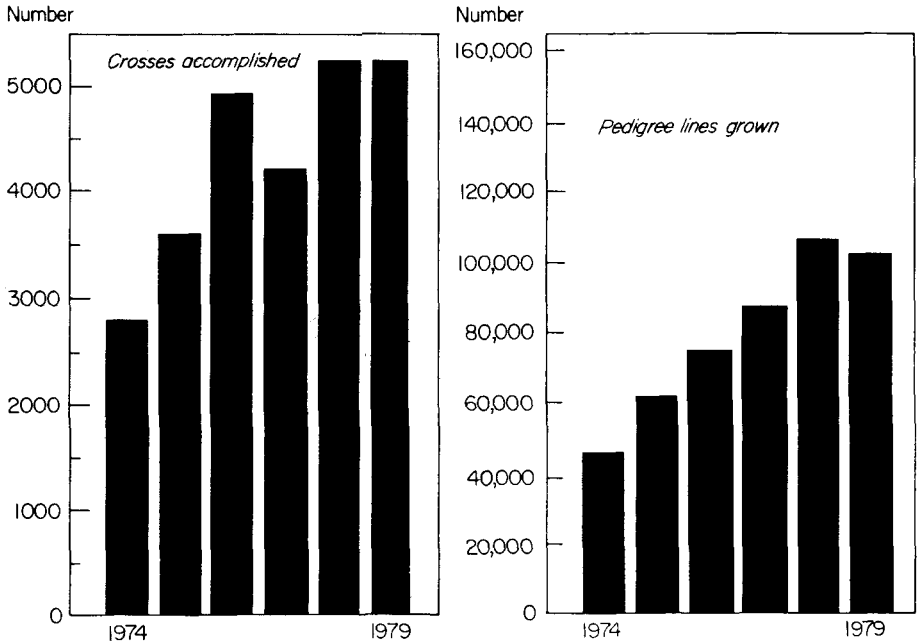
Hybridization program

Annually more than 5,000 crosses are made and more than 100,000 progeny-rows are evaluated at IRRI (Fig. 2). The massive screening requirements are met by use of rapid mass-screening procedures in early generations. Screening techniques have

Table 1. Characteristics being incorporated into improved plant type varieties by mass-screening techniques.

DISEASE RESISTANCE	DEEPWATER, FLOOD TOLERANCE
Blast	Submergence tolerance
Bacterial blight	Elongation ability
Bacterial streak	
Sheath blight	DROUGHT RESISTANCE
Sheath rot	Drought resistance
Leaf scald	Recovery
Stem rot	
Brown spot	ADVERSE SOIL TOLERANCE
Narrow brown spot	Salinity
Bakanae	Arid soils
Tungro virus	Coastal areas
Grassy stunt virus	Zinc deficiency
Ragged stunt virus	Iron deficiency
	Iron toxicity
INSECT RESISTANCE	Manganese toxicity
Striped borer	Aluminum toxicity
Yellow borer	
Brown planthopper	GRAIN CHARACTERISTICS
Whitebacked planthopper	Dormancy
Green leafhopper	Size/shape
Zigzag leafhopper	Appearance
Whorl maggot	Gelatinization temperature
Gall midge[a]	Gel consistency
	Amylose %
TEMPERATURE TOLERANCE	Protein %
Low temperature	
Leaf yellowing	
Sterility	
High temperature	

[a] Not in the Philippines.



2. Growth of the IRRI GEU Program.

been developed for all the traits listed in Table 1, that are being incorporated into improved varieties. Screening starts on F_1 plants in the case of BB. Screening for many traits begin in F_2. The massive numbers of lines to be screened require that early generation screening be stressed. After several generations (F_5-F_6), breeding lines are grown in yield trials at IRRI, in farmers' fields in the Philippines, and finally in specific agroclimatic conditions in collaboration with national scientists in other countries. The screening is conducted jointly by plant breeders and problem-area scientists at IRRI and, in some cases, in other countries. The various screening programs may be directly supervised by either a plant breeder or a problem-area scientist. Since 1975, many promising lines were channelled into the International Rice Testing Program.

Computerized data management

The large quantity of data generated from the mass screening of hybrid material is evaluated through the use of the computer. Statisticians code and store the data and make the results available to all scientists upon request. Computer printouts covering all screening and other evaluation studies are prepared as a routine operation. The GEU data and those of the germplasm bank and the history of IR crosses are interlinked.

The germplasm bank

A worldwide germplasm collection is preserved in the modern germplasm bank at IRRI. The collection serves as the primary source of genetic variability from which the required plant characteristics, resistances, tolerances, and eating qualities can be drawn. The field collection, preservation, and cataloging of germplasm started in 1962. The collection now contains more than 55,000 accessions. It includes staple varieties, primitive rice varieties, and wild species from all parts of the rice-growing world. Many of the improved breeding lines developed by IRRI and national programs are also in the collection.

The collection has been evaluated for some 38 traits, which include plant height, growth duration, tiller number, and other morphological features. Many accessions have been screened for protein content, resistance to diseases and insects, and tolerance for unfavorable growing conditions such as drought, high or low temperature, and adverse soils. A catalog summarizing the information available on 8,628 accessions was published in 1970. Records on 38 attributes for 40,768 accessions have now been completed. The data have been computerized and desired information can be specifically retrieved and printed out to facilitate the choice of cultivars for different research purposes. Samples from the Collection are available to agencies in all countries on request, and duplicate samples of all accessions are in storage at the US. National Seed Laboratory at Fort Collins, Colorado, as an added protection.

The storage capacity of the Rice Genetics Resources Laboratory facility is 120,000 accessions for each long- and medium-term storage. Long-term storage in vacuum-sealed cans at -10° C should maintain seed viability for about 75 years. The medium-term storage, at 4° C, is expected to maintain viability for 20 years. The short-term storage of recently harvested accessions kept at 20° C should keep seed viable for 3-5 years.

Collaborative research in cooperation with other agencies

Other important aspects of the GEU program are the collaborative research with various national programs. Collaborative research studies are also carried out with scientists from developed countries. Such research concerns specific goals that cannot be achieved solely at IRRI headquarters. It may require controlled environments, pests, research expertise, and facilities not available at IRRI. It includes basic studies aimed at gaining a better understanding of the processes, phenomena, and mechanisms of performance of the rice plant.

Liaison scientists

IRRI recently established liaison scientist offices in several parts of the rice-growing world. These offices provide a direct link with national programs and serve a coordinating role for IRRI's resources in given regions or countries. The liaison scientist also provides another invaluable link in the efficient implementation and use of the GEU concept in national programs.

The International Rice Testing Program (IRTP)

The international testing activities of IRRI and the national rice improvement programs are handled by the IRTP. IRTP was organized in 1975 as a formal network of scientists from many countries who systematically test diverse germplasm under a wide range of agroclimatic and cultural conditions. IRTP serves as an integral evaluation component of each cooperating nation's rice improvement program and of IRRI's GEU program. The policies and programs of action are developed cooperatively with national rice program leaders. IRRI scientists coordinate the program, prepare the nurseries, and assemble. analyze, and report data.

The testing and use of varieties from IRRI's germplasm bank, breeding lines developed at IRRI, and varieties and breeding lines from national programs throughout the world are integrated into IRTP nurseries. In the first year of its operation, 457 sets of 12 types of nurseries were distributed to 50 countries. By 1979, the scope of IRTP had been expanded to 17 types of nurseries with 1,100 sets distributed to 70 countries either directly from IRRI Los Baños or through its liaison offices. Through IRTP, the elite germplasm of many countries is made available to all interested national breeding programs.

Many introduced lines have subsequently been released as varieties by several countries following IRTP tests. Many more were used by national breeding programs as parents in their hybridization programs. More than 40 IRRI lines have been released as varieties by national programs.

Monitoring tours

IRTP sponsors a regional monitoring program, which sends teams of scientists pooled from the national programs and IRRI to a region or to selected countries to observe how the varieties and lines perform under different stresses and climatic conditions.

IRTP has developed an effective communications system for monitoring the needs and interests of national coordinators and supplying them with appropriate test materials and information. It has become IRRI's *pipeline* to national varietal improvement programs. Planning sessions, correspondence, monitoring tours, and reports on nursery results and monitoring tours serve as a communication link among the cooperators.

Rapid generation advance

The GEU rapid generation advance is an IRRI program based on the principle of exposing photoperiod-sensitive hybrid populations to appropriate day lengths to induce early flowering. This provides early-generation material to national programs on request. It requires less than 2 years to make a cross, grow F_1 plants, and produce the subsequent F_2 and F_3 bulk populations. This gives national program breeders reasonably stable material (F_4) from which to start screening and selection programs.

GEU training program

A formal GEU training program, in which 16 trainees from 6 countries participated, was initiated in 1975. Now, two 4-month courses are offered each year. Each course is attended by 25-30 trainees.

The training program is skills oriented; it stresses the practical aspects of rice improvement and the need for interdisciplinary cooperation. Breeders and problem-area scientists work side by side in various practical and theoretical aspects of varietal improvement. They work together, planning crosses and developing breeding strategies to be implemented when they return to their respective countries. The trainees attend a 2-week condensed rice production course and a series of lectures and practice for 3.5 months.

The number of breeders and problem-area scientists who have completed the training courses is shown in Table 2. A total of 209 individual scientists trained since 1975. Before 1975 many scientists had received similar training at IRRI but on a less formal basis.

THE INDONESIAN PROGRAM

Indonesia has a long and distinguished record in rice varietal improvement. A high percentage of the improved-plant-type varieties developed by IRRI and national program during the 1960s and 1970s can be traced to at least one (Peta) and sometimes several Indonesian varieties (Hargrove et al 1979). The Indonesian varieties were used at IRRI primarily as sources of plant vigor and a plant type intermediate between the efficient and the traditional types.

Intensified rice production in Indonesia started in a major way in 1967 and 1968 with the introduction of IR8, IR5, and C4–63 from the Philippines. The intermediate plant height of IR5 and C4–63 was much preferred to the shorter IR8 height and within a few years IR5 had spread throughout Java and some of the Outer Islands and record productions were achieved during the next several years.

Indonesia responded immediately to the success of IR5 by developing the Pelita varieties (Pelita I-1 and Pelita I-2) from a cross between IR5 and a local improved variety, Syntha. The Pelita varieties were released in 1971 and soon replaced, to a large extent, IR5 and C4-63 because of their resistance to BB, better eating quality, and essentially the same plant type, maturity, and other features of IR5. The Pelitas were ideally adapted to wetland irrigated areas and to some of the wetland rainfed areas.

In 1973, the BPH threatened rice production in North Sumatra, East Java, and Bali, which had large areas in intensified production. This threat brought about the rapid evaluation and distribution of IR26, which was resistant to BPH biotype 1 and yielded as well as Pelita in most areas. By 1976, BPH biotype 2 was found in North Sumatra, East Java, and Bali. In 1977 the BPH and RSV were seriously affecting more than 200,000 ha, including fields planted to IR26.

This brought about another rapid varietal shift to IR36, which was resistant to the new biotype. Today IR36 is the leading variety grown in Indonesia and production

Table 2. Participants in the GEU Training Program from 1975 to 1980, by country and discipline.

Country	Breeders	Agrono-mists	Pathol-ogists	Entomol-ogists	Physiol-ogists	Soil scientists	Cereal technol-ogists	Genet-icists	Bio-physicist	Total
Bangladesh	16	1	3	2	4	2	1	0	0	29
Brazil	0	1	0	0	0	0	0	0	0	1
Burma	1	8	0	0	0	0	0	0	0	9
China	7	2	3	2	2	0	0	3	1	20
Cuba	0	0	1	0	0	3	0	0	0	4
India	11	3	6	5	0	1	0	0	0	26
Indonesia	17	5	8	5	2	1	1	0	0	39
Iran	3	0	0	0	0	0	0	0	0	3
Korea	3	0	0	0	0	0	0	0	0	3
Liberia	1	0	0	0	0	0	0	0	0	1
Malaysia	4	1	0	1	0	0	0	0	0	6
Mexico	1	0	0	0	0	0	0	0	0	1
Nepal	0	1	3	1	0	0	0	0	0	5
Pakistan	5	2	2	2	0	0	0	0	0	11
Philippines	0	4	0	0	0	0	0	0	0	4
S. Leone	3	0	0	0	0	0	0	0	0	3
Sri Lanka	10	8	2	0	0	0	0	0	0	20
Tanzania	1	0	0	0	0	0	0	0	0	1
Thailand	17	5	0	0	0	0	0	0	0	22
Turkey	1	0	0	0	0	0	0	0	0	1
Total	101	41	28	18	8	7	2	3	1	209

losses from BPH have stabilized. In some areas of Java, more than 75% of the fields are planted to IR36. The 1980 rice crop is expected to set a new record production. How long the BPH resistance of present varieties will continue is a major question facing varietal improvement planners.

A total of 13 varieties with BPH resistance have been released in Indonesia (Table 3). Only five of them are resistant to BPH biotype 2. A number of new breeding lines that have resistance to BPH biotype 3 will soon be released. They also have improved eating quality and a range of growth durations. They should replace IR36 in the near future.

Unfortunately for Indonesia, most of the IRRI varieties have high amylose content, which is not the eating quality that Indonesians prefer. Also, the plant type of Pelita is better suited to Indonesian farming conditions than that of most of the IRRI varieties. The plant height, leaf habit, tillering ability, and sturdy stems of Pelita are highly desirable in Indonesia. Consequently, Indonesia has relied heavily on Pelita and lines of similar plant type in crosses with donor IRRI varieties and breeding lines for resistance to insects and diseases.

The disease situation

As rice production intensified across Java, most of the wetland irrigated areas and some of the wetland rainfed were planted to IR26 and IR36. Attacks by diseases

Table 3. Reaction to brown planthopper (BPH) and eating quality of varieties released in Indonesia.

Varieties developed by CRIA				Varieties introduced from IRRI			
Variety	Reaction to BPH biotype		Eating quality	Variety	Reaction to BPH biotype		Eating quality
	1	2			1	2	
Wetland irrigated:				Wetland irrigated:			
Pelita I-1	S	S	good	IR20	S	S	poor
Pelita I-2	S	S	good	IR22	S	S	poor
Serayu	R	S	poor	PB26	R	S	poor
Asahan	R	S	good	PB28	R	S	poor
Brantas	R	S	poor	PB30	R	S	poor
Citarum	R	S	good	IR32	R	R	poor
Cisadane	R	R	good	PB34	R	S	poor
				PB36	R	R	poor
				PB38	R	R	poor
Dryland:							
Gati	S	S	good				
Gata	S	S	good				
High elevation:							
Adil	S	S	poor				
Makrnur	S	S	poor				
Gemar	S	S	poor				
Semeru	R	R	poor				

such as sheath blight, sheath rot, leaf scald, and stem rot caused increased lodging. The BB resistance of IR36 is no longer effective in some areas. That means that the breeding program must take into account all these diseases.

The GEU program in Indonesia

The Indonesian rice improvement program must provide varieties for more than 8 million ha of extremely diverse environments, including irrigated wetland, a wide range of rainfed wetland, high elevations (wetland and dryland), dryland and tidal swamp and other flood-prone areas. Objectives for each of the groups have been established (Table 4). That provides more efficient use of overtaxed staff and facilities. Irrigated wetland and rainfed wetland production make up more than 70% of the total area but dryland and tidal swamp cultivation are becoming more important as the Government of Indonesia promotes transmigration to these regions of the Outer Islands, particularly Sumatra, Kalimantan, and Sulawesi.

Because of the many and complex breeding problems facing Indonesian rice scientists, a national multidisciplinary GEU program was initiated in 1975. The

Table 4. Rice varietal improvement objectives of Indonesia — GEU program.

Type of culture	Major varietal requirements
A. Wetland irrigated	High yield 100- to 130-day maturity Good eating quality Resistance to brown planthopper Resistance to viruses Resistance to bacterial blight Tolerance for low temperature (high `elevation)
B. Lowland rainfed	High yield 110- to 140-day maturity Good eating quality Resistance to brown planthopper Resistance to virus Resistance to bacterial blight Tolerance for problem soils Tolerance for flood Tolerance for drought
C. Dryland	High yield 100- to 130-day maturity Fast growth Tolerance for drought Resistance to blast
D. Tidal swamp	High yield Submergence tolerance (flooding) Elongation ability Tolerance for drought Tolerance for salty water Resistance to viruses Resistance to bacterial blight Resistance to green leafhoppers

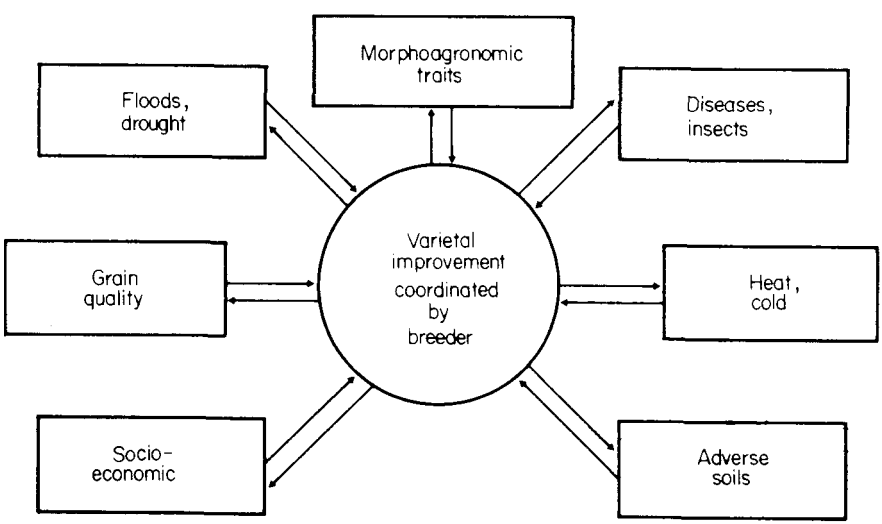
acute varietal situation brought about by the severe outbreaks of BPH, RSV, and GSV prompted its organization.

The GEU program was established primarily:

- to use more efficiently manpower and facilities;
- to speed up varietal development;
- to provide a better understanding of the varietal requirements of the farmer;
- to improve international cooperation; and
- to provide more accurate and prompt information to extension service.

The program is coordinated by the Central Research Institute for Agriculture (CRIA), Bogor, with close linkages between the regional units at Padang (West Sumatra), Sukamandi (West Java), Malang (East Java), Maros (South Sulawesi), and Banjarmasin (South Kalimantan). The frequent attendance at GEU meetings of extension service subject matter specialists and national seed corporation representatives provides research personnel with first-hand information on farm problems. The agricultural universities also participate in the program and attend the monthly GEU meetings. With coordination from the national leaders, the cooperating agencies establish objectives and work toward accomplishing them in the shortest time possible. Through the monthly GEU meetings, the various varietal improvement activities are reviewed and all scientists are kept informed on progress and problems.

Interdisciplinary teams are set up, as required, to carry out both short-term and long-term activities. The program is coordinated by a plant breeder. The nature of cooperation between breeders and problem-area scientists is illustrated in Figure 3.



3. Components of an integrated varietal improvement program (GEU).

Continuous efforts are made to prevent the inputs of problem-area scientists from becoming merely service oriented. The scientists assist by offering improved screening techniques and act as equal partners in the development of strategies.

Screening program

Screening techniques for evaluating breeding materials have been implemented since the late 1960s and today Indonesia is capable of screening breeding lines for most of the characteristics that breeders are incorporating into improved varieties (Table 1). A major difficulty has been the limited volume of the screening units caused by a lack of trained staff and physical facilities.

Indonesia is fortunate in having throughout the country a large number of branch stations. Field screening has been carried out in those stations for many years. Because field screening for certain traits cannot always be depended upon, there has been a backlog of breeding material not screened on schedule. Indonesia has depended heavily on IRRI for BPH, GSV, eating quality evaluation, and other information. It has reciprocated by screening IRRI material for resistance to RTV at the Lanrang, South Sulawesi, facility and for resistance to gall midge (GM) at Bogor, Sukamandi, and Pusakanegara in West Java.

The actual screening is provided by service units either in plant breeding or in problem-area departments. In this way the mass screening of thousands of breeding lines does not interfere with the day-to-day activities of either plant breeding or problem-area departments.

Revised breeding procedures

The limited manpower but abundant locations where breeding material could be grown influenced a revision of breeding procedures whereby many pedigree lines and modified bulk populations could be grown and evaluated in the field. Since 1968 the modified-bulk breeding procedure has been used extensively. Because bulk populations require relatively large land areas, in 1976 a close plant spacing (about 5 × 5 cm) was used and about 10,000 plants/population were grown. A few seeds are harvested from most plants of each population to form the bulk for the next generation advance. This procedure permitted the handling of large numbers of hybrid populations in relatively small areas. Usually bulk populations are grown from F_2 through F_6-F_7.

The populations were grown at sites where they were exposed to BPH, GM, BB, BL, viruses, low temperature, and drought (Table 5). It was not always possible to have adequate insects, diseases, temperature, or moisture situations for effective screening every season, but through the years the screening techniques have been reasonably successful.

The numbers of breeding lines generated from the bulk populations have been extremely large, and innovative methods in handling them have been adopted.

To alleviate this problem, single-panicle selections are harvested from appropriate bulk populations and direct seeded, without threshing, in hills spaced 30 × 30 cm.

Table 5. Branch stations in Indonesia where field screening trials are conducted.

Location	Screening capability[a]
Pusakanegara	BPH, RSV, GM, ShB, BB
Ngale	BPH, RSV, Soil problems
Mojosari	BPH, RSV, GSV, drought
Kendalpayak	BB, BPH, RSV, GSV
Lanrang	RTV
South Kalimantan	Deep water, soil problems
Ciwalen	Cold tolerance
Sukarami	Cold tolerance, BB
Sitiung	Blast
Maros	ShB

[a] BPH = brown planthopper, RSV = ragged stunt virus, GM = gall midge, ShB = sheath blight, BB = bacterial blight, GSV = grassy stunt virus, RTV = rice tungro virus.

The panicle selections from appropriate hills are then entered in conventional pedigree nurseries.

A tremendous amount of breeding material was generated. In 1979, 711 crosses were made and 4,116 bulk hybrid populations, 91,472 pedigree nursery entries, 2,011 observational trial entries, and 501 replicated yield trial entries were grown in varietal improvement nurseries (Table 6). The upgrading of quality and quantity of screening techniques has continued through the GEU interdisciplinary approach, which brings together breeders and problem-area scientists.

International Rice Testing Program Activities in Indonesia

Indonesia in recent years has depended heavily on IRRI for BPH- and GSV-resistant varieties (Table 3). All IRRI-developed varieties were identified through IRTP nurseries grown in Indonesia or from similar nurseries grown before IRTP was organized.

In 1979 Indonesia planted 28 sets of 15 different IRTP trials, and grew approximately 70 IRRI lines in national replicated yield trials and 20 lines in the hybridization block. At least 75% of the single crosses made involved an IRRI line or variety as a parent.

Table 6. Number of crosses made, bulk populations, breeding lines, and observational and replicated trials grown, 1978-79 wet season and 1979 dry season, Indonesia.

	Wet season 1978-1979	Dry season 1979	Total
Crosses	488	223	711
Bulk-hybrid populations	1,562	2,554	4,116
Pedigree lines	48,679	42,793	91,472
Observation entries	850	1,168	2,018
Replicated yield trial entries	258	243	501

GEU training at IRRI

Since the IRRI GEU training program was started in 1975, Indonesia has sent to IRRI for the 4-month GEU training 37 individuals — 17 breeders, 5 agronomists, 5 entomologists, 8 pathologists, 1 soil scientist, and 1 cereal chemist. Before the GEU training program started, several breeders from Bogor were sent for practical training in the Plant Breeding Department of IRRI.

The young scientists receiving this training form an essential part of the technical GEU staff.

IRRI-NATIONAL PROGRAM COOPERATION

The liberal distribution of IRRI breeding lines, information on screening techniques, practical training afforded national scientists, and the promotion of international testing and collaborative studies have all effectively strengthened national varietal improvement programs in all parts of the rice-growing world.

In many countries, inadequate personnel and facilities prevent the full implementation of the complex varietal requirements now facing national breeding programs. It is important that the major varietal improvement developments at IRRI and in the national programs be made available to all countries. The IRRI program is of major value in the worldwide evaluation of breeding material from many countries.

Perhaps the combined capability of all national programs and IRRI would be adequate for the 1980s and beyond if cooperation and coordination are improved.

In the search for improved efficiency of cooperation and coordination, a review of the IRRI-Korea program might be useful. In the mid-1960s, Korean scientists and administrators approached IRRI for technical assistance, training, and germplasm for improving their varieties. The cooperative program brought about the development of the Tong-il rice variety, which revolutionized rice production in Korea.

In the 1970s, the IRRI-Korea program was formalized to provide annual planning sessions for IRRI and Korean scientists. The results of each season's activities are reviewed and new joint activities agreed upon. Through this cooperation, Korea puts major focus on the most important rice production problems, and through the joint research and conferences, IRRI scientists obtain a first-hand insight into problems facing rice farmers in countries other than the Philippines.

In recent years, Indonesian scientists have met with visiting IRRI scientists to determine how IRRI might assist Indonesia in speeding up varietal improvement activities, which were overtaxed by the serious BPH and virus problems.

As an outgrowth of those meetings, elite breeding lines and bulk populations were sent to IRRI for general screening and for growing in pedigree, observational, and bulk population nurseries. Plant selections were made from these nurseries, with one half the seed from each plant selection sent to Indonesia and the other half retained for planting at IRRI and for screening for diseases, insects, and eating quality. This gave Indonesia the benefit of more rapid evaluation of new lines and IRRI additional diverse genetic material to augment the breeding program. Selected Indone-

sian varieties and lines are entered in IRRI hybridization blocks to enable Indonesian GEU trainees to make crosses between their elite lines and IRRI material.

For the future a more formal arrangement of cooperation will involve Indonesia, with a full-time GEU scientist at IRRI assisting in the management of the nurseries and the screening activities. Joint annual planning sessions similar to those in the Korean program are being considered.

Cooperative programs such as those described have been instigated by the national programs. The examples illustrate how cooperative research between national programs and IRRI on national production-oriented problems can help solve national production problems and at the same time give IRRI information on the type of basic research that should be stressed. An interesting sideline on these programs is that the funds involved, compared with the results obtained, have been minimal.

STRATEGIES FOR THE 1980s

In spite of the many outstanding successes in rice varietal improvement during the 1960s and 1970s, major advances will be required in the 1980s if rice yields are to be further increased and yield losses from diseases, insects, and other adversities minimized.

Strategies for maintaining control of important diseases and insects through genetic resistance are needed. A better understanding of the genetic mechanisms of resistance to BL, BB, and the viruses, particularly RTV and RS, is needed. The BPH is now under control in most countries but there is considerable question as to whether the major resistance genes now available to varietal improvement teams will be adequate for control in the future. Minor genes for resistance appear to be available, but their role is not fully understood. Finding the answers to these and many other problems are the challenges to rice scientists in the 1980s.

The GEU program of IRRI and the national varietal improvement programs. which form the international rice varietal improvement complex, must meet the challenges. The avenues of coordination, collaboration, and cooperation, and the free exchange of ideas and germplasm have been opened. In the 1980s and beyond, we must keep these channels open and go a step further by improving the efficiency of international cooperation. As the cooperative programs proliferate, it will be necessary to avoid direct duplication of effort within a given region. In some instances, the cooperation might involve more than one country, at least in certain phases of the research.

The procedures to be stressed should include:

- definition of national program objectives and priorities; the establishment of national program objectives and priorities would assure that the primary research needs are met. Through these processes the varietal improvement funds would be spent on problems that might give the highest potential pay-off to the farmer. Where chemical or cultural control can be economically achieved and genetic control is limited or difficult to achieve, a low priority should be

established. The many traits that need to be incorporated into an array of plant types for specific farming situations can easily overtax the sums that are going into rice varietal improvement. For these reasons a further economic and agronomic analyses of varietal improvement programs would appear to be highly desirable;

- type of cooperation desired from IRRI or other national programs to maximize use of limited resources;
- effective coordination of cooperative programs by national program scientists stationed at IRRI; and
- annual evaluation and planning sessions either at IRRI or at national program headquarters.

The organizational structure, the technical competence, the germplasm, and much of the needed facilities are now available at IRRI and at some rice research agencies of the major rice-growing nations.

Planning, organization, and coordination of efforts to effectively use IRRI and national manpower, germplasm and other resources can assure major advances in rice varietal improvement in the 1980s.

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RICE PESTS

STRATEGIES FOR THE DEVELOPMENT OF AN INTEGRATED APPROACH TO RICE BROWN PLANTHOPPER CONTROL

O. MOCHIDA and E. A HEINRICHS

In the last 10 years, the brown planthopper (BPH) *Nilaparvata lugens* (Stal) (Hom., Delphacidae) and the two virus diseases it transmits have become serious constraints to rice production in South and Southeast Asia. Dyck and Thomas (1979) estimated that recent losses of rice due to the BPH and grassy stunt (GS) disease in Asia amounted to about US$300 million.

Four major genes that impart resistance to the BPH were identified in the rice germplasm at IRRI. When resistant cultivars (IR26, IR28, IR29, IR30, and IR34) with the *Bph 1* gene were released, BPH problems almost disappeared in farmers' fields in some countries of Asia but those cultivars were not resistant to the BPH in India and Sri Lanka. Furthermore, they were at first resistant but after about 2 years became susceptible to the BPH in the Solomon Islands, Philippines, and Indonesia.

Thus, resistant cultivars are threatened by the development of biotypes of the BPH. Chemical control is also not a panacea in the protection of the rice plant against the BPH. Thus, integrated control should be considered for the control of the BPH (Mochida 1978, 1979; Dyck et al 1979; Heinrichs et al 1979b).

TAXONOMY, DISTRIBUTION, BIOLOGY, AND FACTORS ASSOCIATED WITH BPH OUTBREAKS

Fifteen species belong to the genus *Nilaparvata* (Table 1). Among *Nilaparvata* spp. the BPH is the only species that attacks the rice plant and causes economic damage (Mochida et al 1978). It is widely distributed in South, Southeast, and East Asia (Fig. 1).

Biology

The BPH has three stages — egg, nymph, and adult. The developmental period of the various stages depends on the temperature and food source. The ideal temperature is 25° -30° C. The BPH completes a life cycle about every month in tropical wetland areas when a suitable food source is present (Mochida et al 1978). When

Entomologist, IRRI-CRIA, Sukamandi, West Java; Indonesia. Present address: IRRI; and entomologist, IRRI.

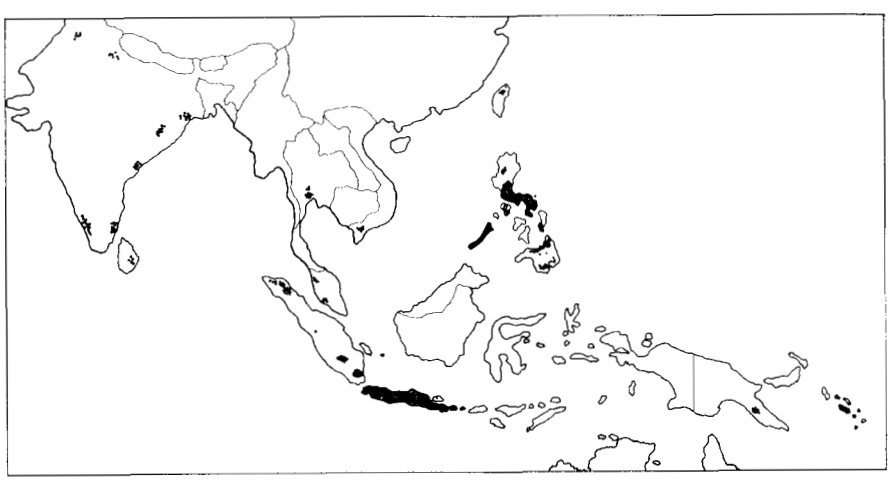
Table 1. *Nilaparvata* spp. and their distribution (Mochida, unpubl.)

Nilaparvata sp	Distribution
N. albotristriata	Australia, Micronesia, New Caledonia.
N. angolensis	Angola.
N. bakeri	Japan, S. Korea, Formosa, Philippines, Sri Lanka.
N. caldwelli	Puerto Rico.
N. camilla	Sudan
N. castanea	China.
N. chaeremon	Sri Lanka.
N. diophantus	Portuguese, Guinea, Senegal.
N. lineolae	China.
N. lugens	From India to Japan, Pacific Is., Australia to Japan.
N. maeander	Sudan, Guinea.
N. muiri	China, Japan, S. Korea.
N. myersi	New Zealand.
N. nigritarsis	Natal, Sudan (Abyssinia).
N. wolcotti	Puerto Rico.

dryland and wetland rice fields are compared, BPH populations are frequently highest on wetland rice. Water management affects BPH population growth to some degree (Mochida 1978, Dyck et al 1979).

The BPH has two wing-forms, macropterous and brachypterous. Macropterous adults can fly over long distances with the movement of air masses. No studies on long-distance migrations have been reported in the tropics but it is suspected that long-distance migration does occur.

Macropterous adults appear to have a key role in initiating oubreaks of BPH on



1. Locations where BPH caused serious damage to rice in 1965-76 (Mochida et al 1977, modified).

rice in the tropics (Mochida et al, unpubl.). The fact that higher densities during the nymphal stage increase the relative proportion of macropterous adults in delphacids was first reported in the smaller brown planthopper (SBPH) *Laodelphax striatellus* (Fallén) by Murata (1930). Later, Kisimoto (1956) showed that the occurrence of BPH wing-forms depends on the population density and food conditions during the nymphal stage, and that poor food conditions produced higher proportions of macropterous adults. Cheng (1977) and Cheng and Chang (1979) indicated, however, that brachypterous adults appeared even on BPH-resistant rice cultivars in Taiwan.

Suenaga (1963) calculated theoretically the maximum total number of oocytes produced within a BPH female as 1.728- 1,984. He recorded the maximum number of eggs deposited by 1 female on rice seedlings as 1,474. Less than 100 eggs female was estimated in the field at IRRI, but in the greenhouse the number of eggs produced by a female was estimated at less than 200 on a susceptible cultivar. Pelita I-1 (Mochida et al, unpubl.). The preoviposition period is shorter in brachypterous females than in macropterous females when temperature is low (Mochida et a1 1978).

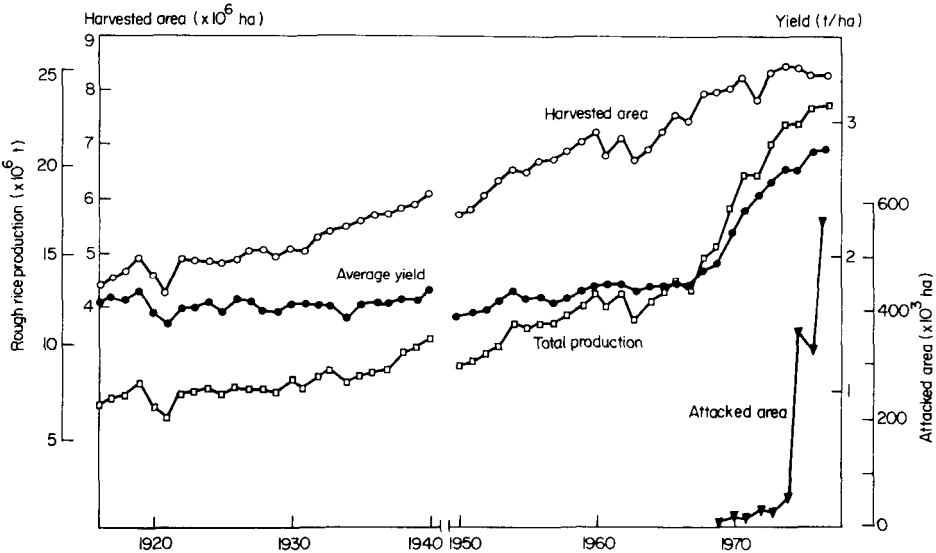
The main host plant of the BPH is *Oryza sativa* but several *Oryza* species serve as host plants for the BPH in tropical Asia. Eight species, for example, are found in Indonesia — *O. granulata, O. longiglumis, O. meyeriana, O. minuta, O. officinalis, O. ridleyi O. rufipogon,* and *O. sativa. Oryza* species such as *O. australiensis, O. barthii, O. brachyantha, O. latifolia, O. nivara, O. punctata,* and *O. rufipogon* may become potential host plants. At least two allied species of the genus *Nilaparvata* are known on *Leersia* spp. (Gramineae). Correct identification of both delphacids and plant species are needed for further studies on host plant relationships (Mochida and Okada 1971, 1979).

Factors associated with BPH outbreaks

Several factors have been suggested as encouraging BPH outbreaks, but they may not be the same in different countries,

Cropping of modern high-yielding rice cultivars susceptible to BPH. Mochida and his coworkers (1977, unpubl.) reviewed the literature to determine the relationships between the time of introduction of modern cultivars and the time of BPH outbreaks as recorded in Indonesia, Malaysia, Solomon Islands, and some parts of India. Most of the outbreaks occurred after modern cultivars without BPH resistance were first grown. The population growth of BPH was greater on modern cultivars without resistant genes than on some local cultivars (Mochda 1978, Dyck et a1 1979).

Nitrogen fertilizers. High fertilizer rates are favorable to the development of BPH populations (Abraham 1957, Dyck et al 1979). Figure 2 shows the results of tests in Indonesia. In many Asian countries, synthesized N-fertilizers are usually applied to modern cultivars but not to traditional cultlvars. The amount of N-fertilizer applied to the rice crop has increased considerably in recent years. In Indonesia, for example, consumption of urea used mainly for rice, estimated at 405 million tons in



2. The total harvested area of lowland and upland rice, average yield, total rough rice production, and BPH-attacked area of rice fields in Indonesia in 1916–77 (Mochida 1978).

1971-72, reached 919 million tons in 1977-78 (Mochida 1978).

Irrigation. In some countries the area of irrigated land for rice production has increased. Irrigation affects the BPH in two ways. First, irrigation occasionally changes rice cropping patterns. Because rice is the main host of BPH, irrigated double or continuous rice cropping provides a suitable host plant throughout the year. Where rice is cropped only once a year, on the other hand, most BPH cannot survive for the dry period because of lack of a host. Second, water content of soil or water management is related to the BPH population growth (Mochida 1978, Dyck et al 1979).

Application of insecticides and resurgence. Generally, it is believed that application of insecticides to the rice crop results in a decrease of the populations of the natural enemies of the BPH. However, the kinds of insecticides and the amounts applied to the rice crop are considerably different in various countries.

There are indications that insecticide-induced BPH resurgence has caused some outbreaks. The role of insecticides in inducing resurgence is discussed in detail in a later section on chemical control.

Coverage of rice plants per unit of area. The number of BPH nymphs per hill and the number of tillers per hill are occasionally positively correlated. There are also positive correlations between the number of nymphs and hill density per square meter and between density of nymphs and the number of tillers per square meter (Dyck et al 1979). The number of tillers per square meter can change due to cultivars and cultural practices such as fertilizer application, spacing, and planting methods.

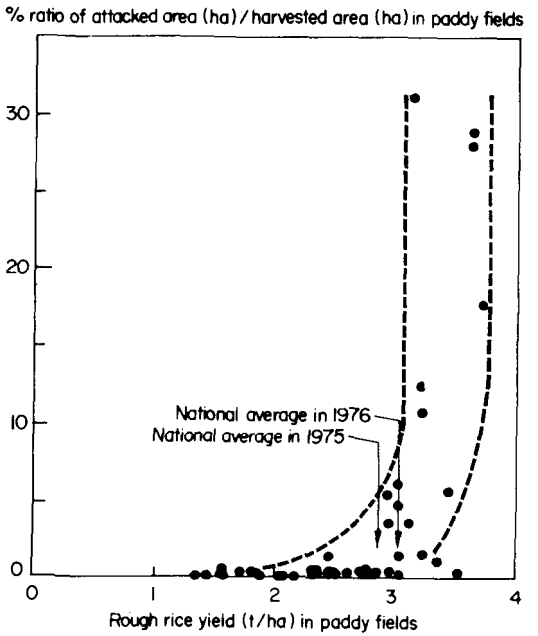
If modern BPH-susceptible rice cultivars produce many tillers when fertilizers, especially nitrogen, are applied at high levels, modern rice cropping would be expected to increase the density of BPH.

Mochida et al (1977, 1978) and Mochida (1978, 1979) indicated that the recent outbreaks of BPH in Indonesia were probably associated with the enlargement of irrigated rice fields, double or continuous rice cropping with high-yielding BPH-susceptible cultivars, and application of N-fertilizers. Mochida (1978) pointed out that such outbreaks have been occurring since about 1970, when average rice yields started to increase, and have been occasionally seen in rice-bowl areas with high yields (Fig. 2, 3).

Although numerous cultural practices affect BPH populations, it has not been possible to experimentally manipulate cultural practices such that BPH would cause hopperburn, except through the application of resurgence-inducing insecticides. Entomologists disagree regarding the causes of BPH outbreaks but agree that BPH is an extremely important pest, which can only be properly controlled through an integrated pest management approach.

DEVELOPMENT OF COMPONENTS FOR THE MANAGEMENT OF BPH POPULATIONS

Rice yield losses caused by BPH and the two virus diseases fluctuate considerably locally, seasonally, and annually. Mochida (unpubl.). over a 5-year period, compared the rice yields in untreated plots with those in plots intensively treated with



3. Relationship between the average rice yields in each province and the area of rice fields attacked by the brown planthopper in Indonesia in 1975 and 1976 (Mochida 1978).

insecticides. Yield losses of a susceptible cultivar (Pelita I–1), four resistant cultivars with the *Bph 1* gene (IR26, IR28, IR30, and IR34), and one resistant cultivar with the *Bph 2* gene (IR32) due to all insect pests were 49.4, 29.1, and 26.4%, respectively. The yield losses in the resistant cultivars were primarily due to BPH, although hopperburn did not occur.

Dispersal and migration of BPH seem to occur frequently in continuous rice-cropping areas, especially with staggered cropping. Continuous movements into the field make it difficult to control the BPH with chemicals. When BPH population was high, frequent applications of effective insecticides were not sufficient to prevent the yield losses of Pelita I-1 due to the BPH (Mochida et al 1977), grassy stunt, and ragged stunt (Mochida et al 1978). Chemical control is effective but it is expensive and its cost is increasing at a faster rate than the price of rice.

It is apparent that no one control technique is by itself entirely satisfactory. The most rational approach to control the BPH is to integrate the various pest management components such as varietal resistance and cultural methods in which insecticides are applied according to the insect population, as measured by an efficient monitoring program.

Economic injury levels and economic thresholds

Knowledge of the relationships between the yield loss caused by BPH and BPH population densities is important. In the Philippines, Dyck and Orlido (1977) identified critical stages for plant damage (Table 2). In the greenhouse, there was usually no significant reduction in grain weight when maximum BPH densities were about 25 BPH/hill in either the second or third generation. In the field, 50-60 BPH/hill at harvest produced no apparent loss in grain yield. Thus, Dyck and Orlido recommended an economic injury level of 1 BPH tiller or about 25 BPH / hill as a rough guide for practical BPH control throughout a crop period. In Taiwan, Yen and Chen (1977) showed that 25 BPH/ hill was a practical control threshold. In Indonesia, greenhouse experiments indicated that all the young plants of Pelita I-1, a susceptible cultivar, were killed within 2 weeks, when 10 macropterous adults/ hill attacked within a week after transplanting (CRIA-IRRI, Sukamandi, unpubl.). In Sukamandi fields, more than 200 adults plus nymphs/hill appeared on 3 cultivars — IR26, IR32, and Kencana (without any major resistant gene) — for a 2-week period at 10-14 weeks after transplanting, but all rice plants of the 3 cultivars survived. However, three other susceptible cultivars were hopperburned (Mochida et al 1979).

In Japan, Nomura (1949) indicated a relationship between the number of BPH adults swept by a net and the loss of grain as:

Adults/100 strokes	*Loss of grain (%)*
500	25
1000	40
1500	55
2000	70
2500	85

Table 2. Grain yield response of IR22 in the greenhouse to direct damage caused by various densities of BPH nymphs caged for 2 weeks on plants of different ages (Dyck and Orlido 1977).

Insects caged[a] (no./tiller)	Yield[b] (g/hill)							
	26-39 DS	40-53 DS	54-67 DS	68-81 DS	82-95 DS	96-109 DS	110-123 DS	124-137 DS
0.0 (Control)	34	21	20	15	14	16	14	14
0.1	21*	22	20	18	17	13	11	12
0.2	29	20	17	12	12	8*	9	14
0.5	20*	24	17	15	12	16	13	14
1	21*	15	16	11	14	16	11	14
2	21*	21	15	14	13	16	13	15
5	5*	20	16	13	10	13	14	14
10	0*	21	21	12	10*	13	13	12
25	0*	6*	20	11	10*	13	9	16
50	0*	0*	15	11	5*	10	11	16

[a]Where number is less than 1, 1 insect/tiller was caged for a fraction of 2 weeks, e.g. 1 insect/tiller for 2.8 days (0.2 × 14). [b]* means significantly lower than the control at the 5% level. DS = days after seeding (plant's age at infestation). Each plant was infested for not more than 2 weeks throughout its entire growth.

Suenaga (1959a) recommended the application of insecticides when there are more than 10 adult BPH/hill at tillering stage and more than 50/hill after heading stage. Kisimoto (1978) indicated that, when there are more than 20-30 immigrant adults/100 hills, hopperburn will be expected in later generations. Yokoyama (1979) recommended insecticide application when more than 20 adults/ 100 hills occur about 1 month after the peak of immigrant adults (or tillering stage), and when more than 10 adults 100 hills occur during the postbooting to heading stage.

Population monitoring

Population monitoring is necessary for preventing the outbreaks of BPH. Various sampling techniques have been developed.

Although various sophisticated techniques for sampling BPH populations have been developed, most are research tools and are not required in a practical pest management program. The simple technique of tapping the plant and estimating the number of insects provides adequate information to enable a farmer to decide whether or not an insecticide application is needed. The need today is to teach the farmers how to sample and identify the BPH and to make a control decision based on economic injury levels.

Biological control

Natural enemies of the BPH and their use as control agents have received little emphasis until recently. Numerous predators, parasitoids, and pathogens attack the BPH. Chiu (1979) listed 19 hymenopterous species as egg parasites, 16 insect species as parasitoids of nymphs and adults, 21 insects and 16 spiders as predators, and 7

species of pathogens. In addition, a mite, two coccinellids (*Harmonia octomaculata* and *Microspis lineata*), and a dryinid *(Digonatopus javanus)* were recorded as natural enemies in Indonesia (CRIA-IRRI, Sukamandi, unpubl.).

Among the egg parasites, *Anagrus* and *Oligosita* are the most common at IRRI. Parasitism averages about 25% (V. A. Dyck, IRRI, pers. comm.). Among the predators, the spider *Lycosa pseudoannulata* and the vellid bug *Microvelia atrolineata,* and the mirid bug *Cyrtorhinus lividipennis* are common. However, the effectiveness of the latter two species as biological control agents is still under study.

The use of insect pathogens as BPH control agents is an area relatively untouched. IRRI and Boyce Thompson Institute (Ithaca, New York, USA) scientists recently initiated a program to identify suitable pathogens and determine their efficacy against field populations of BPH. Fungi such as *Entomophtora* and *Metarrhizium* have potential in BPH control.

Although natural enemies have been shown to exert a significant effect on the regulation of BPH populations, biological control agents cannot yet be manipulated in a pest management program. Today, only a few examples of the use of biological control agents exist. The nematode *Agamermis unka* was introduced from Japan into the Solomon Islands in 1966 for BPH control (Suenaga and Mochida 1969). Ducks are used to control the BPH in most of southern China and have been shown to be effective as BPH predators in IRRI experiments (V. A. Dyck, IRRI, pers. comm.). Conservation and augmentation, however, are areas of potential value as the key natural enemies are identified and more is learned about their biology and ecology.

V. A. Dyck, IRRI (pers. comm.), suggests that in biological control of BPH:

- Ducks can be used to suppress BPH populations but they should be herded in fields where the BPH needs to be controlled, not in fields with low BPH density.
- Where practical, natural biological control agents should not be destroyed through the excessive use of insecticides.
- Based on previous ecological studies, it should be possible to predict the future pest density if the current pest and natural enemy (especially predator) densities are known.
- Fungal pathogens suggest that microbial insecticides be developed in the future.

Chemical control

Throughout Asia, insecticides are an important component in the control of BPH. especially where resistant varieties are not available. However, several factors complicate the use of insecticides in the control of this pest.

- The BPH feeds at the base of the plant near the water level, where it is difficult to be reached directly by insecticides.
- The BPH is a phloem feeder, and systemic insecticides are expected to move primarily through the xylem. Insecticide accumulates in the leaf tips and little of it accumulates in the leaf sheath area.
- Of the various rice planthoppers and leafhoppers, BPH is generally the most difficult to kill with insecticides. Thus, many insecticides effective against other

hoppers are not sufficiently effective against the BPH.

- It is extremely difficult to control the adults migrating from adjacent outbreak areas. Even when fields are sprayed, the insects are capable of laying eggs before they are killed. Many insecticides do not kill the eggs and when eggs hatch, the residual activity of the insecticide is not sufficient to kill the nymphs and, thus, additional applications are required. Timing of application is critical.
- With the high reproductive rate, the BPH rapidly develops resistance to insecticides.
- Many insecticides applied at sublethal rates cause resurgence. Because many farmers use sublethal rates, these insecticides have caused severe problems for farmers.

In this section on chemical control, we discuss some of the progress made in the last decade in overcoming the difficulties mentioned above and suggest areas where additional studies are needed to better cope with the BPH problem in the 1980s.

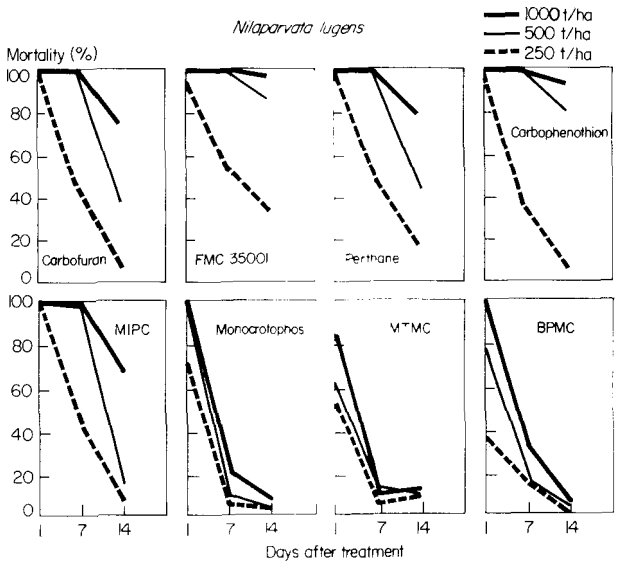
Effective insecticides. Insecticides active against BPH have been identified among those evaluated at IRRI and in national programs (Heinrichs et al 1978, 1979a; Heinrichs 1979; Moriya 1977; Cheng and Liu 1978). The Philippines recommends 10 insecticides for BPH. In Taiwan, 30 insecticides have been registered with the government for use in BPH control. In Taiwan, most of the insecticides are carbamates, with carbofuran granules and MIPC, Hokbal, propoxur, and BPMC sprays being the most effective. Moriya (1977) found that the BPH in Japan was more susceptible to carbamate than to organophosphorus compounds in LD_{50} studies.

Application methods. In Japan, Korea, and Taiwan, dust formulations are commonly used for BPH control but in the tropics granules and foliar sprays are the most common. A survey in Central Luzon, Philippines, found that 27% of the insecticides used for rice insect control was applied as granules and 73% as foliar sprays (W. H. Reissig, unpubl. data).

- *Foliar sprays.* Because the BPH feeds at the base of the plant and is not highly active, it is difficult to contact directly with insecticide.

  In the Philippines, high spray volumes of 1,000 liters/ha are recommended for BPH control when the canopy has closed but a field experiment using Perthane indicated no difference in control among volumes from 190 to 950 liters/ha (IRRI 1978). A greenhouse test comparing the effect of spray volumes of several insecticides on BPH control indicated that for most insecticides, all volumes provided similar initial control but the highest spray volume provided the longest residual toxicity (Fig. 4).

  Application of high volumes (300- 1,000 liters ha) of water, as required in the commonly used knapsack sprayer, is extremely laborious. As a result, farmers use too little water and frequently underdose. Studies at IRRI have indicated that the deposition of insecticide at the BPH feeding site with the ultralow volume (ULV) applicator is similar to the application with a knapsack sprayer (Pickin et al 1980). High wind speeds, however, cause drifting of the small droplets emitted by the ULV sprayer. Recently developed electrostatic sprayers



4. Effect of 3 spray volumes on BPH mortality. Mortality readings were taken at 24 hours after insects were caged on treated plants. Three groups of insects were caged at 1, 7, and 14 days after treatment. All insecticides were applied at 0.75 kg a.i./ha, except carbofuran, which was applied at 0.25 kg a.i./ha. IRRI greenhouse. 1979 (Heinrichs and Valencia, unpubl data).

that add an electrical charge to the droplets, which is opposite to the charge of the rice plant, show promise in overcoming the drift problem because the droplets are attracted to the plant.

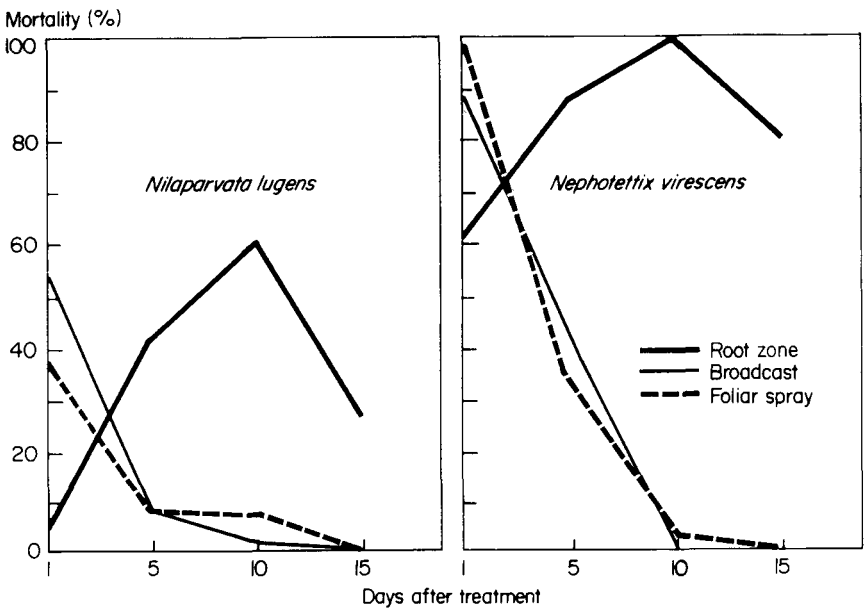
Insecticides applied as foliar sprays, when exposed in the field, have extremely short residual activity. Microencapsulation of insecticides may provide a means of slow release, thus increasing residual activity and also decreasing the hazard to the applicator.

- *Paddy water application of granules.* The use of a granular formulation, which can easily be broadcast by hand, eliminates many of the application problems encountered with foliar sprays. Granules, however, are expensive and the number of effective insecticides in granular formulations is limited. Carbofuran and diazinon granules have been commonly used for BPH control. Carbofuran is highly effective at 0.5 kg a.i./ ha in the greenhouse.
- *Root-zone application.* Insecticides that are highly active when applied in the root zone of the rice plant are being sought but only a few have been identified (Table 3). Root-zone application provides much longer residual activity than foliar sprays and broadcast of granules (Fig. 5). Root-zone application is more effective against the green leafhopper *Nephotettix virescens* than against the BPH. Another disadvantage of the root-zone method is that application is most convenient at or shortly after transplanting. However, under normal circumstances, the BPH moves into the field about 30 DT, after which the residual activity of a soil incorporation is too low for adequate BPH control. To extend the period of control, we are evaluating various slow-release formulations.

Table 3. Activity of granular insecticides applied in the root zone of rice plants at 1.0 kg a.i./ha for brown planthopper *Nilaparvata lugens* control. IRRI greenhouse, 1978.

Insecticide		Mortality[a] (%)		
		1 DT	7 DT	14 DT
FMC 27289	2.5 G	23 abc	60 abc	85 ab
Carbofuran	3 G	15 abc	38 bc	98 ab
Bendiocarb	5 G	15 abc	30 cd	70 b
FMC 35001	2.5 G	10 bc	15 cd	63 b
Isazophos	3 G	5 c	60 abc	80 ab

[a] Av, 4 replications, each consisting of 10 insects caged on treated plants. Means followed by a common letter are not significantly different at 5% level.



5. Field evaluation of 3 methods of isazophos application at 0.5 kg a.i./ha. In the root-zone treatment, insecticide was placed in a gelatin capsule and Inserted into the soil near the roots; in the broadcast method, granules were broadcast into the paddy water. Mortality readings were taken 48 hours after hoppers were caged on treated plants and adjusted using Abbot's formula. Variety IR22. IRRI, 1979.

Modes of insecticide action

The effectiveness of the various insecticides depends on their modes of action. According to Moriya (1977), the killing action of an insecticide can occur through

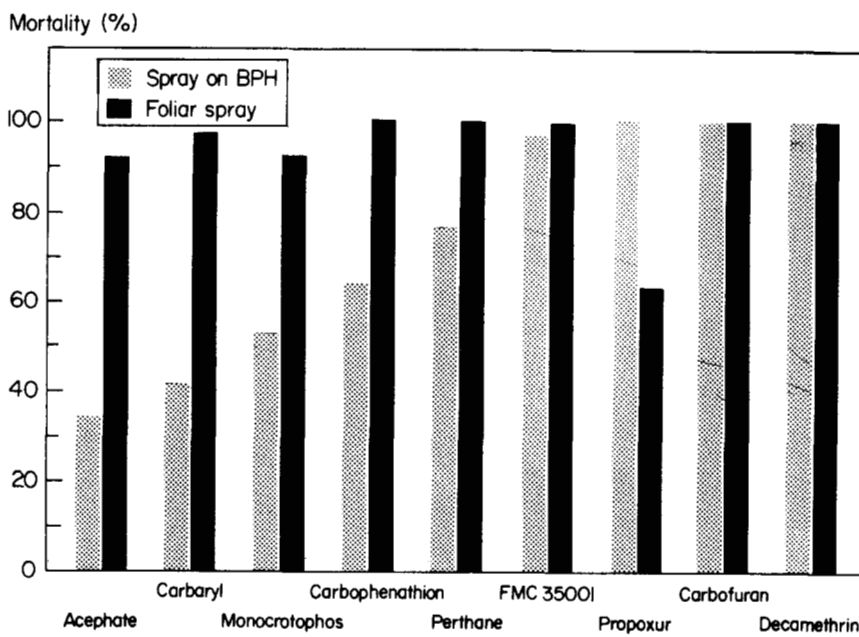
- the chemical's direct application to the body of the BPH;
- contact of the BPH with the insecticide as it moves over the residue;
- BPH ingestion of insecticide present in the plant system (systemic insecticide); and

• fumigation by insecticide vapors.

The most effective insecticides are active throughout all the above actions. Some insecticides are not highly active as contact insecticides but are effective against BPH feeding on sprayed plants (Fig. 6). Perthane and carbofuran, both highly effective against BPH, have a high degree of fumigant action as a foliar spray. Granules applied to the paddy water also act as a fumigant. Studies in Japan by Koyama and Tsurumachi (1968) indicate that diazinon granules also mainly act as a fumigant.

The population density of BPH is usually higher a week after insecticide application than a week before, when applications are poorly timed and many eggs within the leaf sheath tissue hatch and survive because the toxicity of the insecticide dissipated within a few days after application. Thus, insecticides with ovicidal action are desired for more effective BPH control. Carbofuran and triazophos have been shown to be ovicidal as foliar sprays and as paddy water applications in greenhouse studies (Heinrichs and Valencia, unpubl.).

Antifeedant compounds hold much promise for BPH control. The insecticide chlordimeform has an antifeedant action against BPH (Hirata and Sogawa 1976). Both chlordimeform and Perthane are highly effective antifeedants for BPH con-



6. Mortality of the *Nilaparvata lugens* when sprayed directly in the Potter's Spray Tower or when placed on sprayed plants at 1 day after treatment, both with a 0.04% spray. Mortality in the Potter's Spray Tower test was recorded 48 hours after treatment and in the foliar spray test at 48 hours after caging insects on treated plants. Values adjusted using Abbott's formula. IRRI greenhouse, 1977.

trol. The fungicide guazatine triacetate (Panoctine) also had antifeedant activity in IRRI tests (Heinrichs and Valencia, unpubl.). Botanical compounds such as trans-aconitic acid (Koh et al 1977) and neem (*Azadirachta indica*) oil (R. C. Saxena, pers. comm.) have been shown to reduce BPH feeding activity. Neem oil, however, has not been shown to be effective in the field because its residual activity is short.

Timing of application

Proper timing of insecticide application is important to achieve maximum control of the BPH. It is best to apply insecticide when most of the nymphs are in the third to fourth instar because most of the eggs deposited by adults of the past generation have hatched and few eggs have been laid by adults of the next generation.

In studies conducted in a farmer's field in the Philippines (Heinrichs and Aquino, IRRI, unpubl.), application of insecticides for BPH control was timed according to:

- the life cycle of the BPH,
- the number of BPH per hill, and
- a calendar-based schedule.

The highest yield of 7.03 t/ha was obtained when Perthane was applied at the peak population of the first- and second-generation nymphs (based on the life cycle). Yield losses due to BPH were low when a spray was applied once, when the population reached 10 or 16/hill. The benefit-cost ratio for insecticide use was highest (10.7) on the treatment sprayed when the population was 10 BPH/hill, whereas it was only 2.4 in the treatment sprayed 4 times on a calendar basis. The studies showed that fields should be monitored weekly and insecticides applied only when the economic threshold is reached.

Insecticide resistance

Resistance of the BPH to insecticides is primarily a problem in countries where insecticides have been extensively used. However, in Japan, the BPH has not developed resistance to as high a degree as has the green leafhopper *Nephotettix cincticeps* (Nagata 1979) because, it is believed, the BPH cannot overwinter and the migrants that come in early summer apparently have not had much exposure to insecticides. That would be the case if the BPH is coming from mainland China, as reported. Nagata (1979) reported that the level of resistance increased twentyfold from the immigrant generation to the fifth generation.

In Taiwan the BPH was recently reported to have developed resistance to MIPC and MTMC (Lin et al 1979). At IRRI, where diazinon and carbofuran had been extensively used, the BPH developed resistance (Heinrichs 1979). Throughout tropical Asia, however, because of the limited use of insecticides, selection pressure is low and resistance does not appear to be a problem at this time. But, with the increase in continuous cropping and national production programs that promote insecticide use, BPH resistance to insecticides may become a problem in the future.

Insecticide-induced BPH resurgence

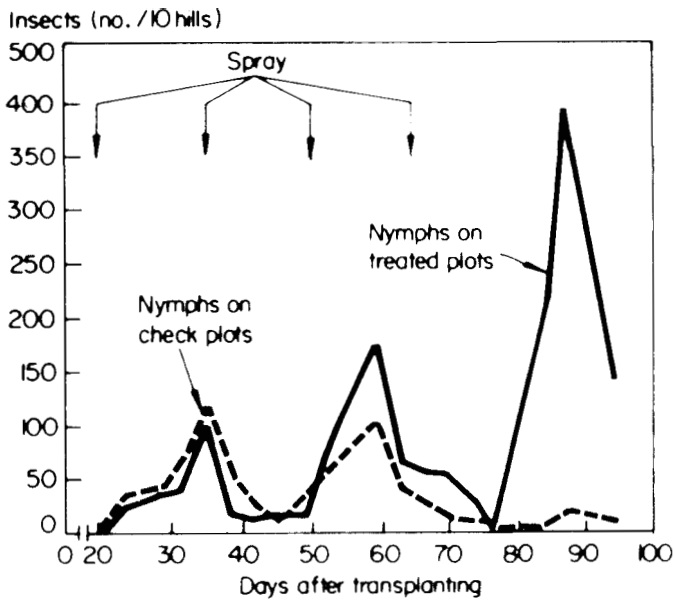
The reasons for the 1972-75 BPH outbreaks throughout tropical Asia is not known,

but many entomologists have implicated the changes in cultural practices that have accompanied the change from local to high-yielding cultivars. However, as previously indicated, it has been difficult to significantly increase BPH populations by manipulating cultural factors. On the other hand. applications of certain insecticides have been observed to cause unusual increases in BPH populations.

Most of the hopperburned fields reported, or actually observed by Heinrichs, in the Philippines and other countries have had a history of insecticide applications before the occurrence of an outbreak.

In the routine field evaluation of insecticides at IRRI, it is frequently observed that after certain insecticides have been applied, the BPH population dramatically increases. Hopperburn results while the BPH population remains low in the untreated check. A significant increase in BPH populations after treatment with insecticides, compared with that in an untreated area, is termed insecticide-induced resurgence (Fig. 7). Insecticide-induced BPH resurgence has also been observed in Bangladesh, India, and Indonesia. Although the role of insecticide in promoting the major 1972-75 BPH outbreaks throughout Asia is not known, insecticides have been suggested as the major cause by Kenmore (1979). Numerous insecticides have the potential to induce resurgence (Chelliah 1979). The list includes insecticides that may provide control at recommended rates but induce resurgence at sublethal rates. Because of the feeding location of the BPH and the short residual activity of the insecticides, the BPH is frequently exposed to sublethal rates.

National rice production programs designed to increase rice yields have encouraged an increase in insecticide use in rice. In the Philippines, methyl parathion was used in the Masagana 99 program. Methyl parathion applied at recommended rates of 0.75 kg a.i./ha is highly active as a resurgence-inducing insecticide (Fig. 7).



7. Four sprays of methyl parathion at 0.75 kg a.i./ha caused marked resurgence of BPH population on IR22. IRRI, 1977 dry season.

Because of its resurgence and hazard to humans, it was removed from the list of recommended insecticides in the Philippines in 1978. In reviewing the insecticides included in the national rice production program in Indonesia, known as the Bimas Program, as listed by Soenardi (1978), it is of interest to note that at least half of the insecticides recommended may cause BPH resurgence.

Evaluation studies at IRRI indicate that there is no apparent class distribution among insecticides causing resurgence since some of the carbamates, phosphates, and synthetic pyrethroids cause resurgence. Field studies are currently under way to screen the recommended rice insecticides for their resurgence potential. The basic mechanism in insecticide-induced BPH resurgence is not understood. Various hypotheses have been proposed. These are:

- selective removal of natural enemies. Studies on the relationship between natural enemies and BPH resurgence have been inconclusive;
- selective removal of competitive species;
- change in the physiology of the plant, which enhances its nutritional value to the BPH;
- increase in growth of the plant, which has an effect on the ecology of the insect;
- control of a BPH pathogen; and
- direct effect of the insecticide on the insect to increase its feeding and reproductive rate. Intensive greenhouse studies have shown that sublethal rates of certain insecticides significantly increase the feeding and reproductive rate of the BPH (Chelliah et al 1980).

Varietalresistance

Varietal resistance to the BPH was first reported from India. A systematic search of the world germplasm collection for BPH resistance began at IRRl in 1966 (Pathak and Khush 1979). Development of an efficient screening system greatly accelerated the identification of resistant sources in programs at IRRl and in Korea, Japan. Taiwan, Thailand, Indonesia, India, Sri Lanka. and the Solomon Islands (Choi 1979). About 37,000 accessions from the world collection have been evaluated at lRRl since 1966 and nearly 300 varieties with high level of BPH resistance have been identified (Table 4). Some accessions have multiple resistance to the BPH, green leafhopper, and WBPH (Heinrichs, unpubl.).

Through genetic analysis of selected varieties, four genes for resistance have been identified (Table 5). Many of those varieties are being used as resistance sources in national programs (Table 6) and BPH-resistant varieties have been released for commercial cultivation in China, Indonesia, Korea, Philippines, Solomon Islands, Taiwan, Thailand, and Vietnam, Bangladesh, India, and Sri Lanka have advanced BPH-resistant lines for possible release in the near future.

Attempts to identify the various biotypes on the basis of characters other than the reaction of differential varieties, as indicated by feeding damage or by the insect's feeding activity on differential varieties, have not been successful.

IR26 (*Bph 1* gene), the first BPH-resistant variety released in the Philippines, was found susceptible when first grown in India. After IR26 had been grown in Indone-

Table 4. Origin of cultivars in the IRRI germplasm collection with resistance to the brown planthopper *Nilaparvata lugens.* IRRI, January 1980.

Origin[a]	Cultivars/accessions	Total varieties (%)
	Oryza sativa[b]	
Australia	1	0.4
Bangladesh	4	1.6
Burma	1	0.4
China	1	0.1
India	47	18.2
Nepal	1	0.4
Nigeria	2	0.8
Sri Lanka	197	76.4
Taiwan	3	1.2
Thailand	1	0.4
Total	258	
	Wild rice species[c]	
Africa	1	3.7
Australia	2	7.4
Costa Rica	2	7.4
Gambia	4	14.8
Guatemala	1	3.7
India	15	55.6
Taiwan	1	3.7
U.S.A.	1	3.7
Total	27	

[a] Sources from which IRRI received seeds. The variety may have originated in another country and come to IRRI from the country indicated. [b]37,000 varieties have been evaluated. [c]93 accessions have been evaluated.

Table 5. Brown planthopper-resistant varieties and genes identified for that resistance (Khush 1977, Lakshminarayana and Khush 1977).

Bph 1	*bph 2*	*Bph 3*	*bph 4*
TKM 6[a]	ASD_7	Rathu Heenati	Babawee
Mudgo	Ptb 18	Ptb 19	Gambada Samba
MTU 15	H 105	Gangala	Hotel Samba
CO 22	ASD_9	Horana Mawee	Kahata Samba
	Palasithari 601	Muthumanikan	Thirissa
	H 5	Kuruhondarawala	Sulai
		Mudu Kiriyal	Vellai illankali
			Heenhoranamawee
			Kulu Kuruwee
			Lekam Samba
			Senawee

[a] Resistance gene is marked by an inhibitory gene.

Table 6. Varieties used as sources for gall midge and brown planthopper resistance in breeding programs of various countries (Animal Institute, Academy of Science, China, 1979).

Bangladesh	India	Indonesia	Sri Lanka	Thailand	IRRl
Kuluhondara-wala Suduru Samba Balamawee Gangala	Ptb 21 Ptb 33 ARC6650 Leb Mue Nahng Rathu Heenati CR57-Mr-1523 ARC1125 ARC6650	ASD 7 Ptb 33 Rathu Hee-nati Babawee	Ptb 33 ARC6650 Heen Rath-kunda Suduru Samba CR57-Mr-1523	Eswarakora Ptb 21	Mudgo ASD7 Ptb 21 Ptb 33 Rathu Heenati Babawee Suduru Samba

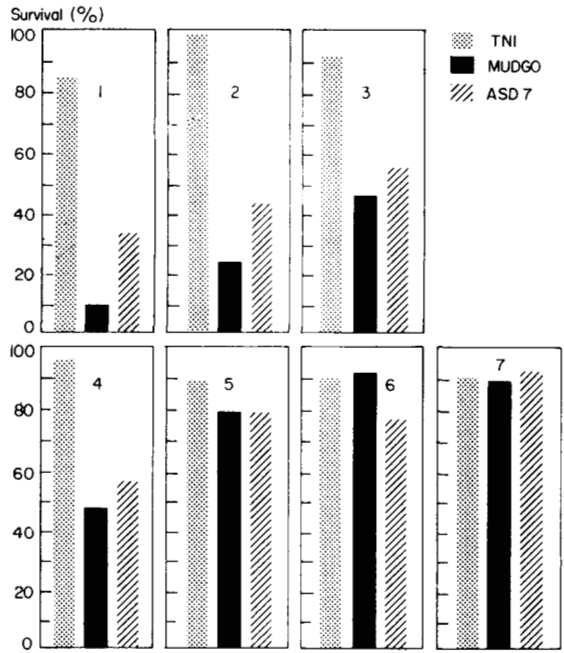
sia and in the Philippines for about 2-3 years, there were reports of high BPH populations causing hopperburn. This indicated that selection pressure resulted in a shift in the BPH population to an abundance of a virulent biotype. Farmers in the Philippines then shifted from IR26 to IR36 (*bph 2* gene). IR26. however, is grown on more than a million hectares in China (G. S. Khush, pers. comm.). The Chinese used IR26 as a restorer parent in 90% of the 5 million ha of hybrid rice grown in 1979.

Laboratory studies have documented the rate at which the wild strain, biotype 1, can adapt to a resistant variety (Pathak et a1 1980). Within 7 generations, biotype 1 became adapted to the resistant varieties Mudgo (*Bph 1* gene) and ASD 7 (*bph 2* gene), as indicated by survival studies (Fig. 8). With 3 generations per crop this would be 3-4 years under a 2 crops/year system. Additional studies indicated that rate of adaption, based on feeding activity and fecundity on the resistant varieties. varied between Mudgo and ASD 7. Biotype 1 adapted at a more rapid rate to feeding on ASD 7 and was more fecund on Mudgo.

Development of BPH-resistant varieties was accelerated through the establishment of the International Rice Brown Planthopper Nursery (IRBPHN) in the International Rice Testing Program. Results of the 1979 IRBPHN at IRRI indicate that advanced breeding lines from the various national programs have resistance to two or three of the biotypes at IRRl (Table 7). Some of the lines are expected to have two major genes for BPH resistance whereas all commercial varieties still have only one major gene.

Breeders are incorporating into rice hybrids multiple resistance to insect and disease pests. Some IR varieties have resistance to the BPH and the green leafhopper *N. virescens,* but, so far, no IR variety has resistance to the WBPH. However, elite breeding lines under evaluation have resistance to the three BPH biotypes, green leafhopper, and WBPH. The Korean breeding program has developed cultivars with resistance to the green leafhopper *Nephotettix cincticeps,* BPH, SBPH, and WBPH.

Although farmers in the Philippines have been growing IR36 for 3-4 years, there have still been no confirmed reports of BPH damage. IRRI studies indicated that



8. Survival of newly emerged nymphs of biotype-l BPH up to 13 days after release on susceptible TN1 and resistant varieties Mudgo (*Bph 1* gene) and ASD 7 (*bph 2* gene) from 1-7 generations. Biotype I is a wild strain originally collected in the field and reared on TN1 for at least 10 years. IRRI 1979 (Pathak et al 1980).

IR36 may possess minor genes, in addition to the major *bph 2* gene. The minor genes appear to be active in imparting resistance in plants after the seedling stage. This is indicated by the difficulty in maintaining a biotype 3 population on 30- to 40-day-old plants; the biotype 3 population thrives on ASD 7, even though it has the same major gene as IR36. Because minor genes, which impart moderate resistance, may provide horizontal resistance to all biotypes and exert less selection pressure for biotype development, methods are being developed to screen for this type of resistance.

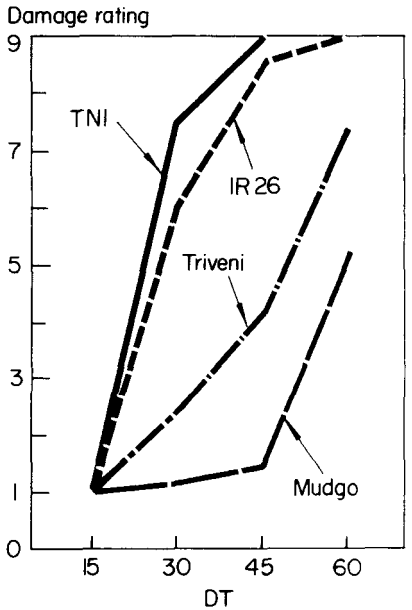
Moderate resistance is difficult to detect by the common seedbox-screening technique used to evaluate 7- to 10-day-old seedlings, which are usually rated susceptible. It is clearly observable, however, in screenhouse or field studies, where planthopper activity generally occurs on older plants. TNl, Triveni, IR26, and Mudgo are all susceptible to biotype 2 in seedbox screening but they show distinct differences in resistance when evaluated as older plants (Fig. 9).

Although IR26 and Mudgo have the same major gene for resistance, *Bph 1,* Mudgo is always more resistant in IRRI field trials than IR26. Triveni, having no known major gene, is always more resistant in field screening than TNl. Tolerance, the ability of a plant to survive and grow despite insect feeding, may be one of the mechanisms operating in the field. Mudgo and Triveni are able to tolerate BPH

Table 7. Degree of resistance of selected entries in the 5th International Rice Brown Planthopper Nursery (IRBPHN) to brown planthopper biotypes at IRRI, 1979.

Entry	Cross	Source	Reaction[a] in greenhouse to			
			Biotype 1	Biotype 2	Biotype 3	Field[b]
CR57-11-2	IR8/Ptb 27	India	R	R	R	R
Kanto PL 2	Reiho/F8269//Tsukushibare	Japan	R	S	R	S
Kav 10661-1	Triveni/IR2071	India	R	R	R	R
Milyang 44	YR657-153/IR26	Korea	R	S	R	S
YR1805-52B	—	Korea	R	R	R	R
IET5122	Vijaya/Ptb 21	India	R	R	R	R
B28508-SI-2-1	B541B-KN-91-3-1/IR2011-15-4-1-2	Indonesia	R	R	R	R
RD9	LY*2/TN1/W1256///RD2	Thailand	R	S	R	S
IR13543-66	R. Heenati/IR3403-267-1// IR34	IRRI	R	R	R	R
IR13240-6-3	IR30S/Babawee//IR2071-625-1-252	IRRI	R	R	R	R
IR13429-47-3	IR4432-53-33/Ptb 33// IR2071-625-1	IRRI	R	R	R	R
Mudgo (check)		India	R	S	R	MR
ASD 7 (check)		India	R	R	S	R
Rathu Heenati (check)		Sri Lanka	R	R	R	R
Babawee (check)		Sri Lanka	R	R	R	R
Ptb 33 (check)		India	R	R	R	R

[a] R = resistant, MR = moderately resistant, S = susceptible. [b] Predominantly BPH biotype 2.



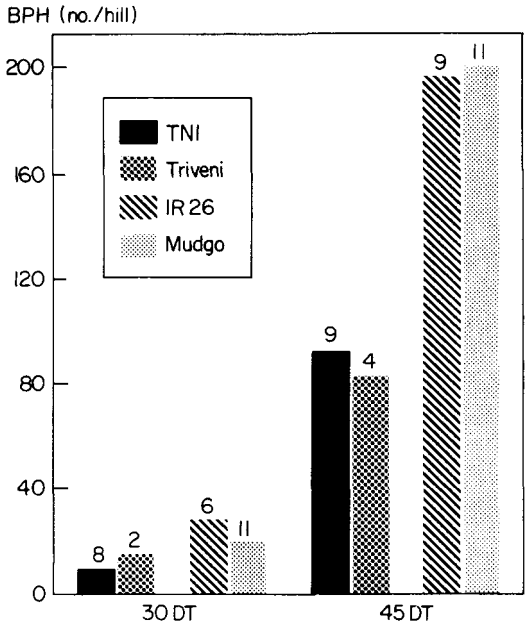
9. Damage ratings of varieties exposed to BPH biotypes 1 and 2 in a screenhouse. 1 = slight damage. 9 = all plants dead. The varieties are all susceptible to biotype 2 when evaluated as 7- to 10-day-old seedlings in the seedling bulk technique. IRRI 1979 (Dang Thanh Ho, unpubl. data).

populations without being as severely damaged as TN1 and IR26 (Fig. 10). Mudgo appears to have, in addition to tolerance, another mechanism that influences the growth and development of the insect (Fig. 11). Survival of the virulent biotype 2 is lower and its developmental period longer on Mudgo than on IR26 and TN1.

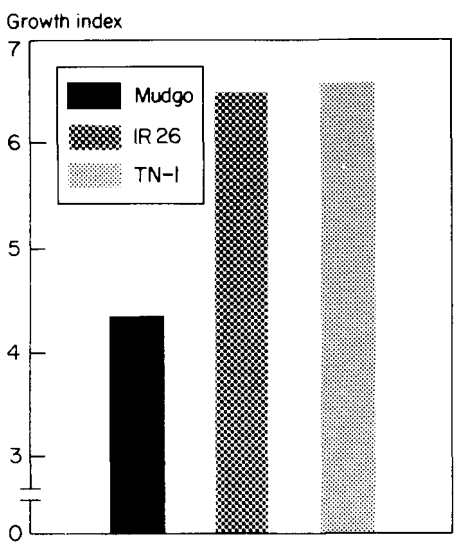
Cultural control

Because of the development of BPH resistance to insecticides, as reported from Japan (Nagata and Moriya 1969, Nagata 1979, Nagata and Djatnika 1980) and Sri Lanka (Fernando 1975), resurgence (Heinrichs et al 1979b), the difficulty of controlling outbreak populations with insecticides (Mochida et al 1977, 1978), and the selection for virulent biotypes (Khush 1979, Mochida 1979, Stapley et al 1979), there is interest in developing cultural control techniques.

Fallow, crop rotation, and sanitation. Although some *Oryza* spp. can serve as potential host plants (CRIA-IRRI, Sukamandi, unpubl.; Oka 1979), the main host of the BPH is rice in the field. Accordingly, BPH populations are expected to be reduced by fallow, crop rotation, and sanitation.



10. Population of brown planthoppers and damage ratings (bars) on varieties exposed in the screenhouse to a mixture of biotype 1 and 2 hoppers at 30 and 45 days after transplanting (DT). 1 = slight damage. 9 = all plants dead. All varieties are equally susceptible in the seedbox screening of 7- to 10-day-old seedlings. IRRI 1979 (Dang Thanh Ho, unpubl. data).



11. Growth index of BPH biotype 2 on 30-day-old plants of three rice varieties. All varieties are susceptible to biotype 2 in the seedling bulk screening test. Growth index - % survival of nymphs to adult stage ÷ days of development of newly hatched nymphs to the adult stage. IRRI 1979 (Pathak et al 1980).

The growing period of rice cultivars generally ranges from 78 to 230 days but that of some cultivars in Kalimantan, Indonesia, is about 330 days. After harvest, ratoon plants and seedlings frequently develop from dropped grain. When rice is harvested by the panicles with an *ani-ani,* or small knife, rice plants occasionally survive for

several weeks. Staggered rice cropping, commonly observed in some areas with adequate irrigation, provides BPH with host plants throughout the year. Thus, fallowing of cultivating crops other than rice should be done simultaneously over large areas and continued at least for 2 months. BPH populations are reduced by destroying living stubble, ratoon plants, and seedlings during the dry season. Sanitation, though difficult in many small farmers' fields in Asia, and fallowing have been successfully used in controlling BPH in the mechanized, commercial rice production areas in the Solomon Islands (MacQuillan 1974).

Water management. Studies indicate that irrigation water is associated with the population growth of BPH, as reviewed by Dyck et a1 (1979) and Heinrichs et a1 (1979b). In Japan, many farmers withhold irrigation water for about 1-3 weeks in the middle of the summer. Some farmers supply water to rice by intermittent irrigation. Farmers believe that midsummer drainage and intermittent irrigation accelerate removal by plants of fertilizer nutrients from the paddy soil and promote the development of the rice root system, and, thus, rice plants grow vigorously and suffer less from the injury of insects and diseases.

Early-maturing cultivars. Early-maturing breeding lines are being evaluated at IRRI, and results indicate that the cultivars have a great deal of potential in the cultural control of BPH. Lines that can be harvested 75 days after transplanting are available. The third BPH generation, which occurs about 80 days after transplanting, usually causes hopperburn in the tropics. The early lines are harvested before the third-generation nymphs occur and thus escape damage (Fig. 12).

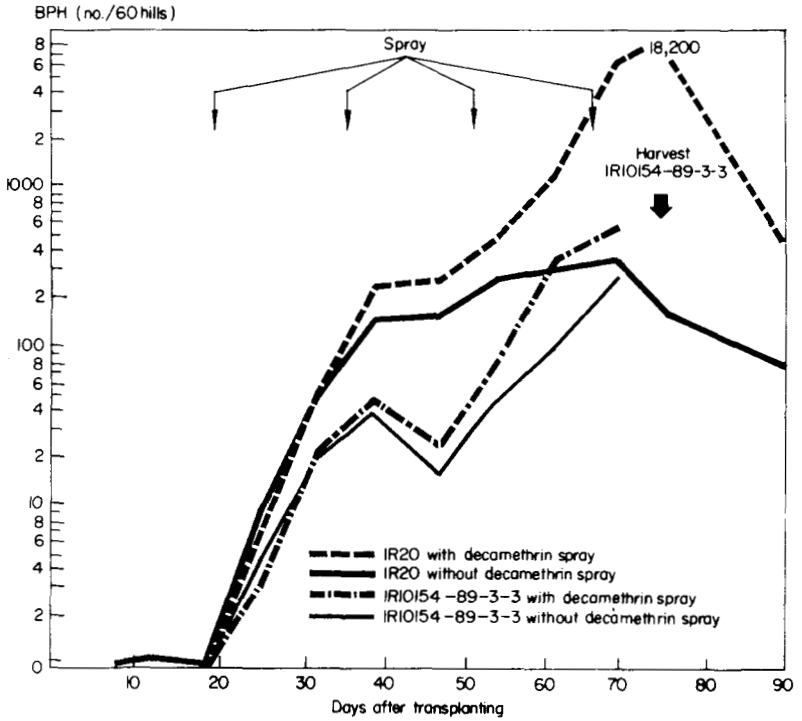
Integrated pest control

As intensive studies now in progress provide basic information on BPH ecology and the role of insecticides, resistant cultivars, and cultural control methods, advances in the integration of these various control components will be made for more effective and economic regulation of BPH populations. Two areas that show promise are:

- the identification and use of selective insecticides, and
- integration of moderate resistance with chemical and biological control.

Studies on the selective toxicity of insecticides to natural enemies and the BPH are receiving more emphasis because of information about the relative importance of the various biocontrol agents in BPH control. Laboratory studies have shown that commercial insecticides vary in their toxicity to natural enemies and the BPH. Some insecticides have a high relative toxicity to the spider *Lycosa pseudoannulata* and the mirid bug *C. lividipennis,* whereas others are relatively more toxic to the BPH (Fig. 13). Additional studies are needed to permit use of selective toxicity data in drawing up control recommendations.

IRRI has recently begun studies to determine the compatibility of moderate resistance with chemical and biological control. BPH that survive on moderately resistant cultivars are smaller and appear less vigorous than BPH on susceptible cultivars. Are these insects more susceptible to insecticide than those on a susceptible variety? If so, lower rates would provide control and thus chemical control would provide greater economic returns. In IRRI studies, carbofuran was more toxic to

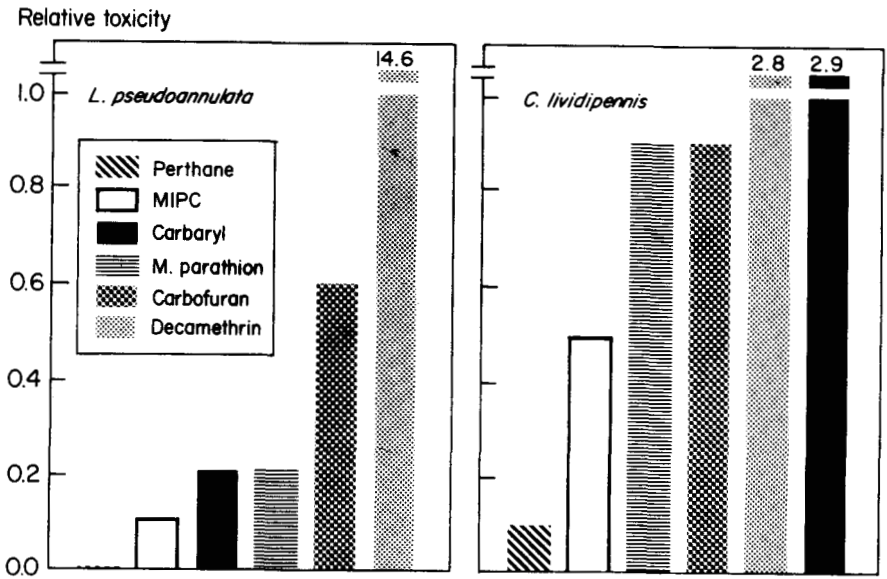


12. Brown planthopper populations on two BPH-susceptible cultivars with and without four application, of a resurgence-inducing insecticide. IR20 is of intermediate duration while IR10154-89-3-3 is early maturing. IRRI, 1979 wet season (Heinrichs and Arceo, unpubl. data).

BPH feeding on a moderately resistant cultivar than to BPH feeding on a susceptible one (E. A. Heinrichs, F. Medrano, and L. Fabellar, unpubl.). Moderate resistance has also been shown to increase the efficiency of the spider *L. pseudoannulata* feeding on BPH (Fig. 14). These initial studies indicate that combining moderately resistant varieties (which exert less selection pressure for biotype shifts) with biological and chemical control is a promising means of BPH control.

STRATEGIES FOR AN INTEGRATED APPROACH TO BROWN PLANTHOPPER CONTROL

When the BPH outbreaks of 1973-75 first occurred in the Philippines, many farmers



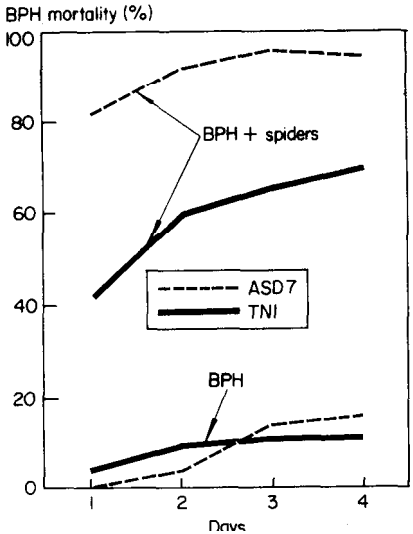
13. Relative toxicity of insecticides applied topically to the brown planthopper *N. lugens* to its predator, the spider *Lycosa pseudoannulata* or the mirid bug *Cyrtorhinus lividipennis*. Relative toxicity = LD_{50} of hopper — LD_{50} of predator. A relative toxicity 1.0 indicates the insecticide is relatively more toxic to the predator. The absence of LD_{50} on *Lycosa* up to 5.000 ppm Perthane indicates its low toxicity to the predator. IRRI laboratory, 1979 (Heinrichs and Fabellar, unpubl.).

were not aware of this pest. Today, through the efforts of extension programs, farmers have been taught to recognize the BPH and to apply control measures before the pest reaches damaging levels. There have been significant advances in the development of components for BPH management. The development of these components has been rapid and their use effective.

Many national rice breeding programs have given priority to the BPH problem, and BPH-resistant, high yielding varieties are successfully being grown or are nearing release in most endemic areas. The availability of additional major genes for resistance and the potential for use of minor genes indicate that varietal resistance will continue to be a major BPH control component in many countries in Asia.

No single control component, however, is in itself a panacea. The BPH is a dynamic insect and is capable of responding to resistant varieties through the selection for biotypes, to insecticides by the development of resistant strains, and possibly even to biological control agents. Recently the BPH has been reported to be the transmission agent of a newly identified rice virus disease, wilted stunt (Chen et al 1978), for which no known sources of varietal resistance have yet been identified.

The BPH will continue to threaten rice production. The force of scientists that has



14. Efficiency of the spider *Lycosa pseudoannulata* when feeding on BPH on a resistant (ASD 7) and a susceptible (TN1) variety. Ratio of BPH to spiders was 20:1. IRRI 1979 (Kartohardjono et al, unpubl. data).

been mobilized throughout Asia must continue and even expand their cooperative efforts in the development of control programs that integrate varietal resistance, chemical control, cultural practices, and biological control to effectively control this pest in the 1980s.

Research strategies

We suggest that the following be included in any strategies developed for BPH research.

Strategies for chemical control

1. Continued work to determine the minimum effective rates of commercial insecticides.
2. Continued research on the volume of spray solution needed for effective control using recommended insecticides at various plant growth stages.
3. Development of insecticides that:
   - are selectively more toxic to the BPH than its major natural enemies,
   - do not induce resurgence,
   - are ovicidal, and
   - have fumigant action.
4. Development of botanical insecticides that can be produced by farmers.
5. Broadening the search for formulations of plant extracts, such as neem oil, which have more stability under field conditions.
6. Search for insecticide formulations that are less hazardous to humans and that provide slow release and increased residual activity.
7. Development of application equipment that can put foliar spray droplets in the

feeding site of the insect.

8. Socioeconomic research and linkage with extension to teach farmers to monitor their fields and apply insecticides only when economic thresholds are reached.
9. Research on insectistatics (Levinson 1975) or chemicals dependent upon the alienation of the normal function of physiologically active compounds, such as hormonal imbalances, nutritional and metabolic disturbances, prevention of mating, antifeedant, etc.

Strategies for varietal resistance

Research strategies for developing varietal resistance to BPH should include:

- the development of new techniques to identify moderately resistant cultivars and the use of moderately resistant cultivars in the breeding program;
- identification of additional major genes for resistance and the incorporation of two or more of those genes into a cultivar;
- characterization of the biotypes in the various rice-growing regions through reactions on differential cultivars (development of isogenic lines will facilitate this study);
- determination of the biochemical bases for resistance and development of a technique to obtain sap from the phloem, the feeding site of the BPH, as a way to greatly facilitate biochemical studies;
- achieving an understanding of the genetic basis for virulence among biotypes; and
- integration of moderate resistance with chemical and biological control in the field.

Strategies for biological control

Research should determine if establishment of exotic natural enemies, release of reared natural enemies, and manipulation of the environment (through cultural or chemical means) to enhance natural enemy action are feasible.

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RICE BLAST CONTROL STRATEGIES

P. CRILL, H. IKEHASHI, and H. M. BEACHELL

Rice blast, caused by *Pyricularia oryzae,* is reported in more than 70 countries. It is present almost everywhere rice is commercially grown. The disease was first described in China in 1637. The pathogen was first described and named in 1891 (Ou 1972).

The economic importance of blast is difficult, if not impossible, to assess. Blast is considered rather insignificant in irrigated wetland rice under intensive management in the tropics (Ikehashi and Khush 1979). It is often epidemic in wetland rice in temperate areas such as Korea, Japan, China, United States, and India. It is well documented that *P. oryzae* can infect rice only when free water is present (IRRI 1977; Ou 1972, 1979). We hypothesize that the difference in blast incidence between tropical and temperate regions may be caused by the length of time that free water remains on rice leaves in the field. Dew forms earlier and lasts longer in the temperate zones than in the tropics.

The blast syndrome consists of lesions that form on the leaves, nodes, panicles, and grains. Leaf blast is probably the most common but least destructive phase of the disease. It is not unusual for seedlings to have an early leaf blast infection that eventually disappears, leaving no damage. Conversely, it is not unusual for early seedling infections of leaf blast to continue to develop, resulting in stunted and dead plants. The least common symptom is node blast. When a rice node is infected by *P. oryzae,* all plant parts above it eventually die.

Panicle blast and neck blast cause direct yield losses. Panicle blast is manifested by infection and symptoms on the branches of the panicle and glumes of the florets and seed. Quite often, such infected panicles, or parts of panicles, are sterile, or grain is formed but fills poorly, resulting in lightweight kernels.

Neck blast symptoms also result in direct yield losses. Neck blast is often referred to as *rotten neck* and *neck rot.* Early neck blast infection may result in no grain formation and total yield loss. Neck rot is the most serious phase of the blast disease because it occurs late in the plant's development — after the farmer has invested all his production inputs for the crop. Neck rot infection occurs at the axis of the

Plant pathologist and head, Department of Plant Pathology, IRRI; plant breeder, Division of Genetics. National Institute of Agricultural Science, Tsukuba, Japan; and plant breeder, Cooperative CRIA-IRRI Program, Bogor, Indonesia.

peduncle and ligule of the flag leaf where free water is often present. It is possible, therefore, to have a high percentage of neck rot infection in a field that has shown little leaf blast.

Ou (1972) studied and summarized the parameters for epidemic development of blast. Numerous researchers — Goto (1965) and Padmanabhan (1965), particularly — have offered estimates of yield losses. Kuribayashi and Ichikawa (1952) and Goto (1965) have developed formulas to estimate losses. But yield-loss estimates remain estimates because time of infection, cultural practices, differences in varietal reactions, etc. all affect actual loss, and such parameters cannot be integrated into loss-estimate formulas.

POTENTIAL STRATEGIES FOR RICE BLAST CONTROL

Among the potential strategies that can be used to combat endemic as well as epidemic forms of the blast disease in rice are:

- regulatory controls to prevent transfer of blast races into an area where they do not exist;
- manipulation of cultural practices to reduce the incidence and severity of blast;
- chemical control through use of systemic and nonsystemic protectant, and eradicant fungicides as seed treatments, soil treatments, and foliar sprays; and
- use of host resistance to develop blast-resistant varieties.

Each of these control strategies may be of value in a given rice production area but the success of any of them is dependent upon the characteristics of the area. Rice blast control strategies successfully used in one country or geographical area will not necessarily be successful in another country or area. Blast control strategies must be selected, developed, and modified by researchers familiar with crop production practices used by farmers in the area for which the strategies are intended. We present potential blast control strategies that are applicable in particular situations.

Regulatory controls

Regulatory controls are outside the control of the individual scientist. Usually the scientist calls attention to the value of such control strategies, but the government regulatory agencies implement them. It is desirable to avoid introducing new races of *P. oryzae* into areas or countries where they do not exist. A general quarantine may prevent their entry for a time, but would probably be met with considerable opposition by the farmers and certain researchers. Because the present knowledge of international distribution of blast races is quite limited, a general quarantine may be a waste of time because the race may already exist within the country imposing the quarantine. When general quarantines are imposed, the flow of germplasm and breeding lines required for variety development programs is often seriously impeded and the development of new varieties is seriously delayed. In such instances, a general quarantine would be much more detrimental than beneficial to rice farmers.

Another way of avoiding the introduction of new blast races into an area is by

determining an area's seed production and seed requirements, and designing strategies to prevent the entry of the new races. Such programs for rice blast control are in effect in Korea and a brief description will illustrate how the introduction of new races can successfully be avoided or delayed.

Avoiding introduction of a new blast race into a relatively small, isolated rice-producing area. In 1976 a new race of rice blast that was pathogenic on the widely grown Tongil varieties was found in farmers' fields in Korea. In 1977 its incidence increased only slightly, but in 1978 it caused a severe blast epidemic throughout Korea, except the Cheolweon area, a valley surrounded by mountains in northeastern Korea, which, to date, has remained free of the new race, and where the varieties Tongil and Josaeng Tongil continue to grow free of blast. Through the use of minimum regulatory practices, including the planting of seed treated to eradicate *P. oryzae* and restrictions on other methods of introducing the pathogen into the area, it has been possible to delay the introduction of the new race into Cheolweon.

Avoiding introduction of a new race of blast into a large area or country. The Korean Government and IRRI, since 1965, have participated in cooperative research, which involves the movement of seed from Korea to the Philippines and back to Korea (Kim 1978). There are in the Philippines several races of blast that do not occur in Korea and possibly vice versa. In a general plan to prevent the introduction or transfer of a race from one country to another, the Korean and IRRI researchers impose strict controls. Rice grown in the Philippines is in wetland paddies where blast seldom is a problem. Although essentially blast free, all seed from such areas is subjected to fumigation and seed treatment to control not only rice blast but also other potential pathogens and insects. In the 15 years the project has been under way, no evidence suggests the introduction of a new race of blast or any other pathogen into Korea from the Philippines or vice versa.

Such regulatory programs significantly reduce the potential occurrence of a blast epidemic caused by a new race of *P. oryzae.* As the exchange of rice germplasm among scientists becomes increasingly extensive and extensive air travel lessens the relative isolation of rice-producing areas of the world, the role of regulatory control strategies becomes more and more important.

The success of such strategies may be limited, however, because inspectors often do not know what to look for. The US has a very strict quarantine on the importation of rice seeds into the country, primarily for disease control. Customs inspectors, however, pay no attention at all to hats manufactured from diseased rice straw in Taiwan. It is possible to isolate *P. oryzae* from such hats and it is quite feasible that races of *P. oryzae* have been spread from one country to another on products made from infected rice straw.

Cultural practices

Manipulation of cultural practices is one of the most widely discussed, most often recommended, and least valuable rice blast control measures available in the tropics. Farmers use certain cultural practices for specific reasons. Often the farmer is unsure of why he grows rice in a certain way. but knows that if he changes a certain practice,

other problems may develop. Disease control strategies that do not allow the farmer to economically maximize yields have no value, even if the disease is controlled.

The application of silica and other micronutrients as well as the manipulation of nitrogen, phosphorus, and potassium may effectively reduce the incidence and severity of blast. Such strategies can be used only in areas of more intensive rice production where farmers have access to technical information and the assistance, methods, skill, and capital required to implement such strategy.

Sanitation practices may reduce the incidence of rice blast in the temperate rice-growing areas. Early plowing of fields to turn under infected stubble and plant parts, to ensure their complete decomposition before the succeeding crop is planted, reduces the inoculum potential of rice blast. The composting, burning, and general destruction of infested straw and crop debris serve the same purpose.

In a few limited rice production areas, planting dates may be altered to avoid the environmental conditions conducive to blast epidemics. Probably rice farmers in most areas of the world have already discovered the advantage of altering planting dates and recognized optimum planting dates as an established cultural practice. This control strategy may be of value in new areas of rice production where farmers do not have a long history of crop performance.

The key to developing rice blast control strategies based upon manipulation of cultural practices is the researcher's comprehension of why farmers follow specific practices. Before farmers can alter the present cultural practices, the researcher must manipulate the specific practices and learn how the change would affect the whole crop production system. Quite often, the suggested cure, based upon changing a particular cultural practice, causes many more problems than it solves.

Chemical control

Chemical control of rice blast in the past has not been favorably considered, especially in the tropics. The pioneering work in chemical control of rice blast has been done in Japan. Japanese rice farmers routinely use various fungicides and methods of application for rice blast control. More recently, in the United States and Latin America, chemical control of rice diseases, especially blast, has become routine among rice farmers. These countries are highly developed agriculturally and industrially and have well-developed scientific, chemical, and extension communities that interact with farmers. Such conditions do not exist in most of the rest of the rice-growing world where chemical control of rice blast is in its infancy.

In agriculturally less-developed countries, chemical control of rice blast has the potential for rapid expansion. Such countries have access to the experience of the more developed countries and should be able to avoid many of the problems experienced early with chemical control. These advances will primarily be made with the systemic fungicides, which are mostly target-organism specific, with little effect on other organisms in the environment. Likewise such fungicides are essentially nontoxic to mammals and relatively nonpersistent. The significant factor is that systemic fungicides can be applied with virtually no investment in application equipment. Very small amounts of certain systemic fungicides can be applied to rice

seed as a slurry treatment and completely protect the crop from time of seeding to harvest.

On the negative side, there is always the possibility that fungicide-resistant races of *P. oryzae* would develop when chemical control becomes widespread. This problem has occurred with other crops and diseases in the agriculturally developed countries and, because it has been successfully overcome, there is little reason why it cannot be overcome in the agriculturally developing countries.

Control strategies for rice blast using systemic fungicides — a concept in its infancy — are quite promising. Researchers have the time to develop sound, workable strategies for blast control and prevent problems that have developed on other crops. Before such a strategy can be implemented, it is necessary for blast researchers to organize large-scale evaluation programs. The more promising systemic fungicides must be obtained from chemical companies through cooperative research-testing programs, and their effectiveness and performance evaluated. When fungicides with the best control potential and benefit are identified, the rate and method of application must be studied and blast control evaluated. The value of the control obtained relative to the cost incurred must be determined for different production areas.

Some of these studies have barely been initiated; others have only been infonnally discussed. The potential of rice blast management with systemic fungicides as a control strategy appears too great to be ignored.

Host resistance

There is indeed frustration among plant breeders and plant pathologists who have worked with host-plant resistance to blast in the tropics. The reason may be the lack of a framework into which fact-finding research should be systematically integrated. There have been interpretations of the nature of resistance and proposals of such countermeasures to blast as alternation of different types of host resistance, pyramiding of several major genes, and developing of multiline varieties. All are rather premature in that they are feasible only with an effective system of differentiating host resistance and fungus races. There is no such system in the tropics.

It is important to focus clearly on the way by which an effective system for identifying host resistance and blast races should be constructed. If we consider the wide range of environments and rice varieties cultivated in the tropics, the construction of an effective identification system for genes for host resistance and blast races would require a long time. Moreover, restriction by law of the exchange of blast races poses another hindrance in the search for races to distinguish host resistance genes. Nevertheless, the construction of such a system is essential to systematic work in the future.

Therefore, it is important to carefully examine the present knowledge of resistance to blast, and to find a way of developing a system of differentiating host resistance and races. Second, it is necessary to devise some preliminary way of differentiating host resistance so that plant breeders may work with adequately diverse sources even before an effective genetically described system becomes available. Understanding

the role of the different types of host resistance in actual rice production may also provide a basis for developing advanced measures to cope with rice blast.

Implications of the perfect stage of *Pyricularia oryzae* in breeding for resistance

The causal fungus of rice blast has been known to lack a perfect stage as reviewed by Asuyama (1965). However, a drastic change in the present picture is now evolving to explain the nature of the fungus. Hebert's (1971) success in forming a perfect stage of *Pyricularia grisea* from crabgrass, and renaming the genus *Ceratosphaeria grisea* was the first step forward. During 1976–77, three groups of scientists in Japan (Kato et a1 1976, Ueyama et a1 1977, Yaegashi 1977, Yaegashi and Nishihara 1976) independently formed the perfect stage of *P. oryzae* in culture between strains from ragi and those from rice. The mating of the fungus was confirmed to be controlled by physiological heterothallism, which is denoted by type A (+) and a (–). These two types are found in natural populations in many rice-growing areas, but there is no evidence yet to substantiate the occurrence of the perfect stage in nature (Kato 1977, Yaegashi 1977).

Pyricularia oryzae infects a number of species of the grass family, including bamboo, in which a strain that can infect rice exists. According to Kato (1977), ragi (finger millet) is a very important crop associated with the occurrence of the perfect stage of the fungus; it is widely distributed in rice-growing areas and blast strains on it have an affinity to those on rice. It is possible to find in natural conditions the perfect stage on ragi plants or other grasses somewhere in rice-growing areas.

Studies of the perfect stage of *Pyricularia* will primarily elucidate the taxonomy of the fungus. The present understanding of blast epidemiology may also be revised if the source of initial occurrence of the disease is found in some crop other than rice, or if the perfect stage is found to have a role in propagating the fungus through a specific common plant. The most significant progress will be through the use of the perfect stage in studying the genetics of the fungus itself. Some research along this line is now in progress. Tolerance for antibiotics may serve as an effective marker gene (Taga et a1 1977) in such studies. Some other mutants also may be readily available for such studies. Cytological studies (Tanaka et a1 1979) are paving the way for the genetic studies. Direct contributions from such research is expected to elucidate the genetics of pathogenicity, and the gene-for-gene theory in the *Oryzae-Pyricularia* host-pathogen system can be developed on a firmer base.

Sexual recombination of genes for pathogenicity in the fungus may drastically alter the present understanding of race variability, especially if it occurs in nature. With sexual propagation, selection pressure on the fungus might be more effective. Furthermore, variation of the fungus through *heterocaryosis* (probably at a low frequency) and fusion of haploid nuclei, as observed by Yamasaki and Niizeki (1965), are other possibilities of pathogenic variation. Mutation remains the major cause of variability in pathogenicity (Kiyosawa 1976).

Sexual propagation or genetic recombination of pathogenicity of the fungus may not be directly related to variation of the fungus. The evidence for this can be seen in the relatively narrow range of race divergence through the International Rice Blast

Nursery (IRBN), where some types of rice are not frequently infected although pathogenic races exist, Some recent trials to monitor race distribution in Indonesia (Kobayashi et al [n.d.]) and Malaysia (Akama [n.d.]) indicated that a few races were infecting resistant varieties of exotic origin, including Tetep and Zenith, whereas they infected almost all native varieties.

These observations suggest that in a given area, the genetic diversity of blast races is rather limited and in balance or stabilized with existing genes controling host resistance. With prevailing native rices there should be prevailing native blast races, as was the situation in Japan before extensive breeding programs were developed with exotic blast-resistant rices such as Tetep or Zenith. If this is true, the basic strategy for blast resistance breeding would remain the same as that developed with the postulation of the absence of the perfect stage of the blast fungus.

Present understanding of genetics of blast resistance

A review of the progress in genetics of blast resistance should help in conceiving the bases for resistance breeding and provide blast researchers with a means to construct a race-identification system. Unfortunately, most of the present knowledge is available from a narrow area, Japan. The available knowledge also covers the genetic background of tropical rices, because a large number of tropical rices have been tested as possible donors for resistance in the past several decades.

STATUS OF BREEDING FOR BLAST RESISTANCE IN JAPAN

Huge resources have been allocated to the breeding of varieties resistant to rice blast, one of the most serious crop diseases in Japan. A number of resistance genes with a distinct reaction have been identified from indigenous cultivars and from introduced foreign varieties. After a half century's effort, however, it is generally understood that a newly introduced gene will provide effective control for only 3-4 commercial crop production seasons because of the eventual increase in population of pathogenic races. Hence, field resistance has aroused Japanese breeders' interests; it is effective against a given race in the absence of a race-specific resistance gene. Naturally the degree of resistance is not as clear as that of race-specific resistance, which is called true resistance and follows simple Mendelian inheritance. True resistance is considered primarily the complete rejection of lesion development, but occasionally production of a hypersensitive reaction, typified as nonsporulating brown spots, is included in this category.

True resistance is detected from the coexistence of genes for resistance in the rice plant and genes for nonpathogenicity in the fungus. Field resistance must be evaluated in the absence of any gene for true resistance to a given blast race. Therefore, no evaluation of blast resistance is possible without a system to monitor resistance genes and pathogenic races. A system to identify and designate existing race-specific genes and types of predominant races has been a focal point of much research on rice blast in Japan. The present system of differentiating races (Yamada 1979, Yamada et al 1976) has been developed into a useful tool in the breeding program and in making varietal recommendations.

Major genes for blast resistance

At present, 13 genes for blast resistance have been located in Japanese varieties From these, *Pi-k*, *Pi-k*^{m}, *Pi-k*^{p}, *Pi-k*^{h}, *Pi-z*^{t}, *Pi-b*, and *Pi-t* were introduced from Reishiko, Hokushi-taimei, Pusur, HR-22, TKM1. Bengawan, and Tjihaja, respectively. The genes *Pi-ta* and *Pi-ta*^{2} were transferred from a Philippine variety Tadukan. Therefore, varieties possessing these single genes may be found in the country from which the genes were isolated (Kiyosawa 1974).

A legitimate question that may arise in the review of the list of resistance genes is whether there would be a larger number of genes in the tropics. Most of the major genes that have been detected in Japan have been associated with races found in Japan. However, the following points should be considered:

- The 10 genes exotic to Japanese native rices have been identified after infusions of genes were made from a large number of foreign varieties used in a backcrossing program. Results from one such program suggest that relatively few genes are in effect in a large number of resistant varieties. In that program a gene, *Pi-z*^{t}, was introduced through an extensive backcross breeding program with resistant varieties TKM1, CO25, CO4, Lewuang Tawng 77-12-5, Chao leuang-11, Morak Sepilai, and Kontor (Nagai et al 1973).
- The number of loci for blast resistance genes seems rather limited. At present, 7 loci are known and some loci have several alleles (Kiyosawa 1974).
- Many resistance genes are common in rice varieties of different geographical origin. For instance, *Pi-a*, a predominant gene in Japanese native rices, is identified in Pusur (Bengal), Zenith (USA), CO25 (India), etc. (Kiyosawa 1974).

These findings may imply that a limited number of major genes exist and the present resistance genes can be used for developing genetics of blast resistance studies for wide areas. There also is considerable research on the genetics of blast resistance in the US, India, Korea, Taiwan, Philippines, and elsewhere but the studies are small and isolated from each other.

In identifying blast resistance genes, which are named in different regions with different races, there are several problems including sterility of *japonica-indica* crosses and long growth duration of tropical rices in temperate regions. Perhaps those races prevalent in the temperate zones would not effectively differentiate host resistance genes from tropical rices, and vice versa, as previously indicated (Kozaka et al 1970).

The restriction or prohibition by law of the exchange of fungus races reduces greatly the dependable means of identifying the genetic relationships among resistance gene sources from different origins. It appears necessary to implement some peparatory steps in gene identification. One way would be to compose a tentative set of differential varieties for each country in the tropics. Such tentative differentials would imply not only the preparation of a base for genetic studies, but also a needed step toward breeders' adequate use of diverse gene sources.

GENETICS OF FIELD RESISTANCE

It may be confusing to discuss field resistance, as there is controversy regarding its definition and its reliability as a means of controlling rice blast. However, major research on blast disease, which has increasingly been directed to the genetics of field resistance may be informative. Reviews by Ezuka (1972, 1979) and Kiyosawa (1979) are available. Researchers in Japan have almost unanimously concluded that there is, at least, a type of inheritance different from that by race-specific genes. This type of resistance, which may be polygenic or oligogenic, sometimes appears monogenic. The reaction is characterized by moderate resistance with additive genic effect.

Many known sources for field resistance maintain resistance to different races for several decades, at least within Japan. Particular interest is drawn to Japanese dryland varieties, which have survived severe blast infections with no indication of loss of resistance.

CONSTRUCTION OF AN EFFECTIVE DIFFERENTIATION SYSTEM FOR HOST RESISTANCE AND FUNGUS RACES

An effective differentiation system is urgently needed to:

- provide breeders with an essential means to diversify sources for breeding, and
- construct a sound base for genetic research on blast resistance.

It may be easy to propose an ideal system from a theoretical point of view, but actual construction of such system should be progressive.

A review of the international differentials

The present international differentials have been proposed after extensive collaborative testing of several sets of national differentials in many countries (Atkins et a1 1967). With the use of eight varieties of the international differentials, all possible races (2^8 = 256) are designated in a naming system (Ling and Ou 1969). Some researchers have relied on the system whose general applicability, however, has not been critically evaluated.

In the International Rice Blast Nursery (IRBN), there were five sets of differentials (USA, Japan, Taiwan, Philippines, and international). Recently only a part of three sets of differentials (US, Philippines, and international) has been included in the IRBN. Data for 1976 and 1977 revealed that the differentials do not effectively sort out dominant races, which instead are distinguished by various host reactions. In the Philippines, Kataktara DA 2 and Raminad Str. 3 behaved similarly, suggesting that they, Carreon, and Ram Tulasi have some closely related blast resistance genes. None of the components of the differentials seemed to represent *O. nivara* type and Sigadis type, which compose a large group of host resistance (Ikehashi 1979).

Thus, the drawbacks of the present differentials in IRBN can be summarized as:

- difficulty in their seed increase because of photoperiod sensitivity or extremely early flowering, and lack of resistance to major pests and diseases;
- lack of clear-cut response to some dominant races, which are discriminated by

present breeding lines; and
- irrelevance to the present prevailing genotypes of host resistance.

Developing differentials through the IRBN

Classification of host resistance into various types in the presence of diverse races to distinguish different genotypes should be a starting point toward the effective identification of races and host resistance. Collection and maintenance of representative fungus races should also be an indispensable part of such work.

From this point of view, the diversity of the races found in IRBN is questionable. A close look at the data cannot help differentiate among such entries as Tetep and Zenith, although there is evidence that the two occasionally differ in their reactions (Bandong 1965). Despite such limitations, examination of the reactions of many entries in the IRBN helps distinguish some types of host resistance; the results can be used to develop some tentative blast differentials. Such a preliminary set of *differentials* should be further tested with appropriate races through artificial inoculation.

A preliminary analysis of the IRBN data indicated that some varieties or breeding lines that show fairly uniform reactions within a group react differently in multisite testing (Ikehashi 1979).

IMPROVED FORMULATION OF IRBN

The specificity of reactions of various entries in the IRBN indicates the importance of selecting the components on the basis of pattern of resistance over many sites rather than on the basis of range of resistance. In other words, preservation of diverse types of resistance can be one of the objectives of the IRBN. Moreover, efforts toward it would make identification of types of resistance for a new entry possible.

Thus, the formulation of the IRBN may consist of two parts:

1. maintaining and refining the representative lines or varieties from each resistance type to develop tentative differentials, and
2. identifying the type of resistance for a new entry by the differentials.

This practice can be programmed with a computer system.

In practice it is not easy to develop a rigid differentiating system to identify the type of resistance of each IRBN entry to all races. One convenient solution is to leave a portion of the IRBN for entries that show specific reactions in a particular country. A regional center or testing program may add certain entries to reflect the regional specificity of the resistance type.

Because IRRI handles the primary formulation of the IRBN, there is need to test the nursery at more sites in the Philippines to facilitate an initial classification of resistant types. More information would be obtainable if the IRBN is supplemented by controlled tests with inoculation of specific races to differentiate some groups of resistance among which natural infection cannot readily discriminate.

SPECIFIC STRATEGIES FOR RICE BLAST CONTROL THROUGH HOST RESISTANCE

Resistance in rice to the blast disease can be genetically separated into two types —monogenic and polygenic. Pathologically, especially epidemiologically, these types have been referred to as vertical resistance and horizontal resistance. From the plant breeding standpoint, a genetic classification of resistance is much more practical than a pathological one. In general, monogenic resistance is race specific and results in the absence of symptoms of disease. Polygenic resistance is not race specific and results in reduced disease and higher yields than those of normal or susceptible rice genotypes. The screening techniques used in the breeding program for the two types are quite different. The genetics of the host-pathogen interaction must be identified as either monogenic or polygenic before the development of rice varieties resistant to blast can progress satisfactorily.

Polygenic resistance

The use of polygenically inherited resistance as a potential disease control method has been extensively investigated for many years. One of the first examples of its use was the introduction of the potato variety Magnum Bonum into Europe shortly after the late blight epidemics of the 1840s (Walker 1952, 1957). Polygenic resistance has been categorized with a number of terms, including horizontal resistance, general resistance, race nonspecific resistance, field resistance, tolerance, etc. Van der Plank (1963, 1968) termed this type of resistance as horizontal resistance and epidemiologically categorized it as being broad spectrum, race nonspecific, stable, and enduring. However, such resistance to blast in rice has been ineffective in epidemic conditions (Crill and Khush 1979: IRRI 1978, 1979).

In Japan, breeding for blast resistance has increasingly focused on field resistance (Ezuka 1972, 1979), which is polygenically controlled. Japanese rice farmers successfully grow varieties with field resistance to blast because most of the crop is grown in flooded paddies, where the conditions generally are unfavorable for blast development. Furthermore, when an epidemic is forecast, chemical control can be used to prevent significant losses. Field resistance to blast in rice is one of the few examples of the successful use of polygenic resistance.

Relying on polygenically controlled resistance as the sole means of averting an epidemic appears dangerous and foolhardy. Polygenically controlled resistance mechanisms are environment responsive and, when appropriate environmental conditions are present, an epidemic ensues. Thurston et a1 (1962) stated that general levels of horizontal resistance, compared with standard levels, do not change from year to year. Polygenic resistance in this sense is stable, but is inadequate in epidemic conditions. As early as 1952, Walker (1952) stated that potato varieties with polygenic resistance to late blight, even though such resistance was quite marked, required fungicide protection in a severe epidemic. If polygenic resistance to blast is to be effectively used for rice, fungicides should be used to avert significant losses in those seasons when environmental conditions are favorable for a rice blast epidemic.

Plant breeders and pathologists should remain aware of the dangers and limitations of polygenic resistance and realize that such resistance becomes ineffective in an epidemic. In flooded paddy rice in the tropics, polygenic resistance to blast should be adequate because environmental conditions are not conducive to epidemics. In flooded paddy rice in temperate regions, polygenic resistance should be used only when a chemical control program can be used in an epidemic. In dryland rice production, it rarely is adequate in preventing disease losses.

Monogenic resistance

Monogenic resistance to disease, first reported by Biffen (1905), has been effectively used by plant breeders to control numerous diseases in a variety of crops. It is relatively easy to work with in a screening program, and resistant plants are recognized by lack of symptoms. The primary problem with such resistance is that it has not been stable — new races of the pathogen capable of attacking the resistant variety usually develop. With relatively few exceptions, the pathogen population has evolved new pathogenic forms capable of attacking newly introduced resistant varieties. This has been quite common for blast.

The underlying explanation for the evolution of new blast races is the gene-for-gene concept, which implies that for every gene for resistance to blast in rice there is a corresponding gene for pathogenicity in *P. oryzae.* This gene-for-gene situation has occurred often enough that particular strategies for the use of monogenic resistance in preventing the evolution and spread of new pathogenic races have been developed. Certain of these strategies may be used in rice blast control using monogenic resistance.

Multiline varieties

A multiline variety is a mechanical mixture of two or more component varieties, one differing from the other by a single monogene for resistance. The component lines ideally are phenotypically indistinguishable from each other except in monogenic disease resistance. Commercially acceptable multiline varieties have been developed for rust control in oats and wheat. The first commercially used multiline variety was Miramar 63 wheat, which was composed of equal parts of 10 component lines with different monogenes for resistance to stripe and stem rust (Browning and Frey 1969).

The basic strategy of multiline varieties is to confront the pathogen with as wide an array of resistance monogenes as possible and thereby reduce the potential for epidemic disease development. A basic assumption of the theory of multiline varieties is that in an epidemic, a collection of resistant monogenes will behave in the same way as polygenically controlled or horizontal resistance. This assumption appears to be valid and the basis of successful disease control.

After a multiline variety is commercially established, the breeder and pathologist have the option to add and remove component lines based upon race surveys of the pathogen. Browning and Frey (1969) considered this a primary advantage of multiline varieties. Other advantages they describe for multiline varieties include:

- use of linked monogenes and monogenes for resistance that are present at the same locus;
- indefinite extension of the life of resistance monogenes;
- eventual reduction in the size of the breeding program; and
- stabilization of varieties.

One final advantage they considered is that a plant breeding center could distribute varieties on a global scale without the risk of homogenizing the pathogen population on a similar scale. Browning and Frey (1969) point out that multiline varieties have been criticized as expensive, agronomically conservative, and a breeding ground for new races, including a super race that could attack all components of the multiline.

The development of a multiline rice variety for blast control is not likely to occur soon because the knowledge about genetics of resistance and pathogenicity is extremely limited. To successfully synthesize a multiline rice variety, one must understand the genetics of resistance and be able to manipulate monogenes for resistance to specific races of blast in the breeding program. As a more complete understanding of rice blast genetics is developed, breeders at centers for rice variety development should explore the value of multilines on the basis of successes and failures in other crops.

Pyramiding of monogenes

Pyramiding of monogenes for resistance to specific races of a pathogen is an old plant breeding practice that has been used in most major food crops. The strategy is quite simple. When a pathogenic race occurs, a resistance monogene is sought and, when found, is incorporated into an acceptable variety. The variety is grown until another pathogenic race develops, and a search is made to locate a resistance monogene. When found, the monogene is then incorporated into the same acceptable variety. This process may be repeated many times and result in the incorporation of several race-specific monogenes for resistance (pyramided) into a single variety. This technique was used by American wheat breeders to produce stem rust-resistant varieties. Such varieties were used quite successfully for a few years after their release until a rust race that could attack the new variety evolved. An epidemic occurred and the wheat breeders released another new variety resistant to the new race. Agronomically, such varieties were highly successful in the US and losses to stem rust were negligible to nonexistent except in a few epidemic years.

Until Craigie's discovery, in 1931, of sexual reproduction in the rust fungus (Craigie 1931), the hopes for gene pyramiding as a control strategy were high because pathogen populations were assumed to be basically static and unchanging. As the concept of variation in the rusts and other pathogens became better understood, it became obvious that pyramiding of resistance genes from different donor varieties into a single variety would not control plant diseases, as earlier anticipated.

Another major problem that soon became obvious was that several resistance genes might be at the same locus. Japanese geneticists have shown that certain genes controlling resistance to blast are multiple allelic (Kiyosawa 1967, 1974, 1976, 1979).

When multiple alleles at the same locus control resistance to different pathogenic races, it is physically impossible to combine them in a single pure-line or hybrid variety with present technology. With the rapid advances being made with tissue culture and DNA recombination in vitro, new technology may shortly be available to overcome this problem.

Nelson (1973, 1978, 1979) has evaluated the concept of gene pyramiding in detail and offers the well-grounded speculation that plant breeders should continue to pyramid *all* genes that control resistance to a specific pathogen regardless of whether they are *major* or *minor.*

Even though plant pathologists have thoroughly criticized the strategy of gene pyramiding, they have offered very few workable alternatives to the plant breeder, particularly the rice breeder. Successful plant breeders characteristically use whatever disease resistance is available to them in a workable form and are little concerned with criticism from plant pathologists. Rice breeders, in general, will probably continue to pyramid genes for resistance to blast because plant pathologists have not offered workable alternatives.

Gene rotation

Walker (1959) aptly summed up the role and value of plant pathologists in variety development programs when he stated, "If pathology and pathologists are to retain their legitimate place in the development of resistant varieties they must continue to ferret out the basic facts upon which new techniques and procedures may be fashioned."

This statement implies that plant pathologists must provide plant breeders with workable and feasible control strategies if they are to be involved in the variety development process. Many of the proposals put forth by plant pathologists for the supposed use of plant breeders fall upon deaf ears because they are not only impractical but are couched in an epidemiological jargon that cannot be translated into the breeders' *modus operandi.* It is well and good to criticize plant breeders' use of host resistance genes in disease control, but such criticism should be accompanied by alternative strategies that plant breeders can evaluate and then adopt or reject. Only in this way will plant pathologists retain their legitimate place in the development of resistant varieties.

The concept of rotating varieties with different genes for disease resistance is not new and has been used by farmers of different crops since ancient times. Before recognition of varieties within a crop, farmers routinely rotated or substituted different types of crops in their farming systems to control disease. As crop improvement evolved and varieties within crops were developed, farmers continued the practice. Filipino rice farmers today routinely rotate varieties as a disease control measure solely because they observe that more disease develops when the same variety is grown successively in the field. It is interesting that farmers who practice variety rotation do not understand the concepts of disease or pathogen. They have adopted the practice wholly on the basis of their own and their forefathers' observations that it results in better yields.

Kiyosawa in 1975 (Kiyosawa 1979) was apparently the first rice scientist to evaluate the concept of gene rotation for blast control. The concept of rotation of resistance monogenes based upon race prediction was first hinted at by Crill et al (1974) and formally defined by Crill (1977) and Crill and Khush (1979). The strategy of gene rotation is predicated upon the concept that races of a pathogen indigenous to a cropping area are a result of the varieties grown in the area (Crill 1977). Furthermore, the evolution of pathogen races is directly controlled by the genes present in the varieties in an area. As such, plant breeders control the evolution of pathogens through the development of varieties (Browning and Frey 1969, Crill 1977, Johnson 1961, Nelson 1979).

The strategy of using gene rotation based on race prediction is neither passive nor negative as are other gene-use strategies but instead is aggressive and positive with pathogen eradication as the ultimate goal. The eradication of rice blast is unlikely but not necessarily impossible. In a discussion on coevolution of crops and pathogens, Buddenhagen (1977) asked the question, "With breeder-pathologists who are clever enough conceptually, why not have extinction (of the pathogen) as a goal?" He then pointed out that the pathogens causing the gumming disease and downy mildew of sugar cane in Australia have been eradicated (Buddenhagen 1977). The pathogen causing Nailhead spot of tomato *(Alternaria tomato)* apparently has been eradicated on a global basis (Crill 1977). Likewise the pathogens causing cabbage yellows and milo disease have been brought under strict control with the use of monogenic resistance, although neither pathogen is extinct (Crill 1977). With such outstanding successes from the past, why should plant breeders, and especially plant pathologists, adopt negative and passive methods of using host resistance to control rice blast on the assumption that the blast fungus is capable of thwarting their every move? Why not accept the challenge of Buddenhagen to be conceptually clever, and that of Walker to ferret out basic facts, and from these, fashion new techniques and procedures for disease control?

The concept of gene rotation for rice blast control using race prediction has been put into effect in Korea through a cooperative effort involving Korean rice breeders and pathologists with the sanction of the administration, the director-general of the Office of Rural Development, and the Minister of Agriculture. The key to the success of this program is the detection of the new race or races, which presumably will arise when monogenically resistant varieties are established. It is adequately documented that "no new variety has been developed and used with resistance to a race before that race has caused a problem" (Nelson 1979).

Resistant varieties grown in Korea will be evaluated throughout the world through the International Rice Testing Program of IRRI, and the race or races of blast that can attack the resistant variety will be identified. From this information, a monogene or monogenes conferring resistance to the race (which is predicted to evolve in Korea) will be used in the breeding program to synthesize a new resistant variety. Seed of the new variety should be available before the new race evolves and causes an epidemic in Korea. The distribution of blast races is monitored throughout Korea, where more than 100 forecasting stations provide information on the epide-

miology of and race changes in blast.

The program of rice blast control in Korea is a direct answer of progressive Korean scientists, administrators, and politicians to the challenges issued by Walker and Buddenhagen. Even if the ultimate goal of making the blast pathogen extinct is not achieved, the goal of having a stable rice production with little or no loss to rice blast is attainable. Furthermore the goal can be attained with the present breeding, testing, survey, and forecasting methods. Only very minor changes in the present rice variety development program will be required.

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WEED CONTROL IN DRY-SEEDED RICE — PROBLEMS, PRESENT STATUS, FUTURE RESEARCH DIRECTIONS

K. MOODY and S. K. MUKHOPADHYAY

We refer to dry-seeded rice as ungerminated rice seeded in unsaturated wetland fields that have been prepared dry and will subsequently become flooded. It is difficult to delineate the time of flooding but its cumulative duration is long enough to exclude the growing of major dryland crops in most seasons when inundation occurs (Moormann and van Breemen 1978). This type of rice culture has been practiced in rainfed areas of northeast India, Bangladesh, Burma, and Thailand for centuries.

In dry-seeded rice, weed seeds and crop seeds germinate and the weeds, being more vigorous, almost smother the crop. A heavy infestation of weeds, mostly grasses, is characteristic of dry-seeded rice. Mukhopadhyay et a1 (1972) indicated that grasses made up 85-89% of the total weed population and 90-96% of the total dry matter (Table 1). *Echinochloa colona* (L.) Link, the predominant grass species, reduced rice yields by 74-98%.

Table 1. Weeds growing in association with dry-seeded rice, West Bengal, India (Mukhopadhyay et al 1972).

Weed class	Species (no.)		Weed wt (g/m^2)	
	1968	1969	1968	1969
Grasses	7	6	55.3	62.8
Broadleaf weeds	10	13	2.5	5.5
Sedges	2	2	7.0	2.0
Total	19	21	64.8	70.3

In some instances, weed competition in dry-seeded rice is so intense that failure to control weeds results in no rice yield. Some past attempts to introduce dry-seeded rice have failed (Prabowo 1977, Gomez and Carandang 1977) because of the lack of an appropriate weed control technology (Moody and Mian 1979). The development of a suitable weed control technology is essential to a successful dry-seeded rice crop.

Agronomist, IRRI; professor, College of Agriculture, Visva-Bharati University, West Bengal, India.

REDUCING WEED PROBLEMS IN DRY-SEEDED RICE

Weeds in dry-seeded rice should be suppressed during the early stages of crop growth because yield reduction that results from weed competition at that time is most severe. Maintaining the crop weed free during the first 6 weeks of crop growth should be adequate (Moody 1981).

Land preparation

A common practice in rainfed rice-growing areas is to leave the field fallow during the dry season after rice harvest. As a result, the weeds that grow during the dry season worsen the weed problems encountered in the dry-seeded rice crop.

In some places in Sri Lanka and India, the land is prepared during the dry season. The rice seeds are broadcast on dry soil and covered. They remain dormant in the soil until the advent of rain. The same practices are observed in Iloilo Province, Philippines (IRRI 1979).

Plowing immediately after the previous rice crop is harvested may have advantages over plowing at the beginning of the next rainy season. Plowing after the rice crop, however, is possible only if the vegetative cycle of the rice crop is shorter than the duration of the rainy season and the soil after harvest is still moist for plowing. Repeated tillage during the fallow period prevents weeds from seeding and exposes vegetative propagules to drying, and significantly depletes weed seed reserves in the soil (Moody and Mian 1979).

In the People's Republic of China, intense land preparation by rototilling and maintaining the fields as a clean fallow during the dry season control weeds, the major problem in dry-seeded rice (Zandstra et al 1977). Additional benefits are soil-moisture conservation and earlier planting at the start of the rains.

Partohardjono and Harahap (1979) reported that in Indonesia tillage is done in the dry season to control weeds. In areas where drought-tolerant upland crops are grown during the dry season, weed infestations are reduced. They note, however, that weeds cannot be totally destroyed by dry soil preparation. In Sri Lanka, the growing of a crop during the dry season or maintaining the land weed-free by herbicides caused no reduction in weed weight in the following rice crop (Siriwardana, unpubl.).

Other research work has indicated that maintaining a weed-free fallow during the dry season significantly reduced the number of perennial weeds (Moody and Mian 1979; IRRI 1979, 1980) and had no effect (IRRI 1980) or significantly increased (Moody and Mian 1979, IRRI 1979) the number of annual grasses.

Crafts (1975) appears extremely pessimistic about the successful use of tillage during the dry season for weed control while Moody (1981) states that the use of land preparation during the dry season in reducing weed problems in the following dry-seeded rice crop seems limited. However, it may take several years for the advantages of tillage during the dry season to be realized in fields heavily infested with weeds. For example, Biswas and Saraswat (1977) reported that the weed density was comparatively less in the second year that an *aus* crop had been planted.

Harwood (1979) recommends dry seeding only in fields where previous weed control has been good.

Further attention should be given to weed control during the fallow period to further elucidate its effect on weed problems in subsequent crops.

The stale-seedbed technique

It may be possible to reduce weeds in the dry-seeded rice crop by the stale-wedbed technique, which involves the removal of successive weed flushes before planting. Chemical, mechanical, or manual methods may be used to remove the weeds. Chemicals have the advantage of not bringing more weed seed to the soil surface where conditions favor germination. If mechanical or manual methods are used to destroy the weeds, the soil disturbance should be as shallow as possible. The herbicides should be applied or the cultivation should be done when most of the weed seeds in the surface soil have germinated and are in the 2- to 5-leaf stage.

The dry-seeded rice crop is sown with a minimum of soil disturbance either before or after the weeds have been killed with herbicide or controlled by cultivation. Theoretically, less weeds should grow in association with the rice because most of those in the favorable zone for germination have been killed. Where light rains occur for an extended period before the onset of the monsoons, or if irrigation is available, it may be possible to kill several flushes of weed growth before planting.

The stale-seedbed method has been used successfully for dry-seeded rice establishment in India (Moody and Mian 1979), in Sri Lanka (Moody and Mian 1979), and in Pangasinan Province, Philippines (Moody 1980, Table 2). Results at IRRI (Moody and Mian 1979), however, have been inconclusive. Moody observed, in Pangasinan Province that a farmer who plowed and harrowed his field 3 times at 1- to 2-week intervals had few weeds in the subsequent dry-seeded rice crop.

The stale-seedbed technique has no advantage if planting is delayed after the start of the rains. Delay in planting results in more weed control difficulties (Moody 1977) and may mean that manual or mechanical weed control techniques cannot be used because fields become too wet soon after crop establishment.

Further research is needed, though, to determine if the stale-seedbed technique is advantageous for weed suppression in dry-seeded rice.

Table 2. Effect of method of land preparation and weeding regimes on the fresh weight of *Echinochloa colona,* 6 weeks after crop emergence, Manaoag, Pangasinan, 1979 wet season.

Weed control method	Fresh wt (g/m^2)	
	Conventional land preparation	Stale seedbed
Butachlor (2 kg a.i./ha) fb hand weeding	80 b	44 b
Butachlor (2 kg a.i./ha)	1172 a	228 a
Unweeded	1120 a	244 a

Zero tillage

Wijewardene (IITA, pers. comm.) reported an excellent crop stand and few weeds in rice that had been directdrilled in a field where the weeds had been killed with a nonselective, nonresidual herbicide before planting. Moody, however, failed to establish a rice crop and to control weeds using the same technique in trials in Nigeria and the Philippines.

The success of a zero-tillage seeding technique depends on availability of suitable herbicides to control the weeds. The likelihood of success is greatly decreased if perennial weeds are present.

When the soil surface remains undisturbed (as it does in zero tillage) and it becomes compacted by rainfall, conditions become less favorable for weed seed germination (Bibbey 1935). In addition, when cultivation is eliminated, the greater part of the original weed-seed reserve in the soil can be disregarded (Bibbey 1935). With zero tillage, different weed problems occur. The weed spectrum is changed compared with conventional tillage but the number or weight of weeds is not necessarily reduced.

The possibility of establishing dry-seeded rice through reduced tillage techniques should be thoroughly studied.

Time of planting

Delayed planting of dry-seeded rice can result in more weeds (Moody and Mian 1979). Planting should therefore be done as soon as possible after the rains start. The possibility of planting before the start of the rainy season should be investigated more thoroughly. This practice may enable farmers to control weeds by manual or mechanical means before the fields become too wet for cultivation.

Jackson (IRRI, Thailand, pers. comm.) reports that in Northeast Thailand, farmers delay dry-seeding of rice until mid-July. If they seed earlier, they have too many problems with weeds.

Research is needed to ascertain the effect of time of planting on weed growth and weed control practices.

Nitrogen application

Nitrogen application early in the growth of the crop may intensify the weed problem. Weed growth is stimulated if nitrogen is incorporated into the soil (Moody 1977).

Weeds also affect the response to nitrogen fertilizer. If weeds are severe, they may use a considerable portion of the nitrogen and the amounts of nitrogen required to obtain maximum rice yields may be higher (Smith 1960, Hoopper 1981). In Bangladesh, the addition of fertilizer to dry-seeded rice that received no weed control resulted in an insignificant yield increase. Weed control without fertilizer addition, however, resulted in a significant increase in yield. Yield further increased significantly when fertilizer and weed control were applied together (Table 3, Islam and Rahman, unpublished).

Ahmed (1979) reported that weed counts and weights in dry-seeded rice increased

Table 3. Relative contributions of fertilizer, weed and insect control, and their combinations on the grain yield of dry-seeded rice, 1977 *aus* season (Islam and Rahman, unpubl.).

Input	Yield[a] (t/ha)
Fertilizer + insect control + weed control	4.2 a
Fertilizer + weed control	3.9 a
Weed control	2.9 b
Weed control + insect control	2.8 b
Fertilizer + insect control	2.0 bc
Fertilizer	1.9 c
Insect control	1.2 c
Untreated check	1.2 c

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

linearly as the rate of basal application of nitrogen increased from 0 to 40 kg/ha. The first weeding was easier and faster in the plots that received no basal nitrogen than in those that received 40 kg N/ha as a basal application because the weeds, primarily grasses, were smaller and easier to distinguish from the rice.

Polthanee (1979) observed in the wet season that there was no significant difference between application methods (broadcast, band placed, or plowed-down broadcast) but significantly greater weed weight occurred in the plots treated with 90 kg N/ha than in those that received 0, 30, or 60 kg N/ha. In Indonesia, Saefuddin et al (1978) reported that in both weedy and weed-free conditions, root-zone placement of 40 kg N/ha was superior to surface banding. In the weed-free plots, surface banding of 80 kg N/ha and root-zone placement of 40 kg N/ha gave equal yields. In the weedy plots, root-zone placement was superior.

Nitrogen application should be timed to prevent weed proliferation and yet obtain maximum benefit from the fertilizer applied (Moody 1977). With dry-seeded rice, the basal application of fertilizer should be delayed until weeds are removed (Evatt 1965, Saefuddin et al 1978, Moody and Mian 1979). That is the practice of farmers in parts of Thailand and India.

Further trials are needed to determine the effect of time, method, and amount of nitrogen application on weed growth; and the most appropriate time of nitrogen application that would bring about the greatest efficiency of nitrogen use, optimum yields, and, hopefully, least weed growth.

Water

Moody and Mian (1979) noted that weeds in dry-seeded rice are controlled better if flooding occurs soon after stand establishment. Harwood (1979) recommended that dry-seeded rice be sown only in fields that can be flooded within 30 days after planting.

Heavy weed infestation in the early stages of crop growth cannot be controlled by submergence later on. Ahmed (1979) observed that the ponding potential of the field had no effect on weed growth. Civico and Moody (1979) reported that greater water

depths were needed to suppress weed growth when flooding was delayed after weed emergence.

If weeds can be controlled, early flooding would be advantageous. If not, early flooding has little advantage with respect to weed suppression. Because rainfed fields are flooded at different times every year, there appears little point in placing too much emphasis on early flooding as a means of weed control. Research on this aspect is probably not warranted at present.

Cultivar grown

With the introduction of the short, modern cultivars, the need for adequate weed control for all types of rice culture, particularly dry-seeded rice, has assumed greater importance.

Harwood (1979) states that there is an urgent need for new cultivars that can compete successfully with weeds. However, for rice, there is a strong negative correlation between competitive ability and yield. Therefore, only limited success can be expected in exploiting cultivar differences for improved weed control (Moody 1979). However, if two rice cultivars are equal in all other attributes, priority should be given to the better competitor against weeds (Moody 1981).

Cultivars that emerge rapidly, have high seedling vigor, and rapidly develop a canopy would be expected to compete better against weeds than cultivars lacking these attributes.

The competitive effect of cultivars against weeds should be examined at a low level of weeding or weed competition. Differences between cultivars may exist such that one cultivar needs less weed control than another to produce maximum yields.

Plant spacing

For dry-seeded rice in nonweeded fields, increasing seeding rates or decreasing row spacing has little influence on weed suppression (Table 4) probably because of the intense weed pressures (Moody 1981). However, closer plant spacing combined with timely weed control may result in less weed control inputs than wider plant spacing.

Research is needed to verify this finding.

Mechanical weed control

Broadcasting is the common practice of seeding for dry-seeded rice. But it makes distinguishing between rice and grass weeds difficult and causes immense trouble in weeding. Farmers in some parts of Asia use mechanical weed-control methods. In Bangladesh and West Bengal, India, it is a common practice for farmers to pass a spike-toothed harrow through their broadcast-seeded fields 5-15 days after crop emergence.

In parts of India (Orissa, Madhya Pradesh, and West Bengal) and Bangladesh, the farmers control weeds by plowing and cross-plowing their fields after flooding when the rice is 30-40 days old. This practice was described in the early 1900s by Clouston (1908) and Graham (191 3). It is known as *bushening* in Orissa, *beasi* in Madhya Pradesh, and *achra* in Bangladesh.

Table 4. Effect of different rates of seeding on weed weight and yield of different rice cultivars grown under dry-seeded, rainfed bunded conditions (Siriwardana, unpubl.).

Cultivar	Seeding rate (kg/ha)	Fresh weed wt (g/m^2)	Yield (kg/ha)
62-355	50	7248	312
62-355	100	5148	417
62-355	150	5000	225
62-355	200	2500	558
62-355	400	2948	242
Bg 34-8	50	8748	92
Bg 34-8	100	7248	83
Bg 34-8	150	8200	103
Bg 34-8	200	7600	91
Bg 34-8	400	8148	833
–	–	8848	–
62-355	100[a]	0	2967

[a] Propanil + MCPA applied for weed control.

Even though some farmers practice mechanical cultivation when they broadcast-seed their crops, sowing in rows is recommended for the practice to be completely successful. However, suitable equipment has to be developed before row seeding can gain widespread acceptance (Moody and Mian 1979). A major problem in Bangladesh is the lack of suitable equipment for interrow cultivation (FAO 1978).

Interrow cultivation works extremely well under ideal climatic and soil conditions but heavy rains soon after planting prevent the use of mechanical weed control techniques in heavy, sticky clay soils. Even if a farmer cultivates his fields, the wet soil reduces the effectiveness of cultivation. Earlier planting increases the farmers' chances of controlling weeds by interrow cultivation before the fields become too wet.

Participants in a meeting on research and development in rainfed crop production in South and Southeast Asia recommended that research for weed control focus on tillage practices such as interrow cultivation and other cultural practices. Such research should be directed toward modifying the native implements already in use before new implements are designed (FAO 1978).

Further research is needed to determine if interrow cultivation can be used successfully in dry-seeded rice and if equipment that can work under a wide range of soil conditions needs to be developed. The possibility of using interrow cultivation in combination with other weed control practices such as herbicides and hand weeding should be explored more fully.

Manual weeding

Hand and manual weeding are the most common methods of removing weeds from dry-seeded rice fields in South and Southeast Asia. These practices have many drawbacks:

- they are slow and laborious;

- complete removal of weeds is difficult;
- weeds regenerate from vegetative propagules left in the field and quickly reappear from weed seeds;
- labor is not available for timely weeding;
- labor is costly in labor-scarce areas;
- they are costly because frequent hand weedings are needed and the amount of labor required for these weedings in dry-seeded rice is huge;
- they are difficult to perform during unfavorable weather conditions;
- costs increase if weeding is delayed; and
- crop injury is possible.

Because of the huge amount of labor involved in hand weeding dry-seeded rice, alternative methods of weed control must be sought. Hand weeding should be used only in conjunction with other methods of weed control that substantially reduce the labor requirement.

Improvement of the hand tools now used by the farmer should be considered. Hammerton (1972) noted that improved hand tools, particularly Lighter hoes, would reduce the effort needed and increase timeliness of weed control.

Herbicides

Labor for hand weeding in dry-seeded rice is a major component of the costs of production. Herbicides are a logical alternative to hand weeding. Higher yields may also result from herbicides that provide more timely weed control or better weed control. Even without yield increases, costs of production of dry-seeded rice can be lowered through use of herbicides (Estorninos et al 1981).

Herbicide combinations are generally superior to single-herbicide treatments for weed control in dry-seeded rice (Moody 1981). When a herbicide is incorporated before planting, it is less subject to weather uncertainties and weed control is more consistent. Preemergence herbicides, on the other hand, are dependent upon moisture for activation. Their application to a dry seedbed without follow-up rain can result in complete loss of effectiveness through deactivation and volatilization.

Results with herbicides in dry-seeded rice have been inconsistent from site to site (Table 5) and from year to year at the same site. The inconsistency could be accounted for by varying weed species, their population, and soil and climatic conditions. Flexibility in use to suit conditions and maximize efficiency is critical to the acceptance of herbicides for dry-seeded rice culture (Moody 1981).

The choice of a residual herbicide has an important bearing on the depth of seeding. Dry-seeded rice should have a seeding depth that will result in optimum emergence and stand establishment and yet give maximum protection against injury from preemergence or soil-incorporated herbicides that may be leached downward by heavy rain after planting. Herbicides are not widely used in dry-seeded rice because of such factors as lack of reliability, phytotoxicity, unavailability of suitable herbicides, and insufficient data on the economics of chemical weed control. Parker (1968) notes that there is enormous scope for a relatively inexpensive herbicide in dry-seeded rice.

Table 5. Grain yield of dry-seeded rice as affected by a combination of preemergence and postemergence herbicides.[a] Iloilo, 1978 wet season.

Treatment[b]	Herbicide rate (kg a.i.[c] /ha)	Yield (t/ha)			
		Site 1	Site 2	Site 3	Site 4
Butachlor + propanil post	2.0 + 2.0	5.2 a	5.8 ab	2 4 abc	5.4 a
Weeded twice (2 and 5 WAE)	-	5.3 a	4.7 b	2.7 ab	5.0 a
Butachlor PE fb propanil post	2.0 fb 2.0	4.6 a	6.2 a	1.6 bcd	5.1 a
Butralin PE fb propanil post	2.0 fb 2.0	1.4 b	4.8 b	3.3 a	4.4 a
Butralin + propanil post	2.0 + 2.0	0.6 b	4.9 b	2.9 a	5.2 a
Propanil post	3.0	0.2 b	5.5 ab	2.5 ab	4.1 a
Propanil fb propanil[d]	2.0 fb 2.0	0.5 b	5.1 ab	1.1 d	4.4 a
Untreated check	-	0.3 b	0.5 c	1.2 cd	4.3 a

[a] In a column, means followed by a common letter are not significantly different at the 5% level. [b] + = applied simultaneously; post = postemergence at 2- to 3-leaf stage of grasses; WAE = weeks after emergence; PE = preemergence; fb = followed by. [c] Active ingredient. [d] Applied 10 and 20 days after crop emergence.

Herbicides should, however, be combined with other weed control practices such as hand weeding (Table 6). When used alone, herbicides may fail to control a group of weeds or a weed species or their control of the major weeds may allow the introduction of weeds that were previously not a problem.

Further research is needed to solve problems and to find suitable herbicides for use in dry-seeded rice. Herbicides should play a major role in controlling weeds in this type of rice culture.

FUTURE RESEARCH NEEDS

Research should aim at preventing loss of yield to weeds in dry-seeded rice and at controlling weeds by the most economic and feasible method. These objectives can be achieved through a better understanding of the biology of different weeds that

Table 6. Effect of various weed control practices on the yield of Saket-4 rice grown in dry-seeded, irrigated conditions (Rathi and Tewari 1979).

Treatment	Yield (t/ha)
Weeded three times	4.6
Butachlor + hand weeding	3.9
Nitrofen + hand weeding	3.8
Propanil + MCPA	3.1
Pendimethalin + hand weeding	2.8
Nitrofen	2.7
Butachlor	2.2
Pendimethalin	0.9
Unweeded	0.2

infest dry-seeded rice fields in South and Southeast Asia and the conditions that favor the growth of a specific weed or population of weeds. The best ways of controlling these weeds must be known and special emphasis should be placed on the control of perennial weeds such as *Cyperus rotundus* L.

The following questions, which were raised in an International Plant Protection Center publication (IPPC 1979), need answers.

- What levels of agricultural technology should be introduced for weed control, given the prevailing economic, social, and political restraints?
- What is the interrelationship of weed control technology and other advanced technology inputs and what priorities emerge as a result?
- How do various weed-control systems economically and socially affect the small farmer, his family, the associated labor pool, and the community?

SUMMARY

The status of weed control in dry-seeded rice (*Oryzae sativa* L.) is reviewed. Possible ways of overcoming the intense weed problems that occur in such a system of growing rice are analyzed and future research directions are suggested.

The best approach to control weeds would probably be one that combines cultural, chemical, and manual methods.

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RICE IMPROVEMENT THROUGH CELL AND TISSUE CULTURE

M. C. RUSH and SHAO QI-QUAN

The potential for plant improvement through the culture of plant cells has been the subject of recent reviews (Scowcroft 1977a, 1978; Melchers 1977; Nitsch 1978). The culture of cells in artificial media in a controlled environment has been termed *cell culture* or *tissue culture.* By culturing cells from somatic or reproductive tissues, it is possible to extend to plant breeding and crop improvement the techniques used in microbial genetics (Bottino 1975). Mutations and changes in ploidy can be induced in single cells by chemicals or radiation (Heinz and Mee 1970, Sung 1976, Skirvin 1978). The environment of the treated cells can be so managed that desirable mutations can be selected through the survival of recipient cells, the culture of those cells into callus tissue, and from the callus the generation of plants with the desired characteristics (Carlson 1970, 1973; Maliga et a1 1973a,b; Green and Philips 1974; Widholm 1976; Chaleff and Parsons 1978; Bourgin 1978). If haploid cells developed from pollen are used, recessive characters are immediately visible and fixed in the resulting progeny. Plants produced through tissue culture often have natural changes in ploidy or mutation (Skirvin 1978). These changes may be exploited as new sources of variation and used in conventional breeding programs.

Cultured cells can be grown in suspension culture and then exposed, either directly or by being plated on solid media, to deleterious substances such as fungal or bacterial toxins (Bajaj and Saettler 1970, Pelcher et a1 1975, Gengenbach et a1 1977), herbicides (Chaleff and Parsons 1978), or salt (Nabors et a1 1975, Dix and Street 1975) to select for variant cells with resistance. When disease resistance or other constraints are mediated by metabolic activities at the cellular level, resistance may be expressed by cultured cells or tissues. In certain host-pathogen interactions, plant tissues in culture directly exposed to the pathogen will show a resistant reaction (Ingram and Robertson 1965; Ingram 1967; Helgeson et a1 1972, 1976).

When pollen from F_1 or F_2 plants from conventional crosses is cultured, homozygosity, after diploidization, is normally obtained in one step with no further segregation (Guha and Maheshwari 1964, Reinert and Bajaj 1977). Where diploidization does not take place naturally, haploid plants produced through anther or

Professor, Department of Plant Pathology, Louisiana State University, Baton Rouge, LA, USA; and deputy director, Institute of Genetics, Academia Sinica, Beijing, People's Republic of China.

ovary culture can be diploidized by treating anthers, callus, or developing plantlets with colchicine. The development of haploids through tissue culture, its significance for conventional breeding, and techniques were recently reviewed by Reinert and Bajaj (1977).

Under certain conditions the heterogeneity still existing in so-called pure-line varieties or breeding lines may be undesirable. Heterogeneity for previously unselected characters may cause considerable experimental error, as in the selection of races of pathogens or insect biotypes using differential varieties, or in physiology studies. Heterogeneity in varieties being screened for resistance to herbicides has caused significant error (W. Ruscoe, IRRI, pers. comm.). In a recent study of the ability of rice varieties and lines to serve as restorers and maintainers for cytoplasmic male sterile lines, it was observed that several breeding lines and the variety IR34 were mixtures of maintainer and restorer genotypes (S. S. Virmani, IRRI, pers. comm.). Varieties or lines used for these or similar purposes can be made absolutely homozygous, barring mutations, through the culture of gametes (pollen). Recent work on the production of haploid plants directly from culture of isolated pollen microspores promises to increase the efficiency of plant production from pollen (Nitsch 1977, Sunderland and Roberts 1977).

The technique of protoplast fusion was developed to make parasexual crosses between species where hybridization through conventional methods has been difficult, and to incorporate foreign nucleic acid or organelles into plant cells (Cocking 1960). The techniques were improved (Power et al 1970, Nagata and Takebe 1971) to the point that viable interspecific hybrids of *Nicotiana* spp. could be developed (Carlson et al 1972). The subject of protoplast production, fusion, and development of plants has been extensively reviewed (Cocking 1972, Kao and Michayluk 1974, Bajaj 1974, Bhojwani et al 1977, Kao 1978, Scott et al 1978). Several recently developed techniques have improved the fusion rate of protoplasts (Wallin et al 1974, Kameya 1979).

Recently, nucleic acid, organelles containing nucleic acid, or whole cells of microorganisms have been directly transferred to protoplasts with the concomitant incorporation of genetic control to produce enzymes and other compounds not previously produced by the cultivar or species (Davey and Cocking 1972, Bonnett and Eriksson 1974, Burgoon and Bottino 1976, Bonnett 1976, Landgren and Bonnett 1979, Niu et al 1980). The development of bacterial plasmids as deoxyribonucleic acid (DNA) vectors for transferring genetic information to plant cells has created possibilities for the genetic engineering first postulated in the 1960s and studied in the 1970s (Cohen 1976, Drummond et al 1977, Langridge 1978). These techniques are now being applied to crop improvement. The applied use of cell and tissue culture techniques in rice improvement will probably become commonplace in the 1980s.

RICE CELL AND TISSUE CULTURE

The term *rice tissue culture* (RTC) will be used to denote any artificial culture of somatic or sexual cells (gametes) of rice. Included will be the culture of somatic cells

in liquid (suspension culture) or solid media, ovary culture, and anther or pollen culture. The term *tissue culture* implies the growth or generation of tissues (organized or unorganized), organs, and possibly whole plants from cultured cells.

The early research involving the culturing of rice organs, tissues, or cells was by Japanese scientists. Ameniya et al (1956), Nakajima and Morishima (1958), and Bouharmount (1961) cultured immature rice embryos in vitro. Other attempts were made to culture rice organs in simple media. During the 1960s intensive attempts were made to culture cells from somatic tissues on more complex media. Furuhashi and Yatazawa (1964) and Maeda (1965a,b) studied the formation of rice callus from cultured seedlings and nodes. They succeeded in producing callus, which they could maintain indefinitely in culture. Guha and Maheshwari (1964), using *Datura,* were the first to produce plants through anther culture (AC). After them, Niizeki and Oono (1968), closely followed by Nishi and Mitsuoka (1969), produced haploid and diploid rice plants through AC. In many countries this began a decade of research that developed RTC into an applied research and breeding tool.

METHODS

The intense interest in RTC in Japan, China, and India quickly led to the proliferation of techniques, AC in particular. The procedures for plating anthers and ovaries to obtain haploid callus or plants are simple. In AC, boots are collected when pollen is predominantly in the uninucleate development stages — usually shortly before heading in most varieties. The boots may be incubated 7-10 days at l0°C before anthers are plated. This procedure increases the percentage of anthers that produce callus. The boot or panicle is surface sterilized in 5% sodium hypochlorite solution for about 30 minutes. The panicle is removed from the boot (using a sterile technique) and branches are placed onto sterile water-agar plates for removal of anthers. Plates with anthers are incubated in the dark at 24-26° C. Calluses begin to form on anthers after 3 or 4 weeks. Calluses may be transferred to a fresh plate or test tube of culture medium and incubated under low-intensity fluorescent light at 24-25°C.

When shoots are about 6 cm long and have developed a root system, the plants are transferred to sterile soil. Plants must be maintained in humidified and shaded conditions for several days because they are subject to damage from intense light, heat, and drying. Root-tip cells should be stained and ploidy determined when the plants are transferred from culture plates to sterile soil (Mukhejee and Mukheji 1979). Haploid plants can be treated with colchicine solution to produce homozygous diploid plants. Seed from diploid AC lines can be used immediately to screen for resistance to insects, diseases, salinity, nutrient deficiencies or toxicities; herbicide tolerance, drought resistance, cold tolerance; grain type and quality; tillering, ratooning ability, height, maturation period, yield, or any other characteristic. Diploidized AC lines produced from F_1 hybrids are normally homozygous.

In ovary culture, the same steps are followed and unfertilized ovaries, collected at the same growth stage as anthers, are dissected from individual florets by sterile

technique, and plated onto culture medium. The plated ovaries may require 4-6 months' culture to produce haploid plantlets (Asselin de Beauville 1980).

RTC research has been reviewed recently (Bajaj 1980, Chaleff 1980, Kucherenko 1980). Early AC developments were reviewed by Niizeki and Oono (1971), Oono (1975), and Chung (1975). Nishi and Mitsuoka (1969) were the first to plate unfertilized ovaries. They obtained only diploid and tetraploid plants. Heszky and Sajo (1972) produced haploid rice plants from plated ovaries. Asselin de Beauville (1980) produced a large number of haploid plants from unfertilized ovaries. Most of the plants grew directly from the macrospores without first forming callus. All the plants produced were green. It appears, however, that AC offers greater opportunities for producing large numbers of haploid plants in culture. The logistics of ovary culture and the low number of plants generated, which differ genetically, limit its effectiveness.

Effect of development stage of pollen on anther culture

Niizeki and Oono (1968) plated anthers containing mature pollen in their first attempts to produce plants through AC. Only 0.57% of the plated anthers produced callus. Guha et al (1970) reported that anthers with immature pollen, collected at the uninucleate stage, were much more favorable for producing callus and embryoids. Niizeki and Oono (1971) also observed an increase in the frequency of callus induction when anthers with uninucleate pollen were plated. This observation was confirmed many times in subsequent AC research (Guha-Mukherjee 1973, Academia Sinica 1974, Chen 1977, Genovesi 1978).

There is general agreement in the literature that the uninucleate stage of microspore development is the most desirable for rice AC. The reported variations in frequency of callus induction at the early-, mid-, or late-uninucleate stages may be a characteristic of the germplasm used. Early AC reports indicated that selection of boots for AC could be made based on the extension of the flag leaf sheath, determined by measuring the distance between the flag leaf collar and the collar of the penultimate leaf (Oono 1975). However, determination of the pollen stage is more reliable and easily accomplished after staining with 0.5% solution of acetocarmine (Khan 1975).

Media used for rice tissue culture

The media initially used for RTC were modifications of those developed by Murashige and Skoog (1962), Miller (1963), Linsmaier and Skoog (1965), and Blaydes (1966). Niizeki and Oono (1968) used the basic Blaydes medium, which they supplemented with indole-3-acetic acid (IAA), kinetin, 2,4-dichlorophenoxyacetic acid (2,4-D), adenine sulfate, or yeast extract. In later studies, Oono (1975) used the medium developed by Murashige and Skoog (1962) and K-1 medium. More recently Chaleff (pers. comm.) developed the R-2 medium for rice AC. Several RTC media have been developed in the People's Republic of China (Liang 1978). The constituents of the more commonly used media are listed in Table 1.

The N_6 medium was developed in China after extensive research on media

Table 1. Media commonly used for rice tissue culture.

Constituents	Media[a] (mg/liter)								
	Murashige-Skoog	Linsmaier-Skoog	Miller	Chaleff's R-2	N_6	SK-3	Szechuan medium	Medium V	Hsien-miao II
NH_4NO_3	1650	1650	1000	400	–	–	–	450	4950
$(NH_4)_2SO_4$	–	–	–	–	463	314.5	463	–	–
KNO_3	1900	1900	1000	2530	2830	2830	2200	1700	1900
$Ca(NO_3)_2 \cdot H_2O$	–	–	347	–	–	–	240	480	–
KH_2PO_4	170	170	300	170	400	641	408	525	510
K_2SO_4	–	–	–	–	–	–	–	140	–
KCl	–	–	65	–	–	–	65	65	–
$MgSO_4 1H_2O$	370	370	35	370	185	280	185	320	370
$CaCl_2 \cdot 2H_2O$	440	440	–	440	166	166	–	–	440
$FeSO_4 \cdot 7H_2O$	27.8	27.8	–	27.8	27.8	48.1	27.8	55.7	55.7
Na_2-EDTA	37.3	37.3	–	37.2	37.2	64.4	37.2	74.5	74.5
Na-Fe-EDTA	–	–	32.0	–	–	–	–	–	–
H_3BO_3	6.2	6.2	1.6	6.2	1.6	1.6	1.6	3.2	6.2
$MnSO_4 \cdot 4H_2O$	22.3	22.3	4.4	16.8	4.4	4.4	4.4	11.2	22.3
$MnSO_4 \cdot 7H_2O$	–	–	–	–	–	–	–	–	–
$ZnSO_4 \cdot 7H_2O$	10 6	10.6	1.5	6.62	1.5	1.5	1.5	4.3	8.6
KI	0 83	0 83	0.8	0.83	0.8	0.8	0.8	0.8	0.83
$AlCl_3 \cdot 6H_2O$	–	–	–	–	–	–	–	–	–
$Na_2MoO_4 \cdot 2H_2O$	0.25	0.25	–	0.25	–	–	–	–	0 25
$CuSO_4 \cdot 5H_2O$	0.025	0.025	–	0.25	–	–	–	–	–
$CoCl_2 \cdot 6H_2O$	0.025	0.025	–	0.025	–	–	–	–	0.025
$NiCl_2 \cdot 6H_2O$	–	–	–	–	–	–	–	–	–
Biotin	–	–	–	–	–	–	–	–	–
Thiamine·HCL	0.1	0.1	0.1	10	1.0	0.5	1.0	1.0	1.0
Pyridoxine·HCL	0.5	0.5	0.1	–	0.5	0.5	0.5	1.0	5.0
Nicotinic acid	0.5	0.5	0.5	–	0.5	2.5	0.5	1.0	5.0
Foric acid	–	–	–	–	–	–	–	–	–
Ca-pantothenate	–	–	–	–	–	–	–	–	–
Inositol	100	100	–	100	–	–	–	100	100
Glycine	2.0	–	2.0	–	2.0	10.0	2.0	–	20.0
Alanine	–	–	–	–	–	–	–	10.0	–
Yeast extract	–	–	–	–	–	1,000	–	800	–
Lactoalbumin hydrolysate	–	–	–	–	–	–	–	–	–
Sucrose	30,000	30,000	30,000	30,000	5,000	60,000	40,000	50,000	30,000
Agar	10,000	10,000	10,000	8.000	1,000	7,500	10,000	9,000	9,000
2, 4-D[a]	–	–	–	–	2.0	20	–	2.0	–
NAA[a]	–	–	–	0.3	–	2.0	–	0.2	1.0
IAA[a]	–	2.0	5.0	–	–	–	–	–	–
Kinetin[a]	–	0.2	–	2.0	–	–	–	–	2.0
pH	5.8	5.6	5.8	5.8-6.0	5.8	5.8	5.8	5.8	5.8

[a] Murashige and Skoog (1962). Linsmaier and Skoog (1965). Miller (1963). Chaleff, R.S. (pers comm.); N_6, SK-3, Szechua, Mediurn V, and Hsienmiao II, Liang (1978).

components (Chu et al 1975, Chu 1978). It has been used in AC experiments with other cereal crops. In general, it has given better results than the Miller's and Murashige-Skoog media. In recent experiments at IRRI, the Chaleff R-2 medium induced callus more successfully than the Miller, Murashige-Skoog, and Chinese SK-8 media (Table 2).

Growth regulators

Growth regulators have been important RTC media constituents from the earliest experiments. The most commonly used growth regulators have been 2,4-D, IAA, NAA, and kinetin. Niizeki and Oono (1968) used IAA, kinetin, and 2,4-D in their media for differentiating callus and plants from pollen in anthers. Saka and Maeda (1969) observed that the addition of kinetin to a medium, on which callus from embryos was cultured, promoted shoot formation. Wu and Li (1970) demonstrated the beneficial effects of 2,4-D on callus induction from various somatic tissues. Nishi et al (1973) indicated that the auxins 2,4-D, NAA, and IAA were active in callus induction from seedlings, roots, shoot nodules, anthers, and ovaries. Organ differentiation was promoted when callus from these tissues was transferred to media without auxins. Nishi et al determined that cytokinins were unnecessary for differentiation of shoots from callus. They concluded that high auxin concentrations cause dedifferentiation in rice tissues, and the removal of auxin causes differentiation, or redifferentiation, resulting in the formation of a meristem and organogenesis. The Kwangtung Institute of Botany, Laboratory of Genetics (1975), showed that the ratio of kinetin to auxins had a major effect on differentiation of green plants. With indica-type rices, the higher the ratio of kinetin to auxin, the higher the differentiation rate. This relationship did not hold for japonica-type rices. The N_6 medium,

Table 2. The effect of different media on callus production by plated anthers of Taipei 309 and IR8, IRRI 1980.

Medium[a]	Plated (no.)	Anthers: Producing callus		Anthers: With multiple callus	
		No.	%	No.	%
		Taipei 309			
Challef's R-2	148	40	27.0	36	24.3
Challef's R-2 + 2, 4-D[b]	476	98	20.6	87	18.3
Murashige-Skoog	507	64	12.6	48	9.5
SK-8	470	72	15.4	54	11.5
Miller's	517	70	13.4	64	12.4
		IR8			
Chaleff's R-2	672	9	1.3	1	0.3
Chaleff's R-2 + 2, 4-D[b]	704	3	0.4	0	0.0
Murashige-Skoog	946	4	0.4	0	
SK-8	479	4	0.8	0	0.0
Miller's	547	5	0.9	2	0.0

[a]Medium constituents are listed in Table 1. [b]2 mg/liter, 2, 4-D added to Chaleff's R-2.

which is used in China for japonica varieties, has no kinetin. The Hsien No. 5 medium developed in China for use with indica varieties has 3 mg kinetin/liter.

Chen and Lin (1976) observed that plants developed directly from callus that was not transferred to a differentiation medium, when 1-2 mg NAA/liter was used in their dedifferentiation medium. Chou et al (1978) compared 22 auxin compounds with 2,4-D for ability to enhance callus formation from embryo tissue. They found that 2-methy1-4 chlorophenoxyacetic acid (MCPA), 2,4, 5-trichlorophenoxyacetic acid (2,4,5-T), and 4-amino-3,5,6-trichloropicolinic acid (TCP, Picloram) effectively induced callus. MCPA was significantly better than 2,4-D for callus induction, increasing callus induction frequency by 15.8%, 37.4% and 64.5% over that produced on medium with 2,4-D in three japonica varieties. The similarity of the effect of 2,4,5-T and TCP to those of 2,4-D suggests that further studies of growth regulators may lead to the discovery of more effective callus-inducing compounds and lead to the elaboration of the cell dedifferentiation mechanism.

Recently a simple potato extract (PE) medium for the in vitro AC of rice was described (Academia Sinica and Hokiang Rice Institute 1977). The medium, which contained 30% PE, worked as well as or better than the Miller and Murashige-Skoog media. The use of potato extract as a medium component has greatly improved callus induction (Chen et al 1979). The cost of producing the medium was low and the procedures were simple. For each liter of medium containing 10% or 20% PE, 100-200 g fresh potato tubers were cleaned with water and sprouts were removed. The tubers were cut into small pieces, boiled in an equal volume of distilled water for 25-30 minutes, and filtered through two layers of cheese cloth. The residual potato pieces were extracted once more in the same manner. The two liquors were mixed for immediate use. Auxin (2,4-D at 2 mg/liter), sucrose (6%), and agar (0.75-0.8%) were added to the PE and the pH of the medium was adjusted to 5.8. The PE medium was better than the Murashige-Skoog medium for green plant induction when kinetin (2 mg/liter), IAA (1 mg/liter), sucrose (3%), and agar (0.75-0.8%) were added and the pH of the medium was adjusted to 6.0.

Sweet potato roots were also used to form extracts for a simplified medium. Chou et al (1978) substituted sweet potato extracts for sucrose, microelements, and other organic materials with good results. The Agricultural Research Institute of County Chando used a 30% sweet potato extract (SPE), with the addition of macroelements from the N_6 medium, $FeSO_4$, and 2,4-D as the dedifferentiation medium for japonica rice and obtained 5.91% callus. The N_6, medium alone gave only 3.93% callus induction. The SPE medium was equivalent to the Murashige-Skoog medium in differentiating green plants.

The use of natural potato extracts in basic media for dedifferentiation and differentiation gives results equal to or better than those produced by the Murashige-Skoog and Miller media. PE media are simple and inexpensive to prepare, may be exploited on a wide scale, and are considered a major innovation.

Preplating and postplating treatments of anthers and pollen

Nitsch and Norrel (1973) reported that they could increase the frequency of

embryoid induction in *Datura innoxia* by applying a cold treatment at the time of the first pollen mitosis. Chaleff et al (1975) experimented with the effects of cold-shock treatment on callus induction from rice anthers. Anthers of the variety Dungham shali treated with cold shock at 6° C for 5 days showed a 22.2% callus induction rate; those without cold treatment 10.5%. The anthers were plated on Linsmaier-Skoog basal salt medium with 1% sucrose and a mannitol osmoticum of 2.13%. Chen (1976) studied the effects of cold shock at 5° and 10° C on the varieties Tainan 5 and H-124. Anthers treated with low temperatures produced calluses at a higher frequency than untreated anthers. Genovesi and Magill (1979) demonstrated that preplating treatment of anthers of Norin 21 at 5° C for 7 days, at 10° C for 7 or 10 days, or at 13°C for 10 or 14 days increased callus induction from 17.9% in the untreated anthers to 73.6%. These results were confirmed at IRRI with the variety Taipei 309 (Table 3). In addition, the frequency of callus induction in anthers heat treated at 40° C for 15 minutes was more than double that in untreated anthers.

Table 3. Effect of preplating temperature treatment on callus and plant production by anthers of rice cultivar Taipei 309 on Chaleff's R-2 medium (IRRI 1980).

Treatment[a]	Anthers[b]					Plants produced (no.)	
	Plated (no.)	Producing callus		With multiple callus			
		No.	%	No.	%	Green	Albino
Plated when harvested	430	27	6.3	25	5.8	4	2
40°C, 5 min	545	45	8.3	34	6.2	10	0
40°C. 10 min	561	47	8.4	42	7.5	2	10
40°C, 15 min	565	71	12.6	64	11.3	11	2
5°C. 3 days	713	88	12.3	85	11.9	3	0
5°C. 7 days	269	42	15.6	31	11.5	1	4
5°C, 10 days	513	35	6.8	27	5.3	12	0
5°C, 14 days	483	18	3.9	13	2.7	9	2
10°C. 3 days	464	106	22.8	95	20.5	5	1
10°C, 7 days	139	34	24.5	26	18.7	10	4
10°C, 10 days	653	120	18.4	90	13.8	15	17
10°C, 14 days	549	120	20.7	99	18.0	3	5
14°C, 3 days	483	71	14.7	62	12.8	13	6
14°C, 7 days	29	4	13.8	3	10.3	0	0
14°C, 10 days	387	61	15.8	49	12.7	7	10
14°C, 14 days	546	77	14.1	74	13.6	20	0

[a] 40°C treatment by placing intact boot in hot water bath for time specified. [b] Numbers of anthers plated varied because of losses to microbial contamination. Anthers with 2 or more pollen grains producing callus were identified as having multiple calluses. [c] With this treatment, 3.7% of the anthers plated produced a green plant.

Incubation temperature and light

Recent studies have shown that incubation temperature and exposure to light of plated anthers and developing callus have significant effects on callus and plantlet induction. Although anthers will generate callus when incubated in the light, the usual practice is to incubate plated anthers in the dark until callus forms. The callus

can then be transferred to fresh medium without 2,4-D and incubated under low light intensity (cool white fluorescent light, 150-500 1x) with a 12- to 16-hour photoperiod (Chaleff, pers. comm.; Genovesi 1978). Incubation of anthers for callus induction is most successful when plates are maintained at 24°-25° C (Song et al 1978). The incubation temperature for inducing plantlets from calluses should also be 24°-26° C, Song et al (1978) showed that decreasing incubation temperature from 29°-31° C to 24°-25° C increased plantlet induction frequency from 28.6 to 9 1.8%. It also reduced albino plantlet formation from 22.1 to 4.1%.

PRODUCTION OF HAPLOIDS, HOMOZYGOUS DIPLOIDS, AND VARIANTS THROUGH RICE ANTHER CULTURE

After the work of Niizeki and Oono (1968), research on RTC, particularly anther and ovary culture, has many times produced haploid and homozygous diploid rice plants. The use of haploid cell culture for developing and identifying artificially induced or natural mutants and for generating polyploid plants is also of interest.

The rate at which plants are produced from anther or pollen culture depends much on the germplasm cultured. Maeda (1967) showed that there was wide variation in the ability of different varieties to produce callus from somatic tissues. Niizeki and Oono (1968) noted that rice varieties varied in ability to produce calluses and plants from AC. Guha et al (1970) screened 20 rice varieties for ability to produce haploid plants in culture. The varieties differed widely in ability to produce callus and plants. Guha-Mukherjee (1973) reported on the ability of 20 rice varieties to produce callus, embryoids, and plants in AC. The wide variation in ability to perform under AC conditions was attributed to genotypic differences. This suggested that the ability to perform is heritable. Many others (Academia Sinica 1974, Chung 1975, Oono 1975, Tsai and Lin 1975, Chen and Lin 1976, Song et al 1978) have demonstrated the variability in performance among varieties and F_1 hybrid plants. Sun et al (1978) demonstrated the variation in response to AC of several varieties and F_1 hybrids from crosses of japonica varieties, indica varieties, and japonica-indica hybrids (Table 4).

In recent work at IRRI, the capability of 87 varieties and breeding lines to produce callus on the same medium in the same environment was evaluated. Callus induction varied from 0 to 18%, depending on the variety or line.

Parent varieties must be screened for ability to produce callus and plants from cultured anthers to ensure maximum efficiency of green plant production from pollen of F_1 plants. Studies should be conducted to determine how the mechanisms that favor callus and plant formation from pollen are inherited. It may be possible to select for high culturability and breed this characteristic into varieties and breeding lines used as parents in crosses.

Wide crosses

Homozygous breeding lines have been developed from japonica-indica hybrids (Woo and Mok 1977, Sun et al 1978). Development of lines by AC prevents the

Table 4. Effect of pollen donor parent on success of rice anther culture.[a]

Variety or F_1	Anthers inoculated (no.)	Callus induced (%)	Green plants induced (%)	Albino plants induced (%)
Japonica crosses				
Nunken 58/Tainan 3 F_1	704	5.8	26.8	19.5
Nunken 58/Bawanbian F_1	4492	19.7	17.7	21.8
733/Ribenchen F_1	4626	8.9	20.1	31.5
Nunken 6/Tainan 5 F_1	372	11.0	7.3	34.1
Jianun 14/Limin F_1	1874	7.5	7.8	44.0
Erwan 3/Jinin 87 F_1	847	5.7	24.4	26.5
Japonica indica crosses				
(733/4121)/IR29 F_1	6993	4.1	12.5	20.0
(Jianun 14/4243)/IR29 F_1	14008	6.9	19.6	15.1
Indica crosses				
Nanyou 2	2416	5.6	5.1	27.9
Aiyou 2	2308	4.4	1.9	42.5
Zensen 97/1R26 F_1	10108	2.3	1.4	13.3
V20/IR26	3738	1.9	2.1	12.7
Varieties				
IR26	16509	1.5	0.8	12.0
IR8	2160	0.4	12.5	37.5
Michuantuye	870	0.5	25.0	25.0

[a] Compiled from data of Sun et al (1978).

problems of divergence and sterility often encountered in attempts to cross japonica and indica rices.

In recent research in China, hybrids developed for specific heterosis were used in AC to develop stable new varieties. Heterosis hybrid combinations have been more successful in callus induction and green plant formation than hybrids selected from the conventional breeding program. Recent tests using plants derived from heterosis hybrid combinations show that it is possible to obtain a new, stable variety with the same yield potential as that of the F_1 hybrid from which it was derived (Ling et al 1978).

There was some concern about the vigor of the progeny of plants produced through AC because of their homozygosity. Shen et al (1978) compared data on time to heading, plant height, 1,000-grain weight, and yield of progeny from plants produced through AC with similar data from the original hybrid combination (F_1) or parent. If the original material was a pure-line variety, the progeny had low vigor, but if it was a hybrid, the progeny's vigor was similar or equal to that of the hybrid source.

The hybridization of *O. sativa* with other *Oryzae* species is of considerable interest to rice breeders. Wakasa and Watanabe (1979) demonstrated that *Oryzae perennis* (*spontanea* type) could produce callus and green plants from pollen in plated anthers. Thirteen of 2,421 plated anthers generated callus (0.53%). Nine calluses were transferred to differentiation medium. One haploid and two diploid green plants

were differentiated from a single callus. These plants were grown to maturity. Woo et al (1978) attempted to derive homozygous lines from AC of single crosses and backcrosses between O. *sativa* and *O. perennis.* Anthers of reciprocal single cross hybrids produced only callus and albino plants. Anthers of F_1 plants from backcrosses to Taichung 65 developed albino and green plants. A total of 96 normal green plants were obtained from 1,297 anthers plated from backcrossed hybrids. The F_1 plants from *O. sativa- O. glaberrima* crosses are highly pollen sterile. They can be backcrossed because some embryosacs remain functional (Sano et al 1979). Woo and Huang (1980) demonstrated that anthers of *O. glaberrima* readily generated callus. Anthers from F_1 hybrids of reciprocal crosses produced callus, but at a much lower rate than those of the two *Oryzae* species. However, 16-72% of the calluses produced regenerated plantlets. When green plants were grown to maturity, their fertility varied. Most haploid plants were completely sterile. Seeds were set on some of the plants generated from the hybrid anthers. The culture of anthers or pollen of hybrid plants from crosses among *Oryzae* species may provide a technique for producing stable homozygous lines with characters of each species used in a cross.

Intergeneric crosses

Chinese scientists have been active in the production of intergeneric hybrids through conventional crossing methods. H. P. Sun (1978) produced early ripening, pollen-derived tines with large panicles, many grains in each panicle, and large kernels from anthers of a rice-sorghum hybrid. These lines are now undergoing production testing.

The Group of Haploid Breeding, Kwangtung Academy of Agriculture (1978) used rice - sorghum, rice - reed, and rice - bamboo hybrids for AC. Green plants were produced from 5 of the 11 hybrids. The N_6 and 30% PE media gave good callus induction. The Murashige-Skoog medium also was effective for green plant induction.

Androgenesis

The pathways of androgenesis in cereal AC were studied by C. S. Sun (1978). His observations suggested that the first meiosis of uninucleate pollen might be assymmetrical (A pathway) or symmetrical (B pathway). The pollen embryoids and callus originated mainly from the vegetative nucleus. The generative nucleus did not play an essential role. However, in rice, in addition to the A and B pathways, there was another pathway of androgenesis. In this pathway, cells derived from the generative nucleus participate in forming pollen embryoids and callus. This pathway has been designated *E pathway.*

Ploidy of plants from anther culture

In a continuation of their studies of rice AC, Niizeki and Oono (1971) regenerated haploid, diploid, triploid, tetraploid, and pentaploid plants. Since their report, there have been many reports of variation in ploidy of callus and plantlets obtained through AC. Academia Sinica (1974) also reported the presence of mutations in

plants derived through AC. It has been repeatedly suggested that the polyploid and mutant plants formed through AC may serve as source of new or unique germplasm for breeding programs. It is possible to supplement the natural differences in ploidy observed in plantlets regenerated from callus by treating the calluses of developing plants with colchicine (Chin et al 1978).

Homozygosity and genetic stability of plants from anther culture

In haploid breeding through anther or pollen culture, the stability of progeny of the plants produced is important. Sun et al (1978) observed large numbers of progeny of plants from pollen. About 90% of the plants produced were uniform and stable in all major traits. Tang (1978) observed the progeny of 429 plants from AC. Among these, the progeny of 394, or 9.8%, were uniform. Thirty-two plants (7.4%) had progeny with slight variation, while three plants (0.69%) had progeny with serious variation from the parents. H. P. Sun (1978) observed 115 plants from pollen of rice (rice/sorghum) hybrids; 96% of the progeny from those plants were uniform. Chen and Li (1978) observed 484 diploid lines from plants regenerated from pollen of 67 F_1 combinations of japonica types. Of those, 434 lines were uniform, which meant that 90% of the plants were homozygous; 50 lines varied significantly. That confirms the observations of many researchers that pollen-derived lines are homozygous. Research by the Academia Sinica (1974) indicated that when seed from plants produced through AC were planted, most of the progeny were uniform in major characteristics. Plants produced through AC from F_1 hybrids had the characteristics of both parents, but did not segregate in subsequent generations. However, the F_2 produced by planting seeds from the F_1 segregated for morphological and agronomic characters. Woo and Su (1975) reported that the progeny of 14 lines derived from AC of F_1 plants from an indica-japonica cross were phenotypically identical.

Homozygosity in differential varieties with many sources of monogenic resistance would be of great value in the study of diseases caused by pathogens that have many races. Control of rice blast by monogenic resistance is dependent on the identification of *Pyricularia oryzae* races and genes for resistance (Crill and Khush 1979). It is also necessary to rapidly incorporate the genes into commercial varieties when a gene-rotation scheme is used. These efforts will be facilitated by the rapid development of homozygous lines by AC. Development of near-isogenic lines with single monogenes for resistance to individual pathogen races could be accomplished through the use of crosses and backcrosses with different sources of resistance and the production of homozygous lines. Isogenic lines with single monogenes for resistance would be invaluable for identifying *P. oryzae* races.

Homozygous lines with different genes for resistance, but similar agronomic characteristics, would also be useful for developing multiline cultivars with disease resistance (Frey et al 1975).

ALBINO PLANTS

The production of albino plants has severely restricted first efforts to produce plants

from callus in RTC. Liang et a1 (1978) studied albino-plant production in tissue culture by using isotope incorporation and protein-gel electrophoresis. Their work suggested that protein metabolism was disturbed in the albino plants.

Sun et a1 (1978) studied the composition of soluble proteins and ribosomal ribonucleic acid (rRNA) in the green and albino plants of rice produced from pollen through the use of polyacrylamide gel electrophoresis. Fifteen bands were recognized in the pattern of the soluble proteins of the green plants induced from pollen. The protein band 3 (Fraction 1 protein) was the most prominent and was characterized by its high intensity. In the albino plants induced from pollen, however, the protein band 3 was hardly visible. The high molecular weight of rRNA of the green plants was separated into four bands, the 25S and 18S RNA of the cytoplasmic ribosomes, and the 23S and 16S RNA of the plastid ribosomes. However, the 23S and 16S RNA of plastid ribosomes were absent or rare in the albino plants. This implied that the origin of albinoism in plants from AC was caused by the impairment of DNA.

Liang et a1 (1978) studied the submicroscopic structure of callus cells that produced green or albino plants by scanning electron microscopy. The callus that differentiated green plants, had a well-defined structure while the callus that differentiated albino plants was not as condensed and well defined. Production of albino plants from pollen appeared to result from metabolic deficiencies in the callus meristem.

Song et al (l978) indicated that the temperature at which the callus was incubated to differentiate plantlets had a significant effect on whether the plants produced would be albino or green. Incubation at 24° -25° C produced new albino plants and many green plants. The frequency of albino plant induction increased as temperature increased. The same phenomenon was observed by Wang et a1 (1978).

IN VITRO SCREENING

Little use has been made of in vitro techniques for screening against crop production constraints, such as pathogens, herbicide injury, cold damage, or mineral toxicities or deficiencies. lshii and Yamasaki (1971, 1972) and Ishii and Sakamoto (1975) attempted to screen callus tissues derived from various rice organs for blast resistance. They inoculated callus from resistant and susceptible varieties with conidia of *P. oryzae* and obtained no differential reaction in culture. Ogasawara et al (1977) directly inoculated several pathogenic and nonpathogenic fungi to rice callus obtained from the somatic tissues of the cultivars Tetep and Norin 20. Both of the rice pathogens tested, *P. oryzae* and *Cochliobolus miyabeanus,* and the nonpathogen *Aspergillus oryzae* invaded and destroyed callus tissues, confirming observations at IRRI that when many nonpathogenic fungi occur as plate contaminants, they can destroy rice callus. That suggests that the mechanisms that make whole rice plants nonhosts for these fungi may not be operating in callus cells. It is possible that an intact epidermis and cuticle play major roles in preventing the invasion by fungi for which rice is not a host.

Chaleff and Carlson (1974) cultured single cells of rice and, after methionine treatment, selected mutants that had increased lysine content. Analogue resistance was used to select for variant rice cell lines that had increased levels of certain free amino acids and higher amounts of lysine incorporated into their protein. Schaeffer (1978) also made cell suspension culture treatments to select for high-lysine mutants. Seeds of plants from one of the analogue-selected cell lines had 14% higher protein, 17% higher free aspartic acid, 3% higher free lysine, and 18% lower tyrosine content than controls.

CULTURE OF ISOLATED POLLEN

Development of a technique for culturing isolated pollen should increase the potential number of plantlets produced from F_1 plants. Wang et al (1979) attempted to culture isolated pollen in liquid culture following the technique of Nitsch (1974). Many pollen grains released into the medium from dehiscing anthers began to develop callus. With time most of the calluses changed color and ceased developing. When the actively growing callus was transferred to a solid medium, albino plantlets were regenerated. Hu and Liang (1979) floated rice anthers on a liquid medium and differentiated green plants from callus produced by the cultured pollen. When colchicine was added to the medium at 50-250 mg/liter at an early stage of culture, the frequency of plantlet induction was increased by 50%. Production of diploid plants increased by 54-78%. Hu and Liang suggested that colchicine and Ethrel be added to the medium to increase induction frequency. The multicellular pollen from dehisced anthers must be isolated just before they rupture the pollen wall, and cultured separately.

Chen et al (1979, 1980) successfully cultured single pollen cells and induced plantlets of *O. sativa* subsp. *japonica* in vitro. Rice panicles with microspores at the late uninucleated stage were collected and pretreated at 8° -10° C for 10 days. The isolated pollen grains were prepared by two methods:

1. After the anthers were precultured on agar or in liquid medium for 2-7 days, the pollen grains were separated by the crush method (Nitsch 1974) or by magnetic stirring. The debris was removed and the pollen suspension diluted to a concentration of 2.5×10^5 microspores/ml.
2. Anthers were placed into liquid medium where they floated on the surface. As the anthers dehisced, pollen grains were continuously liberated into the medium. The anthers were periodically transferred to fresh medium and the free pollen grains shed from anthers in the initial medium were collected. These isolated microspores were incubated in a shallow layer of liquid medium.

The media used for culture were either the Miller or the N_6 basal medium supplemented with serine at 100 mg, glutamine at 800 mg, and m-inositol at 5 g/liter. Pollen that produced callus were transferred to a differentiation medium, where some of them differentiated intact plants. When the culture medium did not contain the three organic additives, the growth of the cultures was suppressed. When the medium contained metabolites from anther tissues, the growth of cultures was significantly enhanced.

RICE PROTOPLASTS

The success of protoplast isolation and fusion techniques with other crop species has generated considerable interest in research with rice protoplasts. Successful development of techniques for regenerating plants from fused rice protoplasts will provide opportunities for hybridization of distantly related species and for incorporating foreign nucleic acid into rice varieties. Maeda (1971) and Harn (1973) isolated rice protoplasts from somatic tissues. Ham observed that protoplasts fused and formed large multinucleate cells. The Somatic Hybridization Research Group and Cytobiochemistry Research Group, Peking Institute of Botany (Academia Sinica 1975) produced a large number of viable protoplasts from callus developed through AC. The protoplasts grew and underwent cell division. Within a month, individual protoplasts regenerated cell walls and formed clusters of more than 30 cells through mitotic divisions. Deka and Sen (1976) produced protoplasts from mesophyll and callus cells. Small calluses were formed in culture after about a month. Pi and Huang (1977) produced protoplasts from callus derived from somatic tissues. Many protoplasts fused and became multinucleate. Both sodium nitrate and polyethylene glycol induced protoplast fusion. Tsai et al (1978) produced large numbers of protoplasts, which in turn formed large calluses. However, no plants were regenerated.

NEW VARIETIES THROUGH ANTHER CULTURE

Several new rice varieties and breeding lines have been developed through AC in China (Table 5).

The Tiensin Agricultural Research Institute, Rice Research Laboratory, and the Academia Sinica, Institute of Genetics, 302 Research Group (1976), developed two new varieties during the period 1971-75 from the cross Nipponbare/Chien Chu Pang. The two lines had bacterial leaf blight resistance and wide adaptability to many locations. They were released for production as Hau Yu I and Hau Yu II. Yin et al (1976) described the new variety Tanfeng 1, which was developed through AC. The variety was released for production in 1975. It yields about 8 t/ ha, is early, and is lodging and disease resistant.

STRATEGIES FOR THE FUTURE

Tissue culture will become an important tool in many areas of rice research. When used with conventional breeding methods, RTC has the potential to revolutionize variety improvement. Continued screening of varieties and important breeding lines is essential to identify germplasm with the ability to perform well in RTC. Studies must be conducted to determine how the mechanisms that allow for successful production of callus and plants from cultured cells are inherited. Identification of genes mediating response in RTC will assist in the identification and elaboration of the mechanisms involved and facilitate the development of elite germplasm that also performs well in RTC. This capability must be bred into major varieties to make

Table 5. List of new rice varieties derived through anther culture in China.

Name of new rice variety	Source	Traits	Breeder	Production situation
Ehua 1 Later keng	Line 733/(Nongken 58/Ewan 1)	For highly fertile land, plant ht 85-90 cm	Hubei Provinces Agr. Institute	1977 production test, 3.73-9.45 t/ha
Ehua 2 Later keng	(Nongken 58/Tielu rice)/733	For medium fertile land, plant ht 90-95 cm	Hubei Provinces Agr. Institute	1977 production test, 4.14-8.36 t/ha
Danfeng 1	–	For highly fertile land, lodging resistance	Heilongjiang Provinces Academia Agr. Sciences	1975 production test, 8.32 t/ha
Danzao 7301	IR661/Zhenzhuai	Early hsien, temperature sensitive for medium fertile land, plant ht 90-95 cm, total vegetative period, 145 days	Guangxi Autonmregion Qinzhou Regional Agr. Res. Institute	Production test, 6-6.75 t/ha
Danzao 7	IR24/Chaoyangai 2-1	For late planting, total vegetative period, 135 days	Guangxi Autonmregion Qinzhou Regional Agr. Res. Institute	1977 production test, 7.81 t/ha
"762" Later keng	Chengbao 2/ Nongguike	For late planting, vegetative period, 145 days	Anhui Provinces Academia Agr. Science	1977 production test, 6.73 t/ha
Tonghua 1 Later keng	"6105" Early keng/ early hsien 7	Total vegetative period, 130 days	Anhui Province Tongling county Agr. Res. Institute	Planted area in 1978, 2666-3333 ha.
Tonghua 2 Later keng	Later keng Nongken 58/Nongju 33	Total vegetative period, 150 days	Anhui Province Tongling county Agr. Res. Institute	Planted area in 1978, 2666-3333 ha.
Tonghua 3 Later keng	Later keng Nongken 58/Nongju 33	Total vegetative period, 150 days	Anhui Province Tongling county Agr. Res. Institute	Planted area in 1978, 2666-3333 ha.
Lidan 1	Later keng Nongken 58/Nongju 33	Total vegetative period, 150 days	Jiangxi Province, Agr. Res. Institute of Lichuan County	6.43 t/ha yield higher in 23.5% than parents
Lidan 6	Later keng Nongken 58/Nongju 33	Total vegetative period, 150 days	Jiangxi Province, Agr. Res. Institute of Lichuan County	8.44 t/ha

Lidan 8	Later keng Nongken 58/Nongju 33	Late hsien, for second crop	Jiangxi Province, Agr. Res. Institute of Lichuan County	6.75 t/ha
Nanhua 23	Nanyou 2	For early planting	Guangdong Province, Institute of Botany	Yield is almost the same as heterosis hybrid F_1
Aihua 27	Aiyou 2	For early planting	Guangdong Province, Institute of Botany	Yield is almost the same as heterosis hybrid F_1
Huanuo 1	"691" hsien rice sterile line/keng rice Italian B (F_7)	Nuo new line, total vegetative period, 115 days	Fuzian Province, Academia Agr. Science	Production test, 5.94 t/ha
75-531	Tacukang/Fuyue 1	Total vegetative period, 128 days	Hunan Province, Agr. Institute of Suangfeng county	Production test, 6.49 t/ha
75-532	Tacukang/Fuyue 1	Total vegetative period, 128 days	Hunan Province, Agr. Institute of Suangfeng county	6.40 t/ha
Dan 215	IR26(hsien)/Nonghu	Blast resistant later keng	Zhejiang Province, Agr. University	Production test, 4.55 t/ha
Dan 242	IR26(hsien)/Nonghu	Blast resistant later keng	Zhejiang Province, Agr. University	Production test, 5.02 t/ha
Yazhenhua	Hsien rice IR661/ Zhenshuai	Very resistant to neck blast, sensitive to temperature	Biological Department, Shamen University	Production test, 6.80 t/ha
Danyou 5-1	Bolizhanai A/IR24	Total vegetative period, 126 days	Biological Department, Shamen University	Production test, 5.44 t/ha
Huayu 1	Nipponbare/Qian-junbang	Total vegetative period, 125-130 days	Genetic Institute, Academia	13,333 ha
Huayu 2	Nipponbare/Qian-junbang	Total vegetative period, 125-130 days	Genetic Institute, Academia	13,333 ha

generation of homozygous lines from future crosses, and the selection of suitable parents for crosses, more efficient. Den (1980) obtained an embryo-like callus from the progeny of rice-maize hybrids that could regenerate plants after four generations of continued culture. Materials of that kind must be identified by screening the rice germplasm resources of the world. Institutions with large germplasm collections should initiate such screening programs.

Plants derived through AC may serve as a source of new gene combinations and variation through mutation and changes in ploidy in the plants produced. AC may also be used to stabilize interspecific and intergeneric hybrids to create genetic combinations not found in nature.

The time for creating new varieties from conventional crosses should be considerably shortened by anther and ovary culture. However, considerable research on the effects of media constituents, growth regulators, and environment on RTC is needed to increase the efficiency of callus formation and plantlet regeneration and thus provide breeders with sufficient numbers of homozygous lines, generated from F_1 or F_2 plants from crosses, to make selections.

Rice suspension culture of cells and protoplasts provides a new system for physiochemical mutagenesis or incorporation of foreign nucleic acid into rice plants. After these techniques are refined, genetic engineering with rice will become fact rather than theory.

Collaborative efforts among basic laboratories in the developed countries, institutes conducting research on rice improvement, and researchers in developing countries must be arranged and extended. As new techniques in RTC are developed, training programs should be established to extend the information to researchers who can apply it to rice improvement programs. The applied researchers can then feed back to basic researchers information on applicability and research needs.

If the already recognized potentials of tissue culture are actively developed in the 1980s, more advances will be made in rice improvement by the year 2000 than in all of the years to date.

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PHYSICAL ENVIRONMENT

RESEARCH STRATEGIES FOR RICE AREAS WITH EXCESS WATER

B. S. VERGARA and N. N. DIKSHIT

Variability in the amount and distribution of rainfall is the most important factor limiting the grain yields of rainfed rice, which constitutes about 80% of the rice grown in South and Southeast Asia. Droughts and floods cause substantial damage to rainfed rice production. But during the main cropping season, too much water, rather than too little water, is most often the problem, not only in rainfed rice lands but in irrigated rice lands where drainage is often not considered in irrigation system planning. Many irrigated areas in the Philippines suffer from excess water and many of those have had the problem only after irrigation facilities were installed.

Most water management research on rice has been aimed at conserving water and has been so refined that water loss is measured in millimeters per day. Not only that, most of the research is on irrigated lands, which cover a minimal area when compared with rainfed rice areas.

Research on excess water, compared with research on water conservation and management of irrigation water, is minimal. Little research on reducing the adverse effect of excess water has been done. A surge in research to solve excess-water problems occurred in the early 1970s but the research was inadequate and definitely far behind the refined state attained by irrigation water management research.

DEFINITION

To fully comprehend the complexity of and problems involved in excess-water areas, a description of the water regimes and a definition of terms are necessary. Unfortunately, the definition of terms was an early bottleneck in deepwater rice research.

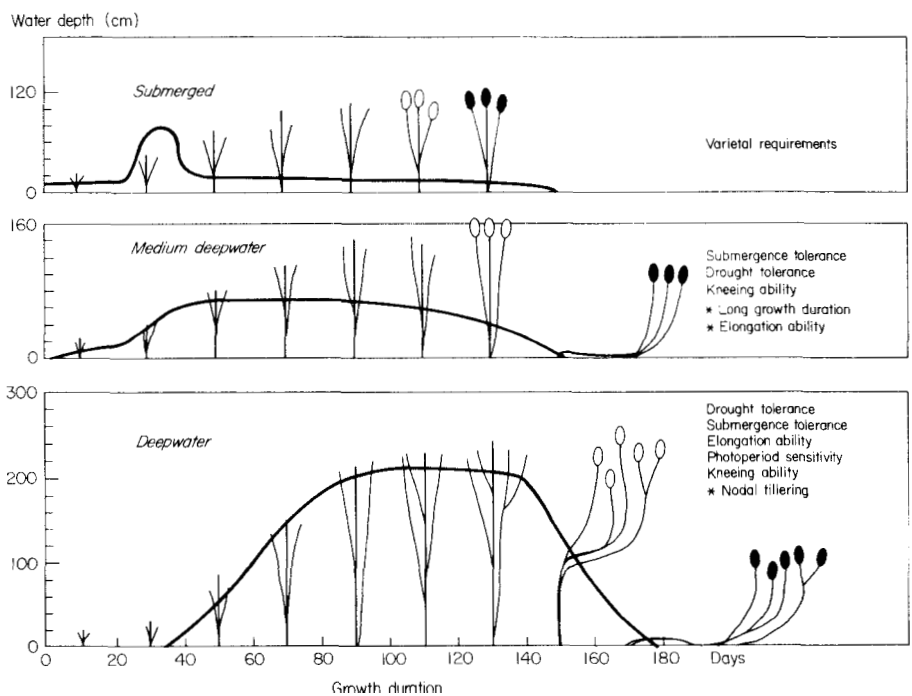
Several scientists, during the last two workshops on deepwater rice (IRRI 1977, 1979), defined the various conditions in which excess water is a problem in growing rice. But until now, there is no consensus regarding the water depths that should be used in classifying excess-water areas. The types of excess water we would like to

Plant physiologist, IRRI: and senior plant breeder, N. D. University of Agriculture and Technology, India.

discuss (diagrammed in Fig. 1) are:

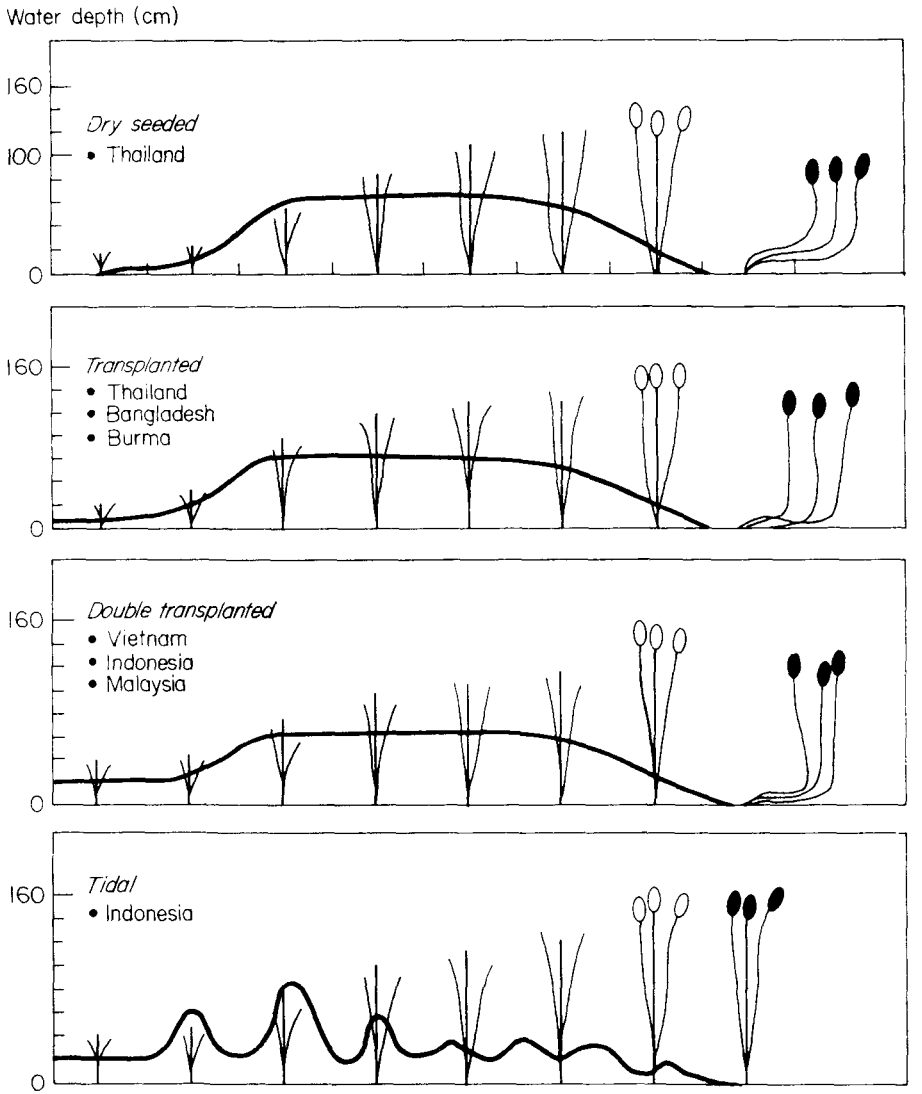
- *submerged areas,* where the water depth and the time of flooding vary but the high water level does not last more than a month. The flash floods commonly occur in tropical rice areas during the monsoon season. Generally, no special varieties are grown in these areas.
- *deepwater areas,* where the water level normally exceeds 100 cm and may reach 600 cm. The water remains in the field for 3-4 months. Special varieties known as floating rice are planted in these areas.
- *medium deepwater areas,* where the water level varies from year to year but the maximum depth does not usually exceed 100 cm. The water remains in the field for prolonged periods. *Semideep, stagnant water,* or *low-lying areas* are other terms used to refer to this condition. Varieties used are usually the tall, indica type and are known as *flood* rice. The floating-rice varieties are also planted in these areas, where major research on deepwater rice has concentrated.

Medium deepwater rice has the most diverse water regime. Briefly, this category may be further divided depending on the cultural method used and the water pattern (Fig. 2). In some areas, rice is dry seeded, as in Thailand and Bangladesh, or transplanted at the start of the monsoon season, as in Bangladesh, Burma, and Thailand. Double transplanting is practiced in areas where the water level rises rapidly. The seeds are sown almost at the same time as the dry-seeded rice. After 30-45 days, the seedlings are pulled, and transplanted to a bigger plot. After another



1. Pattern of changes in water level and varietal requirements.

30-40 days, the seedling are pulled again and transplanted in the main field. This is practiced in Vietnam, Indonesia, and Malaysia, where the time to prepare the land is insufficient and water level rises abruptly. In many coastal areas, such as Indonesia, the water level is affected by the tides so that there is a diurnal and a lunar change in water levels. As shown in Figure 2, this type of water regime needs a nonlodging plant type.



2. Different patterns in changes of water level of medium deepwater rice areas.

PROGRESS

Before a discussion of the research strategy for rice production in excess-water areas, a summary of what has been done is in order. Jackson and Vergara (1979) reviewed the progress of deepwater rice research prior to 1979. The history of deepwater rice research began with the establishment of the Habiganj Station in Bangladesh in 1934 (Alim et al 1962). Most of the research from 1934 to 1970 was on varietal improvement through selection from farmers' varieties. Some work was conducted on genetics, flood tolerance, and fertilizer trials during the period. To date few varieties developed through hybridization have been recommended. The possibility of producing plants of intermediate height that could elongate at 50- to 100-cm water depths was clearly demonstrated in the late sixties by the cross IR442 (also known as T442 in Thailand), which H. M. Beachell made at IRRI, refuting the earlier concept that rice must be inherently tall to withstand deep water. The tall stature of the traditional varieties results in plant lodging, even when the water level is shallow, as in some years, thus reducing yields. IR442 provided the needed stimulus and excited the imagination of breeders and agronomists.

The first international seminar on deepwater rice, held in Bangladesh (BRRI 1975), provided the opportunity to discuss and establish international cooperation on deepwater rice research. It was followed by workshops in Thailand (IRRI 1977), Bangladesh (BRRI 1980), and India (IRRI 1979), which maintained the interest of rice workers and informed them of the latest findings.

The establishment of collaborative research between Thailand and IRRI in 1974 and the formulation of the first International Rice Deepwater Observational Nursery (IRDWON) in 1976 added impetus to deepwater rice research. For the first time, intensive research on pests of deepwater rice was established in Bangladesh in 1976 with aid from the British Government.

The most significant progress so far is the yield trials being conducted in farmers' fields in many countries affected by excess water and the establishment of research stations for deepwater rice research.

Still, we are far from being able to claim any credit for improving farmers' grain yields in the excess-water areas. In most areas, hardly any new variety has been released, there has been no improvement in cultural method, and no improvement in drainage technology has trickled down to the farmer. Much remains to be resolved, tried, and implemented in farmers' fields.

In their report *Progress in deepwater rice research,* Jackson and Vergara (1979) presented 10 questions for consideration in determining research priorities. Three have been answered or will soon be answered:

1. Do the new deepwater-tolerant types respond to fertilizer better than the old varieties? The answer is definitely yes. Work at Huntra Experiment Station in Thailand and the thesis of Kupkanchanakul (1979) showed the advantages of fertilizer application in deepwater rice.
2. How much do we know about the inheritance of elongation? Work in Thailand showed that elongation ability is subject to strong environmental influences.

The crosses studied suggest recessive genotypic expression for elongation ability.

3. Are pests of minor or major importance in deepwater rice? The work at Bangladesh Rice Research Institute (BRRI), aided by the Overseas Develop ment Ministry of U.K., has shown the importance of stem borer and ufra (a nematode disease) and the need to counter these pests either by varietal resistance or cultural practices.

Three of the questions have been answered but the other seven need to be answered and the research strategies determined.

THE PLANT-TYPE STRATEGY

One of the unanswered questions is: *Are our breeding objectives clear?* The plant type that is needed is gradually becoming clearer as rice scientists become more and more aware of the local field problems. Part of this problem is the result of the diverse hydrological patterns from one area to another. However, some general plant-type concepts such as positive response to nitrogen, submergence tolerance, kneeing ability, resistance to stem borer, and erect tillers can be evolved.

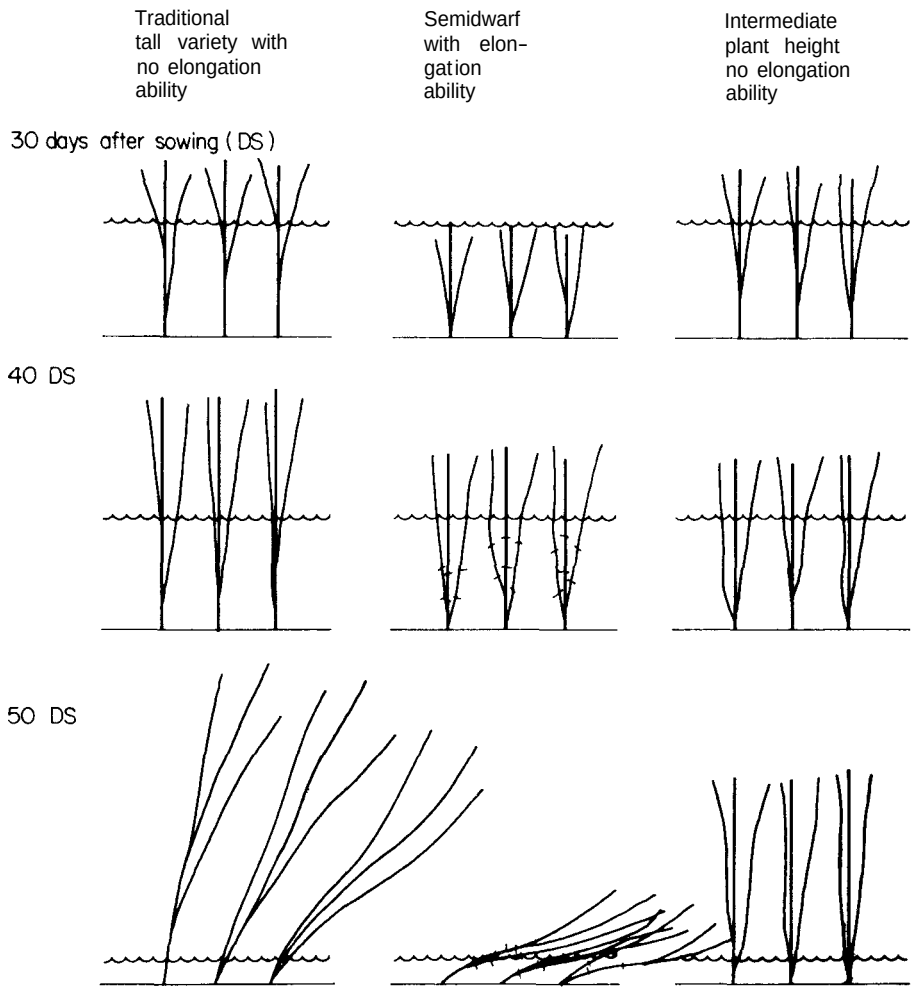
Elongation ability

A good example of disagreement in plant type among plant breeders, agronomists, and physiologists is that on elongation ability. During the first international seminar ondeepwater rice in 1974, most rice workers recommended elongation ability as one of the essential plant characters in deepwater rice. In areas where water depth exceeds 150 cm, internode elongation is necessary. In many areas where water is less than 100 cm deep, scientists are becoming convinced that internode elongation may not be necessary at all. In intermittent and sudden flooding, plants should not elongate under flood stress because elongation produces weak culms and lodging will certainly occur when the short-duration floodwaters recede. If water rises to 100 cm, an intermediate plant height with no elongation ability might be ideal for medium deepwater rice areas and tidal swamp areas (Fig. 3).

A set of varieties with and without elongation ability should be tested at several sites with varying water regimes. The performance of the varieties in terms of growth and growth habit can be evaluated properly. This type of research cooperation will help resolve the question of the need for elongation ability in certain areas. The set of varieties to be tested may be included in the IRDWON. However, more detailed measurements would be needed to evaluate the need for elongation ability.

Plant height

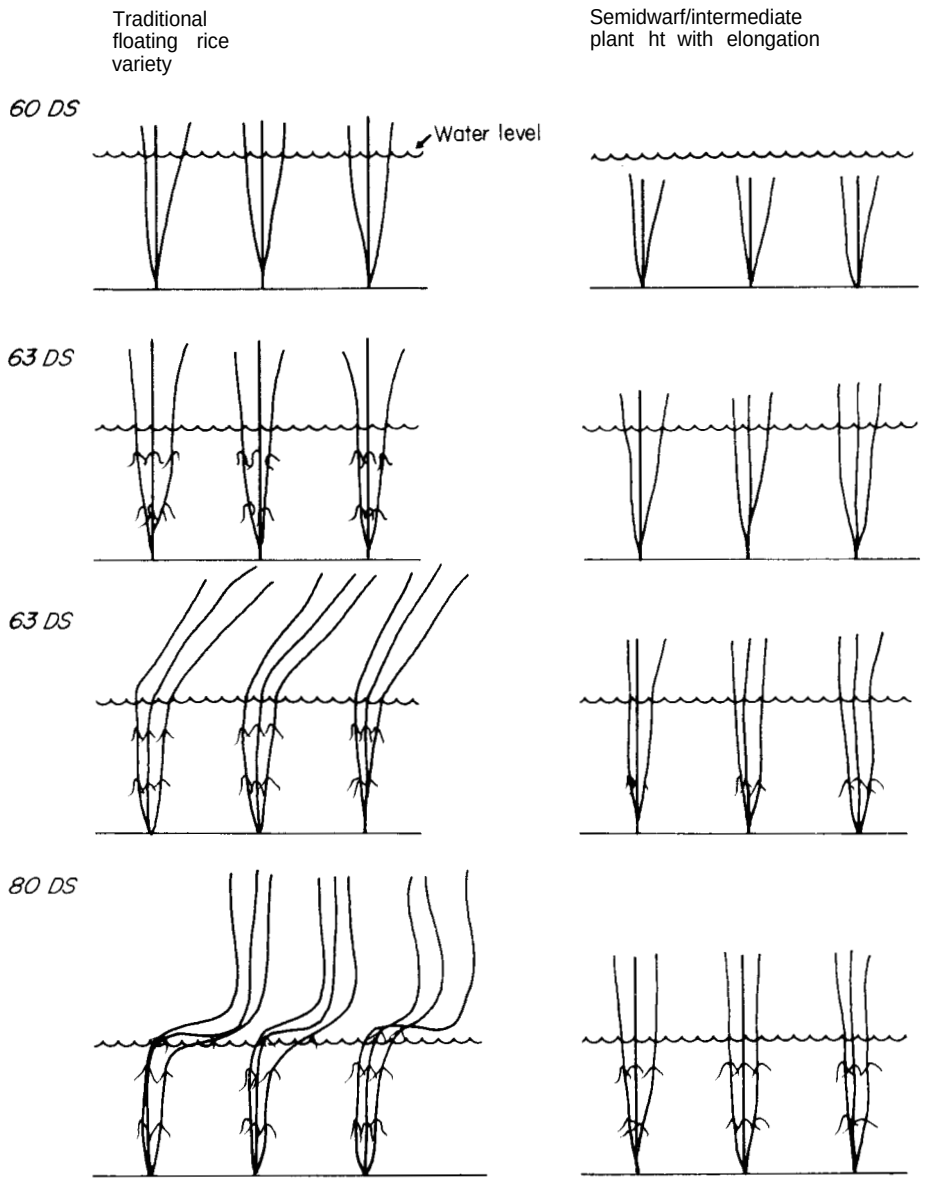
Another question asked during the last deepwater rice workshop was: *Is it possible to develop a semidwarf rice that will perform well at water depths of 2-3 m?* Work in Thailand so far failed to show any semidwarf that can withstand 2-3 m water. After further review of the field conditions in Thailand and Bangladesh, where water



3. Effect of elongation ability and plant height on lodging of plants subjected to short periods of submergence at 30, 40, and 50 days after sowing (US).

might be 2-3 m deep, the question to ask is not, "Is it possible to develop a semidwarf that can perform well at water depths of 3 m?" but "Is it necessary to develop a semidwarf that can elongate up to 3 m?"

In areas where the water is generally deep, and elongation is most likely to occur, lodging is inevitable and the semidwarf character will not be an advantage. As long as there is kneeing ability, lodging can be overcome. However, the traditional floating varieties tend to elongate more than 1 m above the water level and this tendency results in lodging-kneeing-elongation and possibly a repetition of this type



4. Comparison of internode elongation, rooting, and growth above the water level of traditional and improved deepwater rice varieties at 60-80 days after sowing (DS).

of response (Fig. 4). If the semidwarf character is associated with shorter plant height above the water level, the semidwarf (or resulting intermediate plant height) has its merits even in 2-3 m water. The new Thai variety RD19 seems to support this hypothesis. Comparative research on the plant parts above the water level in lines

with similar growth duration is needed. Isogenic lines with different degrees of plant parts above the water level need to be developed and tested in different water depths.

Drought resistance

Scientists agree that drought tolerance is also required in the areas where deepwater rice is grown. In areas where rice is broadcast sown, drought is a serious problem in stand establishment. In transplanted rice areas, drought can occur during the early stages of growth. The question asked regarding drought resistance was, "What do we know about drought resistance in deepwater rice and what collaborative studies should we initiate to identify donors for the trait?"

There has been no definitive study on drought resistance of rice at the seedling stage, although varietal differences have been observed. An effort should be made to understand the factors responsible for this type of drought resistance. This problem should be much simpler than drought resistance during the entire life of the rice plant.

If some of the plant characters associated with drought resistance at seedling stage are known, perhaps greater advances can be made in the screening and selection of donor parents and progenies. Fortunately it has been shown at IRRI that the traditional deepwater rices generally have drought resistance, ruling out any difficulty in combining drought resistance with elongation ability.

We need a concentrated effort to identify from the deepwater rices the varieties that are drought resistant so that they can be used as donors. More efforts than just using Leb Mue Nahng 111 and Nam Sagui 19 as parents should be made to incorporate drought tolerance at the seedling stage into the breeding program for excess water.

A collaborative program for testing drought resistance at the seedling stage, using a common set of varieties, has been set up. This is an important step in identifying the resistant entries, but a more effective program is needed.

Photoperiod sensitivity

Photoperiod sensitivity is a requirement most scientists recommend for medium-deepwater and deepwater rice areas. There is no question about the requirement for photoperiod sensitivity in areas with water exceeding 100 cm. However, the popularity of IR42, C4-63, and IR442 in many medium deepwater-rice areas (including transplanted photoperiod-sensitive aman rice areas of Bangladesh) raises the question of the requirement for photoperiod sensitivity in those areas. Again, a critical look into this problem is needed.

Submergence tolerance

How can we best approach the problem of submergence tolerance? Many questions were asked during the last deepwater rice workshop but very few were answered. However, steps were taken to clarify submergence tolerance and how to tackle this problem.

IRRI identified several varieties that might serve as donors for submergence tolerance earlier. The method used was simple but many workers doubted its relevance and applicability to their own conditions.

During the workshop in India (IRRI 1979), a collaborative experiment was set up. The cooperating scientists used their own or adopted testing methods and conditions on a set of differential varieties. Fifteen scientists used 20 different methods. In all cases, roughly the same set of tolerant varieties always came out best in the test. That convinced the scientists of the applicability of the method and reliability of the results. Hopefully more crosses will be made and screened for submergence tolerance.

Basic research on submergence tolerance is in progress at IRRI. It has received priority not only at IRRI and Thailand but also in Sri Lanka, India, Bangladesh, and Malaysia.

Tiller number

Is the grain yield-limiting factor in deepwater rice the panicle size, the panicle number per square meter, or the amount of assimilates available to the panicle? This question should receive research priority to determine the approach to the problem of increasing grain yields or the tillering ability needed.

Surveys show that the panicle number per unit land area is lower in deepwater rice than in the high-yielding varieties in irrigated conditions. Increasing the seeding rate did not increase panicle number per square meter in the traditional floating rices. The response of the new varieties might be different. Field trials are needed.

If panicle number is the limiting factor, then a high tillering ability and basal fertilizer application are necessary. Data at IRRI and Thailand indicate that for medium deepwater, basal fertilizer application increased the number and percentage-of survival of the tillers. Fertilizer should be applied if the grain yield is to be increased, especially with new high-tillering varieties. Before the floodwater comes, yellowing of leaves, resulting from nutrient deficiency, is quite marked. The leaves turn green after flooding.

If panicle size limits yield, then the tiller number of the traditional varieties is sufficient and breeding should emphasize large panicles. Basal fertilization may not be necessary because the panicle develops when the plant is receiving sufficient nutrients from the floodwater. The concept of large-panicle or high-panicle-weight type is in line with the present farmer's practice of not applying fertilizer in deepwater-rice areas. The long growth duration of the varieties enables the plant to accumulate a large amount of carbohydrates. The reserve is used in elongation. If it is not depleted by a sudden increase in height because of elongation near flowering time, it may be available for grain filling. There is a need to develop heavy panicles and to critically compare the yield response with the panicle-number type.

The new high-yielding varieties for irrigated areas are panicle-nume types of short growth duration. For the deepwater-rice areas, the panicle-number type of long growth duration may not be ideal.

Increasing the panicle weight may mean increasing the strength of the culm to hold the panicle. Also, in areas where the nutrient in the floodwater is not sufficient, nitrogen fertilization may be necessary at panicle-initiation stage to increase the panicle size.

Primary tillers yield the heaviest panicles, followed by the secondary and tertiary tillers. The late tillers or nodal tillers, or both, produce the least panicle weight. Although nodal tillers contribute to grain yield, their importance needs further evaluation. If a primary tiller produces a nodal tiller, it is possible that the total weight of the panicles from the primary tiller and nodal tiller is equal, less, or slightly more than that of a large panicle from a primary, unbranched tiller. This aspect needs to be studied also to enable us to decide the plant type in terms of nodal tillering.

AGRONOMIC STRATEGY

Can improved agronomic practices such as better weed control, sowing methods, and land preparation significantly improve yields? This is a basic question but unfortunately little has been done to answer it. One could hardly imagine that among today's many competent scientists, hardly anybody is doing anything about Iand preparation and weed control. Agronomic experiments on sowing methods and fertilizer rate were started last year by BRRI and Thailand. But many of these problems are site specific and more field trials are needed.

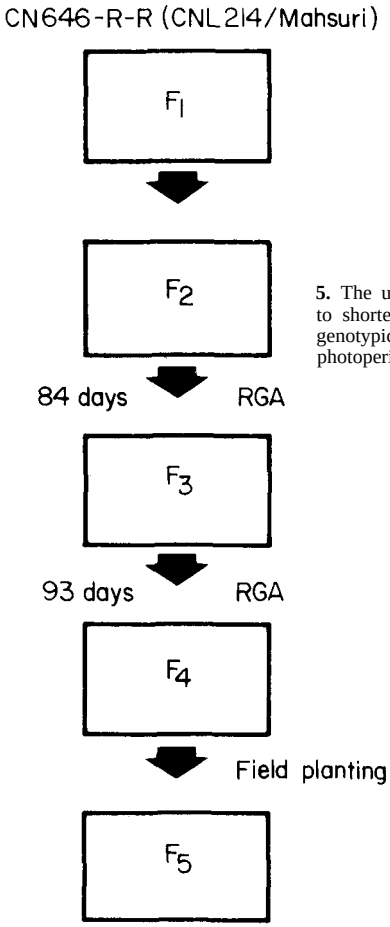
With the introduction of better plant types, the fertilizer rate, sowing density, and even weed problems will vary.

RAPID GENERATION ADVANCE AS A STRATEGY

Many deepwater-rice areas require long-growth-duration varieties. Such modern varieties can be bred by incorporating photoperiod sensitivity. The photoperiod sensitivity requirement makes breeding more laborious because only one generation can be planted a year. With the use of rapid generation advance (RGA), at least three generations a year are possible. Genotypically fixed bulk materials can therefore be provided to interested deepwater-rice breeders within a shorter time after a cross is begun (Fig. 5). In the RGA, the plants are subjected to short days and high temperature so that a growth duration of 180 days in the field is shortened to 80 days in the greenhouse.

The facility and techniques for generating RGA materials are now used at IRRI. However, the possibility of screening for certain plant characteristics during the RGA still has to be fully exploited to make maximum and effective use of the RGA. Thailand and IRRI are looking into such possibilities.

Bulk materials from the RGA are available. The plant breeders at specific sites can make their own selection and increase the materials for further trials and observations. The effectiveness of RGA has yet to be proven by the advance lines that may result from the crosses processed by RGA.



5. The use of rapid generation advance to shorten the period of producing genotypically fixed bulk materials of photoperiod-sensitive crosses.

THE MULTIPLE CROPPING STRATEGY

In the last 5 years, cropping patterns for the deepwater-rice areas have been developing. The farmers of Bangladesh, Burma, Vietnam, and India; BRRI; and the multiple cropping section in Thailand are conducting trials on this important subject. Several cropping patterns have been developed and many are still to be tried.

One established pattern in deepwater areas is the planting of winter or boro rice after deepwater rice. A similar pattern is used in Burma. In some areas, the residual water is used; in others, supplemental irrigation. In many cases, the second crop yields higher than the deepwater-rice crop. Therefore, the tendency is to leave the land unplanted to floating rice to ensure early planting of the off-seaon crop. The possibility of having two good crops might be improved by developing varieties with shorter growth duration and cold tolerance for use during the off-season. In some areas, cold tolerance does not seem necessary. Also, BRRI is studying the possibility

of row-seeding deepwater rice so that the winter rice can be relay-planted between the rows of deepwater rice before harvesting. Many improvements are possible but they should be tested before they can be recommended to farmers.

Another established cropping pattern, practiced by farmers in Bangladesh, is the sowing of a short-growth-duration variety together with a deepwater-rice variety. The deepwater rice continues to grow and produce nodal tillers after the short-duration variety has been harvested and the water level has risen. The possibility of improving this method by row seeding the two varieties alternately is being explored at BRRI and in Thailand. A more definitive study is needed.

In Thailand, the possibility of row seeding and using mungbean between rows was tried last year. The mungbean can be harvested before the water level rises. Much additional research and trials are still needed but the possibility of another crop in these single-crop areas is becoming more and more necessary if we are to increase food production.

RATOONING AS A STRATEGY COMPONENT

Another possibility of increasing land-use efficiency is to sow a photoperiod-sensitive variety with good ratooning ability in November-December after the main deepwater rice crop has been harvested. This variety flowers and matures in 4–5 months and can be harvested 1 or 2 months before the water rises. After harvest, the ratoons develop but remain vegetative because of the longer day length. Flowering occurs in September-October and harvesting in November. This scheme is worth trying now that varieties that have excellent ratooning ability have been identified. Crosses between these varieties and the deepwater rice might give some useful progenies for trials.

This type, however, can be used only in areas where water is sufficient throughout the year, as in low-lying areas where the soil does not dry up completely or where a water pump is available.

THE MULTILINE VARIETY

While we are looking at research strategies for excess water, some wild ideas might be worth examining. In areas where water level is very erratic, including those with no standing water in certain years, a multiline variety might be the answer. The multiline might contain lines with drought resistance for the early seedling stage, some with submergence tolerance or rapid elongation ability for times when the water rises rapidly, some with early elongation ability in cases where water comes in early, and lines with different flowering dates, which might also be considered in cases where the peak water level varies from year to year.

A STRATEGY TO INVOLVE FARMERS

Research priorities can also be determined by visiting farmers' fields — talking to

them, understanding their practices, and knowing their problems, then going back to the workroom and trying to solve such problems. This method is effective but is seldom used. One driving through the rice country seldom finds a farmer near the road to talk to. Perhaps more effort should be made to make it possible for farmers to meet with scientists — or scientists to meet with farmers?

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RESEARCH STRATEGIES FOR IMPROVEMENT OF DROUGHT RESISTANCE IN RAINFED RICES

J. C. O'TOOLE, T. T. CHANG, and B. SOMRITH

Water is a primary factor in determining the world's annual rice production. Except in adequately irrigated areas, all types of rice culture are subject to significant yield fluctuations because of water deficits. The area involved is difficult to estimate because of the lack of statistics on rice areas classified by water-related type of culture — irrigated, shallow rainfed, intermediate rainfed, deepwater, and dryland. The rainfed component of the world's rice crop is estimated, however, to be about 47% of the world's 141 million hectares. In South and Southeast Asia this estimate rises to 66% of the rice-growing area (Table 1).

Irrigating the rainfed areas is the most direct means of coping with drought in the rice crop. The value of irrigation works to society is historically documented in Japan where increased irrigation greatly decreased the social disturbance formerly associated with drought occurrence (Takahashi 1979). However, at current costs (US$500-$2,000/ ha) and given the time such conversion requires, as exemplified by the Chinese and Japanese experience, large proportions of the world's rice areas will remain rainfed during the foreseeable future.

Severe and prolonged droughts on a wide geographic scale, such as those that occurred over much of northern and eastern India, Bangladesh, and north-central Burma in 1979, represent extreme conditions. However, these areas and parts of Thailand, Laos, and Kampuchea constitute large contiguous rice-growing regions where drought is a chronic feature of the risk associated with rainfed rice production.

Figure 1 illustrates the magnitude of the subhumid climatic type. This climatic zone coincides with the drought-prone regions noted above, where large-scale severe drought occurred during 1979. The droughts that were less severe in area and duration contribute significantly to the year-to-year variability in yield that characterizes raided-rice production. In eastern Uttar Pradesh, droughts in 5 of the last 10 years have resulted in marked decreases in rice yield. It should be noted that the areas with subhumid climate (Fig. 1) usually rank low in average total crop season rainfall,

Agronomist and geneticist, Agronomy and Plant Breeding Departments. IRRI; and superintendent, Chiangmai Rice Experiment Station, Chiangmai, Thailand.

Table 1. Gross estimates of rainfed rice area in major rice-producing countries, 1973-75 average. Adapted from IRRI Long-Range Planning Committee Report, January 1979.

Region	Area (thousand ha) and % of total					
	Total in rice	Rainfed				
		Dryland	Deepwater	Shallow rainfed	Intermediate rainfed	Total, by region
South and Southeast Asia	84,242	8,479 (10%)	7,421 (9%)	27,306 (32%)	12,871 (15%)	56,077 (66%)
Other Asian countries	41,653	757 (2%)	0	2,876 (7%)	0	3,633 (9%)
Other regions (including Africa and the Americas)	14,632	4,777 (33%)	0	439 (3%)	995 (7%)	6,211 (42%)
World total	140,527 (100%)	14.01 3 (10%)	7,421 (5%)	30,621 (22%)	13,866 (10%)	65,921 (47%)

thus amplifying the effects of lower-than-average rainfall or abnormal distribution.

In what are termed *chronic drought-prone areas,* such as eastern Uttar Pradesh, drought-mediated variation in yield has far-reaching effects on the stability of social and economic systems as well as of food supply per se. A discussion of these consequences is beyond the scope of this paper.

Because rice is primarily a semiaquatic species, even a few days of mild moisture stress during critical growth phases may decrease yield. Water deficits of this nature, usually not perceived by most agriculturists because of lack or the transient nature of overt water stress symptoms, result in lower yield through small increments of reduced crop growth and adverse effects on yield component development. Thus, drought damage takes many forms - catastrophic consequences of severe drought over wide geographic areas, serious and frequently occurring stress common to chronically drought-prone areas, and relatively mild and perhaps unnoticed stress, which decreases yield through small cumulative effects.

An additional concern is the ominous signs of long-term variability in climate. A cooling trend up to the year 2000 could lead to more frequent droughts in Africa and South Asia (Bryson 1974, Thompson 1975). Stansel (1980) illustrates the global implications of altering temperature, precipitation, and solar radiation across the various rice cultural systems. The possible changes in rainfall totals or distribution patterns provide extra emphasis for the evolution of more drought-resistant cultivars.

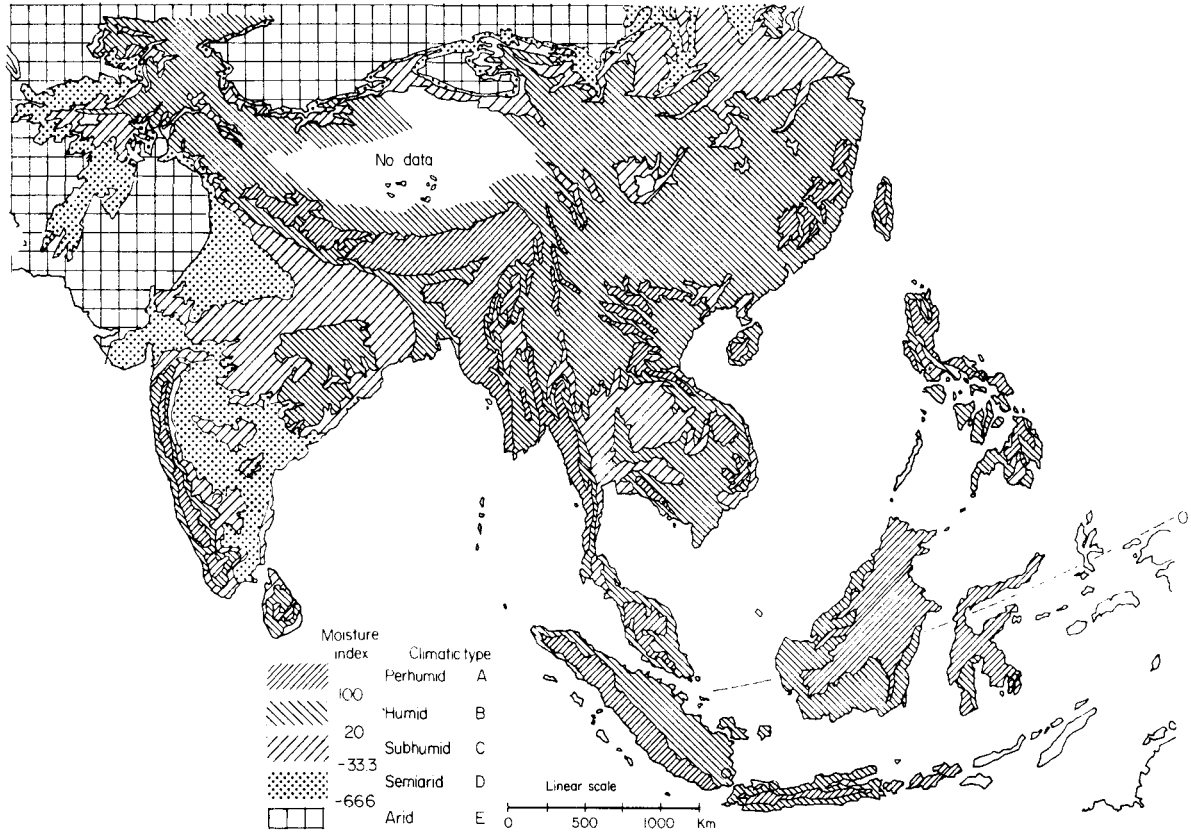
Thus, the short- and long-term returns to the development of genetic technology that will buffer the rice crop against various degrees of drought severity and production losses are significant. Although the importance of drought to rice grain production is obvious to many rice breeders (Hargrove and Cabanilla 1979), fewer drought studies have been initiated on rice than on other major food grains.

Why is that the case?

We believe it is because:

- few research results attest to the existence of significant differences in the rice germplasm;
- proven methods and techniques, such as those used in breeding for insect and disease resistance are not available;
- persons involved in rice breeding had no training and support in soil-plant-water relations to cope with drought; and
- crop improvement for drought resistance in rice as a practical goal is not universally shared.

Krishnamurthy et al (1971) questioned the validity of initiating crop improvement Programs for such nonspecific stresses as low fertility, drought, and salinity. They concluded that drought and salinity affect different rice varieties more or less uniformly. Thus the lack of variation in the germplasm for the nonspecific stresses, unlike for the specific stress associated with disease, precluded success in varietal improvement. Even the rice breeders who have made empirical progress over the years attest to the extraordinary difficulties associated with the breeding and selection for resistance to drought (Rao et al 1971a, D. M. Maurya, S. C. Prasad, pers.



1. Moisture regions of South and Southeast Asia based on the Thornthwaite moisture index (Carter and Mather 1966).

comm.). Those involved readily acknowledge that a lack of relevant and repeatable screening methods for evaluation of donors and progeny discourages a serious sustained effort.

However, we are convinced that sufficient knowledge has been generated over the last decade to allow improvement of rice for this complex trait by planning and implementing research strategies suited to the location-specific ecological conditions describing drought and tailored to the institutional and human resources available to do the job. Before we discuss this further, it would be beneficial to review breeding and selection for drought resistance in other crop species and the progress made with rice in various national programs and at IRRI.

REVIEW OF RECENT PROGRESS

Other cereals

The crop and location specificity of drought resistance has produced a large volume of literature dealing with selection criteria, screening methods, breeding schemes, and attendant physiological studies. So great is the mass of literature, especially on upland cereals such as wheat and sorghum, that only a few reviews will be noted here to illustrate progress made in breeding and selection for drought resistance. Hurd (1971) confidently argued that breeding for drought resistance was feasible and outlined a scheme suitable for wheat breeding in semiarid environments. In a later report (Hurd 1975), he illustrated results of such a scheme and attributed the drought resistance incorporated in new wheat lines to the selection of cultivars with extensive root systems.

Selection for root characteristics has received major emphasis in several drought resistance efforts. In a recent review, Hurd (1976) noted that breeding for rooting patterns had been carried out with barley (Garkavy et a1 1970), oat (Pohjakallio 1945), wheat (Roma 1962, Kirichenko 1963, Hurd 1964, Hurd et a1 1972, Hurd 1975), maize, and sunflower (Kirichenko 1963).

Intuitively, cultivars of upland crops with deeper and more extensive root systems should be more effective in exploiting soil moisture during drought periods or in semiarid environments. An interesting alternative is currently being pursued in Australia. It seeks to breed and select for wheat with root systems that slowly remove the stored soil water over the season instead of depleting it too rapidly. The approach involves selecting for wheats with deep seminal roots but with relatively small-diameter xylem vessels. Scientists of the Commonwealth Scientific and Industrial Research Organization are currently selecting progeny on the basis of previous studies (Passioura 1972, 1976). Although the results are not yet known, the efforts are an example of breeding and selection to tailor the crop to specific conditions.

Sorghum has also received considerable study. Sullivan and Ross (1979) review their philosophy and degree of success in the breeding and selection for both heat and drought resistance in sorghum. They have concentrated on selection for the maintenance of high water status and the capability to tolerate heat and desiccation when maintenance of water status is no longer possible. They have shown that

differences for these parameters exist in sorghum and can be selected for by their techniques. Their results with heat tolerance are convincingly correlated with yield.

Blum (1979), in a paper on drought resistance in sorghum, reviewed three major strategies currently being used in breeding for drought resistance. The first, which assumes that a variety giving superior yields under optimal growing conditions will also yield relatively well in suboptimal conditions, handles yield and stability as one complex. In so doing, it requires an improvement in yield under optimum conditions, which may often be irrelevant in breeding for suboptimal environments.

With the second approach, superior cultivars for drought-prone environments should be selected in situ, with the particular environment applying the appropriate selection pressures. Although appealing, this approach has the advantage that the variability associated with drought-prone environments slows progress and often calls for the testing of large populations, which decreases the efficiency of the total program.

The thud approach involves the selective incorporation of relevant drought-resistance factors into cultivars with superior yielding ability under optimum conditions, thus making them better adapted to the suboptimal conditions. It is analogous to the strategy used by plant pathologists in their efforts to incorporate specific genes for disease resistance into superior lines. This strategy requires the combined efforts of plant breeders, crop physiologists, biochemists, meteorologists, and soil physicists to ensure the full exploitation of available germplasm.

Regardless of the crop or strategy used, progress in plant breeding for drought resistance continues to be difficult to demonstrate in a manner that satisfies the varied concepts of drought resistance held by different disciplines. However, recent work using gradient irrigation systems and dealing with yield and yield stability as well as physiological measurements has made excellent progress toward this end (Sullivan and Ross 1979, Watts et al 1979).

Rice

The major research on drought resistance of rice has been in the national programs of India and Thailand and at IRRI.

India. In north-central and eastern India, drought is accepted as a frequent production constraint. The rainfall zones and the frequency of droughts of varying duration in these sections of India are well documented (George et al 1973, 1974). About 1955, attempts to breed varieties for drought resistance were made in the states of Tamil Nadu and Kerala. Cultivars that suited the particular conditions of those areas were released from Coimbatore and Pattambi (Rao et al 1971). Further breeding for drought-resistant cultivars suited for dryland culture was implemented at the Central Rice Research Institute (CRRI).

The philosophy that was developed and applied resulted in the evolution of the variety Bala in 1971. It was reviewed in several papers by M. J. B. K. Rao and associates (Rao and Choudhury 1969, Rao et al 1971a, b). The early-maturing and drought-resistant semidwarf was derived from N22/ TN1. Its eventual adoption by farmers in the drought-prone states of Madhya Pradesh, Uttar Pradesh, and Bihar

attests to the success of the breeding and selection strategies.

Generally the strategy relied on identification of drought-resistant traditional cultivars well adapted to local conditions. These cultivars were crossed with modern cultivars having more desirable agronomic traits, and the populations were selected in situ at drought-prone sites.

Several studies on the physiological basis of drought resistance complemented the breeding efforts (Murty et al 1967, Murty and Srinivasulu 1968, Bhattacharya et al 1969, Bhattacharjee et al 1971) that are ongoingat CRRI. With the establishment of the All-India Coordinated Rice Improvement Project (AICRIP) in 1965-66, systematic yield trials of promising lines were carried out throughout India's drought-prone districts.

Special AICRIP studies on drought resistance during the 1969-70 kharif identified Bala and other entries for rainfed areas and illustrated the need for short-duration (less than 110 days) cultivars in north-central India (AICRIP 1969, 1970). They further showed that the hybridization of traditional drought-resistant cultivars with modern high-yielding dwarf indicas was a feasible strategy given the ability to test the progeny in drought-prone locations.

Since 1975, efforts to identify and study the most drought-resistant cultivars and breeding lines have been taken up by AICRIP and cooperating plant physiologists at several stations. Studies relating yield and yield components to climatic records, soil moisture, and plant water status have identified striking differences among cultivars (AICRIP 1978).

The AICRIP studies on moisture stress are conducted at some of India's most problematic drought-prone locations: Hathwara (West Bengal), Kanke (Bihar), Faizabad (Uttar Pradesh), Derol (Gujarat), and Hyderabad (Andhra Pradesh). Although grain yield varies greatly due to year and site differences, several entries are common to the list of top five yielders across years and sites. Table 2 lists several of these entries. The crosses apparently reflect the rice breeder's strategy to combine attributes of the traditional varieties with the superior plant type of modern high-yielding cultivars. Unfortunately, the parental sources with the desired attributes are not always grown with the progenies for comparison. However, because of the high frequency of these crosses among the top-ranking yielders, the strategy appears to function under these Indian conditions. The results of these trials as well as of other AICRIP trials for the extremely dry 1979 season may prove valuable in assessing the progress and extent to which it may be possible for rice to be improved for this type of stress.

The AICRIP studies on moisture stress are rapidly developing new information on the response of rice to drought periods and have the interpretive advantage of being carried out in the most drought-prone areas in India. The results should prove quite valuable if properly interpreted and used in future breeding and selection for rainfed cultivars.

Since 1979 eight experiment stations in drought-prone area have collaborated with IRRI in testing a number of varieties and breeding lines. The aim is to broaden the choice of parents for use in India. The hybridization work is being done at IRRI, and F_2 seeds will be supplied to the stations in India.

Table 2. Pedigrees of selected top-yielding entries in the 1976, 1977, and 1978 AICRIP studies on moisture stress trials (AICRIP 1978).

Entry	Cross
CR 141-192	N22[a]/TN1[b]//T90/IR8[b]
CR 143-2-2	N22/TNl1/LaInakanda
IET 1444	TN1//CO29
IET 2914	IR8/N22
IET 4106	Cauvery///Baok/N22//Red
IET 5849	RPA 5824//IR8/N22
IET 5850	RPA 5824//IR8/N22
IET 5851	lR8/LZN//IR8///IR8/Siam 29
IET 5860	RPA 5824//IR8/N22
IET 6148	N22/TN1//CO13
RP 79	IR8/N22

[a] NZL — a traditional dryland variety used in the drought-prone areas of north-central India for over 40 years. Listed as donor of deep root system (IRRI 1976); Lalnakanda — popular dryland variety from the Punjab with good level of drought resistance (Rao et al 1971a, b). [b] TN1, IR8 – semidwarfs with demonstrated wide adaptiveness and high yield potential. TN1 and IR8 are leading examples of the new plant type in tropical rice (IRRI 1972b).

Thailand. A recent report by the Thai Department of Agriculture ascribed losses in rice production to adverse weather in 64 of the 127 years 1831-1957. Droughts, which occurred in 60 of those years, became well recognized as a constraint to stable yield in Thailand (Hsieh and Ruttan 1967, Thai Department of Agriculture 1977).

Researchers in Thailand's Rice Division have separate breeding programs where drought resistance is approached differently because of the nature of the problem: dryland or hill rices in the north, transplanted rainfed wetland rice in the northeast, and intermediate to deepwater rainfed rice in the central plain.

The Khon Kaen Rice Experiment Station in northeast Thailand has served as the center for dryland and rainfed wetland rice improvement for drought resistance. In 1975 dryland drought screening tests started with local varieties, exotic germplasm from IRRI, and breeding lines from stations throughout Thailand. The screening was followed by a vigorous crossing program aimed at improving drought resistance. The distribution of F_2 populations to selected stations has allowed selection for that area. It is interesting to note that coupled with the distribution and testing of new germplasm has been the advent of direct-seeding trials. Some of the new selections have proved better adapted to direct seeding than the traditional popular varieties (Chang et a1 1979, Somrith 1980). Thus a combination of superior varieties and change in cultural practices offers the best opportunity for rice improvement in northeast Thailand.

The Thai breeders have sustained an active program of testing early-generation materials from IRRI and have collaboratively evaluated such materials at several sites.

In much of the rainfed-wetland and deepwater areas, establishment of either

transplanted or broadcast crops is affected by drought during the erratic onset of monsoon rains. This particular problem has been addressed at both the Huntra and Klong Luang stations near Bangkok. Dry-season field screening of local varieties and hybrids for seedling survival has been in progress since 1976. Initial tests were encouraging. Differences in the germplasm for ability to survive and vigorously recover from severe seedling stage stress have proved to be highly repeatable (Nopporn and Jackson, pers. comm.).

During the 1978 and 1979 dry season, drought-screening techniques were modified to suit local conditions and now are a regular part of the deepwater rice program at Huntra and Klong Luang. Repeatedly these trials have identified superior entries such as FR13A, BKN6986-108, and BKN6986-147-2. These results confirmed the good performance of the latter two, as reported by De Datta and O'Toole (1977). BKN6986-147-2 was recently released in Thailand as RD19. It has seedling-stage drought resistance.

The results in Thailand have increased breeders' interests elsewhere. In 1979, in conjunction with IRRI, Thai scientists formed a drought-screening nursery especially for deepwater rice cooperators and distributed the entries to interested parties in Asia and Africa through IRRI's International Rice Testing Program (IRTP).

Three important features of the progress made in Thailand deserve special note:

- researchers have concentrated on defining the type of drought damage and important growth stage interactions;
- local conditions and resources have been successfully utilized to produce repeatable screening results and establish the confidence of the researchers in their techniques; and
- the latter has become obvious to others outside Thailand and has catalyzed international collaboration.

IRRI. Since the 1969 decision (IRRI 1970b) to direct more of IRRI's research toward nonirrigated areas, the awareness of water deficits in plant breeding and technological development programs has increased dramatically.

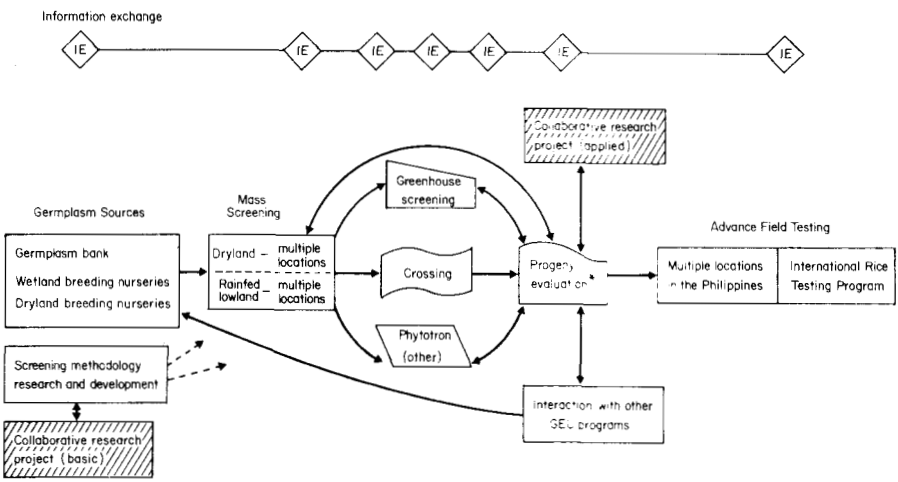
In the late 1960s, field testing of wetland breeding lines had started at drought-prone dryland sites (IRRI 1970a, 1971; De Datta and Beachell 1972). These efforts were enlarged to multilocation trials, which were the forerunners of the IRTP's upland observational and yield nurseries. Concurrently studies were initiated to contrast morphological and physiological characteristics of traditional dryland and wetland adapted cultivars and determine what characteristics were correlated with drought resistance (Loresto and Chang 1971, Krupp et al 1971, Chang et al 1972, Chang and Vergara 1975, Parao et al 1976).

The methods used in identifying cultivars best adapted to drought-prone conditions have increased over the years and substantial scientific and empirical knowledge has accrued (Chang et al 1972, 1974; De Datta et al 1974). The early studies culminated in the publication *Major research in upland rice* (IRRI 1975b), which placed great emphasis on drought resistance (Yoshida 1975, Chang and Vergara 1975, De Datta et al 1975).

When IRRI's Genetic Evaluation and Utilization (GEU) program was formalized

in 1973, a four-scientist team was established for the drought-resistance problem area. The GEU drought team established a plan of action, which is illustrated schematically in Figure 2 and forms the basis of our brief review of progress.

The GEU drought team's approach is to identify variations in response to drought that exist in the diverse rice germplasm at IRRI, and *selectively,* recombine it through hybridization to develop a vast array of genotypes to meet the varied needs of rainfed-rice cultures. An appraisal of the diverse ecologcal background in which rainfed rice is grown and of the ambiguous meaning and use of the word *drought* was a fundamental step. Clarification of the complex nature of interactions between rainfall deficits and other environmental factors greatly aided our understanding of what drought is and the potential for its direct and indirect effects on crop growth and yield (Yoshida 1977; O'Toole and Chang 1978, 1979). Promising parents for drought resistance were generally identified from those areas where water deficit is a chronic problem (Chang et al 1979).



2. Schematic representation of the activities collectively representing the drought resistance component of IRRl's Genetic Evaluation and Utilization program.

At the heart of activities in Figure 2 is crossing. The general approach in hybridization for dryland culture is to recombine the drought resistance and blast resistance of the traditional varieties with the high-yelding ability and pest resistance of the semidwarfs (Chang et al 1975). Parents of the traditional type were drawn from all major production areas: West Africa, Brazil, India, mainland Southeast Asia, Indonesia, Philippines, and Japan. Three-way and double crosses were frequently used to pool the genes from diverse sources. Semidwarfs possessing high levels of disease and insect resistance contributed to a major portion of the donors. Improved dryland varieties of different countries were also included in the crossing program. Since 1973, about 1,500 single crosses and 2,000 multiple crosses have been made to suit different breeding objectives.

Initially, difficulties were encountered when partial sterility and restricted recombination appeared in the distant crosses described above (Hung and Chang 1976, Lin 1978, IRRI 1979). Very few useful progenies were selected from hundreds of F_2 populations. Those progenies were, however, further used in the crossing program to overcome the various restrictions. Gradually we were able to work toward an intermediate type with many of the desirable characteristics of the two contrasting parents. Progenies of moderately tall stature were selected because they generally suffered a less severe reduction in height when grown under dry conditions on a soil of poor fertility. Tall plant stature and long-and-deep roots were frequently positively correlated (Chang et al 1972; IRRI 1976, 1977).

Given the sources of genetic variation for response to drought and for extensive hybridization, much research on development of screening methods and criteria has been conducted. The emphasis on breeding and selection criteria leads to physiological studies as a basis of interpreting the empirical selection methods and further refinement of the selection process. Beginning with observations by agronomists and plant breeders, which gave rise to a large amount of empirical evidence for varietal differences in response of rice to water stress (Rajagopalan 1966; Basu et al 1970; Chaudhary and Ghildyal 1970; IRRI 1971, 1972a, 1973, 1974, 1975a, 1976, 1977, 1978a, 1979, 1980; Bhattacharjee et al 1971; Krishnamurthy et al 1971; Rao et al 1971a, b; Chang et al 1972, 1974; Loresto et al 1976; Alluri and Vergara 1976; Ibrahim et al 1976; T. T. Chang, S. K. De Datta, H. K. Krupp, and S. Yoshida, unpubl. data), efforts were made to identify plant characteristics that contribute to drought resistance, and to examine each characteristic's relevance, and develop selection criteria or screening methods for its identification in both donors and progeny after hybridization. This activity is identified as *screening methodology research and development* in Figure 2.

Absorption of water during periods of drought is related to root system depth and density (Yoshida et al 1974, Paningbatan et al 1975). Varietal differences in both these characteristics have been found and techniques developed to screen germplasm in both the greenhouse and field. These techniques have been used to characterize several hundred genotypes (Changet al 1972, 1974; Yoshida et al 1974; IRRI 1975a, 1976, 1977, 1978, 1979, 1980; Loresto et al 1976; Reyniers and Binh 1977; Binh and Beunard 1979). These varietal differences have also been illustrated by differing water extraction patterns during water stress in field-grown rice crops (Hasegawa et al 1979, Puckridge et al 1979, Tomar and O'Toole 1979). When available soil moisture becomes limiting, shoot characteristics that conserve water during periods of water stress become important in maintaining the crop water status at desirable levels. Stomatal closure, plasticity in leaf rolling, and, to a lesser degree, cuticular resistance, have all received attention (Yoshida and de los Reyes 1976; O'Toole et al 1979a, b; O'Toole and Moya 1978; O'Toole and Cruz 1980). These studies have illustrated that leaf rolling and stomatal closure were highly correlated to leaf water potential. Thus leaf rolling, which is an overt symptom, can be used as an estimate of the other two less-obvious physiological responses to drought. This information is vital to rice breeders because the visual scoring system for field screening uses leaf

rolling and unrolling as indicators of degree of plant water stress (Chang et al 1972, 1974).

Visiting scientists from Australia and United States have contributed greatly to the development of more sophisticated screening approaches such as use of the line-source sprinkler technique (IRRI 1980, Puckridge et al 1979) and the initiation of detailed studies on the causes of rice's extreme sensitivity to stress during reproductive stages (IRRI 1980). In addition, IRRI scientists have entered into collaborative research with specialists from Australia, England, and the United States. These projects have addressed such subjects as root sampling of field-grown rice, osmotic adaptation or adjustment during water stress (Steponkus et al 1980), and abscisic acid accumulation in response to stress.

All the above studies dealt with plant characteristics that function to maintain high shoot-water status by absorption of soil moisture or by conservation of plant water during periods of drought. These traits collectively function to maintain high plant water potential, and degrees of varietal difference have been found for all of them. This information has complemented the empirical type of visual scoring associated with large-scale screening of germplasm. Information from the screening of thousands of entries and from the numerous studies of the physiological mechanisms involved has accumulated rapidly in recent years. However, studies involving the genetics or heritability of these responses and mechanisms are obviously lacking. As an example, many citations illustrated basic differences in the root and shoot system characteristics of rices from differing hydrological backgrounds. But information on the heritability of these traits is empirical or only crudely illustrated (IRRI 1976). Studies on the genetics and inheritance of rooting characteristics should be given high priority because such characteristics are obviously important and easier to interpret quantitatively than the more dynamic shoot parameters.

Figure 2 shows the *screening methodology research and development* being applied to various screening activities: mass screening, greenhouse screening, and phytotron or specialized screening. Mass screening is done in the dry season by agronomists and plant breeders. The techniques used by them have been developed over several years and represent careful observations of the response of many thousands of rice genotypes to drought stress (Chang et al 1974, Loresto et al 1976, IRRI 1975c). The results and description of the techniques are also found in recent annual reports (IRRI 1974, 1975a, 1976, 1977, 1978).

Screening in the greenhouse is basically of two types. The first, a simulation of dry-season screening, is done in a special greenhouse during the wet season (O'Toole and Maguling 1978).

The second type of greenhouse screening seeks to identify rices with tolerance for and ability to recover from drought stress. The procedure was arrived at through a series of studies (Alvarez and De Datta 1973, Sarkar and De Datta 1975, Sarkar 1975) with varying techniques and levels of predetermined soil moisture stress. It is illustrated in the IRRI annual reports for 1976 and 1977 (IRRI 1977, 1978). There is a striking contrast among rices in their capability to sustain themselves and to recover (IRRI 1978). A similar screening technique used the controlled environment

of IRRI's phytotron (O'Toole et a1 1978).

The various research and screening activities interact in the production of new varieties and the evaluation of their drought resistance by varying means before (often at the same time that) the resulting progeny are yield tested in rainfed conditions where drought resistance is only one of the factors determining their performance.

To cope with the unpredictable weather elements and the diversity in soil conditions, we have been testing genetic materials in many locations in the Philippines (IRRI 1977, 1978, 1979). Even when varietal responses were concurrently compared under both the stressed and well-watered treatments, the experimental results often defied simplistic interpretation. Because yield is such a complex end-product of crop development and genotype-environment interaction, we do not consider the high yields obtained from a genotype as a direct indication of drought resistance; we use the relative magnitude in yield reduction between an irrigated and a stressed treatment as the basis for comparison (Chang et al 1974, 1979).

The practical result of the drought team's effort is that in 1978 two lines selected from wetland nurseries and subjected to the various tests and trials were named by the Philippine Seed Board for dryland use: IR43 (lR1529-430-3-1) and IR45 (IR2035-242-1). Other lines involving hybridization with selected drought-resistant parents have advanced to field test trials of the Seed Board.

Another important activity that started in 1974 was the distribution of breeding lines as donors to national programs in Brazil, Indonesia, Ivory Coast, Liberia, Nigeria. and Thailand, as well as international centers such as the International Institute of Tropical Agriculture (IITA), Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (IRAT), and West Africa Rice Development Association (WARDA). To permit local scientists to select lines best suited for their particular ecological conditions, distribution of F_2 populations was begun in 1975. Because of the limitations placed on IRRI's drought resistance program by weather conditions at Los Baños, the distribution of F_2 populations through collaborative breeding programs with breeders in drought-prone locations appears to be a mutually beneficial future activity.

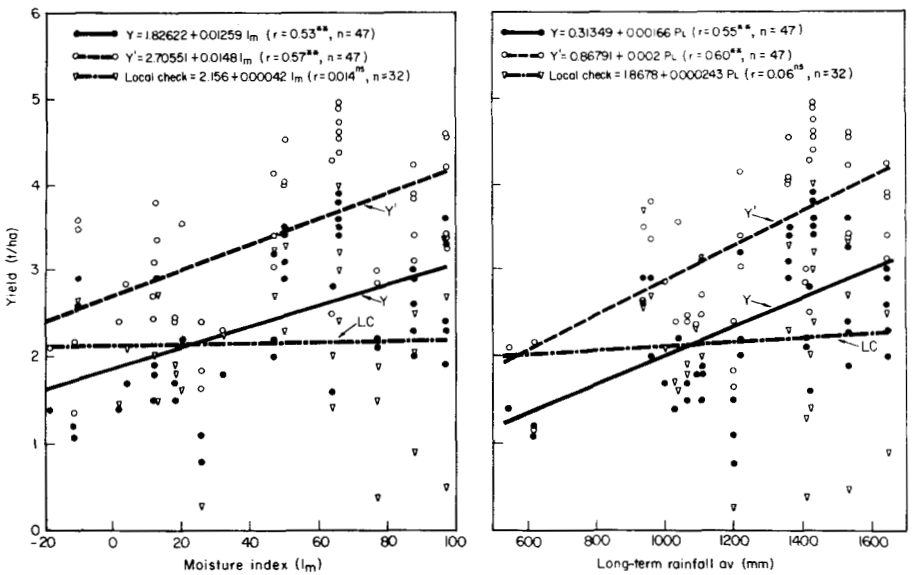
The rainfed yield trials by IRRI and the Philippine Bureau of Plant Industry precede the nomination of only a selected few varieties to IRTP for upland nurseries. Unfortunately, the International Upland Rice Observation Nursery (IURON) and the International Upland Rice Yield Nursery (IURYN) are the only rainfed nurseries in the IRTP program.

During the past 4 years, several IRRI breeding lines known to have high levels of drought resistance in IRRI tests have shown similar merits in many IURON tests as well as in collaborative drought tests in India, Indonesia, and Thailand. IR1746-226-1, IR1750-F5B-5, the IR3880 lines, the IR3646 lines. IR3939-1, IR5178-1-1-4, and IR6115-1-1 have repeatedly shown up as resistant entries. The inclusion in their parentage of a traditional drought-resistant variety indicates the heritable nature of drought resistance, partly expressed by deep and thick roots (IRRI 1976, 1979; T. T. Chang and G. C. Loresto, unpubl. data).

In the schematic diagram (Fig. 2), the nomination of varieties to the IRTP rainfed nurseries would have been the culmination of the IRRI drought team's activity, and, indeed, the progression of donor and hybrid materials through this series of tests is a good example of interdisciplinary research and genetic technology development. But the IRTP has allowed even more to be learned by examining how entries react in other drought-prone environments. However, we faced the problem of classifying the various locations without sufficient information on climate and soils and, often, even the current year's precipitation.

Lacking the basic information on site description and rainfall data, we used available historic records on long-term rainfall during the crop season and the moisture index illustrated in Figure 1 (Thornthwaite and associates 1963, Carter and Mather 1966).

Further analysis of the Asian sites where the IURYN was grown in 1975, 1976, and 1977 is illustrated in Figure 3. In it, the various yields are plotted on the moisture index I_m and the long-term crop season rainfall for each site and season combination. We will stress only a few points in this figure. First, the mean yield (y) and mean yield of the two highest yielding entries (y') at each location show the expected increase with increased I_m or seasonal rainfall. However, the line representing the local check, usually the predominant locally adapted variety, shows that even



3. Relationship of yield of International Upland Rice Yield Nursery (IURYN) entries 1975, 1976, and 1977 and Thornthwaite moisture index (Carter and Mather 1966) and long-term rainfall (Thornthwaite and associates 1963) for the growing season at each location. Y = mean yield of all varieties (n = 25) at a location, Y' = mean of 2 highest yielding varieties at a location; local check = locally adapted variety grown with same agronomic practices as IURYN entries.

though grown in agronomic conditions identical to those in which other entries in the nursery were grown, the checks do not exhibit the modern varieties' potential to use extra water and added nitrogen, They do, however, exhibit the stable quality often referred to, i.e. flat slope. The second point is that at the driest locations the mean yield (y) drops below the local check. However, even at these locations the mean of the two best introduced varieties (y') is equal to, not less than, the local check. The most significant observation is the difference between y' and the local check as rainfall conditions become better. The yield level of the 2 best introductions is no worse at 600 mm, 1 t/ha greater at 1.100 mm, and 1.5 t/ha greater in the high-rainfall areas, > 1,500 mm.

We believe the response of y' compared with the overall mean (y) response, represents the significant contribution of the IRTP in facilitating the distribution of new and potentially drought-resistant germplasm to rainfed areas of Asia.

Further research is necessary to cluster homologous environments in the IURYN and determine what attributes enable the y' varieties within the clusters to yield higher.

In summary, the accumulated results of empirical plant breeding efforts. agronomic trials in rainfed environments, and a host of physiological and ecological studies have illustrated that genetic improvement of rice to make it cope with drought is indeed possible. That experience has illustrated well the need for a thorough understanding of the type of site-specific drought conditions and how they interact directly and indirectly with other primary environmental factors as well as the ontogeny of the rice crop. The lessons learned from the successes and failures in crop improvement efforts for this trait over the past decade should enable rice scientists to significantly better understand the objectives and thus devise superior strategies for the future.

STRATEGIES, RESOURCES, AND INSTITUTIONS

The overall strategy of rice breeders — to recombine the drought resistance, local adaptation, and stable yielding characters of traditional varieties with the yield potential of modern varieties — remains unchanged. However, in the light of our experience in the 1970s, the speed and efficacy with which we progress toward that goal could be much enhanced. We realize that breeding programs and institutions concerned with rainfed-rice improvement vary greatly in both the physical and human resources available.

We feel that the following steps should be incorporated in any overall strategy, regardless of the resource base.

- *Diagnosis.* A plant breeder who recognizes drought as a principal yield constraint in the target area may benefit from interactions with climatologists, crop physiologists, and soil scientists before embarking on a course of action. The details of such preparatory research and discussion are not within the scope of this paper but should entail knowledge of the frequency of drought occurrence and how it relates to the various crop growth stages. Increased awareness of the

dynamic interaction between soil, plant, and weather during a drought period (Hsiao et al 1980), especially during the reproductive phase, may be a great aid in the choice of a sound course of action.

- *Adopting appropriate selection criteria.* The literature is replete with suggested criteria. Very few of these criteria are rapid, inexpensive, simple, and physiologically based on the interaction of drought with crop growth and yield. Unimpaired growth and yield during a rainless period are inextricably correlated with water use by the crop. Thus, we recommend that criteria based on a variety's ability to maintain high water status and efficient water use be most soundly related to productivity in an agricultural sense. In the absence of overt symptoms, visual scoring based on leaf rolling, leaf-tip drying, and panicle development will be useful.

  Further investigations are needed to facilitate identification of the most effective combination of physiological mechanisms — escape (by early maturity or photoperiod sensitivity), avoidance (by deep roots), tolerance, and recovery (plasticity in vegetative growth) — that may suit a particular climatic-hydrologic-edaphic environment and thus provide a balanced approach. Continued assistance from research institutions in developed countries would make such studies possible.

- *Collaborative sharing of germplasm.* Research at IRRI has demonstrated some of the commonalities in drought resistance mechanisms between dryland and raided-wetland culture (Chang et al 1979).

  Several outstanding drought-resistant parents have shown their worth across West Africa, South and Southeast Asia, and Brazil. Promising parents should be identified and pooled in a coordinated hybridization and F_2 seed distribution program so that the useful genes can be pooled and fully used by breeders in national and international programs. IRRI initiated such a germplasm-sharing scheme in 1980.

  IRRI will continue monitoring drought resistance in breeding materials for the wetter regions, collaboratively testing materials in the drier regions outside Los Baños, and assembling appropriate physiological mechanisms for drought to meet specific needs. We also visualize a modification in the improved-plant type for the drought-prone areas — intermediate plant height, moderate tillering ability, adequate panicle size, and good panicle exsertion. Adequate disease and insect resistance, along with the desired grain characteristics, should be incorporated into the final product. More extensive testing will be carried out in farmer's fields within the drought-prone areas.

- *How to measure progress.* Although we have no ready answer for this critical question, we suggest that even though yield is of primary concern, it may be advisable to use caution in the initial stages. On the other hand, stability of yield or its components across crop years (as opposed to high mean yield) may be more meaningful if breeding lines are selected and evaluated in situ where high yield potential would not be realized except in unusually wet years.

- *Pooling of human and natural resources.* The problems associated with resour-

ces are particularly relevant to research on rainfed rice. Very few rainfed or nonirrigated rice experiment stations exist. Additionally it may be said that rainfed stations have been long neglected. While the high-yielding varieties and associated technology in irrigated regions have received national, institutional, and individual attention, research on the rainfed rices has not been adequately supported.

IRRI is ideally located for irrigated rice research, but is poorly situated for rainfed rice research because of the high rainfall and protracted wet season in most years. Thus, it is more advantageous for IRRI to use its physical and human resources to develop research of fundamental significance and to generate germplasm through coordinated hybridization than to pursue the whole course of progeny evaluation and variety development.

- *Prospects for collaborative assault on water-deficit research.* It is most encouraging that a number of national programs are now reassessing the problems of rainfed rice. CRRI in India held a symposium on rainfed rice during 1978. Several institutions such as the Maros Station in South Sulawesi, Indonesia, and rice stations in Karnataka State, India, have launched research programs on rainfed rice. Their initial steps have involved environmental description and subdivision of rice-growing areas by culture type. In Thailand the rainfed-rice program has received funding and the infusion of trained rice scientists from the irrigated-rice program.

Even so, these programs vary greatly in the governmental, institutional, and human resources available. A plant breeder at any one of the stations is faced with a set of practical factors that will eventually determine his choice of tactics and the soundness of that decision. IRRI's main role in the next decade is to provide technology and training that will complement ana supplement the national efforts in developing a greater total impact on rice production in the drought-prone areas.

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RICE RESEARCH STRATEGIES FOR AREAS OF NONOPTIMAL TEMPERATURES

K. TORIYAMA and M. H. HEU

RICE CULTURE AT LOW TEMPERATURE

The yield of rice grown at greater latitudes or higher altitudes generally is reduced by cool temperature. On more than 250,000 ha at lat. 41°-45° N in Japan, rice is grown in cool temperature. In Russia, where rice is grown between lat. 37° and 47° N, cold tolerance is of prime importance. In South and Southeast Asia, modern semidwarf varieties, mostly without cold tolerance, grow on about 7 million ha in mountainous (high-altitude) regions.

The improvement of varieties for low-temperature areas and the development of cultural practices to prevent damage from cold will extend the rice-growing areas and increase the amount of double-rice cropping.

The effect of low temperature on rice growth differs according to growth stages:

- Lowest temperatures for germination are 8°-13°C, depending on variety (Lee and Taguchi 1969, Oka 1954). Nishiyama (1976) observed that at 2°-5° C seeds germinated but seedlings did not grow.
- The critical air temperature for rooting is reported as 15°-15.5° C for seedlings in wetland seedbeds, 14.0°-14.5°C for seedlings from a semi-irrigated seedbed, and 13.0°-13.5°C for the seedlings from a dryland seedbed (Yatsuyanagi 1960).
- The temperature range for leaf elongation is reported as 7°-12°C (Sasaki 1927, Tanaka and Munakata 1974).
- The low critical temperature reported for tillering is 9° C (Chamura and Honma 1973).
- The critical temperature for sterility caused by cool weather is reported at around 17°-21° C depending on the variety (Nishiyama et al 1969).
- Sakai (1949) reported that cell plate formation in meiosis was inhibited at 15° C.
- The minimum temperature for flower opening is reported to vary from 15°-18°C with japonica varieties (Terao et al 1937) to 21°-22° C with indica varieties (Vergara et al 1976).
- Minimum temperatures for seed ripening are reported between 12° and 18° C

Head, Rice Research Division, Tohoku National Agricultural Experiment Station, Yotsuya, Omagari, Akita, 014-01, Japan; and plant breeder, IRRI.

(Kondo et al 1948, Tanaka 1962, Toriyama 1962).

A cold-tolerant variety can differ from another tolerant variety in the expression of tolerance. Also the cold tolerance required for one area could be different from that required for another. Thus, at the beginning of cultivar improvement it is desirable to match the tolerance of a cultivar with that required at a given location.

RICE CULTURE AT HIGH TEMPERATURE

High-temperature damage has not been a major problem in traditional rice culture. The introduction of nonseasonal, high-yielding cultivars and the improvement of irrigation facilities in areas where high temperature occurs have accentuated the problem of high temperature. They have led to changes in planting date that have resulted in flowering of the crop during periods of extremely high temperature.

White leaf tip, chlorotic band and blotches, white bands and specks, and reduced tillering and height were symptoms of heat damage at the vegetative stage (IRRI 1975). Many varieties were stunted at an early growth stage possibly because of high temperature; the depression in early growth continued through maturity and resulted in a significant reduction in dry matter production (Chang et al 1978).

Osada et al (1973) observed an abnormally high percentage of empty grains in some newly introduced photoperiod-insensitive cultivars that flowered in April-May in the Central Plain of Thailand. IRRI (1977) noted that in Pakistan, where 2 crops of rice were grown annually, 40-50% sterility occurred when the crop flowered in the high-temperature period of June-July; in Hyderabad, India, the percentage of spikelet sterility was high when flowering took place in the heat of April. Matsushima (1978) reported that high sterility occurred at Ed-Dueim in Sudan when heading took place in April-May. Chang et al (1978) also noted high temperature-induced sterility in Saudi Arabia.

High temperature during ripening caused impaired grain filling in Japan (Munakata 1976). IRRI (1975) observed 5-15% reduction in 1,000-grain weight at 35°/27° C in some cultivars. IRRI (1976) also reported that the incidence of chalky grains was associated with the spread between optimum and maximum temperature.

Reported studies on the critical high temperature at different growth stages are relatively fewer than those on critical low temperatures:

- The upper limit of germination was reported to be 40°-45° C (Umino 1944, Owen 1971).
- The protoplasmic streaming in the root hair cells ceased at temperatures between 40° and 45° C (Doi 1950), but Ormrod and Bunter (1961) reported that the respiration rate of young seedlings increased at temperatures as high as 43° C.
- The vegetative growth of japonica cultivars ceased at 45°C (Sasaki 1927).
- The maximum temperature for pollen germination was reported as 400 -45° C (Enomoto et al 1956).
- IRRI (1976) reported that at 41° C fertilization was zero whether the cultivars were susceptible or not. After a daily 2-hour treatment at 30º C for 5 days, a

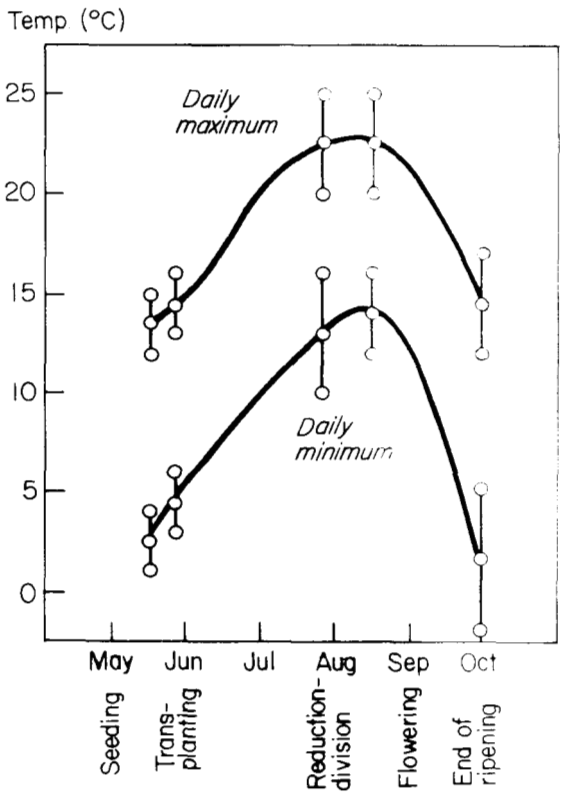
tolerant cultivar showed some fertile grains. Varietal differences in grain fertility were more distinct after treatment at 35° C for 2-8 hours for 5 days.

COLD DAMAGE TO RICE IS DIFFERENT COUNTRIES

Kaneda and Beachell (1974) reported different types of cold injury to rice in selected countries. Failure in germination, slow seedling growth, stunting with more or fewer tillers, discoloration (yellowing of entire leaves, yellowing of only the lower leaves, appearance of white specks on or whitening of leaves), panicle-tip degeneration, prolonged growth duration, increased sterility, and irregular maturity were observed in different countries.

Two types of damage from cold occur in Hokkaido, Japan: the delayed type and sterile type (destructive type). The temperatures from seeding to transplanting are below 15° C, and daily minimum temperatures rarely exceed 15° C throughout crop growth (Fig. 1).

In Hokkaido, differences in growth duration between early and late cultivars are



1. Temperature pattern and rice-growing season at Hokkaido. Japan (modified from Shibata 1979).

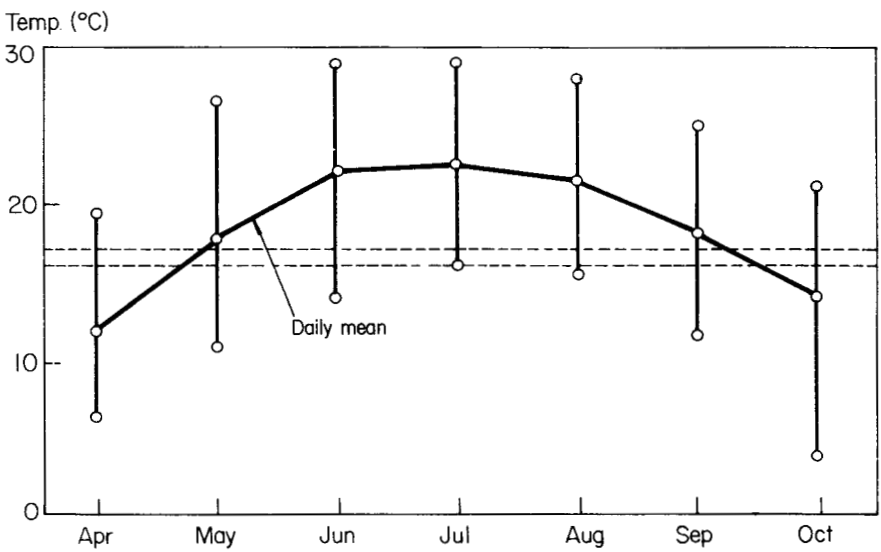
narrow. Slightly lower-than-ordinary temperature distinctly affects germination, seedling growth, rooting, tillering, and heading. It eventually causes improper maturing or grain sterility. Even if plant growth is vigorous, temperature that remains at 14°-16° C for more than 3 days during the period from reduction division to heading will cause serious damage because of grain sterility.

Because temperature patterns at Jumla, Nepal, and at Hokkaido are similar (Shahi and Heu 1979), the low-temperature problems at these two places are expected to be similar.

In Korea, where indica-japonica hybrid varieties are grown, cool temperature is a distinct constraint. Those hybrid varieties do not mature properly when they head after late August. To prevent the late damage, farmers seed the hybrids earlier than they do the conventional varieties. But they then face the cool-temperature difficulties at the beginning of the rice-growing season — poor germination, poor root development, stunted seedlings, leaf discoloration, seedling death, delayed heading, increased sterility, and incomplete maturation.

In northern Taiwan, the first rice crop starts and the second crop ends in winter, when temperature is lowest. That makes the low-temperature problems in the first crop different from those in the second. Reported damages were reduced germination, reduced seedling growth, and reduced effective tillers in the first crop, and delayed and incomplete maturity in the second (L. F. Lee 1979).

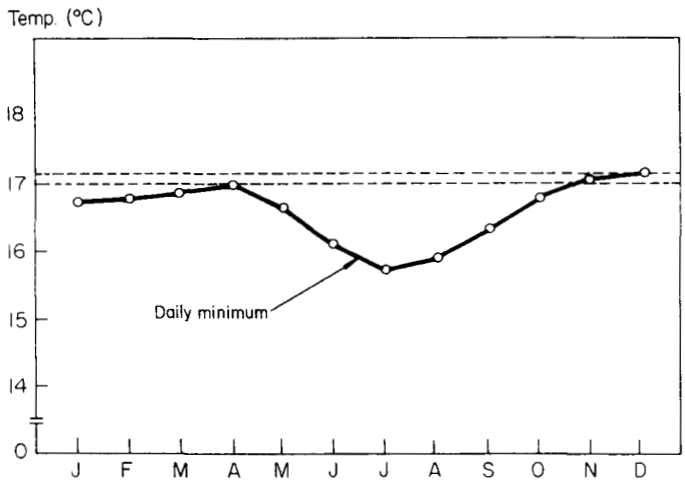
In Kashmir and the Northeastern Hill area of India, semidwarf high yielding indica varieties, have more difficulties than locally adapted conventional varieties during early and late growth stages when the temperature is low (Fig. 2). Hamdani



2. Air temperature at Srinagar, India (1975-78 average) (modified from Hamdani 1979).

(1979) observed poor germination, poor seedling establishment in the seedbed, slow seedling growth after transplanting, stunting, discoloration, and reduced tillering in the vegetative phase. In the reproductive phase, he observed delayed heading, poor panicle exsertion, panicle degeneration, irregular maturity, early senescence, and increased droopiness.

In high-elevation areas of the tropics, the daily minimum temperatures are generally lower than the minimum temperature for rice growing. The seasonal fluctuations are not as distinct as those in temperate areas (Fig. 3) and there are more



3. Average daily minimum temperature at Pacet, Indonesia (modified from Harahap 1979).

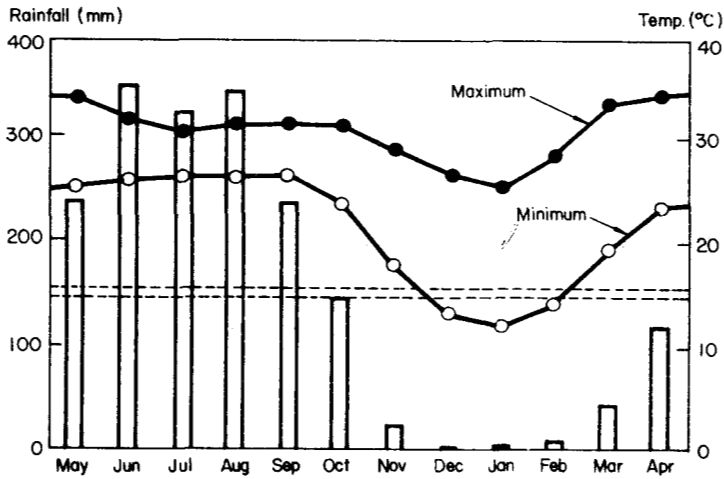
cloudy days than at lower elevations. Too low daily temperature and limited sunshine reduce, delay, or prolong growth. Generally the plants show discoloration, with stunting, and increased grain sterility (Harahap 1979, Ronduen and Dumlan 1979).

In Bangladesh, the boro crop starts after the monsoon and goes into the cool winter season when the daily minimum temperatures are below 15° C (Fig. 4). Poor germination, slow seedling growth, stunting, and leaf discoloration were observed during the vegetative growth; prolonged growth duration, panicle degeneration, increased grain sterility, and irregular maturity were reported during the reproductive growth stage (Kaneda and Ekachell 1974).

In California, USA, the night air temperatures during booting to flowering drop below 17° C. Such low temperatures affect meiosis and, depending on their extent and duration, also cause grain sterility (Rutger and Peterson 1979).

HEAT DAMAGE TO RICE IN THE TROPICS

In a year-round rice-growing experiment in Cambodia, Sato (1960) observed a marked increase in sterility when plants flowered in the hot, dry season of April and



4. Mean daily maximum and minimum temperatures and monthly rainfall at Dacca. Bangladesh.

May. In April, sterility was 100%. Sato stated that the high sterility may be attributable to failure of fertilization caused by the imperfect splitting of anther or wilting of stigma induced by high temperature and low humidity.

Osada et al (1973) observed at various places in the Central Plain of Thailand that some new photoperiod-insensitive cultivars had significantly higher percentages of empty spikelets when they flowered in April or May. From mid-April to mid-May, the mean daily maximum temperatures at Bangkok ranged from 34.20 to 35.1° C and the extreme maximum was 37.1° C.

In the semiarid climate of Hyderabad, India, the daily maximum temperature is 38°-40° C in April and May, when the rabi rice crop flowers and matures. Some rice cultivars flowered in April, and had high percentages of sterility. Apparently, the sterility was largely caused by the high temperature during flowering. Because anthesis of rice occurs from morning to early afternoon, it is important to know what time of day the temperature reaches the critical level for high temperature-induced sterility. At Hyderabad, the temperature reaches 35° C (the critical temperature) at 0930 hours and reaches 39°C at noon. This temperature-rise pattern may apply elsewhere in the semiarid climatic regions (IRRI 1977).

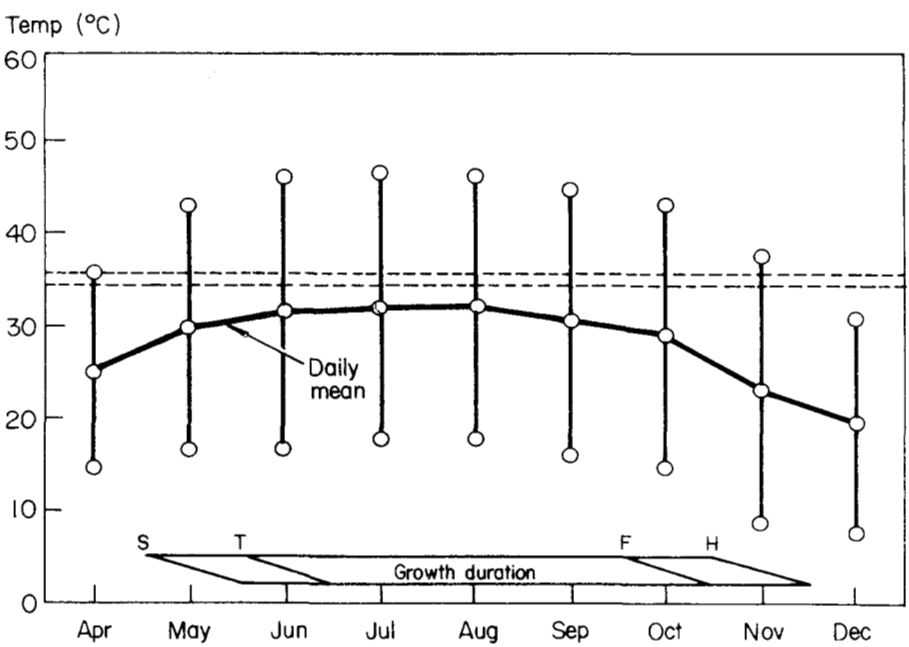
In Pakistan, 40-50% sterility occurred in the experimental rice fields in Lyallpur, where the first crop flowered in July and matured in August, when the temperature was high. The monthly mean temperature in July (30.3° C) was not excessive, but the daily maximum temperature in the first part of the month fluctuated markedly and occasionally was 35° - 40° C. For the first crop at Dokri, where the temperature is higher than that at Lyallpur, rice flowers in June, when the temperature is high, and some semidwarf lines exhibit a high percentage of sterility.

The Al-Hassa Oasis in Saudi Arabia is in the arid tropics and is one of the hottest

regions of the earth. Monthly maximum temperatures during May through October exceed 40° C; those from June to September, 45° C, and the differences in temperature between day and night are wide (Fig. 5). Chang et al (1978) planted 36 rice cultivars in the winter and summer seasons and found two types of high temperature-induced damage. One was stunting in the early growth stage in the summer crop season, and the other was sterility in both crop seasons, especially low fertility of traditional tall indicas in the winter crop season. Sterility appeared to be the main limiting factor for high yield in the winter crop, while vegetative growth contributed much to the yield of the summer crop. The varietal differences in tolerance for the two types of high temperature-induced damages were wide.

IRRI (1977) noted that in the southern part of Iran, the maximum temperature reaches 45° C during June-September. Although this area was reported to have a great potential for increased rice production, the high temperature-induced sterility could be one of the distinct constraints in the realization of the potentials. Matsushima (1978) reported on the high temperature-induced sterility of rice at Ed-Dueim, White Nile Province, Sudan, where the monthly maximum April-May temperature exceeds 400 C. The percentage of imperfectly ripened grains increased when the rice plant headed from late April to late May.

In an oasis area in Egypt, the percentage of sterility or empty grains was also high (Sato 1967). In Senegal and other tropical African countries, high temperature is considered as an important constraint to rice cultivation (Satake and Yoshida 1978).



5. Temperature pattern during growing season at Al-Hassa (modified from Chang et al 1978).

RESEARCH STRATEGIES

Research strategies for improving rice yields in areas with nonoptimum temperatures should include improving cultivars adapted to those temperatures and the cultural practices to be used with those cultivars. To improve temperature-tolerant cultivars, breeders must focus attention on improving screening techniques and assessing the more tolerant donor parents. The recent growth of international cooperation, mainly through the efforts of the International Rice Testing Program (IRTP), significantly improved research efficiently in participating national programs through the exchange of materials and information on improved techniques.

Improvement of screening techniques

Strategies adopted by different breeding programs for screening tolerant breeding lines are divergent. In Taiwan, the breeding strategy for the first crop differs from that for the second. In the hill area of northern India and in Nepal, breeding lines adapted to rainfed paddies in the hilly cool areas are screened.

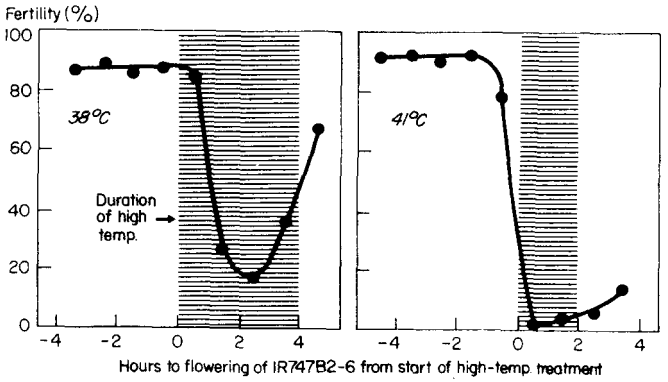
In Hokkaido, Japan, because of the relationship between the climatic pattern and the rice growth pattern, screening research is directed toward the improvement of the selection efficiency of lines that show less delay in growth at low temperature through all the growth stages and less sterility at low temperature during the booting stage and the flowering period, which are critical low temperature-sensitive stages.

In Korea, breeders intend to improve screening efficiency at germination, early plant growth after transplanting, and meiotic pollen growth stages. Preliminary tests have shown promising results.

The screening techniques for cold tolerance at different growth stages have been relatively well developed, but studies on the relationships among the tolerances at different stages are rare. Sasaki (1974) reported the positive correlations between the germinability at low temperature and the initial growth of seedlings, and rooting ability and seedling establishment. Shibata (1979) also reported a positive relationship between seedling cold tolerance and tillering rate. Lee et al (1974) reported relatively high correlation coefficients between grain sterility and reduced rate of culm length, reduced rate of panicle exsertion, and delayed rate of heading. J.H. Lee (1979) found significant correlations between the sterility of plants treated with low temperature at the meiotic stage and the sterility of plants treated at the heading stage. In the cold water nursery, at Chuncheon, Korea, the correlation between seedling test score and fertility score was practically nil ($r = 0.06$).

Research is needed for a better understanding of the relationships among tolerances at different growth stages. That may lead to a refinement of the screening techniques.

Screening techniques for heat tolerance are not well developed yet. Satake and Yoshida (1978) reported on the critical growth stage at which indica rices were susceptible to heat damage (Fig. 6). IRRI has reported on desirable temperatures, growth stages, and characteristics to check for in the screening for heat tolerance. Through these studies, the nature of heat tolerance became much clearer and a



6. Fertility of the spikelets that flowered before, during, and after high-temperature treatments.

number of heat-tolerant cultivars were identified (IRRI 1977, 1978, 1979). Those cultivars identified as heat tolerant showed better pollen shedding on the pistil and high germination percentage when subjected to high temperature at flowering. The same cultivars that flowered early in the morning, when the temperature was still low, escaped high-temperature damage. Screening of early flowering lines requires no special facility, but screening of sterile lines in natural conditions lacks precision.

Considering the status of the breeding facilities in the national programs of countries that require heat-tolerant varieties, the following screening sequences may be suggested;

1. Identify heat-tolerant donor parent at IRRI.
2. Test the identified cultivars, assess their heat tolerance, and identify the traits to be further improved at the problem sites.
3. Make crosses with tolerant parents, and grow F_1s or BC_1 F_1s at problem sites or at IRRI, to get seeds for desirable segregating-generation populations.
4. Send seeds of segregating populations to IRRI to be grown in rapid generation advance (RGA) facilities. At flowering, move the RGA plants to high temperature in the phytotron for 5 days.
5. After 3 consecutive generations in RGA, with heat treatment at flowering time, increase seeds at IRRI and distribute bulk seeds to the national program.
6. Carry out plant and line selections in the national program, under natural conditions.

Identification and use of tolerant donor parents

Many cultivars and breeding materials tolerant of cold air or water have been identified in many countries. Some are commonly recognized in different countries and others are specific to an area. Cold tolerance differs from one variety to another and from one stage of growth to another. Some varieties show tolerance at several growth stages, and some, like Silewah, show less hybrid sterility when crossed with japonicas.

To avoid the close-relative hybrids, a breeder should try to systematically introduce foreign germplasm, such as those with tolerance to the sterile-type damage at higher altitude. Also, to diversify the genetic variability, a breeder must use not only japonicas from USSR, Japan, Nepal, and Spain but also bulus from Indonesia and the Philippines.

In breeding indica-japonica hybrid lines, a japonica parent is used as the cold-tolerant donor and an indica parent as the blast-resistant donor. To enhance the homozygosity in the indica-japonica crosses, the highly productive semidwarf indica parent, whose plant type is controlled by a single recessive gene, could be efficiently used.

In northern and northeastern India, Hokkaido, japonicas and Chinese indicas have been used as cold-tolerant donors. But because of lack of genetic information on the cold tolerance of those parents, improvement was limited. There are a number of reports on the inheritance of cold tolerance but the results are not well proven. Studies directed toward establishing testing methods for genetic analysis of tolerances may minimize the disputable research results and enhance the genetic analysis of identified parents' tolerance to obtain better combining efficient genes.

IRRI has identified several heat-tolerant cultivars. These are not only tall traditional arid tropical cultivars, but also semidwarf breeding lines that were not intentionally bred for heat tolerance. This might imply that there are possibilities of finding more heat-tolerant lines already bred in tropical countries, and that the semidwarf plant type is as good as or better than the tall plant, depending upon other characters.

O. glaberrima has been identified as flowering in the early morning. Some of the lines of *O. glaberrima* start anthesis from 0700 hours. Through an intensive breeding procedure, this early anthesis could be transferred to improved lines. Also, broad inquiries into wild species for early anthesis might be worthwhile.

At anthesis, delayed anther extrusion and early pollen shedding on the pistils (found in the cultivar N22) is also beneficial to increased pollination. How this trait is inherited has yet to be studied.

Breeding methods

In Hokkaido, where only the early japonica cultivars are grown, bulk methods are being effectively used with rapid generation advancing facilities. In Korea, where the indica-japonica hybrid cultivars are grown, three-way crosses or multiple crosses are generally made and early-generation selection is practiced. In Indonesia, RGA is practiced for bulked early generations, and advanced bulked seeds are distributed to the different stations in different altitudes for selection. Almost the same strategy will be adopted by the Indian rice improvement program. To meet the request of national programs, IRRI supplies RGA bulked seeds of different generations.

The use of high-volume crossing techniques and genetic male sterility seems efficient for selective diallel-mating systems to integrate multiple disease and insect resistance. The effectiveness of selective diallel mating in improving cold tolerance

should be worked out in the well-established stations such as those at Chuncheon or Fujisaka.

To minimize the number of segregating generations, the pollen culture technique should be developed. Studies along this line would be interesting, especially in cold countries.

Through active IRTP efforts, diverse donor parents became more easily available. The evaluation and assessment of those IRTP entries might be a more efficient approach than the creation of new varieties in a national program. If adequately tolerable donor parents with desirable growth durations are available, other traits could be easily incorporated by a few backcrosses.

Cultural practices to alleviate damage

The use of cold-tolerant cultivars for minimizing cold damage should be considered first, and improved cultural practices must follow. The kind of seedbed, shape of protective cover, and type of cultivar are, in combinations, being studied at different temperature regimes in Korea. This system of study should be extended to other areas where seedlings are often damaged.

The optimum seedling age is a controversial subject for study, especially where the delay-type injury is often experienced. Generally, the younger seedlings show more delayed establishment than aged seedlings at cool temperature, and stiffer seedlings, expressed by dry matter per height, and seedlings grown in hot, enclosed plastic seedbed show faster establishment and less delay in heading. The stage from transplanting to seedling establishment is one of the most sensitive to the delay-type cold damage, and any cultural practices to speed seedling establishment are expected to reduce the damage.

Rates of nitrogen application must also be considered, especially those higher than optimum, whichcause excessive leaf development, delay heading, and increase the susceptibility to sterile-type cool injury. If nitrogen content in the leaf, at the flag leaf emerging stage, is higher than 3.5%, sterility will be increased. But even with the same high flag leaf content of nitrogen, rice fertilized with organic matter (compost), had significantly reduced sterility, more crude starch, and more root activity. These results suggest studies on the control of plant growth with chemicals, including phytohormones.

Although nitrogen content of the leaf blade at extrusion time of the flag leaf, and percentage of grain sterility were closely related (Amano and Moriwaki 1977, 1978), the combined effects of nitrogen content and sunshine on grain sterility in cool temperature are not well understood. Plant nutrition and fertilizer to minimize cold damage must be studied in connection with growth season, duration, sunshine, and cultivar.

Water management is extremely important in alleviating cold damage. A cold spell during the booting-to-flowering stage causes sterile-type damage in Hokkaido. By this time of the year, the water temperature is generally higher than air temperature. Therefore, deep irrigation (17-20 cm) during this stage is believed to be the best

practice to protect a young panicle from cold and reduce grain sterility. Forestation and netting to stop cold wind is effective in increasing air temperature and water temperature significantly in eastern Hokkaido. Research to raise water temperature should be directed toward exploring the materials, structures, devices, and cultural practices.

International cooperation and collaboration

Systematic international efforts to exchange breeding materials and information related to rice varieties and cultural practices adaptable to the suboptimal temperature conditions have grown since IRRI released IR8.

The International Rice Cold Tolerance Nursery (IRCTN), started in 1976 in the IRTP, has given breeders unexpected benefits. Some Indonesian varieties bred at the Kuningan Station are growing profusely in Korea and many Japanese varieties bred at Fujisaka Station are growing well in the northwestern Himalayas of India and in some parts of the hill area in Nepal. Most of the semidwarf varieties bred in Korea failed to mature in Kashmir and other high-elevation tropical areas.

A Heat Tolerance Collaborative Project with almost the same objectives as those of IRCTN was started in 1978. Heat damage was recognized as a problem only in limited areas of the tropics and only a limited number of researchers were studying it. Relatively less progress was made in improving the screening techniques and identifying more tolerant varieties.

Monitoring tours coordinated by IRTP gave participating researchers precious opportunities to observe the performance of varieties at different locations, assess the ecology of specific test locations, and discuss with the researchers working at the specific sites.

The Workshop on Cold Tolerance held in Korea, jointly sponsored by the Office of Rural Development-Korea and IRRI, collected abundant information on improved screening techniques and identified tolerant varieties for use as breeding materials.

International collaborations have increased recently. Through the collaborative project started between Korea and IRRI in 1977, several thousand test lines are exchanged every year, better screening methods are identified, and many tolerant lines are screened. The collaboration between national programs, directly or through IRRI, is encouraged to increase the efficiency of diversified national breeding programs.

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RICE RESEARCH STRATEGIES IN SELECTED AREAS: ENVIRONMENT MANAGEMENT AND UTILIZATION

D. J. GREENLAND and S.I. BHUIYAN

In developing rice research strategies related to environmental factors, it is necessary to define the physiological stresses that control rice yield, establish their relation to environment, and quantify their significance in terms of their extent and degree of severity. It should then be possible to assess the practical possibility of overcoming these stresses by either management of the environment, or development and improvement of tolerant varieties, or both.

To do that calls for a better knowledge and understanding of the environments in which rice is grown. In particular, there is need for a more complete understanding of the climatic, topographic, and soil factors that determine the water regimes in which the rice crop is grown, and the chemical and physical environment of the roots, and their relation to yield.

Research on soil, water, and crop management at the International Agricultural Research Centers has often been criticized on the grounds that it tends to be *site specific,* whereas studies of crop improvement do not suffer from this limitation. For instance, the varieties of rice developed at IRRI in the 1960s and 1970s were often described as *widely adapted,* and one objective in the breeding program was to remove characteristics such as photoperiod sensitivity, which limited the areas where a variety could be grown. As our appreciation of the differences between environments in which rice is grown has expanded, so has the acceptance that we must develop breeding programs aimed at producing varieties tolerant of specific environmental limitations. The nurseries distributed by the International Rice Testing Program (IRTP) now include those in which selection is based on tolerance for cold, salinity, and alkalinity, and those specifically designed for rainfed and upland conditions where drought may be a major constraint, and deep water, where flooding is a constraint. Thus the importance of environment to crop improvement, as well as to studies of soil, crop, and water management, has become increasingly apparent.

Deputy director general; associate agricultural engineer and head, Irrigation Water Management Department, IRRI.

Most agricultural research organizations are already involved in studies of soil and crop management. Some also have programs concerned with the effects of climate on yield, and of water management on yield. Rarely, however, are these studies coordinated so well that an effective interdisciplinary study is made of all the critical factors affecting yield so that optimum land management practices are developed.

In this paper we, therefore, consider the relationships between rice production and the physical components of the environment — climate, land, soil, and water — and the implications of such relationships for soil, water, and crop management; and finally consider the research strategies that should be followed if the environment is to be effectively used for rice production. Biological and socioeconomic components of the environment, although recognized as important, are not considered.

CLIMATE-YIELD RELATIONSHIPS

Yoshida (1976) has shown that an index based on solar radiation and temperature predicted 81% of yield variation for rice grown at Los Baños (Table 1). Recently, Evans and De Datta (1979) have found that irradiance alone correlated extremely well with yields obtained at Los Baños. Where more extreme temperatures occur, it is undoubtedly necessary to consider the additional influence of temperature. Furthermore, the relationship between irradiation and yield has still to be examined for a number of varieties in a wide range of environments.

In conditions of less well controlled irrigation, and where temperature and other stresses influence growth, the relation between climatic variables and yield is less well established. Evans (1976) referred to the gaps in the knowledge of the effects of components of climate and their interactions on the yield-determining processes of crops as "appalling." Until such relationships are firmly established, an adequate classification of climate in terms of its influence on rice production will be difficult to achieve. An important research requirement, therefore, is a better understanding of the interactions between climatic factors and yield of the rice plant, in a wide range of conditions.

Most climatic classifications developed for agricultural use emphasize the factors that determine the water balance. Where water availability principally determines crop yield, it has been possible to develop simulation models based on climatic data that predict yield rather accurately, as in the case of wheat in Australia (Nix 1976). For rice, of which most is grown in lowland areas where water supply from rainfall may be supplemented by ground water and floodwater, relationships are more complex and involve hydrologic and soil factors as well as climate.

Morris and Zandstra (1979) have indicated how climatic data and land types can be related to develop an agroclimatic classification related to rice, but the prediction of yield in lowland rainfed conditions from climatic data and landscape position has still to be achieved (Angus and Zandstra 1980).

The IRTP yield nurseries should provide valuable data for the examination of the relationships between radiation, temperature, and yield for fully irrigated rice, and

Table 1. Examples of relationships between environmental factors and rice yield.

Reference	Factors	Relationship
Yoshida 1976	Temperature and radiation	$X_{cl} = S\ [a\text{-}b\ (t\text{-}c)2\ ]$ where X_{cl} = climatic productivity index, S = mean solar radiation[a] in ripening period, t = daily mean temperature in ripening period, and a, b, c = constants.[b] For Los Baños, $X_{cl} = S\ [278\text{-}7.07\ t]\ FW$ where X_{cl}, S and t are defined as above, but refer to reproductive stage, F = proportion of filled grains, and W = 1,000-grain weight; and $Y = 1.3 + 0.81\ X_{cl}$ where Y is yield of paddy in tons per hectare.
Wickham 1973	Nitrogen and water	$Y = A + B\ (N) + C\ (N^2) + D\ (S_1) + E\ (S_2) + F\ (NS_1)$ where A, B, C, D, E, F are constants[b], Y = yield of paddy in kilograms per hectare, N = nitrogen applied in kilograms per hectare, S_1 = number of stress days[c] between transplanting and 60 days before harvest, S_2 = number of stress days 60 and 30 days before harvest.
Mandac and Herdt 1979	Environmental variables, input, and efficiency factors	$Y = f\ (X_1, \ldots, X_k, Z_1, \ldots, Z_n, E_1, \ldots, E_n) + U$ where Y = yield of paddy, U = an error term, X_i = input factors (fertilizers, pesticides, seedling age), Z_i = environmental factors including solar radiation, typhoon occurrence,[d] water stress, soil[e], insect damage, and disease incidence, and E_1 = efficiency factors.

[a]Solar radiation = mean daily radiation for 45 days before harvest. [b]Different constants apply when the rice varieties grown, soil texture, and solar radiation (seasons) differ. [c]Number of consecutive days after 3, when there was no free water on the soil surface (not differentiated according to growth stage). [d]Given a value of 0 or 1. [e]Taken as a function of texture, organic matter content, and extractable-phosphorus level.

make possible a useful assessment of genotype-environment relationships, provided adequate radiation and temperature data are recorded at the different sites. For rainfed conditions, the difficulty or establishing the quantity of water available to the crop probably requires that experiments be specifically designed to determine the influence of land and climate on yield.

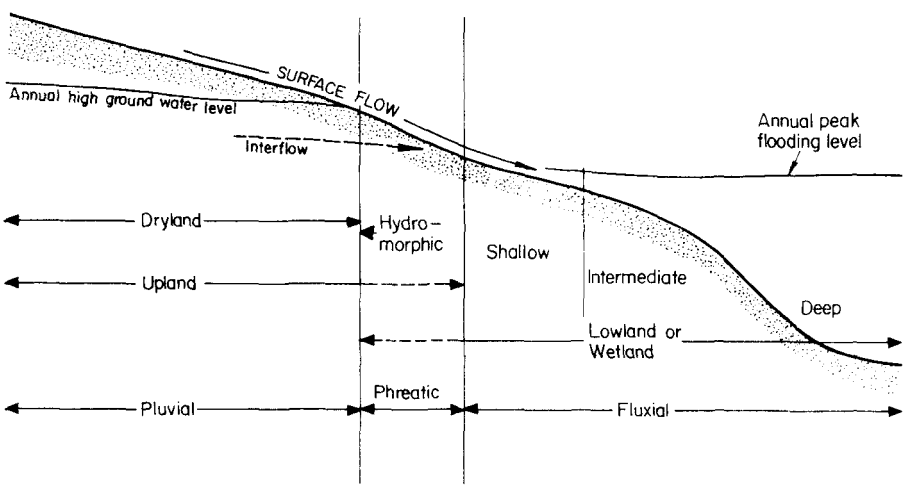
LAND-RELATED FACTORS

Modern definitions of land (FAG 1976, Young 1976, Dudal 1979) tend to be broad. They include characteristics of land surface; the air above it; the soil, rocks, and water below it; and the plants and animals on it. Climatic factors may be considered part of the attributes of land; similarly soil factors are a part of land. Thus it is land

quality that determines crop production. If we could develop an adequate description of land qualities we could use it to predict rice yield for all environments. As we have seen, in regard to water availability for a rice crop, it is essential to include the land factor. The important attributes of land that determine rice production, other than those of soil and climate, are terrain factors related to water table position, run-off accumulation, and flood incidence.

Rice is grown on a wide range of landforms affected by an equally wide range of hydrologic conditions. Several terminologies have evolved to characterize rice lands (Moormann and van Breemen 1978). Terms such as, upland, lowland, hill, or *plateau rice* have been used to characterize the topographic situation; and swamp, *deepwater,* and *rainfed* indicate the natural source of water supply. We agree with Moormann and van Breemen that it is necessary to adopt a uniform system of classification of rice lands based on 1) topographic position and related hydrologic conditions, and 2) natural source of water supply. The three classes of rice land recognized by them are pluvial, phreatic, and fluxial. Their relation to other commonly used terminology is illustrated in Figure 1. Characterization of land according to their definitions can help improve our understanding of its potential productivity. This is, however, only a first step. The depth, frequency, and rate of inundation are often major factors in determining the potential productivity of fluxial rice lands (Kaidha 1971).

The classification of rice production into irrigated, rainfed (shallow, intermediate, and semideep), deepwater, and upland is also widely used. A problem with this terminology is the arbitrariness of the divisions, and the variability from year to year in many of the areas where flooding of fluxial rice lands occurs. Land features tend



1. Terminology used to describe classes of rice land according to topography and water supply.

to be constant, and can be readily recognized. Flood conditions are more variable. The rice plant, however, is sensitive to flooding, and information that will help in determining the probable occurrence of a certain depth of flooding at any time, and the rate at which that depth is established, is needed. Data relating to run-off in the catchment areas where the floodwaters originate are inadequate for those predio tions. Deforestation and soil erosion in the catchments are also likely to cause a higher proportion of rainfall to run off, and floodwater to rise more rapidly. Selection of varieties adapted to flood-prone areas, however, requires some knowledge of the land factors that determine the flood characteristics. Monitoring of floodwater using Landsat imagery may importantly contribute to our knowledge and management of flood conditions.

Dent (1980) summarized the land qualities suitable for rainfed and irrigated rice production. The topographic components (as opposed to soil factors) are listed in Table 2. The attempts to develop quantitative relationships between land qualities and yield have been fewer than those to develop such relationships between climate and soil properties. That reflects our current inadequate understanding of the relationship of landform to yield. Kaidha (1971) developed some relationships that demonstrated the importance of optimum water control, and Fukui (1971) demonstrated the importance of landform differences in deltaic and nondeltaic areas in determining the extent to which high yielding semidwarf varieties were adopted in the Chao Phraya Basin.

SOIL PROPERTIES AND RICE YIELDS

Rice is grown in widely different soils. A number of soil classification systems have been used in the rice-growing countries. In most of them, however, there is no special provision for the classification of paddy soils, unless at a low level in the system (Dudal 1958, Dudal and Moormann 1964), although the dominant use of fluxial lands for rice production and the differences in growing conditions between rice and

Table 2. Topography-related characteristics that determine land suitability for rainfed and irrigated rice production (modified from Dent 1978).

Quality	Land characteristic
Water availability to plants	Depth of water table and its seasonal variation; extent of surface and subsurface runoff
Flooding hazards	Depth and current of floodwater: period and inundation frequency
Ability to maintain surface water	Slope, microrelief, drainage
Suitability for gravity irrigation	Slope, microrelief, slope complexity elevation with respect to sources of supply
Erosion hazards	Slope length, magnitude, and shape

other crops imply the need for special consideration. One system developed by Kanno (1956, 1962) specifically for classifying paddy soils in Japan uses the hydrologic status as the main criterion. His system has received limited acceptance outside Japan, probably because many soils used for rice diverge rather widely from those common in Japan, and also because it gives little prominence to factors important to crop production and soil management.

Soil Taxonomy (USDA 1975) also uses the soil moisture regime as an important soil property that determines many processes affecting the morphology of the soil. The system has wide applicability in soil classification, and, with some changes, offers considerable advantages for classifying soils used for rice production (Moormann 1978). The strength of the approach adopted lies in its conceptual clarity, which recognizes the various units or taxa of soil characteristics at several levels. Its main weakness for use with rice soils is its insufficient responsiveness to possible changes in morphological and physicochemical characteristics in original or natural soil profiles, which are important in wet cultivation of rice. Major permanent modifications in the soil, which may result from the cumulative effects of inundation cycles, and from soil management practices such as leveling and terracing, could be readily accommodated in the system if, as Moormann suggests, an *anthraquic* subgroup for temporarily surface–flooded soils is introduced.

However, to develop a more precise relationship between soil characteristics and rice yield, it is important to appraise soils in terms of their actual and potential productivity, which may be defined as the optimum rice yield possible from the soil when limitations from other stresses are discounted.

When rice is grown under well-irrigated and fertilized conditions, there is a good correlation between yield and solar radiation, as mentioned earlier. If radiation as well as irrigation management is good, as it is for dry-season production in many areas, it should be possible to establish a relationship between yield and soil properties.

The relationship between rice yield and soil properties is complex. Many chemical and physical soil factors can have an important influence on growth. Only when all but one or two are highly favorable for growth do those one or two factors become limiting so that simple correlations with single soil properties can be established. However, there is often a reasonably close association between the level of nitrogen input and yield for a given year, but the relationship at a site may vary considerably from year to year depending on the variability of the climatic factors (Table 1). Barker and Anden (1975) analyzed data from 36 Asian rice-growing villages (36 observations for the wet season and 29 for the dry) and concluded that the environmental factors (solar energy and rainfall) and irrigation accounted for the major differences in nitrogen use between the top 20 and the average of 64 sites. Barker (1978) observed from yield-gap analyses that the farmers in better environments get higher yields and are more receptive to the use of the modern rice technology than the others. But the analyses do not explain whether or how the farmer in the context of his own environment and resource constraints can profitably achieve a higher yield.

The soil properties that principally determine the production of rice in phreatic and fluxial (wetland) areas have been discussed by Kyuma (1973), Kawaguchi and Kyuma (1974a, b; 1975a, b, c), and Dent (1978, 1980), among others. The comprehensive study by Kawaguchi and Kyuma using multivariate statistical methods of 410 major soils from eastern India, Bangladesh, Sri Lanka, Burma, Thailand, Cambodia, Malaysia, and the Philippines resulted in the extraction of three mutually independent and clearly definable fertility component factors that are important for rice: 1) inherent potentiality (a function of clay mineralogy and cation saturation), 2) organic matter — nitrogen status, and 3) available phosphorus status. Kyuma (1973) showed that those three fertility component factors alone accounted for about 60% of variability in rice yield data reported by Malaysian farmers.

For pluvial rice, the Fertility Capability Classification (FCC) system offers a method to group soils that have the same kind of limitations from the point of view of fertility management (Buol 1972). Some information contained in Soil Taxonomy is used in FCC, but soils are grouped only by characteristics that make them similar for fertility management purposes. The classes and subclasses of the FCC system are shown in Table 3. By allowing experimental sites that respond similarly to soil management practices to be grouped together, the system enables agronomists to extrapolate their findings to soils that can be expected to behave similarly (Buol and Couto 1980). Its usefulness in reducing the site specificity of soil management research has been demonstrated in parts of Brazil, Colombia, and Peru. However, FCC, as now formulated, as well as Kawaguchi and Kyuma's indices, give little attention to those physical properties important to retention of water. For many rainfed areas and those with uncertain irrigation, these can be a major factor

Table 3. Soil features used to group soils in the FCC (fertility capability classification) according to their potential for crop production (Buol and Couto 1980). Each type and condition modifier is defined rigorously in the publication cited.

Interpretation of FCC Types (0-20 cm) and Substrata Types (below 20 cm)	
L (loam)	Good water-holding capacity, medium infiltration capacity.
S (sand)	High rate of infiltration, low water-holding capacity.
C (clay)	Low infiltration rates, potential high run-off if sloping, difficult to till except when i modifier is present.
O (organic)	Artificial drainage is needed and subsidence will take place. Possible micronutrient deficiency, high herbicide rates usually required.
SC (sand over clay) LC (loam over clay)	Susceptible to severe soil deterioration from erosion exposing undesirable subsoil. High priority should be given to erosion control.

Table 3. (continued)

Interpretation of FCC Condition Modifiers

The following apply to the soil, when only one condition modifier is included in the FCC class nomenclature. Interpretations may be slightly different when two or more modifiers are present simultaneously or when textural classes are different.

Modifier	Main limitations and management requirements
g (gley)	Denitrification frequently occurs in anaerobic subsoil and tillage operations and certain crops may be adversely affected by excess rain unless drainage is improved by tiles or other drainage procedures.
d (dry)	Soil moisture is limited during the growing season unless irrigated. Planting date should take into account the flush of N at onset of rain.
e (low cation retention)	Low ability to retain nutrients for plants, mainly Ca, K, Mg. Heavy applications of these nutrients should be split. Potential danger of overliming.
a (aluminum toxicity)	Plants sensitive to aluminum toxicity will be affected unless lime is deeply incorporated. Extraction of soil water below depth of lime incorporation will be restricted. Lime requirements are high unless an e modifier is also indicated.
h (acid)	Strong to medium soil acidity. Requires liming for most crops.
i (iron oxide dominant)	High P fixation capacity. Requires high levels of P fertilizer. Sources and method of P fertilizer application should be considered carefully.
x (X-ray amorphous minerals)	High P fixation capacity. Amount and most convenient source of P to be determined.
v (vertisol)	Clayey textured topsoil. Tillage is difficult when too dry or too moist but soils can be highly productive.
k (potassium deficient)	Low ability to supply K. Availability of K should be monitored and K fertilizers may be required frequently for plants requiring high levels of K.
b (basic alkaline reaction)	Basic reaction. Rock phospate and other nonwater soluble phosphate should be avoided. Potential deficiency of certain micronutrients, principally iron and zinc.
s (salinity)	Presence of soluble salts. Requires special soil management practices for saline soils.
n (sodium)	High levels of sodium. Requires special soil management practices for alkaline soils.
c (cat clay)	Potential acid sulfate soil. Drainage is not recommended without special practices. Should be managed with plants tolerant of flood and high level of water table.

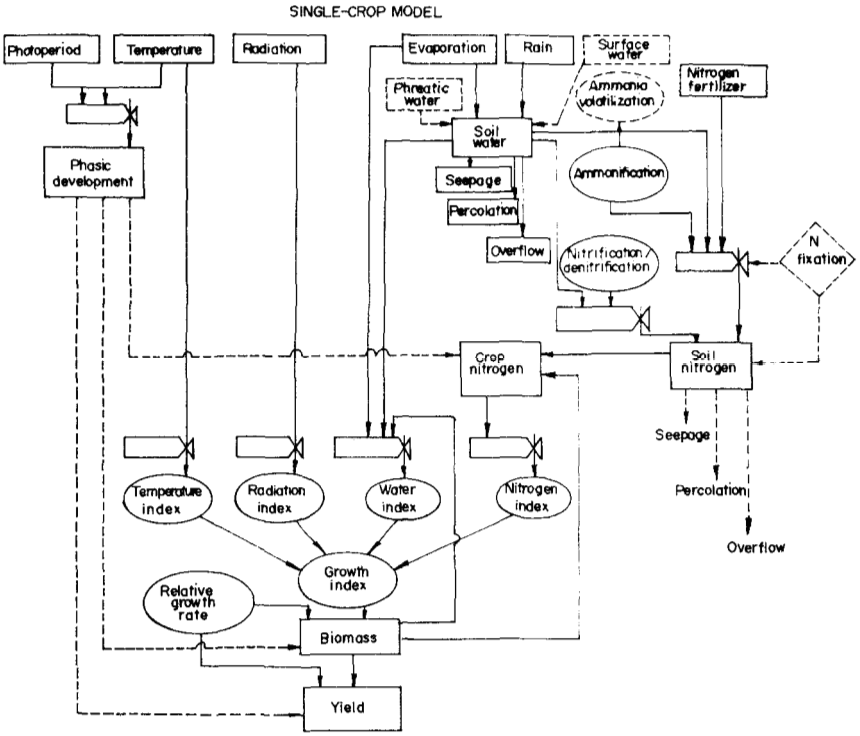
determining the soil's influence on rice yield.

Riquier et al (1970) developed a parametric system of choosing nine soil properties or factors that give more emphasis to physical conditions. The properties are soil moisture content, drainage, effective soil depth, texture and structure of the root zone, average nutrient content, soluble salt content, organic matter in the Al and Ap horizon, mineral exchange capacity, nature of clay in the B or C horizon, and reserves of weatherable minerals in the B or C horizon. Five productivity classes from excellent to extremely poor or nil were used. Dent (1974) tested the system for 14 rice soils of Thailand and concluded that a meaningful correlation with yield could be obtained with some modification of the drainage factor. Frankart et al (1972) used a similar parametric approach and obtained good correlation between the actual productivity index and the yields of irrigated rice on seven soils in northeast Thailand.

The importance of the drainage factor to rice production is still uncertain. A finite percolation rate appears necessary if high yields are to be obtained. In China, a rule of thumb states that if yields are to exceed 6 t/ha, the percolation rate must exceed 10 mm/day (Hseung Yi, pers. comm.). In India, Ghildyal and Patel (1979) observed that recycling drainage water from lysimeters caused a yield loss of approximately 20% compared with the use of fresh irrigation water, although the soils used were not known to present problems of salinity or toxicity. Although rice can tolerate poor drainage by the standards of upland crops, a significant rate of drainage appears important, particularly if organic amendments are used. These normally mineralize to release nutrients, favorably affecting crop yield, but in anaerobic conditions, their decomposition can produce sulfides and, possibly, potentially phytotoxic organic compounds. Lack of drainage in many irrigated areas of the world has resulted in the accumulation of salts and toxic elements in the soil to such an extent that the land becomes useless. Although more common in arid areas, such problems can occur in soils of low permeability in humid areas, and deliberate puddling of the soil to reduce percolation of water is likely to accentuate the problem. There is a clear need for further information concerning the interaction between soil properties, drainage characteristics, and use of organic amendments and puddling practices if we are to understand how these factors relate to yield.

Nitrogen supply to the rice crop is commonly the yield-limiting factor. The processes that affect the amount made available to the crop are shown in the simulation model (Fig. 2). Many of them, notably the extent of nitrification and denitrification and percolation losses, interact with the drainage factor. We know rather little about the rate at which organic nitrogen is ammonified in the soil under different drainage (Eh) conditions. Until these factors are better understood, a real improvement in the present low efficiency with which nitrogen fertilizers are used is unlikely to occur.

The amount of nitrogen made available to rice crops through biological nitrogen fixation is substantial in some circumstances and negligible in others. If the rice crop is to take full advantage of the biological fixation of nitrogen, much more must be learned of the climatic, soil, and other factors that control it.



2. The Angus (1979) flow chart for a rice yield simulation model for flooded, puddled soil. The water balance components lead to the *water index* and the nitrogen balance components to the *nitrogen index.* Components not included in the model are shown by broken lines. Soil factors other than those influencing the nitrogen index are assumed to be nonlimiting.

WATER AND RICE PRODUCTION

Adequate water availability is the most crucial of all factors determining the growth of the rice plant. Being semiaquatic, rice needs a continuous supply of water to produce good yields regardless of the variety. The availability, uses, and management of water will be considered in the following pages.

Rainfed systems

Rainfed rice culture can be divided into *rainfed lowland* rice; *deepwater* rice, which grows in areas usually flooded to water depths of 1 m or more; and *upland* unbunded (pluvial) rice areas. It is estimated that about half of the rice area in South and Southeast Asia is rainfed (Barker and Herdt 1979). Most of the lowland rainfed rice area falls in fluxial and phreatic parts of the landscape although some falls in the pluvial category. Rainfed rice grown in pluvial areas is under high risk of drought

damage throughout the growth period because the crop is entirely dependent on incident rainfall.

Most rice on pluvial lands is found in highrainfall areas in Asia. In certain parts of India, however, it is grown in marginal areas and yields are low (less than 1 t/ha); crops even fail completely in dry years. Characterization of soils and climates in relation to water availability for rice in pluvial areas is important to the development of optimal management techniques for pluvial rice (Hsiao et al 1980).

In phreatic areas drought risk is less than in pluvial lands because they receive seepage water from higher land and because the water table is shallower. The importance of the water-holding capacity of the soil may diminish in phreatic rice land, although where rice is normally established by dry seeding, the occurrence of drought during the early growth period may be critical. In some favorably endowed rainfall patterns, two rainfed rice crops are possible. The potential to produce two rice crops, discussed later in this section, is also dependent to some extent on retention of available water in the soil.

Fluxial land, when not flooded, possesses characteristics similar to those of phreatic land. But flooding is a common feature of fluxial land in monsoonal Asia. The degree and duration of flooding vary according to the rainfall pattern, magnitude of run-off water that accumulates, and drainage outlet condition. Severe flooding, which causes prolonged submergence, may seriously damage the rice crop (Pande 1976), and uprooting or lodging may occur if the floodwater enters the flood plain or recedes from it quickly. At the other extreme, in a low-rainfall year, rice crops in fluxial lands like those of other rainfed areas, can suffer considerable drought damage.

In monsoonal areas of Asia the daily or weekly rainfall amounts peak in the middle of the monsoon and then taper off. Rainfed-rice yields decline substantially if the crop encounters dry conditions during the reproductive stages (IRRI 1978a). The decline occurs when the monsoon is completed early, or if planting is delayed. Nothing can be done to extend the monsoon season, although crops can be saved where supplemental irrigation is possible. On the other hand, late planting is associated with the farmer's willingness to get the seedlings ready and prepare the land for transplanting using a minimum amount of rainfall.

Two rainfed-rice crops have become technically feasible in certain areas where rainfall and topographic factors are favorable, and short-duration varieties can be grown. The first crop has to be grown early and in most cases, dry seeded, whereas the second crop can be transplanted (Morris and Zandstra 1979). The suitability of such two-rice-crop systems can be predicted if availability of cumulative rainfall required for dry seeding is statistically analyzed. Stratification of sites according to soil type and landscape position as well as climatic analysis is necessary for correct assessment of water availability, especially with regard to chances of successful establishment of the dry-seeded first crop, and the final phase of the following transplanted rice crop. A similar environmental analysis can of course also be applied to the determination of the possibility of producing an upland crop after rainfed rice (Zandstra 1981).

Observations of rainfall used by farmers in Gapan, Philippines, for land preparation and transplanting and rainfall probability analyses indicated that farmers who transplanted early (11 July) obtained 25% higher yields, on the average, during the period 1969-74 than those who transplanted 28 days later, because drought affected the late stage of crop growth. Transplanting 40 days later produced 44% less yield (Bhuiyan et al 1979a).

The comparative performance of the two-rainfed-rice-crops system in a relatively high-elevation (phreatic) landscape and in a low-elevation (fluxial) landscape in Bulacan, Philippines (IRRI 1977), illustrates the importance of rice land classification on the basis of landscape and water regime conditions. Only the farmers in the fluxial area made significantly higher net income by growing two crops instead of one crop of monsoon rice (Table 4). The higher elevation farmers incurred substantial additional labor costs to control weeds in the direct-seeded first crop. The two-rice-crop pattern inevitably involves a greater risk, and in 1 of every 3 years, farmers in Bulacan face a high probability of total failure of the second crop because of prolonged water deficit. It is clearly important to define those areas where the environmental conditions are such that the risks of multiple cropping are economically acceptable.

The timing of tillage operations is crucial to the early establishment of rainfed rice. Vast areas in northeast India, Bangladesh, and Indonesia are tilled dry by manual or animaldrawn implements to grow a dry-seeded, early-summer rainfed-rice crop, known as *gogo rancah* in Indonesia and as *aus* in India and Bangladesh. The

Table 4. Grain yield, gross income, total costs, and net income[a] for 2-crop and 1-crop rainfed farms at different elevations, Bulacan, Philippines. Wet season 1976 (IRRI 1977).

Crop, elevation	Observations (no.)	Grain yield (t/ha)	Total cost[b] (US$/ha)	Income (US$/ha)		
				Gross	Net farm	Net family
		2-crop farms				
First crop (direct-seeded)						
High elevation[c]	7	1.82**	162	271	115**	157**
Low elevation	7	3.01	195	447	252	296
Second crop (transplanted)						
High elevation	7	2.62	209	389	181	220
Low elevation	7	2.91	203	433	225	260
		1-crop farms				
All varieties (transplanted)						
High elevation	7	3.34	195	496	301	345
Low elevation	7	3.35	199	498	298	340
IR1561 only[d]	4	3.82	211	568	294	327

[a]Philippine P7.4/US$1. [b]Including family labor costs at US$1.35/man-day. [c]Asterisks denote significant difference at the 1% level between 1 -crop and the indicated 2-crop farms at the same elevation. Only rain yield and net income are tested. Differences between elevations are significant only for the direct-seeded first crop. Single crops planted to IR1561 only are not included in significance testing. [d]Two observations at high elevation and 2 at low.

advantages of this system include early establishment of the plants from the first monsoon rains, reduced labor requirements because seedbed preparation and puddling are not required, and avoidance of insects and diseases that would otherwise multiply in the period required for land soaking in preparation for transplanting. The major disadvantages of the system are the high draft power requirements, intense weed competition, high risk of drought stress accentuated by the comparatively high percolation losses, and less efficient use of fertilizer (De Datta et al 1979).

In spite of these disadvantages, the dry-tillage technique makes a second transplanted crop possible in many areas of South and Southeast Asia. The present yields of both crops are usually low, but development of high-yielding, very early maturing varieties, a greater degree of drought tolerance, economic means of weed control, and paddy management practices to reduce percolation losses and conserve more moisture to minimize drought stress should help obtain stable and reasonably high yields from each of the two crops that can be grown without irrigation, or where only supplemental irrigation water is available. As Hsiao et al (1980) and Zandstra (1981) have emphasized, careful environmental analysis is essential to the successful extension of such rainfed multiple cropping systems to areas where they are not currently practiced.

Development of simulation models to predict the water balance in different conditions is a critical factor in this environmental analysis (Angus and Zandstra 1980). The components in the model developed are illustrated in Figure 2. Further work is necessary to account for the effects of landscape and soil properties for both single and multiple cropping patterns.

Irrigated systems

Irrigated rice culture is found in pluvial, phreatic, and fluxial areas. Pluvial lands are generally best suited for irrigation with pump systems, whereas fluxial and phreatic lands can benefit from storage or diversion type gravity as well as pump systems. Flat topography of fluxial lands where these extend over a vast region, as in Bangladesh, may need pumps to develop the water head necessary for gravity distribution of the irrigation water. Often, fluxial lands need measures such as polder and dike construction to prevent excessive flooding of the irrigated areas during the monsoon period, or intrusion of sea water during storm surges and high tides if the land is near the coast. Facilities for draining accumulated water from excessive monsoon rains are also often required.

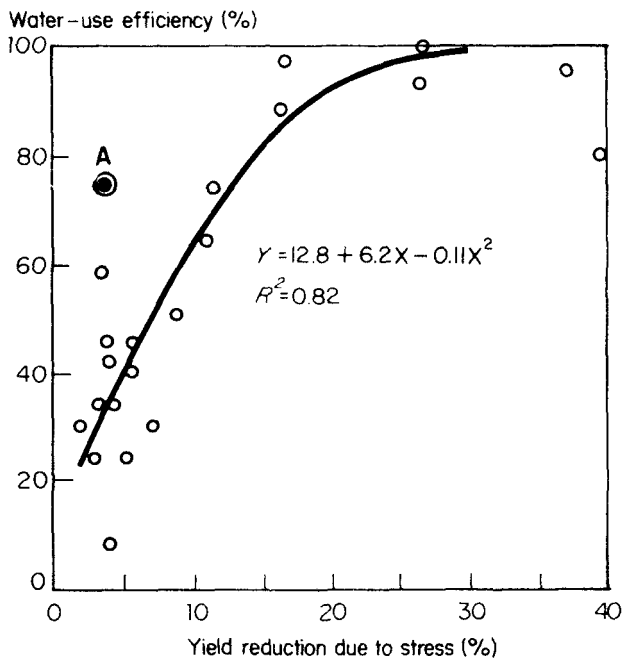
Irrigation development represents a change in the environment that allows improved rice production by providing a controlled but adequate water supply throughout the growing period. Increased rice production becomes possible because

- yields per unit land area are increased by elimination of drought and introduction of modern varieties and required inputs; and
- cropping intensity can be increased, if the water is adequate for crops to be produced in the dry season. Most diversion-type irrigation systems provide increased production only by eliminating the unreliability factor in water supply in the wet season, and because farmers are encouraged to invest in modern

inputs as risks are reduced.

Irrigation development in many countries of South and Southeast Asia has progressed at a tremendous rate over the past decade. In Indonesia, 1.9 million ha, or 43% of total land irrigated currently, was brought under irrigated agriculture during the period 1969-1979 through new development and rehabilitation of old systems, not counting developments in tidal and swamp areas. In Thailand, new irrigation facilities were developed at the rate of about 100,000 ha/year since 1971. Philippine data show development of about 121,000 ha of new irrigated land per year during the 1966-76 period and the anticipated average development for the 1980s is about 100,000 ha/annum. India set a world record by extending the irrigated area by 2.8 million ha in 1 year alone (ISAE 1978). The irrigation development trend and the associated costs are summarized by the Trilateral Commission, which estimated that $52.6 billion must be invested between 1978 and 1993 to develop new irrigation facilities and upgrade existing ones in South and Southeast Asia if self-sufficiency in rice is to be established in the region. They calculate that such investment in irrigation will double the production level of 1974 (Trilateral Commission 1978).

Figure 3 shows the processes involved in the water balance model for rice paddy and how the water used in an irrigation system may differ from the requirement depending on the characteristics of the system and the degree of control exercised. If the water requirements to meet the crop evapotranspiration (*ET*) and soil seepage



3. Relation between water-use efficiency and yield reduction due to moisture stress on 21 crop sites, Luzon, Philippines, 1969-70. 'A' represents a realistic target of 75% WUE at only 5% yield reduction due to water stress.

(S) and percolation (P) are known an approximate measure of the water-use efficiency (WUE) in an irrigation system can be calculated using the formula

$$WUE = \frac{E_1 + S + P}{R + I}$$

where R and I are water amounts from rainfall and irrigation source, respectively. A better estimate is the irrigation efficiency (IE) of the system defined as follows:

$$IE = \frac{E_1 + S + P - R_e}{I}$$

where R_e is the effective rainfall, i.e. the amount of rainfall that contributes directly to water use on the paddy.

The advantage of this formula is that the effects of sites specificity are removed by inclusion of all factors determining the net irrigation water requirement in the numerator. However, because measurement of R_e in the field is difficult, the former formula found popular use in the past. The efficiency of irrigation-water use is useful for comparing the performance of different irrigation systems in various environments and for measuring improvements of irrigation system management.

The water in most existing irrigation systems is inefficiently used. Its efficient use entails much more than the construction of physical infrastructure in the system. For a given level of infrastructure, often what is most needed is the development of appropriate management techniques and personnel capability to exploit fully the potential of the existing irrigation systems and ensure that water is distributed and applied according to the crop requirement.

Wickham (1979) estimated that with the use of modern rice varieties and optimum levels of nitrogen fertilizer, diversion-type irrigation systems in the Philippines would show a yield increase of 1.0) t/ha in the wet season from an average irrigation water supply, which he termed *basic irrigation.* In the dry season, the yield increment from such water availability is about 2.5 t/ha (Table 5). Improved or *ideal* irrigation was estimated to yield an additional 0.2 t/ha in the wet season and 1.6 t/ha in the dry season. The second yield increment should be the actual benefit from improvement of the management of the irrigation system.

Most existing irrigation systems suffer from two major problems: 1) low water-use efficiency, which indicates that much water is wasted; and 2) inequity in water distribution, which suggests that some areas are getting abundant water while others are in shortage. Studies on waterdistribution and -use patterns in a number of irrigations systems in the Philippines and outside have shown that mean water delivery is generally much higher in areas served from the first section of a canal than in those served from the middle or last sections (IRRI 1974, Tabbal and Wickham 1978, Bhuiyan et al 1979a, Early et al 1978, Sumayao et al 1979). The problems are often interlinked. In spite of sufficient water for the whole service area, inefficient operation and management of an irrigation system usually aggravates the problem of inequity.

Table 5. Simulated mean yields and yield differences due to different levels of irrigation performance with optimum rates of nitrogen used on improved varieties. Philippines, 1976 (Wickham 1979).

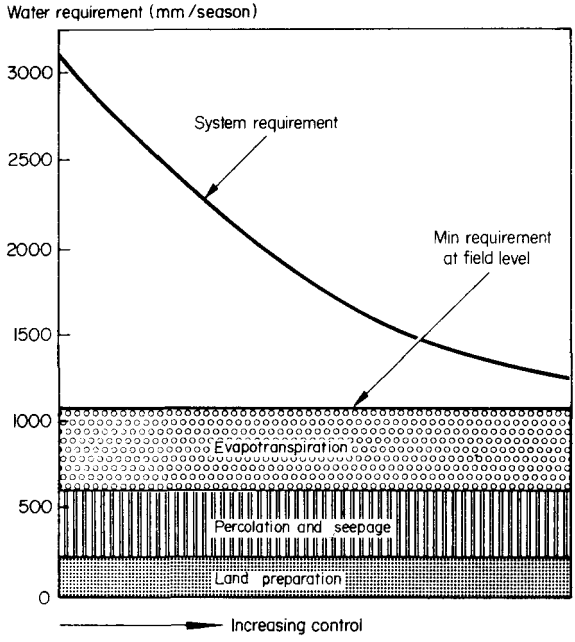
Irrigation performance	Yield (t/ha)		
	Dry season	Wet season	Combined seasons[a]
Rainfed[b]	0.00	1.91	1.91
Basic irrigation[c]	2.47	2.92	3.74
Yield increment I[d]	2.47	1.01	1.83
Ideal irrigation[e]	4.08	3.12	4.48
Yield increment II[f]	1.61	0.21	0.74

[a]Assuming 100% of the command area benefited in the wet season and 33% in the dry season. [b]Mean yield computed for moderate and high seepage and percolation rates, av irrigation. [c]Mean yield computed for conditions of minimum and moderate seepage and percolation rates and poor and av irrigation. [d]Yields with av irrigation minus rainfed yields. [e]Yields with no stress days. [f]Yields with ideal irrigation minus those with av irrigation.

In general, a higher irrigation water-use efficiency is the objective of the irrigation agency, but individual farmers are interested in maintaining a high water adequacy. An ideal objective in irrigation system management may be the elimination of water wastage and, at the same time, of yield reduction due to water stress (i.e. the extreme upper left point in Fig. 3). This is not a realistic goal because some excess water is needed to facilitate its distribution, but it may be feasible to achieve point A in the figure by attaining, say, 75% *WUE* at the farm level and to attain about 95% of the potential yield (Wickham 1979).

There is cumulative evidence from pilot studies that both higher water-use efficiency and increased water distribution equity can be achieved by improving the management of irrigation systems. Such efforts have substantially increased total rice production from the systems primarily because more areas could be provided with adequate water (Valera and Wickham 1976, Early et al 1978, Shanmugarajah and Atukorale [n.d.]). The key element in all the improved system management efforts has been the control of water delivery and distribution. The model in Figure 4 illustrates this point. Increasing control in the system cannot be achieved in a sustained way by unilaterally trying to manipulate the operation of the physical infrastructure alone, or merely by providing more physical facilities in the system. The degree of intended control must be matched by developing the management skills of the personnel involved, attending to social and economic problems of the water users, and removing organizational and institutional problems constraining the effective use of the irrigation water. If these steps are taken, cooperation from the farmer community can ultimately be expected.

Research in this area should include the development of methods to identify accurately the constraining factors, and design and implement appropriate management improvements for different types of irrigation systems. Methods to quantify the benefits of improvements in irrigation system management also need to be developed. There is a considerable gap in our understanding of the design criteria for efficient distribution of water delivered through a turnout or offtake for use by a



4. Example of water requirement for component uses in lowland rice at the field level and irrigation system delivery requirement. as affected by degree of control in the system (modified from Levine 1971).

group of farmers. We need to improve our knowledge in this area to make equitable water-sharing among farmers possible.

Wastage of irrigation water during the land-preparation period is substantial. More than 40% of the total water supplied to lowland rice is often used before the crop is transplanted (IRRI 1974, 1978b). The time required to complete land preparation and transplanting in a tertiary canal area often extends to 2 months, although individual farmers, once they start, usually take approximately 1 month or less to complete all activities until transplanting. Extension of the period of land preparation leads to greater loss of water by surface runoff, evaporation, and seepage and percolation. Inadequate and uncertain flow, lack of preparedness of many farmers associated with late delivery of inputs and credit, and shortage of labor resources are the typical reasons given for the extended period of land preparation (Valera 1977). From climate, land type, and soil data it should be possible to estimate the water requirements for land preparation for a wide range of environmental conditions. The validity of such calculations should be experimentally verified and methods to economize in the use of water for land preparation should be established.

The development of new sources of irrigation water and their required infrastructure is one of several methods of expanding irrigation water availability. An alternative is to improve existing but inadequate irrigation facilities so that larger areas can benefit from the water, and higher cropping intensities can be achieved. The esti-

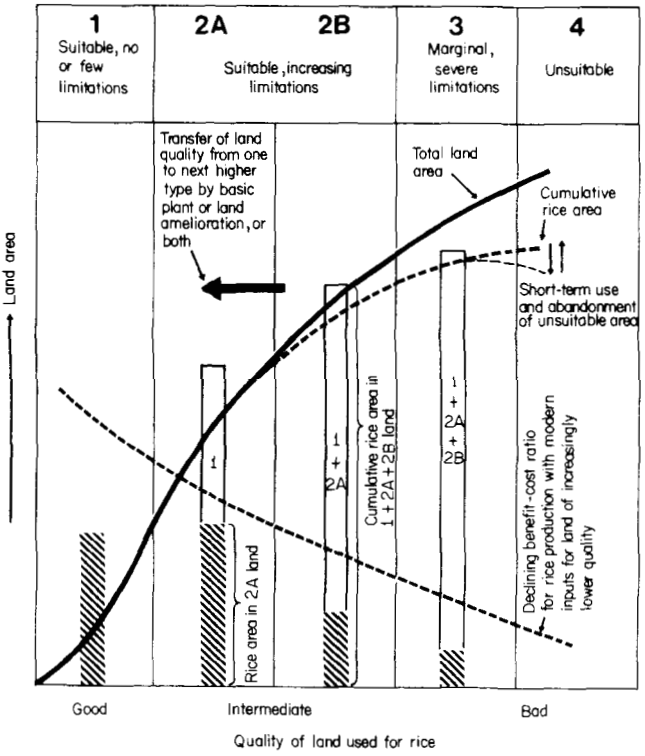
mates made by the Trilateral Commission of costs entailed to provide irrigation to increase the rice yield by 1.0 t/ha per year are $3,000/ha for virgin land, $1,500/ha for providing irrigation to existing rainfed paddies, and $400/ha for improving existing irrigation systems. Although the estimates are somewhat arbitrary and do not take account of differences in costs of land leveling, labor, and materials in different environments, they are useful for a comparative analysis. Clearly, research on the alternatives for expanding irrigation facilities and the optimum mix of alternatives for a given set of environmental conditions should yield high returns. Such research will require interdisciplinary studies involving economists, engineers, hydrologists, agronomists, and soil scientists.

CONCLUSIONS AND RECOMMENDATIONS

The yield of a rice crop is a function of its genetic potential, farmers' cultural practices, and the environment in which it is grown. Improvements in environmental management and utilization are essential if rice production is to be increased. Some environmental factors are nonalterable; for example, solar radiation and carbon dioxide content of the atmosphere. A number of other environmental factors are amenable to improvement through changes in management practices. For example, factors such as topography and water regime may be improved for intensive rice cultivation by terracing and introduction of irrigation water.

In most parts of South and Southeast Asia, there is little opportunity for land not currently under cultivation to be brought into use. Total production has to be raised by increasing the yield of individual crops, or by increasing the cropping intensity. To do either of these successfully, it is critically important to be able to understand fully the relationship between yield and environment. The problem becomes increasingly acute as the pressure on land increases, because most improvements are made initially where economic responses are most easily obtained. Moormann and van Breemen (1978) depicted this in terms of the relationship between land in use for rice production, and inherent limitations to that use (Fig. 5). The single most significant land improvement for rice production is the introduction of irrigation. However, it will certainly be increasingly difficult and costly to develop irrigation schemes as land suited to such development becomes scarcer. Critical appraisal of land suitability for rice production will inevitably become more important, a fact already recognized by many development agencies

Most national governments are giving increasing attention to the appraisal of natural resources. Agricultural research organizations have the responsibility of interpreting how best those resources can be used. The development of functional relationships between environmental factors and rice production depends on proper definition and measurement of the system under study. Multiple regression analyses have been used to develop relationships between rice yields and different components of the environment. While such studies may be of some value in indicating factors of particular importance in some areas, they seldom contribute much to a fundamental understanding of the relationship between the plant and the environment.



5. Relation between land quality and land use for rice culture (modified from Moormann and van Breemen 1978).

The physical environment of the crop is important in determining the nutrient and water supply to the crop, and the occurrence of adverse factors such as salinity. Although we can successfully model crop yield in any given environment, it has not yet been possible to develop models and test them for a wide range of environments. Research needs to be directed to the development of what Evans (1976) termed explanatory models, which relate plant response at the organ level to the external environmental conditions. Only on this basis can successful predictive models be developed for a wide range of environments.

To obtain the necessary understanding of the physical environments in which rice is grown, to define different components of the environments and quantify their relationships to rice yield, and to develop management techniques that will allow optimum use of any given environment, in terms of production of a single crop or the introduction of a more intensive cropping system, it is necessary to have a well-coordinated research program of environmental evaluation, management, and use. The objectives of the research program would be:

- characterization of the principal land systems in which rice is grown, and of the climate, soil, and water components of those land systems,

- determination of the effects of individual climatic and nutritional and other soil factors on component processes of rice growth,
- development of economic management practices designed to make optimum use of the environment to increase rice yields, and the total crop production in a given period.

Some areas where research is needed to achieve these objectives include:

- specific aspects of the relation between climatic factors and yield components, to remove "the appalling gaps in our knowledge,"
- better methods of land evaluation for rice, which will enable yield to be related to land characteristics. Such research programs must be interdisciplinary if they are to be effective. The incidence of water stress, for example, cannot be predicted without an appreciation of the climatic, topographic, and soil factors that control water availability to the plant. Such research programs should also take account of the need to quantify both favorable and adverse soil factors that determine crop yield and the particular problems of rainfed lowland rice,
- properties of the environment that determine the plants' efficiency in taking up nitrogen and other nutrients, the fixation of nitrogen from the atmosphere, and the influence of organic materials and their breakdown products on soil productivity,
- climate, land, and soil characteristics that determine the suitability of an area for more intensive cropping, and the long-term stability of more intensive land-use systems, and
- methods of controlling and managing water distribution in different land systems, for optimum use of water, including institutional needs and the importance of developing a proper understanding of the social and economic implications likely to occur when irrigation is developed in different environmental conditions.

A coordinated program of environmental evaluation, management, and utilization will require interdisciplinary work involving pedologists and climatologists, physiologists and soil chemists, agronomists and microbiologists, engineers and economists. Such a program should lead to a better understanding of the environment and its effects on the performance of a rice variety in the field. It will lead to the formulation of crop performance models that enable the rice production potential of any given area to be assessed from readily measurable properties of the environment. Such models can then be used to improve management practices in the area so that production is brought closer to full economic potential. The immediate economic benefit to be obtained from such a program will be improvements in the efficiency of fertilizer and water use, and successful development of increased cropping intensities, often associated with improved water management in both irrigated and rainfed areas. The program should contribute significantly to the more rapid development of varieties adapted to specific environmental conditions.

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SOIL AND PLANT NUTRIENTS

SALINE SOILS OF SOUTH AND SOUTHEAST ASIA AS POTENTIAL RICE LANDS

M. AKBAR and F. N. PONNAMPERUMA

Four recent developments focus attention on the saline soils of South and Southeast Asia as potential rice lands:

- the pressing need for more food for a rapidly expanding population;
- the scarcity of arable land;
- the failure of the early modern varieties to deliver their potential; and
- the success in breeding salt-tolerant rices with high yield potential.

The population of South and Southeast Asia will grow at about 2.7%/year during the next 2 decades. But food production rates are insufficient to keep pace with growth demand, especially in the poor populous countries (Allaby 1977, ADB 1977, IFPRI 1977). Recently a severe food shortage in the 1980s was forecast (ADB 1979).

IRRI reported in 1976 (IRRI 1976) that the green revolution had bypassed three out of every four rice producers. Most of those bypassed are small farmers who often lack the resources to provide the water control and chemical inputs needed to extract the full potential of modern varieties. Farmers on vast tracts with poor water control or toxic soils in Burma, India, and Thailand, for example, have not adopted the new varieties (ADB 1977). Even where the new varieties are grown widely, national yields are only about a third of experimental yields (Herdt and Barker 1979). Thus the new rice technology alone is not likely to prevent the huge rice deficits anticipated a decade from now.

Increasing rice production by extending area also faces obstacles. The extent of arable land in the densely populated countries of South and Southeast Asia is limited (Duncan 1977, Herdt et al 1977, Wortman 1975). The Asian situation was summed up by Willett (1976) in these words:

> The most crucial problem is in Asia where population density is already extremely high, population growth is increasing and undeveloped land resources are limited.

Overcrowding, food shortages, and land scarcity are driving Asian countries to an attempt to grow food crops on land that has been idle largely because of soil problems. The commonest and most extensive of the soil problems is salinity.

National coordinator (Rice), Pakistan Agricultural Council, Islamabad, Pakistan; and principal soil chemist, IRRI.

SALINE SOILS OF SOUTH AND SOUTHEAST ASIA

There are 380 million ha of saline soils on the earth's land surface. Of these, 240 million ha are not strongly saline (Massoud 1974). About 54 million ha of the strongly saline soils are in South and Southeast Asia (Table 1). Of these, 27 million ha are coastal saline soils, the vast bulk of which are in the humid tropics.

Table 1. Distribution of saline soils in South and Southeast Asia (Massoud 1974).

Country	Area (million ha)		
	Solonchaks	Saline phase	Total
Bangladesh		2.48	2.48
Burma	0.63		0.63
India	2.98	20.24	23.22
Indonesia		13.21	13.21
Kampuchea		1.29	1.29
Malaysia		4.58	4.58
Pakistan	1.10	9.35	10.45
Philippines		0.40[a]	0.40
Sri Lanka	0.18	0.02	0.20
Thai land		1.46	1.46
Vietnam		0.98	0.98
Total	4.89	54.01	58.90

[a] Guerrero (1977).

The coastal saline soils of the humid tropics offer the highest promise as potential rice lands because:

- they are located in areas climatically, physiographically, and hydrologically suited to rice;
- rainfall is adequate for leaching the salt and growing at least one crop of rice; and
- the lands are located close to densely populated areas where the demand for both land and food is high.

Most coastal saline soils are under mangrove vegetation. The trees are used for making stakes, firewood, and tannin. Mangrove swamps are cleared and used as fish ponds and salterns, and for production of rice, coconut, and pineapple.

Of the 400,000 ha of coastal saline soils in the Philippines (Guerrero 1977), 100,000 ha are under mangroves, 175,000 ha are in fish ponds that cost $4,000 to $20,000/ha to construct but whose average annual production is 700 kg fish/ha, and 125,000 ha are idle.

In Indonesia 558,000 ha of tidal swamps are planted to rice. The total cropped area of tidal swamps and polders is 12.6% of the total rice crop area per year. Reclaimed tidal swamps produce 10% of Indonesia's rice. By June 1979, the government had opened 220,000 ha of tidal swamp lands for rice in one transmigration scheme alone (Collier 1979). It plans to open another 250,000 ha in the next 5 years.

The 2 million ha of coastal saline soils of India occur in deltas in a strip ranging from a few kilometers to 50 km from the coast (Agarwal et al 1979, CSSRI 1979). Salinity is due to inundation by sea water and ingress of saline water at high tide. In West Bengal 250,000 ha are protected by dikes. The only crop grown is rice in the rainy season, but deep flooding is a problem. During the rest of the year the land is fallow because of high salinity.

The tidal area of the Bangkok plain is subject to submergence by salt water coming up the creeks and canals during the dry season, when discharge from the river system is low (de Glopper 1971). In the wet season, it is flooded with fresh water.

Characteristics of saline soils

Saline soils contain sufficient salt to impair the growth of crop plants. But because salt injury depends on species, variety, growth stage, and environmental factors, it is difficult to define precisely saline soils. For the purposes of this paper, we define a saline soil as a soil that has enough salt in the root zone to give an electrical conductivity in the saturation extract (EC_e) of 4 mmho/cm at 25° C. That value is the threshold beyond which rice yield declines appreciably as the salt content increases (Maas and Hoffman 1977).

Saline soils vary widely in their chemical and physical characteristics, salt dynamics, and hydrology. The variables include salt source, nature and contents of salts; lateral, vertical, and seasonal distribution of salt; soil pH; nature and content of clay; organic matter content; nutrient status; water regime; relief; and temperature. Mineral stresses other than salinity are in Table 2. Those differences have important implications for the management of saline soils and breeding varieties for salt tolerance.

Table 2. Kinds of saline soils and associated stresses.

Kind of saline soils	Accessory growth-limiting factors
Arid saline soils	High pH; deficiencies of zinc, nitrogen, and phosphorus
Neutral and alkaline coastal saline soils	Zinc deficiency, boron toxicity, deep water
Acid saline soils	Iron toxicity, phosphorus deficiency
Coastal acid sulfate soils	Iron and aluminum toxicities, phosphorus deficiency, deep water
Coastal organic soils	Deficiencies of nitrogen, phosphorus, zinc, copper; toxicities of iron, hydrogen sulfide, and organic substances; deep water

In the Philippines, coastal saline soils fall into four broad hydrological types (Ponnamperuma and Bandyopadhya 1980):

- type 1 — the soil is wet throughout the year and not excessively saline;
- type 2 — the soil is flooded with fresh water in the wet season and submerged by saline creek water in the dry;
- type 3 — the soil is saline in the wet season because of upwelling or seepage of brackish water; and
- type 4 — the soil is inundated by tides.

The first type can grow two salt-tolerant rice crops per year. The second needs flood-tolerant varieties in the wet season and short-duration, salt-tolerant ones in the dry. The third type is suited to the modern, short-stemmed salt-tolerant varieties. On the fourth type, salt injury can be severe and rice growing risky (Ikehashi 1979).

Some characteristics of Philippine coastal saline soils and their effects on rice yields are shown in Tables 3 and 4.

Reclaiming saline lands

Saline soils can be converted into productive agricultural land by:

- preventing the influx of salt water;
- leaching the salts out of the root zone;
- providing surface drainage in areas prone to flooding;
- applying soil amendments to correct acidity or alkalinity: and
- correcting nutrient deficiencies.

Because rice benefits by soil submergence, and its rooting depth is shallow, it is the best crop for saline soils.

The capital and recurrent cash inputs can be reduced by using salt-tolerant rices adapted to the local environment.

SALINITY AND RICE GROWTH

Salinity affects the growth of rice in varying degrees at all stages of its life cycle, starting from germination through maturation. The effect may vary depending on the stage of plant development (Castro and Sabado 1977, Iwaki 1956, Maas and Hoffman 1977, Ting and Fang 1957). Several studies indicate that rice is tolerant during germination, becomes very sensitive during early seedling stage, gains tolerance during vegetative growth, again becomes sensitive during pollination and fertilization, and then becomes increasingly more tolerant at maturity (Iwaki 1956, Pearson 1959, Pearson and Bernstein 1959, Pearson and Ayers 1960, Pearson et al 1966, IRRI [1967]). However, some workers maintain that flowering stage is not sensitive to salinity (Kaddah et al 1973, 1975). In fact, effect of salinity is related to the stage of plant development at which salinity is imposed, salt concentration, nature of salt, and the duration of salinization (Kaddah and Fakhry 1962, Pearson et al 1966). Hence, to know the response of rice plant to salinity, as a whole, it is imperative that the effects be observed at various stages of its development, separately.

Table 3. Summary of varietal tests on 5 Philippine coastal saline soils, 1979 dry season.

Location	Salt source	EC_e trend (mmho/cm)	Soil pH	Soil organic matter content (%)	Other soil problems	Yield range (t/ha)	Best yielders	Remarks
Agdangan, Ouezon	Creek	15 → ?	5.9	5.9	Zn defi-ciency	–	–	Excess salt was lethal
Aparri, Cagayan	Seepage	9 → ?	6.0	14.0	–	–	–	Water supply failed
Mexico, Pampanga	Saline irrigation water from creek	3 → 8	7.0	1.2	Zn defi-ciency	0-0.6	IR45954 IR4432-28	Sterility due to late salinity
Minalin, Pampanga	Saline irrigation water from creek	9 → 1	5.8	2.7	–	1.4-6.5	IR42	Rains depressed salinity drastically
Taal, Batangas	River	3 → 8	7.1	2.3	Zn def. B tox.	1.4-3.6	IR4595-4 IR4432-28	Moderate average salinity

roots and root elongation (Akbar and Yabuno 1974, Iwaki 1956, Ota et al 1958).

In short, the causes of salt injury to the rice plant are complicated. From the studies reported (Akbar 1975; Iwaki et al 1953b; Ota and Yasue 1958; Shimose 1963 a, b; Tagawa and Ishizaka 1963a), it seems that both osmotic imbalance and chloride ion may be responsible for the suppression of growth.

Vegetative stage

The rice plant gains tolerance during vegetative growth (Iwaki 1956, Kaddah and Fakhry 1961, Pan 1964, Pearson and Bernstein 1959, Tagawa and Ishizaka 1963a, IRRI [1968]). This tolerance is usually correlated with the seedling age. Del Valle and Babe (1947), studying the effect of salinity initiated 30, 60, and 90 days after planting, found that salinity was most harmful at the youngest age. As the plants became older, their tolerance for salinity increased; at 90 days, the plants were hardly affected by salt concentrations in the soil as high as 1.0%. Pearson (1959) also reported that the salt tolerance of rice seedlings progressively increases from 1 to 3 to 6 weeks of age.

During vegetative growth, plant height, straw weight, number of tillers per plant, dry weight of roots, root length, and number of days from transplanting to flowering are all affected by salinity (Akbar et al 1972, Iwaki et al 1953b, Iwaki 1956, Kaddah and Fakhry 1961, Tagawa and Ishizaka 1963a, IRRI [1968]). But all the growth parameters are not affected equally (Akbar et al 1972. Pearson 1961). In vegetative growth, salinity has less effect on straw weight and tiller number (Akbar et al 1972; Kaddah and Fakhry 1961,1962; Kaddah 1963). The top growth is often suppressed more than the root growth (Akbar et al 1972). Salinity affects the elongation of roots more than it does the production of dry matter in roots (Akbar et al 1972). During vegetative period, the most common effect of salinity is stunted plant growth; leaf withering is less apparent (Tagawa and Ishizaka 1963b). Salt injury is more severe at high temperature (30.7° C) and low humidity (63.5%) because of increased transpiration and uptake of water and salt by the rice plants (Ota and Yasue 1962).

Reproductive stage

Salinity at the reproductive stage depresses grain yield much more than salinity at the vegetative growth stage (Akbaret al 1972; Iwaki 1956; Kaddahand Fakhry 1961, 1962; Ehrler 1960; Pearson 1959, 1961; IRRI [1967]). Rice at critical salinity levels may give normal straw yield but produce little or no grain (Kapp 1947). Usually the decrease in grain yield is proportional to the salt concentration and the duration of saline treatment (Kaddah and Fakhry 1962, Ota et al 1955). When the plants are continuously exposed to saline media, salinity affects the panicle initiation, spikelet formation, fertilization of florets, and germination of pollen grains, and hence causes an increase in number of sterile florets (Akbar et al 1972, Iwaki 1956, Kaddah and Fakhry 1961, Ota et al 1956).

The greatest injurious effect is on the panicle. Salinity severely reduces panicle length, number of primary branches per panicle, number of spikelets per panicle, seed setting percentage, and panicle weight, thereby reducing grain yield (Akbar et al

1972, Pearson 1961). The weight of 1,000 grains is also reduced (Ota et al 1956). Salt injury also results in small grains because of reduction in grain length, width, and thickness (Ota et al 1955). Salinity also affects the quality of rice (Pan 1964).

BREEDING FOR SALT TOLERANCE

Marginal saline soils could be used for rice cultivation either by changing the environments to improve conditions for normal plant growth or by changing the plants genetically to withstand such an environment. The first approach has been used in the past but there is a great need to exploit the second.

For crops to adapt genetically to salinity, sufficient heritable variability should exist within the target crop. A review of literature suggests that considerable genetic variation exists among the rice varieties (Akbar et al 1972; Akbar and Yabuno 1974; Bhattacharyya 1976; Ikehashi 1979; Kaddahand Fakhry 1961,1962; Kaddah 1963; Ota et al 1958; Pearson et al 1966; IRRI [1967]). Although the number of rice varieties tested for salt tolerance is large enough, there is still a vast rice germplasm at breeders' disposal. IRRI has about 48,000 rice cultivars that could be screened for this trait; increasing the range of varieties tested greatly increases the chance of finding genetic variation.

The genetic variability so far reported in rice has not been used sufficiently in rice breeding programs. The reason may either be:

- a lack of understanding of the complex nature of tolerance and how it is modified by environmental interactions, or
- breeders' usual preoccupation with other breeding objectives such as yield, disease resistance, resistance to lodging, agronomic adaptability, earliness, quality, etc. and, hence, little inducement to consider additional factors of soil toxicities.

Priorities should be reviewed and breeding for salt tolerance given greater importance.

Breeding for salt tolerance seems feasible because there is no antagonism between high yield and salt tolerance (Shannon and Akbar 1978). The F_1 hybrids of tolerant and sensitive rice varieties have shown more tolerance than the parental lines (Akbar and Yabuno 1975). The F_2 exhibited a wide range of variation, and salt-tolerant progenies could be selected from F_3 and F_4 (Akbar et al 1977). Salinity induced two types of sterility in rice varieties, and resistance to delayed-type panicle sterility was found to be a dominant character controlled by a small number of genes (Akbar and Yabuno 1977). Salt-tolerant varieties — SR 26B, Kalarata 1-24, Malta, Hamilton, Bhurarata 4-10, Dasal, Getu, Damodar, and MCM2 — have been developed by pure-line selection from the locally grown germplasm for different states in India (Bhattacharyya and Mishra 1979).

Because tolerance of rice for salt varies at germination, seedling growth, transplanting, vegetative growth, flowering, and seed set, emphasis in breeding program should be placed on the critically sensitive growth stages. Because plant response to salinity is directly related to the duration of exposure, screening at vegetative growth

Table 4. Summary of varietal tests on 7 Philippine coastal saline soils, 1979 wet season.

Location	Salt source	EC_e 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 def.	0.3-1.4	IR4630-22 IR45954	Flood damage, prolonged high salinity
Bani, Pangasinan	Creek	8 → 10	6.1	1.3	–	0.4-1.6	IR4432-20 IR4630-22	Frequent tidal intrusions
Butuan[a], Agusan del Norte	Creek	3 → 4	4.9	9.5	Zn def.	2.4-6.5	IR42	Salt injury was slight
Calapan, Mindorc	Creek	12 → 16	6.7	4.0	–	2.9-4.8	IR2071-88 IR42	Fresh water from creek depressed salinity
Cebu, Cebu	Creek		7.4	6.8	Zn def. B tox.	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	Rains depressed salinity
Taal, Batangas	River	3 → 4	7.1	2.3	Zn def. B tox.	0-1.1	IR4595-4	Severe flood damage

[a] 1978.

Germination and early seedling stage

Rice varieties are tolerant of salinity during germination (Akbar and Yabuno 1974, Kaddah 1963, Pearson 1961, Pearson et al 1966, IRRI [1967]). Salinity delays germination but does not appreciably reduce the final germination percentage (Akbar and Yabuno 1974, Kaddah 1963, Kapp 1947).

About 80-100% germination occurs at an EC of 25-30 mmho/cm at 25° C of saline solution after 14 days (Pearson et al 1966). High salt concentrations, i.e. 2-4%, show strong inhibitory effect and markedly decrease the final germination (Akbar 1975, Iwaki 1956). High salt concentrations (3-l5% NaCl) have been reported to inhibit germination, but the seeds germinated when transferred to distilled water (Ota and Yasue 1958). It has been suggested that salinity has no harmful effect on germinability (Akbar et al 1972). Germination time increases with increase in salt concentration, because it is directly related to the amount of water absorbed by the seeds, which in turn depends upon the salt concentration. Thus osmotic stress, and not the specific ion, may be responsible in delaying germination.

Rice plants are much more sensitive during the young seedling stage (2-3 leaves) than during germination (Akbar and Yabuno 1974, Kaddah and Fakhry 1961, Kaddah 1963, Pearson 1961, Pearsonet al 1966). The EC values for a 50% reduction in germination 1 week after planting ranged from 20 to 30 mmho/cm while the critical level of salinity (LD50) for seedling growth was about 5 mmho/cm (Pearson et al 1966). Growth parameters such as dry matter, seedling height, root length, and emergence of new roots decrease significantly at an EC value of 5-6 mmho/cm (Akbar and Yabuno 1974, Pearson et al 1966). No doubt LD50 for germination percentage and seedling characteristics differ among rice varieties (Ota et al 1958, Pearson et al 1966).

At the early seedling stage, salinity causes rolling and withering of leaves, browning of leaf tips and, ultimately, death of seedlings (Tagawa and Ishizaka 1965). In general, salt injury symptoms first appear on the first leaf (older), then on the second, and later on the growing leaf (Akbar 1975). Salinity suppresses leaf elongation and formation of new leaves (Akbar 1975; Iwaki 1956; Tagawa and Ishizaka 1963a, 1964). Growth decreases with increase in osmotic pressure (Shimose 1963a) as water uptake decreases (Iwaki et al 1953a, Tagawa and Ishizaka 1963a), sodium and chloride in the leaves and stems increase (Ota and Yasue 1962; Shimose 1958. 1963a; Tagawa and lshizaka 1963b), and the desorption of potassium and calcium by rice plants decreases (Shimose 1963a). Most of the chloride is localized in leaf blades. leaf sheaths, and stems, but of all the plant parts (except the panicle), the roots contain the least chloride (Tagawa and Ishizaka 1963b, Ting and Fang 1957). Starch and cellulose contents in leaves plus stems decrease with increasing salt concentration (Shimose 1963b). Photosynthetic function and chlorophyll content decrease in proportion to increased salt concentration (Ota and Yasue 1962). Decrease in the size of stomata, which indicates a low carbon dioxide concentration in the leaves containing more sodium chloride, results in lower photosynthetic rate (Ota and Yasue 1962).

Salinity also adversely affects root development. It markedly decreases lateral

should begin after seedling establishment and continue until harvest. In the hybridization program, segregating generations should be screened at all growth stages for overall performance. In the absence of any proven morphological and physiological gene markers for tolerance (Akbar et al 1972, 1975; Maas and Hoffman 1977; Maas and Nieman 1978), it may not be advisable to correlate injury symptoms in early growth development to sensitivity at maturity.

Because little breeding for salt tolerance has been done, a great deal of work is still required to formulate breeding methods and rapid and efficient techniques for screening and developing selection criteria. Screening techniques and breeding methods for salt tolerance have recently been discussed in detail by various workers (Niemen and Shannon 1976, Ponnamperuma 1976, Shannon and Akbar 1978). The use of quantitative genetic techniques has been suggested (Donald 1968).

According to Kanna (1975), a tolerant line accumulated higher sodium concentrations than a sensitive rice line having comparable potassium and chloride levels. This halophytic feature might be considered in testing rice varieties for salt tolerance.

FIELD PERFORMANCE OF SALT-TOLERANT RICES

Salt tolerance studies are usually in growth chambers and greenhouses, with plants raised in plastic trays or small pots. The application of results obtained in such studies to field conditions, where the distribution of salt is neither uniform in depth nor constant with time, is difficult and requires knowledge of how plants respond to varying salinity levels (Maas and Hoffman 1977). The salt tolerance of any crop is usually expressed as a decrease in yield associated with a given level of soil salinity as compared with yield under nonsaline conditions (Berg 1950; Bernstein 1964, 1974; de Forges 1970; U.S. Salinity Laboratory Staff 1954). The primary salinity factors influencing plant growth are the kind and the concentration of salt present in the soil solution. Salt concentration in soil is usually determined by measuring the EC of a soil saturation extract (EC_e) obtained from the active root zone. Recently, simple, rapid, and reliable instruments — salinity sensors and four electrode probes — have been developed for measuring the EC of soil water (EC_{sw}). By these instruments, the EC_{sw} can be determined in situ (Oster and Willardson 1971, Rhoades and Ingvalson 1971, Rhoades 1975).

At IRRI, field screening is done in a 0. 1-ha plot. Salt is added from time to time to keep the EC_e 8-10 mmho/cm at 25°C. About 1,200 entries/year can be screened. The tolerant lines are tested in the International Rice Salt and Alkali Tolerance Observational Nursery (IRSATON), which is a part of the International Rice Testing Program (IRTP), for further screening in saline fields in Southeast Asian countries. The results of various IRSATONs are summarized in Table 5. About 32 entries have been rated as tolerant. The results of recent replicated yield trials in saline fields with rices bred for salt tolerance, good agronomic characteristics, and resistance to pests are promising.

In India, Bhattacharyya (1976) tested 24 varieties for 3 consecutive years in a heavy-textured soil whose EC_e values varied from 4.0 mmho/cm at planting to

Table 5. Performance of rice cultivars in saline fields.

IRSATON[a]	Year	Tested entries (no.)		Tolerant varieties and lines
First	1975	50	3:	Pokkali, DA29, Nona Bokra
First	1976	71	12:	DA29, Damodar, IET. 5233, Agami MI, BG 34-8, Giza 159, Nona Bokra, Patnai 23, SR 26B, BG 94-2, IR2031-729-2, Pokkali.
Second	1977	77	10:	CSSR1[b] (Damodar), CSSR2[b] (Dasal), IR2058-78-1-3-2-3[b], Nona Bokra, IR4-11, Nonasail (Sel.)[b], Pokkali[b], IR2053-436-1-2, IR2153-26-3-5-2, CuI. No. 102.
Third	1978	72	7:	IR4227-104-3-3-1, Nona Bokra, Getu, IR4-11, IR4630-22-2-5-1-2, IR4763-73-1-12, and Pokkali.

[a] International Rice Salt and Alkali Tolerance Observational Nursery. [b] At both vegetative and maturity stages.

8.6-11.8 mmho/cm at flowering time. The varieties Dasal, Getu, Damodar, IR8, and Rajasal yielded 3.7, 3.6, 3.3, 3.3, and 3.2 t/ha, respectively, and were superior to all other varieties tested. Several salt-tolerant lines and varieties yielded about 1 t/ha under average EC_e values of 5.4-7.7 mmho/cm at 25°C. In the same field, some salt-tolerant lines yielded about 3.5 t/ha while nontolerant varieties yielded about 2.0 t/ha under an average EC_e of 4.2-6.8 mmho/cm at 25°C (Ikehashi 1979). In recent tests, several fixed lines developed from crosses between salt-tolerant donors and modern varieties yielded 3.5-5.5 t/ha (CSSRI 1979).

In the Philippines, the performance of 26 improved salt-tolerant rices was studied in 24 replicated experiments at 14 sites in farmers' fields during 1977-79 (Quidez et al 1980). Soil pH ranged from 4.4 to 7.8; organic matter content, from 1.2 to 14.0%; and nutrient status from moderate to high. Of the high-pH soils, seven were zinc deficient and two boron toxic, whereas the two strongly acid soils were iron toxic. Intrusion of sea water, saline creek water, or saline groundwater, especially in the dry season, affected all 14 sites; deep flooding in the wet season occurred at 4. The salt concentration increased during the dry season and decreased in the wet, with EC values ranging from 1 to 15 mmho/cm. Performance of the rices varied with salt concentration, availability of water in the dry season, and flood damage in the wet. On slightly saline soils not subject to deep flooding, salt-tolerant, disease- and insect-resistant modern rices gave yields exceeding 4 t/ha (IRRI 1978, 1979; Quidez et al 1980). Such rices included IR42, IR2071-88-8, IR2863-39-1, IR4422-164-3, IR4630-22-2, IR2071-105-4, IR4619-48-3, IR4432-28-5, IR9884-54-3, and IR9884-3-3.

GUIDELINES FOR USING SALINE LAND FOR RICE CULTIVATION

Because the rice plant is susceptible to salinity at transplanting (IRRI [1967]) and

gains tolerance with age (del Valle and Babe 1947), it is advisable that aged seedlings (6 weeks old) be planted in saline fields. During the early part of the growing season and at flowering, when rice is sensitive to salt, efforts should be made, if possible, to minimize salinity by frequent irrigation. In areas of high evaporation, water should be replenished frequently to offset the increase in salinity of the surface water, which results from evaporation.

In the reclamation of highly saline soil, rice may be included in a crop rotation as a leached crop. Because rice is a relatively shallow-rooted crop, to establish a stand of rice, it is not necessary to move the salt to greater depth. The severity of the salinity problem would determine the frequency with which rice may be included in the rotation. In some areas the soil may need continual leaching. In such cases it will not be possible to grow any crop except the more salt-tolerant varieties of rice. Besides the use of salt-resistant varieties, a sufficient supply of other essential nutrients is required to obtain high yields on saline fields. Because of nutritional imbalances and differential plant response under saline conditions, a package of production technology (i.e. age of seedlings, time of planting, number of plants per hill, spacing, type of fertilizer and its rate, application of micronutrients, appropriate water management, etc.) must be developed.

PROSPECTS OF INCREASING RICE PRODUCTION OS SALINE SOILS

Several recent developments suggest that the prospects of increasing rice production on current and potential saline rice lands are good. The developments include:

- publication of maps and tables showing the distribution of strongly saline soils (Solonchaks) and slightly saline soils (Unesco 1974, Massoud 1974);
- accumulation of research findings on the chemical and physical characteristics, hydrology, and management of saline soils (FAO-Unesco 1973, CSSRI 1979, IRRI 1979, Karnal 1980, Quidez et al 1980);
- identification of accessory growth-limiting factors on saline soils (Ponnamperuma and Bandyopadhya 1979, Quidez et al 1980);
- the possibility (based on the foregoing) of demarcating areas where salinity, other mineral stresses, deep flooding, and water stress are not too severe to make rice production an economic proposition;
- accumulation of data on the reactions of the rice plant to varying salt concentrations at different stages of its development and provision of management guidelines based on such data (Akbar 1975; Akbar and Yabuno 1975, 1977; Akbar et al 1972, 1975, 1977, 1979);
- increase in knowledge of the physiology of salt tolerance (Maas and Hoffman 1977);
- successful breeding of salt-tolerant rices with high yield potential and resistance to diseases and insects, and exchange of such rices through the International Rice Testing Program coordinated by IRRI (Ikehashi and Ponnamperuma 1978, Ponnamperuma and Bandyopadhya 1980, CSSRI 1979); and
- increase in production through use of improved salt-tolerant rices that yield

more than 4 t/ha in saline rice fields (IRRI 1976, 1977, 1978).

METHODS FOR INCREASING RICE PRODUCTION ON SALINE LANDS

The following methods will increase rice yields on cultivated saline lands and permit rice production on millions of hectares of saline lands where environmental stresses are not severe:

- preparing accurate land suitability maps based on salt dynamics, hydrology, soil toxicities, and nutrient deficiencies;
- constructing dikes to prevent the intrusion of sea water in coastal areas;
- using improved cultural practices and fertilizers;
- correcting zinc deficiency in neutral soils, alkaline soils, and organic soils;
- ameliorating iron toxicity in acid saline soils;
- using salt-tolerant rices of intermediate stature that have submergence tolerance in the wet season, and shortduration, salt-tolerant rices in the dry season;
- transplanting instead of direct seeding;
- using older seedlings for transplanting;
- increasing the level of salt tolerance in rice by appropriate breeding techniques;
- incorporating tolerance for iron toxicity, boron toxicity, and zinc deficiency; and
- improving screening techniques.

Research strategies

To further increase the possibility of using saline lands for rice production, the following strategies are suggested:

1. methodologies must be developed for demarcating saline lands according to the degree of salinity and other hazards;
2. ways must be developed for preventing resalinization of soils;
3. agronomic practices suited to the different kinds of saline soils must be developed;
4. levels of salt tolerance must be increased by using tissue culture and gene accumulation techniques; and
5. the economics of using saline lands for rice production must be determined.

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NITROGEN FERTILITY AND FERTILIZER MANAGEMENT IN WETLAND RICE SOILS

S. K. DE DATTA and E T. CRASWELL

The low fertility of rice soils and a limited supply of inorganic fertilizers are serious constraints to increased rice yields in South and Southeast Asia. Yield-constraints studies in the Philippines suggest that insufficient application or inefficient management of fertilizers, particularly improper timing of application, accounts for a gap of at least 1 t/ha between farmers' actual and potential rice yields during the dry season (De Datta et al 1979). Even in the wet season, when the response to nitrogen fertilizer is lower than in the dry season, the contribution of fertilizer to yield improvement is high (Fig. 1).

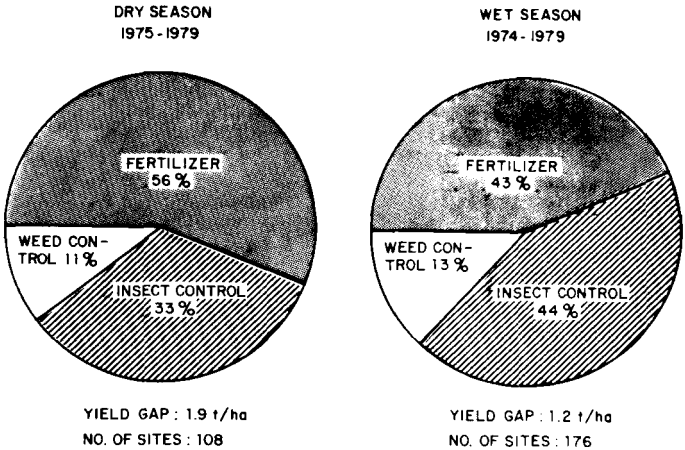
The capacity for nitrogen fertilizer production in many South and Southeast Asian countries is expanding rapidly to provide nitrogen for increased rice production. Stangel (1979) suggests that nitrogen production in South and Southeast Asia will have increased from about 300,000 t in 1978 to 3,000,000 t by 1983 — 85% as urea.

This rapid, large-scale expansion in nitrogen fertilizer production is an important development in the region. But unless high losses and low efficiency of nitrogen fertilizers are prevented, most of the potential benefits from increased use of fertilizer nitrogen may not be realized.

Realizing the urgency of the situation, scientists at international and national research centers are collaborating in projects that need immediate and sustained efforts. Informal collaboration in 1974 led to the formation in 1976 of the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER). There is a need to strengthen this collaboration through careful identification of research topics and development of research strategies for nitrogen fertility and fertilizer management for wetland rice.

The paper summarizes information on relevant research on the nitrogen fertility of rice soils and on fertilizer management for efficient use in wetland rice and, more importantly, suggests strategies to speed research through collaboration between national and international scientists. Table 1 lists the characteristics of the fertilizer materials under study.

Agronomist, IRRI; and soil scientist, International Fertilizer Development Center, Muscle Shoals, Alabama, USA.



1. Relative contribution of 3 inputs (fertilizer, weed control, and insect control) to the improvement of rice yields in farmers' fields in 4 Philippine provinces, 1974-79 (De Datta and Garcia 1980 unpubl. data).

Table 1. Characteristics of experimental urea materials.

Urea material	Particle's mean diam (mm)	Wt of urea (g)
Prills	1.0 - 2.4	about 0.001
Granules	2.0 - 4	0.005–0.045
(marbles)	6.0 - 8	0.147–0.35
Supergranules		
1 g	11.4	1 ± 20%
2 g	14.4	2 ± 20%
3 g	16.4	3 ± 20%
SCU (regular)	1.25–3.33	0.001 –0.02[a]
SCU (forestry grade)	4.0 - 5.7	0.038 –0.11[b]

[a]Assumed to be 78% urea. [b]Assumed to be 84% urea.

NITROGEN FERTILITY OF WETLAND RICE SOILS

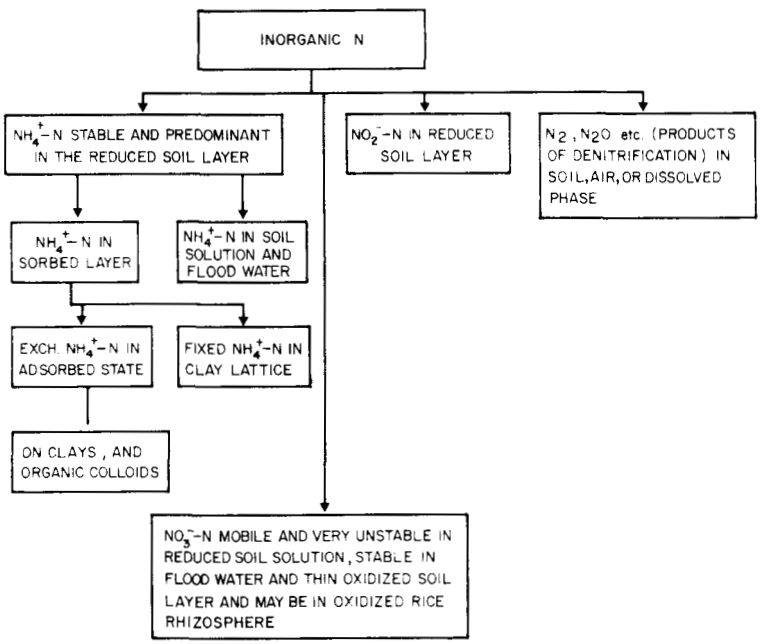
Knowledge about the nature of native nitrogen helps in understanding the dynamics of nitrogen transformations and its availability to the wetland rice plant. In the rice soils of 10 countries studied by Kawaguchi and Kyuma (1977), the total nitrogen varied from 0.08 to 0.29%, with Indian soils containing the least nitrogen (0.08%) and Japanese soils containing exceptionally large amounts (0.29%) (Table 2).

Various fractions present in the inorganic nitrogen pool of a wetland soil, shown in Figure 2, represent a small part of total soil nitrogen. These forms, however, constitute an extremely dynamic nitrogen system in the soil, which is affected by physical, chemical, and microbiological reactions. The predominant form of in-

Table 2. Total nitrogen and carbon-nitrogen ratios (C:N) of rice soils in tropical Asia and Japan (adapted from Kawaguchi and Kyuma 1977).

Country	Soil (n)	Av total N[a] (%)	C:N
Bangladesh	53	0.13 (0.05 – 0.52)	8.7 (7.1 – 12.4)
Burma	16	0.10 (0.04 – 0.18)	11.5 (8.6 – 13.4)
Cambodia	16	0.10 (0.03 – 0.29)	10.7 (7.7 – 13.7)
India	73	0.08 (0.02 – 0.20)	11.7 (4.8 – 18.4)
Indonesia	44	0.12 (0.05 – 0.59)	12.6 (8.3 – 25.8)
W. Malaysia	41	0.28 (0.05 – 0.92)	11.8 (9.2 – 19.8)
Philippines	54	0.15 (0.06 – 0.35)	11.7 (7.7 – 19.0)
Sri Lanka	33	0.13 (0.03 – 0.64)	10.5 (6.5 – 15.6)
Thailand	80	0.09 (0.02 – 0.27)	11.3 (6.0 – 22.2)
Japan	a4	0.29 (0.08 – 0.91)	11.6 (3.6 – 23.2)

[a]Figures in parentheses indicate range.



2. Inorganic tractions of nitrogen in a wetland rice soil (from Savant and De Datta 1980, unpubl. manuscript).

organic nitrogen in the wetland soil is NH_4^+. The concentration of NH_4^+ in soil solution (intensity factor) is relatively smaller than that in the sorbed phase (capacity factor) in soils with high cation exchange capacity (CEC). Although the rice plant absorbs nitrogen from the soil in the form of NH_4^+ and NO_3^-, the contents of these ions in a soil sample frequently do not reflect the soils' nitrogen-supplying capacity throughout the growing period.

The available nitrogen status in wetland rice soils is influenced by many chemical and biological processes. Mineralization of organic nitrogen in flooded soils depends largely upon the chemical environment as well as the microbial population in the soil. In some soils, nitrogen mineralization may proceed at a slower rate in flooded than in nonflooded conditions. However, the reverse relationship has also been observed in many soils with different chemical and biological environments (Waring and Bremner 1964, Patrick and Wyatt 1964). In flooded soils, the product of mineralization is mainly NH_4^+. The reaction, however, proceeds to form NO_3^--N when oxygen is adequate. It has been suggested that the determination of NH_4^+-N mineralized in anaerobic conditions may give a good estimate of the amount of nitrogen available to the wetland rice crop (Patrick and Mahapatra 1968).

Measurement of nitrogen fertility of soils

The complex and dynamic nature of the soil nitrogen regime makes tests for soil, nitrogen much more difficult than tests for soil phosphorus and potassium. The methods of measuring the nitrogen-supplying capacity in wetland soils have been reviewed by Broadbent (1978) and Chang (1978). They include:

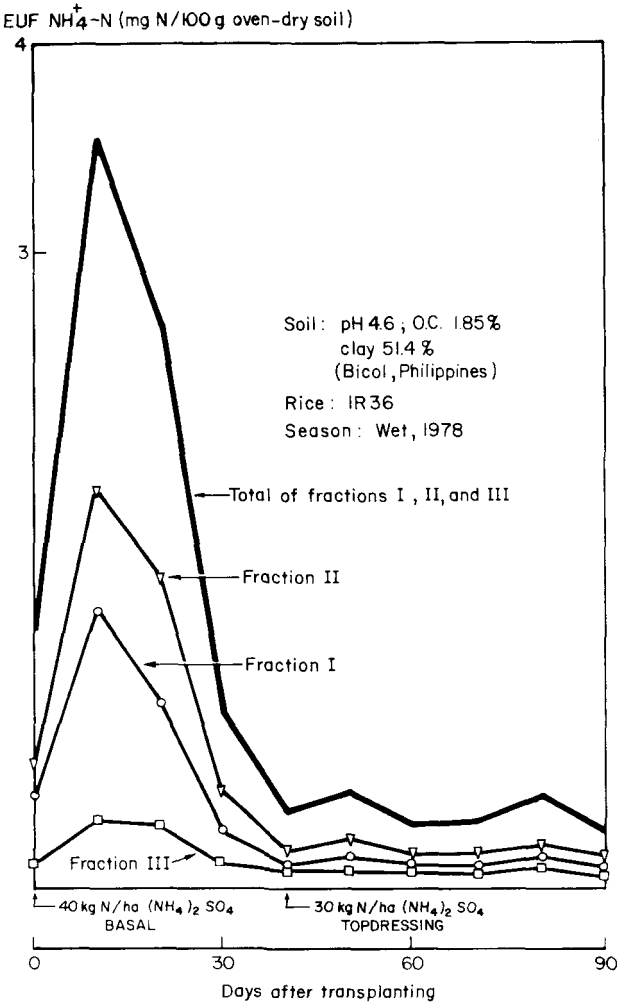
- determination of total nitrogen or carbon,
- measurement of nitrogen mineralized during anaerobic incubation,
- chemical extraction of inorganic forms of nitrogen,
- estimation of ammonium released by treatment of the soil with acid, alkali, or oxidizing agents such as acid or alkali permanganate and hydrogen peroxide,
- determination of carbon dioxide produced when the soil is incubated with a nitrogen-free substrate,
- measurement of microbial growth, and
- determination of *A* values (Ponnamperuma 1978).

Many of these methods have limited value in developing nitrogen fertility management for wetland rice soils.

Ammonium dynamics in wetland soils

Ammonium nitrogen is stable under reduced soil conditions and represents the main nitrogen form for nitrogen nutrition of wetland rice. An electroultrafiltration (EUF) technique (Nemeth 1976) was recently used.

Chemical analyses of wet soil samples from fertilized transplanted fields reveal that with time NH_4^+-N decreases very rapidly. This is evident from the data on NH_4^+-N measured by EUF (Fig. 3). The EUF-NH_4^+-N fractions I, II, and III, representing NH_4^+-N in soil solution (intensity factor). readily exchangeable NH_4^+-N, and difficultly exchangeable (capacity factors) NH_4^+-N, respectively, reached peak values after basal incorporation of 40 kg N/ha as ammonium sulfate and thereafter declined rapidly to near the NH_4^+-N concentration of a check soil within about 40 days after application. The trends for KCl-extractable NH_4^+-N were similar (S. Wanasuria, S. K. De Datta, IRRI, and K. Mengel, Justus Liebig University, West Germany, 1979, unpubl.).



3. Changes in NH_4^+-N determined by the electroultrafiltration (EUF) technique in wet soil samples collected from wetland paddy field. (Before transplanting [0 day] and at 40 days after transplanting, soil samples were collected before application of fertilizer N.) (Wanasuria et al. IRRI 1979, unpubl.).

NITROGEN TRANSFORMATION IN WETLAND SOILS

Nitrogen transformation processes in flooded soils were reviewed by Patrick and Mahapatra (1968) and Tusneem and Patrick (1971). Recently, Broadbent (1978) highlighted the nitrogen transformation processes and Hauck (1979) covered the methodology used by various workers for nitrogen transformations.

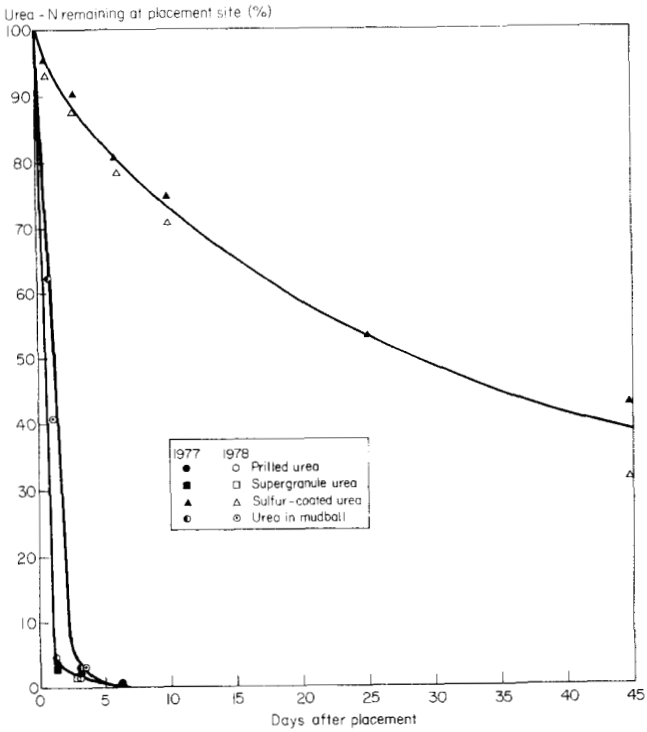
The following sections include the transformation processes that we feel are relevant to the subject of our paper.

Nitrogen release patterns from deep-placement sites

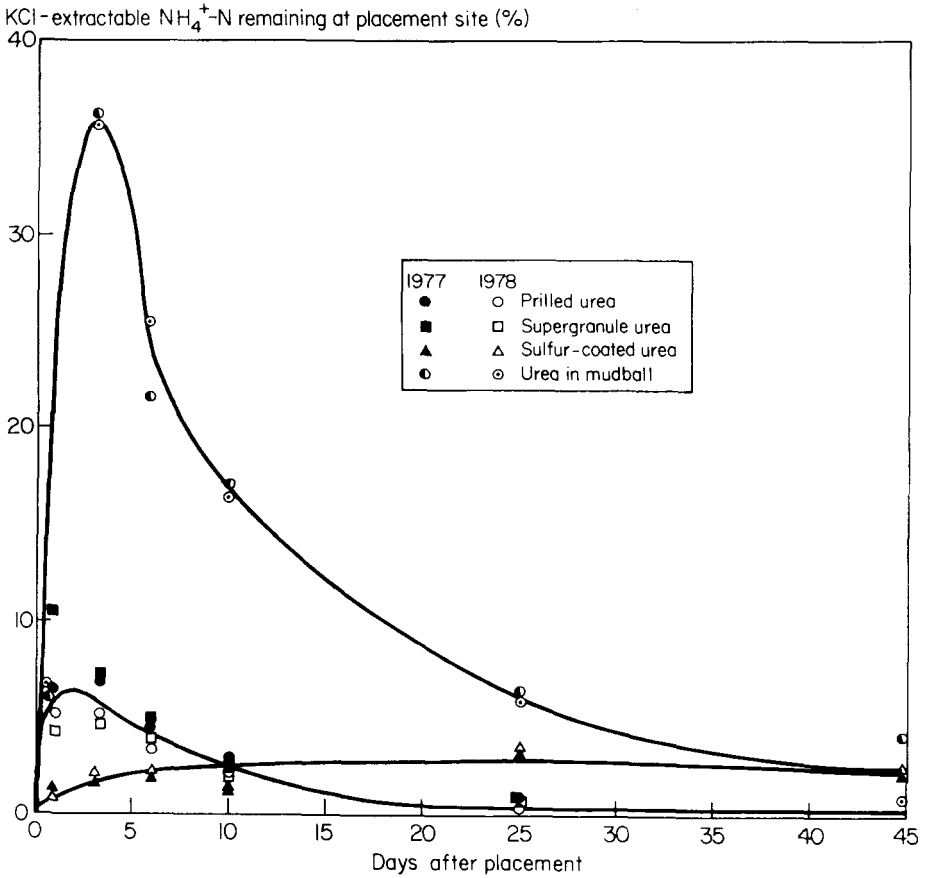
Only one report on nitrogen release from sulfur-coated urea in a flooded soil is

available (Giodarno and Mortvedt 1970). Savant and De Datta (1979a) reported information on in situ nitrogen-release patterns from modified forms of urea placed in a wetland soil. The modified urea materials were supergranule urea (SGU), sulfur-coated urea (SCU), and urea in mudball (MBU). Prilled urea (PU) was included as check. In the placement sites of PU and SGU, urea-N decreased rapidly to as low as 2.2% of the applied urea within 1 day after placement, and nearly disappeared after 3 days. Urea-N in MBU disappeared almost entirely within 3 days after placement. At the placement sites of PU and SGU, and even MBU, urea hydrolysis was rapid (Fig. 4, 5). The relatively higher concentration of urea-N in MBU recovered 1 day after placement supports this assumption and suggests that the mud covering restricts the outward movement of urea-N. Deep-placed SCU released nitrogen at a marked slower rate than MBU up to 45 days after placement. The dissolution of deep-placed SCU appeared to agree with its empirical dissolution characteristics (21% dissolution in 7 days). Through 45 days after placement, 31-43% N still remained at the placement site of SCU.

Figure 6 shows a schematic representation of urea transformation at the placement site in a wetland soil. During the first day of placement. dissolved urea-N, dissolved NH_4^+-N and exchangeable NH_4^+-N were present simultaneously (Fig. 4, 5). Nitrogen release from deep placement sites of the different forms of urea appeared to



4. Changes in urea-N remaining at deep-placement sites after application of different forms of urea to wetland soil. IRRI, 1977 wet and 1978 dry seasons (from Savant and De Datta 1979a).



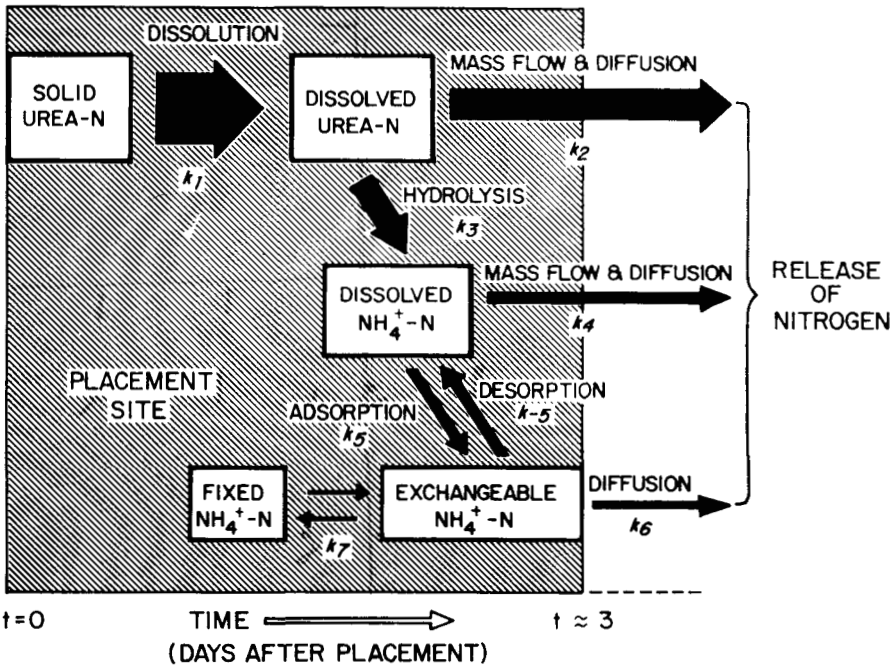
5. Changes in KCl-extractable NH^+_4-N at deep placement sites after application ofdifferent forms of urea to wetland soil. IRRI 1977 wet and 1978 dry seasons (from Savant and De Datta 1979a).

be a diffusion-controlled process (Savant and De Datta 1979a). This information on nitrogen release and distribution patterns helps us understand the movement of deep-placed urea-N in wetland rice soils.

Movement and distribution of ammonium nitrogen

Movement of various inorganic nitrogen species through mass flow or diffusion, or both, and their concomitant distribution in a soil profile play a significant role in making applied nitrogen available to wetland-rice crop. Those processes are important when fertilizer nitrogen is banded or deeply placed in a soil.

Recently Savant and De Datta (1980) studied the movement and spatial distribution of NH_4^+-N after the deep placement of different forms of urea in a wetland rice soil (Aquept). Relatively undisturbed core wet soil samples were collected using the

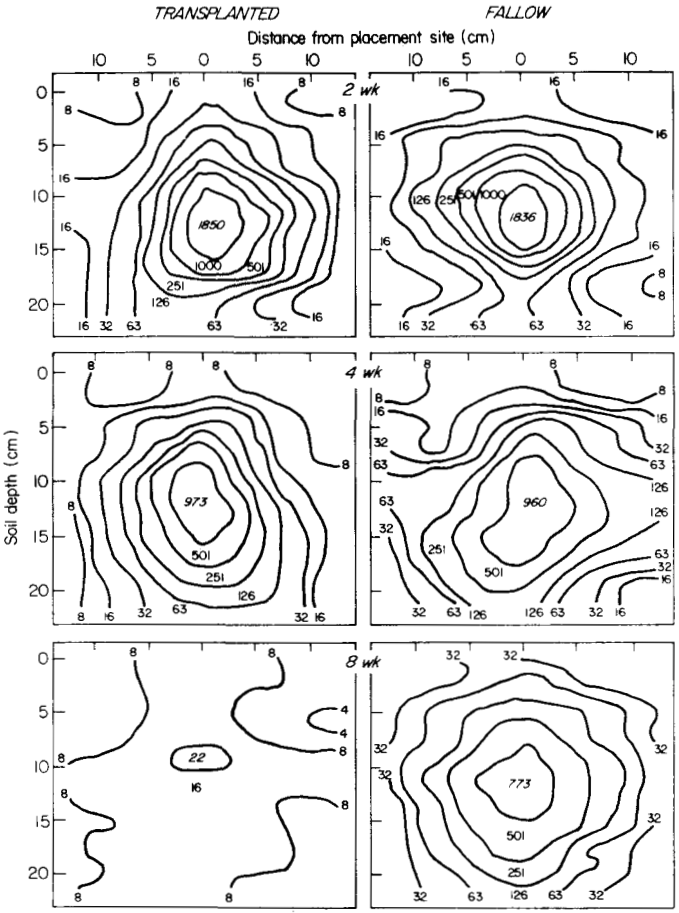


6. A schematic representation of urea transformations at a deep placement site in wetland soil (from Savant and De Datta 1979a).

technique devised by Savant and De Datta (1979b). Data collected on the wet-soil samples were processed using the mathematical procedure (Maximum Likelihood Program) developed by Gasser and Ross (1975) at the Rothamsted Experiment Station, England, for computation of contour plots of NH_4^+-N concentration in the soil-urea interaction zone.

Figure 7 shows calculated contour lines of the NH_4^+-N concentration for deep placement of supergranule urea (SGU) in the transplanted and fallow plots. After 2 weeks, the maximum concentrations of NH_4^+-N near the placement sites of SGU were 1,850 µg N/cm^3 for the transplanted plots and 1,836 µg N/cm^3 for the fallow plots. For the same period, the corresponding values for SC-SGU were 287 and 172 µg N/cm^3. With time, the maximum concentration of NH_4^+-N for SGU eventually decreased more rapidly in the transplanted plots. On the other hand, the maximum concentration of NH_4^+-N near the placement site of SC-SGU continuously increased through 8 weeks, but increased slowly up to 4 weeks, and decreased thereafter in the transplanted plot because of the slow release of nitrogen from SC-SGU and, presumably, the concurrent uptake of nitrogen by rice plants.

The contour lines of the NH_4^+-N for SGU and SC-SGU suggest that the general movement of the NH_4^+-N was of the order: downward > lateral > upward. The upward and lateral movements were presumably the result of diffusive transport.

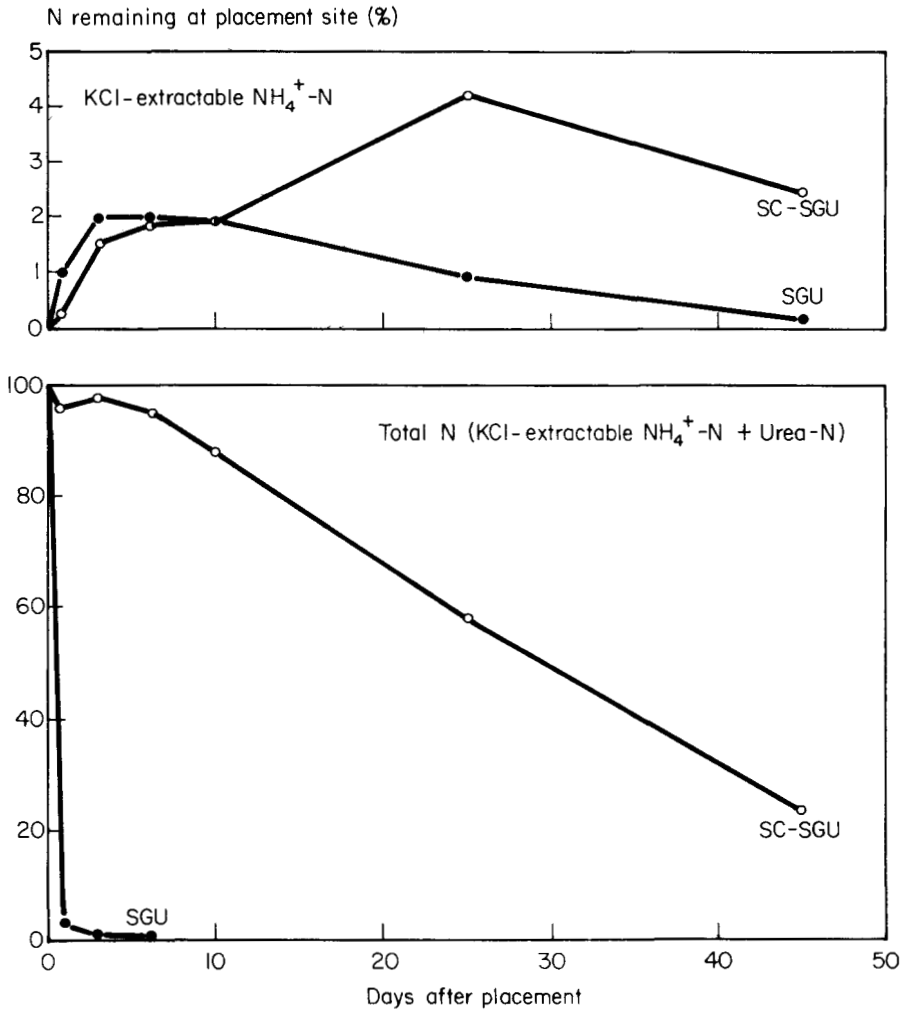


7. Computed contour plots showing distribution patterns of NH_4^+-N (g cm³ wet soil) following 10 cm deep placement of 2 g supergranule urea in a wetland soil. IRRI 1978 wet season (from Savant and De Datta 1979).

The NH_4^+-N hardly reached the floodwater-soil interface because of slow NH_4^+-N and the oppressive effect of downward flow of percolating water. The downward movement of NH_4^+-N was attributed to diffusive as well as convective transports. It appears that during the first few days after placement of SGU, unhydrolyzed urea remaining in the soil solution moved downward via convective transport and then eventually was hydrolyzed (Savant and De Datta 1980).

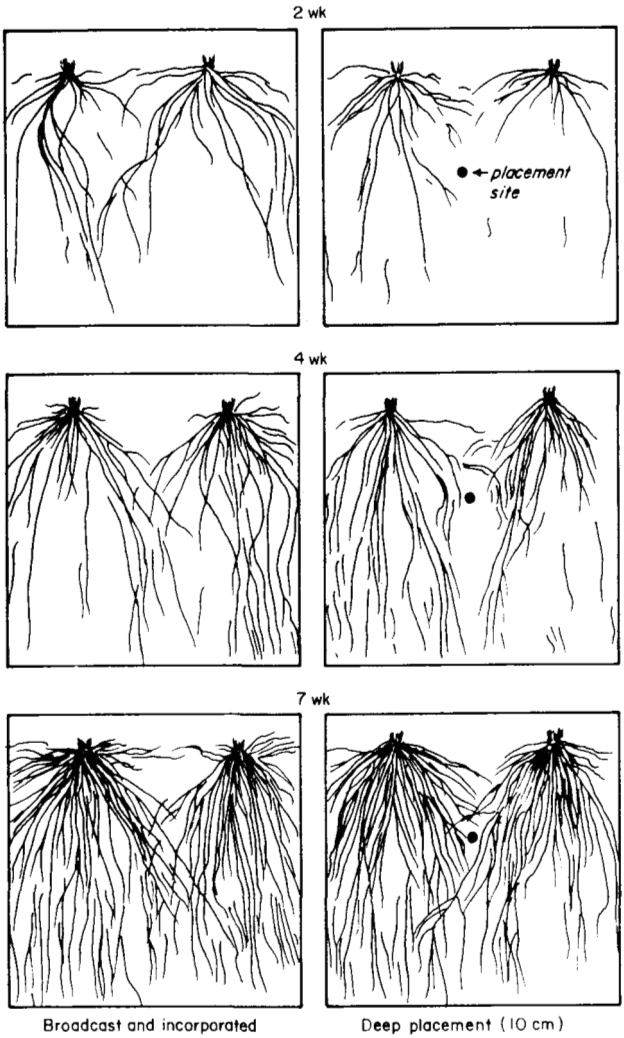
In another study, SC-SGU deep placed in a wetland Maahas clay released about 20% of total nitrogen placed during the first 2 weeks; nearly 20% of the urea-N remained at its placement site after 45 days (Fig. 8). Craswell and Vlek (1978) reported that when they used 1 g SC-SGU, rice recovered 83% of total nitrogen.

In wetland soils with properties similar to those of Maahas clay, a distinct concentration gradient of NH_4^+-N following deep placement of urea will probably exist for 4 weeks or more. During the first 2-3 weeks after transplanting, when the rice plant's nitrogen requirement is low, it may be adequately met from the native-



8. Ammonium-N and total N (NH^+_4-N + urea N) remaining at the placement site after deep placement of 2 g supergranule urea (SGU) and sulfurcoated supergranule urea (SC-SGU) in wetland Maahas clay. IRRI, 1978 wet season (from Savant and De Datta 1980).

nitrogen pool or from the outer diffused zone of soil-urea reaction having low NH_4^+ concentration or from both. This is because the rice roots generally avoid proliferation through the soil-urea reaction zone of steep NH_4^+ concentration gradient. For example, in a root-box study (Savant and De Datta 1980), rice roots avoided the urea-soil reaction zone when urea was placed at 10-cm soil depth during the first 2-4 weeks of rice growth. When urea was broadcast and incorporated during that



9. Comparison of root distribution of IR36 rice when urea was broadcast and incorporated and deep placed at 10-cm soil depth in a root-box study. IRRI, 1978 wet season (from Savant and De Datta 1980).

period, root distribution was fairly uniform (Fig. 9). With time, as a consequence of NH_4^+ movement when the concentration gradient decreased (Fig. 7), the plant roots gradually began to proliferate through the soil-urea reaction zone.

In a separate study at IRRI, Ventura and Yoshida (1978) also noticed very little horizontal movement of NH_4^+-N from the placement site; the distribution of ^{15}N was restricted to the 4 adjacent hills of IR26 rice transplanted at 20- × 20-cm spacings. When Bilal (1977) studied the transport of surface-applied ammonium sulfate in a flooded Sacramento clay, he noticed an appreciable concentration of nitrogen as NH_4^+ remaining in floodwater and at a depth of 1.2 cm. Studies by Savant and De

Datta (1980) reported that in the absence of rice plants, NH_4^+ moved down to a depth of 12-14 cm 4 weeks after surface application of urea in undisturbed flooded Maahas clay.

Ammonia volatilization

Algae play an important role in determining the pH of the floodwater. By consuming carbon dioxide from the floodwater, the growing algae can cause pH to increase to 10 in the floodwater in the middle of the day. The pH then decreases 2 pH units or more at night (Mikkelsen et al 1978). Up to 20% of the nitrogen in broadcast urea is lost from the soil surface. Vlek and Craswell (1979) and Vlek and Stumpe (1978) have recently pointed out that ammonia losses from broadcast urea are likely to be especially large because, on hydrolysis, urea produces alkalinity in the floodwater. Ammonia volatilization depends on the floodwater's aqueous ammonia concentration, fertilizer source and management, soil cation exchange capacity, and algal growth in floodwater (Mikkelsen and De Datta 1979).

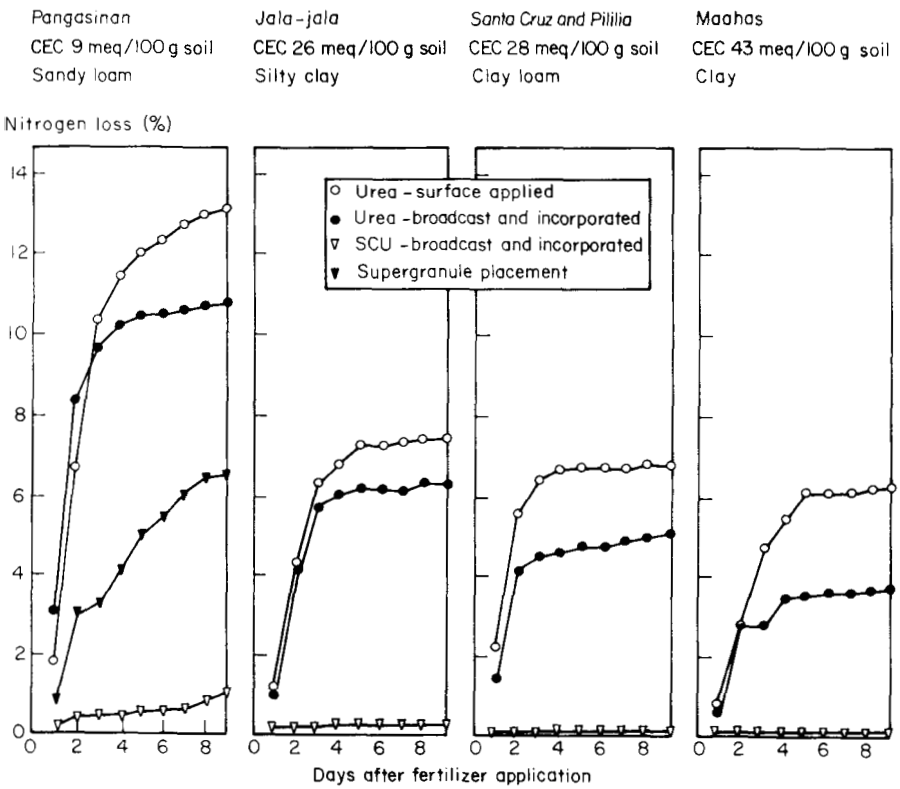
Ammonia volatilization is very difficult to measure directly in the field. Some measure of the potential of the ammonia loss can, however, be obtained by studying the concentration of nitrogen in the floodwater after fertilizer application (Vlek and Craswell 1979).

In a greenhouse study (De Datta and Obcemea 1979, unpubl.), five soils with varying soil texture and cation exchange capacity were used in a comparison of treatments: broadcast and incorporated prilled urea, broadcast and incorporated sulfur-coated urea (SCU), and supergranule placement. Among the different soils, the pH of the floodwater after fertilizer application followed a similar pattern. The pH values were higher with surface application of urea than with broadcast and incorporated SCU. The nitrogen content of floodwater after a surface application of urea always exceeded 150 µg N/ml, compared with less than 10 µg N/ml after an application of SCU.

The high nitrogen content and high pH of the floodwater aggravated nitrogen loss through ammonia volatilization. The nitrogen loss through volatilization from surface-applied urea was always higher than that from broadcast-and-incorporated SCU. The loss was highest in Pangasinan sandy loam — which had a low CEC — and lowest in Maahas clay, which had the highest CEC. That indicates that soil texture greatly affects loss of nitrogen as ammonia. Nitrogen loss from SCU was negligible in all the soils.

Generally, nitrogen loss from surface-applied urea was higher than that from broadcast-and-incorporated urea (Fig. 10). The nitrogen loss from urea fertilizer increased as the CEC of the soil decreased. Placement of urea supergranules in the coarse-textured, low-CEC Pangasinan soil caused a nitrogen loss of 6.5%, with the loss increasing gradually from the day of application.

The study of these soils indicates that modified urea, SCU, and supergranules minimize ammonia volatilization loss in clayey soil. In coarse-textured soils, a slow-release nitrogen fertilizer is better than deep-placed supergranules for minimizing nitrogen losses as ammonia.



10. Ammonia volatilization loss with different forms of urea as affected by cation exchange capacity and soil texture (from De Datta and Obcemea, IRRI 1979, unpubl. data).

The best system of fertilizer application currently available to wetland rice farmers is the so-called best-split application. Two-thirds of the fertilizer is broadcast and harrowed into the soil before transplanting, and one-third is broadcast at the panicle initiation stage of crop growth. Many farmers, however, still broadcast the first dose of fertilizer on paddy floodwater 2-3 weeks after transplanting. Earlier results suggest that this practice leads to high loss of nitrogen as ammonia (Mikkelsen et al 1978).

In a recent field study by Craswell and De Datta (1979, unpubl.), the farmer's method, the best split system, one-time deep placement of supergranules, and broadcast and incorporation of a slow-release fertilizer (sulfur-coated urea) were compared. The effectiveness of different times and ways of applying nitrogen varied widely between the wet- and dry-season crops (Table 3). In the dry season, the farmer's split gave the poorest results; it was followed by best split, SCU, and supergranules. The order was the same in the wet season but the difference between the best split and SCU, or supergranules, was larger. Broadcast applications pro-

Table 3. The 1979 yield of IR36 (dry season) and IR44 (wet season) and apparent recovery of nitrogen from basal and delayed split applications of prilled urea compared with that from slow-release and root-zone placement fertilizers. IRRI, 1979 dry and wet seasons.

Form of urea	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	0	0	0	4.1 e		3.1 cd	
Prilled (best split)	2/3	0	1/3	5.7 b	44 b	4.0 b	35 c
Prilled (farmer split)	0	2/3	1/3	5.4 c	23 c	3.8 b	36 c
SCU[c]	All	0	0	5.8 b	46 b	4.9 a	78 ab
Supergranule	All	0	0	6.2 a	75 a	5.1 a	85 a

[a]DT = days after transplanting, PI = panicle initiation. All basal (0 DT) fertilizers were broadcast and incorporated, except that the supergranules were placed 10 cm deep, at 1/4 hills. All 21 DT and PI applications were broadcast directly on the floodwater. [b]Separation of means within a column, by Duncan's multiple range test, at the 5% level. [c]Sulfur-coated urea, forestry grade.

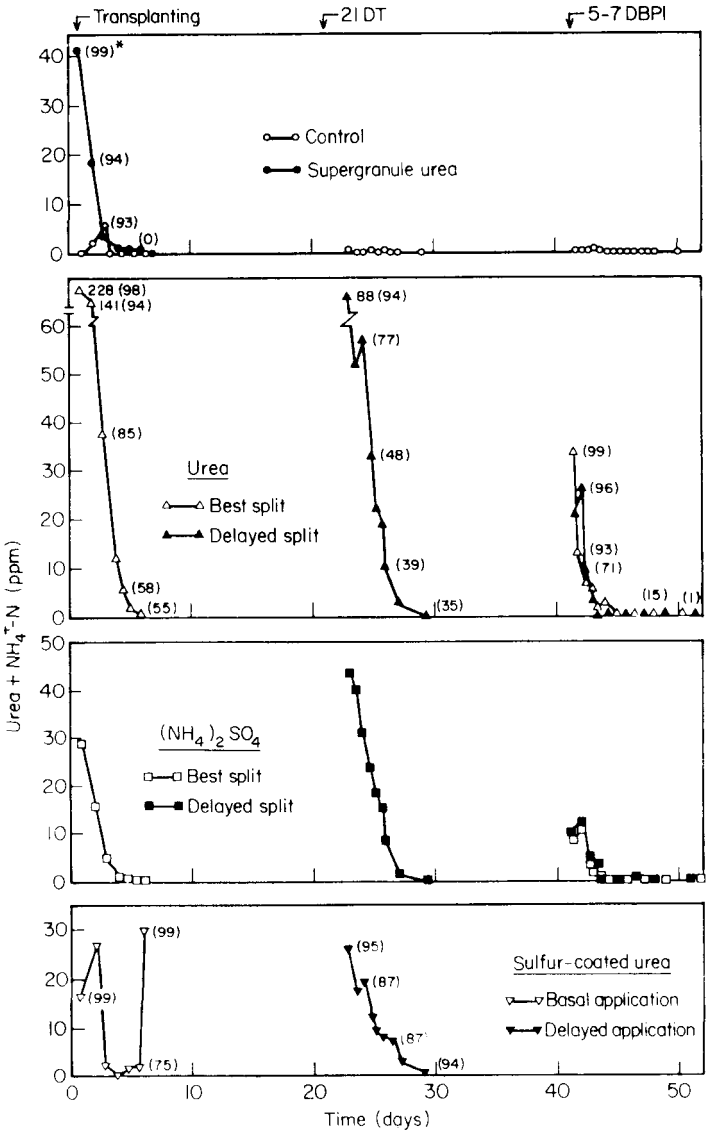
duced higher concentrations of dissolved nitrogen in the floodwater than did those of ammonium sulfate (Fig. 11). Nitrogen concentrations dropped to zero within 4-5 days after fertilizer application. Deep placement and slow-release urea fertilizers produced relatively low concentrations of dissolved nitrogen in the floodwater. The low concentrations in the wet season corresponded with the higher crop recovery of the applied nitrogen. Ammonia volatilization is not the only cause of the disappearance of nitrogen from the floodwater since algal assimilation, plant uptake, and adsorption of the ammonium by the soil exchange complex may also occur. Data such as those shown in Figure 11, however, provide valuable estimates of the potential for ammonia volatilization. Any fertilizer practice that reduces the concentration of nitrogen in the floodwater is likely to reduce losses that occur not only through volatilization but also through surface runoff in areas of poor water control.

Nitrification-denitrification

Nitrification-denitrification occurs in the aerobic-anaerobic soil layer of the wetland soil. However, the amounts of NO_2^- and NO_3^--N found in a continuously flooded soil are practically insignificant because of their high instability.

Traces of NO_3^- and NO_2^- have been reported to exist in floodwater or in the thin oxidized soil layer, or in both, for a certain submergence period when the flooded soil system was fertilized (Racho and De Datta 1968, Bilal 1977). Recent studies at IRRI did not detect NO_3^- in floodwater or soil solution collected at about 20 cm soil depth following 10-cm deep placement of supergranule urea or prilled urea in mudball, or basal incorporation of prilled urea or sulfur-coated urea (SCU-21) in a wetland Maahas clay soil (Savant and De Datta 1978, unpubl.).

Among the factors that influence the nitrification of fertilizer NH_4^+-N in the floodwater-aerobic soil system are: soil pH, soil organic matter content; soil temperature; floodwater depth; amount and forms of, and methods of applying fertilizer



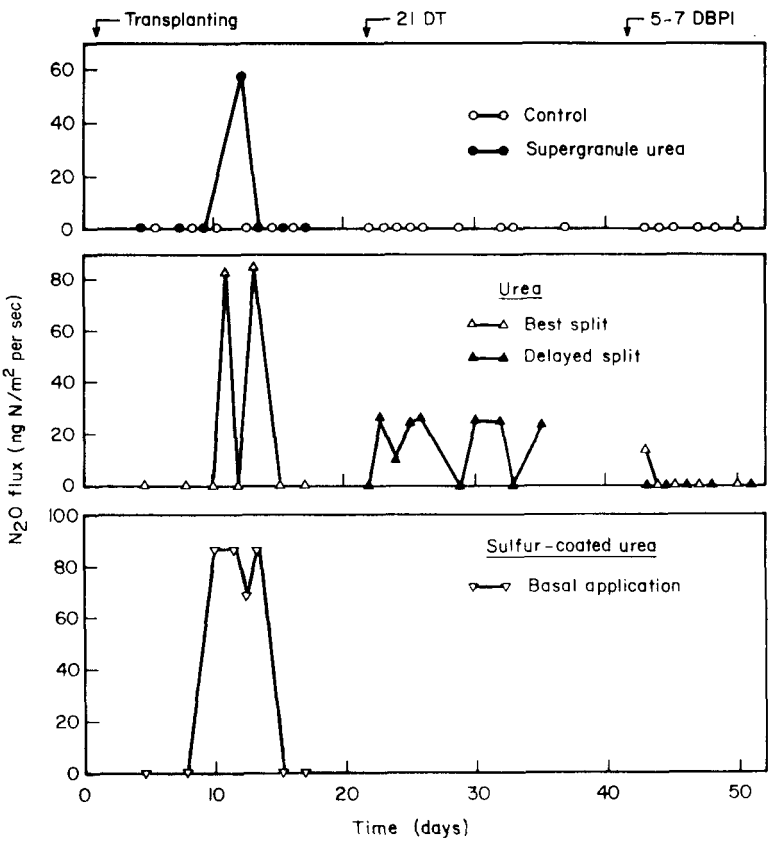
11. (Urea + NH_4)-N in floodwater as affected by time and mode of N application – % urea-N (Craswell and De Datta 1979. unpubl. data).

NH_4^+-N; growth stages of the rice plant; and use of pesticides.

Nitrification-denitrification was traditionally thought to be the major mechanism of nitrogen loss from flooded soils. This conclusion, however, is not based on direct measurements of the gaseous products of denitrification. Very few studies have

measured the gas production directly and virtually no field studies have been reported in the literature. The elemental nitrogen gas, which is produced from denitrification, is extremely difficult to measure against a background of 78% in the atmosphere. However, the other product of denitrification, nitrous oxide, is normally only 300 parts/billion in the atmosphere, and therefore, losses as nitrous oxide can be measured relatively easily.

At IRRI, measurements of nitrous oxide evolution from the experimental plots provide the first direct evidence from the field that nitrification-denitrification occurs in tropical wetland rice soils (Fig. 12). Because nitrous oxide is only a minor product of this process, the relatively low rates of evolution do not represent the total loss due to denitrification. The data indicate, however, that pollution of the stratosphere ozone layer by nitrous oxide evolved from fertilized, continuously flooded rice



12. Effect of time and mode of N fertilizer application on nitrous oxide (N_2O) flux. IRRI, 1979 dry season (Craswell and Hartantyo 1979, unpubl. data).

soils may not constitute a major environmental hazard. The relatively high rates of nitrous oxide evolution in the dry season (Fig. 12) and the flush of nitrous oxide from the panicle-initiation dose of split urea applied in the wet season conform with the high concentrations of fertilizer nitrogen in the floodwater of these treatments.

The wet-season data show generally lower nitrous oxide fluxes. Fluxes were detected in the wet season only because the measuring instrument (infrared gas analyzer) was operated at a higher level of sensitivity. The only high flux in the wet season occurred in the treatment with the panicle-initiation dose of urea. Again, the diurnal fluctuation was large and the rate dropped to zero within 1-2 days. These data suggest that any fertilizer treatment that produces high concentrations of nitrogen in the floodwater will lead to a low recovery of nitrogen by the crop because of ammonia volatilization and nitrification-denitrification. Furthermore, while the nitrous oxide produced from urea and ammonium sulfate is small, nitrous oxide fluxes are much larger when nitrate is added to flooded soil. Nitrous oxide may, therefore, be an important denitrification product that occurs when soils are subject to intermittent floods.

CHEMICAL FIXATION OF AMMONIUM

The kinetics and mechanisms of sorption (or fixation) and subsequent desorption of nitrogen compounds in wetland soils are subject to speculation. The NH_4^+-N not extractable by potassium chloride is deemed *fixed* by some workers: a laboratory study with 12 soils showed that these soils fixed ammonium within 2 hours of application in a way that is rendered unextractable by potassium chloride (Table 4). The ammonium-fixing capacity of the soils increased as the rate of ammonium application was increased but the percentage of recovery of ammonium remained more or less constant (Sahrawat 1978, unpubl.).

The ammonium-fixing capacity of these soils was not related to pH, organic matter, or clay content but significantly correlated with the active iron (r = 0.61*) of the soils. The iron oxides in combination with organic matter and allophanic materials seem to be the probable cause of ammonium fixation.

Savant and De Datta (1979a) reported that the amounts of clay-fixed NH_4^+-N (<0.2% of total N added) at the deep-placement site of urea were insignificant after 45 days in a flooded Maahas clay.

Table 4. NH_4^+ fixation in Maahas day soil with varying rates of nitrogen (Sahrawat 1978, unpubl.).

NH_4^+ –N added (mg/10 g soil)	NH_4^+-N recovered (%)	NH_4^+–N fixed (meq/100 g soil)
1.0	87.0	0.07
5.0	85.7	0.40
25.0	86.6	1.86
50.0	88.1	3.31
100.0	88.0	6.67

Soil *Eh* seems to influence urea adsorption. The oxidized surface soil collected from a wetland field sorbed more urea from solution than the reduced soil from the same field (Savant and De Datta, IRRI 1979, unpubl. data).

There is a lack of information on the extent and energy of sorption of urea by the oxidized and reduced soil layers that would facilitate understanding of the fate of fertilizer urea immediately after its application.

MANAGEMENT OF FERTILIZER NITROGEN FOR EFFICIENT USE

Reports that rice farmers were cutting back on fertilizer use in the face of its rising cost were widespread in 1979. If they are true, fertilizer nitrogen use and crop management practices must be studied thoroughly to minimize nitrogen losses and increase fertilizer nitrogen efficiency in wetland rice. It is imperative to examine each fertilizer material and each management practice critically to increase efficiency of nitrogen use in rice.

Recent reviews by De Datta (1978) and Prasad and De Datta (1979) summarize information on the subject. The following are relevant and most recent research findings on the subject.

Farmers' practices

Many farmers in South and Southeast Asia are applying very little fertilizer in wetland rice. For example, yield constraints studies during 1974–1979 in four provinces in the Philippines, determined the relative contribution of fertilizer, insect control, and weed control to the improvement of rice yields. Results from the large number of trials suggest that 56% of the dry season yield gap and 43% of the wet season yield gap were explained by either insufficient fertilizer or improper timing or method of nitrogen application (Fig. 1). Even today many farmers do not apply fertilizer nitrogen to grow modern rice varieties. Fertilizer nitrogen, when used, is applied to the floodwater 2-3 weeks after transplanting. This is an inefficient method of applying nitrogen fertilizer and is responsible for extensive losses of nitrogen to the atmosphere and to surface waters.

The best system of fertilizer application currently available to wetland rice farmers is the so-called best-split application. Two-thirds of the fertilizer is broadcast and harrowed into the soil before transplanting, and one-third is broadcast at the maximum tillering or panicle initiation stage of crop growth. Incorporation of fertilizer reduces the concentration of ammonia in the floodwater and thus reduces losses.

Alternatives to farmers' practices

There are several promising alternative ways in which fertilizer nitrogen can be efficiently used.

Controlled-release fertilizers. Of the coated fertilizers, sulfur-coated urea (SCU) has been most widely tested on many crops, including rice. In many countries, the crop response to SCU was generally superior to the response to urea in a single (basal) application and often to split application at the same nitrogen rate.

The benefits of using SCU are as follows:

- increased efficiency of fertilizer use,
- reduced nutrient losses,
- reduced toxicity to seedlings,
- reduced application frequency, and
- satisfied sulfur requirements.

The slow-release characteristic of SCU limits the concentration of nitrogen in the soil and floodwater at any one time and thus reduces nitrogen losses. In the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), SCU increased rice grain yield, compared with the best split, in most sites in 114 experiments conducted in 11 countries. The average economic response, based on 30% extra cost of SCU over ordinary urea, shows a US$6-7 return for every US$1 spent on SCU.

At IRRI, in fertilizer-treated plots in direct-seeded rice, broadcast-and-incorporated SCU at 54 kg N/ha gave significantly higher yield than a split application of nitrogen at the same rate. In fact SCU at 54 kg N/ha gave similar grain yield as broadcast-and-incorporated prilled urea at 120 kg N/ha (Table 5).

Deep placement of supergranule urea and urea marbles. The concept of fertilizer placement in the reduced layer of the soil is becoming more relevant since the introduction of modified urea materials such as urea briquets, urea supergranules, and urea marbles. This method of placement replaced the mudball, which was shown to have a very high labor cost. Although the INSFFER data showed variable results between sites, on an average, the results appeared encouraging. There was a US$4 return for every US$1 spent on labor for the placement.

Our recent data at IRRI showed that placement of supergranules or urea marbles of varying sizes gave significantly higher yields than the application of urea in split doses (Table 6). The highest yield of 6.0 t/ha with efficiency of 46 kg rough rice/kg N was obtained with urea marbles each placed at 1 10-12 cm deep in the center of every 4 hills.

Table 5. Effect of forms of urea and application methods on the grain yield of direct-seeded lowland rice. IRRI, 1979 dry season.

Treatment	Rate (kg N/ha)	Grain yield[a] (t/ha)
No fertilizer nitrogen	—	2.8 d
Split application of urea[b]	54	4.9 bc
Plow-sole application of prilled urea	54	5.5 b
Split application, urea marbles[b] (2 - 4 mm)	54	4.9 bc
Sulfur-coated urea, broadcast and incorporated	54	6.2 a
Plow-sole application of sulfur-coated urea	54	5.3 b
Urea marbles (2 – 4 mm), broadcast and incorporated	54	4.9 bc
Urea marbles (6 – 8 mm), broadcast and incorporated	54	4.8 bc
Prilled urea, 2/3 10 DS + 1/3 40 DS[c]	54	4.4 c
Prilled urea, broadcast and incorporated	120	6.7 a

[a]Separation of means by Duncan's multiple range test, 5% level. [b]2/3 broadcast and incorporated + 1/3 topdressed 5–7 days before panicle initiation. [c]DS = days after sowing. CV = 9.0%.

Table 6. Effect of forms of urea at 65 kg N/ha and application methods on the grain yield of transplanted lowland 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] Separation of means by Duncan's multiple range test, 5% level. CV = 8.5%.

Deep placement of nitrogen with machine. An IRRI design plow-sole applicator that attaches to the ordinary plow combines land preparation with fertilizer nitrogen application and increases fertilizer efficiency. A side benefit is the reduction of labor needed to apply a basal dose of fertilizer.

An experiment conducted during the 1979 wet season showed that rice yield was significantly higher when 28 and 55 kg N/ha were applied in the plow sole as urea than when urea nitrogen was applied in the splitdose system suggested for high nitrogen efficiency (Table 7).

IRRI has developed a 10-row liquid injector, which is mainly used for placing insecticides in the root zone. This injector, which is also a row marker for transplanting rice, when used to apply 50% urea dissolved in water, can improve nitrogen efficiency.

Combining deep placement and slow-release fertilizer nitrogen concepts. Another approach is to combine deep placement and slow-release concepts, as in the application of sulfur-coated supergranules (SC-SGU). Although greenhouse results at the International Fertilizer Development Center (IFDC) headquarters in Alabama

Table 7. Nitrogen fertilizer applied with a plow-sole applicator and as a best split treatment — 2/3 broadcast and incorporated before transplanting and 1/3 applied a week before panicle initiation. Nitrogen as urea was applied on IR36 in the 1979 wet season, IRRI.

Treatment	Grain yield[a] (t/ha)
No fertilizer nitrogen	3.11 d
28 kg N/ha	
Plow sole applicator	4.21 b
Best split	3.54 c
55 kg N/ha	
Plow sole applicator	5.14 a
Best split	4.00 b

[a] Separation of means by Duncan's multiple range test, 5% level.

suggested the extreme effectiveness of the material (Craswell and Vlek 1979), field tests of the material so far have not.

Other agronomicpractices to increase fertilizer efficiency in rice. In earlier studies, a number of complementary practices increase fertilizer nitrogen efficiency in wetland rice (De Datta and Malabuyoc 1976, Prasad and De Datta 1979).

In a recent study, the effects of plant density and plant geometry on the grain yield of rice were evaluated. The yield of 2 early-maturing rices — IR36 and IR40 — grown during the 1977 wet season increased by 1.3 t/ha (Table 8), when the plant density increased from 0.67×10^5 to 10^6 hills/ha (Nguu and De Datta 1979).

Without fertilizer nitrogen or with low levels (<60 kg N/ha) of applied nitrogen, rice grain yields significantly increased with increased plant density. At the high level of applied nitrogen (56 kg N/ha), grain yield increased as the plant density was increased to a certain level beyond which the yield decreased with increased plant density (Fig. 13). Results further suggest that plant geometry significantly affected the grain yield of rice. The grain yield response to plant geometry was affected by solar radiation and sunshine hours (Nguu and De Datta 1979).

Efforts are continued to learn about noncash or low-cash management practices such as use of seedlings of the proper age, row spacing, and water management to increase fertilizer nitrogen efficiency in wetland rice.

Use of straw and other organic sources

Rice straw may serve as an important source of plant nutrients besides having other benefits. When incorporated into rice soils, it benefits fertility management because:

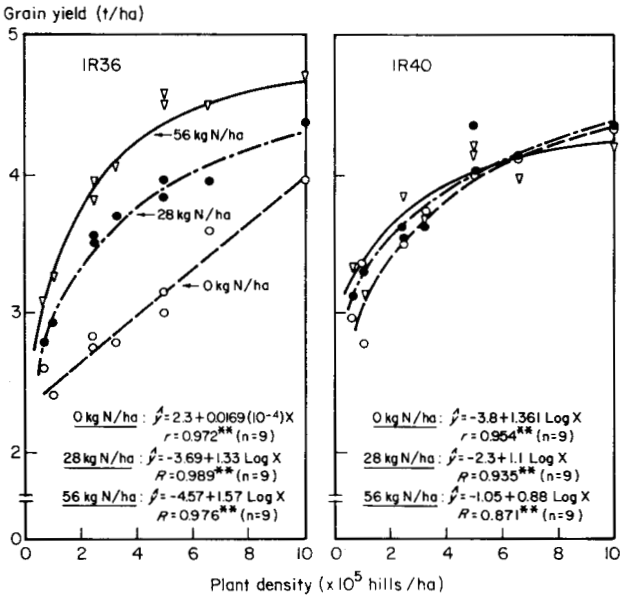
- it contains about 0.6% nitrogen, 0.1% phosphorus, 3% potassium, and 8% silicon in addition to other plant nutrients;
- it increases the nitrogen-supplying capacity of rice soils; and
- it adds organic matter, which may encourage biological nitrogen fixation.

Experiments conducted by IRRI over the years suggest that leaving the rice straw in the field decreases soil pH and increases organic matter content, total nitrogen,

Table 8. Grain yield of IR36 and IR40 rices planted at different plant densities. IRRI, 1977 wet season (from Nguu and De Datta 1979).

Plant density ($\times 10^5$ hills/ha)	Plant spacing (cm)	Grain yield[a] (t/ha)		
		IR36	IR40	Mean
0.67	40 × 40	2.9	3.2	3.0 d
1.1	30 × 30	2.9	3.1	3.0 d
2.5	20 × 20	3.5	3.6	3.6 c
2.5	40 × 10	3.6	3.7	3.6 c
3.3	30 × 10	3.7	3.7	3.7 c
5.0	20 × 10	4.1	4.1	4.1 b
5.0	40 × 5	4.1	4.3	4.2 ab
6.6	30 × 5	4.1	4.1	4.1 b
10.0	20 × 5	4.5	4.2	4.3 a

[a] Av, 7 fertilizer nitrogen treatments; separation of means by Duncan's multipie range test, 5% level.



13. Effect of rates of nitrogen fertilizer application on yield response to plant density of IR36 and IR40 rices. IRRI, 1977 wet season. (Significant at 1%.) (From Nguu and De Datta 1979.)

exchangeable potassium, and available phosphorus (Castro et al 1980).

Straw compost increased the grain yield in 5 out of 13 croppings. Castro et al (1980) further suggest that as much as 77 kg N and 24 kg K are added by returning rice straw to the land. A long-term fertility experiment at IRRI for the past 16 years showed that adding 10 t straw/ha per season did not benefit grain yield.

RESEARCH STRATEGY ON NITROGEN FOR RICE

The transformations of nitrogen in flooded soils are brought about by the influence of the water on soil aeration and by the dissolution in the floodwater of broadcast fertilizer nitrogen. The nitrifcation-denitrification mechanism in flooded soils is unique. Similarly, the process of ammonia volatilization from the floodwater surface is unique because other agricultural soils are not covered by free water.

One difficult problem in the study of various mechanisms of nitrogen loss is that suitable techniques for measuring most of the losses directly under natural conditions are not available. Nitrogen losses can, however, be indirectly measured by using the heavy isotope ^{15}N. ^{15}N-labeled fertilizer is applied to the soil-plant system and, after a period, the soil plus roots and the plant are analyzed for ^{15}N. Any difference in the ^{15}N balance from 100% is a loss. Techniques for conducting such research must be extremely accurate and precise to avoid the false conclusion that an error due to poor technique is, in fact, a loss. Table 9 shows the results of field measurements of fertilizer nitrogen losses by the ^{15}N balance technique. None of the experiments were conducted with transplanted rice culture in the Asian tropics. In

Table 9. Field measurements of fertilizer N losses using the ^{15}N balance technique (from Craswell and De Datta 1980).

Fertilizer amt		N loss
Material	Application	(% added ^{15}N)
	Australia[a]	
$(NH_4)_2SO_4$	Surface	51
	Deep	37
$NaNO_3$	Surface	66
	Deep	96
	USA[b]	
$(NH_4)SO_4$	Broadcast	22
	Deep	25
	Japan[c]	
$(NH_4)_2SO_4$	Surface	18
NH_4Cl	Surface	10
$NH_4^d NO_3$	Surface	20
$NH_4NO_3^d$	Surface	72
$NH_4^d NO_3^d$	Surface	47
$CO(NH_2)_2$	Surface	47

[a]Wetselaar et al 1973. [b]Patrick and Reddy 1976. [c]Koyama et al 1977. [d]Position of ^{15}N label.

addition, ammonium sulfate, no longer the major source of fertilizer nitrogen in rice, was used in most of the trials.

Field experiments have been conducted recently at IRRI and in farmer's fields using the ^{15}N balance technique. The data from these field trials are not yet available. Recent trials included the same fertilizers as those used in the INSFFER, namely: urea, SCU, urea for deep placement as urea supergranules. By conducting ^{15}N balance studies with rice using new fertilizer materials such as those mentioned above, we hope to be able to determine how losses are affected by the soil characteristics and cultural practices used at the different sites.

Research is needed to answer many questions, and new strategies must be developed to provide a greater understanding of the various transformation processes associated with a wetland rice crop.

Information is needed for a better understanding of leaching, movement, and transport of fertilizer nitrogen, and the mechanism and extent of nitrification-denitrification processes occurring in the rhizosphere in the reduced soil systems. The currently available (commercial and experimental) nitrification inhibitor in minimizing denitrification losses should be evaluated in the wetland rice soils in the tropics. The compatibility of biological nitrogen fixation by blue-green algae, azolla, etc. with the deep placement and other methods and timing of nitrogen applications should be studied on different soils and in different environments. Strategies should include the slow-release compounds without sulfur, such as polymer-coated or rubber-coated nitrogen fertilizers. The compatibility of those slow-release fertilizers with biological nitrogen fixation should be evaluated under different soils, water regimes, and climatic environments.

Table 10 shows the major options available to the farmers in the Asian tropics for

Table 10. Major options available for nitrogen fertilization of rice.[a]

Method. form of urea	Release rate	Timing	Application method	Irrigated		Rainfed		Comment
				Trans-planted	Direct seeded	Trans-planted	Direct seeded	
First application[b], prilled	I	Po	Br	√	√	√	√	Common farmer practice
Split, prilled	I	Pr, PO	Br	√	√	√	√	Best available method
Plow sole, prilled	I	Pr	Ba	√	√	?	?	Apply at first plowing
Liquid band	I	Po	Ba	√	—	√	—	INSFFER results variable
Supergranule	I	Po	P	√	—	√	—	INSFFER results promising
Regular SCU	S	Pr	Br	√	√	√	√	INSFFER results promising
Forestry SCU	S	Pr	Br	√	√	√	√	Pre- or post-transplant
SC supergranule	S	Po	P	√	√	√	—	Preliminary testing
Liquid injector	I	Pr or Po	P	√	√	√	—	Untested
Oxamide	S	Pr	Br	√	√	√	√	Untested
Nitrification inhibitor	I	Pr or Po	Br	√	√	√	√	Untested

[a] I = immediate, S = slow, Pr, Po = preestablishment, and postestablishment, Br = broadcast, Ba = band, P = point. [b] Sometimes first application, broadcast and incorporated during final harrowing.

nitrogen fertilization in rice. The research has probably reached an important point in its development. There are sufficient data to suggest that deep placement through use of supergranules or slow-release fertilizers in the form of SCU are generally effective in improving nitrogen fertilizer efficiency in wetland rice (De Datta 1978). It is now critical to evaluate these technologies for farm-level testing on principal soil types and environmental regimes. The sites must be better characterized if the data are to be relevant, interpretable, and understandable.

There is need for further research on the methods of application that looked promising, and those that are being developed. In those efforts, training of researchers at grass-root level would greatly facilitate gathering of quality data. The INSFFER training program is an attempt to strengthen the capability of scientists and technicians in the national programs.

The ^{15}N-balance experiments will only be meaningful if they are conducted in a number of representative sites. Naturally, these efforts will be limited to few countries because of the cost involved and the lack of well-trained personnel. Suitable training programs to improve the capabilities of collaborating scientists will be extremely valuable.

More attention is needed to determine fertilizer efficiency in wetland, dryland, and deepwater rice cultures. All of those raided-rice cultures have unique problems. Therefore, fertilizer nitrogen practices should be adjusted to the specific requirements of a particular rainfed-rice culture.

The ultimate goal of this research is the efficient use of nitrogen sources to maximize, for the farmer, the yield and profitability of rice. Because rice is grown under such widely divergent conditions, no single nitrogen material or management practice is ever likely to be universally successful. Our research strategy must, therefore, recognize the complexity of the problem and develop a conceptual and organizational framework to deal with it.

Based on the above discussion, the following are specific research areas that would need immediate as well as sustained attention.

Specific research needs

A framework for the development, evaluation, and adoption of improved nitrogen sources and management practices for rice is shown in Table 11. Stages 1, 2, and 3 might be termed the basic, applied, and adaptive research phases, respectively. Stage

Table 11. Stages in the development, evaluation, and adoption of a new nitrogen source or nitrogen management practice.

Stage	Organizations responsible[a]
1. Development — preliminary evaluation	IRRI, IFDC, NRA
2. Intensive international testing	INSFFER
3. Extensive in-country evaluation	IRRI, IFDC-NRA/NEA
4. Manufacture and marketing or extension	NPM/FM, NEA

[a]NRA = National Research Agency, NEA = National Extension Agency, NPM = National Policy Makers, FM = Fertilizer Manufacturers.

4 is not strictly research and is not discussed here in any detail. However, its influence on the conduct of stages13 should be considered since the goal of any research and development program is the adoption of the new source or management practice. Stangel and Hignett (1979) recently pointed out that the decision of government policymakers about a new development will depend upon the total resource endowment of the country or region for which it is intended. Thus, during stages 1-3, researchers should keep in mind the agroclimatic, physical, economic, and social environments of the target rice-producing areas, and produce a range of different improved sources and practices with detailed information on the areas and conditions in which each works best.

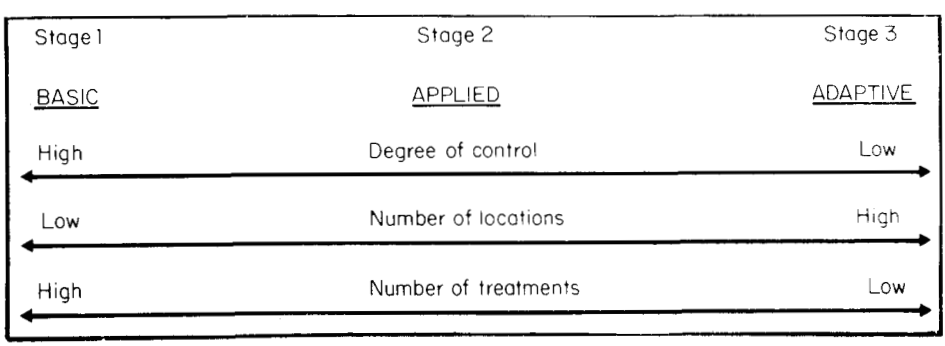
The characteristics of stages 1-3 are shown in Figure 14. The degree of control in the experiments, the number of sites, and the number of treatments included change as the research progressed from basic to adaptive.

Stage 1 — Development and preliminary evaluation of improved nitrogen sources and management practices. Research in this area falls into two categories:

- basic research to determine the causes of poor fertilizer efficiency and to provide a rational basis for
- basic research to identify improved sources and management practices.

Causes of poor efficiency

- *Prediction of nitrogen needs.* Research is needed in developing better ways of predicting the nitrogen needs of rice crops. Optimum rates of nitrogen fertilizer application are difficult to predict because the nitrogen-supplying power of rice-growing soils varies widely. Rapid, simple but accurate tests are needed so that fertilizer nitrogen is not wasted through application on soils that already supply adequate nitrogen for a rice crop. This research could be combined with long-term studies on the effects of different nitrogen management practices on the nitrogen-supplying power of rice-growing soils.
- *Magnitude of nitrogen losses.* More information on the effects of soil characteristics and fertilizer management on the extent of fertilizer nitrogen losses is



14. Scheme relating the stages in fertilizer development to the type of research and experimentation involved.

needed. The ^{15}N balance technique is being used for this purpose, but should now be used more widely in various important rice-growing areas. When the initial phase of such experiments at irrigated sites is over, a similar program will be needed at sites with poor water control. For the rainfed sites, detailed monitoring of the environmental conditions will be necessary.

- *Mechanisms of nitrogen loss.* The main controversy in research in this field is still the question of whether nitrification-denitrification or ammonia volatilization is a major mechanism of fertilizer nitrogen loss. The answer to this question will have considerable influence on the development of improved nitrogen sources and management practices. Research using techniques to measure directly in the field the fluxes of ammonia and the gaseous products of denitrification is therefore urgently needed. The techniques are necessarily sophisticated, so the research can be done at only a limited number of sites. The work should be extended to rainfed sites once sufficient information has been obtained from irrigated sites. Data on the effect of rainfall and soil water conditions on denitrification are especially needed. The importance of nitrification-denitrification in the rhizosphere of rice should also be assessed.

  Research is needed to determine the role of runoff and percolation losses in the poor efficiency of nitrogen fertilizers in rainfed-rice areas. Progress in this area has been hampered by the lack of suitable techniques. Soil chemists should combine forces with water engineers for this research, which has important environmental implications in the pollution of groundwater and surface waters.
- *Proper timing for plant needs.* Current knowledge of the effect of the timing of nitrogen fertilizer application is difficult to interpret because of its confounding effect on losses of fertilizer nitrogen and on the crop's uptake of and response to applied nitrogen. Research is needed to separate these effects to obtain basic data for use in the design of slow-release fertilizers or in the management of split doses of nitrogen fertilizers designed to be *loss-free*

Improved nitrogen fertilizer sources and management practices

The methodology needed to identify, develop, and evaluate new sources and management practices depends on the originating agency. IFDC has assembled a group of soil scientists, chemists, and engineers who jointly design new fertilizers that are tested initially in the laboratory. Materials are then selected for testing under standardized greenhouse conditions. Promising new sources are then evaluated in the field. In the development and evaluation process, research ideas and results should flow freely from the laboratory to the field and vice versa.

The following nitrogen sources and management practices merit further research.

- *Materials for deep placement.* Research is needed to develop inexpensive techniques for making large discrete urea particles for point placement beneath the paddy soil surface. The techniques should be developed for factory- and

village-level production. In the latter case, much can be learned from scientists in the People's Republic of China who have developed relatively cheap pelleting machines to make small briquets. One advantage of this approach is that compound fertilizers formulated for local needs can be pelleted. Chinese scientists have also developed simple applicators for deep placement of the pellets.

The agronomic merit of point placement of large urea particles, as opposed to band placement of prilled urea, should be evaluated under field conditions. Furthermore, long-term experiments on the effect of fertilizer management on biological nitrogen fixation are needed in view of recent findings that deep placement of urea permits algal nitrogen fixation to continue unimpeded. whereas the traditional practice of broadcasting urea inhibits algal fixation completely.

Intermediate-sized (2- to 6-mm diameter) urea granules may become available from some manufacturers. The management of this type of fertilizer has not been studied, but the possibility that, when broadcast, such granules will penetrate 1-2 cm into well-puddled soil should be investigated.

- *Machines for deep placement.* Simple machines for applying prilled urea beneath the surface of flooded soils are needed. This prescription has been difficult to fill in the past because urea is hygroscopic and does not run freely in machines operating in humid tropical conditions. An alternative is to inject the fertilizer as a solution. This approach merits more research, particularly since insecticides could be injected in the same solution for root-zone placement.
- *Slow-release fertilizers.* Further research on alternative coatings to sulfur is, needed. In particular, the possibility of using in the tropics indigenous materials such as rubber as a coating should be investigated. The effect of the particle size of the urea on the cost of coatings should be studied along with the factors determining the rate, mechanism, and extent of urea release from different materials. The release rates should be tailored to the crop's needs, which have yet to be defined for different varieties, seasons, and water management conditions, as discussed above.
- *Slowly soluble fertilizers.* Oxamide, glycouril, linear and cyclic pyrolytic products of urea, and methylene ureas of various molecular weights are some examples of slowly soluble nitrogen compounds that could prove to be more effective fertilizers than urea. These materials, along with more conventional materials of this type such as isobutylidene diurea (IBDU), crotoniledene diurea (CDU), and urea-formaldehyde condensates warrant thorough examination.
- *Nitrification inhibitors.* Both synthetic (nitrapyrin) and natural (neem) inhibitors of nitrification have had varied successes in field trials in the past. Research is needed to characterize better the conditions under which these inhibitors are effective.
- *Urease inhibitors.* Urease inhibitors have the potential to reduce ammonia volatilization losses from broadcast urea applications by delaying, and hence reducing, the buildup of ammonia concentration in the floodwater. Research to evaluate urease inhibitors for this purpose is urgently needed.

Stage 2 — Intensive international resting

Materials or practices that have proven effective in the laboratory, greenhouse, and field should then be introduced to the INSFFER network for intensive testing at a number of sites in rice-growing countries. The experiments of the INSFFER network should be *benchmark* trials aimed at gaining an in-depth understanding of how a particular new fertilizer material or management practice compares with the standard fertilizer-split application of urea. The data should allow us to predict confidently where and when a particular innovation is likely to be economically superior to currently recommended practices.

Some suggestions for the strengthening of the INSFFER network are:

- Past data should be used to provide guidelines for the design of future experiments. Statistical procedures can be used to develop models describing how the performance of a particular material or practice with respect to the standard is influenced by production factors such as rice variety, season, climate, and soil parameters. To build such models, however, we need to know what the important production factors are likely to be and select sites to represent a wide range of each. The soil and climate at each site should be classified according to a uniform system and the level of each site factor carefully recorded.
- The recent development of experiments for rainfed riceshould be strengthened since rainfed rice constitutes about 50% of the rice grown. Rainfed experiments are difficult to conduct because of the risk that the crop may fail or that climatic conditions may be so poor that the crop does not respond to nitrogen. Nevertheless, farmers face the same problem with rainfed rice, and part of this program should be to assess the risk associated with fertilizer use and the possibility that some fertilizer materials reduce-that risk. In this research, dynamic computer simulation of the effects of rainfall on fertilizer response might be a valuable approach. INSFFER experiments with rainfed rice could be used to validate such models.
- INSFFER cooperators should be encouraged to measure additional soil and plant parameters to help interpret their field data. Grain yield is a practical, but often insensitive, measure of the effectiveness of fertilizers. The apparent recovery of fertilizer nitrogen in the plant can be relatively easily measured and may provide an excellent basis for judging how a particular fertilizer source or practice has performed. Another simple measurement is the concentration of nitrogen in the floodwater after fertilizer application, providing a measure of the potential for ammonia volatilization or nitrification-denitrification losses.
- The INSFFER program was recently broadened to include soil fertility as well as fertilizer evaluation. The following three aspects merit attention:
    1. Fertilizer practices for rice should be studied in the context of the whole cropping system. Thus. in the case of slow-release fertilizers, particularly residual effects of nitrogen fertilizer on the growth of succeeding crops, should be determined.
    2. Nitrogen fertilizers should be evaluated in conjunction with other plant nutrients. For example. SCU provides sulfur which may be a limiting

nutrient in some areas. The management of phosphorus fertilizers to maximize biological nitrogen fixation, combined with deep placement of nitrogen fertilizers so that the blue-green algae are not disturbed, may be a promising line of research for INSFFER.

3. Integrated systems of nitrogen management that use compost and crop residues, biological nitrogen fixation, and improved nitrogen fertilizers should be evaluated by INSFFER. The experiments should be long-term studies in which changes in the total nitrogen balance and the nitrogen-supplying power of the soil are carefully monitored. The INSFFER program provides scientists an opportunity to conduct an experiment with a set design using standardized techniques that will allow comparisons between sites in Asia. The sooner the experiments are started, the better the data base will be.

Stage 3 — Extensive in-country evaluation

The purpose of an extensive in-country evaluation is to determine the agronomic, economic, and social benefits of improved nitrogen sources and management practices that have proven effective in the INSFFER program. This evaluation should be made in multilocation trials in farmers' fields. IRRI and IFDC should play an important role in the development of suitable methodology for use by national research and extension agencies.

Agronomic and economic evaluation

- Traditional and improved materials or practices should be compared at sites chosen to represent soil types, water management systems, and socioeconomic conditions prevailing in the major rice-producing areas of the country. At some sites, the rate of nitrogen should be varied to obtain agronomic and economic response curves that can be used to refine nitrogen recommendations already developed by the national agency concerned. Improved fertilizers, for example, might need to be applied at only a fraction of the rate of conventional materials presently used by farmers.

Farmer acceptance of products or practices

Research will be needed to identify constraints to the adoption of new or improved sources or practices. This socioeconomic research should be conducted in association with the trials in the farmers' fields. Specific guidelines on ways to introduce new materials should come from this work.

CONCLUSIONS

Over the last 20 years, a firm base of scientific knowledge and of interpersonal and interorganizational liaison has been developed. IRRI and IFDC will continue to conduct and catalyze research aimed at increasing rice production through efficient use of all sources of nitrogen. In some rice-growing countries national research agencies have had major programs in this field for some time, whereas others are just

beginning. INSFFER will continue to play a central role in the coordination of these efforts.

The potential for large increases in the yield of modern rice varieties grown under good water control through the use of improved nitrogen fertilizer products and practices has already been demonstrated by INSFFER. Thus, for irrigated rice, the most urgent need is for adaptive research to determine the practical implications of this new technology. In the case of rainfed rice, for which modern varieties are not so widely available, the current use of nitrogen fertilizer is very low, probably because available fertilizer products and practices are completely unsuitable for this type of rice culture. Since 55% of the rice-growing area is rainfed, research to develop a practical means of supplying nitrogen to rainfed rice deserves high priority. Such a development could have a tremendous impact on rice production in the coming decades.

In those total efforts in increasing nitrogen economy, nitrogen fertility, and fertilizer nitrogen efficiency, a multidisciplinary team approach is the logical step toward developing sound strategies in nitrogen research in the coming decade.

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DISCUSSION

ROY: The present technology on the efficiency of N-placement or a slow-release N source works well with controlled water but not under poor water management. What should the research strategy be to help rice farmers of Asia who grow rice in an uncontrolled water situation?

De Datta: We should initiate some careful studies to evaluate slow-release and deep-placement concepts with uncontrolled water supply. We should do research in the dry season under alternate wetting and drying cycles. We should also do research in the wet season with completely rainfed conditions.

JUGSUJINDA: Could the loss of N applied to soil be minimized by applying N on the rice leaves? Would you comment on N loss through the leaves and recovery of N by foliar spray.

De Datta: Results from foliar application of N have been extremely variable. There are other methods of application of N fertilizer such as those using deep-placement and slow-release concepts that are more efficient and less difficult to adopt than foliar application.

SHAHI: In the case of slow-release fertilizers, a sizable quantity of N remains available even at flowering. Our experience is that this causes floral sterility. How about your experience?

De Datta: I have never obtained results that would suggest floral sterility due to basal application of slow-release N fertilizers.

SHAHI: As plant density increases, yield increases (as shown in your figures). Were the plants under maximum protection from insect pests and diseases? How about experiments with no plant protection or minimum protection?

De Datta: The experiments on the effects of plant density on grain yield response were with good agronomic practices including optimum pest and disease control. I did not conduct any trial on plant density with minimum insect protection.

HADIWIDJAJA: What pH was prevailing during the experiments?

De Datta: The pH of Maahas clay soil was about 7.0.

HADIWIDJAJA: How much time did it take NK_4^+, from the time of application, to reach a height of about 50 cm in the plant?

De Datta: The rice plant absorbs both NH_4^+ and NO_3^- forms of N almost immediately. In the case of urea, it is hydrolyzed first before it is taken up. However, urea nitrogen is also taken up by the rice crop.

GUNAWARDENA: With the wide genetic diversity and variability known in rice, it is to be expected that different varieties would differ in absorption and utilization of N and may even differ in N requirements at different growth stages. As such, would the results you obtained be applicable in general terms? Alternately, what view would you hold for a strategy of applying N fertilizer in a manner that would minimize losses based on the best available information for particular environments and to breed varieties of rice under such fertilizer management practices?

De Datta: There are distinct varietal differences in reactions to N response at low soil fertility conditions. However, even those varieties that do well under somewhat low fertility conditions yield higher with fertilizer. Breeding environment-specific varieties, particularly to cater to moisture regime, is a must before proper fertilizer management practices can be developed.

MANDAL: What is the recommendation for the best time and method of N application for rice where water accumulates from 15 to 150 cm during the rainy season in rainfed wetland rice culture?

De Datta: We just initiated a project on fertilizer management requirements in deepwater rice. Therefore, we do not have any specific suggestion to offer, except that probably the fertilizer application should be limited to basal application using slow-release and, in some instances, deep-placement concepts. Our major focus is to develop fertilizer management practices for areas where the maximum water depth is 50 cm or below.

SATARI: Nitrogen fertility and fertilizer management in wetland rice soils will be different if we grow fish between the rice plants. Growing fish in an irrigated rice field is a common practice in Indonesia. What is your comment? Are you intending to do research on this aspect?

De Datta: At this time, we have no plans to include fish culture in studies on nitrogen fertility management.

BHATTI: There is a controversy in Pakistan between researchers and fertilizer firms. Can nitrate forms (nitrophos) be used for a rice crop with equal efficiency as ammonium forms (urea)?

De Datta: The rice plant takes up the ammonium form as well as the nitrate form. However, for basal application, it is desirable to use NH_4^+-containing or NH_4^+-producing fertilizers. For topdressing NH_4^+ and NO_3^--N are equally effective because the plants would take up NO_3^--N before it is leached and subsequently denitrified.

RICE RESEARCH STRATEGIES IN SELECTED AREAS: SOIL AND PLANT NUTRIENTS — BIOLOGICAL NITROGEN FIXATION

G. S. VENKATARAMAN and I. WATANABE

The moderate but stable rice yields observed in many areas in the temperate and tropical zones where no nitrogen fertilizer has been added provide evidence of the role of biological nitrogen fixation. In long-term fertility plots without added nitrogen fertilizer, positive nitrogen gains ranged from 10 to 60 kg N/ ha per crop in wetland rice fields (Watanabe et al 1980, Koyama and App 1979).

In a 1978 IRRI symposium on nitrogen and rice, a group of scientists made recommendations for IRRI and cooperating institutions concerning research and training activities to exploit and maximize biological nitrogen fixation (IRRI 1979). In the same symposium, Watanabe and App (1979) discussed the research needs for management of nitrogen fixation in flooded-rice systems.

The unusual nature of the flooded wetland rice soil ecosystem with respect to biological nitrogen fixation lies in the presence of aerobic and anaerobic zones in three major ecological layers:

- the floodwater and the surface soil,
- the anaerobic plow layer, and
- the rice plant and its rhizosphere.

The floodwater and soil surface, because of their direct exposure to light, provide a site for aerobic phototrophic nitrogen-fixing microorganisms. The reduced zone, rhizosphere, and histosphere of the rice plant are sites for heterotrophic nitrogen fixation.

Heterotrophs and phototrophic aerobes have different energy sources. The former depend on exogenous energy sources and the latter on sunlight. This paper covers:

- quantitative approach to nitrogen fixation,
- blue-green algae,
- *Azolla-Anabaena* symbiosis,
- heterotrophic N_2-fixation, and
- integrated nitrogen management.

Project coordinator, Indian Agricultural Research Institute, New Delhi, India; and soil microbiologist, IRRI.

A QUANTITATIVE APPROACH TO NITROGEN FIXATION

Many of the nitrogen-balance estimations for flooded rice soils have originated in Japan. Estimations for flooded rice soils in the tropics are few. The most feasible way to estimate net nitrogen fixation is to determine the net nitrogen gain in long-term fertility plots and subtract the possible nitrogen gain other than that from biological nitrogen fixation. The limitations lie in analyzing soil nitrogen changes. First, the error of soil nitrogen analysis, particularly that caused by sampling, is so great that the possible nitrogen gain (about 50 kg N/ ha per crop) falls within the error of soil nitrogen analysis. Only long-term (hopefully longer than 10 years) trials can minimize soil analysis error. Unfortunately, some existing long-term fertility trials were started without an analysis of the initial soil nitrogen status.

After years of continuous growth of wetland rice without nitrogen, an equilibrium between the decrease of soil nitrogen by plant uptake and nitrogen gain might be established. Under this condition the nitrogen uptake of the rice plant in no-nitrogen plots should give an approximation of the nitrogen gain in a soil.

Because phosphorus and lime accelerate nitrogen fixation, the treatment that lacks only nitrogen can give valuable information about the effect of other elements (particularly phosphorus and lime) on nitrogen fixation (Yamaguchi 1979). In acid sulfate soils in Thailand, a phosphorus-potassium treatment has induced higher rice yield than the treatment with no nitrogen fertilizer (Cholitkul et al 1980).

Blue-green algae

The ecological and agricultural importance of free-living blue-green algae depends on the ability of certain species to carry out both photosynthesis and nitrogen fixation. The significant contribution of these algae to rice yield provides presumptive evidence of their agronomic role (Venkataraman 1979). The experience in India shows that the algal technology is no longer a scientific concept but a low-cost package of practices that should be transferred to the farmers in the shortest possible time. If properly extended, it promises 20-30 kg N/ha per cropping season and a 10-15% increase in rice yield.

There are, however, many areas that need greater scientific research of a nature that can be done only through coordinated efforts. Because the amount of fertilizer used in the developing regions is much less than the recommended level, we are immediately concerned not so much with a substantial reduction in fertilizer use as with the additional yields and cash returns to the farmers that are possible with the use of algal biofertilizer. Table 1 supports our view.

The beneficial effects of biofertilizers, particularly those of free-living systems, are generally not dramatically visible. The farmer must, therefore, be educated and convinced of the benefits of the low-cost and economically and ecologically profitable technology. A close involvement of the extension personnel and the farmers' training centers in biofertilizer studies will lead to a greater interaction at the user's level. The ultimate success of this technology depends not only on the creation of an awareness, through trials and demonstrations, but on trained manpower capable of

Table 1. The additional grain yield and net profit to Indian farmers from the application of blue-green algae. The values are means for 20 farmers.

Nitrogen (kg/ha)	Grain yield t/ha	Grain yield % increase	Net profit[a] (US$/ha)	Economic efficiency
100	4.2			
100 + BGA	4.8	12.8	66.40	25.9

[a] Net profit calculated after deduction of the cost of all the network of inputs, including the algal (BGA) material. P:K 50:50; cost of BGA, US$2.56 (20 Rs)/ha.

applying the existing knowledge and initiating further studies.

In India, the Directorate of Extension, Ministry of Agriculture and Irrigation, periodically conducts regional training courses in this technology. The courses are often complemented by the state-level courses organized by the departments of agriculture.

The extensive use of algae by farmers will require large-scale production of the material. The *open-air* method developed by Venkataraman (1972) works well and has been adopted in the field in India. An average production of 1.5-2 t/2,000 m^2 per 30-40 days, can give the farmer an income of US$128-US$192 from the sale of the material. Government agencies and a few progressive farmers produce and propagate algal biofertilizer. Expansion of this activity could provide the additional rural employment and income. and diversify the activities of capital-intensive establishments. Village-level cooperatives for production and marketing could be organized under rural reconstruction programs, and a concerted effort could be directed toward creating a consumer demand through field-level extension workers and mass media.

The quantification of algae in soil ecosystems, unlike that of bacteria, is rather difficult and time consuming. Quality-control procedures should be specified to the certified producers to prevent the inflow of spurious material into the market. Although generic and specific identification is easier microscopically, an immunological technique similar to that used for bacterial systems should be considered.

Indigenous nitrogen-fixing blue-green algae in the rice fields show a seasonal periodicity and succession, and their nature and abundance are influenced by the manurial practices and the crop's growth stages (Table 2). A closer understanding of the ecology and distributional pattern of the native flora could lead to the strengthening of the biomass of the useful forms and to maximizing their activity.

The success of inoculation depends on the introduced strains' survival and competitive ability to attain a population buildup in the shortest possible time. Current understanding of the physical, chemical, and biological factors that may exert environmental and ecological pressures in an ecosystem is inadequate. Areas where establishment of the blue-green algae is poor must be identified, and experiments must be planned to gain an understanding of the various factors influencing the growth and establishment of the introduced algae. The competitive and suppressive effect of other algae such as the green algae is little understood. Selection of fast-growing and herbicide-resistant strains may be a profitable approach.

Table 2. Succession of the indigenous blue-green algae in relation to crop growth (from Srinivasan 1979).

Period	Blue-green algae
Before planting	*Chroococcus minor*
After planting	
1-20 days	*Aphanothece pallida, Anabaena doliolum, Nostoc verrucosum, Microcoleus Lacustris*
21-40 days	*Wollea bharadwajae, Anabaena circinalis, Nostoc sphaericum, Microcystis marginata*
41-55 days	*Plectonema boryanum, Anabaena sphaerica, Microcystis marginata*
56-78 days	*Cylindrospermum muscicola, Microcystis marginata*

Equally little is known about the changes brought about by algal inoculation on the physical properties of the soil, although there is an indication that the inoculation improves the soil's aggregation status (Roychoudhury et al 1979).

Fixed nitrogen has been transferred from the algae to other plants (Mayland and McIntosh 1966, Stewart 1967), including rice (Renaut et al 1975, Venkataraman 1979), with the use of ^{15}N. There is, however, a need to evaluate the nitrogen economy of a rice ecosystem as a consequence of the direct input of industrially fixed nitrogen and algal fixation, both singly and in combination.

Blue-green algae synthesize and excrete a variety of organic substances (Hellebust 1974), including auxin-like ones (Venkataraman and Neelakantan 1967). One wonders whether the effect of additive algae on the crop can be attributed solely to nitrogen fixation or to growth factors, to nitrogen fixation and growth factors, or to other factors.

Associative symbiosis between rice genotypes and blue-green algae is unlikely but may be worth looking into.

Several years ago it was suggested that saline-alkali soils could be reclaimed by algal growth (Singh 1961). Some areas are reclaimed by growing kalar grass *(Diplachene fusca),* the rhizosphere of which harbors thick algal growth. Practically nothing has been done on this lead. Preliminary investigations suggest that the reclamative capacity of blue-green algae inoculation followed by leaching is almost comparable to the application of gypsum and leaching. This finding needs further testing in the field, and a suitable technology must be developed.

Research needs. Because much information about blue-green algae is not clear, further research should involve planned international cooperation and collaboration. An immediate requirement is the establishment of a regional culture collection of nitrogen-fixing blue-green algae of the rice soils (RCCA). While such small collections have their own localized importance, they would not serve the larger interest as much as they should, unless they are organized on a regional scale, so that other workers can have access to them.

Such regional collection would:

- act as a depository for newly isolated cultures of potential agricultural importance,
- collect cultures either as new isolates or from other collections,
- conduct studies on methods of preservation and maintenance of cultures,
- do comparative research with other apparently related organisms,
- assist and advise other researchers and field workers in their activities, and
- supply materials for inoculation purposes.

Such an agency should also serve as a clearing house for information on all aspects of cultures held there, including the best methods for their long-term preservation, their shelftime in relation to time and temperature, conditions of storage, and methods of resuscitation. To implement these activities effectively, the culture collection and activities staff must be linked to a research project. The collection may be established at the Indian Agricultural Research Institute, New Delhi, where a fairly good collection already exists, or at IRRI, with the assistance of the international agencies such as FAO, UNEP, and Unesco.

Other research needs are:

1. initiation of active research programs to isolate, identify, and characterize different blue-green algal strains native to their respective environments and deposit them with the regional culture collection;
2. ecological and physiological characterization of the promising strains with special reference to nitrogen fixation and excretion;
3. induction and selection of nitrogenase derepressed strains; and
4. standardization of growth requirements, tolerance for stresses, competitive ability, and multiplication techniques for suitable isolates.

The materials development, extension, and training needs are:

1. Efficient multiplication of algal strains in the laboratory and field at different locations and in testing different agroclimatic conditions under a coordinated program.
2. Organization, initially with the help of an expert, of an intensive short-term training program in each interested country.
3. Periodic workshop and in-service training of the extension personnel should be organized and technology should be popularized in local languages.
4. Large-scale demonstration must be set up in farmers' fields.

These trials should be simple in small-sized plots, normally with no replications on the same field. Carrying out a relatively large number of these trials can ensure the reliability of the results. Extension specialists should also establish large, compact block demonstrations in which several techniques are contrasted under various natural and artificial conditions in a particular area.

Azolla-anabaena symbiosis

A small freshwater fern, *Azolla pinnata,* is widely distributed in the tropical and subtropical areas in Asia and Africa. Symbiotic blue-green algae *Anabaena azollae,* found at the lower part of upper lobes of the fern, fix molecular nitrogen probably by

using solar energy directly (Peters et al 1979, Becking 1979). The fixed nitrogen is transferred to the host plant, enabling the fern to grow profusely in nitrogen-free medium. Under optimum conditions, the fern doubles its weight in 2.5-3 days. The fern has 24% protein in dry matter. The optimum temperature is about 25°C. When the fern fully covers the water surface, the maximum biomass of *Azolla pinnata* is about 18 t (fresh weight)/ha or 0.9 t (dry weight)/ha. Its nitrogen content is 36 kg N/ha. The maximum daily nitrogen-fixing rate recorded at IRRI was 3.1 kg N/ha per day and the maximum annual nitrogen gain in 22 continuous crops of azolla was 450 kg N/ha (Watanabe et al 1980a).

In India, Singh (1979) recorded a nitrogen yield from azolla of about 800 kg/ha per year. Because of high nitrogen content and nitrogen-fixing activity, azolla has superior potential as a green manure in the paddy field. Unlike most other green manures, azolla grows only in flooded soil. It is also used as animal food. In China and Vietnam, farmers have used azolla for centuries (Liu 1979, Dao and Tran 1979). In northern Vietnam, azolla is grown before spring rice and is incorporated into the soil. In China, azolla is used on 1.34 million ha and is grown with both the early and late rice crops.

Results in experiment stations in other Asian countries confirmed the value of azolla in increasing rice yield (Singh 1979, Sawatdee et al 1978). Because of renewed interest in the use of azolla in rice culture, IRRI organized a network of activities to test such use of azolla (INSFFER) and a training course to pursue those activities.

Research needs

Centers for the collection of various species and strains of *Azolla* and for the testing of their characteristics and the exchange of strains must be established. Methods of sending fresh azolla should be improved, and regional centers should be set up.

As a means of maintaining strains and promoting or suppressing their sexual reproduction, the conditions in which sporocarps form and the methods to control their formation should be investigated.

A network effort to test the effect of azolla on rice yield and on soil properties, and to identify problems should be further strengthened.

Most of the procedures of technique dissemination discussed in the blue-green algae section are valid for azolla technology.

If azolla is to multiply in large areas and its inoculum distributed to farmers, it must be grown continuously and multiplied. The strains should be kept alive all year round. For that purpose, azolla-multiplication centers should be set up at the village level.

The successful growing of azolla requires a lot of care. It involves split application of phosphorus, beating of azolla clumps, water control (drainage before incorporation), insect control, dividing azolla into small plots, and so on. Farmers and extension workers must be aware of these factors. Simple spreading of azolla never succeeds. At the initial stage in farmers' trials, fields where the previously mentioned requirements are easily met must be used.

Heterotrophic nitrogen fixation

Heterotrophic nitrogen fixation in paddy fields takes place in the reduced soil remote from rice root and in the rhizosphere and tissue within the root and basal shoot of the rice plant. The anaerobic conditions or mix of anaerobic and aerobic conditions are apparently favorable for biological nitrogen fixation (Watanabe 1978).

Obviously, heterotrophic nitrogen fixation depends upon the organic matter supply to the soil. In the soil remote from the rice root, the crop residue (root and part of shoot) and weed and algae residue would be major sources of organic matter supply. Nitrogen fixation in soil occurs in the plant debris, which is mechanically separated from soil (Wada et al 1979). The quantity of plant-residue addition is still obscure.

In most South Asian countries, farmers use straw as animal food or fuel. Farmers in some areas bum straw in the field. If straw is incorporated into the soil, recycling nitrogen removed by straw and enhancing biological nitrogen fixation increase nitrogen gain. A small number of laboratory and greenhouse experiments showed that a ton of straw produces a nitrogen gain of about 3 kg over the nitrogen in the straw (Watanabe 1978).

A certain amount of nitrogen fixation is associated with wetland rice roots. Since the initial research by Yoshida and Ancajas (1971, 1973) and Rinaudo and Dommergues (1971), a lot of information has been accumulated about nitrogen fixation associated with wetland rice, called associative nitrogen fixation. Associative nitrogen fixation was confirmed by acetylene-reduction assays (Dommergues and Rinaudo 1979) and a $^{15}N_2$ feeding experiment (Ito et al 1978). A variety of bacteria — *Azospirillum, Enterobacter, Beijerinchia,* and *Achromobacter* — type Gram-negative bacteria were found (Dommergues and Rinaudo 1979, Watanabe and Barraquio 1979) on the washed root and basal portions of rice stems. The nitrogen fixed by the associative bacteria does not appear to be as quickly transported to shoots as that fixed by the nodule bacteria.

Because of technical difficulties, the quantity of nitrogen fixation associated with wetland rice is still obscure. Based on acetylene-reduction assays, the amount may range from 5 to 10 kg N/ha per crop.

Varietal differences with respect to acetylene reduction associated with wetland rice were reported (Lee et al 1977, Dommergues and Rinaudo 1979, Hirota et al 1978, Watanabe et al 1979). But the difference depends on the growth stage of rice. Meaningful varietal difference would be revealed only if the associative nitrogen fixation is measured during the whole growth period of rice. Total Kjeldahl nitrogen analysis is the most feasible way to determine varietal difference with respect to associative nitrogen fixation but meaningful and reproducible varietal differences have not been found.

Nitrogen fertilizer appears to repress heterotrophic nitrogen fixation less than phototrophic nitrogen fixation.

Research needs. Areas that require study are:

1. the effect of straw addition on soil nitrogen fertility under varying conditions;

2. cultural practices that enhance heterotrophic nitrogen fixation, the possible effect of phosphorus and of nitrogen fertilizer (its amount, its method of application, its chemical form) on heterotrophic nitrogen fixation;
3. the establishment of the bacteria in the root zone before the inoculation trial of nitrogen-fixing bacteria like *Azospirillum* is recommended. Attempts should be made to modify the rhizosphere bacterial community to allow the establishment of the inoculum strain; and
4. the possibility of enhancing associative nitrogen fixation in wetland rice. Long-lasting basic research in cooperation with international organizations and expert scientists is needed in this area.

NEEDS IN BIOLOGICAL NITROGEN FIXATION RESEARCH

Every country should use its own national genius and expertise to develop a pattern of organization for the transfer of technology from the research laboratory to the field. In agriculture, the clientele consists of the farmers and their immediate contact points for any innovation or recommendation are the village-level workers, who form a part of the extension machinery. The extension service requires an effective research program to sustain it. Efforts to translate the concept of biological nitrogen fixation into an agronomic reality should, therefore, be based on an integrated approach to research, development, and extension through national and international collaboration. These regenerative natural resources have great potentialities.

INTEGRATED NITROGEN MANAGEMENT

Because the amount of fertilizer used in developing countries is still far below the recommended level, we are not as much concerned with the reduction in fertilizer use as with the increase of the efficiency of nitrogen fertilizers and the simultaneous enhancement of biological nitrogen fixation. At IRRI, it was shown recently that deep placement of urea or application of slow-release nitrogen fertilizer does not disturb the nitrogen-fixing population and its activity in the floodwater. Surface application of nitrogen fertilizer to floodwater, which is still practiced by tropical farmers, depresses biological nitrogen fixation, mainly by an effect on blue-green algae in the floodwater.

Deep placement of urea or ammonium fertilizer is the most efficient way of reducing nitrogen losses in flooded soil, and gives an additional bonus to the rice farmer by supporting nitrogen fixation. The practice makes nitrogen fertilizer use compatible with nitrogen fixation.

Azolla can also be grown in N-fertilized plots if nitrogen fertilizer is placed deep into soil, where it has little effect on azolla growing in the floodwater.

Heterotrophic nitrogen fixation in soil is less responsive to nitrogen fertilizer, because ammonium is adsorbed on soil colloids and is absorbed by plant and thus, its content in soil solution is reduced.

If we combine the techniques that reduce fertilizer nitrogen losses and those that

encourage biological nitrogen fixation, the limited amount of nitrogen fertilizer applied is expected to produce more rice yield than the amount of fertilizer currently used.

We call this combination of techniques integrated nitrogen management.

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WETLAND RICE-NUTRIENT DEFICIENCIES OTHER THAN NITROGEN

U. S. JONES J. C. KAWAL, C. P. MAMARIL, and C. S. PARK

SUMMARY

In addition to N deficiency, the nutrient deficiencies possible in culture are those of P, S, K, Ca, Mg, Fe, Mn, Cu, Zn, Si, B, Cl, and Mo.

The scientific literature relating to deficiencies in rice of all these elements was reviewed. The data reported are on critical concentrations in soils and plants, forms and transformations in soils, yield response to natural and manufactured nutrients, and geographical occurrence of deficiencies in Asia.

The *state of the art* of rice soil fertility management and gaps in the art were determined through extrapolation from the data and from each of the author's experiences. Rice research needs for the future are proposed.

Soil submergence greatly influences the availability of nutrients to the rice plant. It improves the availability of P, K, Ca, Mg, Fe, and Mn, and decreases that of Si, S, Cu, and Zn. This paper emphasizes the needs of wetland rice for those essential nutrients and cites research relevant to a better understanding of such needs in underdeveloped nations. Deficiency of at least 1 of the nutrients has been reported in 1 or more of 15 areas in Asia (Table 1). Deficiencies of P, K, S, and Zn are somewhat widespread. Deficiency of Ca occurs but it is more related to abnormal soil pH than to Ca itself. Deficiencies of Mg, Cu, Fe, Mn, and Si are not as widespread as the other deficiencies. In this paper we integrate the findings of soil scientists and rice scientists, hoping to improve the knowledge of soil fertility and plant nutrition, and to increase rice yields.

PHOSPHORUS

Rice plants deficient in P are stunted and have few tillers. Their leaves are narrow and short, erect, and dirty dark green, with a purplish tint, and the older leaves die prematurely. Ripening is delayed and the panicle produces a high percentage of empty grains.

Visiting scientist, IRRI and the Southeast Asian Regional Center for Graduate Study and Research in Agriculture; project coordinator, All India Coordinated Scheme of Micronutrients in Soils and Plants, Punjab Agricultural University; agronomist, Central Research Institute for Agriculture, IRRI; and visiting scientist, IRRI.

Table 1. Deficiencies of nutrients other than nitrogen in wetland rice in Asia.[a]

Area	P	S	Zn	Si	K	Ca[b]	Mg[b]	Cu	Fe	Mn
Bangladesh	+	+	+		+					
Burma		+								
Cambodia	+									
India	+	+	+		+	+	+	+	+	+
Indonesia	+	+	+		+			+		
Japan	+	+	+	+	+				+	
Korea	+		+	+	+	+	+			
Malaysia	+				+					
Nepal	+				+					
Pakistan			+							
Philippines	+	+	+		+					
Southeast China	+		+		+					
Sri Lanka	+				+	+				
Taiwan	+	+	+	+	+	+				
Thailand	+	+	+		+	+	+			

[a] A plus (+) sign indicates the presence of deficiency. [b] Liming materials containing Ca or Mg, or both.

Phosphorus stimulates root development, earlier flowering, and ripening, enabling the plant to counteract the unfavorable effects of late transplanting. It induces the plant to tiller more actively. In temperate regions, adequate P enables rice plants to withstand abnormally cool weather. Phosphorus improves the food value of rice and ensures normal grain development.

Concentration in plant

The concentration of P in the rice plant depends on plant age, variety, season, and P level in the soil. Ishizuka (1965) reported that the percentage of P is high in seedlings: it decreases after transplanting, gradually increases, peaks at primordial initiation, and decreases after the flowering stage until the dough stage. Its concentration is related to the absorbing power of the rice roots, which is high during the reproductive period. The absorption curve for P is sigmoidal, with peaks at the vegetative and reproductive stages. The P concentration in the leaf and stem ranged from 0.44% at transplanting to 0.13% at ripening (Table 2). The values were higher in the grain than in the straw.

Table 2. Nutrient concentration of rice plants grown in the field (Ishizuka 1965).

Growth stage	Plant part	Nutrient concn (% of dry matter)		
		P	K	S
Transplanting	Leaf, stem	0.44	3.01	0.40
Active tillering	Leaf, stem	0.29	2.51	0.26
Primordial initiation	Leaf, stem	0.37	1.95	0.22
Flowering	Leaf, stem	0.35	1.16	0.11
	Ear	0.21	0.56	0.09
Dough stage	Leaf, stem	0.15	1.40	0.05
	Ear	0.31	0.41	0.09
Complete ripening	Leaf, stem	0.13	1.64	0.04
	Ear	0.31	0.32	0.09

The P absorbed by the rice plant can be translocated from the older to the younger leaves. Because of its mobility, adequate P supplied at early growth stage ensures adequate P for grain development. Patnaik et al (1965) observed that *indica* rice varieties of different maturation periods efficiently used the P absorbed during the tillering stage and produced optimal grain yield. Phosphorus taken up after tillering tended to accumulate in the grain, straw, and roots with no advantage to grain yield.

A crop of rice takes up relatively less P than it does N and K. Table 3 shows the P uptake values for a crop of rice in different countries.

Critical level in plant

The critical levels of P in rice plants vary according to crop age and plant part. Tanaka and Yoshida (1970) reported that rice plants whose P concentration in the leaf blade at tillering stage is 0.1% or lower are P-deficient. Those whose P concentration in the straw at maturity is 1.0% or higher suffer from P toxicity. Fageria (1976a) reported that 0.4% is the critical concentration in the tops of 100-day-old plants grown in culture solution. Using grain weight as yield index, Coronel and

Table 3. Amounts of P and K taken up by rice plants.

Area	Variety[a]	Season	Grain Yield (t/ha)	Nutrient uptake			
				P		K	
				kg/ha	kg/t grain	kg/ha	kg/t grain
India (von Uexkull 1970)	Local	Dry	2.69	18	6.7	60	22.3
		Wet	2.66	18	6.8	50	18.8
	HY	Dry	7.42	32	4.3	249	33.6
		Wet	4.14	14	3.4	150	36.2
India (Saolapurkar and Balkundi 1969)	Assorted	Kharif	3.26	15	4.6	108	33.1
		Rabi	5.01	24	4.8	148	29.5
Philippines (IRRI [1963])	Assorted	–	4.74	20	4.2	218	46.0
Philippines (von Uexkull 1978)	Local	–	1.50[b]	6	4.0	33	22.0
Philippines (von Uexkull 1978)	HY (unfertilized)	–	3.24[c]	12	3.7	71	1.9
	HY (with NPK)		5.93[c]	23	3.9	129	1.8
Japan (Kemmler 1970)	Assorted	–	6.63	29	4.4	167	25.2
Taiwan (Chiu 1969)	Assorted	1st and 2d	4.34	17	3.9	86	19.8
Av			4.21	18	4.6	118	27.5

[a] HY = high yielding. [b] Av, 5 crop seasons. [c] Av, 10 crop seasons.

Wallihan (1971) found that the critical concentration in the *Y* leaf was 0.3% when the supply of the other elements was adequate, but when either N, K, or Mn was deficient, it decreased to 0.14%.

Shiga and Yamaguchi (1977) found that rice plants that had 0.65% P at maximum tillering had a maximum yield of 6.99 t/ha. Komoto (1977) reported that in warmer regions of Japan, when the shoot had less than 0.3% P, tillering was affected; when it had less than 0.13-0.20% P, brown-rice yield was affected.

Forms and transformations in flooded soil

Most mineral soils contain from 0.09 to 0.18% P (Patrick and Mahapatra 1968). Phosphorus is present in them as soluble phosphate, both organic and inorganic, and as slightly soluble salts (Ponnamperuma 1972).

All soils may contain Fe, Al, and Ca phosphate. Depending on the relative amounts of those phosphate forms (Chang 1976), they can be roughly classified into four categories:

1. dominant in Fe phosphate (including occluded phosphate) (such as lateritic soils with strong acidity);
2. dominant in Fe and Ca phosphates (most soils with medium to slight acidity);
3. dominant in Ca phosphate (soils with neutral to alkaline reactions, such as calcareous soil); and
4. dominant in Al and Fe phosphates (soils developed from volcanic tuff).

Perumal and Velayutham (1977) reported that Al and Fe phosphates constituted 55% of the total P while Ca phosphate formed only 12%. The P forms are distributed as follows: Unidentified P> Fe - P> Al - P> Ca - P = reductant soluble P> salloid - P.

The behavior of phosphate in flooded soils is markedly different from that of phosphate in upland soils. The relationship between extractable soil P and plant response that is observed with dryland crops has little value when the land is used for wetland rice. In general, wetland rice is much less responsive to phosphate than are dryland crops grown on the same soil, because flooded soils have more available native and added phosphates than welldrained soils. In the reviews of the works of several investigators, the increased concentration of water-soluble P in submerged and reduced soils is attributed to:

- the reduction of ferric phosphate,
- release of occluded phosphate, and phosphate sorbed on amorphous Fe and Mn oxides after soil reduction,
- desorption following reduction of Fe (III) oxides, and
- desorption by clays and Al oxides after pH increase.

Chang (1976) claims that the reduction of Fe phosphates is the main source of available P for wetland rice. Besides the transformation of the various P compounds into soluble forms, increased P diffusion also contributes to increased availability of P in flooded soil and subsequently to the increase in its uptake by rice plants.

When soluble phosphate fertilizer is added to the soil, most of it is fixed initially as Al phosphate, some as Fe phosphate, and the least as Ca phosphate, except in

calcareous soils. The initial fixation could be attributed to the greater sorption of P from solutions high in P inanaerobic conditions. In solutions initially low in P, as in almost all rice soils, more P is released into the soil solution. The greater P sorption in reduced conditions may be due to the probable greater surface area generated by the transformation of oxyferric hydroxide to more reactive ferrous compounds (Khalid et al 1977).

Critical level in soil

Many soil testing methods commonly used for phosphates have proven inadequate in determining the P-supplying capacity of wetland rice soils. Better correlations between available P and yield response are obtained from pot experiments but the results from field trials are often disappointing. Acid extractants that dissolve only Ca and Al phosphate give a poor indication of the available phosphate in soils containing appreciable amounts of Fe phosphate and reductant-soluble phosphate that become available to the crop after waterlogging. Chang (1976) has categorized the suitability of the more commonly used test methods:

- When Fe phosphate is dominant (usually with pH above 5.5), most of the methods often give good correlations.
- When Ca phosphate is dominant (usually with pH above 6.5), the use of an alkaline extractant, as in Olsen's method, is preferable.
- When the various phosphates have mixed distribution patterns, alkaline extractants. such as those used in Olsen's method, and weak acidic extractants containing a complexing radical for trivalent cations (Al, Fe), such as those used in Bray's No. 1 method, are desirable.

Rice plants grow normally when the P concentration in the soil or culture solution is maintained at 0.1 ppm (Tanaka 1962).

In alkaline soils of Punjab, India. a critical P level of 4.25 ppm was obtained through the use of Olsen's extractant.

Shiga and Yamaguchi (1977) determined the amount of extractable P needed to attain the critical P level of 0.29% in the plant at maximum tillering stage as 9.7 mg P/100 g dry soil by Bray's No. 2 extracting solution and as 3.3 mg P/100 g dry soil by Bray's 2.5% acetic acid extracting solution. In warmer regions the critical P value may be lower, 2.6 mg P/100 g soil. as determined by Bray's No. 2 solution.

Komoto (1977) reported that values lower than 9-13 mg P/100 g soil, obtained with Bray's No. 2 solution. affected tillering. and values lower than 2.2 mg P/100 g soil decreased yield.

Trials conducted in 226 districts in India suggested the following soil fertility classes according to the level of available P.

Fertility class	*Soil test (kg P/ha)*	*Nutrient index*
Low (1)	<10	<1.67
Medium (m)	10-25	1.67-2.33
High (h)	>25	>2.33

Occurrence of deficiency

The information in the literature reviewed shows that P deficiency is next in importance to N deficiency.

Phosphorus deficiency is perhaps the most important factor limiting rice yields on Ultisols, Oxisols, Sulfaquepts, and Andosols, and on some Vertisols, which not only are low in available P but also fix large amounts of added phosphate fertilizer. Furthermore, P deficiency is often associated with other limiting or retarding factors, as shown in the following:

Soil class	*Other growth-limiting factors*
Acid sulfate soils	Strong acidity, Fe toxicity, low nutrient status, base deficiency, salinity
Strongly acid lateritic soils	Fe toxicity, base deficiency
Regur soils	Zn deficiency, Fe deficiency, salinity, alkalinity

On the basis of field trials and soil testing in 49 important rice-growing districts in India, soils in 30 districts (or 60% of all the districts studied) have been identified as P deficient (Goswami 1975). About 50% of the soils in the 49 districts also had high P-fixing capacity; they include the black, laterite, red and yellow, and coastal and deltaic Al soils.

Kawaguchi and Kyuma (1968, 1969) reported that more than 60% of the soils in Thailand, Malaysia, and Cambodia are deficient in P, if 1.32 mg Bray No. 2 soluble P/100 g soil were considered the lower limit.

In the Philippines, a large group of rice-growing soils are deficient in P. They are generally clay to clay loams in texture and have a low pH; high contents of active Fe. Al, Mn; and a high P-fixing capacity.

The wetland rice soils of the north coastal region and the coastal areas of the southeastern region of Thailand are P deficient (Cholitkul and Tyner 1971). The soils have a low pH, low organic matter and cation exchange capacity, wide C-N ratios, and low P absorption coefficient.

Latosols, red-yellow podzolic, and coastal alluvial soils of Indonesia; acid sulfate soils of Malaysia and South Korea; Andosols of Japan; and black, red, and laterite soils of India have also been reported as P deficient (Goswami and Banerjee 1978).

In Taiwan, areas dominant in Latosols or comparatively strong acidic soils, and areas dominant in light-textured soils are deficient in P.

Sources of phosphorus fertilizer materials

Ordinary superphosphate, triple superphosphate, diammonium phosphate, and ammonium phosphate are most commonly used for wetland rice. However, fused magnesium phosphate, urea ammonium phosphate, ammonium phosphate sulfate, hyperphosphate, nitric phosphate, and rock phosphate have also been used in certain places.

The availability of fertilizer phosphate to rice growing in a waterlogged soil is

dependent on both the composition of the fertilizer and the time of fertilizer-soil contact (Poranandond and Searle 1977). Not all the phosphate from monocalcium phosphate, the principal phosphate compound of superphosphate, passes readily into solution; a proportion is retained, at least initially, in the relatively insoluble residue of dicalcium phosphate. Both the solubility of the material and the distance of movement of soluble P determine the effectiveness of fertilizer materials. Thus, the high availability index of monoammonium phosphate results from a large distance moved by phosphate (low phosphate sorption by soil) and high solubility. The low availability index of rock phosphates results from the very small distance moved by the phosphate and low solubility.

There is an increasing interest in rock phosphate as a source of P for wetland rice. However, the literature relating to rice indicates its lower availability than that of other P fertilizers. It does best on acid peats and acid sulfate soils low in P.

Application rates

Under *normal* conditions, applications of 26 kg P/ha should be sufficient to maintain high rice yield and a satisfactory level of soil P. The rates may be higher for soils that have not received P from an outside source for a long time, especially those, where high-yielding varieties or varieties sensitive to P deficiency have been continuously grown.

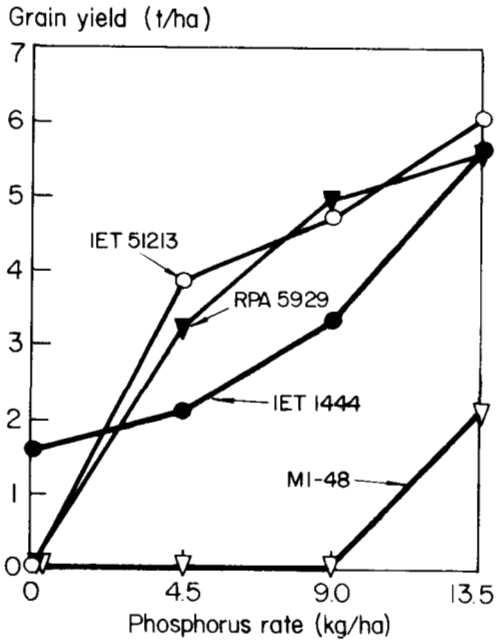
According to von Uexkull (1976), soils with high P-fixing capacity (acid volcanic ash soils, strongly acidic soils high in soluble Fe and Al) may require high initial dosages of P (up to 400 kg P/ha) to become productive. After such amelioration, the normal annual maintenance application of 18-26 kg P/ha may be sufficient.

Varietal difference in tolerance for low phosphorus

In areas where P deficiency is widespread and the supply and price of P materials are critical, rice varieties tolerant of low P may be recommended to farmers.

Marked varietal differences in response to low P availability have been established (Katyal et al 1975). One such example of differential performance of 4 rice varieties is presented in Figure 1. These data reveal that the threshold level of P at which tolerant varieties (IET 1444, IET 51213, RPA 5929) could grow was remarkably lower than that for the susceptible variety (M1-48).

In a screening nursery conducted at IRRI, IR20, IR26, IR28, IR1514A-E666, and IR2061-464-2 were relatively tolerant of low soil P, whereas M 1-48, IR2061-405-1-2, and IR2061-728-1 were the least tolerant. Resistance may be caused by either the variety's low requirement for P or its high foraging ability for soil P, or by both (Chang 1976). To clarify this point, Koyama et al (1973) compared the Thailand rice varieties Dawk Mali 3 and Muey Nawng 62 M, using both soil and water culture. In the soil culture, Dawk Mali 3 absorbed more P than Muey Nawng 62 M, but, in the water culture the two varieties absorbed similar amounts. Furthermore, in the field experiment, when P supply was adequate, there was little difference in yield between the two varieties. When P was in short supply, Muey Nawng 62 suffered more from



1. Differential response of rice cultivars to phosphorus application (Katyal unpubl.).

P deficiency than Dawk Mali 3. Therefore, the difference in response to phosphatic fertilizer between the two varieties was caused by the difference in the foraging power for soil P, rather than by the differences in the physiological requirement for P.

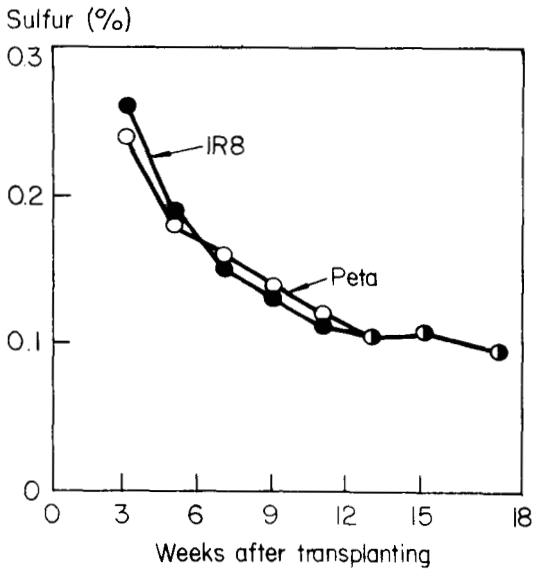
SULFUR

Sulfur is involved directly or indirectly in many plant processes, and its deficiency can change the plant's chemical composition. Sulfur-deficient rice plants in the field show general yellowing of all leaves, stunted growth, and reduced tillering. Pronounced elongation of roots is another symptom of S-deficient plants in culture solution (Yoshida and Chaudhry 1979). Except in extreme deficiency, yellowing does not occur uniformly throughout the field and is usually evident during the early stages of growth — between 2 weeks after transplanting and maximum tillering. The plants in high spots of the field are greener and more vigorous than those in low spots. That could be partly due to differences in the redox potential of the soil between the high and low spots. At about maximum tillering, yellowing disappears and the plants tend to recover and become greener.

Concentration in plant

The content of S in plants varies considerably, but is generally equal to or less than that of P. The average S concentration of the whole plant tops of rice is 0.15% of the dry matter. Yoshida and Chaudhry (1979) reported that in normal indica rice varieties, the S concentration of leaves and culms was about 0.25% at 3 weeks after transplanting, declined as growth advanced, and decreased to about 0.10% at maturity (Fig. 2). Ishizuka (1965) observed the same trend in japonica varieties.

Sulfur concentration is higher in rice grain than in the straw (Table 2). The amount of S taken up by rice plants depends on many factors, among them variety and its corresponding yield (Table 4). Peta, a tall Indonesian variety, removes more S from the soil than a semidwarf high-yielding variety. The amount of S taken up by a rice crop also depends on the rate at which S is applied. Because both N and S are constituents of proteins and their ratio in plant tissue tends to be constant, rice is expected to have higher S requirements as it absorbs more N with increased application of N fertilizer (Table 5). Sulfur uptake is also greatly affected by water management or water regimes (IRRI 1975). In aerobic soil, S uptake is greatly increased but dry matter yields are lower than those in submerged soil. Apparently, that is related to the amount of available S in the soil. In flooded soil, sulfate S is



2. Sulfur concentration in the shoot (Yoshida and Chaudhry 1979)

Table 4. Uptake of S by rice crops (Wang 1976).

Variety	Grain yield (t/ha)	S uptake	
		Kg/ha	Kg/t grain
IR8	9.13	14.7	1.61
Peta	6.09	16.8	2.76
Apani	4.08	7.75	1.90
IR661-1-127-3-3	6.24	9.29	1.49
IR22	5.83	8.68	1.49
Av	6.27	11.44	1.85

Table 5. Effect of S and N fertilization on S uptake by a rice crop (Wang 1976).

S rate (kg/ha)	S removed (kg/t grain)	
	N_{60}	N_{120}
0	0.64	0.66
50	1.21	1.75
100	1.23	1.90

reduced and is not available to the plants. Sulfur removal is also affected by status of other nutrient elements. Lockard et al (1972) reported that applications of B significantly increase the S content in rice plants.

Critical level in plant

The level of available soil S is often reflected in its concentration in rice plants. The term most commonly used to establish adequacy is *critical level.* Yoshida and Chaudhry (1979) used two criteria for critical level: DC_{50}, the S content required in plant tissue for 50% of maximum yield, and DC_{100}, that required for maximum yield. The more generally accepted definition is the nutrient content required to produce 95% of maximum yield.

Three criteria of the S status of plants have been used with varying degrees of success: sulfate S, total S, and N-S ratio. Several workers used the total S criteria (Table 6) and obtained critical S levels ranging from 0.05 to 0.16% depending on the plant part and growth stage. Others combined two or three parameters. The

Table 6. Critical levels of S in the rice plant.

Plant part	Growth stage	Critical level (% total S)	Reference
Straw	Tillering	0.16[a]	Yoshida and Chaudhry 1979
Straw	Flowering	0.07[a]	Yoshida and Chaudhry 1979
Straw	Harvest	0.06[a]	Yoshida and Chaudhry 1979
Straw	Maturity	0.068	Ishizuka and Tanaka 1960
Leaves and culms	Tillering	0.10	Suzuki 1977
Leaves and culms	Maturity	0.05	Suzuki 1977, 1978
Leaf blades	Flowering	0.15[b]	Osiname and Kang 1975
Straw	Maturity	0.10	Osiname and Kang 1975

[a] Minimum S concentration necessary to obtain maximum yield. [b] Dryland rice.

argument advanced by Blair and Crafts (1970) for the use of more than one criterion was that when a secondary deficiency is present, the S status in the plant may not reflect what really exists. Therefore, Blair et al (1978a, b) proposed a guide for identifying S deficiency or N deficiency, or both (Table 7). Yoshida and Chaudhry (1979) claim that because both critical S content and critical N-S ratio vary with growth stage, the S content in plant tissue is a better tool for diagnosing the S status of the rice plant. The determination of the N-S ratio has the disadvantage of increasing analytical cost.

Forms and transformations in flooded soil

The total S content in soils varies considerably. The work of several workers, according to the International Fertilizer Development Center (IFDC 1979), indicates that soils in the tropics contain 27-510 ppm S, with a mean of 106 ppm. The S in soils is a variable mixture of

- primary minerals — the metal sulfides of plutonic rocks;
- sulfate ions in solution — generally below 10 ppm in soils of humid regions with considerable fluctuation;
- absorbed sulfate — varies widely and depends on the nature and extent of active oxide surface, clay content, clay type, and pH;
- organically bound ester sulfates — consist largely of organic sulfate, contain ester linkages, and are found to constitute from 20 to 70% total S in the soil; and
- organic S compounds — chemical nature is not clearly defined but 30% of it may be made up of S-containing amino acid cystine, cysteine, and methionine.

A large proportion of the S in humid soils is in the organic form. Because plants absorb mainly sulfate S, organic S must be mineralized and oxidized to sulfate. Many factors affect the mineralization of organic S: Ca-S or N-S ratio, rhizosphere effect, time, pH, soil moisture, and soil temperature.

Elemental S and sulfides are not found in well drained dryland soils. In wetland soils, however, sulfides are found and, in some instances, elemental S is deposited.

In dryland soils, the main transformations of S are oxidation of elemental S, sulfides, and organic S compounds to sulfate; in wetland soils, they are reduction of sulfate to sulfide and dissimilation of proteins to hydrogen sulfide, thiols, ammonia, and fatty acids (Wang 1976). Because Fe (III) reduction to Fe (II) precedes sulfate reduction, Fe (II) will always be present in the soil solution by the time hydrogen sulfide is produced, so that hydrogen sulfide will be converted to its insoluble ferrous

Table 7. Preliminary classification of N and S status of whole rice tops sampled from tillering to flowering stages.

Category	N (%)	S (%)	N–S ratio	Status	
				N	S
I	>1.6	<0.10	>15	Adequate	Deficient
II	>1.6	0.10-0.15	>10	Adequate	Marginal
III	>1.6	10.15	<10	Adequate	Adequate
IV	<1.6	>0.15	<10	Deficient	Adequate
V	11.6	<0.10	Variable	Deficient	Deficient

sulfide form (Patrick and Reddy 1978). The rate of sulfate reduction in submerged soils depends on soil properties. In neutral and alkaline soils. concentrations as high as 1,500 ppm SO_4 may be reduced to 0 within 6 weeks of submergence.

Because rice plants, like other plants, absorb S primarily in the form of sulfate, the reduction of sulfate to sulfide in wetland soils reduces the availability of S. The production of hydrogen sulfide at a certain level adversely affects plant growth. Mitsui et al (195 1) demonstrated by solution culture that a hydrogen sulfide concentration as low as 0.07 ppm is toxic to rice. The reaction of hydrogen sulfide with Fe (II), Mn (II), Cu (II), and Zn (II) to form insoluble sulfides (Ponnamperuma 1978) protects the rice plants from the toxic effects of hydrogen sulfide. Only in low-Fe organic soils, where the reducible Fe content is likely to be low, does hydrogen sulfide become stable and subsequently injurious to rice plants.

Although sulfides may dominate S forms in flooded soils, rice roots may still obtain S from the soil by bacterial oxidation of the insoluble sulfides or by the oxidation of hydrogen sulfide in contact with the oxidized rhizosphere (Engler and Patrick 1975). This suggests a research strategy to correlate a soil test for S that takes into account the sulfides as well as sulfates in flooded soils. This could be accomplished by determining the response of flooded rice to varying rates of flowers of added S to a very low-S soil, compared with varying rates of SO_4-S added to the same soil type.

Response of rice to applied sulfur

Although S has been known for more than a century as an essential element for plant growth, it has received little attention. The first report of S deficiency in wetland rice was probably that of Sen (1938) in Burma. One reason why S deficiency in rice has been observed only recently is that the common fertilizer materials applied to provide NPK also contained S. Table 8 shows the countries where S deficiency has been observed. The reasons for the increased occurrence of this problem are:

Table 8. Countries where S deficiency of rice was observed.

Country	Experiment	Reference
Bangladesh	Pot	Karim and Majlish 1958
	Pot	Karim et al 1970
	Pot	Alam and Karim 1972
Brazil	Pot, field	Wang et al 1976a, b
Burma	Field	Sen 1938
	Field	Aiyar 1945
India	Pot	Acharya 1973
	Field	Saran 1949
Indonesia	Pot	Yoshida and Chaudhry 1979
	Pot	Laijder and Aldjabri 1972
	Pot	lsmunadji et al 1975
	Field	Mamaril et al 1976
Nigeria	Pot	Osinarne and Kang 1975
Philippines	Pot	Lockard et al 1972
Thailand	Field	IRRI 1977

- increased use of high-analysis, S-free fertilizers such as urea and triple superphosphate;
- use of high-yielding rice varieties that produce higher yields than the traditional varieties:
- decreased use of S-containing pesticides and fungicides:
- environmental control of sulfur dioxide emissions in industrial areas: and
- a greater number of experiments to study S as a nutrient in its own right.

The response to added S varies considerably. Wang et al (1976a,b) reported yield increases as high as 400% in pot experiments. In field experiments the average responses were much lower — from 34 to 100% more than that of the control — at rates of application as high as 40 kg S/ha. The relative response to S was lower at 120 kg N ha than at 60 kg N/ha.

Mamaril et al (1976) reported that yields in farmers' fields in South Sulawesi, Indonesia. were 12-45% higher with application rates as high as 100 kg S/ha than those in the control. In another set of 28 trials in South Sulawesi, Indonesia, Blair et al (1979a) reported responses to S as high as 279%, and average grain yields 18.6% higher than those in zero-S plots at 18 sites. In 3 sites, 3 S sources — ammonium sulfate, gypsum, and elemental S — were equally effective (Blair et al 1979b).

Osiname and Kang (1975) reported marked response in Nigeria to applied S in OS-6, a tall variety, and IR20, a semidwarf grown in dryland conditions. Yield increases ranged from 310 to 1,490%. Grain yield increases were higher in IR20 than in OS-6. The greater response of IR20 was attributed to its shallow rooting.

Critical level in soil

Because of the dynamic nature of S in flooded soils. the few studies that correlate soil test values to yield response of rice show inconsistencies. Lockard et al (1972) found that rice plants grown in a soil containing 11 ppm ammonium acetate extractable S before flooding had high S content and were nonresponsive to S compared with plants grown on a soil with 51 ppm. which responded to S. They suggested that the lack of relationship may have been due to differences in organic matter content, which affected the degree of reduction in the paddy. This conclusion was not supported by data on a third soil, which contained the same amount of organic matter as the 11 ppm soil and was tested at 30 ppm S. That soil showed maximum response to applied S.

Wang (1976) suggested that the critical level of soil S for rice is 10 ppm sulfate S. Under high N-S and Ca-S ratios, this value may not be applicable because considerable immobilization of the sulfate S by microorganisms may be taking place, thus depriving plants of available S.

Sulfate S contents of soil samples collected by Wang et al (1976a) from wetland rice areas where the crop showed S-deficiency symptoms ranged from 1 to 3 ppm. Those of samples from areas where the crop showed no deficiency symptoms ranged from 2 to 50 ppm, but only 3 of the 18 soils from these areas had more than 3 ppm soil sulfate.

Suzuki (1978) inferred that the critical level of phosphate-extractable S in soil is

7-11 ppm. His conclusion was based on the findings that 2 of the 11 test soils that responded to S had 7-11 ppm phosphate-extractable S.

Because the sulfate status of a flooded soil depends not only on the S content but also on the degree of soil reduction, it is doubtful if testing for sulfate status before flooding will have any value (Blair et al 1978a). Furthermore, because many factors influence the balance between sulfide and sulfate in flooded soils, a determination of sulfide concentration would again have little or no value.

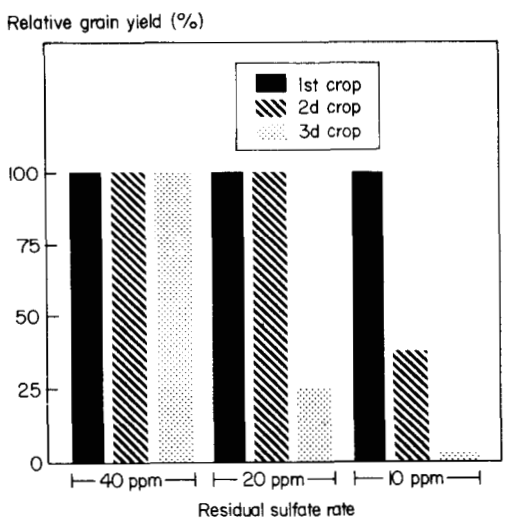
Sources of sulfur fertilizer

The most common S sources for rice are ammonium sulfate (24% S) 2nd single superphosphate (14% S). Blair et al (1979b) have shown, however. that gypsum and elemental S are as effective as ammonium sulfate. The probable reason why elemental S and sulfate-containing materials are equally effective is that sufficient oxidation takes place in the root rhizosphere, converting the elemental S to sulfate S.

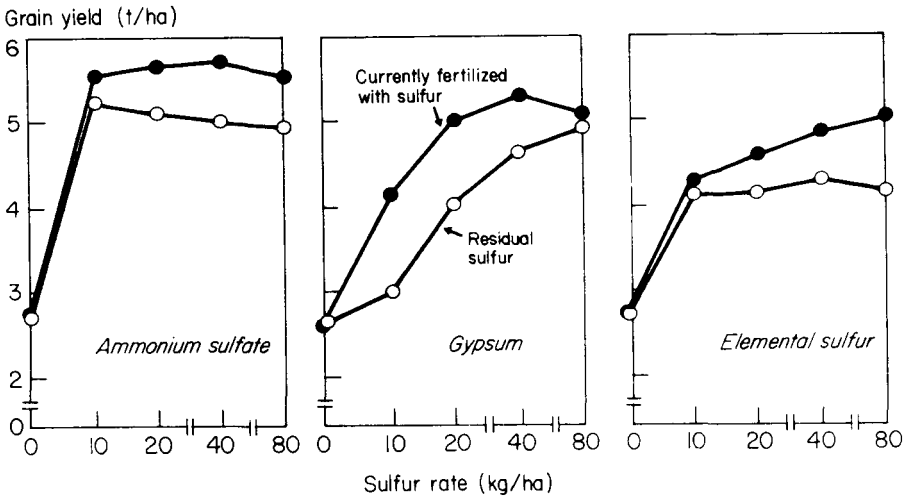
The residual value of S application must be considered in a S fertilization program. In a pot experiment, the number of succeeding crops with no S deficiency was directly related to the amount of initial S applied (Wang 1976, Fig. 3). Experiments in Indonesia also showed that even 10 kg S/ ha from ammonium sulfate will provide residual S to support another crop (Fig. 4). Duration of the residual effect will depend on the amount of leaching.

POTASSIUM

Rice plants deficient in K have dark, dirty-green leaves on short, thin stems, and appear stunted. Tillering is not affected except in extremely deficient conditions. Dark, rusty brown spots develop; they start from the tips of older leaves and spread over the whole leaf. At a more advanced stage of deficiency, the leaf tips and leaf



3. Effect of residual sulfur from previous applications on rice grain yields of cultivar Awini in pot-culture conditions (Wang 1976).



4. Comparative residual effects of 3 sources of sulfur.

margins dry and become reddish brown; older leaves senesce early.

During periods of high temperature and low humidity, young leaves of K-deficient plants may show signs of water stress by rolling. The panicles are long and thin and a high percentage of the grains are sterile and poorly filled. The smaller roots decay prematurely. Rice plants with adequate K are less prone to blast and *Helminthosporium,* and respond more to P application in P-deficient soils.

Concentration in plant

Potassium content in the rice plant varies with age, plant part, variety, and available Kin the medium. Ishizuka (1965) reported K concentration in the leaf and stem from 3.01% K at transplanting to 1.64% at ripening (Table 2). Potassium values of 4% and higher were obtained at early stages, especially in culture solutions. Concentrations are higher during the initial growth stages and gradually decrease to very low values during or after reproductive growth. At all growth stages, the top parts of plants grown in culture solution had higher K concentration than the roots. At harvest, K content was higher in the straw than in the grain.

Active absorption of K starts from transplanting and continues until the dough stage. An absorption lag period between maximum tillering and ear initiation has been observed in medium- (145-150 days) and late- (160-170 days) but not in early-duration varieties. Su (1976) reviewed the work of a number of Japanese investigators on the effects of K absorbed at various growth stages on yield-determining factors. He summarized their finding:

- Potassium absorbed at about the stage of maximum tillering increases the number of panicles and grains.
- Potassium absorbed at the early formation stage increases panicle and grain

numbers as well as the 1,000-g weight.

- Potassium absorbed after panicle formation improves the weight of the grains.

A rice crop takes up 33-249 kg K/ha (Table 3). However, when K uptake is expressed per ton of grain yield, the variability becomes smaller. In modern, high-yield rice culture, K uptake in double cropping areas may exceed 332 kg K ha. Detailed investigations in Japan showed that the average K uptake is 22 kg K/t rough rice (Takahashi 1966).

Critical level in plant

When the K content of the straw at harvest or that of the leaf blade at tillering stage is 1.0%, a K deficiency is likely to exist (Tanaka and Yoshida 1970). Su (1976) cited results from 20 sites in an area of Latosols in Taiwan where the critical K value, at which 98% of the maximum grain yield was attained. was 1.7-1.8% of the dry matter at full heading and at harvest.

Because the critical level of K in the rice plant may be influenced by the relative amounts of other soil nutrients such as N and P, von Uexkull (1978) has proposed the use of the ratio of K in the straw of control plots to that of N or N-P plots as a more reliable predicter of response to K. Von Uexkull applied the concept on results from the Philippines and Indonesia and proposed the following categories and the corresponding level of expected K response:

Potassium ratio in the straw from 0:N or NP plots	*Expected response pattern to applied potassium*
<1.0	Sone
1.0-1.1	Slight
1.1-1.3	Moderate
1.3-1.5	High
>1.5	Very high

On the other hand, Chang and Liang (1978) reported that if the ratio of K and N absorbed by the plant is less than 0.25, a yield increase could be expected with the application of K.

Forms and transformations of potassium in flooded soil

Potassium exists in the soil in four forms, which are in dynamic equilibrium:

Soluble K (Readily available K) ⇄ Exchangeable K (Easily mobilizable K) ⇄ Nonexchangeable K (Slowly mobilizable K) ← Mineral K (Semi-permanent reserve)

Potassium in soil solution and the exchangeable K are the forms available to rice plants. The K concentration in the soil solution is not primarily related to the concentration of exchangeable K, but is related to the quantity and the type of clay minerals. In clay rice soils the K concentration in solution increases slightly with

increasing amounts of exchangeable K, but in sandy soil it increases rather sharply (Fig. 5).

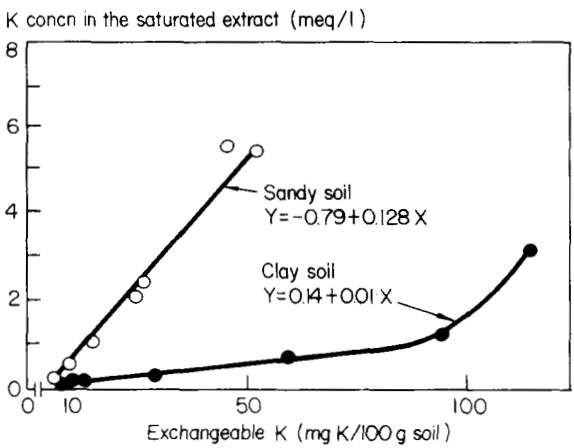
Flooding enhances the release of exchangeable K to the soluble form. Clark and Resnicky (1956) observed that K concentration in the soil solution almost doubled after submergence. Such increases were also observed in several soils that were kept submerged at IRRI. Maximum soluble K values were reached at the peak of reduction and the increases were highest in the sandy soil rich in organic matter and in acid clay soil. Such increases appeared to be associated with the contents of soluble Fe (II) and Mn (II). Islam and Islam (1973) also observed that submergence increased the concentration of K in solution. Flooding increases exchangeable K but the increase was more pronounced in an alternate wetting-and-drying cycle.

Tanaka and Yoshida (1970) reported exchangeable K values ranging from 0.06 to 1.21 meq 100 g for 63 soil samples from 10 Asian countries. In Sri Lanka. 75% of the rice soils in the wet zone had an exchangeable K content of less than 0.15 meq 100 g soil, which is considered below the critical K level (Thenabadu 1973). Exchangeable K in some major Philippine soils grown to rice ranged from 0.20 to 0.90 meq; 100 g soil and averaged 0.50 meq 100 g soil (Biswas 1974. von Uexkull 1978).

Critical level in soil

Exchangeable K is usually well correlated with yield response of dryland crops. However. K tests for wetland soils have been quite controversial. As a result. there is some variability in critical soil K values. On the basis of pot experiments, with black soils in India. the critical value of exchangeable K is 0.26 meq 100 g soil. In a series of experiments in farmers' fields. Indian workers also obtained the critical value of 0.26 meq 100 g for ammonium acetate extractable K in a high-yielding rice variety.

Su (1976), who summarized several studies in Taiwan, concluded that the availability of K may be better represented by nonexchangeable K than by more rapidly available forms, if the extraction is done soonafter the depletion of the latter, and the time allowed for the restoration of the equilibrium is insufficient, or if the comparison is between soils with widely different pedological origins and different nonexchangeable K contents but less variable exchangeable K. Nevertheless, Su (1976)



5. The potassium concentration of the soil solution as influenced by the exchangeable potassium in a sandy and clay soil.

suggested that in Latosols the critical exchangeable K level is 0.18 meq/ 100 g soil.

Japanese workers considered 10 mg exchangeable K.O (or 8.3 mg K/ 100 g soil, equivalent to 0.21 meq K/ 100 g) the critical level.

Irrigation rate and potassium use

Despite the importance of K and other fertilizers, farmers in some Asian countries fail to apply needed rates of K and other essential nutrients, because irrigation and cropping intensity are not optimum.

Along with fertilizer, irrigation rate is an important factor affecting increased rice production. There is a close correlation between irrigation rate, total nutrients, and grain yield in Asia (Table 9). A research strategy to double rice yield in Asia must be approached within the framework of these correlations. This can be accomplished by conducting field experiments with rates of fertilizer on flooded and rainfed fields simultaneously.

Responses to potassium application

The response of rice to K depends on the fertility level of the soil, yield, variety, and season. Based on experiments with 3 rice varieties at 3 sites in the Philippines, the average response to 50 kg K/ ha without P, was only 0.33 t/ ha and 1.1 t/ ha when 26 kg P/ ha was applied (IRRI 1973,1974). In the absence of P, IR20 failed to respond to K, whereas IR8 and IR26 yielded an extra 500 kg grain/ ha. In the presence of P, the response to K was 1.4 t/ ha for IR8 and 1.3 t/ ha for IR26, and only 0.6 kg/ ha for IR20.

In Southeast China, on some calcareous alluvial bog soils deficient in P, Zn, and K, applying either P, Zn, or K fertilizer alone increases yields over the control plots by 5.7-8.5% (Changand Liang 1978). But when a combination of 2 of these elements or when all 3 are applied, yield increases over the control ranged from 31.7 to 50.7%.

In India, the average response to 60 kg K/ ha from 785 trials of kharif rice was 6.7 kg grain/ kg K and that from 378 trials of rabi, 8.48 kg grain kg K (Kanwar 1974). The high-yielding varieties responded better than the local tall varieties.

Table 9. Fertilizer use and irrigation rate for rice and rice yields in some Asian countries in 1974-76 (von Uexkull 1978, Okita and Takase 1976).

Site	Fertilizer use (kg/ha)				Irri-gation rate[a] (%)	Grain yield (t/ha)
	N	P	K	Total		
Japan	96	44	76	216	97	5.69
Korea	127	24	44	195	85	5.15
Taiwan	125	15	31	171	85	4.22
Malaysia	40	9	4	53	48	2.90
Philippines	25	7	4	36	42	1.61
Thailand	6	2	0	8	30	1.60

[a]Percent irrigation rate = (irrigated paddy area/total paddy area) X 100.

Long-term fertility trials in IRRI show that with intensive rice monoculture systems, the response per unit of K applied increases with time compared with N applied alone (IRRI 1972, 1973, 1974). That suggests that K should be applied in rice areas that had previously been continuously grown to high-yielding varieties and to which only N or P has been added.

Von Uexkull(1978) proposed a table of K requirements for various yield levels of rice as a guideline in determining the rate of application (Table 10).

Areas where potassium deficiency is likely to occur

In time, K may be needed on almost any soil. Initially, however, it will be needed only in the following (von Uexkull 1978):

- light-textured soils, soils that are developed from limestone or parent materials low in K, older Latosols, and soils high in organic matter;
- where irrigation water comes from watersheds with calcareous rocks, and the high concentrations of Ca and CO_2 tend to suppress K uptake;
- where drainage is poor and water saturation of the soil throughout the year causes poor K uptake; and
- where high-yielding rice varieties and high rates of N (and P) have been used for a long time, especially when crop residues are not returned to the soil.

Sources for fertilizer

Potassium chloride containing 50% K is the most common source of K; K sulfate (42% K) is the next most common. The latter may not be recommended indegraded soils such as those in Japan. But this material may be recommended where S deficiency occurs. In several countries, some complete fertilizers such as 14–14–14. 15-15-15, 20-10-10, and 10-15-15 are applied basally. In Japan, N-K compounds such as 16-0-20 or 17-0-17 are widely used for topdressing (von Uexkull 1976).

Table 10. Potassium requirements for various yield levels of rice.

Yield level (kg/grain per ha)	K_2O requirement[a] (kg/ha)	K_2O supply (kg/ha)					K_2O required[d] (kg/ha)	KCl required[e] (kg/ha)
		Soil	Water[b]	Straw[c]	Total	Balance		
1000	30	50	10	10	70	+40	–	–
2000	60	50	10	20	80	+20	–	–
3000	90	50	10	30	90	0	–	–
4000	120	50	10	40	100	-20	30	50
5000	150	50	10	60	110	-40	60	100
6000	180	50	10	70	120	-60	100	165
7000	210	50	10	80	130	-80	130	215
8000	240	50	10	90	140	-100	160	270

[a]Assuming that 30 kg K_2O/ha is required for every 1000 kg grain. [b]Assuming that the irrigation water contains 4 ppm K_2O, 25% of which can be used by the crop. [c]Assuming that 2/3 of the K_2O absorbed is returned to the soil, 50% of which is used. [d]Assuming 60% use of K_2O applied as fertilizer. [e]KCl with 60% K_2O.

SOIL pH AND LIME

Chemically, lime is Ca oxide, but the term is broadly used in agriculture to include any material containing Ca or Mg, or both, in forms capable of correcting soil acidity, including the oxide, hydroxide, carbonate, and silicate of Ca and Mg.

The most accurate and widely used soil tests are those that determine lime requirements and pH. pH values between 5.5 and 6.5 are favorable for rice production. Themicronutrients Fe, Zn, Mn, Cu, and Bare more soluble and therefore more available to rice grown in low-pH acid soils. In high-pH alkaline soils these five micronutrients are less soluble and therefore less available to rice.

Deep-well irrigation water often supplies wetland rice with Ca and Mg carbonates equivalent to 800-1,000 kg/ha each year. Over a period of years. the soil pH increases and values up to about pH 8.3 have been attained. At the other extreme, acid sulfate soils irrigated from reservoirs often have pH values less than 4.0.

Fortunately one of the major electrochemical changes in submerged soils is an increase in pH of acid soils or a decrease in pH of alkaline soils. The increase in pH of acid soils is due to soil reduction, but the decrease in pH of calcareous soils is due to the accumulation of CO_2.

Rice nutrition problems caused by excessive amounts of soluble Fe and Al associated with acid soils are discussed by Ponnamperuma (1972). On page 38 (Sources of fertilizer), the use of Mn as an antidote to excessive Fe in the soil solution is discussed. The problems of Zn and Cu deficiencies associated with near-neutral to alkaline soil pH are also discussed on the following pages.

Sources of agricultural lime

The common forms of agricultural lime include finely ground calcitic and dolomitic limestone, marl, burned lime (CaO), hydrated lime [$Ca(OH)_2$], and industrial byproducts such as paper mill sludge, sugar beet and cane mud, wood ashes, marble dust, gas work waste, and various slags from industry, including basic slag and Ca silicate slag. The use of Ca silicate slag as a liming material and as a source of Si as a plant nutrient is discussed under Silicon.

Liming acid sulfate soils

Additions of about 2 t lime/ ha are used on acid mineral soils. In Sierra Leone, on young acid sulfate soils (Sulfaquepts), rice yields of 2 t/ha were obtained with 5 t lime/ ha application without seawater leaching. With 2.5 t lime/ ha, in conjunction with seawater leaching at the end of the dry season, 2 t rice/ ha were obtained. Without lime, rice would not grow (Hart et al 1963). Because of renewed acidification from pyritic subsoil during the following dry season, lime additions are necessary yearly. Such an expense for lime is uneconomical at the current yields and prices. If the water table could be maintained above the pyritic subsoil, preventing prolonged drying of surface soil, the pH, which controls all other adverse factors, could be kept in a safe range.

In such soils, research that includes the interaction of irrigation not only with fertilization but also with liming is needed. Agricultural lime should be spread evenly

on the rice field before flooding and uniformly and thoroughly mixed with the furrow slice of soil. Alternate wetting and drying greatly increases the lime requirement on acid sulfate soils.

Lime-deficient regions

Liming increased rice yields in Indonesia, Nigeria, Vietnam, Korea, and Sri Lanka (Table 11). Rice also responds to lime in many peat and acid sulfate soil regions (Fig. 6). The response to lime on acid sulfate soils is associated with the precipitation of excessive Fe in the soil solution.

CALCIUM

The essentiality of Ca for rice growth can be easily demonstrated by interrupting Ca supply to the roots. The growth rate is immediately reduced because Ca is required for cell elongation and division. A deficiency of Ca in rice results in discoloration of new leaves and deformation of leaf tips. A deficiency of Ca is rarely seen on wetland rice plants in the field because most mineral soils are rich in Ca and in most fields irrigation water supplies it in sufficient amounts. Most reported abnormalities are those associated with low pH and excessive amounts of Al and Fe rather than with a deficiency of Ca.

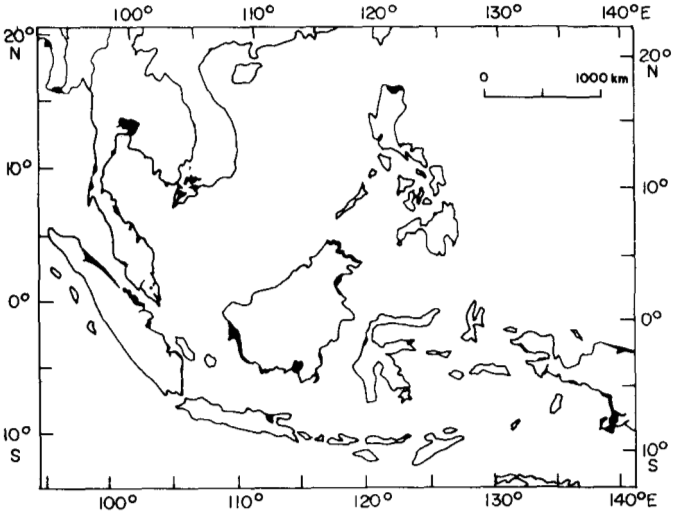
Concentration in plants

Monocotyledons such as rice have lower Ca requirements than dicotyledons. Under most conditions, however, both have higher Ca contents than needed for maximum

Table 11. Effect of liming on wetland rice yield in acid soils in different locations.

Site	Soil description	Yield (t/ha)		Recommended rate (t lime/ha)	Remarks
		Without lime	With lime[a]		
Magbolontor, Nigeria	Valley				
Magbolontor, Nigeria	Swamp	2.33	2.88*	2.0	P also added
Magbolontor, Nigeria	Drained	1.74	2.30*	2.0	Basic slag
Magbolontor, Nigeria	Waterlogged	0.88	1.76*	2.0	Basic slag
Magbolontor, Nigeria	Drained	3.38	4.13*	2.0	Lime + basic slag
Magbolontor, Nigeria	Waterlogged	2.95	3.49	2.0	Lime + basic slag
Vietnam	Sulfaquept	1.20	2.60*	7.0	Calcitic lime
Korea	21 soils	3.22	3.55*	2.0	Dolomitic lime
Korea	21 soils	3.22	3.78*	2.4	Ca-silicate
Southwest Sri Lanka	Lateritic clay	2.27	3.07*	6.0	$Ca(OH)_2$ 1956
Southwest Sri Lanka	Lateritic clay	1.94	2.82*	–	Residual 1957

[a]A single asterisk indicates significant difference at the 5% probability level. Source: IITA 1977, Pham-Huu-Ahn et al 1961, Park 1970, Ponnamperuma 1958.



6. Major areas of peat and acid sulfate soils in Southeast Asia.

growth. A 10-t rice crop removes about 40 kg of Ca, which amounts to a 0.4% concentration.

Critical limit in plant

Values of less than 0.15% Ca are considered deficiency levels for rice, in which Ca concentration varies from about 0.2 to 0.5%. These high concentrations, however, principally result from high Ca levels in the soil solution rather than from the efficiency of root cells' Ca uptake mechanism. Generally, the concentration of Ca in a wetland soil solution is 10 times greater than that of K, but the uptake of K by rice is about 10 times that of Ca.

Forms and transformations in flooded soil

Flooded calcareous soils contain, for the most part, carbonates and bicarbonates of Ca in addition to exchangeable Ca adsorbed on the clay and humus colloids. Soils with a pH above 6.5 also contain small amounts of hydroxides and phosphates of Ca. Flooded acid soils contain available Ca almost exclusively in the exchangeable form. Small quantities of Ca are present in the acid soil solution but are in equilibrium with exchangeable Ca.

On both acid and calcareous soils, the concentration of Ca increases rapidly with time of submergence, reaches a maximum, and then decreases.

Concentration in soil

The concentration of Ca in soils varies widely from as much as 2% in a calcareous soil containing 5% free lime to as little as 1 meq Ca/100 g (0.02%) in acid sandy soils. A soil from the Banaue rice terraces of the Philippines, which have been farmed for

at least 2,000 years with no fertilization or liming, contained 13.2 meq Ca/ 100 g, a total base saturation of 22 meq/ 100 g, a cation exchange capacity (CEC) of 46 meq/ 100 g, and a pH of 5.3. Its parent material was dolomite.

Critical limit in soil

Patnaik (1978) reported that maximum rice growth occurs when Ca is 8-20% of the CEC. The Banaue soil had a Ca saturation of

$$\frac{13.2}{46.0}$$

or a little more than 20%. Calcium is seldom in short supply. A sufficiently accurate method for determining lime requirement involves the change in pH of a buffer solution when a soil sample is added to it.

Most textbooks (Jones 1979) give a pH range of 5.5-6.5 as suitable for rice on mineral soils. On peat soils, a pH of 5.5 should not be exceeded. The lime requirement of acid sulfate soils is discussed in the section on pH and lime.

Bandyopadhyay (1973) conducted experiments on several acid soils (including laterites, submontane, and alluvial) with pH values of 4.9-5.4, and CEC values of 3.2-6.2 meq/ 100 g. He concluded that wetland rice requires liming if soils have pH values lower than 5.0 and high exchangeable Al. In similar experiments, Ponnamperuma (1958) obtained on a Southwest Sri Lanka acid clayey laterite of pH 4.43 and a sandy loam soil of pH 4.76 good yield response from as much as 6 t $Ca(OH)_2$/ ha but associated the response to the lowering Fe concentration in the soil solution.

Sources for fertilizer and method of application

The most economical sources of Ca for rice are the various limestones and slags, which are broadcast and incorporated with soil. Ordinary superphosphate contains 20% Ca; triple superphosphate, 13%; and rock phosphate, 33%. When it is desirable to add Ca without changing the soil pH, the application to soil of neutral salts such as $CaSO_4$ and $Ca(NO_3)_2$ is suggested. When a foliar application of Ca is necessary, $CaCl_2$ in solution is used.

Calcium-deficient regions

Regions where acid soil conditions in wetland rice have been corrected by liming are given in Table 11. Available knowledge indicates that liming will be necessary on acid sulfate soils and desirable on some other strongly acid soils.

MAGNESIUM

The symptoms of Mg deficiency and those of K deficiency, when compared in laboratory experiments, are similar. However, Mg deficiency does not influence shoot length, and the symptoms on the lower leaves are more pronounced.

High plant concentrations of K and NH_4 tend to restrict Mg uptake.

The amount of Mg taken up by a 10-t rice crop is about 20 kg/ha, or 0.2% concentration in the whole crop. Rice grain contains more Mg than the straw, but less K and Ca. The Mg content in straw at maturity varies from 0.06% to 0.18%. The Mg contents of 184 rice leaf samples analyzed in Arkansas averaged 0.18% for samples from alluvial soils and 0.19% for samples from loessial soils (Jones et al 1972).

Critical limit in plant

The critical limit of wetland rice is about one-half that of other crops. Magnesium concentration of less than 0.1% in mature straw is considered the critical deficiency level by Tanaka and Yoshida (1970). The critical value for the occurrence of deficiencies on many other crops is about 0.2% Mg. Large amounts of soil Ca, especially in the form of Ca carbonate, reduces the uptake of Mg by rice.

Forms and transformations in flooded soils

The less active forms of Mg in soils are ferromagnesian minerals, dolomite, and secondary minerals such as montmorillonite clay. The more active forms in flooded soils are exchangeable Mg, and Mg in the soil solution. There is usually about 25-50% as much exchangeable Mg as exchangeable Ca. Because exchangeable Mg is not held as tightly as Ca by soil clays, flooded soils often contain as much Mg in solution as Ca. The concentration of Mg, like that of Ca, increases rapidly in submerged soils, reaches a peak, and then decreases. In flooded calcareous soils, Mg concentration reaches its peak in the 5th week after submergence but Ca concentration does not reach its peak until the 9th week (Islam and Islam 1973). The soluble Mg in flooded soil exists as simple bicarbonate, sulfate, and chloride salts.

Concentration in soil

Total Mg concentration of mineral soils varies from about 0.3% in humid regions to 0.6% in arid regions. Exchangeable Mg may vary from 0.1 meq/100 g soil in acid sands to 6-8 meq/100 g soil in semiarid region. Perhaps 10% of the exchangeable Mg may be found in the soil solution of submerged soils. The exchangeable Mg plus the Mg in soil solution, is available to plant roots.

Critical limit in soil

Soil analysis is widely used in diagnosing deficiencies and predicting the needs of rice and other crops for Mg. Dryland rice has the best level of soil Mg for plant growth when about 10% of the CEC is saturated with Mg and the weak-acid-soluble Mg exceeds 50 kg/ ha (Jones et al 1972). For wetland rice, Mg deficiencies are rare but according to the available literature, a deficiency may appear when the Mg concentration drops below 3-4% of the CEC and the pH is below 5.5. When Ca and K dominate the CEC to the exclusion of Mg, the absolute amount of Mg in the soil is less important than the Ca-Mg and K-Mg ratios.

Sources and methods of application

Dolomitic limestone is the most widely used and economical source of Mg for many soil and plant conditions. Where the soil pH is satisfactory for suitable growth and no change in pH is desired, a soluble neutral salt such as $MgSO_4.7H_2O$ (Epsom salt) is broadcast and incorporated into the soil. It can also be dissolved in water (750 liters with 5 kg Mg/ha) and sprayed on foliage. Foliar application may not be effective if the soil pH is below 5.5 (Jones et al 1972). Other Mg materials offered as fertilizers include magnesia (MgO), kieserite ($MgSO_4.H_2O$), langbeinite ($K_2SO_4.2MGSO_4$), and Mg ammonium phosphate ($MgNH_4PO_4.H_2O$). The first and last are slow-release or difficultly soluble salts (Jones 1979).

Magnesium-deficient regions

Kaolinitic soils on the Bangkok Plain and a few soils on the older rice terraces of the northern Thailand valley region have exchangeable Mg levels less than 1 meq/100 g soil. The soils of eastern Khorat (Thailand) are poor in exchangeable Mg (Kawaguchi and Kyuma 1969).

Singh (1967) studied the Mg status of India rice soils and found Mg deficiency in rice on the acid laterite soils of Kerala, the red soils of Mysore, and the red and yellow soils of Tripura. There are several reports on an increase in rice yield from dolomitic lime in Korea, and in Southeast Asia (Table 11). How many of these experiments were on soils low in Mg is not known, but the available knowledge indicates that liming will be necessary on acid sulfate soils, and desirable on some other strongly acid soils.

MANGANESE

Because most wetland rice soils contain adequate levels of available Mn, very few of them respond to additions of Mn, which explains the few reports of Mn deficiency. In rice, Mn deficiency is first characterized by a change in the interveinal leaf color to pale greyish green and later by the appearance of marked brown spots.

Manganese deficiency and Mg deficiency are similar in that interveinal chlorosis of leaves occurs in both. Manganese deficiency, however, first appears on young leaves whereas Mg deficiency first appears on the older leaves. In contrast to the Fe deficiency syndrome, chlorosis caused by Mn deficiency may appear as small yellow spots instead of whole leaf chlorosis.

Concentration in plants

On acid soils high in available Mn, the concentration of Mn in the rice shoot can be more than 6,500 ppm. It can vary from 25 to 2,500 ppm with no apparent abnormalities. In this respect Mn is probably the most variable of the mineral nutrients.

Manganese uptake in rice is influenced by Fe uptake; Mn uptake was low when Fe was high, and vice versa (Jugsujinda and Patrick 1977). Rice plants have a higher requirement for Mn than for iron.

A high Mn concentration in rice tissues is frequently associated with high yields, indicating that high Mn uptake is associated with various favorable soil conditions. However, the total amount of Mn needed by a 10-t/ha rice crop is low — 500-1,000 g.

Critical limits in plants

Values of less than 25 ppm Mn are considered deficiency levels for many crop plants including rice. About 20 ppm in the shoot is considered the lower limit for rice, although the stage of growth, the cultivar, and the environmental conditions may modify this limit (Tanaka and Yoshida 1970).

Forms and transformations in flooded soils

The chemistry of soil Mn is important to the nutrition of wetland rice. Along with the reduction of NO_3 that accompanies O_2 depletion in flooded soil, insoluble oxidized Mn (IV) forms are reduced to the more soluble Mn (II) compounds. An increase in Mn (II) in the soil solution and in the soil colloidal exchange material is one of the first measurable effects of reducing conditions brought about by flooding. Manganese is present in flooded soils as reducible and less active free oxides and as hydroxides, carbonates, and silicates. The solubility of Mn increases with flooding. The release of Mn from insoluble forms, upon flooding, precedes the release of Fe by several days. Transformations of Mn are similar to those of Fe but the degree and intensity of transformation vary because Mn shows a higher redox potential than Fe.

Concentration of manganese in soil

Most soils contain adequate levels of available Mn and the addition of Mn is unnecessary. The total amount of Mn in upland mineral soils is 0.02-1.0%. Manganese deficiency most often appears in rice grown in calcareous peats, which are particularly low in Mn, and in dark-colored sandy soils. In deep, low forest peats from Sumatra and Kalimantan, the total Mn content of the 0- to 25-cm soil layer is 4.1 to 25 kg/ha and that in the 80- to 100-cm layer 1.1 to 7.1 kg/ha (Driessen 1978).

Critical limit in soils

Acid soils, high in Mn and organic matter, build up a high water-soluble Mn (II) concentration within 1 to 2 weeks after submergence but show an equally rapid decline to a stable level of about 10 ppm. Alkaline soils and soils low in active Mn rarely contain more than 10 ppm water-soluble Mn at any stage of submergence. Calcareous and sodic soils contain not more than 0.5 ppm water-soluble Mn. Thus, the concentration of soluble Mn (II) in the soil solution is highly dependent on both pH: and redox potential except at pH values below 5, where pH alone can control solubility. At pH 5.0, almost all the soil Mn is converted from the reducible to the water-soluble plus exchangeable fraction even at a redox potential as high as 500 mV. In sharp contrast, at pH levels between 6 and 8, most conversion took place at the low redox potential of 200-300 mV (Jugsujinda and Patrick 1977).

The critical soil test level for Mn in flooded rice is no more important as a diagnostic tool than a measure of the pH, redox potential, organic matter, and soil texture. When these factors are considered, the critical level of Mn becomes more meaningful. A value of 1.0 ppm Mn soluble in DTPA + $CaCl_2$(pH 7.3) has been found useful as a critical level in rice soils (Randhawa et al 1978).

Sources of fertilizer

Manganese frit, chelate, sulfate, phosphate, and oxide have been offered as fertilizer materials. Basic slag, a byproduct of iron and steel manufacture, contains Mn, probably in the form of manganic oxide, MnO_2. A product containing 40% manganous oxide, MnO, has been offered by manufacturers of ferromanganese metal. Manganese sulfate, $MnSO_4 \cdot 3H_2O$, is the most widely used fertilizer grade. An analysis of 48 samples of fertilizer-grade Mn sulfates shows average contents of 25.1% Mn, 14.5% S, 1.9% Mg, 6.6% Ca, 0.05% Cu, 0.08% Zn, and 0.3% B. Manganese sulfate can be used as a soil amendment or as a foliar spray. It is usually the least expensive of all Mn carriers used for fertilizer. It has been effectively used on rice as a soil amendment, as a foliar spray, and as an aqueous solution for soaking seeds before planting.

Manganese oxide is suggested as an amendment on flooded soils where excess reduction products, Fe (II) or CO_2, limits growth. The concentration of CO_2 will be lowered by the formation of $MnCO_3$, and Fe uptake by plants will be lowered by the partial substitution of Mn for Fe. This suggests a research strategy using Mn as an antidote for Fe toxicity in rice.

Methods of application

Spraying 1-5 kg Mn/ ha sufficiently offsets deficiency in most crops. For rice, less than 1 kg Mn/ ha has been effective as either a seed coating or a foliar spray. A mixture of several micronutrients for tropical peats, which includes 15 kg $MnSO_4 \cdot 3H_2O$/ ha (about 4 kg Mn/ ha), has been suggested as a soil application (Driessen 1978). Where soil Mn test with DTPA is less than 1 ppm and (or) rice shoot at tillering stage is less than 20 ppm, a soil application of 4–10 kg Mn/ ha for peats, mucks, and dark-colored sandy loams and 4-5 kg Mn/ ha for other mineral soils can be used. The lower rate of 4 kg Mn/ ha should be used on peats at pH 5.8-6.4 and the higher rate of 10 kg Mn/ha at pH of 7.3-8.5.

Unless banded, the application of Mn salts to calcareous peat soils is not likely to alleviate deficiency. Generally, for soil application, $MnSO_4 \cdot 3H_2O$ is superior to Mn chelates. Yield increases have been obtained on deficient rice soils by soaking seeds with an 8% solution of $MnSO_4 \cdot 3H_2O$ before planting. Increases also have been obtained by spraying with a 100-ppm Mn solution at 560 liters/ha, which is calculated to be 0.056 kg Mn/ha (Table 12).

Manganese-deficient regions

Liming and combined treatments of liming and MnO_2 increased dry matter yield of IR5 on acid-sulfate soils from Kalimantan, Indonesia (Sudjadi and Mursidi 1972).

Table 12. Effects on yield of treatments for correcting manganese deficiency in wetland rice.

Site	Soil description	Yield (t/ha)		Recommended rate (kg Mn[a])		Remarks
		Without Mn	With Mn	Soil	Foliar	
Tirur, Tamil Nadu, India	Oxisol	3.11	3.77*	–	–	Seed soaking with 8% $MnSO_4.3H_2O$
Lucknow, U.P. India	Sandy loam	1.14	1.96*		0.06	100 ppm Mn in 560 l/ha
Coimbatore, Tamil Nadu, India	Black clay	1.98	2.23*	2.8		11.2 kg/ha $MnSO_4.3H_2O$
Coimbatore, Tamil Nadu, India	Black clay	5.60	6.67*	2.0		10 kg/ha $MnSO_4.4H_2O$
Coimbatore, Tamil Nadu, India	Black clay	5.60	5.82	3.0		10 kg/ha $MnCl_2.2H_2O$
Coimbatore Tamil Nadu, India	Black clay	5.60	6.18*	6.0		10 kg/ha MnO_2

[a] As $MnSO_4.3H_2O$ or MnO containing 65% Mn. Source: Pillai 1967, Mohapatra and Kibe 1972, Vamadevan and Mariakulandai 1972. A single asterisk indicates significant difference at the 5% probability level.

Rice response to Mn at several locations in India (Table 12) has been reported by Vamadevan and Mariakulandai (1972), Pillai (1967), and Mohapatra and Kibe (1972).

COPPER

Copper regulates enzymatic reactions in the rice plant, one of which relates to sterility and the failure of rice to set grain on peat soils. Inhibited phosphorylation in the presence of toxic phenols and Cu deficiency is thought to cause sterility.

Experiments with rice and other cereals clearly show that Cu deficiency decreases grain yield in favor of the formation of vegetative plant material. Although the critical level of Cu in rice grains has not been reported, that in oat grains has been found to be 2.5-3.0 ppm in the dry matter.

Concentration in plant

The Cu concentration in most plants, including rice, is 2-20 ppm in the dry plant material. It is about 10% of the Mn concentration. The uptake of Cu is largely independent and related primarily to the levels of available Cu in soil. Using excised roots from different plant species, Keller and Deuel in 1958 established that Cu displaces most other ions from root-exchange sites and is strongly bound to the outer root membranes. That explains the finding that roots are frequently higher in

Cu than other plant parts.

Critical limit in plant

Because the total Cu concentration in plant material is normally less than 10 ppm, the Cu requirement is also small. The critical deficiency level in mature rice straw is 6 ppm (Tanaka and Yoshida 1970).

Copper and several other elements interact in plant nutrition. An example is the inverse relationship found between Mo and Cu in mature rice straw (Dube 1964).

Forms and transformations in flooded soil

Copper is present in the soil as oxides, carbonates, silicates, and sulfides. In general, soil flooding decreases the available Cu and slightly increases Mo. The chemistry of Cu in flooded soils is similar to that of Zn in that the decreased concentration is caused by the precipitation of hydroxides, carbonates, and organic chelates. all of which are indirectly affected by pH changes. Whatever the mechanism involved. the removal of Cu from soil solutions in flooded soils is so pronounced that Cu is apparently removed from the organic chelating agents that are capable of keeping it in place in dryland soils.

Concentration in soil

In dryland mineral soils, the total amount of Cu present is 5-150 ppm. In deep lowland forest peats of Indonesia, the total Cu concentration in the 0-25 cm depth was 0.8-8.0 ppm and 0.2-0.8 ppm in the 80- to 100-cm depth. Subsoil Cu concentrations are commonly much lower than surface samples, suggesting that Cu is involved in nutrient cycling.

If all the grain and straw in a 5-t rice crop were removed from a hectare of paddy every year, it would take 25 years to remove 1 kg of Cu.

Critical limit in soil

Soil Cu availability to plants depends on soil pH; it is lower in thealkaline range and higher in the acid range. Most Cu deficiencies occur on sandy soils with high pH, or on soils with 5% or higher organic matter. The critical soil-test value for Cu in flooded soils may not be more important as a diagnostic tool than a measure of the pH, organic matter, and soil texture. When the latter factors are considered, the critical level of Cu becomes more meaningful. A value of 0.2 ppm Cu soluble in Diethylene triamine pentaacetate (DTPA) + $CaCl_2$ (pH 7.3) has been found useful as a critical level in rice soils (Randhawa et al 1978).

Sources for fertilizer

Copper frit, chelate, phosphate, sulfate, and oxide have all been suggested as fertilizer materials (Jones 1979). The frit, containing 3-7% Cu, is a very insoluble glassy material that is difficult to dissolve in water but is soluble in weak acids. Copper is included as a component of the lignin sulfonate chelates. Copper ammonium phosphate is another relatively water-insoluble material containing 30%

Cu. Fertilizer-grade $CuSO_4$ is soluble in water and is made up of about 25% Cu, 12.8% S, and 0.55% Zn. Copper oxide has a Cu content of 60-80%, and in field tests it is as effective a source of Cu as $CuSO_4$. Bordeaux mixture, a fungicide consisting of $CuSO_4$, lime., and water used to control *Cercospora* leaf spot and other diseases, also supplies Cu as a plant nutrient.

Low levels of Cu will kill algae. For rice, where blue-green algae growth can contribute 25-50 kg N/ha, the concentration of Cu should be carefully controlled to avoid killing the beneficial algae.

As a herbicide for aquatic weeds $CuSO_4$ is also effective.

Copper-deficient organic soil

The rates of Cu commonly used on rice grown in organic soils are 3-6 kg/ha at 3-year intervals. Where no data are available for tropical peats, the suggested standard application of micronutrients in addition to Cu consists of 15 kg $MgSO_4$ (Cu deficiency frequently occurs along with Mg deficiency, especially on acid sands with 2-5% organic matter), 15 kg $ZnSO_4$, 7 kg $MnSO_4$, 0.5 kg $NaMO_4$, and 0.5 kg borax/ha. Additionally, NPK fertilizer and liming to a pH of 5.0-5.5 with several tons of dolomitic limestone are suggested. Some rice cultivars have been found to be tolerant of the micronutrient deficiencies on tropical peats.

Wetland rice is an attractive crop for peats because it keeps the soil in a reducing condition and minimizes shrinkage and oxidation of the organic material, thus helping to preserve the peat. High rice yields have been obtained on shallow clayey organic soils and on peats that receive an influx of goodquality river water free of salinity. But the majority of tropical peats are deep and low in mineral admixtures and definitely not suited for cultivation of wetland rice.

In Asia, there are 22 million hectares of such land and if sterility of wetland rice on deep peat can be corrected, millions of hectares could be added to the world's rice area. This suggests a research strategy for increasing rice production in Asia.

It might be possible to destroy the Cu-fixing organic compounds by draining the peat for a short time. That should be done at the beginning of the reproductive stage of rice, when Cu deficiency is most pronounced. Copper deficiency usually occurs in peat and acid sulfate soils (Fig. 6) and it also occurs in mineral soils. A summary of response data, by site and soil type, is given in Table 13.

Methods of application

Repeated direct addition of Cu salts to wetland rice soils gives no positive results because of rapid fixation or inactivation of the Cu. Adding Cu in one of the slowly soluble forms, such as frits or Cu ammonium phosphate, in such a way that it remains in contact with roots may be a possibility. Foliar and seed application of Cu are other avenues of approach. Foliar sprays of about 0.5% $CuSO_4 \cdot 5H_2O$ have been successfully used on rice to control deficiencies of Cu on clay soils in India and Bangladesh (Table 13).

Table 13. Effect on yield of treatments for correcting copper deficiency in wetland rice.

Site	Soil description	Yield (t/ha)		Recommended rate (kg Cu[a]/ha)		
		Without Cu	With Cu	Soil	Foliar	Remarks
Varanesi, U.P. India	Clay loam	1.99	2.65		0.28	560 1/ha of 50 ppm Cu
Varanesi, U.P. India	Clay loam	1.60	1.70*	3.3		solution
Ratnagiri, Maharastra, India	Poor soil	1.00	2.00	1.0		Seacoast
Warangal, A.P. India	Poor soil	2.00	2.14	4.0		
Tamil Nadu, India	Peat	Rusty brown	Green	+ cu		25% increase
Indonesia	Peat	Penjabit habing	Normal	12.0		To first crop 1 kg/ha annually
Everglades, South Florida	Peat	Reclam. disease	Normal	12.0		To first crop; afterwards 2 kg/ha annually
Joydebpur, Bangladesh	Clay	3.8	4.2*		0.13%	BR3 variety 80 kg N/ha

[a]Copper as $CuSO_4 \cdot 5\ H_2O$. Sources: Joshi and Joshi 1952, Driessen and Suhardjo 1976, Sharma et al 1968, Primavesi and Primavesi 1970, BRRI 1980. *Significantly different at the 5% probability level.

ZINC

Zinc deficiency symptoms vary with crop age and variety. However, the general symptoms are chlorotic midribs, particularly toward the base, and brown rusty spots that coalesce and appear mostly on the lower leaves (Nene 1966). Plants deficient in Zn are stunted. In acute deficiency, the older leaves dry and the plants usually die. A Zn-deficient field gives a brown rusty appearance, and the rice stand is uneven.

Zinc deficiency symptoms appear in 10- to 30-day-old transplanted rice or 2-10 days after permanent flooding in drilled rice. If the deficiency is not acute, the plants recover, but maturity is delayed by 10-20 days.

Concentration in plants

Analysis of a large number of plant samples by Katyal (l972) indicates that the Zn content of normal rice plants growing on submerged soils seldom exceeds 50 ppm, although higher values have been observed. Zinc concentrations in rice grown on dryland soils, or on wetland soils allowed to dry during the dry season, are consider-

ably higher (Castro 1977). The differences in Zn concentration between dryland and wetland rice plants are more pronounced on acid soils than on neutral and alkaline soils.

The suppression in Zn uptake in submerged soils is possibly induced by a decline in water-soluble Zn, a high solution concentration of HCO_3 and organic acids (Katyal 1972); and reduced Fe, Mn (Kausar et al 1976), and Mg (Katyal and Ponnamperuma 1974). The inverse relationship between Zn and Fe, Mn and Mg is supported by plant analysis. High concentrations of Fe, Mn, and Mg in Zn-deficient plants diminished once the disorder was corrected (Table 14).

Critical limit in rice

The levels of Zn at or below which rice shows deficiency symptoms or gives a significant response have been established by several workers (Table 15). These data reveal that the limit for growing rice is around 15 ppm.

Forms and transformations in flooded soil

Zinc occurs chiefly as the sulfide mineral sphalerite (Krausk off 1972). In soils Zn is predominantly associated with the clay fraction. Zinc exists in limited amounts on exchange sites of clay minerals and organic matter (and complexes), and is adsorbed on the solid surface provided by amorphous oxides of Fe and Al. A minute fraction of the total Zn is present in the soil solution.

Whether judged by plant uptake or by available Zn, soil submergence causes a

Table 14. Effect of zinc application on mineral composition of IR22, 28 days after transplanting.[a]

Treatment	Zn (ppm)	Mn (ppm)	Fe (ppm)	Mg (%)
No Zn	11.2	597	257	0.47
Zn	13.2	472	200	0.35

[a] Source: Katyal 1972.

Table 15. Critical limits of zinc in rice plants.

Plant part	Age	Critical limit (ppm Zn)	Reference
Whole shoot	2 weeks	10	Yoshida and Tanaka (1969)
Leaves	–	15	Sedberry et al (1973)
Leaf blades	–	10	IRRI [1968]
Third leaf	–	10	Krishnamoorthy et al (1971)
Whole shoot	4 weeks	15	Katyal and Ponnamperuma (1974)
Straw	Maturity	25	Katyal (1972)
Leaf blades	–	15	Agarwala and Sharma (1979)
Whole plant	–	15	Soepardi et al (1977)
Whole plant	–	17.4	Kausar et al (1976)
Whole plant	–	18	Chapman and Boundy (1977)

decline in the availability of Zn, which can be related to some unique properties of rice soils.

The pH of flooded soils tends to buffer around neutrality. Thus, the decreased Zn concentration in the floodwater on acid soils may be partly explained by the rise in soil pH, because each unit of pH increase brings down Zn solubility 100 times (Lindsay 1972). On the contrary, the gain in water-soluble Zn resulting from the fall in pH of calcareous and sodic soils is offset by the formation of insoluble ZnS (Katyal 1972). Solubility criteria suggest the occurrence of ZnS in submerged soils. In addition, soils rich in $CaCO_3$ or $MgCO_3$ may adsorb water-soluble Zn and remove it from the soil solution. Other insoluble compounds that are present in the rice paddies are $ZnNH_4PO_4$ and $ZnSiO_3$ (Katyal 1972).

Recently, Sims and Patrick (1978) demonstrated that Zn and other micronutrient cations are complexed by organic matter to a greater extent in reduced soils. They argued that the fall in water-soluble Zn is related to this phenomenon.

Concentration in soil

Mikkelsen and Kuo (1977) summarized the data related to total Zn in several rice soils. They concluded that the total Zn in rice soils is in about the same range as that reported for dryland soils. However, total soil Zn has limited value because it has been insignificantly related to rice growth and yield (Katyal 1972).

Critical limit in soil

The critical limits of available Zn have been established to differentiate deficient soils from nondeficient ones. A perusal of the data in Table 16 reveals that critical limits are variable even if the extractant is unchanged. These data further point out the lack of a single satisfactory extractant for determining available Zn in rice soils.

Because of the sensitivity of Zn availability determination in submerged soils, the

Table 16. Critical limits of zinc in rice soils.

Extractant	Critical limit (ppm Zn)	Reference
0.005M diethylenetriarnine	1.4	Friaz et al (1974)
pentaacetic acid + 0.1M	0.7	Cox and Wear (1977)
triethanolemine + $CaCl_2$	0.5	Mikkelsen and grandon (1975)
(pH 7.3)		
(Lindsay and Norvell 1969)		
Dithizone + N NH_4OAc (pH 7.0)	0.75	Randhawa and Takkar (1975)
(Shaw and Dean 1952)		
0.1 N MCI	1.2	Sedberry et al (1971)
(Wear and Sommer 1948)	1.8	Cox and Wear (1977)
0.05 N HCI	1.0	Katyal and Ponnamperuma (1974)
(Katyal and Ponnamperuma 1974)		
0.01M EDTA + M $(NH_4)_2CO_3$	1.5	IRRl (1970)
(pH 8.6)	1.5	Katyal and Ponnamperuma (1974)
(Trierweiler and Lindsay 1969)	1.8	Randhawa and Takkar (1975)
0.05 N HCI + 0.025N H_2SO_4	1.4	Cox and Wear (1977)

wisdom of analyzing air-dry soils is debatable. To settle this question, Tiller et al (1979) recommended preincubation of flooded soil samples for 1 week before their extraction. However, Sedberry et al (1979) could not confirm the superiority of analyzing preflooded soils. Despite the conflicting results, it appears that the influence of flooding merits attention in the calibration of an extractant for wetland soils.

Sources for fertilizer

A number of inorganic compounds, synthetic chelates, natural organic complexes, and glass frits have been used as Zn carriers (Jones 1979). Among these, Zn sulfate is by far the most commonly used. Zinc oxide is also frequently used. Regardless of their solubility, the performance of inorganic Zn carriers has been more or less alike (Sedberry et al 1971, Yoshida et al 1973, Giordano 1977). But the soil-applied synthetic chelates, whether measured by plant uptake or by yield (Westfall et al 1971, Mikkelsen and Brandon 1975, Giordano 1977), are inferior to inorganic Zn sources, probably because of the chelates' instability in reduced soils (Reddy and Patrick 1977).

Methods and levels of application

The rate of Zn application to soil depends upon soil characteristics, source of Zn, method of application, and severity of Zn deficiency. Data from several greenhouse and field experiments indicate that the optimum level of Zn added before sowing or transplanting varies between 8 and 100 kg Zn/ha (Table 17). Nonetheless, 10 kg Zn/ha was adequate in most of the situations.

Zinc carriers can be incorporated with the soil or added to the soil surface without incorporation but surface-applied Zn without incorporation is two to three times more efficient.

Table 17. Response of rice to applied zinc.

Country	Soil characteristics	Optimum level	Response (t/ha)	Reference
India	Saline alkali, pH 10.6	10 kg Zn/ha	1.0	Abrol et al (1972)
	Aquic Camborthids	11.2 kg Zn/ha	1.4	Takkar and Singh (1978)
	Calcareous red soil, pH 7.5	10 kg Zn/ha	1.8	Krishnamoorthy et al (1971)
Pakistan	Calcareous	100 kg Zn/ha	2.6	Yoshida et al (1970)
Philippines	Calcareous	50 kg Zn/ha	4.8	Yoshida et al (1973)
	Hydrosols	Root dipping in 2% ZnO	4.4	Katyal and Ponnamperuma (1974)
Thailand	–	15 kg Zn/ha	0.4	Snitwongse (1975)
United States	Norman clay	9 kg Zn/ha	7.0	Mikkelsen and Brandon (1975)
	Crowley silt loam	27 kg Zn/ha	0.7	Cox and Wear (1977)
	Crowley silt loam	8 kg Zn/ha	2.4	Sedberry et al (1971)

Crop recovery of Zn during the first year seldom exceeds 10% of the total applied. Thus, one application is expected to suffice for several seasons.

Dipping roots of seedlings in 2-4% ZnO mixed with enough water to treat the seedlings to plant 1 ha is almost equal to an application of 20 kg Zn/ha. Coating of rice seeds with Zn fertilizers (Castro 1977), soaking of the seeds in Zn sulfate solution (Singh 1970), and enrichment of the seedlings by applying Zn to the nursery (Yoshida et al 1970) have all been successful.

When Zn deficiency is discovered in a growing crop, foliar applications of soluble Zn salts, including chelates, are effective (Nene 1966, 1968; Yoshida et al 1970).

Varieties tolerant of zinc deficiency

Varietal differences, determined on the basis of either yield or ability to absorb Zn, have been reported (Katyal and Ponnamperuma 1974). Cultivating tolerant varieties and draining the paddy are management methods of controlling Zn deficiency that offer opportunity for future research strategy. However, tolerant varieties usually do better when treated with Zn, and drainage is not often desirable because of benefits to be expected from flooding.

Zinc-deficient regions

Since Zn deficiency was reported by Nene in 1966, more and more rice lands suffering from it have been identified. Perhaps, it is the most widespread micronutrient disorder in all the rice-growing regions of the world (Table 18). In India alone it is suspected to adversely influence 8 million hectares of rice.

Widespread Zn deficiency has been closely related to near neutral or alkaline soil pH (Table 18).

Land leveling may lead to Zn deficiency through the removal of the top soil and exposure of the Zn-deficient subsoil.

Response to zinc application

Response to applied Zn varies with the severity of the deficiency and environmental variables (Table 17). Nonetheless a greater increase in yield is brought about by Zn application on permanently wet soils, sodic soils, and calcareous soils.

IRON

Iron deficiency symptoms appear first in the new leaves because of the relative immobility of Fe from older to younger leaves. The typical symptoms are chlorosis or yellowing of younger leaves, followed by complete loss of chlorophyll and necrosis. If the deficiency is severe, the entire plant becomes chlorotic and dies. Iron deficiency occurs in irregular patches in the field. Green and chlorotic hills often grow side by side (Katyal and Sharma 1980).

Concentration in plant

Unlike with many other essential plant nutrients, the diagnosis of Fe deficiency by

Table 18. Regions of zinc deficiency.

Site	Soil characteristics	Criteria	Local name of zinc disorder	Reference
India	pH 8.3 Saline alkali Diverse soil types	Response	Khaira	Nene (1966, 1972) Abrol et al (1972) Katyal and Sharrna (1979)
Pakistan	Calcareous pH 7.9-8.6	Deficiency symptoms	Hadda	Yoshida and Tanaka (1969) Tanaka and Yoshida (1970)
Philippines	Calcareous pH 6.9-8.2 Hydrosols	Response, deficiency symptoms	Taya-taya Apaya-Pula, Pupong	Tanaka and Yoshida (1970) Yoshida et al (1973) IRRI (1970) Katyal and Ponnam-peruma (1974)
Taiwan	pH 7.6	Response	Suffocating disease	Yoshida et al (1973)
Japan	pH 6.5-8.1	Response	Akagare-II	Tanaka et al (1969)
Korea	–	Response	–	Ahn (1973)
USA	pH 7.5-8.5	Response	Akagare-II Alkali disease	Giordano (1977) Westfall et al (1971) Mikkelsen and Brandon (1975)
Brazil	Dark-red Latosols, hydromorphic	Response	–	Malavolta and Neptune (1974)
Egypt	–	Response	–	Elgabaly (1978)
Indonesia	High pH, high organic matter	Response	–	Soepardi et al (1977)

plant Fe concentration has not been successful. Several workers (Katyal and Sharma 1980) obtained higher Fe values for chlorotic plants than for healthy green ones.

Studies that followed an earlier suggestion that plants be analyzed for active Fe (Oserkowsky 1933) instead of total Fe gave conflicting results. Similarly, diagnosis of Fe chlorosis by determining certain nutrient ratios has not found universal acceptance. Use of enzyme activities as a yardstick for distinguishing Fe deficiency in plants (Del Rio et al 1978) is impractical for routine analysis. Because of the indispensable role of Fe (II)-iron in the biosynthesis of chlorophyll and its susceptibility during deficiency to transformation into less active Fe (III), the plant analysis for Fe (II)-iron appears more tenable. Green plants contain more Fe (II) and less total Fe than chlorotic plants (Table 19).

Table 19. Iron concentration in rice plants determined by 2 methods.[a]

Site no.	Total iron (ppm)		o-phenanthroline (ppm Fe [II])	
	Green	Chlorotic	Green	Chlorotic
1	135	260	51	27
2	170	200	55	29
3	140	220	53	29
4	130	270	50	34
5	160	260	52	30

[a] Source: Katyal and Sharma 1980.

In light of the results of Katyal and Sharma (1980) and several other workers, the use of a critical limit of 50 ppm total Fe for rice (Tanaka and Yoshida 1970) is debatable.

Forms and transformations in flooded soils

Iron in soils occurs as primary and secondary minerals, hydrated oxides, and their organic and inorganic derivatives. The aerobic-anaerobic cycles in rice soils have a pronounced effect on the weathering of ferromagnesian minerals (Kawaguchi et al 1957) and on degradation and formation of Fe-containing secondary minerals (Brinkman 1970).

In wetland soils, hydrated magnetite and some hydrotroilite make up the largest proportion of the reduced Fe. Other Fe compounds specific to rice soils are siderite, vivianite, lepidocrocite, and jarosite (Ito 1975).

Based upon its abundance, Fe dominantly regulates the chemistry of rice soils (Patrick and Reddy 1978). According to Ponnamperuma (1972), the most significant change that happens in submerged soils is the reduction of Fe (III) to Fe (II). Consequently, the concentration of water-soluble Fe (II), which is negligible in upland soils, increases in flooded rice soils. Thus, wetland rice suffers from Fe deficiency less frequently than dryland rice.

High levels of readily decomposable organic matter, either native or added, hasten the fall in Eh, and thus, favor the early buildup of Fe (II)-iron in flooded soils. On the contrary, low temperatures and the presence of the large amounts of NO_3, and MnO_2 slow soil reduction and hence delay the release of Fe (II) (Yamane 1958, IRRI [1963]).

While Eh regulates mobilization of insoluble Fe to soluble Fe (II), the pH controls its concentration in the soil solutions, as shown by the following equation:

$$pH = 0.5\ pFe\ (II) - 5.4$$

This relationship shows that with each unit rise in pH, the solubility of Fe (II) falls 100 times. At pH 6.5 a submerged soil may contain excessive water-soluble Fe, whereas at pH 8.0, the Fe concentration may be so low that rice suffers from Fe deficiency. This conforms to the often-observed occurrence of Fe deficiency, despite

submergence, in alkaline soils (Place and Adams 1966, Tanaka and Yoshida 1970, Westfall et al 1971).

Critical soil-iron solution concentration

Ishizuka et al (1961) reported that in nutrient culture, 0.1 ppm Fe was enough for the healthy growth of rice. Recently, Agarwala and Sharma (1979) indicated that rice in soil with 2.0 ppm Fe or less, developed visible symptoms of Fe deficiency. However, they observed severe chlorosis even in soils with 5 ppm Fe if the source of N was NO;. Katyal(1977) reported Fe deficiency symptoms in rice growing on calcareous soils with about 2 ppm Fe (II) in soil solution. Thus, it appears that occurrence of Fe deficiency symptoms may depend on such factors as pH and redox potential associated with Fe uptake rather than with a critical concentration of water-soluble Fe (II) alone.

Sources

Sources of Fe include inorganic Fe salts, naturally occurring Fe compounds, natural and synthetic chelates, and Fe frits. Among the inorganic sources tested so far, ferric sulfate has excelled others in increasing rice yields; for soil application, the natural and synthetic chelates have been less effective than inorganic Fe sources (Westfall et al 1971).

Methods and levels of application

In soil application, an Fe source is broadcast and the soil is harrowed lightly. Foliar applications of Fe are made as soon as symptoms are visible, and are repeated until the symptoms disappear, usually in about 2 weeks. Cold weather, high alkalinity, and calcareous soil accelerate Fe deficiency. The net effect is a substantial increase in the optimum level of Fe application. Thus, a recommendation for one general optimum level is difficult.

Workers from California suggested applications of ferric sulfate ranging from 12.5 to 100 kg Fe/ha to correct chlorosis of wetland rice. The most successful application rate in Texas was 100 kg Fe/ ha (Westfall et al 1971). The level reported in Arkansas by Place and Adams (1966) varied between 25 and 50 kg Fe/ ha. Despite such high rates of ferric sulfate, they were able to check chlorosis in only 6 out of I5 experimental sites. Subsequent Arkansas research by Wells et al (1973) suggested that the rice response to high rates of ferric sulfate resulted from soil acidity generated by it or from Zn impurities in the Fe salt.

Foliar application of soluble Fe salts or chelates can save on cost. A 0.l-0.5% aqueous solution of Fe sulfate or Fe citrate is suggested for foliar sprays. Foliar applications of Fe do as well or better than soil application.

The major cause of Fe deficiency is high pH. Physiologically acid fertilizers such as ammonium sulfate and ammonium phosphate sulfate (16-20-0) may reduce the Fe deficiency problem. The addition of quickly decomposing organic manures (especially green manure), which achieve an early decrease in pH and an accompanying increase in Fe availability in lowland soils (Katyal 1977), is an expensive and

effective way to control Fe deficiency.

The vulnerability of lowland rice to Fe deficiency may be attributed to the roots' oxidizing capacity, which is inversely related to Fe uptake (Armstrong 1971, Yoon et al 1975). Rice varieties may differ in the intensity of oxidation of their root rhizosphere and, thus, in susceptibility to Fe stress. Genetic control of Fe nutrition (and other nutrients) is well established (Brown et al 1972). Isolation of crop varieties tolerant of Fe deficiency and their adoption on Fe problem soils will make rice cultivation more economical.

Regions of deficiency

The following soil conditions adversely influence Fe nutrition and favor Fe deficiency:

- Calcareous soils: High pH and exchangeable Ca are closely correlated with the occurrence of chlorosis (IRRI [1968], Tanaka and Yoshida 1970).
- Alkali soils: High HCO_3 interferes with iron uptake and thus promotes Fe deficiency (Westfall et al 1971).
- Organic matter contents of soils: Low organic matter retards soil reduction and results in poor availability of Fe (IRRI [1963]).
- Texture: Sandy soils that are exceptionally well drained internally remain oxidized and therefore, decrease availability of Fe.
- Nutrient interactions: High pH and anaerobicconditions favor Mn uptake (van der Vorm and van Diest 1979), aggravating Fe deficiency. High water-soluble silica, nitrate, and available P also antagonize Fe uptake by rice.

SILICON

Several scientists consider Si essential for rice-growing because yield increase that cannot be explained otherwise is attributed to it.

Silica concentration in rice varies with the availability of soil Si, N in the growth media, and plant age, and varies among the plant parts. Yoshida (1975c) reported that Si (SiO_2) concentration ranges from 4 to 20% in straw and from 2 to 15% in different plant parts at maturity.

Imaizumi and Yoshida (1958) reported maximum grain yield when straw SiO_2 concentration was 13%. However, the Si-N ratio in the plant was an additional criterion for plant diagnosis of rice nutrition. A yield of more than 10 t/ha was produced when whole aerial parts of the rice crop had a SiO_2-N ratio of 11.2.

Forms and transformations in flooded soil

From 60 to 80% of soil SiO_2 occur as constituents of insoluble quartz and alumino-silicate minerals, which are not available to plants. The accessibility of Si to plants depends largely on how rapidly weathering takes place, bringing Si into soil solution. The form of Si available to rice roots is monosilicic acid $Si(OH)_4$. The common method to determine available Si consists of extracting 1 part dry soil with 10 parts by volume of 1 N NaOAC buffer (pH 4.0) solution for 5 hours at 40° C or for 90 minutes at 60°C. The available Si, thus determined, increases with soil pH and

Table 20. Positive correlation coefficients[a] of available SiO_2 and total carbon with other soil analysis data in paddy soils of tropical Asia (adapted from Kawaguchi and Kyuma 1974).

Standard component	pH	Exchangeable cation			CEC	Clay (%)	14A° clay (%)	Total	Total PN	NH_4-N
		Ca	Mg	K						
Available SiO_2	0.625	0.701	0.527	0.514	0.718	0.470	0.527	0.415	–	0.222
Total carbon	–	–	–	–	0.233	0.313	–	0.292	0.958	0.514

[a] Correlation coefficients of less than + 0.200 are omitted.

temperature, and decreases with Eh.

The concentration of Si in solutions of wetland soils increases slightly after flooding and then gradually decreases. It is lower after several months of submergence than at the start. Available Si is positively correlated with pH, exchangeable Ca, Mg, K, CEC, percentage of 14A° clay, and soil P (Table 20). Kawaguchi and Kyuma (1977) reported that available Si was also correlated with Mn_2O_3 and MnO_2.

Critical limit in soil

Park (1970) reported that the critical limit of available Si in air-dry soil for maximum grain yield of wetland rice was 130 ppm SiO_2, with additions of about 100 kg N/ ha. Kono (1969) found the critical limit to be higher under increased N supply from either soil or fertilizer. Park (1977) suggested a critical limit in terms of the ratio of available SiO_2 to organic matter in soil, the optimum being about 100.

Source

The soil is a good source of available Si. Deep plowing to turn up a large quantity of fresh soil sometimes helps increase available Si in soil. Slags produced by the steel industry are common sources of silicate fertilizer. Ground basic slags usually contain variable amounts of Ca, Mg, Mn, and Si, as well as AI and Fe. Wollastonite, an almost pure Ca-Mg silicate, is known as an excellent quality silicate fertilizer. Both silicate fertilizers have dual effects. They serve as a source of available Si and as a liming material in acid soils.

Silica-organic matter relationship

The rate of application of silicate fertilizer generally recommended for a deficient area is 2 t/ha. However, the need must be decided upon by the available SiO_2-organic matter ratio. If the ratio is less than 100, Si must be added; if more than 100, organic matter must be added. The silicate fertilizer requirement to maintain the desired level G of available Si in top soil can be estimated from the equation:

$$Y = 0.00384\ (G - X)\ D$$

where Y is the silicate fertilizer requirement in tons per hectare; G is the desired level of available SiO_2 in soil in parts per million; Z is the available SiO_2 in parts per

million; and *D* is the depth of the topsoil, in centimeters.

However, the critical SiO_2 organic matter content (Park 1977) may be more helpful for practical recommendations when the supply of fertilizer N is limited.

Methods of application

Silicate fertilizers are commonly recommended for basal application, but top dressing at panicle initiation gives the same effect in grain yield increase. Topdressing silicate is difficult but it controls the release of N to rice at a critical time. It increases pH, encourages the volatilization of ammonia and increases the mineralization of organic matter. Interrupting N uptake soon after panicle initiation is considered desirable.

Silicon-deficient regions

Low Si uptake by the plants commonly reduces grain yield in high rice-yielding regions where farmers have been using large amounts of chemical fertilizer for a long time. In regions where fertilizer use limits yield and crop residues are burned in the field, the soil is rich in available Si but low in organic matter. Such soils show a relatively high SiO_2-organic matter ratio, but do not usually respond to Si, Those soils where the Si&-organic matter ratio is less than 50 and a high rate of fertilizer is used suffer from Si shortage. On them a response to Si is expected and large amounts of silicate fertilizer are used every year (Table 21).

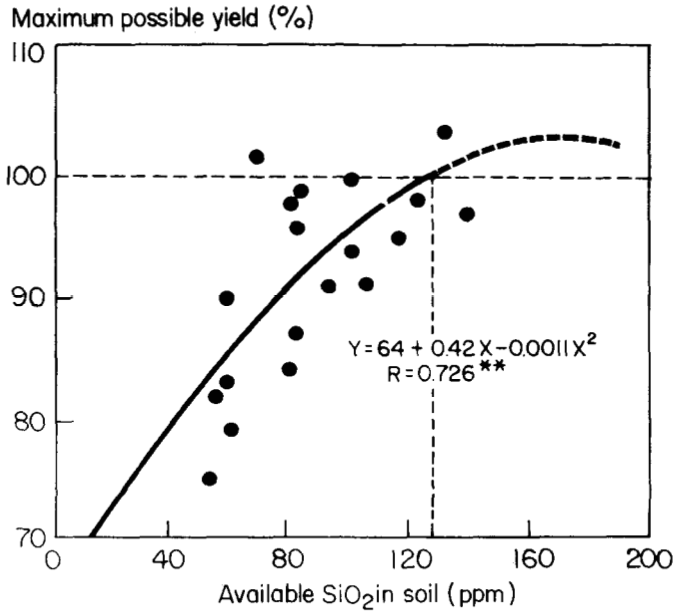
Table 21. Average available SiO_2 and organic matter (O.M.) content, and their ratio in Asian countries (adapted from Kawaguchi and Kyuma 1977).

Countries	Sample size	Available SiO_2 (ppm)	O.M.[a] (%)	SiO_2-O.M. ratio
Tropical Asia	410	270	2.44	111
Bangladesh	53	129	2.04	63
Burma	16	221	2.10	105
Cambodia	16	113	1.89	60
India	73	347	2.40	145
Indonesia	44	629	2.40	2 62
W. Malaysia	41	104	5.81	18
Philippines	54	454	2.87	158
Sri Lanka	33	216	2.44	89
Thailand	80	122	1.82	69
Mediterranean countries	80	239	3.15	76
North East Asia	449	122	3.17	38
Japan	84	195	5.76	34
Korea[b]	365	78	2.60	30

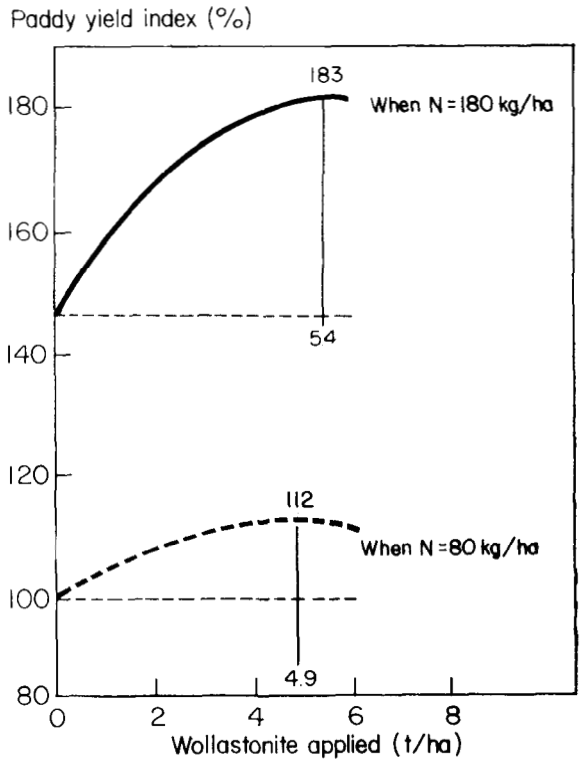
[a] Calculated from T-C × 1.73. [b] Supplemented by C. S. Park.

Summary of response data

A highly significant positive correlation coefficient of 0.726 was obtained between available soil SiO_2 in Korean paddy topsoil and rice yield (Fig. 7). In a greenhouse study on a sandy soil with 29 ppm available SiO_2, rice responded to Wollastonite at



7. Relation between available silica and percentage of maximum possible yield (Park 1970).



8. Effect of Wollastonite ($Ca \cdot Mg \cdot SiO_2$) on paddy yield with 2 rates of nitrogen. (Available soil silicon = 14 ppm.)

rates of 5 t/ha. At 80 kg N/ha, yield increased by 12% with the application of Wollastonite at 4.9 t/ha; at 180 kg N/ha it increased by 36% with the application of Wollastoniteat 5.4 t/ha (Fig. 8). Summarizing the data from 8 Korean provinces on 21 different soil series, Park (1970) concluded that about 9% yield increase can be expected by maintaining the available soil SiO_2 concentration at 130 ppm.

BORON, CHLORINE, AND MOLYBDENUM

Although B, Cl, and Mo are essential elements for rice, their concentrations in soil and plant are more often excessive than deficient. All three are sometimes found in excessive amounts in irrigation water. Such plant-soil-water related problems are discussed elsewhere in these proceedings. Excessive Mo is thought to be a Mo-induced Cu deficiency.

Rice does well with as little as 0.1 ppm Mo and 3.0 ppm B in straw at maturity. Chlorine deficiency in rice has not been recorded. A recent review of research in the rice-growing areas of the Southeastern United States revealed no reports of B or Mo deficiency (Jones 1979). Only one scientific report of B deficiency in rice is known in Asia. Lucas and Kuezek (1972) reported no significant response of rice to Band Mo even though soil and environmental conditions favored their deficiency.

FUTURE RESEARCH NEEDS

Fundamental research on the mechanisms of soil fertility and plant nutrition in wetland soils is badly needed. In particular, the activity of nutrients at the soil-root interface in the anaerobic soil layer needs study. Such research would shed light on mechanisms of interest as regards deficiencies, as well as mechanisms of interest as regards uptake of excessive amounts of elements such as Al, B, and Cl.

One research strategy that can be productive has the objective to reduce the amount of nutrient needed by selecting breeding lines that are tolerant of low levels of nutrient, but still capable of high yields.

Another general research strategy applicable to all nutrients is the close correlation between fertilizer rate, irrigation percentage, and mean national productivity of rice. Adequate irrigation is a basic prerequisite for the full exploitation of modern rice production practices in Asia, including the practice of optimum nutrient fertilization.

Other proposed research needs are presented, element by element.

Phosphorus

Research is needed on the application of copious amounts of water-soluble ammonium phosphate on the seedbed, encouraging luxury consumption of P in the seedling stage, and thus later transplanting the seedling containing a high enough concentration of P to support it to maturity.

Sulfur

The most obvious gap in S research in Asia is the paucity of data on the concentra-

tion of S in air and precipitation. Research is needed to determine the impact of atmospheric S deposition on wetland rice. Research is also needed to correlate a soil test for S that takes into account reduced sulfate-sulfur in flooded mineral soils. On organic low-Fe soils, research on modifying the sequential reduction system to eliminate H_2S toxicity is needed.

pH and lime

The effectiveness of lime to improve acid peats and acid sulfate soils (sulfaquepts) depends on the prevention of deep drainage during the dry season. Research is needed on how best to maintain the water table above the pyritic subsoil, preventing prolonged drying of the surface soil, so that the pH that controls all other adverse factors could be economically kept in a safe range by liming.

Iron

Because of the essentiality of Fe (II) in the biosynthesis of chlorophyll and because of its susceptibility, during deficiency, to be transformed to less active Fe (III), the plant analysis of Fe (II) should be evaluated as a tool for diagnoses. Green plants contain more Fe (II) and less total Fe than chlorotic plants.

Manganese and iron

The release of Mn from insoluble forms, upon flooding, precedes the release of Fe by several days. Transformations of Mn are similar to those of Fe in flooded soils but the degree and intensity of transformation vary because the Mn system has a higher redox potential than Fe. Thus, a research strategy is suggested with the double objective to reduce Fe toxicity in Sulfaquepts and other acid soils by the addition of lime to control pH and the addition of Mn to act as an antidote for Fe in the plant.

Copper

On peat, wetland rice sometimes fails to set grain, apparently because of phenol toxicity and copper deficiency. The sterility is similar to that in blast. This suggests a research strategy involving the interaction of disease control with soil fertility and water control. Does copper sulfate, which not only supplies the nutrients Cu and S but also is a well-known pesticide and herbicide (for aquatic weeds), act as a plant nutrient, a fungicide, an aquatic herbicide or all three in controlling *peat reclamation* disease of rice?

Zinc

Draining the paddy and cultivating tolerant varieties are management methods that will help in controlling Zn deficiency. However, tolerant varieties generally do better when treated with Zn and drainage is not often possible or desirable because of benefits to be expected from continuous flooding. Therefore the addition of Zn appears to be the most practical control of Zn deficiency. Soil tests designed to predict likely areas of Zn deficiency before it occurs is a suggested research strategy for the future. A comprehensive survey of the amount of available Zn in Southeast

Asian soils is suggested.

Silicon

Low silicon in rice reduces yields in some areas. An optimum SiO_2-organic matter ratio in soils is about 100. A suggested research strategy is to determine how best to add SiO_2 or organic matter to maintain an optimum SiO_2-organic matter ratio for rice.

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RICE-BASED PRODUCTION SYSTEMS

RESEARCH STRATEGY FOR RICE-BASED CROPPING SYSTEMS

A. A. GOMEZ and H. G. ZANDSTRA

Rice culture can be grouped into different categories depending upon the water regime under which it is grown, — dryland, lowland, or deepwater rice — and the zone of its culture — tropical or temperate. In suggesting a research strategy, we place primary emphasis on the tropics and on wetland rice. Wetland rice culture (irrigated and rainfed) covers about 82% of the 83.4 million hectares grown to rice in Asia (Barker and Herdt 1979).

There are important reasons for emphasizing wetland rice. First, by excluding dryland and deepwater rice, variability in water regime, the most important crop ping pattern determinant, is greatly reduced without much reduction in rice crop covered (only 17% less). Second, among the three types of rice culture, wetland rice has received the most research attention, and there is a substantial body of information for developing and evaluating alternative strategies for future research. Third, wetland rice areas in Asia are generally located in the most densely populated areas that have good roads and access to markets. In such areas the potential for more intensive land use is bright.

We describe the characteristics of rice-based cropping systems on rice farms in South and Southeast Asia and the ways cropping systems research develops production technologies to fit those farms. We identify four types of cropping systems research: technology generation, adaptive research, technology verification, and environmental classification. Finally, we formulate a research strategy that emphasizes the need for technology verification and adaptive research in the national programs, and for technology generation and environmental classification for the international centers.

RICE-BASED CROPPING SYSTEMS

Rice farms in South and Southeast Asia vary substantially. In the cropping systems network sites, average farm size varies from less than 0.5 ha to more than 6 ha, with rice yields that range from 0.6 to more than 3 t/ha per crop. Some areas depend on

Professor in Agronomy, University of the Philippines at Los Baños, Philippines; and head, Cropping Systems Program, IRRI.

manual labor for land preparation and some areas have all plowing and harrowing done by 4–wheel tractors. At some sites farmers cannot grow a single rice crop in all years, whereas at other sites farmers grow three crops in sequence each year or practice complex intercropping and relay-cropping techniques. Examples of sequential cropping patterns are: rice - fallow, maize - rice, rice - mungbeans, rice - wheat, rice - vegetables, rice - wheat - maizete, and rice - rice (Table 1).

Table 1. Existing and potential cropping patterns for rainfed wetland ria, in some parts of Asia.

Location	Rainfall pattern[a]			Cropping pattern[b]		Source
	Total (mm)	Wet months (no.)	Dry months (no.)	Existing	Potential	
Iloilo, Philippines	2057	5-6	5-6	F-R-F F-R-UC	R-R-F R-R-UC	Magbanua et al (1978)
Khon Kaen, Thailand	1124	1-2	6-7	F-UC-F F-R-UC	UC-R-F R-R-F	KKU-Ford Foundation Cropping Systems Project (1976)
WestJava, Indonesia	2310	5-7	3-5	F-R-F R-R-UC	R-R-F R-R-UC R-R-R	Sjahri (1975)

[a] Wet months are those with rainfall exceeding 200 mm. Dry months are those with rainfall below 100 mm. [b] F for fallow, R for rice, and UC for upland crop.

Some farmers till only one land type, but most farmers in rainfed sites manage two or three land types of completely different qualities. They naturally use different cropping patterns on these and may satisfy different needs — food, cash, or fodder — in their crop production on different land types. Farmers prefer patterns that demand few purchased inputs and use low inputs where no credit and retail system is developed, where there is no access to markets, where crops have low yield potential or value product, and where crops are on land that do not respond to increased use of purchased inputs. It appears false that high-input production systems are confined to irrigated land (Antonio and Banta 1974), but large or unpredictable yield fluctuations will deter farmers from investing much cash in any crop.

Our research experience at several sites has shown that crop intensification is made possible by the following mechanisms:

1. Early-maturing varieties allow farmers to gain as much as 45 days in a growing season for additional crop production (Table 2).
2. A rice crop established early by direct seeding can be harvested 15-30 days earlier than transplanted rice crops. Direct seeding is not expected to reduce grain yield (Table 3).
3. The use of older rice seedlings (up to 35-40 days) can reduce the field time of rice to only 75 days.

Table 2. Relative yields and maturity of early–maturing, recommended and traditional varieties of 4 annual crops.

Species	Maturity (days to harvest)	Yield t/ha/crop	Yield kg/ha per day
	Rice[a]		
Traditional	126	–	–
Recommended	110	6.80	62
Early maturing	90	5.40	60
	Corn[b]		
Traditional	95	3.77	40
Recommended	98	4.87	50
Early maturing	74	3.53	48
	Sorghum[c]		
Traditional	105	4.10	39
Recommended	110	4.46	41
Early maturing	81	3.16	39

[a] Yields are from 1978 replicated trials at IRRI. [b] Three trials (IRRI 1975, lRRl 1976, Carangal et al 1977). [c] Seven trials (Gomez 1970).

Table 3. Grain yield of rice under 3 methods of seedling establishment. Manaoag and Iloilo, Philippines, 1977. (Int. Res. Team 1978, Gines et al 1978).

Seedling establishment	Farms (no.)	Av yield (t/ha)
Dry seeded	62	4.6
Wet seeded	41	4.8
Transplanted	35	4.3

Table 4. Relative productivity of some upland crops grown under zero and high tillage in rice paddies.

Tillage level	Farms (no.)	Yield (kg/ha)	Net return ($/ha)
	Cowpea		
High tillage	5	815	44
Zero tillage	5	1033	227
	Mungbean		
High tillage	2	255	9
Zero tillage	13	260	83
	Soybean		
High tillage	5	565	a
Zero tillage	2	342	9

4. Residual soil moisture after wetland-rice culture often produces a short-duration well-rooted upland crop, if care is taken to reduce water loss from the soil surface during land preparation and the early vegetative stage of the upland crop (Table 4).

Table 5. Relative yield of rice as a monocrop and as an intercrop with corn (IRRI 1974, 1975).

Test factor	Treatments (no.)	Monocrop yield (t/ha)		Intercrop yield (LER[a])	
		Rice	Corn	Av	Range
Spacing	13	3.6	5.1	1.1	0.9 -1.5
Nitrogen	4	1.38	6.8	1.37	1.33-1.46
Variety × nitrogen	36	3.0	4.6	1.18	0.98-1.52

[a]Land equivalent ratio is an index that compares the efficiency of land use of the intercrop relative to the monocrop. Thus an LER of 1.0 indicates no gain due to intercropping while a value of more than 1.0 means intercropping is more efficient than the monocrop.

5. Intercropping and relay cropping effectively increase dryland productivity by structuring the canopies, which are more efficient than those of sequential sole crops, over the length of the growing season (Table 5).

RESEARCH STRATEGY

The main purpose of developing a strategy is to maximize the efficiency with which a given objective can be accomplished. We divide this section into five topics: I) the objective, 2) the efficiency measure, 3) the research activities, 4) the impact on productivity, and 5) the strategy.

Research objective

The ultimate objective of cropping systems research is to develop new cropping technology that will result in an increase in farm productivity. Although there are several measures of productivity, for the purpose of research strategy development, productivity is defined simply as the yearly output of physical product per unit area ofcultivated land. Thus, the total increment in farm production due to the adoption of a new technology over a given farm area can be defined as:

$$DP = A\ (N - C) \tag{1}$$

where DP = total change in production over all farms, A = area (ha) using the new technology, N = yield in tons per hectare of the new technology, and C = yield in tons per hectare of the current farmer's practice.

Efficiency measure

The efficiency of a research strategy can be defined as the change in productivity resulting from the use of an additional unit of the most limiting research resource. Since we have already defined change in productivity (equation 1), all that is needed is to identify the most limiting resource for conducting research in cropping systems. The three alternatives are manpower, money, and time. All three, however, are related because research that requires more time usually also requires more money and manpower. While the proportionality among these three measures is usually not

perfect, for strategy development, we designate time as the primary index of the most limiting research resource. T_1 is the time lapse from the initiation of research to the development of a technology and T_2 is the time lapse from the initiation of research to the time the developed technology is used in actual farms. On the basis of T_1 and T_2, we can define two measures of efficiency:

$$E_1 = \frac{\Delta P}{T_1}, \text{ and} \tag{2}$$

$$E_2 = \frac{\Delta P}{T_2} \tag{3}$$

where E_1 and E_2 are the two measures of efficiency, ΔP is as defined in equation 1, and T_1 and T_2 are as defined above.

Research activities

To develop a research strategy for rice-based cropping systems, we arbitrarily divide the total research activity into four aspects: 1) generation of new component technologies, 2) incorporation of newly developed component technologies into the physical and socioeconomic resource structure of the farm (adaptive research), 3) verification of the applicability of the newly developed technology, and 4) environmental classification based on crop performance.

Generation of component technology. These experiments are designed to maximize biological yield and to devise economically feasible management techniques that approach the maximum. Procedures for achieving this objective are many and diverse, but they share some common features:

a) The production technique is usually broken into specialized components that are studied separately; hence, the term component technology (Zandstra 1979). For example, the soil problems are isolated and studied by a soilsman, the pest problems by an entomologist, or the seed improvement problems by a plant breeder.
b) Many different speculative techniques are tried and while many are expected to fail, a few exceptionally productive ones may be identified.
c) The experiment usually requires good control and close supervision by the senior scientist and is usually conducted at an experiment station.

Adaptive research. As the name implies, adaptive research aims at incorporating new technological components into crop production methods, which are adjusted to the physical and socioeconomic conditions of the farm. Because the best cropping pattern, the pest profile, the yield potential of component crops, and the costs and availabilities of production factors differ greatly from site to site, technological components cannot be simply added to an existing or newly designed crop sequence.

Adaptive research is related to a specific production environment; allows farmers to participate in the design and testing of new multiple cropping technologies; considers several commodities and crop-to-crop interactions; is multidisciplinary;

and provides a clear identification of the different tasks to be executed by the research team members.

A framework for adaptive research that considers the whole cropping system (developed by the Asian Cropping Systems Working Group) consists of site selection, site description, cropping pattern design, and cropping pattern testing. Research activities and instruments have been developed for each of these phases so that the type of research conducted at a site is a result of the farm environment that prevails. The adaptive research phases include:

a) Selection of the target areas. One or more geographical areas representative of a large homogenous production zone are selected. In addition, the area should be a priority area for development by the national government. In this way, when the potential for production increases has been demonstrated, support for production programs will be given.
b) Site description. The first activity of the adaptive research is to describe existing cropping patterns, the physical environment, constraints to production, socioeconomic environment, etc. The characteristics of the farm environment will decide research priorities at the site and at supporting research stations. At this time the area is also divided into different land types, each of which may require a different production recommendation.
c) Design of cropping patterns. The design of alternative cropping patterns for a particular site should take into consideration the physical and socioeconomic site characteristics, the performance of cropping patterns, and the available component technology for crops in the pattern. There are numerous practices that must be specified for all crops in each pattern. Many can be specified on the basis of existing knowledge and local methods. Others warrant separate experiments to establish optimal input levels. This component technology research may be conducted in national, regional, and other experiment stations or in the cropping systems research sites.
d) Testing of cropping patterns. This involves the testing of the designed cropping patterns and selected management components in their respective environments in farmers' fields. Farmers participate in the testing by managing the cropping patterns with frequent advice and constant monitoring of research staff. On the basis of the agronomic and economic performance of designed cropping patterns, compared with prevalent farmers' patterns, problems that limit intensification of production can be identified and fed back to discipline- or commodity-oriented researchers active in technology-generation research. This scheme helps orient such research to solve relevant problems of the target farmers.

This procedure for on-farm cropping systems research allows most of the component technology pertinent to site to be evaluated and incorporated into a limited number of alternative cropping patterns that are acceptable to farmers. This process has been successfully applied in several places. It takes 2-4 years, and can be executed by junior researchers specifically trained for the task.

Verification of newly developed recommendations. Research must evaluate the suitability of recommended practices beyond the area where they are generated. That is achieved in farmers' fields by comparing the productivity of a new technology with that currently used by the farmer. If the difference is substantially in favor of the new technology, research must find out how farmers can be persuaded and helped to shift to the new technique. The design of experiments for this type of research is fairly uniform and has the following features:

a) Where the recommended and existing cropping patterns are the same, the recommended technology is compared with the farmers' practice on a component-by-component basis to identify the components that contribute significantly to improvements on the current farmers' management. Where the cropping pattern is different because of changes in the crop sequence, either with the addition of a new crop or with the use of a different part of the growing season for a given crop, the crop change itself is considered one of the components that must be evaluated and compared with that of the farmers. Obviously, for those crops in the pattern that remain unchanged, each component technology can still be evaluated separately as if the cropping pattern has not changed.
b) The test is conducted in many farms that are chosen as samples of the domain of adaptation of the new technology. The farmers' practice or pattern in a sample farm is then defined as that used by the sample farmer and is expected to vary from one farm to another.
c) The average difference in productivity among sample farms is an estimate of the production gap between the recommended and the existing farmer's practice.
d) Some examples of research for technology verification in a single crop are those conducted by Gomez et al (1979) for rice and by Mercado (1978) for corn. An example comparing alternative cropping patterns is provided by Gomez (1979).

Environmental analysis and classification in relation to crop productivity. Crop ping pattern performance is highly environment specific. That is, the performance of a cropping pattern varies from season to season, and from site to site such that the best pattern for one environment is not always the best for the others. The main objective of environmental classification is to facilitate the identification of cropping patterns and their component technology that are most suited to a given environment. Environmental classification also aids in the specification of characteristics required in new varieties or management techniques. Thus, the classification of the environment, in ways relevant to crop scheduling and productivity estimation, will make research for new technology as well as adaptive research more efficient.

To classify the environment in relation to crop productivity, the following activities should be completed:

a) Testing of various cropping patterns at different locations such that productiv-

ity in diverse environments can be measured. A common set of environmental and management data must be measured in all trials. A good illustration is the cropping-pattern monitoring program for the Asian Cropping Systems Network in which the different member countries have agreed to record a common set of climatic, land, and socioeconomic data for most of its cropping pattern trials in different locations.

b) Through regression analyses, the data in (a) can be analyzed to identify relationships that provide insights into the effects of some environment and management factors on yield. For example, a 1-day delay in planting the second rice crop reduced yields by 40-70 kg/ ha. That led to the identification of the approximate rainfall required for the second rice crop, using a relationship between yield and the rain received by the crop (Zandstra 1979). Historical records were then used to estimate the probabilities of receiving the required rainfall at different dates as an aid to crop scheduling and to the evaluation of the feasibility of producing two rainfed rice crops at a given site.

c) Development of functional relationships between crop productivity and the environment and management factors. This can be done through a simulation model using some key environment and management factors such that productivity under various environments can be predicted. An example is the yield prediction of the second rice crop for rainfed wetland conditions based on an expected water balance in the paddy. This crop production simulation allows long-term evaluation of the second rice crop using historical rainfall records. It identifies the soil-crop-weather variables to which rice yields were most sensitive and evaluates alternative (rapid) measurement and computational methods for relating rice yield to water stress.

d) Inventory of the environment. This is a periodic measurement of the physical and socioeconomic environment at strategic locations of each country. The procedure is fairly standardized and is designed to serve not only the agricultural sector but also a wide array of other programs and policy issues of the country.

Impact of research on productivity

An estimate of the impact of research on productivity is shown in Table 6 for rice-based cropping systems. The estimates are only for technology generation and the combined impact of adaptive research and technology verification. The impact of environmental classification, whose primary usefulness is to improve the efficiency of the three other research activities, is difficult to quantify and is excluded from the table. Table 6 is constructed under the assumption that rice is the best crop to grow whenever water is not limiting. Thus maximum yield potential is estimated from the highest recorded rice yield per crop (Barker 1979) and the largest number of possible crops per year using the earliest maturing varieties. The best farm yield for irrigated rice is assumed to be the same as that obtained in a continuous rice production system (Morooka et al 1979), while that for rainfed rice is estimated from

Table 6. Yield potential, best farm yield, and average yield per hectare for rice in the humid tropics of Asia.

Item	Yield per crop (t/ha)	Crops (no./year)	Yield per year (t/ha)	Source of estimate
Maximum yield potential				
irrigated	11.0	4.0	44.0	IRRI (1979), Barker and Herdt (1979)
rainfed	7.0	3.0	21.0	— ditto —
Best farm yield				
irrigated	6.0	4.0	24.0	IRRI 1979
rainfed	4.5	2.4	11.0[a]	Authors
Average farm yield				
irrigated	3.0	2.0	6.0	IRRI 1979
rainfed	1.6	1.2	1.9[a]	Authors

[a]Includes the yield of other grain crops grown in sequence with rice.

the best yields of a rice - rice - upland crop pattern. Average farm yields are estimates based on the reports of IRRI's Long Range Planning Committee (IRRI 1978) and from national production programs (IRRI 1979).

The potential for increasing farm productivity, represented by the difference between maximum yield potential and average farm yields (Table 1) is very large, indicating the existence of a substantial pool of highly productive technologies that is not used in actual farms. The difference between maximum yield potential and average farm yield can be divided into two portions:

- the difference between average and best farm yields, which represents the increase in yield that can be achieved by using available technology, and
- the difference between best farm yield and maximum yield potential, which represents an increase in yield that can be obtained by farmers only after additional component technology has become available.

The target of technology generation research is to develop new techniques that can increase maximum yield potential and thereby increase the future best farm yield. The target of adaptive and verification research is to narrow the gap between actual and best farm yields by identifying those cropping patterns and management techniques that are better than the existing practices and are acceptable to farmers. Once identified through on-farm research, these techniques can be immediately recommended for use by farmers.

Strategy

The research activities described in the previous sections are so closely related to each other that the potential benefit of one activity is greatly affected by developments in the others. Take the case of technology verification. The benefit from this activity is greatly influenced by the productivity level of the technology to be verified. The more productive the new technology, the faster is its acceptance and the larger is the benefit. Since substantial improvements in the productivity of new technologies are usually the result of technology generation research, the success of technology

verification must necessarily be dependent upon the results of technology generation.

Because of the interdependence and mutually reinforcing relationship among the four research activities, the proposed strategy assumes that all have to be simultaneously addressed. What needs to be specified is the relative emphasis to be given each activity such that the improvement in farm productivity per unit of research resource can be maximized. To accomplish this, two types of information are needed:

1. the resources available for research, and
2. the estimated efficiency for each research activity.

The existing institutions that are actively working in rice-based cropping systems constitute the major bulk of the research resource. These institutions are either national or international.

- International institutions are usually established on the basis of a clearly identified problem that involves many countries or a large number of people, or both. National institutions, on the other hand, are usually established to address some general and broad objectives that change with time and the personality of its administrators.
- Funds for international institutions are usually more adequate than those for national institutions.
- International institutions have access to the best scientists all over the world while national institutions are usually limited to those inside the country.

Table 7 shows the potential impact that can be expected from technology generation and adaptive research activities described in the previous section. It also shows the estimated time required to achieve such activities and the efficiency for each activity. While technology generation has a high potential for increasing yield per unit area, its estimated time cost is high, such that its time-based efficiency is lower than adaptive research and technology verification. This feature makes adaptive research and technology verification attractive activities for national programs whose need for increased output is urgent and immediate.

Table 7. Estimated potential and efficiency with which research can improve grain yields in wetland rice.

	Yield increase (t/ha)		Time required[c] (yr)		Efficiency[d] (t/yr)	
Research activity	Total[a]	Research[b]	T_1	T_2	E_1	E_2
Technology development						
irrigated	20.0	14.0	15	20	0.93	0.70
rainfed	10.0	7.0	15	20	0.47	0.35
Adaptive and technology verification						
irrigated	18.0	16.2	–	5	–	3.2
rainfed	9.1	8.2	–	5	–	1.6

[a]Derived from Table 6. [b]Assumes that 70% and 90% of total can be bridged by research due to technology development and verification, respectively. [c]Authors' estimate. [d]Computed using equations 2 and 3.

We suggest the following research strategy, based on the previous information:

1. The national programs should immediately increase their investment on adaptive and technology verification research for two compelling reasons. First, and probably more important, the return per unit of time invested is high (Table 7). Second, the procedures required are fairly uniform, and can, therefore, be readily implemented by national programs.

   To develop an effective adaptive research and technology verification capability, national programs should conduct on-farm cropping systems research at sufficient sites to capture the important agroclimatic conditions in their countries. Technologies considered suitable for the farmers in these locations are then evaluated for suitability to similar environments through technology verification.

2. The international programs should concentrate their efforts on the following activities:

   - Technology generation. As shown in Table 7, the potential for technology generation in rice-based cropping systems is high. The time-based estimate of efficiency of technology generation research (E_2), however, is lower than that for adaptive and verification research. This is primarily due to the long gestation period required for the identification of newly developed technology and its formulation in a way that makes it useful for adaptive research, especially when techniques are radically different from the current practice. While this feature may reduce the attractiveness of technology generation activities to national programs whose main basis for efficiency is E_2, it is not expected to have the same effect on international programs whose measure of efficiency is more closely related to E_1.

Some examples of new biological mechanisms that can result in a substantial increase in productivity are:

improving minimum tillage techniques,
improving the productivity and yield stability of ratoons in annual crops,
increasing complementarity among intercrop components,
long-term effects of intensive cropping on soil productivity,
selection of dryland crop varieties to fit growing conditions before and after wetland rice,
development of crop production models for rainfed areas,
control (cultural, varietal, chemical) of diseases common to rice and upland crops,
methods and equipment for zero-tillage planting of dryland crops in wetland rice fields,
weed control in dry-seeded rice,
reduction in water requirements of irrigated cropping patterns, and
the use of residual effects and crop-to-crop interaction for reducing chemical input requirements.

   - Methodology development. Although IRRI has developed a fairly uniformly applicable on-farm research methodology, further work is needed

to improve the rate at which adaptive research and technology verification can make new component technology acceptable to farmers. Particular emphasis is needed on the inclusion of the animal production system in the research framework and on ways to ensure that production programs are formulated to support the extension of research results.

- Training. International institutes can make major contributions to the development of an adaptive research capability in national programs by increasing the emphasis on training of national program research staff in the interdisciplinary on-farm research methods.

3. The task of characterizing the relationship between crop performance and the environment provides a good opportunity for cooperation between national and international institutions. The Asian Cropping Systems Network is a good example. National programs provide the input for getting data on crop performance and the environment at many sites all over the region, while the international center provides the expertise for summarizing and rationalizing the resulting diverse data. Clearly, an understanding of the relationship between yield and the environment is the final product of this research activity — a task that requires a level of expertise and financial support more easily available in international institutions than in their national counterparts.

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FARM RESOURCE PRODUCTIVITY CONSTRAINTS IN A CROPPING SYSTEMS FRAMEWORK

E C. PRICE, R. A. MORRIS, and S. MATHEMA

Optimizing the use of resources on small farms is difficult. Conditions that affect a crop are highly variable through the year and place highly seasonal demands on farmers' resources. At the community level, seasonal patterns of resource use are evident in wages and land rents, and in institutions that regulate farmers' exploitation of the resources they nominally control and those they trade with others. The commercial value of marketed crops depends upon the harvest calendars and consumption demand over wide regions. The productivity of resources, their costs, and the value of farm production regularly vary across the year and complicate the farmers' problem of planning the most profitable mix of farm activities.

The researchers' problem of developing multicrop technologies more productive than the farmers' present cropping patterns and acceptable to them, is similarly complex. The proposition that new technology for growing a better rice crop under specific environmental conditions goes only part of the way toward increasing food productivity and incomes on small Asian rice farms brought about cropping systems research at IRRI in 1967. Adding more crops in sequence implies the consideration of growing crops at other than the most favorable time.

Nevertheless perplexity is giving way to insight. Major managerial and resource constraints to increased cropping intensity can be identified and directions for future research suggested. We present here, first, some of the seasonal features of land productivity in relation to environmental conditions, and identify related managerial constraints to optimum crop sequences. Second, we discuss levels of technical-input use and constraints to their optimization in a whole-farm context. Finally we suggest research directions that may provide ways of alleviating the key limitations and argue for the development of a robust number of technological choices from which farmers may piece together more intensive sequences for specific environmental conditions.

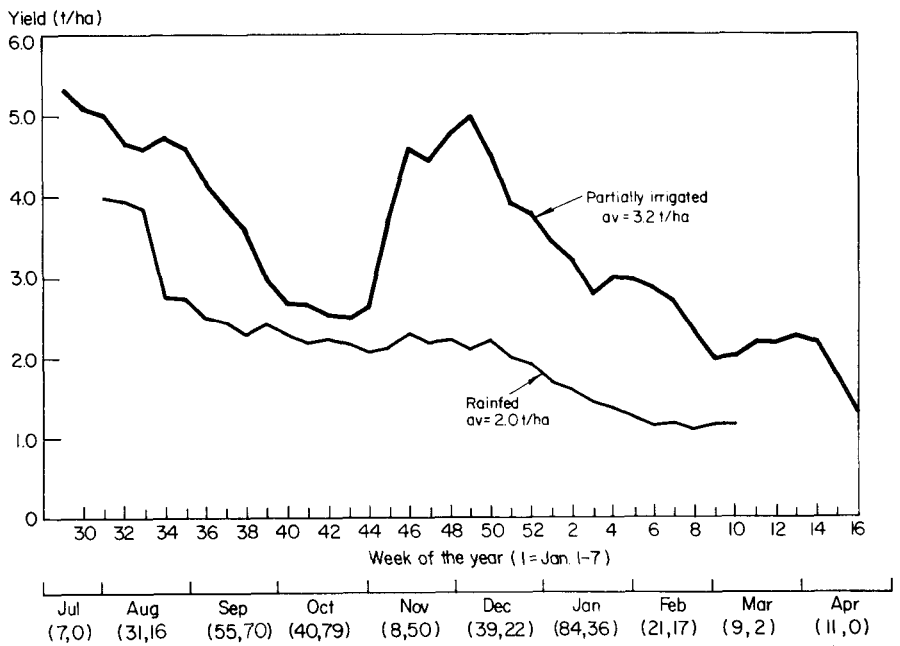
Agricultural economist and agronomist, IRRI; and agricultural economist, Cropping Systems Project, Department of Agriculture, Integrated Cereals Project, Kathmandu, Nepal.

SEASONAL RESOURCE PRODUCTIVITY AND ASSOCIATED CONSTRAINTS

Much of the cropping systems research at IRRI has focused on a fuller use of water in rainfed areas. Farmers traditionally transplanted a single crop about 2 months after the onset of monsoonal rains. Rainfall in the early months was not used to support crop growth. With the advent of photoperiod-insensitive rice varieties, it became possible to shift rice crops to various segments of the rainy season. With short-maturing varieties, it became possible to plant two rice crops per season. Direct seeding, in both dry and puddled soil, allowed still further adjustment of the range of possible planting and harvest dates.

From 1975 through 1979, half of all the land planted to traditional rice varieties on rainfed land in Iloilo, Philippines, was harvested between 9 and 23 December. Since the adoption of direct seeding of photoperiod-insensitive. early-maturing varieties, prospective planting dates extend from mid-April through the end of October, and harvest dates from early August to late February. With partial irrigation — systems dry for at least 2 months in the dry season — the range of possible planting and harvest dates is 12 weeks longer.

Yields are seasonally affected by crop water status, solar radiation, and pest buildup. The yields of crops planted during June and harvested in October decline (Fig. 1). Again they decline when soil moisture in irrigated and rainfed areas becomes deficient late in the crop year. Plantings with irrigation or early rains in late April and early May yield highest. On irrigated lands. the yields of rice crops planted



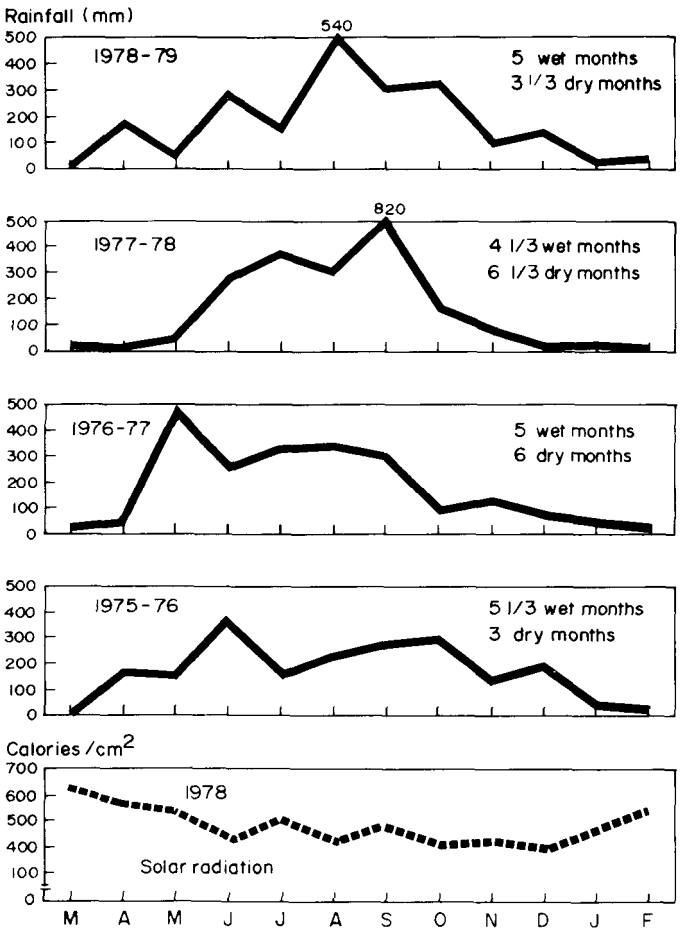
1. Five-week moving average rice yield (IR28, IR30, IR36) by week of harvest on 45 lloilo farms. 1976-77 to 1978-79 (Numbers in parentheses indicate number of plots harvested per month, partially irrigated and rainfed, respectively).

in August and harvested from mid-November to mid-December are also relatively high. Although yields on rainfed lands do not improve during November harvests, they stabilize at about 2 t/ha before declining further in January.

Patterns of rice-yield decline in the wet season are similar in the Pangasinan, Philippines, cropping systems research site (IRRI 1979) and in the dryland rice-growing area in Cale, Batangas (Price et al 1978).

Figure 2 shows the rainfall in Iloilo for the 4-year yield data in Figure 1. Monthly solar radiation in September-October varies insufficiently from that in other months to be a major cause of yield decline. That suggests that insect and disease problems exist. From December onward, moisture stress may have caused the yield decline, which averaged 50 kg/day on partially irrigated land and 20 kg/day on rainfed plots.

In experiments on farmers' rainfed fields, yields declined at 70 kg/ ha per day in second rice crops alone (IRRI 1978). The difference was probably due to the use of



2. Monthly rainfall in Oton and Tigbauan, Iloilo, 1975-76 to 1978-79, and solar radiation, Iloilo City. 1978.

higher levels of fertilizer and insect control by researchers than by farmers. An average farmer used about 60% less fertilizers and insecticides on rainfed plots and 40% less on irrigated plots than researchers.

Tables 1 and 2 show the total expected yield of a two-crop sequence on rainfed and irrigated land in Oton and Tigbauan, Iloilo. The data in Figure 1 reflect the actual yields of IRRI early-maturing rice varieties (IR28, IR30, and IR36, mostly the latter) grown by 45 farmers from the 1975-76 crop year through the 1978-79 crop year. A delay in the seeding of first crops obviously postpones the seeding of second crops. About 16 weeks is required for growing and harvesting the early-maturing crops. Assuming that similar delays occur in both first and second rice crops, the diagonal values in Tables 1 and 2 with origin at (0,0) indicate an average 66-kg/ha decline in rice yield for 2 crops for each day's delay in seeding on irrigated land, and 46 kg/ ha on rainfed land.

Over the 4 years of cropping systems research in Iloilo, farmers on irrigated land planted 28% of their first rice crops before 20 May, to be harvested in the high-yield period, and 29% of their second rice crops between 1 August and 15 September to get high-yield harvests. During the 4 crop years from 1975-76 to 1978-79, an average of 13 weeks elapsed between the date of first rice plantings and the establishment of the last of the first crops. That is seen in Figure 3, which also shows the percentage of total land with standing crops, by week of the year, on 45 Iloilo farms. The upward sloping portion to the first peak at the completion of the first crop's establishment varies from 11 weeks (1977) to 14 weeks (1976).

Part of the spread in farmers' planting dates of first rice crops is due to differential rates of water accumulation across farms because of topographic differences. Figure 4 shows the number of days per week that standing water can be held at various positions of the landscape in rainfed wetland rice plots and on irrigated plots. All landscape units become flooded at least 6 days a week at about the same time, and, except for the sideslopes, remain flooded for at least 2 months.

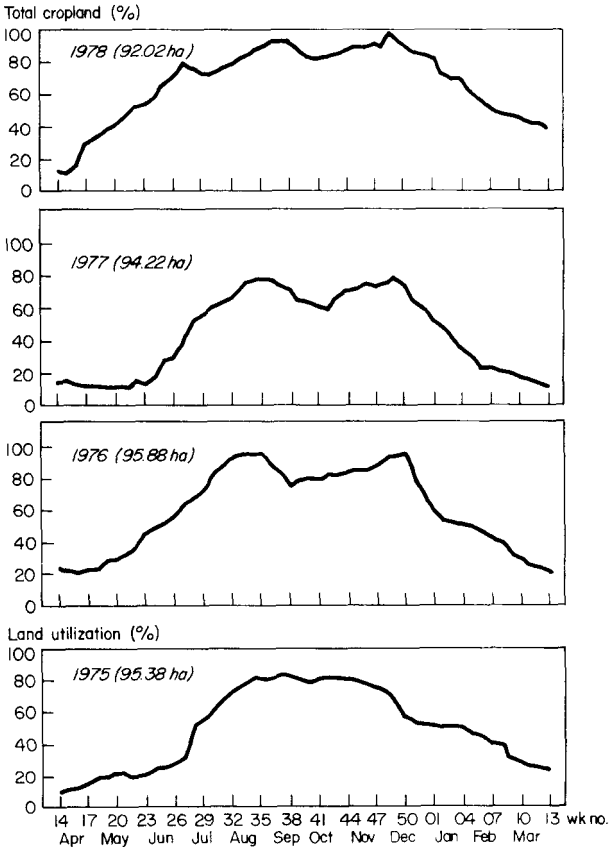
Table 3 shows the landscape composition of Iloilo farms. Twenty-nine percent of the land on rainfed farms is a single landscape unit and therefore has a relatively

Table 1. Expected total yield of a 2-rice-crop sequence in relation to planting dates based on farmers' average yields using IRRI early-maturing rice varieties on rainfed land, Iloilo, 1975-76 to 1978-79.

Delay (wk) in planting first rice crop after 16-22 April	Expected total yield (t/ha) of 2 rice crops when planting of second crop was delayed by						
	0 wk	2 wk	4 wk	6 wk	8 wk	10 wk	12 wk
0	5.1	4.9	4.6	4.2	4.3	4.0	3.9
2	4.8	4.5	4.1	4.1	3.9	3.7	
4	4.3	3.9	3.9	3.7	3.5		
6	3.6	3.6	3.4	3.2			
8	3.7	3.5	3.3				
10	3.3	3.1					
12	2.9						

Table 2. Expected total yield of a 2-rice-crop sequence in relation to planting dates based on 5-week moving average of farmers' yields using IRRI early maturing rice varieties on irrigated land, Iloilo, 1975-76 to 1978-79.

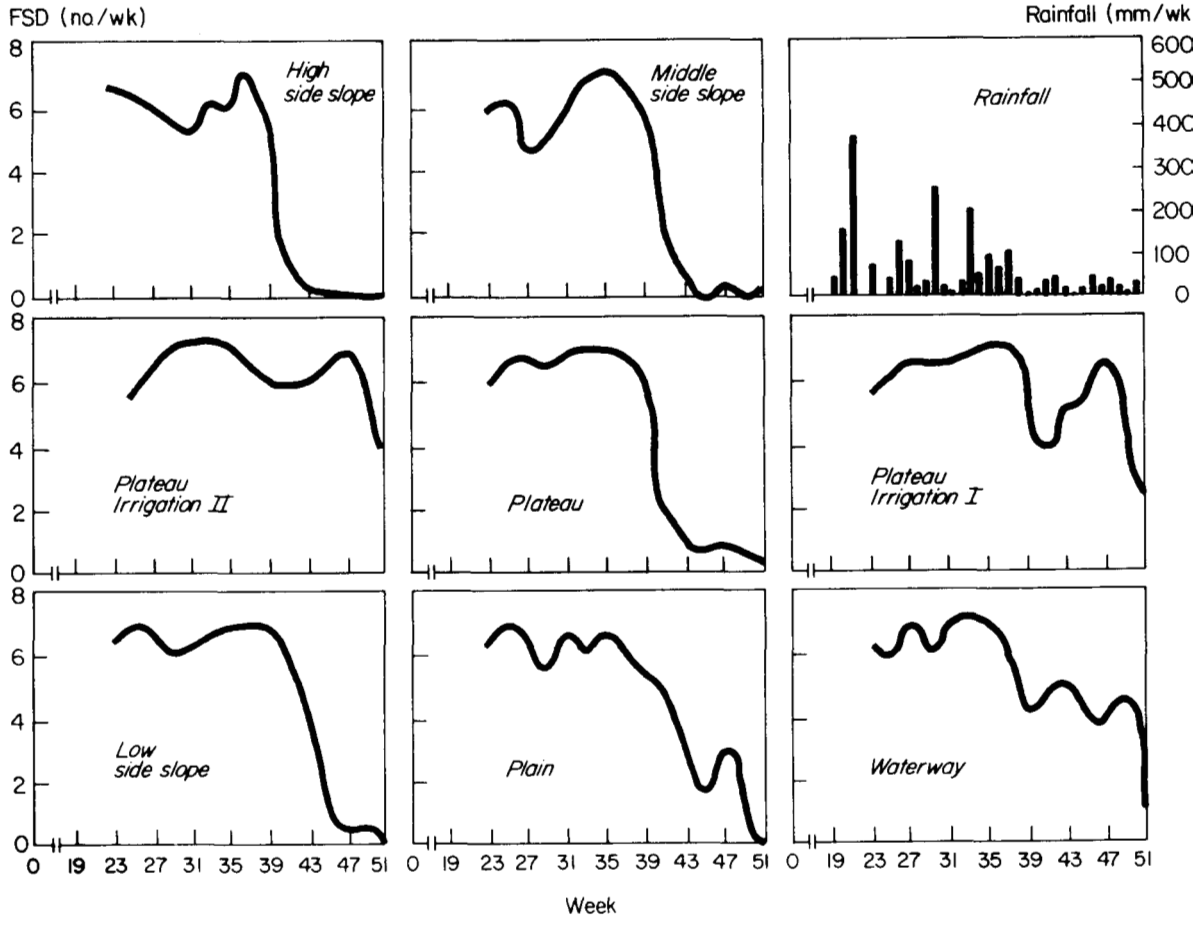
Delay (wk) in planting first rice crop after 9-1 5 Apr	Expected total yield (t/ha) of 2 rice crops when second rice crop planting was delayed by										
	0wk	2wk	4wk	6wk	8wk	10wk	12wk	14wk	16wk	18wk	20wk
0	8.7	9.0	8.5	7.9	7.5	7.5	7.5	7.0	6.1	6.0	5.9
2	8.9	8.4	7.8	7.4	7.4	7.4	6.9	6.0	5.8	5.8	
4	8.2	7.7	7.3	7.2	7.3	6.8	5.9	5.7	5.7		
6	6.7	6.4	6.3	6.3	5.8	4.9	4.8	4.8			
8	5.8	5.7	5.8	5.3	4.4	4.2	4.2				
10	5.6	5.6	5.1	4.2	4.1	4.0					
12	5.1	4.6	3.7	3.6	3.5						
14	5.1	4.2	4.0	4.0							
16	5.3	5.2	5.2								
18	5.4	5.5									
20	4.9										



3. Percentage of weekly land use by 45 farmers in Oton and Tigbauan. Iloilo, 1975-76 to 1978-79.

more homogeneous water supply. Twenty-five percent of farms are on 2 landscape units and 46% on 3. Scheduling of land preparation and planting in accordance with water accumulation may account for a small part of the spread of first-crop plantings. But, as demonstrated in Figure 4, the slight variation in early-season flooded days by landscape position presents difficulty perhaps only for those on the middle sideslope. Water regime is not the only major factor causing crop establishment in unfavorable periods.

Farmers are aware of the magnitudes of gains and losses that result from the



4. Weekly total rainfall and estimated flooded status regimes for 8 heavy-textured rainfed and irrigated Iloilo land units, weeks 19 to 51, 1976.

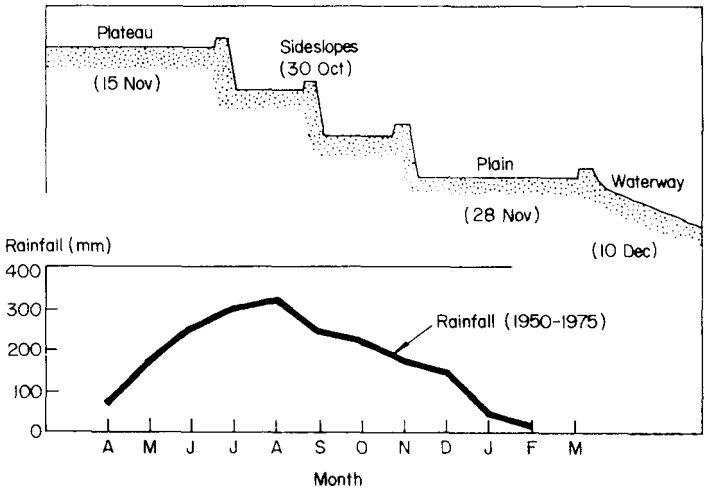
Table 3. Number of landscape units per farm in rainfed lowland areas, Oton and Tigbauan, Iloilo, 1976-77.

Landscape unit	Farms (no)	Total area (ha)	Av area/ farm (ha)
	1 land units/farm		
Plateau (PLT)	13	13.3	1.0
Plains (PLN)	4	3.8	0.9
Sideslope (SS)	2	1.3	0.7
Waterway (WW)	–	–	
	2 land units/farm		
PLT-SS	3	5.9	2.0
PLT-WW	2	5.7	2.9
SS-WW	1	0.9	0.9
SS-PLN	1	3.3	3.3
	3 land units/farm		
PLT-SS-WW	4	16.4	4.1
PLT-SS-PLN	4	9.1	2.3
SS-PLN-WW	2	4.2	2.1
All farms	36	63.9	1.8

crop's date of planting. They state that first rice crops yield higher the earlier they are planted. They also articulate their views regarding the feasibility of second crops according to planting date, recognizing the differences in landscape (Fig. 5). On sideslopes, where water retention is most problematic, they do not attempt second rice crops after 20 October, yet will consider second crops on well-watered land (waterways) until 10 December. They regard power constraints as the most important to timely crop establishment, and labor and cash availability secondary but nevertheless important (Table 4).

In common with rainfed-rice farmers throughout the Philippines, Iloilo farmers have a single work animal with which, they claim, they can prepare 1 ha/month, indicating that 2 months are required to plow and plant an average farm of 2 ha. Research on field operations has indicated that a first plowing requires about 100 hours/ ha and a second plowing, if necessary, about 80 hours. The first harrowing requires 20 hours; the second, and third, if necessary, about 15 hours. One plowing and two harrowings, the usual practice, require 135 hours/ha, or about I7 days. Various work interruptions for other farm matters and rest periods for work animals cause the longer duration, compared with technical time.

The distribution of time among crop operations between first and second rice crops on a sample of 28 rainfed plots is shown in Table 5. The estimates are consistent with the total turnaround times on 111 rainfed and irrigated plots on 45 Iloilo farms, shown in Table 6. Twenty percent of the turnaround period on a given plot is spent in field operations on that plot. Plots average 0.4 ha in sue or about 20% of the typical whole farm of 2.0 ha. When no operations are being conducted on a given plot, much time is spent on other plots on a farm.



5. Farmers' concensus on latest feasible planting dates of second rice crops by landscape positions, rainfed lowland, Iloilo, 1977.

An analysis by Tinsley et a1 (1977) of the relation of cumulative area of crop establishment in relation to cumulative rainfall further indicates that crop establishment proceeds as rapidly as possible. Figure 6 shows that from 1974 through 1976 on rainfed farms in Iloilo, the area of rice planted was consistently related to cumulative rainfall, at about 0.07 ha / mm rainfall. The high statistical significance of the relationships is due to the mutual association of the cumulative functions with

Table 4. Farmers' consensus on the relative importance of socioeconomic factors affecting land preparation for the second rice crop, Iloilo, 1977.

Factor considered	Farmers reporting[a] No.	%	Ranking
Power constraints [b]	33	87	1
Labor availability [c]	18	47	2
Cash available	18	47	3
Nonfarm jobs [d]	5	13	4
Off-farm work [e]	4	10	5
Others	44	10	6

[a]Total number of respondents, 38. [b]Related to both farmers' practice to prepare the land by himself and one carabao and the unavailability of threshing and power tiller in the area. [c]Laborers are not hired to prepare the land. [d]Nonfarm activities such as tricycle driving, buying and selling, etc. [e]Refers to farmers working in another person's field.

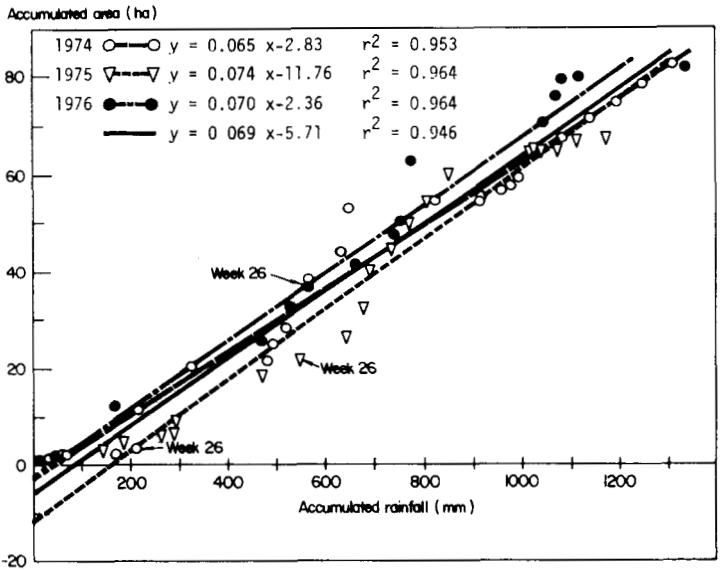
Table 5. Field operations and their contribution to the turnaround period on farmers' fields planted to 2 rice crops[a], Iloilo, 1976-77.

Operation	Days (no.)			
	WSR WSR	WSR TPR	TPR WSR	TPR TPR
Observations[b] (no.)	12	4	4	8
Harvesting to start of first plowing	8.1	13.2	10.3	12.4
First plowing	(2.8)	(3.1)	(2.1)	(2.7)
First plowing to start of first harrowing	4.7	5.4	4.4	5.7
First harrowing operation	(1.2)	(1.9)	(1.4)	(1.8)
First harrowing to start of second harrowing	2.3	3.3	2.8	3.8
Second harrowing	(1.1)	(1.2)	(0.8)	(1.6)
Second harrowing to start of third harrowing	2.2	–	–	–
Third harrowing	(1.0)	–	–	–
Third harrowing to planting	0.9	0.1	0.6	0.4
Total time in field[c]	6.1	6.2	4.3	6.1
Total turnaround time	24.3	28.2	22.4	28.4

[a] WSR = wet-seeded rice; TPR = transplanted rice. [b] Average plot size, 0.4 ha. [c] Sum of all figures in parentheses

Table 6. Average turnaround periods on the rice-rice cropping pattern according to method of establishment on 45 farms, Iloilo, 1976.

Pattern group	Plots (no.)	Av/date		Turnaround period (days)
		1st crop harvesting	2d crop planting	
WSR-WSR	55	7 Sep	30 Sep	23
WSR-TPR	19	14 Sep	11 Oct	27
TPR-WSR	21	3 Nov	26 Nov	23
TPR-TPR	16	2 Nov	30 Nov	28
Weighted av		27 Sep	22 Oct	25



6. Cumulative rainfall in relation to cumulative area planted to rice, 45 farms, Oton and Tigbauan, Iloilo, 1974-75 to 1976-77.

time. However, at a given time, for example, week 26 (about 1 July), shown in the figure, planted area and cumulative rainfall are at quite different levels each year. The consistency of the relationship between years suggests that land preparation and crop establishment proceed at a fairly constant rate, related to the draft power capacity on farms, following the onset of monsoon rains.

In a linear programming analysis of new rice multicrop technology on Iloilo farms, Jayasuriya (1979) found that direct seeding of early-maturing varieties greatly increased the value of labor and power during land-preparation periods, particularly in the turnaround period in late October and November. Indeed, increases in rice multiple cropping have been closely followed by mechanization of threshing and land preparation. On 15 sample farms that became irrigated, and where we earlier observed the most substantial losses from suboptimum timing of crops, the number of carabao rapidly declined and the use of tractors increased (Table 7,8). In 1975 no mechanical threshers were used on farms in the Iloilo research but by 1978, threshers were used in 72% of the irrigated farms and in 43% of the rainfed farms.

Direct-seeding of rice, by reducing labor demand, has also assisted more timely establishment of crops. But, as indicated in Figure 3, the cultivation period is still sufficiently long to prevent rice double cropping on entire rainfed farms. On rainfed wetland, where double rice cropping appears feasible on a maximum of about 30% of land, mechanical land preparation is still uncommon, but on about 90% of

Table 7. Number of carabao in selected farms formerly rainfed, Iloilo, 1975-78.

Year	Characteristic	Carabao (no.)	Decrease (%)
1975	Rainfed	26	
1976	Partially irrigated	24	8
1977	Irrigated	18	25
1978	Irrigated	11	39

Table 8. Number of available tractors over a 3-year period in irrigated areas that formerly were rainfed, Iloilo, 1975-1978.

Year	4-wheel tractors (no.)	16-hp hand tractors (no.)	8- to 10-hp threshers (no.)
1975[a]	0	0	0
1976[b]	3	5	3
1977[b]	3	6	5
1978[b]	3	9	17

[a]All under rainfed conditions. [b]Under irrigated conditions.

irrigated wetland, some mechanization is used.

Our review of the quality of environmental resources in relation to rice production suggests there are substantial gains in land productivity when the timing of individual crops coincides with high-yield periods, and in a manner that permits multiple cropping. During the period when rice is grown in Iloilo, the yields of two early-maturing rice crops grown by farmers may vary from 9.0 to 3.5 t/ha on irrigated land, depending upon the timing of crops, and from 5.1 to 2.9 t/ha on rainfed land. These are differences as great as the influence of any single factor used in production, including fertilizer, insecticides, and varietal choice.

The gains have been achieved partly by use of mechanical threshing and land preparation to permit better timing of crops with respect to rainfall, periods of pest incidence, and solar radiation, but clearly much of the potential has yet to be realized. With the current labor and power resources of farmers, it is difficult and perhaps impossible, to achieve the productive potential of rice afforded by the physical environment. Further research on cultural techniques leading to crop sequences that can be executed across entire farms in periods most favorable to crops can lead to substantial gains in food production.

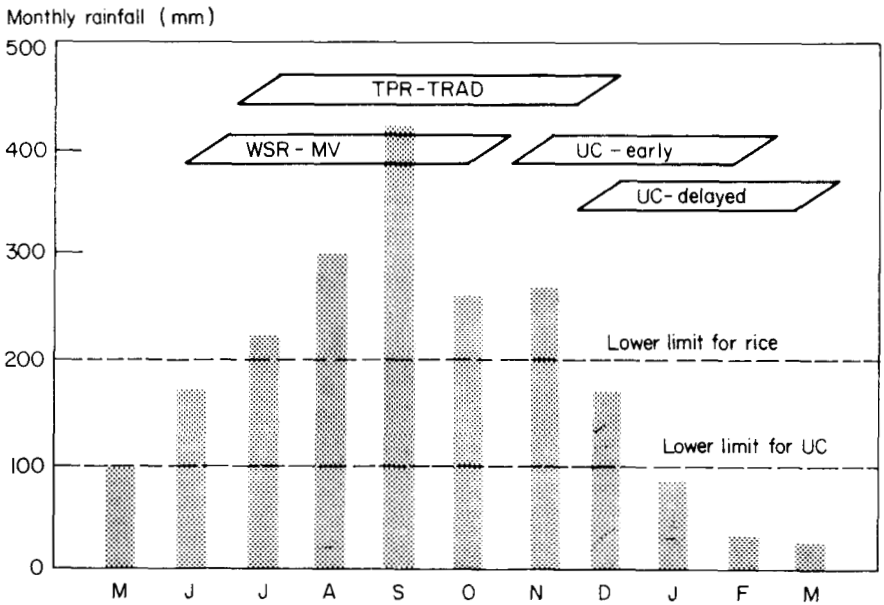
To this point in its evolution, cropping systems research methods have dealt with farmers as individuals. The management variables, which have been adjusted within cropping systems research, have by and large been those controlled at the individual field level (seeds, fertilizer, and pesticides). This approach has been successful but it ignores possible opportunities for gains arising from adjustments at the community level.

Farmers are reluctant to grow cropping patterns that deviate from their neighbors' patterns. In Pangasinan and Iloilo, two obstacles have surfaced, one relating to water management and the other to tillage operations (Fig. 7). With most of the farmers growing a traditional, long-duration, single-rice-crop pattern, the farmer who attempts to grow a modern shortduration rice crop followed by a dryland crop finds that:

- because the neighbors have standing rice crops in advanced stages of development, he cannot enter his field to till for the dryland crop without causing damage as he crosses his neighbors' fields, and
- when he is successful in getting a dryland crop planted, as scheduled, he finds that seepage of water from his neighbors' fields causes stand loss or poor growth. Or, neighbors will drain water through a farmer's dryland field to prepare for rice harvest. Given community conventions for avoiding conflict, most farmers delay the second crop until surrounding crops are harvested; but the dryland crop suffers because it is pushed into a drier environment.

These are but two examples. A frequent observation is that farmers who plant out of pace with their neighbors often suffer from excessive rat, bird, and insect damage, because the pests from the surrounding area concentrate on the few isolated crops that are at a vulnerable growth stage.

To obtain improved community-level actions, group decision-making is needed at the level of the individual farm field. Some type of consensus is needed to permit



7. Traditional single crop and improved two crop patterns, and mean monthly rainfall

progressive farmers to use their land more effectively. At what levels should that occur? What mechanism is needed? What production factor should be involved? How can it be implemented? Although China is an extreme case, it gives the impression that Chinese leadership recognized that agricultural intensification would advance at a pace determined largely by the least progressive and conservative farmers in the community. Hence, following agrarian reform in the late 1940s, group farming organizations progressed through a sequence of mutual aid teams, preliminary collectives, advanced collectives, and finally to people's communes (Zandstra et al 1977). However, the point at which farm management decisions were made reverted to production teams or brigades after the first few years of experience with decisions made at the commune level. The succession seemed as much to obtain progressive production organization and management as it did to obtain efficiencies of scale in the physical sense (e.g. irrigation and drainage systems and mechanization) or for ideological purposes. Because development was urgent, a background group averse to making bold changes was not given a chance to hamper progress. Wong (1979) states that the rice peasants were no doubt protected to use their skills for a speedy rehabilitation of the agricultural sector. The national leadership realized that because of the resource situation in China at the time, the main source of agricultural intensification would have to come from institutional reorganization rather than from technological transformation. Furthermore, the leadership recognized that the early cooperatives were only rudimentary and required to go through several stages of development before achieving the true or ideological model.

The unique Chinese experience probably can not be repeated elsewhere (Wong 1979). However, it indicates that some type of group decision-making will lead to improvements in cropping patterns and in use of resources that belong to the community.

PRODUCTIVITY OF VARIABLE INPUTS AND CONSTRAINTS TO THEIR USE

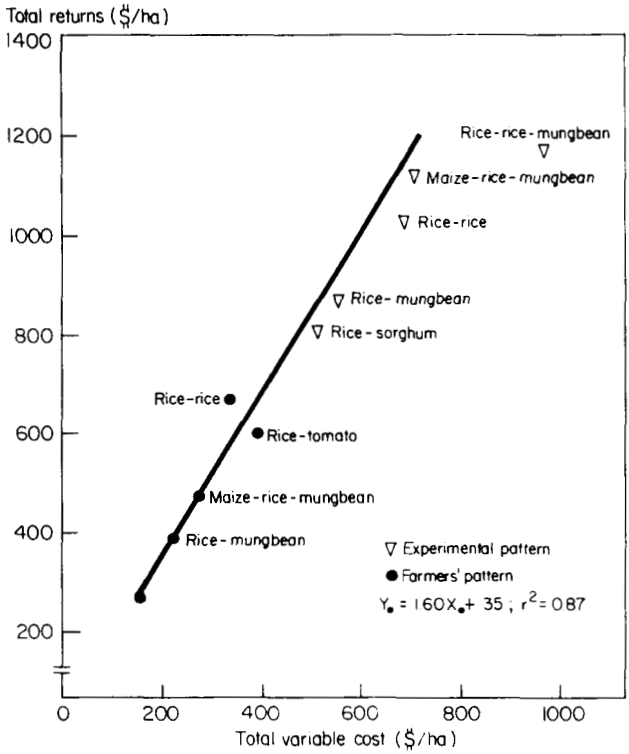
IRRI research on constraints to higher rice yield has given considerable attention to the relationship of technical inputs to rice yield. The influences of variety, fertilizer, insecticides, and other factors of production on yield are discussed in a number of IRRI research papers reporting the constraints research (see Shah and Flinn 1979, Mandac and Herdt 1978), and in IRRI (1979). Here we focus on points specifically relevant to rice and other crops in a cropping systems framework: complementarities in multicrop production and optimum resource use in limited farm resource conditions.

Production complementarities

Probably no issue concerning the use and efficiency of variable inputs in a multiple cropping context is of greater interest than the hypothesis that labor and materials can be used more efficiently in multicrop combinations than in monocrops. Crops in a multicrop combination are said to complement one another if the increased

production of one crop increases the production of another (Lee 1975). Some of the hypothesized reasons are the beneficial effects of a leguminous crop on subsequent crops, of use of residual fertilizer, of decreased weed incidence on intensively cropped land, and of soil structure improved by intensive cropping.

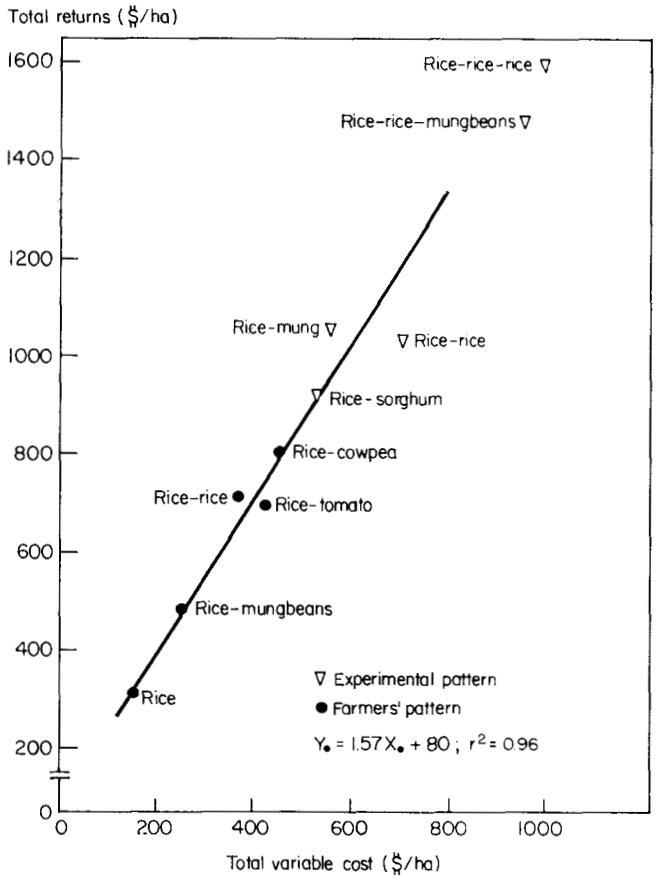
Complementarities in the multicrop sequences in IRRI research on either farmers' or experimental cropping patterns have been few. Figure 8 shows the mean values of variable costs and returns, across 3 years, of the principal crop sequences planted by farmers on rainfed land in Manaoag, Pangasinan. It also shows the 3-year mean performance of experimental pattern trials on farmers' fields under joint IRRI and farmer management. The curve in Figure 8 is fitted through points



8. Costs and returns of experimental and farmers' cropping patterns on rainfed land, Manaoag, Pangasinan. 1975-78

representing farmer technology, of which rice-mungbeans remains the dominant cropping pattern. The costs of production and variables. including material inputs and labor, bear a relatively constant relationship among technologies, reflecting a rate of return of about 1.6 on investment in variable inputs. At the same site, but on partially irrigated land, the results are similar, also reflecting a 1.6 rate of return on variable costs (Fig. 9).

While in both cases the farmers' rice - rice pattern showed some cost-efficiency advantage over the general input-output relationship, the difference is not great.

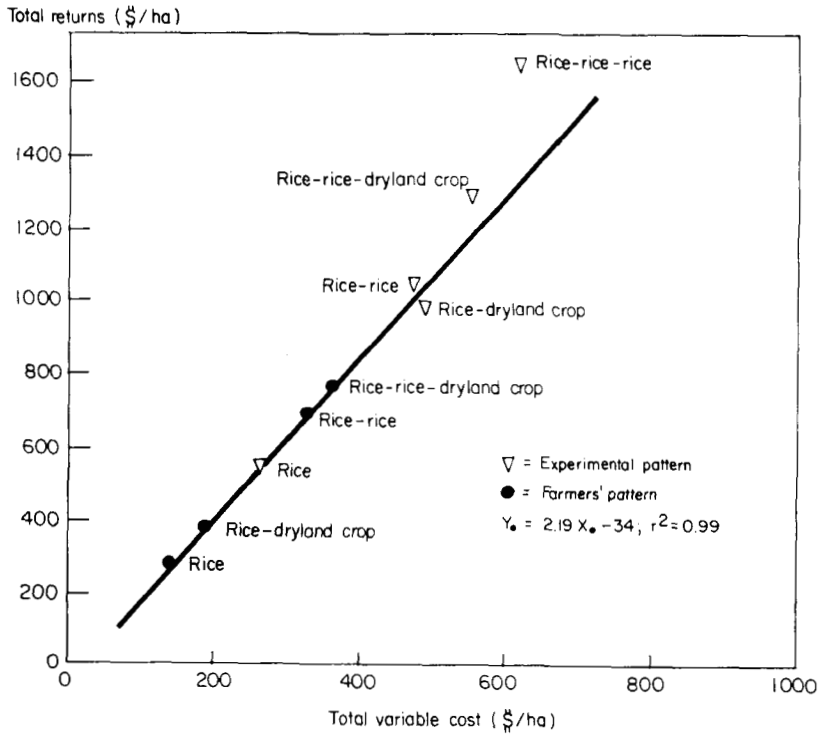


9. Costs and returns of experimental and farmers' cropping patterns on partially irrigated land, Manaoag, Pangasinan, 1975-78.

The costs and returns of the rice - rice pattern grown by farmers, are lower than those of the pattern grown by researchers, and the difference is associated with an improvement in the benefit-cost ratio. By reducing costs and returns, farmers achieve a more favorable rate of return on investment. On rainfed land the performance of rice - rice improves from about a $130 shortfall in returns expected at the researchers' level of investment (experimental) to a $90 excess, about the amount of returns expected for the level of investment. (This is indicated as the vertical distance of the rice-rice returns, experimental and farmers', from the fitted curve.)

Included in the 3-year data is the performance of the patterns in the first year of trials. Subsequently experimental input levels are adjusted in accordance with the observed productivity in the previous year. As a result, final recommendations often are consistent with a more favorable performance, providing resource-use efficiencies nearer or superior to those of farmers.

The returns on investment in variable costs across farmers' technologies are stable also in Iloilo. The mean results of experiments on the performance of farmers' and experimental patterns are shown in Figure 10. The fitted curve for Iloilo reflects a higher benefit-cost ratio (2.2) than that for Pangasinan. Again farm multicrop



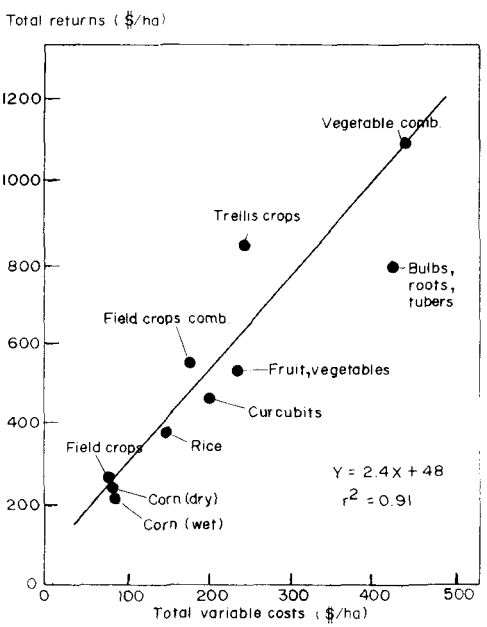
10. Costs and returns of expenmental and farmers' cropping pattern, in Oton and Tigbauan, Iloilo, 1975-78.

technologies do not reflect complementarities in production. The increasing rates of return indicated by the experimental data points for rice single crops, rice double crops, and rice triple crops may be largely caused by irrigation, the data for which were not controlled.

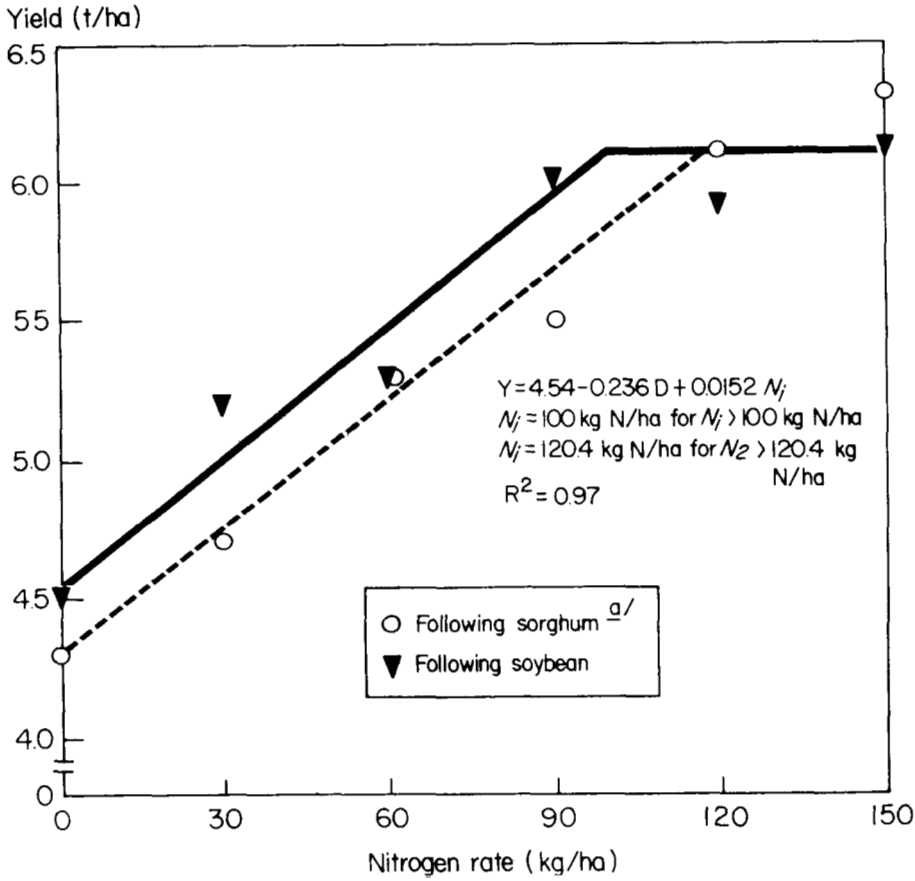
Farmers have widely adopted the experimental multicrop technologies in Iloilo. In 1974-75, 82% of the land in that province was single cropped in rice, now only 14%. The favorable performance of experimental patterns, relative to the fitted curve, must have encouraged adoption. Nevertheless, upon farmers'adoption of the multicrop patterns, new technologies assumed a performance characteristic similar to that of the older technologies — a constant benefit-cost ratio of 2.2 to 1.

Cale, Batangas, Philippines, was the first cropping systems research site off IRRI. Researchers went there mainly to observe and learn from farmers' multiple cropping systems. Partly because of an extended farm development project conducted there by the University of the Philippines in the late 1950s (von Oppenfeld 1969), farmers have intensively cropped vegetables and field crops in sequential and intercrop combinations.

Figure 11 shows costs and returns of crops and crop combinations grown in Cale from the 1973-74 crop year through 1976-77, as monitored by IRRI researchers. The fitted curve indicates a high rate of return of 2.4:1 on variable costs of the 10 classes of crop activities. Crops grown on permanent horizontal wire trellises 2 m above ground show relatively high rates of return, reflecting in part a return on the trellis investment. The low rate of return on bulbs, roots, and tubers results from the declining prices for ginger and garlic, and these had practically disappeared from the system by 1977.



11. Relation of value of production to total variable costs for various crop groups in Cale, Tanauan, Batangas, 1973-77.



12. Yield response of dry-seeded rice to applied N_i following soybean (N_i) and sorghum (N_2). Iloilo CY 78-79. [a]Means of 4 replications in separate experiments conducted in adjacent fields.

The rather gross comparisons of total variable costs and returns across years are likely to hide the complementarities that occur in multicrop sequences. Interactions are common in crop experiments. Figure 12 shows the response to nitrogen fertilizer of dry-seeded rice following sorghum and of that following soybeans. A yield advantage of about 0.2 t/ha was indicated for rice following soybean over rice following sorghum in an experiment in Iloilo in 1978-79. This yield gain is small compared with the differences in value of production of different crop sequences shown in Figures 8-1 1. Other issues with respect to possible markets for crops, and their comparative fit to the physical environment in specific seasons may outweigh consideration of complementarities as a criterion for technology design.

Certain features of farm-resource productivity evident from the cross-site, cross-year data presented are especially significant for cropping systems research. Substantial complementarities in production have yet to be realized from multiple

cropping. This conclusion follows from both farmers' patterns and experimental cropping pattern trials. Rather, new multiple cropping patterns have provided a way for farmers to earn high incomes at proportionately higher costs. This in itself is remarkable because decreasing proportionate returns are normally expected when factors of production are increased.

Optimum resource use in limited farm-resource conditions

The possible production gains from timely plantings and crop sequencing, noted earlier, may be realized through higher costs. That is, measures taken to speed crop plantings in the early season may require additional investments in farm capital such as mechanical power, or time-saving current inputs such as herbicides to correct higher weed incidence on early plantings. Through cropping intensification, farmers will continue to get what they pay for, no more no less.

While, within a location, benefit-cost ratios of different farmers' technologies appear relatively constant, current inputs are more productive at some locations than at others. In the examples given, they range from 1.6:1 to 2.4:1. While a rate of return of 2:1 on variable costs appears a likely general standard against which the performance of experimental technology is gauged, productivity of resources varies markedly between locations and should be separately examined.

The differences in costs and returns between patterns grown by farmers and the same patterns grown under research direction in farmers' fields reflect differences in variable inputs, labor and materials, and crop responses to these inputs. Farmers can increase their net income by planting crop sequences lying above or closely below the plotted curves. However, rather than execute new patterns at the input levels recommended by researchers, farmers reduce inputs, and, consequently, returns, to levels nearer the performance of their present technologies. Farm-resource limitations are a possible reason farmers seek to maximize net returns on their whole farms, given their resource constraints, instead of applying economically optimum levels of inputs, as indicated individually for separate technologies.

The case of fertilizer application to rice is instructive. Consider the farm budgets in Table 9 for 20 farmers in 2 Pangasinan locations and 45 farmers in Iloilo. The data were taken from records of crop activities from 1975-76 to 1978-79. Between 27 and 31% of the farmers' total cash expenses are for farm production. The amount is comparable to that spent on food for the household. Much of it is spent for hired labor, some for equipment rental, purchase, and upkeep, and some for livestock and land rent. In Pangasinan 6% of the total cash expenses is for fertilizer, in Iloilo 11%. More severe weed problems requiring hired labor for weeding, and less use of labor-saving methods of direct-seeding largely account for a smaller proportionate share of farm expenses for fertilizer in Pangasinan.

Farmers' fertilizer budget of $50-$70 will buy 75-112 kg nitrogen fertilizer. Dollars were converted to kilograms of nitrogen using actual fertilizer prices in each year and the relative mix of urea and complete fertilizer. About 30% of fertilizer expenditure is for complete fertilizer, mainly 15-15-15. Adjusted for number of crops of rice per year per farm, available nitrogen fertilizer rates vary from 35 to 43

Table 9. Farm cash expenses and nitrogen applied per crop at 3 Philippine locations[a] 1975-76 to 1978-79.

	Pangasinan[b]		Iloilo
	LWT	HWT	
Total farm expenses ($/farm)	841	800	618
Expense items (% total)			
Food	34	21	28
Household	39	51	41
Farm	27	28	31
Fertilizer	6	6	11
Other	21	22	14
Value of fertilizer ($/farm)	51	49	67
Fertilizer (kg N/farm)	83	75	112
Rice area (ha/farm)	2.4	2.4	2.6
Fertilizer (kg N/ha per crop)	35	31	43

[a]Pangasinan data cover 20 farms, 10 in each location from 1975-76 to 1977-78; Iloilo data cover 45 farms from 1975-76 to 1978-79. [b]LWT = low water table location, HWT = high water table location.

kg N/ha per crop. These levels of nitrogen application are consistent with plot-level survey data from other sources (e.g. Roxas et al 1978) and substantially below the recommended rate of 90-100 kg N/ha per crop (Morris and Price 1980).

Roxas reported that in the 1976 wet season, Iloilo farmers applied on wet-seeded plots 41 kg N/ha to modern varieties, and 23 kg N ha to local varieties, and on transplanted plots 38 kg N/ha and 28 kg N/ha to traditional varieties (Roxas et al 1978). The budgeted and observed rates are also consistent with farmers' nitrogen applications reported by IRRI's constraints studies (IRRI 1979). The data suggest that farmers distribute their cash resources widely over their farms to maximize income from total farm resources, although not necessarily maximizing profit from given plots or crop activities.

Whole-farm analysis using linear programming of 2 farms in Iloilo and Pangasinan showed that farm plans that maximize income, identified analytically, closely resembled the actual activity mix of farmers (Barlow et al 1979). The results were further confirmed in a similar analysis of five farms in Iloilo and five in Pangasinan, in which also the optimal farm solutions were quite similar to those actually adopted by farmers (Jayasuriya 1979).

Taken together — the farm budgets presented above, reflecting low rates of technical input application, and the analytical conclusion that farmers' combinations of their known technologies are economically optimum — the data suggest that either higher farm incomes be generated gradually over years from small internal cash surpluses allocated to new technologies, or farm credit schemes be implemented to support higher levels of technical-input application.

A number of studies also using farm-planning techniques lead to similar conclusions. For rainfed dryland farms in Lampung, Indonesia, Arifin (1978) concluded

that more intensive cropping in Lampung, South Sumatra, would increase the net incomes of farmers but its adoption is generally constrained by family labor and cash availability. From his study of cash liquidity and adoption of new cropping systems, Bachtiar (1978) reported that the adoption of new technology is highly responsive to internal cash flow and credit availability on Central Lampung farms. Furthermore, increasing the level of interest rates is likely to cause a shift from improved cropping patterns to traditional cropping practices (Bachtiar 1978). A linear programming of farms in Northeast Thailand indicated that more intensive cropping is constrained by family labor but, in turn, labor hiring is affected by cash availability. Vanchainavin (1978) concluded that increased credit is needed for increased production and income in the area.

While the analysis strongly suggests that improved credit facilities complement the introduction of improved cropping systems, there is good reason to design and introduce technologies that can be used at farmers' levels of resources. New cropping sequences that offer higher incomes are followed in Iloilo and Pangasinan (Fig. 8-11), but at lower than the recommended rates of variable inputs. A typical supervised credit loan of $130-$150/ha per crop is almost as large as food expenditures and double the current rates of cash-input employment per crop. A crop failure would jeopardize food purchases and other family needs. Farmers probably regard the use of lower rates of purchased inputs as a long-term but safer way to higher incomes.

TECHNOLOGY TO ALLEVIATE RESOURCE CONSTRAINTS

With present technology, seasonal features of land productivity, resource cost, and product price place critical demands upon the organization of resources for food production at the farm, community, and national levels. But technology itself can be responsive to the more permanent features of the resource structure. A wider choice of technology may largely alleviate the major constraints cited. The critical timing of rice crops for wetlands results in part from the paucity of technology for growing crops other than rice on rainfed and partly irrigated lands. While we have suggested that cropping systems research at IRRI has not uncovered major complementarities in multicrop systems, we have yet to exploit possibly beneficial rotations of cereals with grain legumes. We suggest that greater attention be given these areas of research.

Nutrients in cropping systems

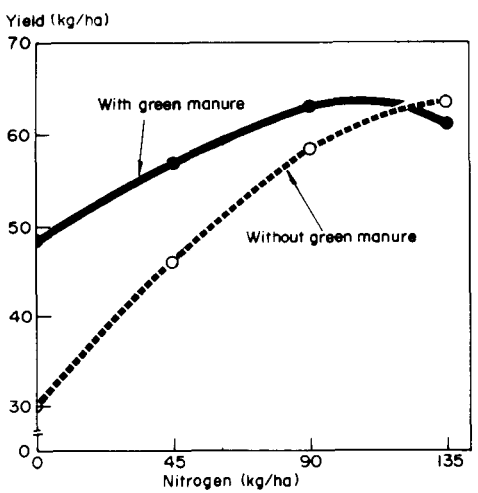
Nutrient deficiency can be a major constraint to increasing cropping intensity. For example, the cropping systems survey at Pumdi Bhumdi, Nepal, showed that most farmers relied on compost as the only supplemental source of plant nutrients for their crops. All fields are deficient in plant nutrients, and compost supplies only a fraction of nutrients needed for high yields. A dryland crop is grown before or after wetland rice when compost is available, that is, in farms that have compost in excess of that used in dryland fields and in farms that have no dryland parcels. Single-

cropped wetland rice parcels receive little or no compost, and therefore have low fertility. Under such conditions, inorganic fertilizers can play an important role in crop nutrition but should probably not be the only nutrient source to be relied on. Inorganic fertilizer, which is becoming more expensive on a worldwide basis, is often difficult to obtain in a developing country like Nepal. The amount of fertilizer imported into Nepal is still limited and fertilizer frequently cannot be found in local markets. In such situations alternative means for increasing soil fertility must be sought and applied fertilizers must be used to their fullest capacity. The use of leguminous crops, the addition of tree leaves, and better compost management may increase the potential for adding another crop to a pattern and raise yields of crops already in the pattern.

During the Nepalese winter, nearly 40% of the total cultivated land remains fallow. The major constraint is a deficiency of plant nutrients. The growing of various green manures after rice harvest in winter will improve soil fertility and increase cropping intensity. Autumn-planted vetch grown as a green manure over winter produced a rice yield response equivalent to 50 kg N/ha, on the average, over 5 years in California (Williams et al 1972). Similar green-manure effects may be found during seasons too cool for rice in the subtropics.

In the warmer portions of monsoonal Asia, short-duration legumes, probably of the large-seeded type, which make rapid early growth, may be grown to the bloom stage, during the transition before or after rice, when it is too risky to grow a high-value crop. Research cited by Staker (1958) showed encouraging yield increases, sometimes over 1 t/ ha but often in the range of 0.5-0.9 t/ha, but near the yield limit of the varieties grown.

Because the microsymbiont *Rhizobium* fixes atmospheric nitrogen and supplies it to the leguminous crop, grain legumes or leguminous green-manure crops may logically be included in some patterns. Grain legumes are also an important source of food and income for many Asian farmers. Growing a grain legume as an alternate to a coarse grain crop may reduce the requirement for nitrogen on the subsequent rice crop (Fig. 12). Turning it under as a green manure also reduces the nitrogen requirement (Fig. 13). Many studies on green manuring for rice, most notably in



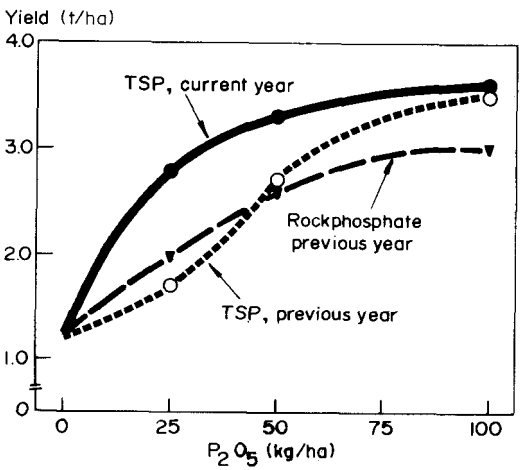
13. The effect of applied nitrogen fertilizer and an autumn green manure crop on rice yield, California. Means of 6 replications, 5 years and 2 straw-incorporation levels (Williams et al 1972).

Indonesia and India, were reviewed by Staker (1958). Despite promising yield responses, little of the work cited by Staker was continued into the 1960s, apparently because nitrogen fertilizers became comparatively cheap. There is also scope for using tropical grain legumes in intercropping to increase the nitrogen available to the companion crop and the subsequent crop (Agboola and Fayiem 1972).

Nitrogen may cause the greatest concern, but deficiencies of other nutrients, if they occur, must be considered simultaneously with nitrogen deficiency. Because other authors in this symposium will discuss soil fertility and chemistry for rice in general, we discuss the residual effects of phosphorus, a matter of concern in cropping systems studies.

Residual effects from phosphorus fertilization are rather common on phosphorus-deficient soils in temperate and tropical areas. Carry-over responses have been detected on phosphorus-deficient rice soils in the tropics. As an example, first-year residual phosphorus effects from two phosphorus sources on a Thai soil are shown in Figure 14. Other studies in Thailand have shown strong residual effects over 3 years from 4 common phosphorus sources (Jugujinda and Songmuang 1971). In another illustration, after examining residual effects, Brams (1973) concluded that the level of soil phosphorus built up rapidly and remained available to corn, upland rice, and peanut crops grown over 3 consecutive years. The implications are clear from these two examples that in evaluating cropping patterns, the cost of phosphorus applied to a crop may be partially charged against subsequent crops. Residual effects should be examined to determine how fertilizer rates should be adjusted in following years and how the cost of phosphorus should be distributed over years.

The examples cited are cases of long-duration residual effects. Where lowland rice immediately follows a nonrice crop, the phosphorus fertilizer requirement is often comparatively high for the crop grown under nonflooded conditions because of increased phosphorus availability after soil reduction. In patterns with dryland cropwetland rice sequences, residual phosphorus from the fertilizer application on the dryland crop may be sufficient for the ricecrop. This argument is supported by



14. The residual effects of phosphate fertilizers on yield of rice grown on a phosphate-deficient Kuan Jot soil, Thailand (Jugsujinda and Werasopon 1971).

Table 10. Effect of green manure with and without phosphorus treatment[a] on rice yields.[b] Mean of 5 years, 4 replications/year. Hyderabad, India (Rao and Murthy 1962).

Treatment	Yield (t/ha)
Control	0.9
Phaseolus trilobus without P_2O_5	1.5
Crotalaria juncea without P_2O_5	1.5
Phaseolus trilobus with P_2O_5	1.7
Crotalaria juncea with P_2O_5	1.7

[a] 25 kg P_2O_5/ha. [b] Rice variety HR 19.

investigations of Hayami (1975). The residual effect may also have operated in studies by Rao and Murthy (1962), who combined the green-manure treatments with phosphorus treatments (Table 10). Their data show an additional rice yield response from the phosphorus applied to green-manure crops, but it is not clear whether the phosphorus effect was through an increase in green manure or a carryover of phosphorus in the soil, or both.

Remote agricultural areas tend to have a greater subsistence component in their economy, with limited opportunities and means to buy modern fertilizers in the market. Studies on green manures, including low phosphorus fertilization regimes where phosphorus is deficient, can therefore lead to an improved economic level, perhaps sufficient to support an occasional phosphate fertilizer application. The potential of leguminous green manures, and perhaps composts, should be examined for such remote areas.

Cropping systems studies in partially irrigated areas

The Trilateral Commission Report advocates great increases in irrigated land to meet world food needs (ADB 1979). The World Bank, the Asian Development Bank. and other aid agencies continue to fund the development of large irrigation systems. Nonetheless, water will continue to be in short supply seasonally in most systems because irrigation depends on run-of-the-river flows. Many systems will fall into a *partially irrigated* grouping, and are not irrigated in the sense usually conveyed by that word. Differences in irrigation duration, reliability, and distributional efficiency obviously are not denoted by the simple term irrigated, and the farmers of such irrigated land are keenly aware of the instability of the field water regime in their irrigated fields.

In IRRI's cropping systems research, land is generally classified as rainfed or partially irrigated with two or more subclasses of the latter principally determined on duration of water application beyond the normal end of the dry season. The classification used in Iloilo and the number of flooded days per week within one land type under different irrigation classes are shown in Table 11 and Figure 4, respectively. In Pangasinan, farmers in the Lipit-Pao partially irrigated communal system knew with a fair degree of certainty the month in which water deliveries would cease.

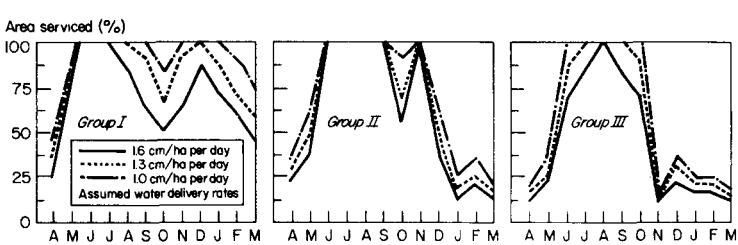
Table 11. Description of the water sources in the Iloilo test site.

Class	Description
Rainfed	Strictly rainfed; nosupplemental irrigation; depends entirely on rainfall for water accumulation.
1	Partially irrigated, with supplemental irrigation at least 1 month after the end of the rainy season.
2	Partially irrigated, with supplemental irrigation 1-2 months after the end of the rainy season.
3	Fully irrigated, with available water 11 or more months of the year.

In that communal system, water flows gradually diminish and become less reliable during the transition from the wet season to the dry. Fields far from the canals are less favored with water deliveries during such transition. In many major Central Luzon Valley gravity irrigation systems, delivery declines in a pattern similar to that of the Lipit-Pao system (Fig. 15). The general pattern of discharge in Group 3 systems were most similar to declines in the Lipit-Pao communal system. Monsoon rains cease in October and by December, the area of coverage has dropped significantly unless a system has a storage component, as in the case of Group 1 systems.

Despite the intentional concentration on rainfed areas in both the Iloilo and Pangasinan cropping systems projects of IRRI, irrigation systems were constructed in portions of the original site areas. Moreover, in both sites, farmers either individually or collectively installed pumps to lift surface water for rice and other crops where there was opportunity to do so. Ironically, to find an accessible rainfed area in Tuguegarao, Cagayan Province, a new cropping systems research project was located in an *irrigated area.* The canals and structures have been in place for 4 years but irrigation water has yet to flow through them and probably never will, because the area is remote from the main canal.

Experiences of this nature plus published information on planned areas of irrigation expansion and their potential for intensification have encouraged consid-



15. Irrigation water delivery patterns of the Lipit-Pao system, Central Luzon, Philippines, 1978.

eration of partially irrigated systems. In the partially irrigated areas, there are ample opportunities:

- to test and refine our technical knowledge for growing dryland crops before and after rice, and
- to use, in collaboration with farmers, research methods suitable for obtaining a reasonable on-farm test of new technology and a better quantification of the physical biological-socioeconomic environment within which the technology must fit.

The second point is most intriguing from a cropping systems methods perspective, but the cropping systems program has unique qualifications and can consider both points. For the first point we will extend our thinking to applications of limited amounts of irrigation water to dryland crops. Timely water applications not only increase actual evapotranspiration, which gives a direct yield increase, but also reduce tillage and improve plant emergence. Probably the most serious problem is the distribution of water from systems in which the density of ditches is adequate at only 50 m ha (and is often even less), and which were designed for continuous or long-term rotational flow for rice. Technology design would be extended beyond the seed-tillage-fertilizer-pest control management alternatives that had been considered in the past to include on-farm water management. Furthermore, because of the nature of irrigation systems, it will be necessary to work with groups of farmers simultaneously, rather than individually. It would also be necessary to communicate with irrigation-system personnel, first to determine theduration and reliability of the irrigation system in a manner analogous to studies of rainfall data, and, second, to define a level within the operating system at which farmer-cooperators could interact to convert continuous-flow or long-term rotational flow systems into short-term rotational flow or demand-flow systems during the seasonal transitions after dryland crops.

Cropping systems studies introducing irrigation as another variable must recognize the arguments of both Chambers (1980) and Levine (1980). Chambers pleads *for understanding which has application* and makes provoking comments on who should undertake such studies. From Levine's discussion. one understands that all the basic functions of irrigation systems (water delivery, maintenance and conflict management) have requirements for both physical infrastructure and nonphysical managerial inputs. and that there is a significant degree of choice of, and dependence between. the physical infrastructure and nonphysical managerial inputs. One must conclude from Levine, however, that once the irrigation system is constructed, the choice of managerial inputs becomes limited, and in that context, a cropping systems project would work, gauging the alternatives within each of the describe-design-test evaluation phases of cropping systems research methods.

Direct IRRI cropping systems involvement would not be novel, however, because irrigation has been considered to some extent in several national cropping systems research programs, sometimes as a static component and sometimes as an interactive component. With investment increases in irrigation, decision-makers in national organizations are bound to encourage on-site research to increase crop

production and system efficiency, especially in systems with nonexistent or limited storage capacity, in systems on soils with moderate to high percolation rates, and in systems where pumps are used to lift water.

In short, introducing an irrigation element would add a significant and complicating layer to describe-design-test-evaluate methods, but one that would have a high payoff in both a greater comprehension of the irrigation-farming systems and the development of cropping systems methods relating to irrigation that other projects could use.

A NOTE ON FARMER PARTICIPATION IN TECHNOLOGY DEVELOPMENT

Regardless of the technical content of future cropping systems research, it is clear that farmers themselves strongly influence its postadoption significance by altering various features of recommended cropping patterns. Before formal research and technology introduction, farmers are usually aware of the individual technical components researchers combine in new crop sequences. Farmers tentatively experiment in small ways with new crop-and-management configurations. By taking risks and assuming costs of changes in cropping systems, research expedites a natural on-farm process of technical adaptation. Without research, farmers could arrive years later at the same level of technical advancement as that resulting from cropping systems research. Indeed new rice technology today is partly based upon a long history of farmers' experimentation and selection.

In this perspective, researchers' awareness of what farmers are doing and why they are doing it provides a basis for identifying means for increasing agricultural production and farmers' welfare. There should be a two-way process of learning between farmers and researchers. It is crucial that a research organization appreciate the value of joint farmer-scientist planning, testing, and evaluation of technological changes (Harwood 1979). Farmers' technology can contribute to the development of new technology.

RESEARCH STRATEGIES SUMMARIZED

New technology and improved services to the agricultural sector can assist farmers in the fuller use of the productive capacity of their resources. Research at IRRI can play an important role in increasing food production through the development of rice technology that enables farmers to grow sequential crops in periods when the physical environment favors high productivity and the identification of needed research on nonrice crops for partially irrigated and irrigated rice farms and of features of farm infrastructure and farmer organization that will increase productivity.

The seasonal features of resource productivity are determined by physical environmental conditions, that are not subject to farmers' control such as rainfall and solar radiation. To better exploit resources with respect to their seasonal productivity, farmers must adjust cropping practices such that crops are grown in periods that

favor higher yields. The need to develop planting and management techniques that promote more rapid crop establishment and harvest has been highlighted. Only a fraction of rice crops is grown on rainfed farms in periods when productivity is highest. Minimum-tillage techniques, earlier maturing varieties, and measures to speed turnaround times between crops are indicated. It appears that given the variability in water regimes within farms and a limited labor and power capacity for crop establishment and management, a wide choice of alternate rice cropping practices should be made available to offer farmers latitude in adjusting their technological response to changing conditions over time and space. In this research effort, farmers' assistance — their knowledge and judgment — should be elicited and used by researchers.

Rice researchers should increasingly address the problems of multiple cropping, including the production of nonrice crops, on irrigated and partially irrigated rice lands. It is possible that in drier periods, when the energy costs of lowland rice production are highest, dryland cereal and grain legume production is more efficient.

Expanding food production through higher levels of current inputs is clearly subject to farmers' decision and control, but farmers' application of purchased inputs appear to be closely tied to their ability to internally generate operating capital. This slow process of agricultural development is more likely to be accelerated by more productive, low cash-intensive technologies than by periodic infusion of credit. Complementarities in crop production are not strongly evident in present multiple cropping technologies, but grain-legume cereal rotations demonstrate potential in this area. Closer attention should be given to the residual effects of fertilizer and the appropriate adjustment of fertilizer applications in sequential crops. A more important role of compost and green manures on low-cash and remote farms is indicated.

The importance of infrastructure and farmer organization has been reviewed. These socioeconomic aspects of the environment are not subject to the control of individual farmers, but of groups of farmers and society at large. Research is needed to identify the possible gains from farmers' concerted efforts in the adoption and use of new technologies. Do the gains warrant the development and use of a methodology of farmer organization to promote synchronous activities, and can such a methodology be used in a wide range of cultural and crop-production situations?

Based on the gains made in multiple rice cropping in rainfed areas, a strategy for rice cropping systems research at IRRI that emphasizes irrigated conditions, dryland crops to be grown in sequence with rice, and low cash-input technologies capitalizing on beneficial crop interrelations is suggested. Where expanded food production necessitates the introduction of crops new to a locale, or coordinated farmer activities, a generalizable approach to methods of socioeconomic intervention at the farm and village levels must be developed and articulated to national programs.

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AN APPROACH TO DEVELOPING AND USING FARM MACHINERY ON ASIAN RICE FARMS

A S. KAHLON and J. A. McMENNAMY

This paper presents a conceptual framework that may serve as a reference for planning the development of agricultural engineering technology specifically tailored to the needs of tropical Asia's small rice farmers. Information from selected areas is used to exemplify the role of engineering technology in aiding the development of agriculture production systems. The role of different types of institutions in this technology development process is also identified.

The rice-growing areas of Asia are diverse in many ways. We do not believe it is practical to present a precise development strategy that can be applied to every socioeconomic and institutional environmental mix found in Asia. We do believe, however, there are clearly delineated concepts that can form a framework for developing strategies for each environment. We apply these to several diverse environments to illustrate the proposed approach.

The framework we envision has three elements:

1. problem or target identification,
2. definition of the problem-area environment, and
3. identification or establishment of the technology delivery system.

PROBLEM OR TARGET IDENTIFICATION

Research questions typically exceed the available resources for finding answers. Program strategies and research topics must, therefore, be carefully chosen to optimize the use of available resources.

The ancilliary question of who can most efficiently find the answer should also be answered early. The overworked saying, *The engineer should be part of the solution and not part of the problem,* reminds us that misguided efforts can stifle develop ment efforts by otherwise capable institutions. For example, technology that embodies excellent engineering but does not suit the needs of the socioeconomic environment to which it is applied, or worse, is not commercialized, is totally inappropriate or useless to the casual observer.

Chairman, Agricultural Prices Commission, Department of Agriculture, New Delhi; and agricultural engineer, IRRI.

On the other hand, planners and policy makers assume that a technology that works well in one agroclimatic environment must work well in a similar agroclimatic environment, not realizing that in most cases the socioeconomic environment must also be similar. The unsuccessful experience in introducing in India power tillers designed for conditions in Japan illustrates the point.

Economics alone cannot always be used as the sole criterion for estimating the acceptability of a new technology. Often, only the economic benefit derived from reducing labor use is considered. The drudgery and risk associated with traditional farming practices in developing countries are not easily quantified, but they compel farmers to adopt technologies that permit them to perform tasks faster and less arduously. For example, IRRI developed several machines to increase the efficiency of fertilizer in flooded paddy fields (Labro et al 1978). The machines place the fertilizer in the root zone. They save capital through reduced fertilizer requirements but increase labor requirements. In field tests, the substitution of labor for capital was economically favorable and the performance of the machines was technically satisfactory. But farmers would not adopt the machinery. We hypothesize that farmers value their leisure more than they do the economic return on added labor.

Interdisciplinary project selection at IRRI

Many problems in food production systems and in rural development have solutions that include engineering technology components, which often are identified by nonengineers. At IRRI, engineers work with agricultural economists and biological scientists who help identify engineering problems and select projects that would efficiently use available resources (McMennamy 1979). An interdisciplinary team, the Project Selectionand Review Committee, has the objective ofassisting the IRRI Agricultural Engineering Program Staff in:

- developing criteria for assessing the potential viability and acceptability of specific mechanization projects;
- developing project priorities for the allocation of program resources;
- establishing methods to monitor and assess the progress of individual projects; and
- interacting with the engineering staff to develop design criteria for specific projects.

The committee serves in an advisory capacity to broaden the experience and perspective required in developing appropriate systems for machine design and mechanization. The overall goal is to achieve a high level of efficiency and acceptability in the execution, release, and extension of IRRI designs and to ensure and verify the validity of each project before significant resources are committed to its development.

The committee meets only when new project proposals are available for review and evaluation. Membership includes permanent representatives from IRRI's Cropping Systems Program and the departments of Agricultural Economics, Irrigation Water Management, and Agronomy. The Engineering program staff serve as

permanent members. When projects focus on applications outside the disciplinary expertise of the standing committee, additional members with capabilities in those areas are added.

Such a committee should be part of a technology development program, and an arrangement similar to that used at IRRI can be adjusted to most public research organizations. Research managers are generally aware of the advantages of employing interdisciplinary teams to work on problems, and the establishment of a group similar to IRRI's Project Selection and Review Committee is one way of fostering cooperation between disciplinary groups.

Likewise, in the private sector, commercial organizations can benefit from interdisciplinary cooperation with nonengineering groups within and outside the organization. The most obvious and strongest linkage should be with the marketing group because they are in direct contact with the technology users. In addition, the input from government extension workers and policy makers can be valuable in identifying viable projects and establishing product specifications.

DEFINITION OF THE PROBLEM-AREA ENVIRONMENT

Worldwide concern about protecting the earth's delicate ecological balance prejudices our thinking about the term *environment.* Often the term is used to refer only to the physical characteristics of the atmosphere and soil, but it is used here in its broadest meaning and also includes the surrounding social, economic, and political structure.

The social environment for agricultural production differs greatly between developed and most Asian countries, but some people try to apply to the Asian situation the criteria used in developed countries for selecting mechanization. In most developed countries, mechanical technology in agriculture sought to alleviate the problems of labor shortage created by rapid development of the vast areas of cultivable land. On the other hand, in traditional Asian agriculture, labor shortages are generally not a serious problem, and land and water are normally the scarcest resources. Use of mechanical technology in Asia has evolved through a different process of screening and selection and has ultimately become a tool for increasing land productivity (Kahlon 1978). This orientation deserves recognition in the strategy development process.

With the rapid growth of economies in the developed countries and particularly with the rapid expansion of secondary and tertiary sectors, the proportion of population in the agricultural sector declined while farm size experienced continued enlargement. Capital, not being scarce, was increasingly substituted for labor. This path of economic growth paved the way for development and rapid adoption of large-scale mechanization as an integral part of the strategy of rapid development.

The resource endowment of most Asian countries presents a contrast. Most of them have not experienced an agricultural or industrial revolution, capital is scarce, their population remains bottled up in the agricultural sector, and the man-land ratio continues to increase. The margins for extensive cultivation were reached early.

An appropriate mechanical technology for these countries is one that provides intensification of agriculture — an increased intensity of cropping that provides gainful employment to a large labor force seeking employment in the agricultural sector, higher output per unit area, and increased profits.

Any major deviation from these criteria poses a threat of displacement of labor, which these countries, already faced with serious problems of unemployment, can ill afford. This is underscored by the experience of Pakistan where a World Bank study showed that introduction of the tractor, without due consideration of the local institutional framework, resulted in the elimination of 879 farmers (McInerney and Donaldson 1975). Associated labor-use decreased by 40% because of *extensification* of agriculture in the operational area of the study. The most striking change that followed the introduction of tractors was the growth in the average farm size by a factor of 2.4 — from 18 to 44 ha/farm. About one-half of the farm size increase was due to the landlords' resuming control of previously rented land. Cropping intensity increased marginally from 115 to 119%, and the overall before-and-after cropping patterns within and between seasons were not statistically different. The lesson learned was that the technology developed in the western world was not compatible with this type of farmer-tenant relationship.

Resource development for technology adoption

The food situation demands, in addition to the development of an appropriate mechanical technology for the intensification of production systems, the substantial reduction of crop losses in the postproduction operations such as harvesting, handling, drying, threshing, cleaning, and milling.

One of the most significant developments is high-moisture harvest of paddy, which gives high yield and minimizes grain cracking (Duff and Toquero 1975, Kunze and Prasad 1978). However, in the absence of graindrying facilities, high-moisture harvest of paddy is not commonly practiced. Grain-drying facilities should be made functional at the village level or in the grain markets. Lack of organizational support to incorporate this technology in the postharvest sequence operations seems to have hurt both the producers and consumers of agricultural produce.

In some respects, identifying engineering problems and perceiving their effect on environment are not separable. In fact, the analysis of farming systems can unfold opportunities for applying engineering solutions to production-limiting problems. The literature is full of push-pull theories about cause-and-effect relationships governing the behavior of social and economic systems, but it seems mechanization in Asian countries is most often pulled into the system. In other words, mechanization is adopted to relieve a production constraint that has expressed itself.

For example, in the Punjab region of India and Pakistan, the introduction of high-yielding varieties in the 1960s induced the use of chemical technology (fertilizer and, in some cases, plant-protection chemicals) without which the new cereal technology could not be sustained as an economic proposition. And without the mechanical input, the proper placement of new seeds, fertilizers, and other chemicals could not be ensured. It also soon dawned on the farming community that an

assured supply of water was a prerequisite for reaping the full benefits of improved seeds and higher fertilizer rates. Large-scale installation of tubewells over a period of 7-8 years played a crucial role in the evolution of a new agricultural technology. Indeed, increased use of diesel engines and electric motors to pump water represented a significant expansion in the use of mechanical technology in agriculture.

New biological, chemical, and water technologies led to a continually increasing volume of harvest, particularly for wheat, which could not be managed through conventional threshing techniques. Locally developed stationary threshers, therefore, increased at nearly the same unprecedented rate as pumps and tubewells. Today, almost all the major operations of water pumping and wheat threshing are mechanized in Punjab. Even small farmers have rapidly adopted the use of threshers. The wide range of designs and low cost have put threshers within their financial reach. Another reason for the widespread adoption of the thresher was the damage the early monsoon rains cause to unthreshed wheat. The Punjab's experience demonstrated a high adoption of indigenously evolved technology.

In Thailand and the Philippines, IRRI-type paddy threshers have been rapidly adopted for the same reasons. In Iloilo, Philippines, mechanization has followed the introduction of the seed-fertilizer-cropping systems technology and the transition from 1 rice crop/ year to 2 crops/year. From an analysis of the power availability in that area, it is clear that the double-cropped area would be relatively small if farmers had not adopted the use of power tillers and threshers. Apparently, farmers adopted mechanical technology to relieve production constraints to capture the full benefits of the improved biological technology (McMennamy and Zandstra 1979).

Checks and balances in the adoption of farm mechanization

A pertinent unanswered question is: To what extent should rice production systems in Asia be mechanized? Adoption of machinery will vary depending upon the variations in farm sue, stage of economic development, institutional organizations, and ecological balance.

In India, some agriculturally-advanced states such as the Punjab and Haryana have economic incentives to use even combine harvesters to manage the increased output from improved rice-wheat rotations. Combine harvesters were initially introduced to obtain more efficient handling of the wheat crop. During this period, about 1% of the expanded wheat output in the Punjab was harvested with combines, mainly to remove the crop from the field before the onset of the monsoons (Kahlon and Verma 1979).

Now that a rice-wheat rotation has become highly profitable, combines are needed to manage higher levels of production of both rice and wheat so that the wheat crop can be sown on time. There is empirical evidence to show that a delay of even 1 week in sowing wheat reduces its yield by 400 kg/ ha.

There is also evidence that a delay in transplanting rice after July results in substantial reduction in rice yield. It is, however, necessary that adoption of such technologies as combine harvesters, which largely displaces labor, is properly monitored and controlled. It should be allowed to expand only to a point where the rising

output of wheat, rice paddy, and other crops can be managed with manual harvesting and power threshing. The combine harvester should not be introduced in conventional rice-growing areas of northern, eastern, and southern India where labor constraints do not arise in the current rice production system. Research that considers the differential adoption of various machines in various regions of Asia and different parts of each country is therefore needed.

Presumably, farmers will not adopt labor-saving machines in areas with very low wage rates. IRRI is developing a manually-operated rice-transplanting machine that reduces transplanting labor requirements by about one half. In an analysis by Echevama (1980), it was estimated that the transplanter will be economical if used to transplant 2 ha/ year in areas where transplanting labor earns $5/ day, but 11 ha per year must be transplanted if labor receives only $1 /day.

IDENTIFICATION OR ESTABLISHMENT OF THE TECHSOLOGY DELIVERY SYSTEM

Once problems have been identified and solved in ways that are compatible with the environment, means of transferring the technology to farmers must be found. The development of useful technology is normally a process requiring several years of concentrated effort. Consequently, newly established organizations initially have little need for an extension component. This situation can foster complacency about extension, which often makes public research and development organizations paper mills that have little impact on farmers. Instead of focusing attention on helping farmers, they become obsessed with the pursuit of a *perfect technology.* Industry in the private sector represents the other extreme. It is normally so intent on producing a marketable product that the development process is often abbreviated and resulting developments are unacceptable or have marginal benefit.

In most Asian countries, agricultural institutions and extension workers have developed for farmers packages that contain agronomic, soil conservation, and plant protection practices but do not purposefully incorporate an engineering component. As a result, mechanical technology is not synthesized with hydrological, biological, and chemical technologies and there is danger that mechanical technology, coming from outside the package, would become incompatible with the other components of the technological package and prevent the adopters of the package from achieving optimum results.

Following the Farm Management Approach to the problem of economic development of agriculture, it would be highly important to develop packages of improved methods of production and practice that contain the necessary elements of all technologies, including engineering technology. So far, this development has been weak because various departments, which evolve different technologies, are only too eager to push their own work (technology) in the fields and the system of rewards encourages this approach. To develop a proper interface between different technologies and make optimum use of agricultural resources, management should promote a system of rewards that promotes interdisciplinary research.

The success of government-backed efforts to improve agriculture production and

postharvest technology depends upon correct identification and measurement of the dynamic forces that induce farmers to adopt improved engineering and biological technologies. It is in the public interest to help the farmers develop adequate capability to adopt and modify his operations, including components of mechanical technology, so that his operations do not suffer from undue imbalance. For example, the Kelantan Agricultural Development Administration and the Muda Agricultural Development Authority programs of the Malaysian Government heavily emphasize (in the rice-growing regions) mechanical seedbed preparation when two or three crops of rice can be grown. Public agencies owning suitable tractors and land-preparation equipment provide the facilities. Farmers are responsible for all operations after initial land preparation. Timely land preparation with mechanical equipment has helped increase cropping intensity and yields in the region, thereby offsetting any unemployment created from the limited application of labor-saving technology.

Most operational holdings in Asia are too small to maintain work animals on an economic basis. Empirical evidence shows that the economics of custom-hiring services favors the small farmer relative to his maintaining work animals or owning farm machinery on his small holdings (Grewal and Kahlon 1972). These areas should establish a supporting infrastructure to provide the requisite custom service, tailored to specific needs and operations. Specifically, there is a need for integrated services and the organization of implement rental, machinery hiring and repair, and plant protection and pest control services.

That only larger farmers can benefit from the use of mechanization is a misconception. Rural development is a dynamic process. Some social scientists recognize that suitable engineering technologies can change the economic thresholds at which mechanical operations are competitive with alternative practices, but they are also apprehensive that machines will displace the rural labor force. Machines that increase labor efficiency are seldom economically competitive with rural labor at wage rates prevailing in traditional agriculture. When production-increasing technology is introduced, however, wage rates normally rise during periods of peak labor demand.

Farm machinery technology delivery system elements

The farm machinery technology delivery system can take various forms, but it normally contains four essential elements:

1. conceptualization and development,
2. manufacturing,
3. marketing or distribution, and
4. service and repair.

In free, developed economies, the farm machinery industry assumes a major role from technology development through delivery and support of the technology at the farm level. In developing economies, public support may initially be required in the development of technology and, in some cases, in the performance of other roles. It is beyond our scope to address the relative merits of public and private participation

in the system. Because of the diversity of social, economic, and political environments in rice-producing areas, it is unlikely that one mix of public-private role-playing is *right* for every region or country, but the system must be functionally complete to be effective.

Farm machinery manufacturing. The arguments favoring the local manufacture of farm machinery over its importation are familiar, numerous, and, in our opinion, well-founded. Local manufacturing helps develop industry, creates jobs, and saves foreign exchange.

The rice-growing countries of Asia have a local capability to manufacture farm machinery. Although often small, this capability does not represent a constraint to supplying farmers with useful engineering technology. Proponents of so-called *appropriate technology* often advocate labor-intensive production methods, but cost effectiveness should be the criterion used in selecting the manufacturing technology. If economic development is a goal, the production technology chosen should be compatible with the country's resource base, economical (cost effective), and in harmony with the social framework.

Technology conceptualization and development. We have stressed the importance of carefully targeting development efforts and defining the problem-area environment. We must now address the question of who should perform these tasks.

The local farm machinery industry in Asia has been a major developer of successful machine concepts. We find many examples of innovation by private industry (in Thailand, the Philippines, and India). Public research efforts may be more productive if they concentrate on development of sound concepts that can be transferred to industry for *fine tuning* to local environments and eventual commercialization. This approach, currently followed by IRRI, has achieved some degree of success. As the economic development proceeds, industry may become more involved in machinery development work. Over time, national and international research programs must shift from applied to more basic research and development topics.

Farm machinery distribution, service, and repair. The farm machinery technology delivery system cannot function without the physical transfer of machinery from the factory to the farmer. Once the transfer is done, the machines will not remain operational for long unless they are serviced and repaired. Some government planners have not given this area the attention it deserves. Even private manufacturers are often weak in the marketing and service areas.

As stated earlier, local manufacture of farm machinery helps develop industry and create employment, but the strongest argument for local production is that it streamlines the distribution and service network. Inadequate service and repair parts rather than technical inadequacies have often caused the failure of efforts to introduce imported farm machinery in Asia.

In many developing countries, much of the capability and expertise for developing farm machinery is found in universities, which traditionally have a long-term objective of training personnel. National planners should carefully consider the trade-off between using university faculty for finding solutions to current research

problems and using them in meeting the increasing need for more trained manpower.

IRRI has a farm machinery development program because the farm machinery industry in developing countries still requires some guidance in assembling the critical mass of personnel and expertise required for this type of work. In cases where national programs have been established to develop farm machinery, IRRI plays a supportive role. It has established several cooperative programs to assist in strengthening the linkages between industry and national farm machinery development programs.

International research centers, such as IRRI, can neither design a machine that meets the needs of every environment nor develop all the machines required for every environment. The logical role of the centers in engineering technology development is to focus on general, widespread problems and support the efforts of national programs, which can concentrate attention on specific problems. National institutions in almost every Asian country are making progress in their efforts to strengthen local farm machinery development capabilities. As these capabilities increase, IRRI's role can, and should, shift from machinery development to the development of basic information needed to develop farm machinery for tropical rice-growing conditions.

FUTURE NEEDS FOR ASIA

Engineers and social scientists debate on the use of farm machinery on Asian rice farms but generally agree that certain types of machinery can promote the general social welfare in specific cases, and the opposite situation is also true.

It is imperative that a strategy to use farm machinery to increase general welfare in rice farming carefully identify the machines and the geographic areas in which they will be introduced. Once that has been done, the elements of the farm machinery technology delivery system must be identified. If elements are missing, they must be created because the system will not function without all component parts.

Last, and most often overlooked, is the need for linkage or coordination between the elements of the technology delivery system. IRRI has increased its efforts to establish and strengthen the linkages between machinery development and manufacturing with favorable results. If *appropriate* farm machinery is developed, but the design is not manufactured, distributed, serviced, and repaired, then the technology development effort is in vain.

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RICE MARKETING IN ASIA: IMPLICATIONS FOR RESEARCH IN RICE-BASED CROPPING SYSTEMS

R. BARKER

The rapid growth in food grain production in Asia has caused many marketing problems and there is a growing recognition that market inefficiencies can severely constrain development.

The conventional view in Asia is that marketing activities controlled by the private sector are typically highly inefficient. The image conveyed is one of a handful of middlemen monopolizing power to buy low and sell high, thereby reaping exorbitant profits through their trading activities. Particularly in times of crisis, when supplies are short, the public sector is encouraged to enter into marketing activities, the assumption being that the elimination of profiteering middlemen will lead to substantial social benefits.

Rice-based cropping systems encompass a wide range of crops, many of which have unique marketing and distribution problems. This paper focuses on the marketing and distribution of rice. However, in examining the various marketing issues, many of which have been well researched in rice, I hope to provide insights regarding the focus of marketing research for other crops.

Before World War II, about 70% of the rice crop in South and Southeast Asia was milled by hand on the farm or in the local community. Less than one-third entered into commercial marketing channels.

Since World War II, however, increases in rice production and in urban population have necessitated a radical change in rice processing and distribution. In the last 3 decades, Asian rice production has grown by 3%/year, but the volume of rice marketed has probably grown by more than 4%. By the 1970s more than half of the rice crop was marketed, and hand pounding had become obsolete in all but a few areas. Although there is a great deal of heterogeneity in marketing institutions among the countries of Asia, there are discernible patterns and predictable trends.

MARKETED SURPLUS

Paddy (unhusked rice grain), once harvested, is used for home consumption, for seed, or as payment in kind, or is sold for cash. In general, paddy consumed or used

Professor of agricultural economics, Cornell University, Ithaca, N.Y.

by the farm family does not enter the commercial marketing channel although farmers may sell paddy at harvest and buy milled rice later in the year. Much of the payment in kind finds its way into the marketing channel.

There are few official statistics on the proportion of the total rice production that is market directed. Scattered information is available from a number of countries (Table 1). Neither the size of the marketed surplus nor the trend in the proportion of rice that is market directed seems to have been estimated with a high degree of accuracy.

Table 1. Estimated marketed surplus of paddy as a percentage of production for selected areas in Asia.[a]

Location	Marketable surplus (%)				
	Prewar	1940s	1950s	1960s	1970s
India	40	27	31		
Andhra Pradesh	53	47	50		
Bihar	30	22	21		
Orissa	–	15	31		
Punjab	60	30	64		
Tamil Nadu	65	32	25		
Uttar Pradesh	–	–	20		
West Bengal	46	27	32		
Indonesia			20		
Philippines			39	54	60
Taiwan					68

[a] Source: For India: India Directorate of Economics and Statistics, 1973; for Taiwan: APO 1979; for Philippines: Mears et al 1974; for Indonesia: Mears 1961.

Urban population has been increasing by 50-100% more rapidly than total population throughout Asia. Increased urban consumption needs would normally be supplied from increases in marketed surplus or in rice imports, or in both. An exception to this is the case of the exporters. In Burma, for example, rice exports and market surplus declined sharply in the early 1970s because of slow growth in rice production.

Only a few empirical studies provide direct estimates of the price and output response of farm households on allocating the produced output between home consumption and market (Bardham 1970, Bardham and Bardham 1971, Haessel 1975, Toquero et al 1975). A number of indirect inferences were drawn from earlier studies (Behrman 1966; Krishna 1962, 1965; Mangahas et al [n.d.]; Mubyarto and Fletcher 1966). The weight of evidence supports the hypothesis that the response of marketed surplus to a change in current price is positive.

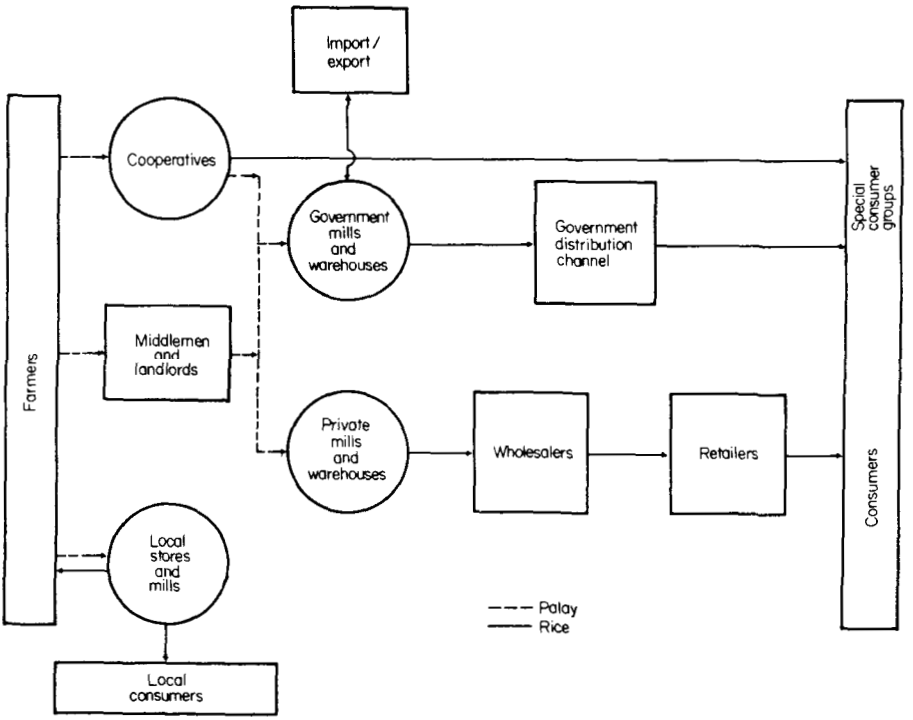
All the results based on direct measurement have shown that the output elasticity of marketed surplus for food grains is greater than unity and that implies that the cultivators' income elasticity of demand for food grains is less than unity. Therefore, as output increases, the farmers will retain a smaller percentage for home consumption. The reported output elasticities of marketed surplus for food grains are 1.78

and 1.60 (Bardham 1970), 1.97 and 1.75 (Haessel 1975), and 1.38 (Toquero et al 1975).

It seems reasonable to conclude from the foregoing evidence that the marketed surplus of rice for Asia, as a whole, has been growing more rapidly than production. Growth has been most rapid in the areas of most rapid production increase. In areas where production has stagnated, marketed surplus may have declined. One might venture to guess that if the marketed surplus were around 30% in 1950, it would be close to 5% today.

ORGANIZATION OF THE MARKET SYSTEM

The portion of rice production that is sold in the market passes through a series of either private or government channels, changing hands (and usually ownership) several times as it moves from the farm to the consumer. Figure 1 shows a highly simplified diagram of the principal marketing channels. Rice normally crosses between channels more freely than is suggested by the diagram. Local channels are important in all countries; they account for at least 30-40% of the rice, much of which is consumed at home. The importance of government and cooperative channels



1. Traditional rice marketing channels (adapted from Mears et al 1974).

varies considerably among countries. In general, the cooperatives have been effective only when they have received special government support. Their lack of success is one indication of the competitiveness of the market.

There are a number of common elements in the structure and functioning of Asian rice markets. First, paddy is collected from a large number of producers, who often market only a small quantity; it is transported, stored, and processed by a relatively small number of *middlemen*, and finally distributed to a large number of consumers.

Second, as paddy moves through the marketing channel, costs are incurred for transportation, storage, and milling. Services such as packaging, important in rice marketing in countries such as the United States, are not important in most of Asia. However, the product that enters the marketing channel and the final product that is sold in the market differ substantially throughout Asia. For example, in Indonesia, harvested rice is commonly sold in the form of stalk paddy. and the miller removes the stalk along with the husk. In Japan and Korea, on the other hand, the farmer normally removes the husk and sells brown rice. The degree of milling and the amount of polishing differ substantially as does the percentage of broken rice, reflecting the high variability in quality demanded in Asian markets. Rice is parboiled in much of South Asia.

A third common element in the structure is the differentiation between marketing channels that service the rural consumers and the primary wholesale and terminal markets that serve the urban consumer. In village markets paddy is usually milled by a small single huller, but paddy for the urban consumer is processed in a larger mill where milling consists of several passes through hullers, separators, whiteners, and polishers.

In summary, most marketing channels have three major components: the local market, which is largely private and serves the rural consumer; the private marketing channel serving the urban consumer; and the government marketing channel, which procures domestic rice for urban consumers, special urban consumer groups such as civil servants, the army, or the urban poor, and the export market. Both exports and imports are normally handled through government channels, a notable exception being Thailand's export market.

EFFICIENCY AND COMPETITION

The notion of efficiency in the marketing of rice is related to the cost of performing such services as transportation, storage, and processing, and to the degree of competitiveness in the market. A high marketing margin (spread between farm and retail prices) will inhibit production and weaken the signals for supply-demand changes (Mellor 1969). Several potential sources of inefficiency will increase marketing margins. They include:

1. inadequate investment in information, transportation, storage and pressing facilities, and related new technology development;
2. poor management in the performance of services;

3. collusion among buyers; and
4. underutilization of capacity.

Of course, these sources are not independent of each other. For example, inefficiency resulting from the first two categories may tend to encourage collusion.

In much of South and Southeast Asia — except, notably, Burma and Sri Lanka — the private sector has traditionally played a dominant role in rice marketing. In East Asia and China, on the other hand, the government has played the dominant role. However, even in those areas where the private sector predominates, public sector investment in transportation and infrastructure services importantly influences the efficiency of the system. Government has often intervened, either directly in rice procurement activities or in the establishment of cooperatives, on thegrounds that there is collusion or monopoly of power in the market and that farmers lack bargaining power. The domination, in many countries, of the rice trade by particular cultural groups — Chinese in Southeast Asia and particular castes in South Asia - tends to reinforce the belief that collusion exists and that farmers are being squeezed by middlemen.

There are two approaches to investigating the issue of competitiveness in the market. Many studies combine them.

The first approach is to establish whether the structure of the market tends to conform with the following general criteria for competitiveness:

1. a large number of marketing firms;
2. freedom of entry to establish a business in marketing; and
3. suppliers' access to information on prices.

The second approach is to determine whether price movements and price-and cost relationships reflect a state of competitiveness in the market. The investigation can, of course, take place at several points in the marketing channel and can concern several functions.

Marketing structure

Ruttan (1969) notes that much of what passes for market analysis represents little more than a repetition of conventional wisdom regarding middlemen behavior. Few studies have examined whether the rice market conforms to the conditions of competition defined in economic theory. Studies by Lele (1971) for India, Farruk (1972) for East Pakistan (Bangladesh), and Siamwalla (1975) for Thailand have addressed this issue largely on the basis of their own inquiries and available and descriptive information.

Lele systematically examined data from Tamil Nadu and West Bengal on the number of traders in village and primary markets, the number and capacity of rice mills, and the degree of concentration of the market. She concluded that there is widespread evidence of

1. a good private network of market intelligence on price;
2. free entry into the grain trade; and
3. extreme self-interest of traders, which generally discourages collusion action (Lele 1971).

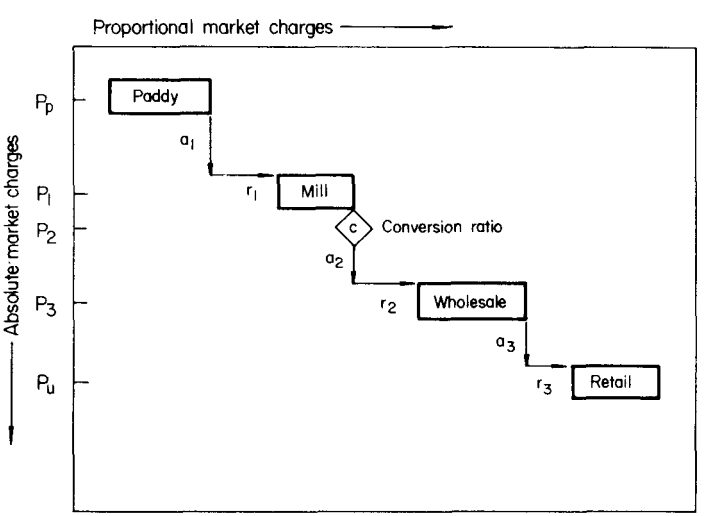
Farruk (1972) observed that intermediate and terminal markets in East Pakistan were dominated by small groups of *Aratdaris* who handled 70% of supplies. While Farruk found no direct evidence of excessive commission rates, he argued that there were elements in the *Aratdari* system, such as the strong barrier to entry of new firms, that could degenerate the competitive forces.

Siamwalla (1975) argued that the degree of competitiveness in the marketing of a crop in Thailand is related to the cost of shifting from one buyer to another. This cost is related to the nature of the commodity itself, and to the technology used in both production and marketing. The rice milling industry consists of a number of small-scale firms that are well dispersed in Thailand. The farmers and the various intervening middlemen thus face a relatively low *shifting* cost and do, in fact, sell to many different buyers over the years. Unfortunately, this observation is not well documented either in Thailand or elsewhere. I know of no studies in which farmers were asked how many different buyers they have sold rice to over the past several years. The conventional view is that regardless of the potential number of buyers, the effective number is reduced to one by the indebtedness of the farmers to the middlemen. However, available evidence suggests that loans from middlemen and rice millers form only a small portion of rural credit (Siamwalla 1975).

Marketing margins

A large number of studies have investigated rice-marketing margins. The general procedure is to compare the price differential with actual costs for the farm-teretail margin or for selected functions such as transportation, storage, or milling to determine whether there are signs of excess profit.

Figure 2 represents a highly simplified schematic view of the rice marketing system



2. Rice marketing systems reflecting charges due to change in time (proportional) and in form and space (absolute change). Adapted from Timmer (1974).

from farm to retail, ignoring the various channels depicted in Figure 1. The vertical dimensions of Figure 2 reflect movements to the higher level of the marketing system and changes in space and form. The horizontal axis relates to changes in time. The transportation and milling costs associated with the vertical axis are absolute charges in the milling system. The storage costs associated with the horizontal axis are likely to be proportional to the value of rice. Thus, although the marketing margin is normally expressed as the ratio of the difference between the retail and farm price divided by the retail price, this proportion should not remain constant because rice prices fluctuate over time. In fact, the bulk of marketing costs consists of transportation and milling, which are absolute charges.

Table 2 summarizes the findings of selected studies of rice marketing margins. For each site two or more margins are reported — estimated for different years, usually by different researchers. The producer's share ranges from 58 to 83%. Except in Taiwan, where the retail trader's profit seems to have risen sharply, marketing margins in more recent years tend to decrease. The margin between farm and retail is, of course, lower than in developed countries such as the United States, where farmers receive less than 50% of the retail price. The high margins in the developed countries reflect the demand for more services. In fact, the data in Table 2 tell us nothing about marketing efficiency either within or among countries. Marketing margins are often considered excessive, but the actual cost under a given marketing system can be judged as high or low only in comparison with costs similarly defined and measured under an alternative marketing system (Krishna 1967).

Few studies have compared alternative systems. Mears et a1 (1974) compared marketing margins for private, cooperative, and government marketing channels in the Philippines. He drew no strong conclusion about relative efficiency, suggesting that there would be a slight advantage for the private sector under an assumed condition of no windfall profits.

Ruttan (1969) interpreted evidence from regional analysis of Philippine price series as indicating relatively competitive markets. His conclusion was based on the high level of correlation between farm and retail prices. These correlations were not significantly different than 1.0 (i.e. the margins were constant). Nichols (1941), however, argued that market inflexibility is consistent with the tight oligopophistic control. In the short run, margin flexibility (margins increasing as demand increases relative to supply) is consistent with rational maximizing behavior under perfect competition.

Blyn (1973) also commented on price series correlations as a measure of market integration. Considering the imperfections of competition and the possible range of local-market price fluctuations, which could still be consistent with integrated market, it is plausible that the overall correlation coefficient for the group of markets could be much lower than has been indicated in some studies.

In Indonesia, marketing margins vary appreciably over the year. Rural and urban prices are strongly dependent during periods of relatively abundant domestic supply, but are often unconnected during the lean months of heavy importation into urban areas. During those periods, rural prices can at times exceed urban prices. The Thai

Table 2. Marketing margins for rice in selected sites in Asia, 1953-1974.

Source	Location	Year	Site		Distance (km)	Producers share (%)	Portion of total cost		Trader's margin (%)	Market-ing margin (%)
			Production	Market			Processing, storage, and trans-portation costs (%)	Trans-portation costs only (%)		
Yeh (1955)	Taiwan	1953	Pingtung	Taipei	400	67.9	30.6	3.6	1.5	32.1
APO (1976)	Taiwan	1974	Pingtung	Taipei	400	58.3	26.6	3.2	15.1	41.9
Mears (1961)	Indonesia	1955	Krawany	Djakarta	100	60.0	–	–	–	40.0
Adiratma (1969)	Indonesia	1955	Krawany (Channel I)	Djakarta	100	79.8	11.5	–	8.7	20.2
			Krawany (Channel II)	Djakarta	100	72.5	20.2	–	7.3	27.5
Mears (1981)	Indonesia	1975-79	Krawany	Djakarta	100	90.0	–	–	–	10.0
India, Directorate of Marketing and Inspection (1954)	India	pre-WWII	W. Godavari	Madras	500	63.2	25.2	9.6	11.6	36.8
George and Choukidar (1973)	India	1970	W. Godavari	Madras	500	82.9	13.8	8.7	3.3	17.1
Mearset al (1974)	Philippines	1966	Central Luzon	Manila	100	80.3	12.9	3.3	6.8	19.7
Mears et al (1974)	Philippines	1970	Central Luzon	Manila	100	78.5	12.6	4.4	8.9	21.5

farm price is closely linked to the Bangkok wholesale price, which in turn is affected by export demand. Thus, the price-making force flows from urban to rural areas rather than from rural to urban, as in the case of the Philippines and most rice importers. In both the Philippines and Thailand, marketing margins are appreciably higher at harvest than at other times of the year because of a shortage of milling capacity and the inability of producers to finance their own storage operations. Marketing margins varied by about 30% from peak to trough in the Philippines (Mearset al 1974) and Thailand (Pinthong 1977). Increased farm storage could raise farm prices, narrowing the margin at harvest.

Market integration and transportation

The analysis of pricedifferences between regions, as between stages of marketing, is based on the same methodology — the price spread between markets being compared with the cost of handling and transport. A price spread between markets approximating transportation costs suggests a competitive situation.

The transportation system of Asia has undergone a complete change in the past three decades. As the road networks developed throughout Asia, there was a substantial shift from rail and water to truck transportation. For hauls exceeding 100-200 km, truck traffic is more expensive than either rail or boat (Mears et al 1974). However, the greater flexibility of trucks favors their use even when rates for alternative modes of transportation are less expensive. Data from both Mears et al (1974) and Pinthong(1977) indicate that as hauling distances extend beyond 200 km, the cost of transportation rapidly exceeds the cost of milling, these being the two major items of marketing expense. Transportation costs as a percentage of total costs for selected areas are shown in Table 2.

The rapid improvement in transportation and communications has increased the general level of market integration in Asia. Studies by Lele (1971) for two states of India and by Pinthong (1977) for Thailand concluded that there is a high degree of market integration. Studies of the island economies of the Philippines and Indonesia suggest a much lower degree of integration. In Mindanao, Mears et al (1974) noted that when market margins are twice the level of Central Luzon's, poor transportation and large mills suggested a greater opportunity for inefficiency and collusion. Timmer (1974) reported that marketing margins are higher in the outer islands of Indonesia.

Storage

A final note on efficiency and competition concerns storage. There are issues related to both technical efficiency and the loss of rice and to economic efficiency and the cost of storage.

Rice is stored as paddy or in milled form both in bulk and in sacks. Estimates of loss in storage range from less than 1% to as high as 10%. Several studies have investigated the profitability of storage (Lele 1971, Mears et al 1974, Pinthong 1977, Tubpun 1974). There is general agreement that storing rice is extremely risky. The financial riskiness of storage may be the main reason why cultivators market heavily

soon after harvest. By selling at harvest, the farmer transfers his risk to the trader whose trading margin should be sufficient to cover the risk. The volume of rice purchased by traders and the profit rate earned vanes from year to year. There is no basis for accurately predicting whether profit or loss will result from holding stocks during any specific year. The high-loss probabilities present quite a contrast to the picture of windfall profits inferred by the stereotype (Mears et al 1974).

RICE MILLING

The development of the rice milling industry in Asia has passed through a number of distinct phases. Before World War II, most rice was milled by hand pounding, an operation typically done by members of the household. However, in the areas of surplus and export-oriented production, large rice mills were established in the later part of the 19th century near major port cities such as Bangkok, Rangoon, Saigon, and Madras.

As transportation and communications improved, and as Europeans gave way to indigenous ownership and management after the turn of the century, the small up-country mills grew rapidly. Location of the mills near the source of supply reduced both transportation and labor cost, rural labor normally being in excess supply during the height of the milling season.

For the local market and home consumption, hand milling or home pounding gave way to the single huller — a recent transition in the areas of surplus labor and deficit food grain production such as Java and eastern India. Table 3 shows the extraordinary contrast in milling practices among regions in India and Burma before World War II. The officially recorded number of rice mills in India increased from 20,000 in the 1950s to 50,000 at the end of the 1960s. with single hullers representing most of the increase (Lele 1971).

The transition from hand pounding to the single huller, and subsequent attempts to modernize the milling industry by replacing the single huller with a more complete

Table 3. Percentages of machine milled and hand pounded rice in selected states of India and in Burma before World War II.[a]

State	Machine milled (%)	Hand pounded (%)
Assam	3	97
Bengal (India and Bangladesh)	16	84
Bihar and Orissa	10	90
Hyderabad (Andhra Pradesh)	62	38
Punjab (India and Pakistan)	90	10
Sind (Pakistan)	90	10
Total India	27	73
Burma	92	8

[a] Source: India Directorate of Marketing and Inspection 1954.

mill caused considerable controversy. Opponents of modernization emphasized the labordisplacing features and capital intensity of the modern technology. Advocates of modernization pointed to the higher recovery rates that could be achieved not only through the milling itself, but through a more integrated approach toward processing, including more scientific drying, storage, parboiling, and milling of paddy.

The milling process

The earliest and crudest form of rice milling was by hand pestle with mortar or hollowed log, but the steel huller is the most widely used milling machine in Asia today. The equipment is designed to remove the husk and the bran layers of rice in a single operation. The most popular type the Engleberg huller, was originally manufactured in Syracuse, New York, but the design was copied and modified in Indian foundries even before World War II. The hullers are simple in design and easy to maintain and are now locally manufactured throughout most of South and Southeast Asia. Their capacity ranges from 200 to 1,000 km paddy hour. The major shortcoming of the steel huller is its low recovery rate and large percentage of broken grains. while its advantage is its flexibility — it can be located near the site of production to minimize transportation costs. Thus, most of the single hullers are found in the villages where the service area is small, transportation facilities are poor, and quality standards are not assumed to be critical (Esmay et al 1979).

In much of South Asia, large mills selling to the commercial market use as many as 5 hullers set in tandem, with the rice passed from one huller to the next. The hullers can be adjusted to reduce the percentage of broken grains and improve the recovery rate.

A second type of mill commonly found in Asia uses the disc-sheller frequently known as the cono system. It has two stages: the first, when the husk is removed, producing brown rice. and the second. when the brown rice is whitened or polished. In the first stage, the paddy passes through one or more sheller units consisting of two cast-in discs coated with abrasive material. The upper disc is stationary and the lower one rotates. The contact of the grain as it passes between the two discs removes the hulls from the kernel. The brown rice is then passed through two cone polishers.

Compared with the steel hullers, the cono mills have a higher milling recovery, and a higher percentage of head rice. The mills range in capacity from less than 0.5 t hour to more than 4 t hour.

In South Asia. the most common large commercial mills used both hullers and disc-shellers. reflecting an apparent gradual transition in technology.

A third general category of mill uses a rubber roller technology developed in Europe and Japan (Duff 1972). The rubber rollers replace the discs in the hulling operation. permitting a higher rate of recovery and a higher percentage of head rice. The comparatively high initial capital cost and high cost of frequent replacement of rubber rollers have discouraged their widespread adoption in South and Southeast Asia.

Comparison andcomplementarity of alternative systems

The factors to be considered in the comparison of systems include: the input requirements of capital and labor, the cost of milling, the milling outrun, the quality of the milled rice, and the value of byproducts. Table 4 shows the composition of equipment found in typical mills of the type previously described. There are many variations. For example, in Thailand, disc-sheller mills typically have grading equipment to satisfy the demands of the export market.

Table 4. Milling equipment in typical huller, disc-sheller, and modern rice mills.[a]

Equipment	Mill type		
	Huller	Disc-sheller	Modern
Precleaning			×
Paddy grading			×
Hulling	×	×	×
Husk separator		×	×
Paddy separator		×	×
Whitening		×	×
Polishing			×
Rice grading			×
Conveying			×

[a] Adapted from Esmay et al 1979.

In a technical sense, the milling efficiency is measured by the recovery rate. The higher the recovery rate, the smaller the price spread between rice and its paddy equivalent. Table 5 shows that in the transition from hand pounding and steel hullers to disc-shellers and rubber rollers, both the total rice recovered and the percentage of head riceincrease. Results from both the Indian research in the 1960s (CFTRI [n.d.]) and the Philippine research in the 1970s (IRRI 1978) are based upon the investigation of an extremely limited number of mills. One would expect a wide variability in

Table 5. Percentage of milling recovery for 4 types of rice milling.[a]

Type of milling	Husk and bran (%)	Milled rice (%)	Milled rice (%)	
			Head	Broken
		Indonesia		
Hand pounding	37.5	62.5	66.7	33.3
		South India		
Steel huller	36.6	63.4	73.3	26.7
Disc-sheller	32.5	67.5	82.8	17.2
Rubber roller	30.0	70.0	88.6	11.4
		Bicol, Philippines		
Steel huller	33.8	66.2	41.7	58.3
Disc-sheller	31.0	69.0	75.8	24.2
Rubber roller (multipass)	31.0	69.0	77.1	22.9

[a] Indonesia — Timmer (1973). India — Central Food Technological Research Institute (n.d.). Philippines — IRRI (1978).

performance of mills of the same type under actual operating conditions, particularly with respect to percentage of head rice.

There is a sizeable difference in the capital and labor requirements for the mills of the types described previously. The estimated capital and labor requirements for the principal technologies, based on a study by Timmer (1973) of choice of rice milling technology in Java, and subsequent suggested revisions by Collier et al (1974), are shown in Table 6. Timmer (1973) concluded that, in Java, single hullers were superior to larger modern mills, even allowing for a wide range of variation in existing capital and labor costs. At the time Java was moving rapidly away from traditional hand pounding, Timmer sought to convince the Indonesian Government that locally manufactured hullers were superior to larger and more costly imported Japanese mills. His analysis showed that the latter would lead to a substantial reduction in employment without visible economic benefit.

Collier et a1 (1974) criticized Timmer for underestimating the impact of the demise of hand pounding on employment by overestimating the efficiency of hand pounding. The labor efficiency of the huller over hand pounding is greater than 20 to 1. The fact that until 1970 more than 70% of Indonesian rice was hand pounded reflects the extraordinarily low opportunity cost of labor. However, even at the low wage rates that prevailed in Java, the cost of hand pounding is nearly three times that of the huller.

In contrast, Lele (1971) criticized the Indian Government for neglecting the matter of modernization ''while emphasizing the merits of hand-pounding, if not in deeds at least in words." She contended that the government policies indirectly encouraged the expansion of single hullers by hampering the growth of organized mills.

It is, in fact, generally recognized that both single hullers and larger mills have a distinct but important role to play, the former servicing the local village community and the latter the market-oriented producers. Thus, the composition of single hullers and larger mills should change over time with the shift in the proportion of marketed surplus. Duff and Estioko (see Araullo et a1 1976) indicated that in the Philippines in 1968, 80% of the rice mills were single hullers, accounting for 53% of the rated capacity; the remainder were disc-shellers. In India, in the mid-1970s, about 85% of the mills were single hullers. Therefore, a considerable amount of Indian rice destined for commercial channels was still processed in the single huller. Until the early 1970s, in Indonesia, a sizeable portion of marketed surplus was hand pounded.

Table 6. Investment costs and labor requirements for various milling facilities in the early 1970s.

Type of milling	Milling capacity (kg/h)	Investment cost (US $)	Laborers (no./mill)	Labor input (h/t)
		Per unit		
Hand pounding	4	0	2	500
Steel huller	200	3,000	5	25
Disc-sheller (1 t/h)	1,000	10,000	27	27
Modern (10 t/h)	10,000	100,000	39	4

Utilization

A common feature of the rice-milling industry in Asia is the inadequate use of its technical potential or installed capacity (Table 7). The installed capacity of a rice mill is usually calculated by multiplying the per-hour capacity by the number of hours the mill can technically operate during the year — a hypothetical or ideal potential of operating capacity (FAO 1965). The underutilization observed in Table 7 is often referred to as the problem of *excess capacity.* It would be incorrect, however, to conclude that such excess capacity is a sign of inefficiency.

Table 7. Degree of utilization of capacity in rice mills for selected countries, 1964.[a]

Country	Mills (no.)	Installed milling capacity (1000 t/yr)	Amt milled (1000 t/yr)	Degree of utilization (%)
India	44,057	28,485	8,605	30
Japan	39,128	18,510	5,968	32
Sri Lanka	1,100	935	462	49
Thailand	14,099	42,297	5,029	12
USA	55	3,115	2,223	71

[a] Source: FAO (1965).

Seasonal variation in production and in demand for processing services is one obvious reason for excess capacity. Utilization of the small single-huller service mills, particularly, is closely related to the seasonal pattern of production and marketing. Because variable costs (fuel, labor, etc.) per unit of rice milled do not differ greatly among the types of mills, those mills with larger fixed costs must have a higher utilization rate to achieve a break-even point between cost and returns. In the Philippine study cited above, the steel huller mills surveyed were operating at approximately 20% of capacity (i.e. 3,500 hours/year), the small cono mills (1 t/hour) at 35%, and the large cono mills (10 t/hour) at 65% (IRRI 1978).

The commercial mills purchase and store paddy. The purchase of paddy requires a substantial amount of working capital. Funds are often borrowed at high interest rates, and, as previously noted, substantial risks are associated with a possible decline in the rice price. The optimum level of utilization, therefore, reflects a balance between the economies associated with size and the financial constraints associated with storing large amounts of paddy.

A substantial part of calculated underutilized capacity (Table 7) reflects apparent, rather than real, excess capacity. However, excess capacity arises as a result of the changing structure and location of the rice milling industry. As the rural areas of Asia have developed, commercial rice mills have gradually moved nearer the source supply. Excess capacity tends to occur in the areas of traditional milling near the urban centers.

Most governments in Asia have attempted to control the expansion, location, and operation of rice mills through licensing. Such controls, however, do not seem to

have been particularly effective in promoting the orderly development of the rice milling industry. In fact, government attempts to *modernize* the rice processing industry have met with limited success.

GOVERNMENT INTERVENTION

Government intervention in the Asian rice market became pronounced after World War II. The objectives were both social and economic. They included:

1. appropriation of trading profits;
2. supply of subsidized food grains to low-income consumers or other special-interest consumer groups;
3. control of unhealthy competition or of monopolistic power;
4. redistribution of marketing activity between different social classes;
5. the commercialization of subsistence agriculture; and
6. the promotion of *modernization* or improvements in marketing.

The methods of intervention included regulatory measures, direct or indirect financial support in the construction of transportation, storage, and marketing facilities, and direct procurement of a portion of the rice stock. In the achievement of government goals, some measures were more efficient than others.

Regulatory measures

Government pricing of rice is an important regulatory measure and nearly all governments engage in various forms of price regulation. Among the less developed countries of the region, pricing policy appears to have had a consumer bias, as central governments have sought to ensure a cheap supply of rice from the rural areas to meet urban demands. Gradually, as countries develop, there appears to be a pronounced shift toward producer bias in rice policy (Table 8). Philippine and Indonesian prices are close to the world market level. The prices in Malaysia and the East Asian countries are significantly higher, reflecting a strong producer-oriented policy. Those in Thailand and Burma are much lower, reflecting the fact that these exporting countries tax producers to obtain government revenue. A ratio of retail rice to farm paddy rice of about 2 reflects a reasonable marketing margin but does not necessarily indicate the absence of excessive middlemen profits. When the ratios are significantly lower, governments may be subsidizing marketing operations.

Another popular form of regulation is the licensing of firms and dealers, usually with the objective of controlling entry. As noted previously, government licensing in India seems to have encouraged the proliferation of single huller mills and to have discouraged the entry of larger and more modern mills (Lele 1971). In the Philippines the Rice and Corn Board was established in 1958 to license rice traders to specifically reduce the control of Philippine rice marketing activities by Chinese middlemen.

Most Asian governments have established a grading system for the purchase and sale of rice to improve quality and reduce loss or spoilage. However, except in the

Table 8. Relation of farm and retail rice prices, mid-1976 to mid-1978.[a]

Location	Farm paddy rice ($/kg)	Retail milled rice ($/kg)	Kg milled/ kg paddy	Bias
Bangladesh (Joydebpur)	0.12	0.21	1.8	C
Burma (Rangoon)	0.06	0.13	2.2	C
China (Kwantung)	0.10	0.14	1.4	C
India (Coimbatore)	0.11	0.22	2.0	C
India (Cuttack)	0.11	0.21	1.9	C
India (Waltair)	0.10	0.21	2.1	C
Indonesia (Central Java)	0.17	0.32	1.9	N
Japan (Ibaraki)	0.78	1.15	1.5	P
Korea (Suweon)	0.51	0.67	1.3	P
Malaysia (Selangor)	0.19	0.40	2.1	P
Nepal (Kathmandu)	0.18	0.26	1.4	N
Pakistan (Punjab)	0.09	0.30	3.3	C
Philippines (Central Luzon)	0.15	0.28	1.9	N
Sri Lanka (Kurunegala)	0.19	0.27	1.4	N
Taiwan (Taichung)	0.24	0.37	1.5	P
Thailand (Suphan Buri)	0.10	0.20	2.0	C

[a]Source: Palacpac (1980). C = Negative producer bias, N = neutral, P = positive producer bias.

more developed countries of the region, government grading standards are not implemented at the farm level. Traders have tended to develop their own quality standards and it is frequently argued that this is one mechanism by which they exploit producers. Siamwalla (1975) noted that interest in quality on the part of middlemen is not a constant factor, with the buyers being more quality conscious in times of falling prices. It is difficult to discern how much of this grading acts to depress prices received by farmers.

Other steps have been taken in an apparent effort to reduce middlemen profits in the rice market. They include the promotion of cooperatives as an alternative marketing channel. However, the failure of rice marketing cooperatives in countries such as Malaysia and the Philippines is another indication that Asian rice marketing tends to be highly competitive. By contrast, the earlier success of the cooperatives in Taiwan must be explained largely in terms of the monopolistic control bestowed on them by the government, particularly for the purchase of rice and sale of fertilizers through the now-defunct rice-fertilizer barter system.

Transportation and communication

Improvements in transportation and communication automatically improve the efficiency of marketing in many ways (Krishna 1967). Price differentials between markets are reduced because supplies can be more cheaply transferred from low-price to high-price markets. Isolated producing regions are opened to the extent that marketing margins are reduced and the production incentive is increased. Recognizing the importance of keeping farmers and traders aware of demand-supply and

price conditions, many governments disseminate daily information on rice prices.

Government procurement

Government procurement operations vary widely among countries and within a given country over time. In some exporting countries, such as Burma, and exporting regions, such as the Punjab of India, the government has traditionally procured most of the marketed surplus and has thus retained the trader's profit. In Thailand, on the contrary, exports pass through private channels and the government extracts revenue through taxes. The subsidization of production and marketing activities in countries such as Japan and Sri Lanka and, more recently, Taiwan and Korea, had led to a high level of government procurement. The Philippine and Indonesian governments have historically procured only a small portion of the total rice crop, their efforts in part being directed toward bolstering rural prices in years of surplus production.

In periods of shortage, governments typically attempt to defend price ceilings through importation. In periods of surplus, they defend price floors by stepping up the purchase of domestic supplies. During these periods the private marketing system comes under attack and middlemen are accused of reaping excess profits through hoarding or through purchase of paddy at low and discriminating prices. Governments frequently become more active in procurement during these periods. For example, government procurement as a share of total production rose dramatically in India during the period of severe shortage in the mid-1960s and again during a period of significant surplus in the mid-1970s. Philippine Government purchases rose sharply in the mid-1970s also during a situation of relative surplus.

Periods of rapid increase in government procurement do not necessarily imply an expansion in facilities. Government operations are frequently carried on through lease of private facilities or direct contract with private firms. For example, in Sri Lanka, despite the procurement of a large portion of the rice for distribution under the government rationing program, the bulk of the rice is milled in private facilities.

There is much debate regarding the government's role in the direct procurement of rice stocks. Ostensibly the government intervenes to protect consumer and producer interests. However, evidence suggests that private marketing is relatively efficient, and that middlemen profits are not excessive. Any loss in efficiency through government operations should be offset by equivalent social gain. Where the government has limited resources and controls only a small portion of the crop, government buying and selling activities often serve the interests of only a few privileged producers and consumers. This appears to have been the experience in countries such as Indonesia and the Philippines.

A few government activities, such as the improvement of transportation and communications, can enhance marketing efficiency. Other activities have social objectives. Whether the social benefits of many of these activities exceed social costs is a subject of continuous debate and little serious research. However, governments are often more effective than middlemen in exploiting many for the benefit of the privileged few.

MODERNIZATION

The rice milling industry is competitive. At the same time, the existing high level of *technical* inefficiency leads to considerable loss between the time the rice is harvested and the time it finally reaches the consumer. Low milling recovery rates and high losses in storage are evidence of technical inefficiency. Since the 1960s there has been increasing talk about modernizing the processing industry. However, steps taken in that direction have frequently failed. To understand why, we need to understand the concept of *modernization* as it is commonly described and understood.

Modernization of processing implies an improvement in the recovery rate of rice from paddy and in the quality of the final product. Both the recovery and the quality can be improved by improving the technical efficiency of postharvest operations, including drying, handling, storage, parboiling, milling, and transport. For example, the use of mechanical driers, instead of traditional sun drying of the grain, can reduce the number of brokens; bulk storage in well-constructed sites can reduce losses due to rodents, insects, and moisture damage; and rubber roller mills can give the highest recovery.

In the late 1950s four large milling complexes with on-site storage were constructed in the Philippines as one of the first attempts to introduce modern facilities. These facilities have been idle after a year's use. The reasons given for failure are numerous — faulty design and construction, wrong location, poor management, etc. In Sri Lanka, four modern complexes constructed by the government in the mid-1970s are virtually idle. The reasons for failure are similar.

A second type of failure was recently experienced in Indonesia. Although technically successful, the introduction of modern Japanese milling equipment in the 1970s has led to an excessive substitution of capital for labor and hence an economically and socially inefficient outcome (Timmer 1973, Collier et al 1974).

Less radical but more successful attempts at modernization have involved the modification of existing mills. For example, in a large number of mills in Thailand rubber rollers have replaced the second of two disc huskers in the hulling operation (Somboonsub 1976).

The most comprehensive attempt to study the technical efficiencies of modernization involved the comparison of seven modern rice mills in India with traditional mills (CFTRI [n.d.]). The recovery rates from this study, reported in Table 6, provide a reasonably accurate picture of recovery rates among milling systems.

In recent years research workers have come to recognize rice processing as a system that, like the farm production system, must be viewed holistically. Whether this new focus on the rice processing industry as a system can assist in indentifying technology appropriate for achieving social and economic, as opposed to technical, efficiency remains to be seen. The problem is that most policy planners and technicians continue to associate modernization with technical efficiency.

IMPLICATIONS FOR MARKETING RESEARCH IN CROPPING SYSTEMS

A major focus of cropping systems research is the design and development of new

technology for production. Although marketing problems are often blamed for the failure in attempts to introduce new crops and new technology, marketing research has received relatively little emphasis. Furthermore, in rice-based cropping systems, most of the attention on marketing has been focused on rice. Knowledge of the marketing of other crops is much less extensive. Yet, it is perhaps reasonable to assume that the problems in marketing these other crops are more severe largely because the markets are less well developed. Two useful articles that form much of the basis for my discussion in this section are by Siamwalla (1975) and Smith (1973).

Despite the rapid increase in production that accompanied the introduction of the new rice technology in many parts of Asia, problems of marketing have not been as serious as might be expected. In some regions, and in some years, an acute shortage of storage and transportation facilities has resulted in large losses. In general, however, the constraints on production were more clearly associated with problems in distributing new inputs such as seeds, fertilizer, and chemicals, than with the problems in marketing the product. The reason seems clear. The market structure for rice, although not modern by western standards, was well developed and reasonably efficient. Furthermore, to the degree that there was excess capacity, this was undoubtedly a benefit in handling a rapid growth in supply.

A major objective of cropping systems research is to design new technology and introduce improved cropping patterns. To understand the implications of these changes for marketing, it is useful to distinguish among crops with basically different marketing structures.

Traditional subsistence crops, including rice, maize, and cassava, generally have welldeveloped markets and offer few problems. Until recently the purchased input requirements for these crops tended to be low. The processing industry is relatively small scale. A fairly simple investigation can determine the degree to which markets are competitive, marketing margins are reasonable, and farm production is either subsidizing or taxed.

A second set of commodities, with large-scale processing industries, includes sugarcane, pineapple, and, in some instances, soybean for feed. The large processing plants must operate reasonably near capacity to spread the heavy fixed costs. Given the risk involved in these large investments, it is sometimes considered advantageous on the part of the processing industry not to rely on the market mechanism and the growers' decisions for their supply. The sugar mills, for example, conclude, at planting time, contracts with a number of producers or middlemen who agree to supply them with the required amount of cane at harvest. The delivery schedule is also worked out in advance. Forward contracting for supply facilitates the advancing of credit to the growers for purchase of inputs.

A third and more important category of crops from the perspective of rice-based cropping systems is the relatively less important field crops such as mungbean, peanut, sweet potato, and soybean. Markets for such crops are more highly developed in some parts of Asia than in others. Opportunities for broadening the market for a crop are determined by a combination of the characteristics of the crop and the characteristics of the market. For example, the degree of perishability of the crop,

and the relative efficiency of the marketing and transportation network will determine whether the crop can be exported from a given region to urban consumers. With a thin market and a highly perishable crop, the producers are obviously more subject to the risks of price fluctuations and the monopolistic control of the buyers. The government would, in this situation, appear to have a stronger role in promoting market development, stabilizing prices, enforcing grading standards, and curbing monopolistic activities than in the case of rice. In fact, the success of most governments in this area is mixed. An initially low capacity to administer such activities in developing countries is inherent to the development process. Improvement of transportation and communications, and other facilities, such as storage, should initially receive the most government attention. In this respect, the recommendation for government intervention is no different than that in rice marketing. The extension of credit for marketing and for production and, in some cases, the promotion of institutions such as marketing cooperatives may be justified.

Research workers attempting to understand the market structure of various crops in the rice-based cropping systems are also faced with limited resources. Detailed studies of the marketing systems for each of the crops may not be possible. It is important to recognize that the marketing system, like the production system, can benefit from the design and introduction of new technology. For example, without marketing innovations, Taiwan could not readily have achieved its success in agricultural exports. Should the design of cost-reducing marketing technology be an integrated part of research in rice-based cropping systems?

It is also important that some judgment as to the potential for broadening the market be made. Smith (1976) has developed a series of questions that would be useful in assessing market potential. These brief survey schedules are designed for questioning producers, consumers, and processors to obtain insights into the structure and potential capacity of the markets. The general categories of information could be classified as follows:

1. Price data — Information on seasonal price fluctuations is important in designing the cropping sequence. Price information at the farm level and at different market outlets is important in assessing the marketing margin and the likely competitiveness of various crops in different markets. Ultimately we would like to know the effect of increased production on farm price through estimates of the price and cross elasticities of demand and the effect of increased incomes over time on consumption, or the income elasticity of demand. Crude estimates of these impacts would suffice as a start.
2. Consumption — What are present local, national, and international consumption levels and trends for the commodity in question?
3. Production — If prices are maintained at current levels, what is the potential increase in production in the area? Are production trends rising, stable, or declining?
4. Marketing channels — What are the present marketing channels and what proportion of the crop is marketed outside of the local producing area? What is the status of transportation and the capacity of storage and processing?

The procedure outlined above might be described as rapidmarket assessment. A primary objective of such research is to answer the question, "If crop production is expanded, what will happen to the farm price?" The results of such analysis may point to constraints in the marketing structure, which, if removed, could lead to expansion in production.

Finally, it should be remembered that because of the inelastic nature of demand for many farm commodities, any benefit of improvement in production technology and marketing may ultimately be transferred largely to the consumers in the form of lower prices.

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GROWTH AND EQUITY IN NEW RICE TECHNOLOGY: A PERSPECTIVE FROM VILLAGE STUDIES

M. KIKUCHI and Y. HAYAMI

Asian village communities have been experiencing a major change. In some areas, land-labor ratios have been declining rapidly due to an explosive population growth rate. To sustain a subsistence level of income, attempts have been made to increase land productivity — efforts that are reflected in the development and diffusion of a modern seed-fertilizer technology and in the expansion of irrigation systems. Despite those efforts, the value of labor has declined relative to the value of land. These shifts in resource endowments and technology work as a strong pressure for change in village institutions that were molded under a relatively stationary condition.

The village institutions that relate to labor, land, and other inputs are the critical channels through which population pressure and technological change influence production and income distribution in the rural sector. They are also the channels through which government policies, such as the land reform and irrigation development programs, affect the welfare of rural people.

In this paper, on the basis of a comparison of an Indonesian and a Philippine village, we attempt to analyze the process by which village institutions change in response to changes in resource endowments, technology, and government policies. In so doing, we try to assess the influence of new rice technology on economic growth and income distribution in rural communities.

VILLAGES STUDIED

An Indonesian and a Philippine village were compared, The Indonesian village is in the Subang Regency of West Java and the Philippine village is in Laguna Province at the southern edge of the Central Luzon Plain. The two villages were among those covered by a larger study to identify changing patterns in village institutions and income distribution.

The two villages were selected, partly because they are fairly representative of respective regions in their socioeconomic characteristics, and partly because they have similar environmental conditions. Both villages are in rice monoculture areas

Associate agricultural economist, IRRI; and professor, Tokyo Metropolitan University, Tokyo, Japan,

characterized by double cropping in well-irrigated fields. Both are relatively self-contained and similar in degree of urban influence, commercialization, and off-farm employment opportunities, but highly different in other characteristics such as man-land ratio and land tenure.

DATA COLLECTION

Data were mainly collected from interviews, in the Laguna village in November 1976-January 1977 and in the Subang village in January 1979. The surveys covered all households in the villages. Data collected refer to mainly those of 1976 for Laguna (stock data such as population and landholding as of the end of 1976, income data for 1976, and rice farming data for the 1976 wet season) and those of 1978 for Subang (stock data as of the end of 1978, and income data for 1978, and rice farming data for the 1978 dry season). To the extent possible, historical data for the past decade were collected.

A major advantage in selecting the two villages for comparison is that earlier data with which historical changes can be ascertained are available. Umehara (1967) made a survey of the Laguna village in December 1966. The Subang village was covered by the Rice Intensification Survey (*Intensifikasi Padi Sawah*) by the Agro-Economic Survey of Indonesia for 1968-69 and 1972-73 wet seasons. Our analysis compares changes in Laguna during 1966-76 and Subang during 1968-78.

AGRARIAN STRUCTURE AND INCOME DISTRIBUTION

Although the two villages have similar environments, their land tenure systems and farm-size distributions are highly different. Rice farming in the Subang village, like most other villages in Java, is characterized by owner cultivation (Table 1). In contrast, almost all farmers in the Laguna village were tenants; as much as 98% of

Table 1. Distribution of households by land-tenure status in sample villages in Indonesia and the Philippines.

	Subang, Indonesia 1978		Laguna, Philippines 1976	
	No	%	No	%
Farmer	*83*	*75.4*	*54*	*49.6*
Owner	67	60.9	0	0
Owner/leasehold	1	0.9	3	28
Owner/share	12	10.9	0	0
Leasehold	0	0	28	25 7
Share	3	2.7	15[a]	13.8
Leasehold/share	0	0	8[a]	7.3
Nonfarmer	27	24.5	55	50.4
Noncultivating landlord	3	2.7	1	0.9
Landless laborer	24	21.8	54	49.5
Total	110	100.0	109	100.0

[a] Includes subtenants.

the rice land was owned by landlords living outside the village. Traditionally the dominant form of tenancy was sharecropping, but because of the land reform programs, most of the tenants became leaseholders from the late 1960s to the early 1970s. The rent of leasehold land was fixed by law at 25% of average output for 3 normal years before the conversion in tenure status.

The percentage of landless laborers was much higher in Laguna than in Subang. About 50% of households in the Laguna village and only about 20% in the Subang village belonged to the landless labor class. However, in Subang about 25% of households were *near landless* and cultivated less than 0.1 ha and depended mainly on wage earnings from farm work. On the other hand, in Laguna the *near landless* who cultivated less than 0:5 ha were rare exceptions, mainly because landlords had traditionally tried to avoid subdividing tenants' operational holdings into small units because of the larger transaction costs involved. Considering the high proportion of near landless households in Subang, the percentages of population whose income depended primarily on wage earnings were about the same for Laguna and Subang.

In both villages there was a high degree of class differentiation in distribution of incomes and landholdings among households (Table 2). In terms of the Gini coefficient, the farm distribution was less equitable in Laguna than in Subang, whereas the income distribution was more equitable in Laguna. Such reverse orderings in degree of equality in the distribution of landholdings and incomes reflect different patterns in the use of labor in farm production.

The average size of landholding per household was much smaller in Subang than in Laguna. The Subang village had 419 persons in the 113 households whose living mainly depended on only 24 ha of rice land. The average operational landholding per household was only 0.23 ha. The man-land ratio was as high as 16 persons/ha. The Laguna village had 644 persons, 109 households, and 108 ha of rice land; the average landholding per household was about 1 ha and the man-land ratio was 6 persons/ ha. The smaller farm size and the higher man-land ratio in Subang were associated with the lower per capita income than in Laguna (Table 2).

POPULATION PRESSURE, IRRIGATION, AND NEW TECHNOLOGY

Typical of irrigated rice-growing areas in Asia, both villages are densely populated and put strong population pressure on the land. Java has long experienced population pressure and has had a population density of nearly 193 persons/ km^2, one of the highest in the world.

The Philippines had been characterized, until recently, by open cultivation frontiers and an abundant supply of unexploited land. However, with population growth at more than 3%/ year, the supply of unexploited land began to be exhausted toward the end of the 1950s, and the man-land ratio in agriculture has since increased.

Such differences in the demographic pattern between Java and the Philippines are, to some extent, reflected in the trends of population and man-land ratio

Table 2. Size distribution among households of land holdings and incomes in sample villages in Indonesia and the Philippines.

Quintile class	Subang, Indonesia, 1978			Laguna, Philippines, 1976	
	Operational landholding (ha/house-hold)	Land ownership (ha/house-hold)	Income [a] (kg/person)	Operational landholding (ha/house-hold)	Income [a] (kg/person)
		Class av			
I (bottom)	0	0	167	0	326
II	0.05	0.05	260	0	477
III	0.15	0.13	350	0.17	637
IV	0.27	0.24	467	1.30	817
V (top)	0.66	0.70	1510	3.44	1808
Total	0.22	0.23	599	0.99	914
		Class share (%)			
I (bottom)	0	0	5	0	5
II	5	5	8	0	9
III	13	12	11	4	13
IV	24	21	17	26	22
V (top)	58	62	59	70	51
Total	100	100	100	100	100
Gini coefficient	0.54	0.56	0.47	0.66	0.42

[a] Incomes in local currencies are converted to the rough-rice equivalents based on local rice prices.

Table 3. Changes in population, cultivated land area, and man-land ratio in sample villages in Indonesia and the Philippines.[a]

Year	Subang, Indonesia			Laguna, Philippines		
	Land area[b] (1) (ha)	Population (2) (persons)	Man-land ratio (2)-(1) (persons/ha)	Land area[b] (3) (ha)	Population (4) (persons)	Man-land ratio (4)-(3) (persons/ha)
1900	13	67	5.2	52	94	1.8
1940	24	220	9.2	94	226	2.4
1950	24	276	11.5	104	281	2.7
1960	24	333	13.9	104	349	3.4
1966				104	393	3.8
1970	24	387	16.1	107	518	4.8
1974				111	549	4.9
1976				108	644	6.0
1978	24	41 9	17.5			

[a]Land area and population are estimated by extrapolation and interpolation of benchmark data. [b]Paddy-field area.

(Table 3). Both villages were settled by migrants from neighboring villages in the late. 19th century and recorded high rates of increase in both population and farmland for the first few decades of the 20th century. However, the cultivation frontier in Subang closed before 1940 and the population growth has since decelerated. The man-land ratio more than doubled from 1900 to 1950 but increased by 50% from 1950 to 1978. On the other hand, the cultivation frontier was not closed in the Laguna village until the 1960s but the population growth rate did not decelerate as in Subang, and the man-land ratio more than doubled after 1950. Note that although the population growth decelerated 2-3 decades ago in the Subang village, a high rate of growth in labor force continued until recently because children born earlier successively joined the labor force.

With the supply of cultivated land limited, an increase in labor force results in greater competition for employment on a limited area. *Ceteris paribus,* the wage rate is bid down, corresponding to the decline in marginal productivity of labor applied in a larger amount per unit of land area. Correspondingly, both the land rent and the marginal productivity of land rise. The population pressure on limited land area results in the accruing of the higher share of income to landlords and of the lower share to laborers, as postulated by classical economists like Ricardo (1951).

In fact, efforts have been made to counteract the decreasing return to additional labor applied per unit of land. In the Laguna village the national irrigation system was extended to the area in 1958. The system enabled the farmers to double-crop rice in all fields, thereby doubling the effective crop area.

Another major change was the introduction of modern semidwarf rice varieties developed at IRRI and its neighbor, the University of the Philippines at Los Baños. According to the Umehara survey (1967). no one in the village had tried modern varieties in 1966. In 1976, 100% of the farmers planted them. The diffusion of modern varieties was accompanied by the application of fertilizers and chemicals and by the adoption of improved cultural practices such as intensive weeding and

straight-row planting.

As a result of the improvements in irrigation and technology, the average paddy yield in this village increased from a single crop of 2.5 t/ha in 1956 to a double crop of 6.7 t/ha in 1976.

The traditional communal irrigation system in the Subang village was well developed and rice double cropping commonly practiced, but no significant improvement was recorded for the past several decades. As in the Laguna village, the introduction of modern varieties began in late 1960s — under the *Bimas* program — but because the new rices were highly susceptible to insects and diseases, many farmers who tried them shifted back to traditional varieties. At the time of our survey, only 14% of the farmers were still growing modern varieties although as many as 83% of them had once tried modern varieties. We note, however, that the experience in this village was not necessarily typical because modern varieties were successfully introduced in many areas in Subang.

Fertilizer application in Subang increased, however, from about 180 kg/ ha in 1968 to 230 kg/ ha in 1978. It appears that this increase was induced by the sharp decline in the fertilizer-rice price ratio, which resulted to a large extent from a government subsidy on fertilizer under the Bimas program.

The average rice yield in Subang for 1968-71, estimated from the earlier survey, was about 2.6 t/ha, whereas the average yield for 1978 from our survey was 2.9 t/ha. The relatively modest increase in rice yield corresponds to the absence of modern varieties adequate for the environmental condition specific to this area. It is difficult to ascertain from our data how significant the yield increase was, because the yields were affected by weather fluctuations. However, if we assume that the data reflect the real yield increase, the increase must have resulted mainly from the increase in fertilizer application.

WAGE RATES AND LABOR INPUTS

Reflecting its more unfavorable man-land ratio, the real wage rate, as measured by an average daily wage in paddy terms was about 40% lower in Subang than in Laguna (Table 4). Furthermore, the wage gap widened over time. In Subang the real wage rates declined more than 10% for 1968-78. In Laguna the real wage rates for land preparation and weeding showed rising trends although transplanters' wages declined. The data suggest that the real wage rate in Laguna, on the average, increased slightly or, at least, did not decline.

The slightly rising or stable trend in the real wage rate in the Laguna village suggests that the decreasing return to labor due to the population pressure on land was compensated for by the upward shift in rice production function resulting from the diffusion of modern varieties and related technologies. In the Subang village, a decrease in the real wage rate occurred because new technology suited for the area was not developed to counteract the decreasing return to labor.

Changes in labor inputs for rice production also followed different patterns (Table 5). Both villages recorded similar rates of growth in total labor input per hectare; in

Table 4. Changes in wage rates in sample villages in Indonesia and the Philippines.[a]

Location, year	Nominal wage rate[b] ($/day)			Paddy price ($/kg)	Real wage rate[c] (kg/day)			
	Land preparation	Trans-planting	Weeding		Land preparation	Trans-planting	Weeding	Av.
Subang, Indonesia								
1968	0.30	0.16	0.16	0.03	9.5	5.2	5.2	6.6
1978	0.88	0.48	0.48	0.10	8.5	4.6	4.6	5.9
			Rate of change (%)					
1968-71 to 1978	197	200	200	235	-11.0	- 12.0	- 12.0	-11.0
Laguna, Philippines								
1966	0.61	0.46	0.41	0.05	11.3	8.5	7.5	9.1
1976	1.63	1.14	1.09	0.14	12.7	8.2	7.8	9.5
			Rate of change (%)					
1966-78	189	147	1 67	155	12.0	-4.0	4.0	4.0

[a] $1 = 625 Rp. = $7.35. [b] Includes the cost of meal. [c] Nominal wage rate divided by paddy rice.

Table 5. Changes in labor inputs for rice production[a] **in sample villages in Indonesia and the Philippines.**

	Labor input (mandays[a]/ha)											
	Subang, Indonesia						Laguna, Philippines					
	1968			1978			1966			1976		
	Family	Hired	Total	Family	Hired	Total	Family	Hired	Total	Family	Hired	Total
Land preparation	16	37	53	23	42	65	14	4	18	5	6	11
	(30)	(70)	(100)	(35)	(65)	(100)	(78)	(22)	(100)	(45)	(55)	(100)
Transplanting, weeding, and other crop care	12	28	40	22	33	55	25	12	37	22	35	57
	(30)	(70)	(100)	(40)	(60)	(100)	(68)	(32)	(100)	(39)	(61)	(100)
Harvesting and threshing	0	41	41	0	41	41	0	32	32	4	34	38
	(0)	(100)	(100)	(0)	(100)	(100)	(0)	(100)	(100)	(11)	(89)	(100)
Total	28	106	134	45	116	161	39	48	87	31	75	106)
	(19)	(79)	(100)	(28)	(72)	(100)	(45)	(55)	(100)	(29)	(71)	(100)

[a] One manday = 8 hours. Figures within parentheses are percentages.

Subang it increased by 20%, from 134 days/ ha per crop season to 161 days/ ha in 1978 and in Laguna by 22%, from 87 days/ ha in I966 to 106 days/ha in 1976. However, changes in the distribution of labor inputs among tasks were very different.

In Laguna, the labor required for land preparation was reduced because of a substitution of power tillers for carabaos. However, this reduction was more than compensated for by the large increase in weeding labor that accompanied the diffusion of modern varieties. In Subang, labor use for land preparation increased because of the substitution of animal plowing by hand plowing; the shift from animal power to manual labor resulted from the decline in the labor wage rate relative to the animal rental cost. Such contrasting patterns show that the population pressure reached a much more serious stage in Subang, where new land-saving technology failed to develop to counteract the decreasing return to labor.

Another major contrast can be observed in changes in the composition of family and hired labor. The percentage of family labor increased in Subang but it decreased in Laguna. The increase in hired labor for weeding was especially marked in Laguna. The relative increase in use of family labor in Subang seems to reflect the fact that small farmers whose landholdings were further fragmented by growing population pressure tried to supplement their reduced income by reducing the use of hired labor. In Laguna, share tenants who became leasehold tenants with low fixed land rents captured major income gains from rice yield increases because of developments in irrigation and new rice technology. The income effect worked to substitute hired labor for family labor.

CHANCES IN RICE HARVESTING SYSTEMS

Growth in labor force and the resulting decline in the real wage rate have had pervasive impacts on employment relationships among villagers. Changes in labor contracts and their effects on income distribution have been expressed most dramatically in the changes in rice harvesting systems. Rice harvesting represents the most important occasion in the village economy — the time at which the output is shared among various resource contributors, such as landlords, farmers, and laborers. Traditionally, in rice-growing areas in Asia, all villagers were allowed to participate in harvesting and receive a certain share of output. Such traditional institutions based on the community principles of mutual help and income-sharing have been induced to change by changes in relative factor endowments and technology.

In Java the traditional bawon system that allowed wide sharing of output has been replaced by the new tebasan system in which farmers sell a standing crop to middlemen who limit participation in harvesting to contract workers and reduce the harvesters' share (Collier et al 1973, 1976; Utami and lhalauw 1973).

In the Subang village, as well as in neighboring villages, the tebasan system has not been introduced. However, the traditional bawon system has been replaced by another system called ceblokan, which also limits participation in harvesting. In the

ceblokan system, only the workers who performed extra services without pay for such tasks as transplanting and weeding are employed for harvesting. The adoption of the *ceblokan* system has reduced the real wage rate of harvesters because the same share of output *(bawon)* is paid for a larger amount of work. Although *ceblokan* was introduced into the Subang area rather recently, it is old in several other places in Java (recorded since the 19th century); and has long been a common practice, especially in the northeastern West Java (Hayami and Hafid 1979).

Surprisingly enough, an almost identical change in the rice harvesting system occurred in Laguna, as in Subang, despite differences in histories and socioeconomic conditions. In the traditional system in Laguna called *hunusan,* everybody in the village was allowed to participate in rice harvesting, and the harvesters were entitled to the one-sixth of output. The system has been rapidly replaced by a new system called *gama,* in which only those who did weeding without wages were employed in harvesting for the same share of output. The *gama* system has diffused widely in the province of Laguna and some other provinces in Central Luzon (Kikuchi et al 1979).

Diffusion of *gama* in the Laguna village under study began in 1960, and by 1976 more than 80% of the farmers had adopted the system (Table 6). The *ceblokan* system was first introduced in the Subang village in 1964 and more than 95% of the farmers were adopting it by 1978. It may appear that the change in harvesting systems began later in the Subang village than in the Laguna village. However, significant changes had occurred in Subang before the *ceblokan* system was introduced.

Even before the introduction of *ceblokan,* not all the farmers in Subang had practiced *purely open bawon,* which allowed everyone to participate in harvesting. The system nearest to the traditional purely open *bawon* harvesting as a communal activity was that in which harvesting was open only to villagers in the same village. Another system placed a further limit on the maximum number allowed to participate. Restriction was severe when participants were limited to those who received specific invitations from farmers. Farmers gradually shifted from more open *bawon*

Table 6. Diffusion of gama and ceblokan systems in sample villages in Indonesia and the Philippines.

Year	Farmers adopting (%)	
	Ceblokan in Subang, Indonesia	Gama in Laguna, Philippines
Before 1960	0	0
1960	0	3
1962	0	5
1964	27	14
1966	52	30
1968	70	31
1970	88	48
1972	92	63
1974	93	80
1976	96	83
1978	96	

Table 7. Changes in rice harvesting system in a sample village in indonesia.

	Farmers adopting (%)								
	Bawon[a]			*Ceblokan*[b]					
Year	PO	OV	OM	1/6(T)	1/7(T)	1/7(T+W)	1/7(H+T)	1/7(H+T+W)	Total
1978			4		72	19	1	4	100
1976-77			4	7	67	18	2	2	100
1974-75			7	15	67	10	1		100
1972-73			8	17	67	8			100
1970-71		2	10	33	51	4			100
1968-69	1	4	6	19	44	24	2		100
1966-67	3	10	8	27	52				100
1964-65	9	16	16	32	27				100
1962-63	16	34	33	17					100
1960-61	29	31	21	19					100
1950s	35	29	18	18					100

[a]*Bawon* system: PO = purely open, OV = open for villagers only, OM = open with maximum limit, LI = limited to invitees. [b]*Ceblokan* system: 1/6,1/7-harvesters' share, T, W, H = obligatory operation to establish the harvesting right (T = transplanting, W = weeding, H = harrowing).

to more restricted *bawon* until *ceblokan* was introduced (Table 7).

Likewise, the *ceblokan* system itself includes a spectrum of arrangements in terms of harvesters' share and obligatory works. Originally, ceblokan harvesters received a traditional share of one-sixth for the additional service of rice transplanting without pay (usually meals were served even though cash wages were not paid). Later, their share was reduced to one-seventh, and weeding and harrowing were added to the list of services required to establish the harvesting right. Changes in harvesting systems, as summarized in Table 7, show successive shifts from more open and more generous arrangements to more restrictive and less generous ones. Underlying this process was the decline in the return to labor relative to the return to land and capital because of the growth of labor force against limited land resources.

Both the *ceblokan* and the *gama* systems can be considered as an institutional innovation for theemployer farmers to reduce the wage rates for harvesting to a level equal to the market wage rates. In earlier days, when labor was scarcer and rice yield lower, the one-sixth share of output under the traditional *bawon* and the *hunusan* systems might have been equivalent to the market wage rate close to the marginal product of harvesters' labor. However, as the labor supply became more abundant and the rice yield increased, one-sixth of the output would have become substantially larger than the marginal product of labor.

In such a situation, farmers could increase their income by replacing the *bawon* or *hunusan* system with the labor of daily wage workers. However, the cost arising from resistance to a change in the long-established custom in the village community would have been quite large. Another possibility was to reduce harvesters' share in the *bawon* system. That was easier and was, in fact, practiced. However, the reduction of the share rate, too, would not have been quite so consistent with the

basic moral principles in the village such as mutual help and income sharing. In terms of the patron-client relations in the village community, it would have involved less social frictions to add some other obligations while maintaining the same share rate.

Thus, we hypothesize that both the *ceblokan* and the *gama* systems were institutional innovations that entailed the least cost for the societies to reduce the payment for harvesters to that which would result from the same task performed for a market wage rate. As a test, imputed costs were calculated for *ceblokan* and *gama* labor based on cash market wage rates and compared with actual output shares of harvesters. In the calculation for the *ceblokan* case, meals served for obligatory operations such as transplanting and weeding were valued as one-half of the cost of purchased meals (meals were not served in the case of gama).

In *ceblokan* the actual share of harvesters was 40% lower than the imputed value of harvesting labor alone; adding transplanting labor to harvesting labor reduced the gap to 20%; further adding weeding labor to the imputation made the imputed labor cost almost equal to the actual share of harvesters (Table 8). Likewise, in *gama* the surplus of the actual share of harvesters over the imputed cost of harvesting labor was eliminated by adding weeding labor to the imputation. Such results are highly consistent with our hypothesis.

Another factor underlying the diffusion of *ceblokan* might be that it helps strengthen the patron-client relationships between employers and employees by giving specific laborers an exclusive right to harvesting. With a tighter patron-client bond, the patron farmers can economize on the labor enforcement cost to supervise the performance of laborers. The employee might also prefer *ceblokan* because the stronger patron-client bond may increase their security and reduce the uncertainty in finding employment.

Ceblokan and *gama* were both motivated by a desire to reduce harvesters' share of output to a level consistent with market wage rates. However, the economic forces that resulted in the gap between the market wage rate and the wage rate implicit in the harvesters' share were different. In Laguna, the major factor was the increase in the rice yield per hectare due to irrigation improvement and technological progress; under the output-sharing contract, the yield increase automatically resulted in the increase in harvesters' implicit wage rates that diverged from the market wage rates, as observed in Table 4. That is, the institutionally established wage rate increased beyond the market wage rate. In contrast, the gap in Subang was created mainly because the population pressure under the constant technology caused the market wage rates, but not the harvesters' output share, to decline.

CHANGES IN INCOME DISTRIBUTION

The picture drawn of the economy of the Subang village is dismal:

- income and asset distributions are highly skewed even though the average income and the average size of landholdings are very small;
- population pressure had long before reached its limit and the population growth

Table 8. Comparison between the actual shares of harvesters and the imputed costs of *ceblokan* and *gama* labor.

	Working days (no./ha)			imputed wage for labor (kg/ha)						
	Harvesting, threshing	Trans-planting	Weeding	Harvesting, threshing (1)	Trans-planting	Weeding	Total (2)	Harvester's actual share (3)	(3)-(1)	(3)-(2)
Ceblokan										
Subang, Indonesia										
1[a]	40.5	13.9	–	299	51	–	350	421[c]	122	71
2[b]	40.5	13.9	18.4	299	51	68	418	421[c]	122	3
Gama										
Laguna, Philippines	33.6	0.0	20.9	370	–	167	537	504[d]	134	-33

[a]With obligatory transplanting. [b]With obligatory transplanting and weeding. [c]Assuming an output share of one-seventh. [d]Assuming an output share of one-sixth.

decelerated but labor force has continued to increase;

- technology has been stagnant because modern varieties effective in the environment of this specific location have not been available;
- gains in rice yields have not been so significant;
- the increase in labor force against limited land resources under stagnant technology has resulted in decreased economic return to labor;
- the decline in real wage rate has induced the substitution of hand hoeing for animal plowing; and
- the real wage rate for harvesting operations has been reduced through the institutional change in the form of the shift from the *bawon* to the *ceblokan* system.

The whole process suggests that the income distribution has become more skewed.

The Laguna village has also been subject to the strong population pressure on land. However, successful adoption of modern varieties, together with irrigation improvements, seem effective in counteracting the population pressure and preventing the decline in the real wage rate. It appears reasonable to expect the income distribution in Laguna not to have deteriorated as badly as that in Subang.

Unfortunately the data are not available to identify changes over time in the size distribution of income. Therefore, we try to infer on the basis of changes in relative factor shares in total income from rice production, as estimated in Table 9. The relative factor shares were the percentages of factor costs in total rice income. Rice income or value added was obtained by subtracting the value of current inputs such as fertilizers from the total value of rice output. The cost of labor was calculated by adding the imputed family labor value to the actual wage payment to hired labor. The cost of land was the land rent actually paid to landlords. The cost of capital was estimated as the sum of irrigation fees, and paid or imputed rentals of draft animal, tractor, and other machines. A residual, after subtracting the costs of labor, land, and capital from the total value added, was defined as *operator's surplus.* Those factor costs were divided by the total value added to produce the relative factor shares.

Table 9. Changes in relative factor shares in value added from rice production in sample villages in Indonesia and the Philippines.

	Change (%)					
	Subang, Indonesia			Laguna, Philippines		
	1968	1978		I966	1976	
	Owner	Owner	Tenant	Share tenant	Leasehold tenant	Sub-tenant
Value added	100	100	100	100	100	100
Factor shares:						
Capital	5	4	2	11	15	13
Labor	56	50	49	41	41	38
(Family)	(19)	(17)	(17)	(16)	(11)	(10)
(Hired)	(37)	(33)	(32)	(25)	(30)	(28)
Land	–	–	46	39	26	49
Operator's surplus	39	46	3	9	18	0

In Subang, the share of capital declined, reflecting the substitution of hand hoeing for animal plowing. Despite the increase in labor use, the share of labor declined. The reduction in labor's share mainly resulted from the decrease in the share of hired labor; this implies that the income position of the landless and near-landless class, whose major-income source was hired farm works, deteriorated over time. Operator's surplus (residual) recorded a major increase in the case of owner-farmers. In the case of tenant farmers, operators' surplus was almost zero and land rent paid to landlords was equivalent to owner-farmers' surplus. Such results show clearly that the operators' surplus of owner-farmers consisted mainly of the return to their land. Thus, the major gain in owner-farmers' surplus implies the increase in the economic rent of land. Altogether, the results show that the relative income share of landowning farmers increased and the relative share of the landless declined.

In Laguna, capital's share increased, reflecting the mechanization of land preparation by use of power tillers. Despite the strong population pressure. labor's share did not decline. Especially noteworthy was the sharp increase in the share of hired labor in expense of family labor's share. The share of operators' surplus rose sharply relative to landlords' share for the tenants who were converted from sharecroppers to leaseholders by the land reform programs. In contrast, the share of land rent paid by subtenants was very high and no surplus was left to operators. Such results clearly show that the land reform programs served to transfer a part of economic rent from landlords to tenants, which was captured in most cases as a surplus from tenants' own farm operations but in some cases in the form of rent by subrenting their leasehold land. The new leaseholders captured a major gain from the rise in rice yields due to modern varieties for a fixed rate of rent. The effect of increased income of leasehold tenants was the substitution of their own labor by family labor. As a result, the income share of hired laborers increased.

GROWTH AND EQUITY

The dismal process of growing poverty and inequity in the Subang village approximates the world predicted by classical economists such as Ricardo (1951). As population growth presses hard on limited land resources under constant technology, cultivation frontiers are expanded to more marginal land and greater amounts of labor applied per unit of cultivated land; the cost of food production increases and food prices rise; in the long run, laborers' income will be lowered to a subsistence minimum barely sufficient to maintain stationary population, and all the surplus will be captured by landlords in the form of increased land rent. It seems that exactly the same thing occurred in the Subang village.

So far the Laguna village has been able to escape from the Ricardian trap through the improvement in irrigation systems and the introduction of new rice technology. The land reform programs were successful in retaining major gains from yield increases in the hand; of tenants. The increased income of the tenant farmers spilled over landless workers in the form of increased employment opportunities through the income effect to substitute hired labor for family labor.

The comparison of the Subang and the Laguna cases rejects a hypothesis on the trade-off between growth and equity that has been assumed in much of development literature. Modern technology and irrigation investments have often been blamed because they promote unequal income distribution by benefiting only the landlords and large farmers. However, it seems clear that unless the source of income streams was enlarged by such means, the Laguna village would have followed a route similar to that of the Subang village. Even though the land reform programs were effective in fixing rent, no major gain for tenants and laborers would have been produced unless yield gains were significant. Growing poverty and inequality will be an inexorable fate for Asian village communities if the efforts to improve land infrastructure and to develop land-saving and labor-using technology will remain insufficient for overcoming the decreasing return to labor caused by the growing population pressure on land.

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HUMAN RESOURCES DEVELOPMENT

RICE RESEARCH STRATEGIES FOR THE FUTURE COMMENTS ON DEGREE TRAINING PROGRAMS

E Q JAVIER

Early in the development of IRRI, it was recognized that although its major contribution might be in the discovery of new, relevant knowledge about the rice plant, progress would be possible only if there were sufficient numbers of national scientific and extension personnel to plan and implement the rice production programs in their respective countries. Thus, in addition to the research programs in IRRI, which have expanded considerably in the past few years, there is a deepening commitment to training.

In view of my University's involvement with the human resources development component of IRRI's activities, I am pleased to share some views about what IRRI's strategy could be in the training of people.

As in other matters dealing with development assistance, it had become obvious to IRRI, to the Consultative Group on International Agricultural Research, to the Foundations, and to the other international agencies that the permanent and lasting solution to the problems of poverty and hunger in the developing countries lies in the developing of their respective national capabilities to help feed themselves. Food aid and other forms of material assistance, while most welcome, provide, at best, temporary relief to the malaise affecting these countries.

This suggests that, without discounting the incalculable contributions that IRRI and the other international agricultural institutions have made in the past and will continue to make in the future, the greater part of the solution will have to be sought in the establishment, as early as possible, of competent national research and extension systems. If one takes a close look at the emerging success stories in rice productivity among the less developed countries, one finds that the countries that have profited most from IRRI's outputs are those that had previously achieved some sophistication in their national research and extension systems.

The primary role, therefore, of the international institutes is supportive of and complementary to that of the national research and extension systems. The extent to which IRRI, among the growing family of international institutes, has succeeded in this role can be judged from the increasing numbers of national entries in the

Professor of agronomy and chancellor, University of the Philippines at Los Baños, Philippines.

international rice testing nurseries. It is indeed ironic that one possible measure of IRRI's success in the coming years will be the absence of IRRI-developed lines among the international rice nurseries and their complete replacement by national entries.

This is consistent with the premise that the international institutes' task is to phase themselves out of the roles that the national systems ought to perform. The institutes should move on to the more demanding *trail-blazing* activities and other functions that call for international coordination and monitoring.

DEGREE-GRANTING TRAINING AT IRRI

IRRI conducts two basic types of training — degree and nondegree. The nondegree component will be discussed by the next speaker so I will refrain from referring to it. It will suffice to say at this point that both types are necessary and useful for particular purposes and objectives.

The degree-granting component consists of opportunities for selected individuals, who by virtue of their present positions as well as their potential, are expected to make significant contributions to the rice programs in their respective countries or regions, or both, to work toward master's or doctorate degrees at UPLB.

Because of IRRI's proximity to UPLB, it has been possible for its fellows to be admitted to the Graduate School at UPLB, to take regular courses at the University, to conduct a dissertation on relevant rice research at IRRI laboratories and facilities under the advisorship of IRRI scientists and University faculty, and to obtain a graduate degree from the University. IRRI's location on the UPLB campus was not coincidental. Its founders, three of whom IRRI has honored by naming the Institute's first three major buildings after them, had foreseen, the advantages of the mutual reinforcement that could be derived from the association of an international agricultural research organization with an outstanding agricultural university. I believe that such an association was part of IRRI's original strategy and should be part of its continuing strategy to achieve relevance and excellence in its training and research activities.

National program continuity

The close association of IRRI with UPLB presents a combination that should be exploited to the fullest. The continuity of the many national rice programs through whose endeavors IRRI's contributions find amplification and fulfillment depends upon the availability of competent, dedicated, and highly trained scientists in the different disciplines. With the possible exception of India, there is not enough highly trained manpower in the different countries to provide the kind of staffing the national programs require. The few who are available may spend time initially with the national rice programs but are soon drawn to important administrative posts in the ministries or universities. Of course, many end up with international development organizations, including IRRI. There is, therefore a continuing need to train people to maintain, and further increase, the corps of specialists and administrators

of food programs in the developing countries.

Perhaps there is no need to justify here the rationale for advanced graduate training. But lest you miss a minor cultural point, perhaps I should point out that in the hierarchy of bureaucracies and organizations in many developing countries that deal with rice, rank and status are often determined by educational degree. Thus, knowledge and experience should be matched with the appropriate degrees so that competent workers with the appropriate background would be placed in positions of influence.

The relevance of training

The relevant issue at this point is what sort of training or preparation the IRRI scholars should have, not so much in their technical competences because the discipline loyalties in academe take care of those, but in their perspectives and outlook. While IRRI's mandate may appear to be limited only to rice, that mandate is in fact much broader. In many societies and countries in Asia, rice permeates almost all realms of human activity — economic, social, political, and cultural. I recall that at the beginning, IRRI confined itself mainly to breeding and economics of rice production. Recently, there was an expansion into the cropping systems program, influenced no doubt by the realization that at the level of the small farmer, rice culture, although a major endeavor, is only one of several concurrent enterprises and concerns. Where a commodity such as rice is closely interwoven into the cultural, social, economic, and political matrices of the national societies where it is a major staple, a monocommodity outlook is too simplistic and self-limiting.

A first consideration, therefore, in the training of the scholars of IRRI who are expected in due time to provide leadership and vision to the national rice programs, is the cultivation of broader perspectives of the rice problem complex, in addition to the expertise in depth expected of each of them in their respective disciplines.

A second consideration is the cultivation of the proper attitudes for teamwork and interdisciplinary research. The GEU program of IRRI is an excellent example of the synergisms that obtain from the open collaborative efforts of professionals and scientists who in the spirit of a shared common goal at times submerge their individual identities for that of the working group. This is not to suggest that independent scholarship is out of date, but only to emphasize the increasing imperativeness of team-building in problem or goal-oriented research.

Experience accumulated in development work in the past two decades points at the inadequacy of production programs per se in providing for the food needs of the sectors of the population that are in most dire need for food. In the drive to attain self-sufficiency goals at the shortest time possible and at the least cost, the concentration of efforts naturally gravitated to the farms favored with fertile soils and blessed with irrigation water. As a consequence, the marginal lands, and the marginal farmers who tilled those lands, were largely left in the process of development.

Of course, at IRRI now we find very substantial efforts to improve the productivity of rainfed rice farms. Increasingly, tolerances for drought, deep water, and soil toxicities and deficiencies are being bred into rice varieties, which would enable

farmers with the problem soils and environments to achieve at least moderate gains of productivity.

Likewise, each and every development in technology invariably influences the distribution of benefits to different sectors of society. If indeed the priority of development is for the very poor, a genuine feeling for the poor and a deep commitment for their welfare is a very necessary attitude for the world's future rice researchers, workers, and leaders. We shall need rice workers who not only are competent scientists able to work with others in the pursuit of desired objectives, and see the rice grain in its full context as a societal concern, but also are competent humanists who can articulate in their societies the necessity for taking affirmative action to enable the still impoverished millions in the developing countries to finally live with dignity and in freedom.

Finally, a note on the role of agricultural universities in the rice and other food production programs, and in rural development as a whole. Today we are talking only about rice. If we repeat the exercise for wheat, maize, potato, and other prime food commodities and for many other problem areas such as soil conservation, energy for rural development, rural employment, etc. we shall come around to the identical conclusion that, above all, the need is for highly trained people who will give flesh and blood for all these development plans. And to provide for the number and quality of people necessary to adequately staff these development programs, each country must have the capability within its national borders to offer at least the bulk of its training requirements.

The UPLB is a good case in point. The investments of the Filipino people in the institution with generous support from the US government, the Rockefeller Foundation, the Ford Foundation, Cornell University, and, more recently, the World Bank are now paying off. Apart from the few faculty it sends abroad to replenish its capital stock of expertise, UPLB now provides the bulk of the high-level training needs of the other agricultural colleges and universities and the different ministries working for rural development in the Philippines. Even as it takes care of national needs, the UPLB is able to open its doors to about 400 graduate students, mostly from Southeast Asia, but with increasing numbers from tropical Africa.

A STRATEGY FOR HUMAN RESOURCES DEVELOPMENT

Returning to the strategy of IRRI for human resources development, I wonder if it is not now opportune for IRRI to consider forging a similar link to that of UPLB with one or two other agricultural universities in the region. This could expand considerably the pace of training students for advanced degrees.

I believe that with the experience with IRRI scholars at UPLB, it is now accepted that the developing countries need not send their people to the Western universities to obtain relevant comparable graduate education in food, agriculture, forestry, and animal sciences. In addition to the cost factor, students graduating from an Asian institution similar to their own have less difficulty in readjusting to their environment after completing graduate studies.

While UPLB is willing to continue with the mutually beneficial arrangements with IRRI in the training of the Institute's graduate students, there are other institutions in the region which, with a little assistance, could offer essentially similar arrangements. If IRRI could forge linkages with one or two other agricultural universities, the rice networks' capacity to turn out researchers with the appropriate training could be doubled or tripled. Such arrangements could involve:

- upgrading university competencies in terms of manpower and facilities in the areas where the host institution is relatively weak;
- seconding of some IRRI scientists to serve as visiting professors to the host institution, as may be required;
- coursework of students at the host institution and conduct of thesis at IRRI headquarters (additional courses could be taken at UPLB during thesis residence at IRRI); and
- institution of master-of-professional-studies type of curricula that would enable relatively homogeneous groups of rice workers to undergo a more or less fixed program of study (tripartite arrangements among IRRI, UPLB, and the host university should be possible),

HUMAN RESOURCES DEVELOPMENT: RELEVANCE ORIENTED

S. M. HASANUZZAMAN and J. RITCHIE COWAN

The accumulation of research knowledge that can be translated into new technologies has little value if it becomes solely a matter of acquiring such knowledge and carefully and methodically filing it away in libraries around the world or feeding it into various computer mechanisms capable of storing an infinite amount of knowledge. Information storage is important but will not alone solve the present and future world food challenges. The requirement is for the transfer of that knowledge to users. We examine here the need for human resources development as a major element in achieving effective transfer of knowledge from researcher to farmer.

National research and food production programs in developing nations have their deficiencies. Dr. Javier has just carefully delineated the role of advanced study in developing the human resources needed to increase and improve the efficiency of food production in the future. Persons with formal academic training are few and far between in most developing countries. A real effort is being made to speed the training of more academically prepared persons. However, training takes time. It would be a mistake to staff a research agency solely with holders of a Ph D, an MS, or even a BS. The support staff is absolutely essential. It needs special training or retraining from time to time. Thus, if a national program is to succeed, it must have not only well-trained and prime leadership in its scientific manpower but also support staff whose training and knowledge is relevant so that team progress can be made rapidly.

We cite. for example, the Bangladesh Rice Research Institute (BRRI). Its administrators believe the continuous progress of agricultural research can only be achieved by team effort. The team should consist of able researchers, support service personnel, and a team leader, and should formulate and implement research programs. Within the team, an organizational system must be developed to provide continuing leadership. Such a balanced development of manpower at all levels is BRRI's major objective.

Until now, the educational system, in general, and technical education, in particular, have not been well developed. The classical system of education based upon the

Director, Bangladesh Rice Research Institute; and IRRI liaison scientist, Bogor, Indonesia.

dogma of *art for art's sake or science for science's sake* is no longer justified. Consumer-oriented education to make the graduate capable of undertaking the work on national development has not yet been conceived. Technical education with major emphasis on theories described in the textbooks written abroad can undoubtedly broaden the knowledge of the graduate but in no way give him the practical knowledge he needs to tackle the domestic or local problems. This is particularly true for agriculture when the components are entirely different from the western monocrop and high resource-based mechanized system.

The professional training at the postgraduate level, therefore, is necessary to offset the deficiencies of the graduate-level education.

Because of lack of expertise at the domestic level, the development of training facilities remains limited. Therefore, it has become necessary to train a significant number of bright and active research personnel who will form a basic cadre upon which further expansion, particularly at the domestic level, can depend.

In the past, several nations assisted Bangladesh in developing its technical and scientific manpower. Without a national master plan and coordination among the benevolent, aid-giving agencies, the development program became erratic and fragmented. The agencies' best efforts failed to solve the problem.

It was also thought that more training would serve the purpose. Hundreds of persons (with no basic or standard curriculum) — unable later to provide needed leadership in research — were trained abroad. The opportunity for advanced education leading to a Ph D, followed by a few months of professional training under appropriate scientists in their fields of endeavor, would have immensely benefited a few talented, dynamic youngsters. Therefore, an appropriate training curriculum is also important in developing effective manpower systems for any given country.

As a research institution, IRRI, now on the threshold of its majority (21 years of age!), has had many successes and has contributed much to the welfare of the rice-growing areas of the world. But it could easily become encapsulated as a research institution in itself. It must look outward and recognize the needs of the national programs. That is more easily said than done.

There is no better way of understanding the needs of any particular area or region than residing in that area or region. Hence, the alumni of training programs, already numbering into the thousands within the short span of 20 years, can become extremely important *listening posts* and sources of counsel and guidance for future research programs. They must not be ignored. Those in remote areas of a country probably have more to offer than those in the better developed areas. It is easy for them to become lost and quite isolated. In some instances the alumnus' training experience is his last contact with IRRI unless he is visited by its representative. But each alumnus is proud to be identified as a graduate of one of IRRI's training programs.

There are many means by which IRRI can keep in regular contact with the alumni, and it can create more. Hence, these contacts may become a two-way street. The trainees are sent back to their assignment and responsibility with a better

appreciation and a knowledge of new technologies, which they can use or modify according to their needs. The faculty member must, therefore, be creative and innovative in his instruction so that the students will take home with them new attitudes toward their work and new methodologies that can be adapted to their situations and usually limited resources.

International agricultural centers, along with ongoing agriculture research in high-income countries, are not substitutes for a first-rate national agriculture research enterprise. Thus, everything that IRRI can do to help strengthen and stabilize national research programs on rice and rice-based cropping systems will have a long-lasting benefit. One of the better ways to do this is assisting in relevant *human resources* development. That means that the Consultative Group for International Agricultural Research, the boards of trustees, and the administrations must give careful attention to the development of a strong international (outreach) program for such centers as IRRI. Even though *international* is a key word in its name, IRRI could easily retire into the seclusion of the laboratory or headquarters and not deal with the real problems of the day. That is one of the most poignant challenges IRRI must face as it approaches the next decade if it wishes to serve the kind of climate that its Articles of Incorporation suggest it should.

THE PROGRESS OF IRRI

Human resources development at IRRI had gradually evolved in the last 20 years. Initially, once IRRI had made programs in obtaining new information and in evolving new technology, its assistance in training persons who would better understand the *IR8 concept* was sought. It seemed appropriate to begin a training program that would primarily focus on extension-type education. But IRRI realized that research was a big job and considered extension education as the primary responsibility of the national programs. It was, therefore, somewhat restrictive in the kinds of programs that might duplicate the programs of the national agencies. However, to familiarize subject-matter specialists in the extension area with the new technology, a 6-month training program in rice production was initiated. The program was comprehensive and popular and it has not been possible to accommodate all requests for participation.

Cropping systems

As IRRI research progressed and new concepts and principles evolved, national programs sought the opportunity to collaborate in some of its research activities. Even though IRRI was initially assigned to work on one crop — rice — it could not isolate itself entirely from other crops that are directly or indirectly associated with rice production. Efficient use of soil and water resources frequently dictates that it is wiser to grow a crop that requires less moisture than rice. The knowledge of agronomy for such a shift was not available.

The rice-based cropping systems phase of research has been highly developed. It

has provided some invaluable information, counsel, and guidance for the more efficient use of rice-growing soil. As this program became well established in its research repertoire, a need to assist research personnel in national programs in this area of activity through short-term training developed. Thus, the now successful 6-month cropping systems training program began. It contributed substantially to the training of young men and women interested in the multidisciplinary approach to improved production. This training was initially designed to meet the needs of training support staff working with several crops that might be integrated into a cropping pattern with rice as the main crop. The very nature of this training program has prompted many officials responsible for extension activities related to rice and rice-based cropping systems to send their subject-matter specialist for training. The program now involves the training or retraining not only of those doing research primarily in cropping systems research, but also of extension subject-matter and extension personnel in the various facets of cropping systems as a research area and in specific knowledge of the agronomy of the individual component crops, thus providing another channel for disseminating new rice production technology.

GENETIC EVALUATION AND UTILIZATION

In the mid-1970s IRRI conceived a multidisciplinary approach in varietal improvement. The plant breeder plays a key role in the development of a new variety. However, the challenge that faces rice improvement researchers today is complex and many different disciplines must join in the effort to develop and identify a variety that would meet the increasing needs of modern-day rice production. The entomologists, physiologists, plant pathologists, agronomists, soil scientists, agricultural engineers, socioeconomists, and others have an important role to play, directly or indirectly, in the development of a modernday variety. The logical coordinator of such a group is the plant breeder who has the basic training and background in the sciences of plant breeding, genetics, cytogenetics, and statistics, and must ultimately make the decision as chairman of the Board. Because each discipline plays an important role in research techniques for determining how selection should be made, variety development becomes a team effort, for which IRRI proposed and adopted the term Genetic Evaluation and Utilization (GEU). Many teachers of plant breeding consider the concept ideal. However, in many research institutions around the world, the concept has been difficult to implement. IRRI feels that it has real merit and has strongly committed itself to it. The concept provides a procedure whereby scientific manpower is more efficiently used. Subsequently, the 4-month GEU training program was established in the mid-1970s. It has been most attractive and successful. Although the program could be improved, its popularity has led to the scheduling, during the later part of the decade of the seventies, of two sessions a year.

INTERNATIONAL NETWORK FOR SOIL FERTILITY AND FERTILIZER EVALUATION FOR RICE

A 4-month training course known as INSFFER (International Network for Soil

Fertility and Fertilizer Evaluation for Rice) was established late in the 1970s to develop a technology for fertilizer efficiency. The course aids in training staff for national programs collaborating on the international network of fertilizer efficiency research.

INTERNATIONAL RICE AGROECONOMIC NETWORK

There is always a certain amount of social resistance to the introduction of new technology, particularly in the cultures where major changes have been minimal over the centuries. Thus, when a new technology that could substantially increase production is not readily used, questions are raised. Some excellent presentations during the week reflect the importance of studying socioeconomic impact. Some of the studies must be strictly national. Others can be done more effectively and efficiently on an international basis. Hence, a 2-month International Rice Agroeconomic Network (IRAEN) training program has been established. National staff members responsible for work in the socioeconomic area have received somewhat specialized training under the IRAEN training program.

IRRIGATION WATER MANAGEMENT

Of the many ingredients essential in producing a crop, probably one of the most important is water and its time of availability. The soil may be excellent and highly fertile, varieties well adapted, and fields weed free, but unless water is available at the right time and in the right quantity and there is proper drainage, production potentials will not be met. Water management is a somewhat illusive area of activity. One would argue that IRRI should not devote any of its resources to it. Traditionally the responsibility for irrigation has been assigned within government as a function of public works. Irrigation is usually engineered to meet certain specifications by people who have little or no knowledge of the farmer's needs. Agricultural engineers specializing in soil and water management and conservation have a greater knowledge of on-farm needs. It has been difficult to bring together these two groups of specialists who are responsible for the delivery of water and its use. Hence, IRRI's Water Management Department instituted a training course that would bring together engineers in charge of the containment and impounding of water and its initial delivery, and those who assist in solving the problems of its on-farm use. The 6-week training course has become popular in its short period of existence.

AGRICULTURAL ENGINEERING

The Engineering Department develops prototypes of machines and equipment appropriate for use on small farms. After these prototypes have been evolved, modified, or supplemented, appropriate blueprints and instructions for their construction are developed and made available to manufacturers of small equipment. These manufacturers, although keenly interested in producing such equipment,

frequently need additional professional help — the services of a consulting engineer or training in the construction of the prototypes. A 2-week agricultural engineering course intended for individuals from the engineering staff of cooperating industries that manufacture, or plan to become associated with the manufacture of, IRRI-designed machines has been in operation since the later part of the 1970s. It is an apprenticeship type of course.

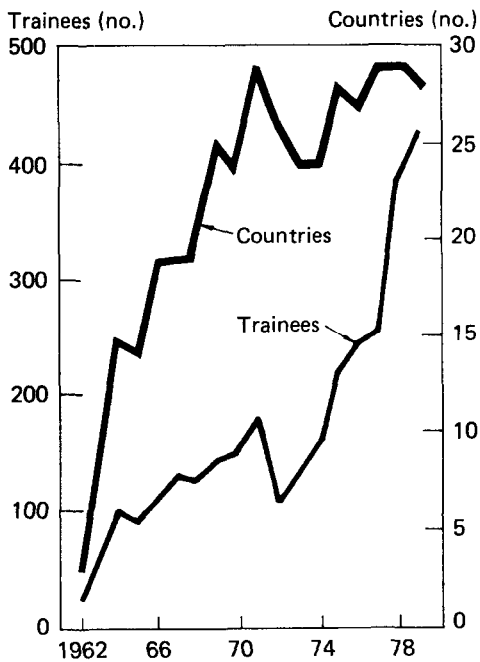
GROWTH DURING TWO DECADES

Figure 1 reflects the growth in number of participants trained in number of countries involved in the professional improvement program. Interestingly the number of countries gradually increased during the first 10 years and has remained generally constant during the last 10. The number of participants, however, has steadily increased to many times the original number in 1962 (Fig. 1).

CATEGORIES OF TRAINING

There have been several rather broad categories of training. Training may be classified into four types:

- short course



1. Participation of IRRI training 1962-79.

- attachment
- nondegree
- post-MS and doctoral

Short courses

The short-course approach is essentially used for the programs described in the preceding section.

Attachment courses

The attachment program is designed to meet the request of scientists who wish to associate with or attach themselves to a specific program at IRRI for a given period of time, usually limited to 3 or 4 months. The program provides the scientists an opportunity to at least complete an experiment in the laboratory or go through a complete season of growing material in the field. This type of program tends to be attractive to those who have just completed graduate training, and have been given an assignment specifically on rice, but whose previous training was not in this area. Also, it is attractive to older scientists who may wish to associate with an IRRI scientist who is working in the highly specialized area in which they wish to become better qualified.

Nondegree courses

A nondegree program has been established for some staff members who wish to pursue advanced study but either do not qualify because their previous academic record is below the minimum set for admission or cannot be away from their assignment for the duration of time required for a degree program. It provides the candidate an opportunity to begin working with a scientist in his discipline, preferably at the beginning of an academic term at the University of the Philippines (UPLB). The candidate may enroll in a limited number of courses in addition to the assignment with an IRRI scientist. If he demonstrates the ability to handle graduate-level courses at the end of the nondegree training period, his request for graduate-school admission may be reconsidered. If he does not qualify for such advanced study, the program still provides some excellent training to make him a much more valuable staff member when he returns to his post in his home country.

Postmaster's and postdoctoral courses

The postmaster's and postdoctoral programs are designed for persons who have earned the MS or Ph D degree and wish to receive additional training under eminent scientists in their particular fields of interest. These programs serve a dual purpose. Their expertise supplements that of the IRRI staff. Hence they make a significant contribution. At the same time, they are permitted to carry out advanced, independent research under the guidance of and in collaboration with IRRI scientists, thereby developing their intellectual capability and knowledge. This type of formal academic exposure within the IRRI laboratories and research fields makes them

much better qualified to assume leadership in areas to which they are assigned in their own countries.

FUTURE NEEDS

IRRI deals with a dynamic clientele. It has been and will continually be changing. At times IRRI has tended to seek protection behind the statement, "We are training the trainers." That rings a very wise and eloquent note!

But training does not work that way entirely. Logically, in due course the nations with which IRRI works should be developing similar training programs; many are making such progress. However, some forms of professional improvement in this regard will always be a function of IRRI. As IRRI *comes of age,* it should give time and dignity to this area of professional improvement as it has to its research program. That may sound like an idle statement but it needs careful examination. The persons who have been trained or assisted in their professional improvement are IRRI's most important heritage. From their ranks shall come tomorrow's rice scientific leadership and the instructions for the kind of program that would enable national programs to best meet the needs in the ever-changing rice-growing world. Hence, our thesis is that IRRI's role in professional improvement will be one of its most significant contributions. Scientific leaders should bear that in mind in organizing and determining the objectives of future programs. Instructional faculty should plan and present instructions that are simplistic and adapted to national needs.

The scientific community may soon face a serious creditability crisis. Agriculture has modestly and quietly established itself as an important scientific model. Perhaps agricultural scientists have been so modest about their achievements that they have failed to articulate them properly in support of the need to continue a strong program in agricultural research. At times they may have pretended to know more than they really do. Science is a treasure chest but every treasure chest is also a Pandora's box and the scientific community cannot escape the negative consequences (as well as the good) of increased knowledge. That makes their responsibility in the professional improvement of their present and future colleagues more serious and more challenging. New technology frequently creates so-called *second-generation problems,* which the uninformed may interpret as scientific failures rather than as mere natural dilemmas! The faculty member developing syllabi, class projects, and course content must make his presentation simple, accurate, and wherever possible, should show how it can be adjusted or adapted to situations that have less resources than he is privileged to have.

In many developing countries where scientific leadership is minimal, the support staff and middle-level officials carry a role more important and demanding than they might in other situations. Therefore, within reason, it is extremely important that they understand not only the benefits to be derived by the new technology obtained or being sought but also some of the potential pitfalls. Politics in many developing countries evolves around the success, or the lack of it, in providing adequate supplies of nutritious food stuff. Hence politicians, on short notice, make decisions on the

basis of successes or failures. Therefore, those engaged in the search and the dispensing of knowledge must use good judgment at all times.

Programs such as the attachment program and others where the training and apprenticeship are on a one-to-one basis provide the student with the greatest opportunity to learn the philosophy and be inspired by his teacher. A definite quota limitation is this technique's primary constraint.

Some scientists are excellent teachers; others are excellent researchers. Some prefer to teach and devote a minimal amount of time to research. Frequently administration assigns an instructional role to persons who are not dynamic and inspirational teachers. This is not to discredit the quality and the nature of the contributions of these scientists as researchers. It is, however, the responsibility of administration to select staff members who have the greatest capability and enthusiasm for, and the interest in, inspiring students and passing on new knowledge.

IRRI is not a degree-granting institution. It has facilities, staff, and specific knowledge on rice and rice-based cropping system that no university has. Thus, it is in an enviable position to offer some very specialized training where it is needed. It must complement rather than duplicate the university's endeavor.

What about the future? If IRRI had all the answers, there would be no need for it to be organized into the institution that it is. It must be speculative, imaginative, and innovative in its goals. It must also be flexible. A great deal of energy can be expended in planning for things that may never happen or that may have little consequence when solutions are found. Thus, IRRI's leadership must be prepared to adjust on short notice and use its human resources wisely to meet the challenges of time. As it matures and gains status and prestige, it faces the constant danger of falling into a stereotype pattern and of not being able to change when the occasion requires it.

At present, the training areas — at least the broad categories that have been defined in this paper — will continue to serve the professional improvement dimension of IRRI's program well. These areas are broad, and considerable latitude and flexibility can be built into the present framework. When a training program has served its purpose, it should be dropped. On the other hand, perhaps it needs to be continued but only after a major overhaul. in the syllabus, for example, to meet the current needs of trainees at that point in time.

In the early days of IRRI's professional improvement program, many persons who sought training were senior scientists looking for an opportunity to learn about the skills and the *hand-on-type* of experience of the new technology being evolved. Fewer and fewer persons of this kind will seek such training, but there will always be a number. Most of these persons will come from agencies interested in having some of their professional staff acquire knowledge in some of the latest technology in rice production although they may not be directly involved in rice improvement, production, etc., or the rice-based cropping systems.

Most of the future clients, at least those in the 1980s, and perhaps through the 1990s, will be support staff or middle-level officers. Some will be older, with considerable experience, whose retooling or regular professional improvement

would benefit their programs. Such professional improvement program will develop within the national programs much more slowly than had been anticipated a decade or so ago. The reason, although obvious, is frequently overlooked by administrators and planners. The persons best qualified as the *faculty* are the scientists themselves. The number of well-qualified scientists and the amount of time they can devote to activities other than the conduct of research are limited. Unless they have a strong research program, they would not be a satisfactory faculty for this kind of professional improvement.

IRRI's faculty must consider innovative teaching techniques, such as more group discussions within national groups. They must emphasize and reemphasize that the ideas and concepts being imparted can be used in a variety of ways. It must be pointed out that the sophisticated equipment and facilities at IRRI are necessary in carrying out its multinational responsibility. Everything possible must be done, and, of course, within reason, to prevent its trainees from going home with an inferiority complex. The trainees must learn how to be innovative and imaginative in the use of limited resources. As the national training programs evolve, IRRI's help will be needed in lectures, laboratories, and seminars. That will require budgeting of the scientists' time but it may become one of the best avenues through which to introduce the IRRI-developed technology into a national program.

There are many emerging training needs, but time and space do not permit us to elaborate on them. But we suggest IRRI consider the following:

- Offer, on an alternative-year basis, a regular training course for research farm managers or superintendents.
- Offer a 2-week workshop on organizing and operating a national rice production program.
- Offer training for research assistants, fieldmen, laboratory assistants, etc.
- On an annual basis, bring agricultural ministers of major rice-producing nations together for a *rice policy conference,* which should be a joint venture with the International Policy Research Institute.

Many more suggestions could be made. Any major change in the responsibility of the professional improvement program will require reallocation of fiscal and scientific resources. But a dynamic situation demands a reevaluation.

IRRI will need to organize itself differently to meet the anticipated needs of the areas. No longer can professional improvement for training be treated as a *byproduct.* It must have the dignity and status of any other major program. It will need the leadership of persons well oriented and enthusiastic about teaching. A part-time Director who has other major responsibilities can no longer suffice. Because professional improvement is definitely an international function, it should be organized as a function of the international division of the institution. It is entitled to a full directorship under the Deputy Director General for International Programs. At least two professionals should be attached to this director's office, which will need a complete support staff to handle the many logistics required in the conduct of such a program. Status should be given to those ivolved in instruction.

ORGANIZATIONAL STRUCTURE

The heart of any professional improvement program is its faculty, their sincerity, inspirational ability, and enthusiasm for assisting people to learn. Many excellent research scientists do not have these qualities. As resource persons, they can offer some excellent lectures or demonstrations in the laboratory, greenhouse, or field. Therefore, the administrative office for professional improvement must carefully identify and select persons for different roles as faculty members in the professional improvement programs. The instructors must have a definite empathy for training.

The clientele, particularly if made up predominantly of support staff, will have some misgivings because of the distinguished reputation their teachers have earned, at least in their judgment and estimation. Thus, the instructor must bear in mind not only that the students are of many nationalities and cultures, but also that they will, initially at least, feel somewhat uncomfortable in the presence of scientists who are outstanding in their fields of specialization but in many instances may actually be peers in their responsibilities. From time to time it may be advantageous to bring IRRI international (outreach) staff from the field into the headquarters to offer certain types of instruction. They can bring an understanding of the needs of the trainees that resident staff might find difficult to appreciate or comprehend. Thus, a certain fluidity must be built into the general approach to identifying the instructional staff.

Most of the candidates who come to IRRI for professional improvement usually know the names of leaders in their particular fields. It is most unfair and unfortunate if these key senior scientists do not appear regularly in the classroom, the experimental field, or the laboratory to get acquainted and share with the students some of their philosophy and knowledge.

The scientists can unconsciously consider themselves so involved with research that they have little time to formally meet the students. Administration also frequently unconsciously encourages this kind of attitude. The senior scientist under extreme pressure of very demanding schedules either issues handouts, assigns assistants to present the materials, or uses some audiovisuals to present his particular subject in his absence. There is absolutely nothing wrong with using these aids, most of which are marvelous teaching tools and provide reference materials that a student returning to his duty post at home prizes very highly. However, for the student there is no substitute for the opportunity of getting acquainted with and formally interacting with the scientist.

When the scientist is evaluated for salary adjustments or promotions, major emphasis, if not sole emphasis, is placed on research productivity; little or no importance is placed on the capabilities he has shown and the contributions he has made as a teacher which, in fact, defy definition. Nevertheless, the alert and supportive administrator of instruction can catalog and identify the traits of those involved if he works at it. The other major weakness of administration is that, too frequently, when retaining staff for an assignment, no mention or only minimal mention, is made of the person's responsibilities in the area of instruction in the

professional improvement of those who come to IRRI to seek such training.

Thus, administration must discipline itself to examine carefully the amount of human and fiscal resources it allocates to professional improvement training and make sure all staff members clearly understand their relative responsibilities in this regard. If that is not done, staff members will resent the instruction responsibility for using up their research time. This attitude is most unfortunate but must be *carefully assessed and recognized* if IRRI, as an international institution dedicated to the improvement of rice and rice-based cropping systems is to succeed.

The international (field) staff members can contribute much to the development of appropriate professional improvement programs. Too frequently they are not asked for advice regarding syllabi, skills, approaches, etc. Because the candidates for professional improvement come from national programs, the advice of the international staff who are in residence in many countries around the rice-growing world should be sought. There is seldom only one way to achieve a given goal. The methodology that appears appropriate in a resource-abundant environment may not be relevant in a national program. International staff working in a variety of national environments can provide an insight and dimension, which otherwise might be overlooked. The resident staff members know best the nature and scope of their particular research effort and hence the kind of knowledge that they might best be prepared to share with those who would come to study under them and seek their own professional improvement. International staff could more readily offer suggestions for simplification of items that might be superfluous.

A conference in which international staff and resident staff can interact and together come up with appropriate syllabi for the improvement programs must be held from time to time. IRRI has not capitalized on the tremendous wealth of knowledge which its international staff has acquired over the years in a variety of situations while residing among many who will seek the opportunity to study for their personal professional improvement. Such conferences should not be meetings lasting only for a half day or one day and held in conjunction with some major conference. They must be of reasonable length and organized solely for the improvement of professional training.

TRAINING QUALIFICATIONS

Those who seek to improve themselves professionally at IRRI should have certain minimum qualifications in previous academic attainments and facility with the English language. Because the courses are taught in English, it is only natural that the candidate possess a reasonable facility with this second language.

All candidates should have a BS or its equivalent. However, as more and more trainees come from the support-staff category, applicants with a BS will be fewer. In some national programs, those who are retained for certain support scientific posts cannot be hired today, if they have more than a diploma. In other countries, persons who have had only an agricultural high school level training but many years of experience and hold relatively responsible positions need this kind of training.

Therefore, a blanket rule that limits admission to only those with a BS or a higher academic attainment denies many who need such training the opportunity for professional improvement.

Thus the admission requirements must be flexible. The international staff and liaison officers (where they exist) must spend more time in carefully interviewing potential candidates and becoming acquainted with their background. When making the final decisions at headquarters, they should place more weight on recommendations than on whether the applicant holds a BS. Wherever international staff are located, their services should be more than just clerical. This is an extremely important and delicate issue. Reducing the number of applicants, thereby better meeting the limitations concerning classroom size, lodging, etc., provides a screening mechanism, but it denies many the opportunity they should have. Hence, administration and international staff who have everyday experience in the field in this regard should carefully evaluate this requirement. The decision should not be unilaterally made at headquarters. Each case should be evaluated and decided upon on the basis of its specific merits. The Director for Professional Improvement must have sufficient staff so that he can spend more time in *the field* on training matters.

An international scientist once said, "Everyone gains by having had the experience of spending some time at IRRI!" That may seem an overstatement. The time the trainees spend at IRRI will represent a *gain* only if the training experience is planned in keeping with their needs. For those who work regularly in the field it is probably an understatement. Participants who are relatively poor in English but who observe and listen intently and ask questions of their colleagues, when given the opportunity, gain substantially from this type of learning experience. Therefore, the degree of English proficiency demanded of the potential participant depends on the nature of the training being offered. The IRRI faculty must constantly work to meet the needs of their students rather than vice versa. They must make conscious effort to use minimum vocabulary. Taping of lectures or discussions will enable students to listen to the tapes at their convenience and pace.

RESOURCE MATERIALS AND TEACHING AIDS

A good instructor always uses many teaching aids. For the more formal academic type of training, literature citation is a standard and traditional practice. For the trainees this approach should be used sparingly; its use is appropriate for post-MS, postdoctoral, and nondegree training.

Other tools of the teaching profession should be used wisely. The participants in nondegree programs, upon their return to their specific assignments within their national programs, will depend much upon the materials and ideas received from their professional-improvement experiences. Instructors should refrain from detailed complicated sophisticated lectures that have been reproduced from a paper presented at a scientific meeting. Such documents contain some extremely valuable information for trainees, but generally that information will not be communicated unless it is carefully translated. The instructor should, therefore, avoid passing on

that kind of material, which has little value to the trainee. Outlines, highlights, or condensed versions, on the other hand, could be extremely valuable. For example a set of questions identifying the objective for any given lesson would help the scientist organize his presentation and the trainee determine the most important points.

As discussed earlier in the section on qualifications, there will be a greater range and capability in English proficiency among the trainees than with a similar cross section of those working toward an advanced degree. Hence, the instructor must reflect relatively more compassion and empathy as he works with these participants so that they might return to their duty posts with as much new information as possible and without an inferiority complex. Most individuals who have had to study in a foreign country have found adjustment difficult.

The evaluation of performance must provide a learning experience for the participant and not a *threat.* The exposure to new ideas itself will be valuable. Appreciating the reason for pursuing such ideas will make the participant that much more valuable as a scientist. An improvement in attitude and enthusiasm is progress. There are many ways of evaluating positive intellectual growth.

The feature that scientists and their support staff in developing countries frequently lack most is skills. Sometimes it is lack of confidence to try! Hence, guidance in acquiring expertise in carrying out research is extremely important. A minimum amount of time should be spent in the *lecture hall* and the maximum amount in the laboratory, greenhouse, and field actually *doing.* In multidisciplinary courses such as the GEU and Cropping Systems courses, the instructors should not give *lip service* to the very concept of these courses but devise a means whereby the student experiences the value of multidisciplinary approach. For example, in the GEU course it is quite unsatisfactory to permit the student to revert to his particular discipline as the training nears completion.

If the approach is to be truly multidisciplinary, the trainees must be organized in multidisciplinary teams and given projects in which they could work together. Team teaching (two or more disciplines) on the part of the instructional faculty will make the approach work. If the trainees are told that the course is multidisciplinary but only one scientific discipline is represented at a time, the trainees may raise questions as to whether or not the course is truly multidisciplinary. If staff members are to do the kind of job expected of them, they must set aside time for planning and execution. The role of the teaching assistant is extremely important. He can take care of many of the important and necessary logistics but cannot serve as a substitute for the person whose subject is being presented. The senior scientists must be *visible* from time to time to monitor the type of material being given to the students or the skills being taught.

The Director's Office for Professional Improvement must be constantly alert to new techniques and teaching aids that the instructional faculty may find useful. These may be audio visual, written materials, art forms, or plant specimens. It is possible that some of them can be prepared as prototypes for the students to take back home to either modify or adapt to particular needs or use as initially prepared. Someone capable of coordinating this kind of activity should have a flexible

schedule, permitting him to travel to areas where such materials might be used and assistance may be offered in their adoption.

There is no better means of transferring the new technology generated by IRRI's laboratory, greenhouse, and field research programs than the human resources available in the national programs. These human resources, if well trained and convinced of the value of the new technology and how it might be used in the local situation, will be its most enthusiastic supporters and will implement it much more quickly than if they have not become a part of the total system.

ROLE OF ALUMNI

IRRI's professional improvement program (training) has turned out many hundreds, perhaps thousands, of alumni during the last two decades. The number is impressive. It reflects the interest of administration and officials in developing countries in having their staff experience this opportunity of self improvement.

Too often, however, the alumni are forgotten once they have received their certificates and return home. If given appropriate and timely encouragement, they can be some of the strongest supporters of the basic concept of IRRI. Their services can be used in several ways in which they are a potential reservoir from which candidates for further advanced degree study can be identified. Although some of them will not be interested in advanced study, their lack of interest does not mean that they will not play an important role as support scientific technicians. As they work in the field, laboratory, and greenhouse, they will observe many things that, if passed on, can be extremely valuable.

A complete and current roster of these alumni and their addresses must be kept, and regular contact must be made, particularly with those located in remote areas. The alumni should regularly receive a copy of IRRI's *Research Highlights.* The investment will be substantial but it will pay handsome dividends. The copies will be used and retained with pride by the alumni. Too frequently it goes only to the senior scientist or administrator and quietly reposes on the bookshelf, out of reach of persons who could use it every day. If the copy is addressed directly to the participants who can use it as their own immediate reference material, it will be used frequently and read from cover to cover! The participants should regularly receive the *International Rice Research Newsletter* (IRRN), which will give them contact with researchers throughout the rice-growing world and help them keep up on their English. The availability of these reference materials in their offices or laboratories will generate a dimension of public relations among their fellow colleagues that is not possible in any other way.

As IRRI moves into the decade of the 1980s, and plans for activities anticipated for the 1990s and into a new century, its support will be based largely on how well it informs national programs of the nature of its activities. There can be no better *public relation corps* than the alumni of the professional improvement (training) group. They understand IRRI's nature and goals and how it wants to render assistance on an international basis. Those who have spent considerable time in the

field on international programs know the significance of this group of *graduates.* They have a better appreciation of the nature of IRRI than those who have received fellowships and scholarships to work toward advanced degrees and have spent relatively little or practically no time at IRRI's laboratories, greenhouses, and research fields.

CONCLUSION

Human resources development (training) has a relevance orientation, as far as IRRI's future is concerned. That professional improvement must be a significant integral function of IRRI. Research endeavors alone will not suffice if IRRI is to progress and grow intellectually. There must be an outlet for information. The information must be designed and organized simply and accurately so that the *human resources* element will readily absorb it for the benefit of those with whom and for whom they labor.

Most of the trainees who have come and will come to IRRI are leaders or potential leaders in their own institutes or organizations. They may not have Ph Ds and or list of publications to their credit, but are responsible directly or indirectly for the agriculture (rice) research programs upon which the rice-growing world's future rests. They are entitled to treatment as colleagues and peers. Their attitudes and feelings when they leave largely determine the future of IRRI's relationship to national programs. The trainees should be convinced that if the appropriate technology is used in an appropriate manner, maximum returns can be anticipated. Those in research should not believe that their future professional growth and recognition will be based solely on their publications. They should not get caught up in the "publish or perish" syndrome. The written word is a primary medium of communication, but there are many ways in which it can be effectively used. Let the hallmark of IRRI's success be thought provoking, understanding, and emphatic teaching.

This phase of professional improvement must receive appropriate recognition and a dignified role in the scheme of things as IRRI evolves its administrative structure. It cannot be treated as a *byproduct;* if it is, the chances are rather great that IRRI's usefulness and influence as an international institution will quietly and subtly fade away.

INTERNATIONAL COOPERATION

INTERNATIONAL NETWORKS

H. E. KAUFFMAN, M. J. ROSERO, and V. R. CARANGAL

The concept of international agricultural networks originated in the early 1900s. Scientists in the United States exchanged wheat germplasm from the world collection with scientists in several countries to test them against stem rust disease. This exchange gradually increased and in 1950 when, in response to the alarm caused by a new race of the wheat stem rust fungus in the United States, a systematic network was developed to cooperatively evaluate wheat through the first international nursery — the International Spring Wheat Rust Nursery (Loegering and Borlaug 1966).

Borlaug and his colleagues identified and used the dwarf wheats in the Mexican breeding programs and evaluated them against rust around the world. When the now-famous Mexican-bred wheat *8156* was found to be high yielding and disease resistant in South Asia, a formal network of wheat scientists was established to give scientists in Asia and Africa access to the Mexican wheats and to get feedback about yield and disease performance to the scientists in Mexico. Borlaug initiated a training component for the network, and young scientists from many countries participated in various aspects of the varietal improvement and testing programs at the wheat research stations in Mexico.

The widescale adoption of the Mexican wheats in India and Pakistan and the wide acceptance of the rice variety IR8 led to the coining of the term *green revolution.*

During IRRI's first decade, an informal network of rice improvement scientists was established and breeding material was freely exchanged. The first international nursery of rice — the International Rice Blast Nursery — was established in 1963 (Ou 1965). During the late 1960s promising IRRI breeding materials were tested in national programs such as the All India Coordinated Rice Improvement Project, which had cooperating scientists at more than 100 sites throughout India.

IRRI systematized the international network for rice improvement scientists with the creation of the International Rice Testing Program (IRTP) in 1975. The United Nations Development Programme provided IRTP funds for 5 years to test rice

IRTP joint coordinator, IRRI; IRRI liaison scientist, Centro Internacional de Agricultura Tropical. Cali, Colombia; and network coordinator, Cropping Systems Program, IRRI.

genetic materials worldwide, to systematically train rice improvement scientists, and to conduct workshops and monitoring tours to foster national, regional, and international cooperation.

All the International Agriculture Research Centers now use an international network to disseminate and evaluate germplasm. At IRRI the network approach is also used for cropping systems research (Asian Cropping Systems Network), soil fertility evaluation studies (International Network on Soil Fertility and Fertilizer Evaluation for Rice), constraints research (International Rice Agro-Economic Network), and farm machinery development (Farm Machinery Development Network) (Table 1).

Role and objectives

The international networks of the international agricultural research institutes have many roles. The primary role is to involve and use the expertise of the national and international scientists in solving problems of mutual interest and, at the same time, provide the institute scientists ways to do research in different environments and cultural conditions. The networks permit research personnel to work collectively on problems that individual scientists or national programs cannot do alone. Thus limited financial and manpower resources are efficiently used in strengthening national programs. An especially important aspect of the networks is the ability to rapidly generate, test, adopt, and transfer new technology from the researcher to the farmer through the interaction of scientists, extension personnel, and farmers, which is made possible by training, workshops, and joint travel-study programs. Thus the networks have the potential to serve a dual role — they provide lead research and also serve as an extension network for the results obtained.

Common format for network organizations

To be successful, the networks' results must be directly applicable to help various countries improve their research capabilities and increase their food production. A

Table 1. Size and scope of the International Networks coordinated by IRRI, 1980.

Network	Participating countries (no.)	Region	Sites (no./ organization)	Cooperating scientists (no.)
International Rice Testing Program	75	Worldwide	200	500
Cropping systems	9	Asia	22	178
International Network on Soil Fertility and Fertilizer Evaluation for Rice	12	Asia and Africa	35	30
International Rice Agricultural Economics Network	6	Asia	10	50
Farm Machinery	9	Asia, Latin America	12[a]	20

[a] Number of projects is 12 and number of manufacturers 50 in 10 countries.

desirable format for network organizations includes working or advisory groups consisting of leading scientists in the participating national programs, relevant program scientists from the international center, and internationally known experts working in the program area. Scientists and cooperators in a working or advising group represent the various component views of the program. The group's smallness (less than 20), fosters active discussion among the members. Where networks are worldwide, regional groups are created. The international center provides a scientist with responsibility to coordinate the activities of the network.

A working or advisory group should meet at least once a year to:

- review and evaluate the previous year's activities,
- discuss significant findings that will have cross-country implications,
- develop plans for the coming year, and
- chart the network's long-term strategies and objectives.

WORLDWIDENETWORK OF RICE IMPROVEMENT SCIENTISTS: THE INTERNATIONAL RICE TESTING PROGRAM (IRTP)

During its 5 years of operation, the IRTP network has established working contact with more than 700 rice scientists at about 300 rice research stations, institutes, and universities in 75 countries in Asia, Africa, North and South America, and Europe (IRRI 1980). Those scientists are actively developing improved high yielding varieties for the developing countries of the world.

From IRTP's inception the paramount need was the involvement of the world's rice scientists in program planning and evaluation. Annually, cooperators share in planning and reviewing the program by participating in monitoring tours, the annual International Rice Research Conference at IRRI, regional subject-matter workshops, and the advisory group meeting. Various IRRI scientists who make field visits and participate in national workshops discuss ways and means of improving the IRTP. Correspondence provides cooperating scientists an additional opportunity to give suggestions for program improvement.

At IRRI scientists in the Genetic Evaluation and Utilization (GEU) program help formulate the various IRTP nurseries and participate in the monitoring tours and workshops. IRRI liaison scientists in Latin America (Centro Internacional de Agricultura Tropical) and in Africa (International Institute for Tropical Agriculture) coordinate IRTP programs in their regions.

IRTP activities

Nurseries are prepared for each of the major rice-growing conditions — irrigated wetland, rainfed wetland, deepwater, and dryland. Since 1975 there has been a gradual expansion of IRTP nurseries and the number distributed annually (Table 2, 3). The various nurseries are sent to the requesting national coordinators who distribute them through the national programs. Entries in the IRTP nurseries, which are composed at IRRI, are also evaluated in special IRTP regional nurseries in Latin America; in Africa the best entries are entered into the regional trials of the

Table 2. Types of International Rice Testing Program nurseries in 1980.

YIELD		
Irrigated	–	Very Early (IRYN-VE) Early (IRYN-E) Medium (IRYN-M) Late (IRYN-L)
Rainfed	–	Upland (IURYN)
OBSERVATIONAL		
Irrigated	–	General (IRON) Arid (IRARON)
Rainfed	–	Upland (IURON) Lowland (IRLRON) Deepwater (IRDWON)
STRESS SCREENING		
Temperature	–	Cold (IRCTN)
Soil	–	Salinity/Alkalinity (IRSATON)
Diseases	–	Blast (IRBN) Tungro (IRTN)
Insects	–	Brown planthopper (IRBPHN) Gall Midge (IRGMN) Stem Borer (IRSBN)

Table 3. Types and number of nurseries coordinated by International Rice Testing Program, IRRI, 1975-79.

Year	Types of nurseries (no.)			Total nursery sets dispatched (no.)	Countries participating (no.)
	Yield	Observa-tional	Stress screening		
1975	3	2	7	457	40
1976	3	3	8	573	42
1977	4	3	8	577	42
1978	4	5	6	852	52
1979	4	5	6	886	61

West Africa Rice Development Association (WARDA).

Around the world, the planting seasons differ widely. That causes a spread of data returns from a given set of nurseries over 12-14 months. As a result, a preliminary and a final report are prepared for each nursery. Most of the preliminary reports include data from wet-seaon planting in Asian countries, and are prepared and discussed in April at the annual International Rice Research Conference. The final reports are published 6 months after the preliminary reports. A separate publication highlights the best entries in each nursery. The preliminary, final, and highlights reports help scientists in national programs in planning their respective rice improvement programs.

Use of IRTP test entries and data

The usefulness of IRTP nurseries can be measured by the number of IRTP entries selected by national scientists for use in their hybridization program for further testing in local, state, or national yield trials. A key measure is the number of IRTP entries released directly as varieties for farmers. As of 1979, more than 30 IRTP entries have been released as varieties in more than 18 countries (Table 4). These varieties now grow on several million hectares.

Many research leads have been identified through the IRTP. For example, the existence and patterns of variation of biotypes and strains of major rice insects and pathogens would not be known without the network testing. Of special significance is the identification of regional biotypes of the BPH.

Table 4. Entries originating from International Rice Testing Program nurseries recommended for release or released as varieties in national programs.

Region or country	Designation	Origin	Name given
SOUTHEAST ASIA			
Burma	BG90-2	Sri Lanka	Sinthiri
	BR51-91-6	Bangladesh	Sintheingi
	IR34	IRRI	Sinshwethwe
Vietnam	IR2071-625-1	IRRI	NN 3A
	Jaya	India	
	Pelita I-1	Indonesia	
	Biplab	Bangladesh	
	IR2307-247-2-2-3	IRRI	Nong nghiep 6A
	IR2823-399-5-6	IRRI	Nong nghiep 2B
	IR2797-115-3	IRRI	Nong nghiep 3B
SOUTH ASIA			
Bangladesh	IR2061-214-3-8-2	IRRI	BR6
	IR2053-87-3-1	IRRI	BR7
India [a]	BR5146-C1	Bangladesh	–
	IR30	IRRI	IR30
	IR34	IRRI	IR34
	IR36	IRRI	IR36
	Intan	Philippines	Intan
Indonesia	IR26	IRRI	IR26
	IR28	IRRI	IR28
	IR30	IRRI	IR30
	IR32	IRRI	IR32
	IR34	IRRI	IT34
	IR36	IRRI	IR36
	IR38	IRRI	IR38
	IR2307-247	IRRI	Semeru
Nepal	BG90-2	Sri Lanka	Janaki
	IET2938	India	Durga
	IR2061-628-1-64-3	IRRI	Laxami
	IR2071-124-64	IRRI	Sabitri
AFRICA			
Ivory Coast	Jaya	India	–
	IR2058-78-1-3-2-3	IRRI	–

Continued on next page

Table 4 continued

Region or country	Designation	Origin	Name given
Mali	IET2885	India	–
	IR269-26-3-3-3	IRRI	–
	IR1529-680-3	IRRI	–
	Jaya	India	–
Niger	IR1529-680-3	IRRI	–
Senegal	Jaya	India	–
Sierra Leone	Cica 4/IR665/Tetep	CIAT	ROK 11
	Cica 4/IR665/Tetep	CIAT	ROK 12
Sudan	IR2053	IRRI	IR2053
Upper Volta	IR1529-680-3	IRRI	–
	Vi jaya	India	–
LATIN AMERICA			
Belize	Cica 8	CIAT/ICA	Cica 8
Bolivia	IR1529-430-3	IRRI	Saavedra V5
Cuba	IR1529-430-3	IRRI	IRI529
Honduras	Cica 8	CIAT/ICA	Cica 8
Panama	Cica 8	CIAT/ICA	Cica 8
Paraguay	Cica 8	CIAT/ICA	Adelaide I

[a] Named in certain states.

Monitoring tours — workshops and publications

Publications of nursery results, and individual monitoring tour and workshop reports help cooperators and administrators to quickly share the vast amount of information collected in the network (Table 5).

Monitoring tours are an important component of IRTP. Scientists from various countries travel together and look at IRTP nurseries and other research of mutual interest. Since 1975, 32 monitoring tours have taken 188 scientists from 35 countries

Table 5. International Rice Testing Program publications, 1975-79.

Type of publication	Publications (no.)				
	1975	1976	1977	1978	1979 [a]
Fieldbooks	12	14	15	15	17
Nursery reports					
• Preliminary	2	8	14	15	17
• Final		12	13	15	–
• Highlights				1	–
Activities report	1	1	1	1	1
Planning and review	1	2	2	3	1
Monitoring tour reports-workshops	2	1[b]	3	9	3
Standard Evaluation System for Rice	1				
Master fieldbooks				1	1

[a] Some 1979 reports are in press. [b] Combined report for 7 monitoring tours.

to visit 126 rice research stations or institutes in 32 countries on 4 continents. Tour participants benefit from observing rice research activities and scientists at the host institute gain from interacting with the international group of scientists. The monitoring tours have helped improve the quality of the IRTP trials and have given incentive to cooperating scientists to participate in regional and international programs. Regional or national workshops and *so-what* discussion sessions are usually a part of each monitoring tour.

A regional IRTP network: the Latin American model

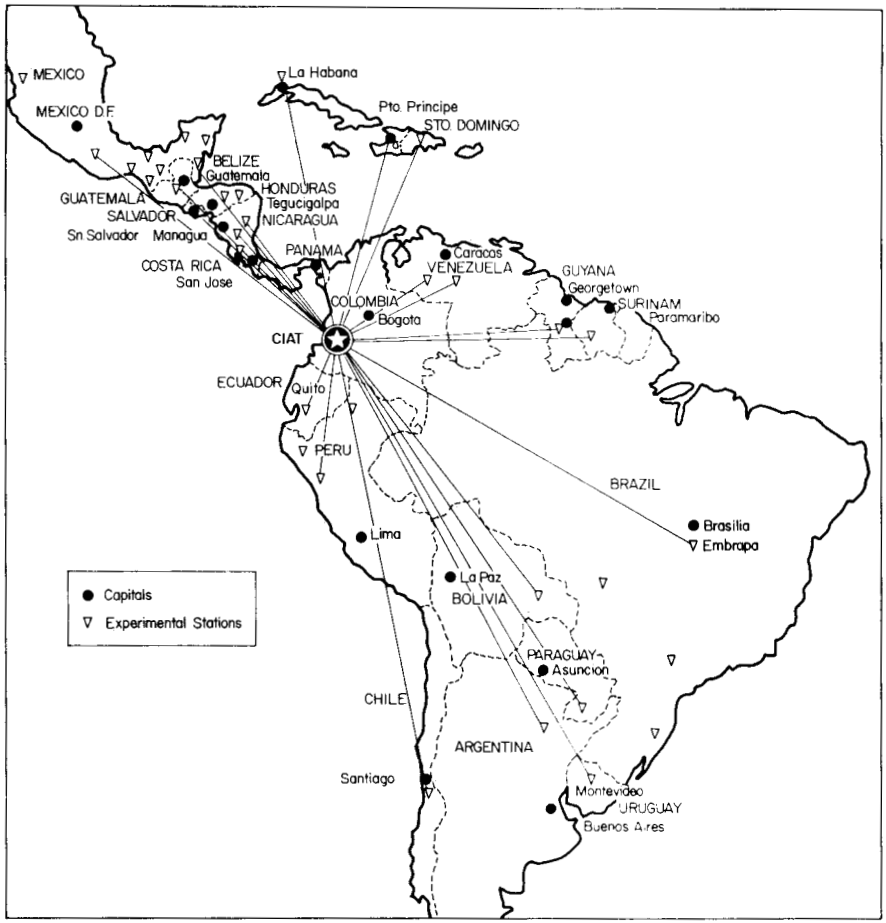
It was recognized, that to best meet the unique regional needs of rice scientists, production experts, and farmers, regional networks must be established. The Latin America-IRTP network serves as a model of a successful regional network in varietal improvement research.

The CIAT-ICA rice program in Colombia, which was established in 1967, was a precursor to the IRTP network. It developed improved varieties for irrigated and rainfed wetland conditions of tropical Latin America, which led to significant gains in rice production in Colombia and several other Latin American countries. In 1976, IRRI stationed a liaison scientist at CIAT to devote full time to strengthening the regional network through the establishment of an IRTP in Latin America.

The first Latin American IRTP conference was held at CIAT in 1976 to organize the network. The various national program leaders recommended that several yield nurseries be established and, at two subsequent conferences held in 1977 and 1979 (IRRI 1976, 1977, 1979b), several additional yield and screening nurseries were recommended. The Latin American trials were dispatched to 21 countries in the region (Table 6, Fig. 1).

Table 6. International Rice Testing Program nurseries for Latin America distributed in 1977-79.

Nursery	Entries (no.)			Sets (no.)		
	1977	1978	1979	1977	1978	1979
Yield nurseries						
Early (VIRAL-P)	10	–	23	28	–	39
Medium (VIRAL-T)	15	14	23	28	26	28
Late (VIRAL-Tar)	–	–	19	–	26	9
Upland (VIRAL-S)	14	19	24	22	31	30
Deepwater (VIRAL-F)	8	8	15	5	5	8
General (VERAL)	–	–	14	–	–	22
Observational nurseries						
Irrigated (VIOSAL)	–	60	97	–	37	14
Upland (VIOSAL-S)	–	–	52	–	–	25
Screening nurseries						
Leaf scald (VIOL-R)	–	–	61	–	–	18
Blast (VIPAL)	–	185	120	–	131	131
Sheath blight (VIAVAL)	21	20	16	9	11	12
Salinity & alkalinity (VIOSAL)	37	25	10	4	7	8
VITBAL	–	–	23	–	–	10
Total	105	331	497	96	148	254



1. Network of the International Rice Testing Program in Latin America.

Although some genetic materials in the nurseries sent from IRRI had value for Latin America, much of them were inappropriate because of different consumer preferences, and disease and insect problems, and because rice is mainly direct seeded instead of transplanted. Because most rice programs in Latin America had few trained personnel and limited resources, they primarily needed genetically fixed breeding materials for direct release as varieties for farmers.

The germplasm in the Latin American nurseries originates from nurseries composed at IRRI and from the CIAT-ICA rice breeding cooperative project, as well as from several national breeding programs. Entries from the IRRI-composed nurseries are selected on the basis of field and laboratory performances at CIAT and several other selected locations.

The return of results from various nurseries has been encouraging — 59% in 1977 and 68% in 1978 — indicating that the regional network is well accepted by national scientists. Several entries from the CIAT-ICA breeding program and various breeding programs in Asia have performed better than existing commercial varieties.

Network strategies for the 1980s

During the past 5 years, the IRTP has laid the groundwork for a productive network of varietal improvement scientists but the network should be used more effectively to strengthen all aspects of the varietal improvement programs. Central to future activities should be an understanding of the individual needs of cooperators and of the individual collective benefits accruing from the network mechanism for joint planning, reviewing, testing, and reporting. The following strategies for the 1980s will bring greater benefit to the national and international programs:

- The existing testing program should be diversified to include three levels of trials for network cooperators: regular nurseries, special screening sets, and stress-resistant donor sets. The type of trial for each stress would depend on the importance of the problem, the amount of resistant germplasm available, and the variability of the causal organism or insect.

  Yield and observational nurseries would continue with major emphasis on observational nurseries for each of the major rice-growing conditions. Major stresses nurseries would continue as new germplasm and breeding materials are generated or identified for testing. Special screening sets for each minor stress would be composed to more systematically identify and incorporate resistant sources into breeding programs. Most screening sets would have relatively few entries but for several diseases — or where varieties with high levels of resistance have not been found (i.e. stem borer, sheath blight) — the special screening sets might have large numbers of germplasm bank entries tested in several hot spot test sites. The stress-resistant donor sets, on the other hand, would be limited to sources with well-proven resistance to all stresses for use in hybridization programs or genetic studies.
- National network scientists should be more involved in planning and directing the activities of the network, which should include not only the nurseries but also other components of the international cooperative programs such as planned hybridization, early-generation testing, and varietal-improvement-oriented collaboration projects, to ensure that the projects mesh with the overall varietal improvement program and thus contribute to the strengthening of the national programs.
- Breeding of materials for nonirrigated areas should be more diversified through a systematized international crossing block and more *in situ* testing of segregating populations.
- The rice environment must be better characterized to guide and interpret network activities.
- Research information from multilocation tests must be increased.
- As the computer facilities improve at IRRI, the types of nursery reports should

be more diversified and tailored to meet the individual cooperator's needs.

- The network must be used to better monitor races of disease pathogens and insect biotypes. Trap nurseries composed of leading commercial varieties, differentials, and a few elite breeding materials should be tested at selected sites for several of the major diseases or insects (i.e. blast and BPH), which have variable pathogens or insects. Such nurseries would give an early warning of the breakdown of resistance.
- Linkages with production and cropping systems programs must be improved.
- Network coordination at IRRI must be improved. IRRI GEU activities such as breeding operations, genetic studies, genetic resources and conservation, stress screening, seed technology, and many of the problem-area activities must be linked to, and guided by, the needs of national programs.

THE ASIAN CROPPING SYSTEMS NETWORK

Because cropping systems are dependent on highly specific physical and socioeconomic environments, cropping systems research must be in different rice environments of the region. A network of Asian cropping systems research sites was therefore established in 1974 in major rice-growing areas in collaboration with national programs.

The main goal of the Asian Cropping Systems Network is the joint generation by national programs and IRRI of technology to increase food production in Asia through the identification of more productive rice-based cropping systems that are acceptable to small-scale farmers. The specific objectives are to:

- develop cropping systems technology for the major rice-growing regions in Asia;
- enable IRRI to extend relevant methodology and technology into national programs;
- provide a series of data points on the Asian agroclimatic grid for determining the cropping systems potential in major areas of the region;
- provide a mechanism for long-term upgrading of national efforts;
- provide a mechanism for joint program planning and review between the national programs of the region and IRRI; and
- help organize international and regional meetings on cropping systems.

A methodology for conducting cropping systems research has been developed (Zandstra 1976). The general methodology is to identify a target area and select a research site of one or more villages representing the target area. Research on cropping systems and component technology in farmers' fields combines the expertise of the researcher and the experience of the farmer.

The cropping systems research team is interdisciplinary with at least an agronomist, a crop protection specialist, an economist, plus supporting staff. The team lives near the research site. Because the farmer and the research team work together, there is development of relevant technology and more adoption of the technology.

Site and network organization

The cropping systems working group, composed of leaders from national programs involved in the network, developed the conceptual framework of technology generation, verification, and extension for network (IRRI 1974, 1975b). Program leaders in Asia agreed to follow this framework in developing their national cropping systems research and production programs.

After a research site is selected, its agricultural characteristics must be described through classification of the environment and the existing production systems. The next step is design of cropping patterns and component technology research based on the information from the description and available technology for the crops involved in the patterns. The major site activities are the testing of the designed patterns in farmers' fields and component technology experiments in either farmers' fields or rented land to further refine the technology for that environment.

After testing and identifying the most profitable patterns, the next step is to verify the performance of the patterns through multisite testing within the environmental complex. That involves testing of one or more cropping patterns at many sites to further refine the recommendations. From the results of multisite testing, the research team identifies a package of technology specifying the recommended varieties and management practices for each crop in the patterns, which can be used for a pilot production program. The final step then is a regional or national production program.

All national programs participating in the network have implemented the testing of cropping patterns at their sites. Philippines, Thailand, and Bangladesh have implemented multisite testing. Pilot production has been initiated in the Philippines and Sri Lanka (Fig. 2). Scientists from Indonesia, Philippines, Thailand, Sri Lanka, Malaysia, Bangladesh, South Korea, Burma, and India now participate in the network. Each country has continued to expand its cropping systems work and established its own national network.

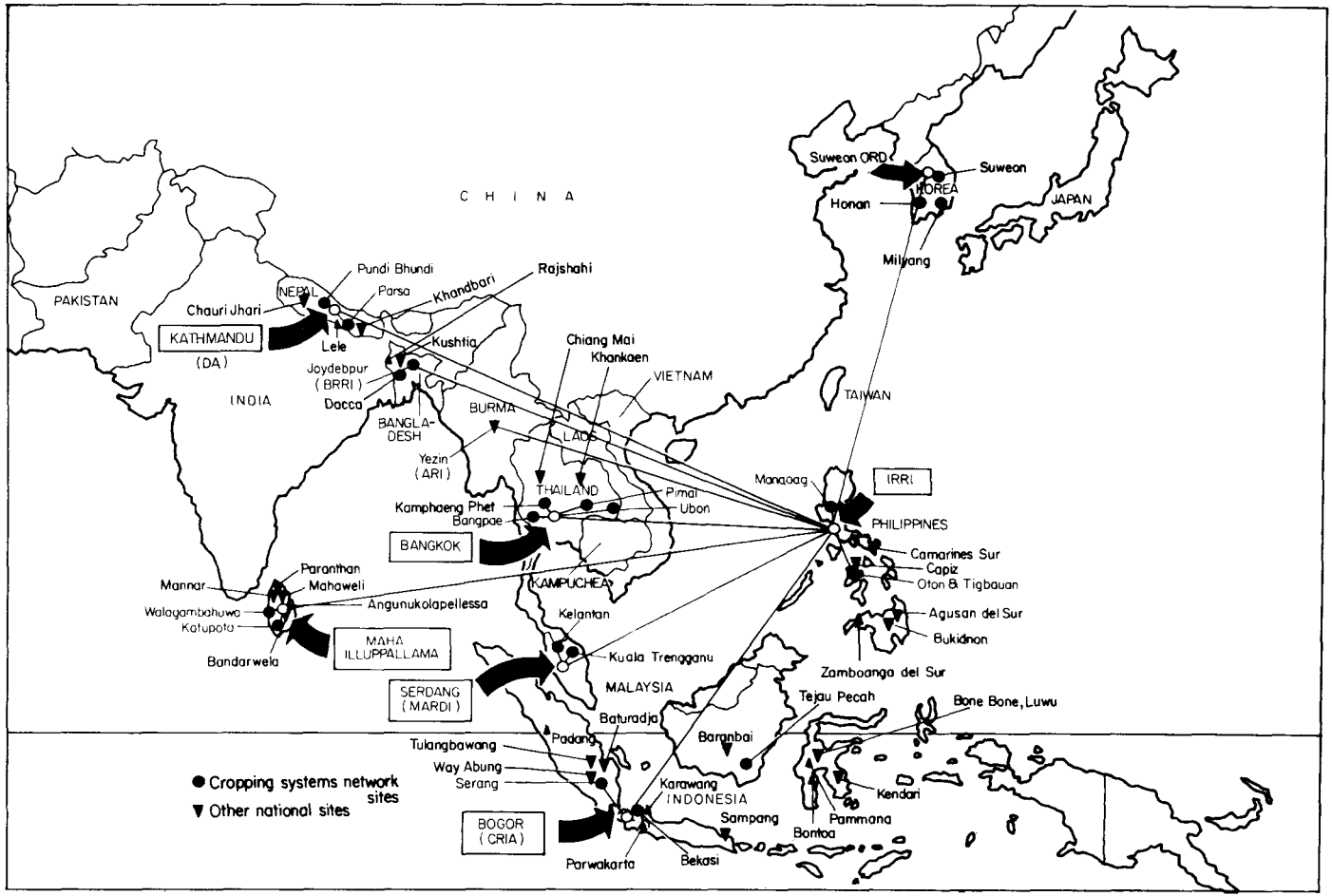
In 1979, there was a total of 55 operational research sites in 8 countries — 22 of those fully operational in the network (Table 7). The sites represent a broad range of climatic zones, soil types, soil textures, and socioeconomic conditions in the major rice-growing countries. The main focus in each site is to increase cropping intensity from 1 to 2 or more and from 2 to 3 or more crops/year, and at the same time increase crop production and overall net income.

The amount of research on component technology varies from site to site depending on the need, available funds, and manpower. Likewise, the number of cropping patterns tested varies depending on the kind of rice land and environment.

At most sites, the objective is to increase production through increased cropping intensity. Improved varieties of rice and other crops are used in the promising patterns and mostly local varieties in traditional patterns (Table 8) (IRRI 1978, 1979c). Special attention is given to early maturing varieties of all crops tested.

Collaborative research

There are two major collaborative research areas in the network. One is cropping



2. The Asian Cropping Systems Network sites, 1980.

Table 7. Number of research sites in various types of rice land in participating countries in 1979[a].

Country	Total (no.)	Rainfed wetland	Partially irrigated	Dryland	Irri-gated	Deep-water
Bangladesh	4(2)	2(7)	1(1)		3(1)	1(1)
Indonesia	15(3)	6(2)	2(0)	7(2)	2(0)	1(1)
Malaysia	2(2)	2(2)			2(0)	
Nepal	5(2)	42)	1(1)		3(1)	
Philippines	7(3)	4(2)		4(1)	4(0)	
South Korea	9(3)				9(3)	
Sri Lanka	7(3)	30)	2(1)		3(0)	
Thailand	6(4)	5(4)			1(0)	
Total	55(22)	26(15)	6(3)	11(3)	27(5)	2(2)

[a] Number within parentheses ( ) indicates sites involved in the network.

pattern monitoring and the other varietal testing of dryland crops. Varietal testing is an important part of component technology research at the various network sites. IRRI-University of the Philippines at Los Baños (UPLB) and national programs collaborate in the testing of varieties from a special project at UPLB's Institute of Plant Breeding. National programs test varieties and do seed increase at experiment stations. Each country selects the best performing entries at the experimental station for testing at the research sites. Therefore, trials are not uniform from country to country.

Sharing research information

The Cropping Systems Network provides a forum for the exchange of ideas and

Table 8. Traditional and promising cropping patterns at selected network sites, 1979.

Site	Consecutive months (no.) Wet	Dry	Predominant traditional pattern	Promising pattern
Rainfed wetland rice				
Madura, Indonesia	5	4	Rice-upland crop	Rice-maize+peanut
Bekasi, Indonesia	7	2	Rice-rice Rice-upland crop	DSR rice-WSR rice soybean
Pangasinan, Philippines	3-4	5-6	Rice-mungbean	Rice-mungbean Rice-ratoon-mungbean Rice-rice-mungbean
Iloilo, Philippines	5-6	2-4	Rice-fallow	Rice-mungbean Rice-cowpea Rice-rice Rice-rice-cowpea
Bangpae, Thailand	3	4	Rice-mungbean	Mungbean-rice-Mungbean
Katupota, Sri Lanka	2+2	1	Rice-fallow Rice-rice	DSR rice-rice DSR rice-mungbean DSR rice-cowpea

Continued on next page

Table 8 continued

Site	Consecutive months (no.)		Predominant traditional pattern	Promising pattern
	Wet	Dry		
Paranthan, Sri Lanka	3	9	Rice	Rice-sesame
Pimai, Thailand	1-2	7	Rice	Mungbean-rice Peanut-rice
Ubon, Thailand	3	6	Rice	DSR rice-rice Peanut-rice Green maize-rice
Bhogra, Bangladesh	5	5	Rice-rice	Rice-rice
Parsa, Nepal (Terai)	5	6		
Purndi Bhumdi	7	2	Rice Rice-wheat-maize Rice-wheat	Rice-barley Rice-lentils Rice-wheat-maize
Partially irrigated rice				
Manaoag, Pangasinan, Philippines	3-4	5-6	Rice-mungbean	Rice-ratoon-mungbean Rice-rice-mungbean Green maize-rice-mungbean
Walagambahuwa, Sri Lanka	3	4	None or rice	DSR rice-rice
Parsa, Nepal	5	6	Rice Rice-wheat	Rice-wheat Rice-potato
Laskarchala, Bangladesh	5	6	Rice-rice Rice-wheat	Rice-blackgram-wheat Rice-wheat
Irrigated rice				
Salna, Bangladesh			Rice-rice	Rice-rice-rice
Suweon, South Korea			Rice-fallow	Potato-rice Rye-rice
Hona, South Korea			Rice-fallow Rice-barley	Pea-rice
Milyang, South Korea			Rice-wheat Rice-barley	Potato-rice
Dryland rice				
Madura, Indonesia	5	4	Maize+peanut-maize Peanut-maize+peanut	Farmers pattern
Tajau Pecah, Indonesia	6	4	Maize+upland rice-maize	Maize+dryland rice/ Cassava+peanut
Bukidnon, Philippines	5-6	2	Maize-maize Upland rice-maize	Dryland rice-maize-mungbean

research information and a mechanism for joint program planning among scientists working in the region. Central to these activities is the working group, which meets twice each year in a participating country. The network had a cropping systems workshop in March 1975, a seminar for research administrators in February 1976, a

symposium on cropping systems research and development for the Asian rice farmer in September 1976, and a cropping systems conference in March 1980.

Study tours have been held since 1977 to orient scientists new to cropping systems research, program supervisors, site coordinators, and component technology researchers involved in site research. The network also coordinates the distribution of research papers to cropping systems scientists around the world.

Training

To support the activities of the network and national cropping systems research, IRRI sponsors several types of training for research and extension workers. Since 1974 a total of 188 scientists have attended an annual 6-month general course. Many scientists have participated in on-the-job training on various component technologies of the cropping systems research such as entomology and economics. Eighteen scientists completed the MS and six the Ph D under the supervision of the IRRI cropping systems staff, and students were pursuing advanced degrees in 4 IRRI departments during 1979.

Strategies for the 1980s

Cropping systems research is now becoming an integral part of the national research system in the various countries involved in the network. Agricultural research activities arc increasingly focusing on the on-farm research. Indonesia, South Korea, Philippines, Sri Lanka, and Bangladesh are expanding their cropping systems programs to cover the major rice environments in their countries. However, in Burma, Malaysia, Nepal, and Thailand, more sites have to be established to strengthen cropping systems research. Although India joined the network in 1979 and will establish one site, this collaboration can hopefully be expanded to other rainfed areas. China sent a participant to the 1979 cropping systems conference and will be invited to join the network soon. Collaborating countries will benefit from China's experiences, particularly in irrigated rice systems.

There is major interest in some national programs to expand the scope of their cropping systems program to include livestock in farming systems research. Most Asian farmers have livestock, and indications are that cropping systems are affected by the livestock component of the farm. Some national programs are now starting to work on farming systems.

With the expansion of the programs, there is a need for the training of more research and extension personnel. IRRI should consider two 6-month courses a year to accommodate more trainees during the next 2 years. National training programs should be established in various countries, particularly for interdisciplinary research and extension workers who will conduct the research and multisite testing, and for extension workers involved in production programs. More economists are now being recruited to strengthen the economics component of national cropping systems programs, and more entomologists and other discipline-oriented researchers are being involved in the program to provide technical backstopping to the site research and multilocation testing. There is a need for IRRI to provide these

scientists short-term training.

To get a better understanding of the relationship between environment and crop performance, site research staff must collect more data on environment, management practices, and farm operations in their cropping pattern testing. A uniform format was developed by the cropping systems working group for this purpose. This information is important in extrapolation within the same ecological zone and in designing multilocation testing in different environments.

There is a need to develop improved varieties of dryland crops that fit into the various rice-based cropping systems. Dryland crops may be planted before and after rice in rainfed wetland as an intercrop or sequential cropping in dryland rice and after wetland rice toward the dry season. Most current varieties are for dryland conditions and generally are commodity oriented.

Breeding programs must exert more efforts and resources to develop and identify dryland crop varieties that are suitable for intensive cropping.

INTERNATIONAL NETWORK FOR SOIL FERTILITY AND FERTILIZER EVALUATION FOR RICE

Although national programs have identified optimum rates of fertilizer, many small-scale farmers do not have enough capital to purchase the recommended amounts. Because fertilizer is becoming more expensive. researchers must focus on increasing the efficiency of fertilizer so farmers can attain good production and high income. Thus more work on thevarious types and rates of fertilizer and the methods of application is needed.

At the International Rice Research Conference in 1974. rice agronomists and soil scientists from Asia and IRRI agreed to focus their studies on increased fertilizer efficiency in rice. At the 1975 conference, participants from 10 Asian countries organized an informal network to collaboratively study fertilizer nitrogen efficiency. This research was expanded in 1976 to cover soil fertility and fertilizer management, and in 1977, the International Fertilizer Development Center (IFDC) joined the program, and the network became a three-way collaboration. To further expand its scope to include biological nitrogen fixation, the network was renamed the International Network for Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) in 1979.

Six experiments are conducted in the network:

- nitrogen fertilizer efficiency in rice (irrigated).
- long-term fertility trials,
- nitrogen fertilizer efficiency in rainfed wetland rice.
- effect of azolla inoculation,
- azolla growth as affected by phosphorus and strains and its seasonal variations, and
- sources of fertilizer phosphorus for wetland rice.

Major INSFFER results

The major objectives of the first network experiment, nitrogen fertilizer efficiency in

rice, were to:

- obtain an insight into the relationships between nitrogen source, nitrogen management, and nitrogen efficiency under a variety of environmental conditions, and
- monitor nitrogen availability and nitrogen-uptake patterns throughout the growing season to help explain observed differences in nitrogen efficiency under different soil and climatic conditions.

From 1975 to 1978, there were 32 trials in the dry season and 73 in the wet season. The treatments changed somewhat during the period but basically consisted of two rates of nitrogen fertilizer and three forms of urea: urea (prilled), briquets, and sulfur-coated urea (SCU) with different methods of application. Of special interest was the deep placement of fertilizers. In 107 of the 115 trials there was a significant response to nitrogen. In the 32 dry-season trials, the highest grain yield was obtained with SCU at the medium nitrogen rate followed by urea in mudballs and urea briquets. At the low nitrogen rate, SCU and urea in mudballs performed equally well, and the best split application was slightly better than urea in bands. Urea in mudballs, urea briquets, and SCU gave high grain yields at medium nitrogen rate in the 73 wet-season trials; SCU and urea in mudballs gave significant increases over the best split application in 50 and 49 trials, respectively, out of 106 trials; and urea briquets gave significant increases in 38 trials.

The long-term fertility experiment was started in 1976. The main objective is to monitor fertility changes over time under intensive cropping. The treatments included various combinations of nitrogen, phosphorus, potassium, and zinc. There were 14 sites involved (Table 9). Of the 41 trial results received there was response to nitrogen at 13 locations, response to phosphorus in 9 sites, and response to potassium in 110 sites.

Because at least 60% of the rice area in South and Southeast Asia is rainfed wetland, the INSFFER participation in April 1978 agreed to implement an Interna-

Table 9. Countries participating in the various International Network on Soil Fertility and Fertilizer Evaluation for Rice trials.

Country	Trials on nitrogen fertilizer efficiency (no.) 1975-78	Sites for long-term fertility experiment (no.) 1976-78	Azolla experiments (no.) 1979
Bangladesh	14	2	–
China	–	–	1
Egypt	1	–	–
India	27	1	3
Indonesia		13 1	–
Korea	3	–	–
Malaysia	5	1	–
Nepal	5	1	–
Philippines	26	6	1
Sierra Leone	3	1	–
Sri Lanka	8	1	–
Thailand	10	–	9

tional Trial on Nitrogen Fertilizer Efficiency in Rainfed Wetland Rice for areas where water depth does not exceed 1 m.

In 1979, collaborative research on azolla started with the objective of testing it as a green manure and evaluating the efficiency of various strains. The experiment on the effect of azolla inoculation has nine treatments evaluating the effects of azolla alone and combined with various rates of nitrogen fertilizer. The second azolla experiment evaluates three strains of *Azolla pinnata* from Bangkok, India, and the Philippines as well as three treatments of phosphorus. Initially, four countries are collaborating (Table 9).

IFDC and IRRI are also collaborating with several scientists in the national programs to determine nitrogen balance in wetland rice systems using ^{15}N-labelled fertilizer. Hopefully, an understanding of the basic mechanisms of fertilizer nitrogen in wetland rice soils will help in developing management practices to increase fertilizer efficiency.

A training program for young scientists involved in the collaborative research is conducted at IRRI. The training includes a 2-week course on rice production; planning field activities and planting an INSFFER experiment; collection and statistical analysis of data from the field experiments; lectures on basic soils with emphasis on soil fertility, chemistry and microbiology, fertilizers, and fertilizer management; and experiments on growth requirements of azolla. The first training program (1979) was attended by 22 scientists from 9 countries. During 1980, 20 scientists from 7 countries (People's Republic of China. Bangladesh, Indonesia, Malaysia, Thailand, Philippines, and Sri Lanka) will participate.

Strategies for the 1980s

In the future, the national programs, IRRI, and IFDC must exert efforts to develop more relevant methods of fertilizer application and optimum rates of fertilization for the millions of small-scale rice farmers in Asia. The collaborative research on fertilizer use must be strengthened to identify the best method and time of application, kinds of fertilizer, and rates of application for different rice environments in Asia. The collaborative efforts must improve fertilizer efficiency to give maximum efforts to the farmers' investment.

Additional sites for the collaborative experiments must be selected to represent each major set of rice-growing conditions in Asia. The environment at each testing site must be characterized to better understand the crop performance and interpret the response of fertilizer rates and methods of application to the environment. This understanding is necessary in comparing the results between locations and in extrapolating the data to other areas.

It is especially important that the soils at each site be analyzed by a standard procedure before the collaborative experiments are conducted. Without the soil data, it is difficult to determine the relationships between available elements and responses to fertilizer treatments. Therefore, original or check plot soil samples from each site should be sent to IRRI for soil test calibration studies.

Each national program should also have a mechanism to further test the findings

of the collaborative experiments in the national fertilizer testing program. The best treatment should be tested through the national testing program not only in the experiment stations but also in farmers' fields so that recommendations can be made for production programs.

The long-term fertility trials should be expanded to more sites to sample the different soil environments of major rice-growing areas, especially in Asia. The number of sites should be increased in most of the countries and include other countries like China, South Korea, India. and Thailand.

Azolla research should strive to refine methodologies for culturing and inoculating the water fern and work to popularize azolla use throughout Asia.

INTERNATIONAL RICE AGROECONOMIC NETWORK (IRAEN)

The foundation for the International Rice Agro-Economic Network (IRAEN) was laid in 1971-73 when development specialists in agricultural economics, rural sociology, and related fields did a survey in 36 villages at 14 sites in India, Indonesia, Malaysia. Pakistan, Philippines, and Thailand (IRRI 1975a). The primary purpose of that research was to collect information about on-farm changes associated with the introduction of the new rice technology and seek answers to the question of physical, environmental, and socioeconomic factors limiting further growth in rice production. The working relationships among Asian social scientists played an important role in organizing the subsequent investigations on constraints work.

IRAEN was formally organized in 1974 by cooperating agronomists, economists, and statisticians from Thailand, Indonesia, Sri Lanka, Bangladesh, Taiwan, and IRRI. The purpose was tojointly plan and conduct studies to determine constraints that keep rice yields on farmers' fields lower than anticipated from research results. Specifically the objectives were to provide quantitative information on:

- the rice yield gap over a wide range of environments.
- the proportions of the gap that may be attributed to selected test factors,
- the cost and returns associated with moving from the farmers' practices to a higher yielding technology, and
- in some cases, the impact and interaction of environmental factors with test factors on rice yields.

From 1974 through 1977 there were 410 wet-season trials and 372 dry-season trials at 10 sites in the network. Across all areas studied there was an average yield gap between optimum inputs and farmers' inputs of nearly 1 t/ha in the wet season; in the dry season the gap was slightly higher. Increased levels of fertilizer and insect control significantly raised wet-season yields on the farmers' fields while high fertilizer levels contributed more than half of the gap in the dry-season yield and insect control much less. To reach high yield levels. the average cost-benefit ratio of the inputs was higher in the dry season than in the wet. Weed control contributed a relatively small amount to the yield gap in either season (IRRI 1979a).

The socioeconomic constraints explained why farmers were not taking advantage of the yield potential of the modern varieties. In the wet season, the cost of inputs

exceeded the value of added yields in many locations, whereas in the dry season the high level of inputs increased net benefits in 9 of 10 sites. In the dry season the significantly high returns from high levels of fertilizer generated a strong incentive for fertilizer use. But high levels of insect and weed control were not sufficiently attractive to farmers in many locations.

The trial results implied that although the amount of rice loss to insects is substantial, the current technology is too costly to effectively protect the rice from damage. This finding has stimulated rice entomologists in Asia to seek a less costly, more effective insect control method. Furthermore, in most instances, fertilizer is applied inefficiently. Other networks (i.e. INSFFER) are now examining ways to increase the productivity of fertilizer use.

Besides identifying some key constraints in rice production, the constraints methodology handbook provides a ready reference for scientists and policy makers seeking answers to the questions mentioned (De Datta et al 1978). The handbook outlines ways to determine the importance of several factors contributing to a yield gap in areas where the existing technology is capable of producing substantially higher yields but is not used by farmers.

Strategies for the 1980s

Although formal IRAEN studies on rice yield constraints were completed in 1978, the philosophy and procedure of the constraints network are continuing in various national programs. Scientists in Pakistan and India have initiated constraints research, and scientists in countries that participated earlier have continued it.

In the future it is important that each constraints group pursue the research most appropriate to their conditions. They must critically select the right technology and the appropriate factors and levels to make their constraints effective. The overriding importance of fertilizer in most locations indicates that fertilizer as a test factor should be continued. Other test factors such as weed, insect, and disease control should be dependent on the site and the growing season. In many places it will be necessary to include new test factors that contribute to increased yield. Of special interest is the work on water regimes, especially rainfed rice. Although varieties are important, they are beyond the scope of this network. In some places, additional emphasis should be placed on the importance of risk to the farmers'decision-making (Herdt and Mandac 1979, Flinn 1979).

To broaden the scope of the constraints work, it may be advisable to expand the studies from the level of individual paddies or rice crop to include studies on socioeconomic and biotechnical constraints at the level of the farm. Because the philosophy, methodology, and activities of the cropping system, and the constraints network are complementary, the participants of the two networks should synthesize and integrate approaches and share resources and results in the future (IRRI 1979c).

INTERNATIONAL AGRICULTURAL MACHINERY NETWORK

The agricultural engineering program at IRRI develops designs of small equipment specifically to meet the needs in the small- and medium-sized rice farmers in the

developing countries. During the past 10 years, IRRI-designed machines have contributed to crop intensification, which is a profitable way to increase rice production in Asia. Increased crop intensity results in timely farm operations for land preparation, threshing, and planting. Other engineering techniques, such as soil incorporation of insecticides and fertilizer, improve efficiency and reduce costs. Low-cost pumps to provide supplemental irrigation during periods of critically low soil moisture also directly increase yields.

The machinery extension network

In 1974, an industrial extension workshop was convened at IRRI to suggest means of improving the IRRI agricultural machinery program and to develop a technology-transfer network. Workshop discussions noted significant differences in level and composition of mechanization in the various countries represented and the ability to translate basic design information into viable, low-cost, locally produced machines acceptable to farmers. Therefore, the group identified, as priority areas, the strengthening of the national capabilities of the agricultural engineering institutions for research on and development of relevant farm machines and for the extension of the technology to the local manufacturing sector.

A formal network of 11 organizations in 10 countries outside the Philippines was established to work with IRRI-designed machines and adapt them to participating countries. A basic tenet of the program is that mechanization based on local production conserves foreign exchange, expands opportunities for local industries, strengthens linkages between agriculture and other sectors of the economy, and enhances training opportunities for small-scale manufacturing.

Collaborative projects in Pakistan and Thailand have several support staffs who provide technical assistance to neighboring countries as well. Industrial extension engineers work in these two countries and in Indonesia and the Philippines. IRRI agricultural engineers stationed in Burma and Bangladesh contribute to the extension program in addition to other specific responsibilites. Subcontract programs in Sri Lanka, India, Malaysia, and Columbia are funded by specific grants.

The network provides opportunities to test and improve technology under local conditions before the machines are passed on to cooperating manufacturers. Information interchange through newsletters, progress reports, personal correspondence, and personal visits has been an important component of the program. A 2-week training course held twice each year on the design, operation, and maintenance of IRRI-designed machines has helped familiarize the staff of cooperating organizations and manufacturers with the machines and the network philosophy.

The significant success of the network is reflected by the large number of machines built in various countries in 1979 (Table 10). During the past several years, production of machines has increased at 40% year.

Strategy for the 1980s

Agricultural mechanization programs in the 1980s must focus on ways to significantly cut rice production costs. High fuel prices demand the development of

Table 10. Number of IRRI-designed machines commercially produced during 1979.

Country	Manufacturers (no.)	Machines (no.)				
		Power tiller	Axial-flow thresher	Portable thresher	Dryer	Axial-flow pump
Burma	1	–	50	–	–	–
Colombia	1	–	–	–	90	–
India	3	100	5	5	–	–
Indonesia	8	54	–	20	–	22
Philippines	21	1337	1850	2290	47	13
Pakistan	5	–	28	–	–	–
Sri Lanka	2	–	–	71	–	–
Thailand	22	134	2160	4	–	–
Egypt	2	–	100	–	–	–
Total	65	1625	4193	2390	137	35

fuel-efficient machines and machines that increase the efficient use of costly inputs such as fertilizer and insecticides. From the current survey on mechanization being conducted in several Asian countries, future program leads should be identified.

The momentum of network activities developed in the late 1970s must be continued through the existing collaborative and subcontract programs. Focus on one or two IRRI-designed machines most uniquely adapted to individual countries will likely bring most productive results.

As in the past, the key to the success of the network will be in the generation of new IRRI-designed machines from Los Baños and from the inputs of subcontract programs. Major breakthroughs in the design and development of machines for transplanting, crop drying, and deep placement of fertilizer and insecticides may have a high demand in many Asian countries because they reduce production costs.

CONCLUSION

In the short time that the networks have been active at IRRI, they have played a significant role in the internationalization of IRRI's work.

Now that the networks have been established, future strategies must focus on strengthening the networks to best meet the local needs of the cooperators and at the same time collectively generate appropriate technologies and research information that can be used by the world community of agricultural development scientists and farmers.

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INFORMATION DISSEMINATION

SCIENTIFIC PUBLICATION: TRENDS AND NEEDS IN RICE IMPROVEMENT

T. R. HARGROVE and V. T. JOHN

The publication of technical papers in scholarly journals or books is a strong force in the sociology of science. Most of the world's rice scientists work in developing countries, but appear to rely largely on the scientific literature published in the highly developed countries (HDCs) as information sources and as outlets for their best research findings. Some researchers feel that such a reliance forces scientists from developing nations into a dependence on HDC scientific norms, which could be counterproductive to the development of agricultural technology in tropical Asia, Africa, and Latin America (Jennings et al 1979, Swanson 1974).

To look at scientific publication entirely as a means of communication would be misleading. Publication is a means of "peer criticism" to preserve rigid scientific standards. Scientists also publish to establish themselves as having first discovered a new piece of knowledge. De Solla Price (1963) called scientific publication a reward mechanism and noted that the strong force that called the research paper into being, and has kept it alive since, was the establishment and maintenance of intellectual property.

Publication has also been termed as a type of academic gift-giving. Hagstrom (1965) pointed out that manuscripts submitted to scientific periodicals are often called contributions for which an author seldom receives payment. But subsequent researchers adapt the established knowledge to develop technology, or add to it to expand the *frontiers of knowledge.*

Scientists generally acknowledge groundwork that previous scientists have laid in a research area by citing the research pioneers in their papers. A scientist's recognition and prestige are often determined by his publication record, by the prestige of the journals in which his papers are published. and by the citation by subsequent scientists of his work. The scientist's promotions and salary are also often affected. Hence, the worldwide scientific community has evolved an important — yet often unwritten — law that it facetiously refers to as *publish or perish.*

But acceptance of papers for publication is not easy, particularly in the most prestigious journals. When a scientist submits a paper, the journal usually sends it

Editor, International Rice Research Institute; and senior plant pathologist, All India Coordinated Rice Improvement Project, Rajendra Nagar, Hyderabad 50030, Andhra Pradesh, India.

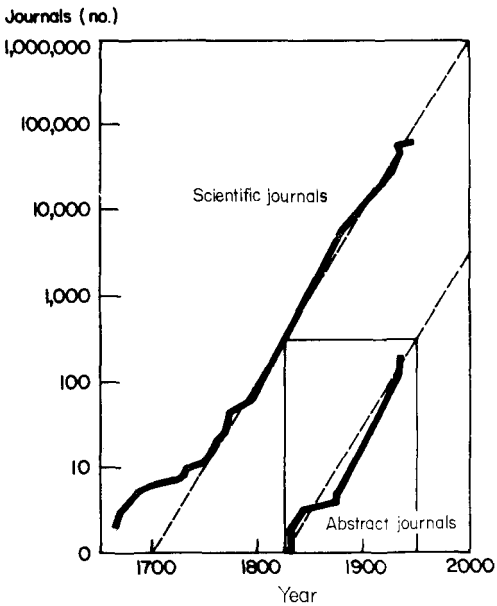
through review by two or more scientists working in the same or a closely related field, who recommend acceptance, rejection, or revision of the article for publication. An additional barrier to publication is that the most prestigious journals are mainly published in the HDCs by discipline-oriented, scientific societies. That may restrict publication to society members and require membership fees that are often prohibitive for scientists in the developing countries. Thus, the developing-nation scientists' research results may be denied international access and the scientists themselves, international recognition.

Development of the scientific journal

Zinman (1969) suggested that the creation of the scientific paper about 300 years ago may be the key event in the history of modern science, whose destruction would seriously affect the entire scientific enterprise.

The oldest surviving scientific journal is the *Philosophical Transactions* of the *Royal Society of London,* first published in 1966 (de Solla Price 1973). The number of scientific periodicals had grown to about 100,000 by 1960 (Fig. 1). By about 1830 it became evident that no scientist could read all the published work relevant to his interests and the abstract journal appeared on the scene. By about 1950 the abstract journals had reached the critical number of about 300 and scientists began to feel the need for *abstracts of abstracts* to handle the information explosion in science.

In about the mid-1960s the computer area began to permit selective dissemination of information, information retrieval, information consolidation, and systematic



1. Increase in the number of scientific journals since 1965 (de Solla Price 1973).

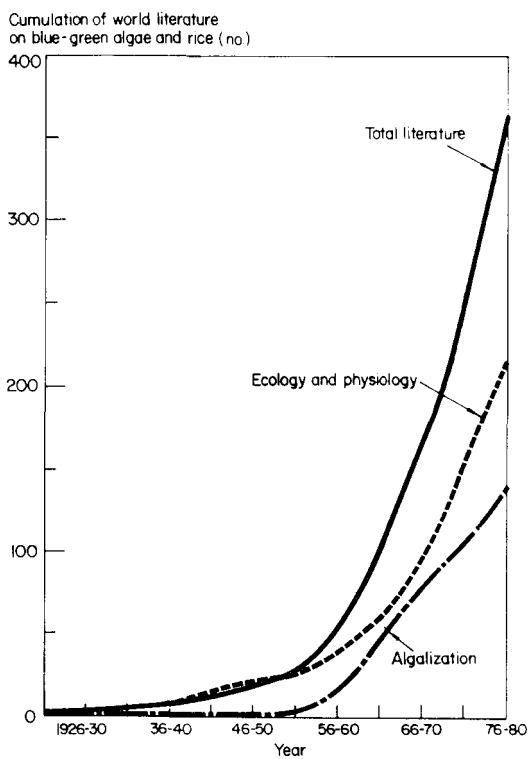
and rapid movement of information to users. Scientists in the HDCs, particularly in fields of study such as atomic energy, chemistry, or rare earths, gained access to the electronic systems more than a decade ago. But most of the rice world still remains outside the new information technology.

SCIENTIFIC LITERATURE IN RICE

We traced the growth in the volume of rice research literature to determine similarities and differences in the production and use of scientific literature among rice scientists in the developing countries, the HDCs, and international organizations.

Exponential growth in rice literature

Roger and Kulasooriya (1980) documented the scientific literature on the role of nitrogen-fixing blue-green algae in rice from 1926 to 1980. They found an exponential growth curve similar to that observed by de Solla Price (Fig. 2).



2. Growth of literature on blue-green algae in rice production, 1926-80 (Roger and Kulasooriya 1980).

The first *International Bibliography of Rice Research,* published in 1961, listed 1,056 references. By 1971 the *Bibliography* listed 2,766 references, and in 1978 it had 5,684 references, making its growth rate also exponential (Fig. 3). Figure 4 shows the exponential increase since 1962 of only one type of IRRI information material — technical books.

Ratio of developed to developing-nation journals

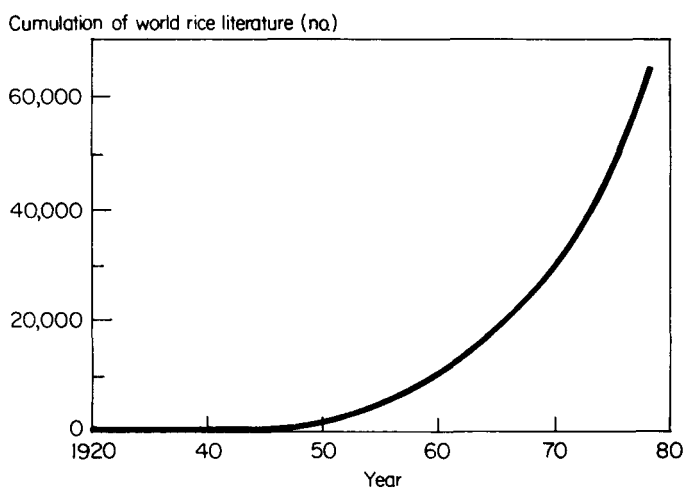
We surveyed 1,093 journals that published at least one of the rice articles listed in the *International Bibliographies* from 1961 through 1978. Seventy percent of those journals were published in HDCs.

The contents of 20 randomly selected HDC and 10 developing-country journals from the *Bibliography* were analyzed. The HDC journals averaged 6.7 pages vs 6.0 pages/ article for developing-country journals; 110 vs 96 pages, issue; and 6.4 vs 3.1 issues/ year.

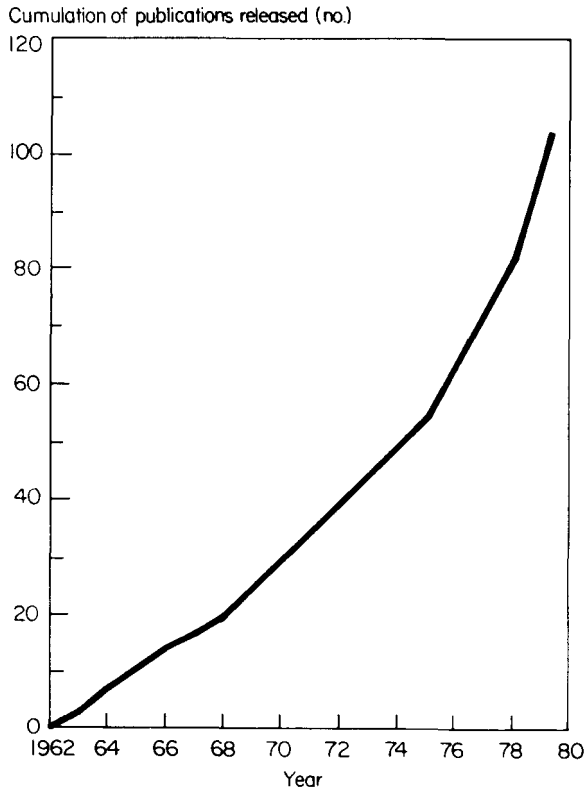
Of 33 journals listed for the first time in the 1978 *International Bibliography,* 79% were from HDCs.

Publication productivity

De Solla Price (1963) wrote that half of the publications produced by a population of n scientists are authored by the most productive of $\sqrt{n}$ of the population. The inverse-square root law has held from the early 17th-century journals through today among chemists, physicists, and other basic scientists in the HDCs. Hargrove (1979) calculated the scientific publications authored by 38 Asian rice breeders and found that 50% of the publications were authored by 6 of the breeders — roughly the



3. Growth of world's rice literature, 1930-78. Data from 1920-50 are from Lawani and Seriki (1974); subsequent data are from the *International Bibliographics of Rice Research.*



4. Books on rice research and production released by IRRI. 1962-79.

square root of the sample. Thus the scientific publication norms — at least in terms of publication productivity — among rice scientists in national programs and their peers in the HDCs appear similar.

DEPENDENCE ON LITERATURE OF THE HIGHLY DEVELOPED COUNTRIES

Kramer and Williams (1979) studied communication patterns among agricultural scientists at international agricultural research centers and in national programs. They described the agricultural development scientists as nonmembers of the formal research establishment who were dedicated more to the generation of technology than of knowledge per se. They found them, however, highly dependent on HDC information channels.

Information gathering

Kramer and Williams found that the typical international center scientist spends about 7 hours week reading scientific information — 4.4 hours HDC literature and

2.6 hours regional (developing-country) literature.

Of the scientific publications that scientists at international centers rated most important to their work, 93% originated in the HDCs; national scientists reported 70%. Both groups reported Crop Science and Agronomy Journal (both published by the American Society of Agronomy) as their two top HDC information sources. Both groups reported the HDC journals as highly credible. However, the international center scientists reported the HDC journals as highly accessible, while national scientists reported their accessibility as only medium.

Similarly, Hargrove (1979) found that of the seven sources of published information most important to Asian rice breeders, three were published in HDCs, two by IRRI, one by an international organization, and one — the *Indian Journal of Genetics and Plant Breeding* — by a national program. Trends of percentage of use were similar.

The ratings of the national journals are relatively low partly because much rice research is site specific and partly because the dissemination of national journals is generally limited to the nations where they are published. When the information-source ratings only for the rice breeders in India were examined, the *Indian Journal of Genetics and Plant Breeding* was the second most important source of published information.

Publication of research results

Kramer and Williams (1979) found that the national-program scientist spent an average of 4.5 hours/ week preparing manuscripts for publication. About 23% of his published papers he considered most important appeared in HDC journals. The international center scientist spent 5.5 hours/ week preparing manuscripts; 42% of the papers he considered most important appeared in HDC journals. Kramer and Williams pointed out that their figures may not reflect the actual publication desires of the agricultural development scientists. Hargrove (1979) reported that although Asian rice breeders published only 18% of their scientific papers in HDC journals, more than half named an HDC journal — usually *Crop Science* — as their first choice for publication of an article.

Although Kramer and Williams considered a national-program scientist as far from governed by the law of *publish or perish,* they found that he considered his professional reputation dependent to a considerable extent on the number and quality of his publications, both in the HDCs and within his region. They found the national scientist, like his HDC peer, concerned with publication to claim intellectual property and to gain professional recognition.

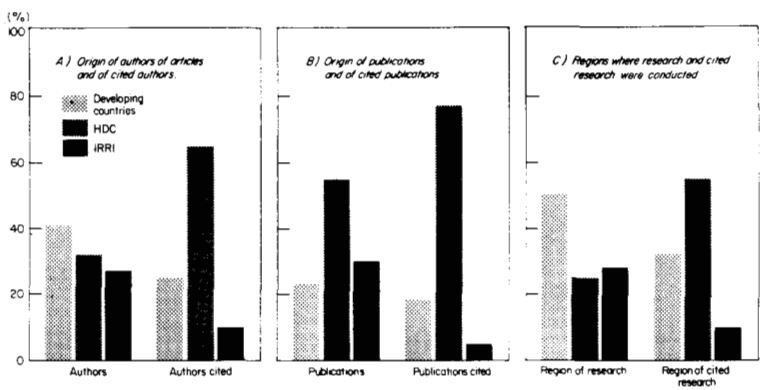
CITATION ANALYSIS OF RICE LITERATURE

Citation analysis has been used to determine the literature foundations of a science or the impact of particular papers (de Solla Price 1965, Cole and Cole 1967, Lawani 1977). Operating on the principle that only the more important scientific papers serve as the building blocks for subsequent research on a subject and thus are cited in

the newest literature, we analyzed the materials cited in both the literature on blue-green algae (BGA) and the *International Bibliographies of Rice Research.*

Blue-green algae literature and citations

We examined 22 articles on BGA published in 1978-79 that included reviews of literature (Roger and Kulasooriya 1980). Developing-country authors make up 41% of the BGA authors; HDC authors, 32%; and IRRI authors, 27%. But when we analyzed the 517 citations listed in the bibliographies of those articles, we found that *65%* of the senior authors cited were from HDCs (Fig. 5*A*). Only 23% of the 1978-79 BGA articles were published in journals originating in developing countries and 55% in HDC journals. But of the journals cited, even fewer were published in developing countries and 77% were published in HDCs (Fig. 5*B*). Half of the research data were obtained in developing countries, but 55% of the cited research was done in HDCs (Fig. 5*C*). IRRI authorsand publications made up 27-30% of the total 1978-79 literature on BGA and 5-10% of the citations. The citation rate was relatively low perhaps because of IRRI's later entry into BGA research.

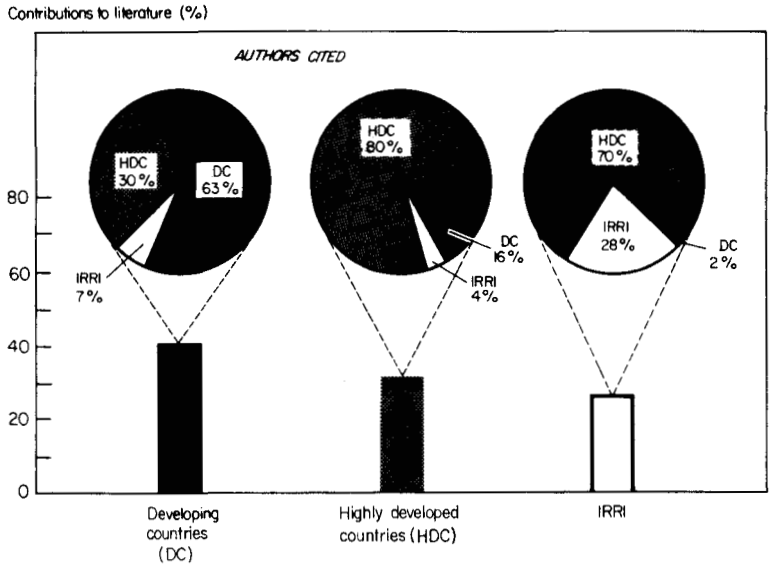


5. Analysis of the 22 research articles on the role of blue-green algae in rice, published in 1978-79, and of 517 papers cited in their reviews of Literature. Adapted from Roger and Kulasooriya (1980).

The literature citations by authors of each category were compared to determine if citation behavior differed. We found that 63% of the citations of the national authors were of other national authors and 30%, of HDC authors (Fig. 6). The HDC authors cited 85% HDC authors. IRRI authors cited other IRRI authors at about the same rate at which they generated literature (27-28%), but their other citations were mostly HDC.

Bibliography literature and citation

The authorship and citations for 80 randomly selected articles that included literature reviews in the 1978 *International Bibliography of Rice Research* were analyzed.

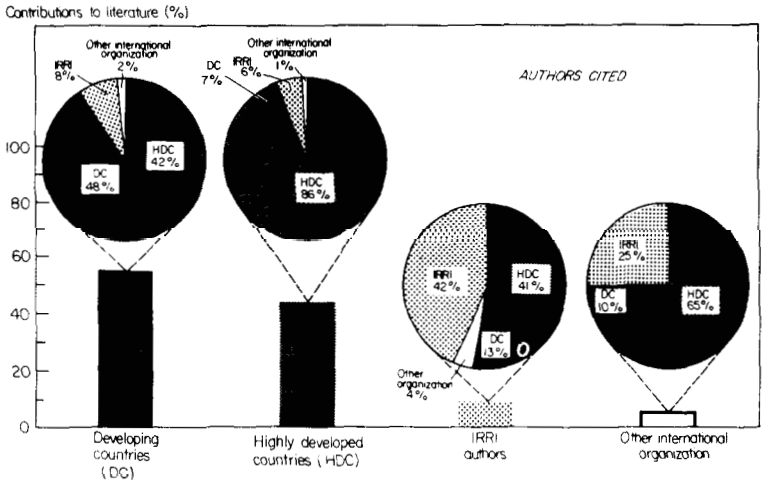


6. Analysis of 517 papers cited by the three categories of authors of 1978-79 articles on the role of blue-green algae in rice. Adapted from Roger and Kulasooriya (1980).

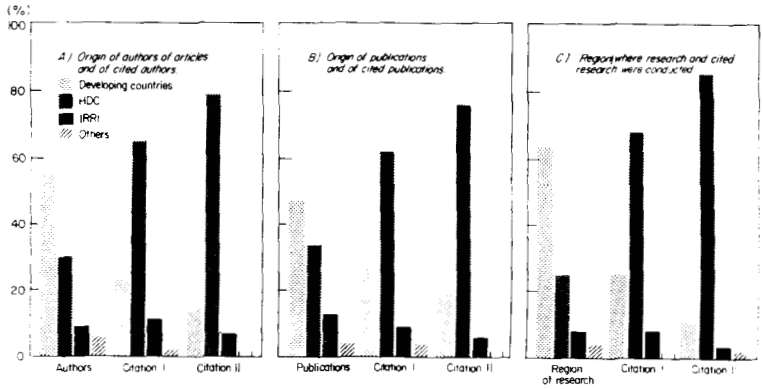
Fifty-five percent of the senior authors of the articles were from national programs, 47% of the articles were published in developing-country journals or books, and 64% of the research reported was conducted in developing countries (Fig. 7). Only 25% of the literature originated from HDCs. But only 23% of the authors and of the 602 articles *cited* in the research papers and only 27% of the cited journals were from developing countries. On the other hand, 65% of the cited authors, and 62% of the cited journals were from HDCs.

A stratified random sample of 41 publications was drawn from the literature cited by authors who had themselves been cited in the 1978 *Bibliography.* (To prevent bias, the distribution of citation samples was: 65% from HDC, 23% from national programs, and 11% from IRRI.) We found an increasing dependence on HDC authors and journals (Fig. 7, *citation 2).* The finding that developing-country authors and journals were more heavily cited in the more recent literature may indicate that developing-country literature is gaining strength.

We then compared the literature that authors of each category cited in the 1978 *Bibliography.* About 50% of the developing-country authors' citations were of other national authors and 42% of HDC authors (Fig. 8). In BGA research, HDC authors tended to cite other HDC authors. IRRI authors tended to cite other IRRI authors and HDC authors about equally — and much more frequently than developing-country authors.



7. Analysis of 80 articles published in the 1978 *International Bibliography of Rice Research,* of the 602 citations in their reviews of literature (citation 1), and of a stratified sample of 598 citations Included in the literature reviews of the cited literature.



8. The origin of authors of 602 articles in the 1978 *International Bibliography of Rice Research* and of authors cited in those papers.

IMPLICATIONS OF DEPENDENCE ON HIGHLY DEVELOPED COUNTRIES

We found similarity in trends of scientific publication among developing-country, international-center, and HDC scientists. Developing-country scientists appear largely dependent on HDC information channels not only as information sources,

but perhaps more important, as a place to publish their best results and thus gain international recognition. But HDC and international-center scientists do not generally use or acknowledge literature from the developing countries. What are the implications of this incongruity?

Misdirection of research

Some observers feel that publication of agricultural development papers in the HDC journals may misdirect scarce scientific resources. Swanson (1974) stated that publication in HDC journals requires knowledge-generating rather than technology-generating research because a paper's likelihood of acceptance in an HDC journal is often judged by whether it extends the frontiers of knowledge in a discipline. But the knowledge frontiers in developing countries often differ markedly from those in the HDCs. Thus, to publish in an HDC journal, the developing-country scientist must conduct research toward the edge of science and therefore removed from the pressing problems of local farmers. Furthermore, the developing countries generally lack the strong agribusiness sectors of the HDCs that adapt theoretical research into farm technology. Therefore, the developing-country scientists' research must be more applied than the HDC scientists'. In addition, the disciplinary nature of most HDC journals may discourage the interdisciplinary research needed to solve farm problems in developing nations.

Jennings et al (1979) wrote that the only realistic criterion of professional success for rice scientists is the degree to which they help increase rice yields, and that rice farmers and consumers around the world would benefit if scientists were judged more by that criterion than by the number of publications written, conferences attended, or reports prepared.

Kramer and Williams (1979) felt that scientists inagricultural development use the HDC publications not because they perceive of themselves and of their efforts as integral parts of that research establishment, but because no other credible channels are available, or, if alternative channels are available, they suffer low credibility. Kramer and Williams see the HDC literature as a less-than-ideal set of information provisions that fill a vacuum. They state that the current situation does not encourage the diverse scientists in the developing countries to coalesce individual contributions into an interdisciplinary critical mass that assures rapid and sustained agricultural development in the tropics.

Dependence on HDC literature is also costly to the developing countries in terms of time and money. Communication through the scientific journal is slow. A scientist who follows the standard formula is likely to first report his research at a conference. A year — often 2 years — later, it is published. A year after that the paper is abstracted and a year later it may be summarized in a literature review. In our study we found that the most important rice research findings in Asia, Africa, or Latin America reach other rice scientists in HDC journals from North America, Europe, Japan, or Australia. After the lengthy process of review and publication, the HDC journals are usually mailed to developing countries by sea, and take about 6 months to reach their destinations. Furthermore, HDC publication of the best

research results perpetuates the stagnation of scientific publication systems in the rice-growing region.

Dependence on the HDC literature strains overall rice budgets. Many scientists and rice improvement centers cannot afford subscriptions to a sufficiently wide range of HDC journals. Furthermore, after accepting the rice scientist's article, many HDC journals have printing fees that run to hundreds of dollars per article.

The professional advancement system in the developing nations themselves often perpetuates dependence on HDC literature and the stagnation of national or regional publication. Scientists are promoted in rank and salary partly on the basis of their publication records. A scientist often receives more credit for promotion for papers published in HDC journals than for papers in local journals.

We do not suggest that rice scientists refrain from using HDC literature. Scientists everywhere can gain from the sharing of research knowledge. Similarly, it would be unrealistic to suggest that rice scientists refrain from publishing their best data in the most prestigious journals.

Instead, we suggest that ways be considered to refocus the powerful force of scientific publication to speed the dissemination of needed information and to focus developing-country research as strongly as possible on the improvement of farmers' yields.

OPTIONS FOR BETTER COMMUNICATION

The most feasible way to focus the flow of the best research knowledge directly to the users who need it most seems to be to open alternative communication channels that carry prestige equal to that of the HDC journals. Kramer and Williams (1979) suggested that the international centers initiate commodity-based journals to decrease dependence on the HDC publications and that the centers greatly expand their technical publications that serve as media for the interchange of technical information among all researchers (as opposed to those that serve as technical house-organs of the centers).

Similarly, participants at the Conference on the Communication Responsibilities of the International Agricultural Research Centers recommended that centers initiate, or encourage the initiation by other organizations of, new scientificjournals in which developing-country scientists can publish their findings (ADC and IRRI 1980).

IRRI established the *International Rice Research Newsletter* in late 1976 to publish concise summaries of rice research findings from all rice-improvement programs. The Newsletter received more than 370 contributions in 1979; the main reason for its popularity seems to be its fulfillment of a need for wide and rapid distribution of preliminary research achievements. The time lag between receipt and publication of *Newsletter* contributions is about 2.5 months and the publication goes to about 11,000 rice workers and libraries in about 60 nations.

The *IRRI Research Paper Series* (IRPS) was established in 1976 as an informal bulletin to rapidly disseminate information from IRRI authors to potential users.

More than 50 IRPS papers have been published. But non-IRRI authors cannot publish in the IRPS.

Thus, the national-program scientist who makes an important advancement in rice improvement usually sends his paper to a scholarly journal in the HDCs.

A prestigious rice publication, open to all authors but focusing on applied rice science for developing nations, could help adjust the scientific reward system by recognizing those scientists who concentrate on research to serve farmers' needs.

One rapid and relatively inexpensive way to accomplish this would be to transform IRPS into a formal referred research publication, and open it to all scientists. Individual research papers could be sent to the persons who could best use them through IRRI's computerized mailing system, which categorizes the information needs of thousands of individual rice workers, coded by discipline, problem area, and work allocation (research, administration, extension, etc.).

An alternative could be the establishment of a prestigious, carefully reviewed, international journal of applied rice science that will emphasize problem-oriented and multidisciplinary research efforts.

Either option would require editorial and financial inputs. But costs of those would be relatively low when one considers the resources invested in rice improvement and the increased potential returns. More application-oriented information would be rapidly directed to those who are ultimately responsible for the development of the technology needed to alleviate hunger — scientists in the rice-improvement programs of the developing countries.

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STRATEGIES FOR INFORMATION DISSEMINATION FROM RESEARCHER TO PRODUCER

L. D. HAWS

IRRI, as an international research body, is essentially a disseminator of information from scientist to scientist. That topic is being covered by others at the conference. The dissemination of information from researcher to producer is another matter. In IRRI's first decade, there was an appropriateness — an acceptability — of a direct approach to farmers; of dissemination of information almost directly from researcher to producer. Essentially, IRRI got close to an *extension function* in that early decade.

As national capabilities for research developed, often with close IRRI cooperation, and as national capabilities to organize and conduct extension-type programs grew, closeness to the extension function became less appropriate.

In the words of more than one director of the international agricultural research centers, "Dealing directly with farmers regarding the new crop technology is a national prerogative. Such dealing should be through national extension-type bodies."

That "extension didn't always function" was also much bemoaned. Information moved from researcher to researcher but it did not move as fast as it should from national researchers to farmers.

THE EXTENSION MODEL

The Cooperative Extension Service created in the United States in the early 1900s remains unique. No other country has adopted such a system of service and education. The legislative act providing for US cooperative extension work points to a need for disseminating information from researcher to producer. The Smith-Lever Act includes the following words: "In order to aid in diffusing among the people of the United States useful and practical information on subjects relating to agriculture and home economics, and to encourage the application of the same. . ."

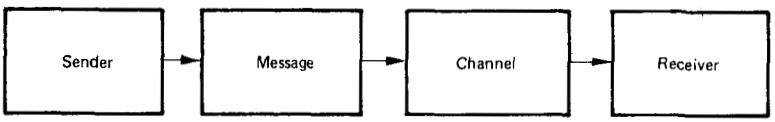
The wording implies the need, if one seeks to develop agriculture, for communication in addition to dissemination. The communication should be not only of a new

Crop production specialist, IRRI, Los Baños, Philippines.

idea, innovation, or technology works but also of what it can do for a person or group of persons, what it means in terms of higher income, of better living, and of a better quality of life.

Information can easily be disseminated. But until somebody uses it, acts on it, and changes because of it, it has not been communicated.

Communication, then, is what really counts. For communication to take place, there must be a message to be sent, a *sender,* a *channel* for carrying the message, and a receiver of the message (Read 1972). The Berlo model for communication is outlined in Figure 1. With it, in the first step, an IRRI scientist is the sender. The *message* could be, for example, success with direct-seeded rice to allow 2 crops a



1. The Berlo model for communication (Read 1972).

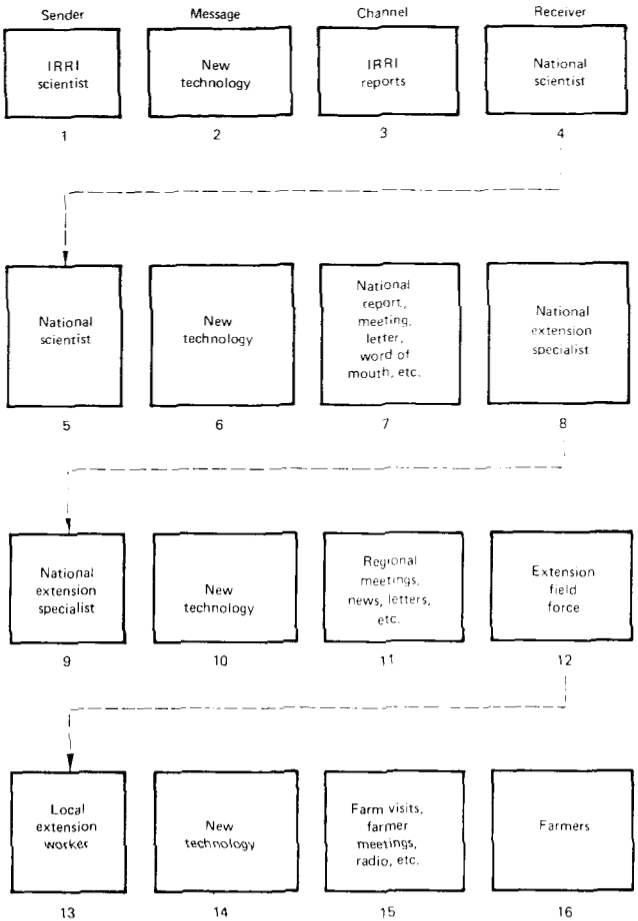
year on rainfed fields. The *channel* may be the IRRI Annual Report or the IRRI Reporter, Research Highlights, the International Rice Research Newsletter, a technical paper presented at a meeting, or a journal article, or several of those channels. The *receiver* is another scientist.

When the report arrives on the receiver's desk, dissemination of information has taken place. Only when it is read, understood, and can be used effectively by the receiver, does communication take place.

An ideal flow, or system, for effective dissemination of information from researcher to producer is illustrated in Figure 2. It depends on a multiple run of the communication model. Before an information reaches the farmer, its senders and receivers change many times. It is also essential that the flow be continuously reversible so that feedback plays a role.

Figure 2 implies that direct dissemination of information about the new technology from researcher to farmer is nearly impossible. In the highly developed agriculture of some countries, a few farmers with advanced degrees go directly to the researcher for the latest and best technology. But, even in the United States, where a unique system links education, research, and extension through the land-grant universities, most farmers still depend largely on their local extension agents for information.

In the less developed agricultures of the world, with which the international research centers deal, the dissemination process ideally should be the same as that outlined in Figure 2. The problem faced is often one of identifying effective senders and receivers.



2. The flow, or dissemination, of information from IRRI to the farmer, based on the basic model for communication.

WHAT IS THE SITUATION AT IRRI?

Since its early days, IRRI has been involved in disseminating information from researcher to producer. In 1964, just 4 years after it was founded, William Golden started the training and extension work. He was involved with training people how to manage and use the new rice technology. Those trainees, in turn, trained others, or themselves introduced the new technology to farmers.

In June 1969, Vernon E. Ross joined IRRI after 6 years of work in India. Ross

had a strong extension background, and an unusual ability to persuade people to his way of thinking and to identify constraints and design practical research to overcome them. In his Indian experience, the research support he found did not provide the practical answers needed to help the Indian farmer. Thus, it was necessary to do field research. The Ross approach was to work with a small interdisciplinary group of researchers whose main task was the removal of constraints facing farmers on their farms.

He developed a workable technology and taught it to a few extension agents, who in turn, taught it to selected farmers. His results in a short period of time were astounding.

Ross moved to Tamil Nadu State in India in 1967, where the same procedures used to increase maize production in Mysore were applied to increase rice production. Again he organized a multidisciplinary team that set out to teach extension workers to overcome production constraints for rice. An increase of 1.3 million tons was attained in 24 months.

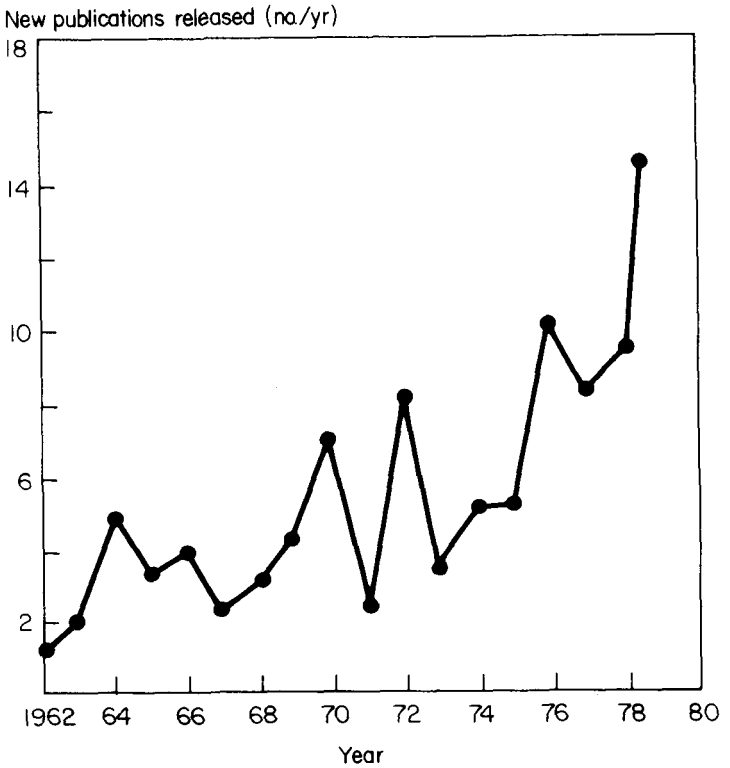
In his first annual report at IRRI, Ross wrote, "Rice scientists are developing new means of increasing rice yields at a rate faster than they can be put to use by farmers. To make maximum use of this technology, massive field testing must be carried out."

Since Ross wrote that paragraph, much has changed in relation to the output of new information. On this 20th anniversary of IRRI's founding, it is interesting to look at the increase in new scientific information being generated at IRRI. In 1963 (Fig. 3), the first scientific publication was produced. Since that time, there has been a continuous increase in publication of new information. In 1979, IRRI released 15 new major publications. During 1979, it printed 15 million pages of new information. Now, there are about 15 publications and other editorial work underway for 1980. Three thousand books per month are distributed.

In addition, in 1979, 12 conferences or symposia on rice or rice-based cropping systems were held. More than 600 scientists attended these meetings. IRRI is now a major SOURCE (sender) of information on rice for scientists of the rice-growing world. The MESSAGE is going to scientists in highly acceptable channels. But the information still does not reach farmers as effectively as it should.

In 1970, drawing on his extension background and his success in developing and extending information to farmers in India, Ross started working with all Philippine agencies with extension functions — Bureau of Plant Industry, University of the Philippines at Los Baños, Bureau of Soils, agricultural colleges, and the National Food and Agricultural Council — in an effort to start applying research in a field program. He advocated taking the newly developed rice technology and teaching it to extension personnel, who in turn, would teach it to farmers. Ross reviewed published research information and conferred with IRRI scientists to identify research results that would solve problems. In some cases, however, he had to do some on-farm field research. He trained extension specialists, who, then, trained local extension workers and worked with farmers.

From Ross' work, a methodology started to develop. That methodology followed



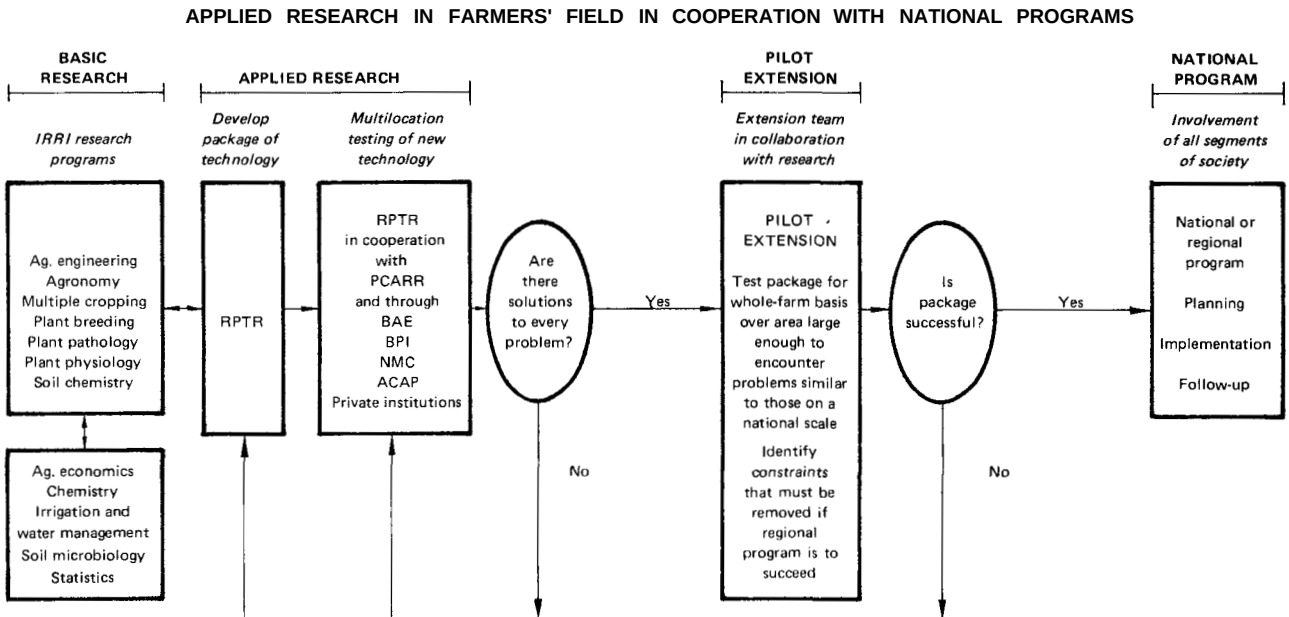
3. Number of new publications released per year. IRRI, 1962-79.

steps on technology development and transfer. The first step included technology development and could be completed with research activities conducted at IRRI.

The second step took the newly developed technology to farmers' fields and evaluated it in small plots to determine if it suited the environment. The third step —a cautious but larger one — put the new technology on a 200- to 500-ha pilot area to determine if all serious constraints could be overcome. Finally, with success on the pilot area, a regional or national program could be organized. This concept has been further developed, as shown in Figure 4.

With this procedure a nationwide rice production program was developed in the Philippines. The pilot phase was named MASAGANA 99. *Masagana* means *bountiful* and 99, refers to the number of cavans (4.4 t) to be produced. The Masagana 99 is still making rice production history in the Philippines. The country with a rice deficit of 800,000 tons in 1973 exported nearly 500,000 tons in 1979.

During this same period the idea of growing two crops of rice in one wet season was conceived. This concept is revolutionary in rainfed areas but would not have been possible without the short-maturing rice varieties developed at IRRI.



4. Applied research in farmers' field in cooperation with national programs.

RESULTS OF A PRODUCTION PROGRAM USING THE NEW PROCEDURE

Partial results of the pilot extension program in Iloilo, code named KABSAKA, have been reported since its inception in 1975 (IRRI 1977, 1978, 1979). As a regional program directed by the Regional Director of Bureau of Agricultural Extension (BAEx) since 1977, KABSAKA has expanded throughout the region. As a part of the plan for agricultural development (Fig. 4, the pilot area must be evaluated to determine:

- its effectiveness as a means of introducing new technology, and
- the effect the new technology had in increasing the standard of living of the rice farmers in Asia and, more specifically, in the Philippines.

An evaluation of the KABSAKA area was completed in 1979 and some of the major findings are reported here. A major goal of the project was to increase the income of the farm family through the growing of two rice crops in rainfed areas where only one used to be grown. In some cases, a third (dryland) crop was grown.

Three years (1976-77) after the initial launching of KABSAKA, farmers using its technology were able to acquire things they could not afford before. The adoption of improved technology (e.g. high-yielding variety, new cropping patterns, fertilizer, insecticide, and herbicide) was accompanied by a great increase in crop yield and income. Improvement in the levels of farm family living was largely shown by investments in farm and household assets, house improvements, and higher education for children (Tables 1-4).

Table 1. Farmer capital assetsacquired by financed and self-financed farmers after KABSAKA, Santa Barbara, Iloilo, August 1979.

Asset	Farmers reporting (no.)	Quantity of items (no.)	Total value ($)	Av value/ farmer ($/farm)
	Financed			
Hand tractor[a]	4	4	10,027.03	2,506.76
Pump irrigation[b]	4	4	1,513.51	378.38
Rice mill	1[c]	2	7,567.58	7,567.57
Thresher[d]	5	7	4,810.81	962.16
Work animal	2	6	1,581.08	790.54
Livestock for market	2	7	229.73	114.86
Plow/harrow	5	8	133.11	26.62
Sprayer	11[e]	11	491.89	44.73
	Self-financed			
Hand tractor[f]	1	1	1,081.08	1,081.08
Sprayer	5	5	151.35	30.27
Plow	2	3	121.62	60.81
Harrow	2	3	43.24	2 1.62
Work animal	1	1	94.59	94.59
House improvement	1	1	32.43	32.43

[a]3 tractors (10 hp each), 1 tractor (12 hp); excluding 2 farmers who had hand tractors even before KABSAKA. [b]1 pump (10 hp), 2 pumps (8 hp), 1 pump (4 hp); excluding 2 farmers who had pumps even before KABSAKA. [c]This farmer owned 2 rice (cono) mills. [d]Two farmers had 2 threshers each. [e]Excluding 1 farmer who had sprayer even before KABSAKA. [f]10 hp.

Table 2. Household assets and other improvements acquired by financed farmers after KABSAKA, Santa Barbara, Iloilo, August 1979.

Asset	Farmers reporting (no.)	Quantity of items (no.)	Total value ($)	Av value/ farmer ($/farm)
Television	3	3	959.46	319.86
Stereo	3	3	513.51	171.22
Gas stove	1	1	6.76	6.76
Oven	1	1	337.84	337.84
Refrigerator	3	3	918.92	306.35
Motorcycle	1	1	1,243.24	1,243.24
Sala set	3	3	175.68	58.51
House improvement	10	10	3,986.49	398.65
Artesian well/drilling	2	7	81.08	40.54

Table 3. Percentage of increase in total gross return and net return on material costs over the previous year (pre-KABSAKA), 30 farmers, Santa Barbara, Iloilo, crop year 1978-79.

Farmer classification	Return[a] ($/ha)		Increase (%)
	Pre-KABSAKA	Post-KABSAKA	
	Total gross		
Financed	459.19	1,093.78	138
Self-financed	258.92	836.89	112
	Net on material costs		
Financed	396.62	852.84	115
Self-financed	359.19	659.46	84

[a] US$I = 7.40

Table 4. survey of farm machinery ana power equipment in 9 barrios covered by KABSAKA project, Santa Barbara, Iloilo, August 1979.

Barrio	Hand tractors (no.)	Threshers (no.)	Water pumps (no.)
Tigtig	6 (8-10.5 hp)	5 (10 hp)	–
Calaboa Oeste	3 (7-10 hp)	1 (10 hp)	1 (12 hp)
Calaboa Este	3 (5.5-10 hp)	3 (8-10 hp)	2 (Unspecified)
Mangacina	4 (5.5-10 hp)	6 (8-16 hp)	6 (8-12 hp)
Tuburan	–	–	2 (8-10 hp)
Miraga	3 (10-11 hp)	2 (10 hp)	–
Conaynay	3 (10-10.5 hp)	–	–
Canipayan	4 (4.5-15 hp)	4 (7-8 hp)	–
Agusipan	4 (10-16 hp)	4 (10-16 hp)	3 (4-6 hp)
Total	30	25	14
Av (all barrios)	3.3	2.8	1.6

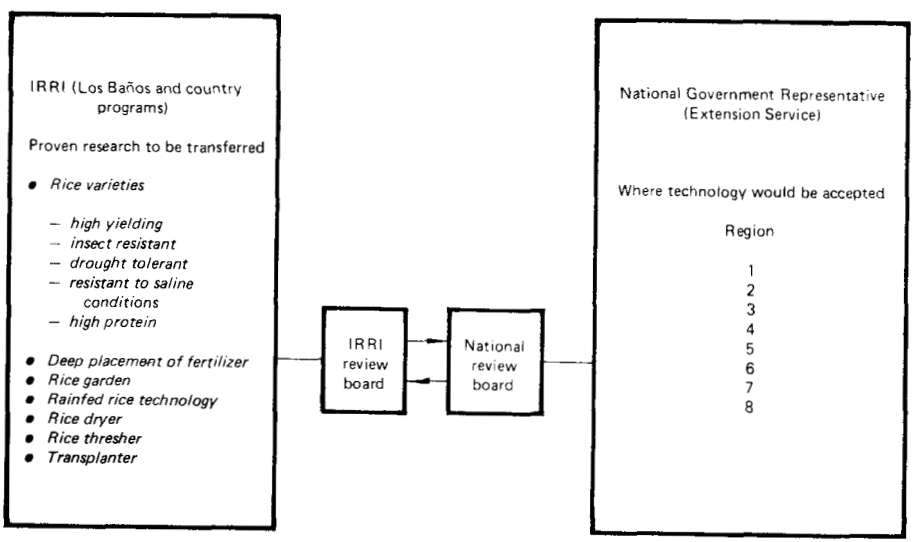
KASATINLU in South Cotabato, another rainfed program, is now being evaluated and its results look promising.

The remaining problems include repair of roads and making transportation available to improve the rice-marketing systems. A rice dryer large enough to give supporting services to the farmers, especially during the wet months, is also needed. Last, but not least, is the need for extension of credit to encourage wide adoption of the modern technology accompanying the program.

STRATEGIES FOR THE FUTURE

How can the system of successful transfer of new rice technology to farmers be used in national programs? From the early days of IRRI, all new seed to be released as a new variety was presented to a review board at the Institute. If the data presented at the board meeting showed the superiority of the new variety, the board recommended that it be presented to the National Seed Board for approval. If approved, the new variety was named and released. Breeder seed was given to the Bureau of Plant Industry for increase and use in the country.

The movement of other proven technology developed at IRRI and how it should be passed on to national programs were discussed recently (Fig. 5). Following the procedures established by the IRRI seed review board, a committee could evaluate the proposed new technology developed at IRRI. With the committee's agreement,



5. Illustrating potential movement of newly developed technology from IRRI to national programs.

new technology would be presented to a national review board — the Bureau of Agricultural Extension in the Philippines and similar bodies in other countries. The new technology could then be accepted or rejected by the host country. That would formalize movement of new technology.

The methodology for the rainfed rice technology could serve as an example of the procedure. It could be evaluated by a committee at IRRI for stability and productivity or other previously determined criteria. If the new technology passed the IRRI review board, it would be passed on to a national review board for acceptance or rejection. That could serve two main purposes.

1. ensure the relevance of applied research at IRRI to national needs, and
2. identify receivers of the newly developed technology and provide knowledge when a project was completed.

Another problem that hinders evolution and transfer of technology involves technology that comes from research at IRRI. With the exception of rice varieties, it is not generally refined enough for use in specific environmental areas, especially in rainfed areas. A major link still missing is the cooperation between research and extension specialists or even between extension specialists and farmers in determining the needs of the farmers.

There is a breakdown in the national programs at stages 5, 9, and 13 of the communication model in Figure 2. Field trials being conducted in the Philippines are designed to determine the fit of a cropping pattern, or the domain of its agronomic fit. There is a breakdown because results from field trials are sent to Manila for analysis and evaluation. Generally, the good results that are obtained and the areas identified as areas where the technology *fits* are never exploited. The exploitation of the newly identified area is the start of a pilot program (Fig. 4). This is a simple explanation for the lack of transfer of the new technology, but we believe it is an accurate one. That means that the major constraint on transferring technology is the lack of a plan to move it into a program that has been developed to use it.

If that is the case, how is the problem overcome? Training, I believe, is the answer. It is possible to train people to use the methodology outlined. Training managers to evaluate the newly developed technology and to organize and conduct production programs is a major need. Persons to assume the responsibility must be carefully selected.

A 1-year training course for 15-20 young men a year could be established at IRRI. Two rice crops could be grown in this period. The first 6 months would be devoted to learning the basics of rice production and the procedure for evaluating and transferring the new technology. The second 6 months would involve actual work in the field where multilocation sites would be established to evaluate the technology and the site where it is to be introduced. Pilot areas could then be selected and organized by the trainees as part of their training.

With the network operating from IRRI, the newly trained. highly motivated. and now knowledgeable young men could then be assigned positions within extension services in the network where production programs are needed. Supervision from IRRI could be continued. Budgets are always a problem but this procedure is the

least expensive for any current program. IRRI field research (RPTR) operates throughout the Philippines on a budget of $25,000-$30,000.

Leadership and *supervision* are two essential words in the program to continue to produce the food needed to feed future populations. Professional management in implementing proven production programs is essential to identify the best technology, place it in an area where it will be successful, identify constraints, and help remove them. This procedure has worked in the past, is now working, and will work in the future. Decisions on the use of these methods must be made at high levels. Administrators should therefore evaluate all known procedures to develop and transfer technology to farmers and then select the proper one. Their support will be necessary for the program to work.

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