International Rice Research: 25 Years of Partnership

International Rice Research Institute

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

IRRI receives support, through the CGIAR, from a number of donors including:

the Asian Development Bank
the European Economic Community
the Ford Foundation
the International Development Research Centre
the International Fund for Agricultural Development
the OPEC Special Fund
the Rockefeller Foundation
the United Nations Development Programme
the World Bank

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FOREWORD

On the occasion of its 25th anniversary, the International Rice Research Institute (IRRI) takes pride in publishing *International Rice Research: 25 Years of Partnership*. This is not a history of IRRI, nor a recounting of IRRI's accomplishments. Those aspects were adequately covered in R. F. Chandler's 1982 history of IRRI.

In this book we present the fruits of 25 years of cooperation with national rice research programs and with advanced scientific institutions in both developed and developing countries. Our record of progress is an outstanding example of the power of purposeful collaboration.

The past 25 years have seen marked increases in the quantity and quality of rice production. From our early work to develop high yielding modern varieties we have moved to develop varieties with genetic resistance to the many insects and diseases that attack rice. While we first considered rice as a crop in isolation to achieve a breakthrough in raising the yield ceiling, we now emphasize rice as part of a whole farm system, and also the whole plant rather than just grain utilization, to increase farmers' income.

The accomplishments are those of IRRI's partners in what Chandler called an "adventure in applied science." This book is about pathways of cooperation and the resulting gains for farmers and consumers.

During the past 25 years, the population of rice growing and consuming countries has increased 50%. This has eroded to some extent the economic and nutritional advantages that the production gains would have otherwise conferred. Hence there is no time to rejoice and relax. What is needed is more research to produce more rice from less land.

I am grateful to the International Agricultural Development Service for providing the services of S. A. Breth, former head of the IRRI information office, to edit this commemorative volume. My special thanks are due to Dr. J. C. Flinn, head of the Agricultural Economics Department, for assembling the material and to William H. Smith, editor, and other staff of the Communication and Publications Department for their dedication to the cause of excellence in publication.

M. S. Swaminathan
Director General

CHAPTER 1

RICE AND THE ROLE OF IRRI

Rice is the most important food crop of the developing world. It is the primary staple for more than 2 billion people in Asia, the world's most densely populated region, and for hundreds of millions of people in Africa and Latin America. Rice is also the main livelihood of rural populations living in these developing regions. Because of the large numbers of people who are sustained by rice, annual output must increase by over 5 million tons a year just to keep pace with population growth.

Rice is a semi-aquatic cereal which originated in the tropics, where vast areas of flat, low-lying land are flooded annually during the monsoon season. Except for taro, rice is the only other major food crop that can grow with its roots under water. The center of rice cultivation remains the lowland humid tropics, but owing to human selection and natural dispersal, rice is now cultivated as far north as the banks of the Amur River (53° N) on the border between the USSR and China, and as far south as central Argentina (40° S). Rice is also grown in cool climates in the mountains of Nepal and India, and under irrigation in the hot deserts of Pakistan, Iran, and Egypt. It is an upland crop in parts of Asia, Africa, and Latin America. At the other environmental extreme are floating rices, which thrive in the seasonal deep flooding of large river deltas — the Mekong in Vietnam, the Chao Phraya in Thailand, the Irrawaddy in Burma, and the Ganges-Brahmaputra in Bangladesh and eastern India. Rice performs better than other grain crops in areas with saline, alkali, or acid-sulfate soils. Clearly, rice adapts well to diverse growing conditions. It is now harvested from about 150 million hectares, over 10 percent of the world's arable land. Total production is about 420 million tons of unhusked rice yielding about 275 million tons of milled grain.

RICE, THE STAPLE FOOD

In 1985, the 21 political units listed in Table 1 together include over half the world's population and two-thirds of the people in them depend on rice as their major source of food energy. The populations in these countries are increasing at a rate markedly higher than in the rest of the world. Population density is already at extraordinary levels in these rice-eating areas. There are, in 1985, 142 persons for each square kilometer, which is about 7 times the population density of the remainder of the world.

The high population-to-land ratio helps to explain other characteristics of the rice arc that stretches from Pakistan to Japan. Here the crop is raised chiefly on small farms without mechanization. The annual rice crop provides a major portion of the total farm family income, and often a significant portion of the harvest stays on the farm to provide food for the coming year. The farm population dependent on rice as a major crop totals at least 1.1 billion people, comprising 260 million families. Many of these families have no land at all, depending on farm labor for their income. Even those who do own or operate the land control an average of less than 1 hectare per family. The vast majority of rice farmers live close to the margin of existence. Surpluses of food and of money are minimal. A poor harvest in any given year can mean serious hardships to the individual family, while reduction of yield over a broad area can easily lead to disaster.

The FAO lists 112 countries as producers of rice, but the output of the 17 leaders accounts for 97 percent of world production. Even more striking is the fact that countries of South and East Asia account for 91 percent of world production (Fig. 1). Per capita rice consumption in most Asian countries exceeds 100 kilograms a year, which is twice the consumption of wheat, the

1. Distribution of global rice production.

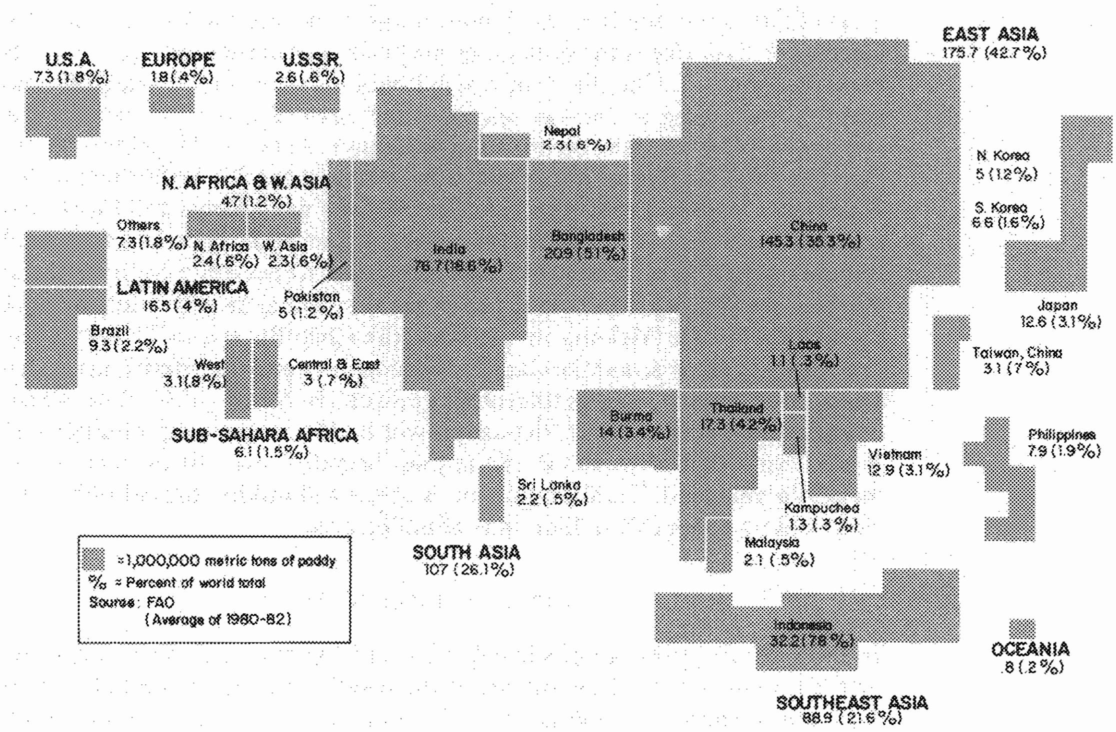


Table 1. Estimate of population whose major food is rice: South, Southeast, and East Asia, 1985.

	Area[a] (thousand sq km)	Population[b] Total (million)	Density (no./ sq km)	Annual growth (%)	Rice eaters[c] % of population	No. (million)	Per capita consumption (kg/year) Rice	Wheat
China[d]	9,600	1,088	113	1.4	63	685	101	72
India	3,136	763	243	2.1	65	496	74	52
Indonesia	1,906	168	88	2.1	80	134	150	9
Japan	382	121	317	0.6	65	79	90	52
Bangladesh	143	103	720	3.1	90	93	155	28
Pakistan	796	100	126	3.0	30	30	24	125
Vietnam	330	60	182	2.1	90	54	151	16
Philippines	300	56	187	2.5	75	42	102	17
Thailand	517	53	103	2.0	80	42	177	4
Republic of Korea	98	43	439	1.5	95	41	140	50
Burma	679	39	57	2.4	90	35	218	2
Taiwan province, China	36	20	556	1.8	70	14	144	—
People's Rep. of Korea	122	20	164	2.3	90	18	141	40
Nepal	141	17	121	2.5	60	10	96	30
Sri Lanka	66	16	242	1.8	90	14	109	36
Malaysia	333	16	48	2.2	80	13	108	31
Kampuchea	181	6	33	1.9	90	5	145	—
Hongkong	1	5	5,000	1.7	90	5	84	—
Lao People's Republic	237	4	17	2.0	85	3	203	—
Singapore	1	3	5,000	1.2	80	2	93	—
Bhutan	47	1	21	2.2	50	—	—	—
Total	19,065	2,702	142	1.9	67	1,815	95	—
Other countries	116,765	2,187	19	1.5	—	—	—	—
World	135,830	4,889	36	1.7	—	—	—	—

[a]Source: Gale Research Company (1979), *Countries of the world and their leaders,* 5th ed. [b]U.S. Bureau of the Census (1983), *World production 1983: recent demographic estimates for the countries and regions of the world,* Washington, D.C. pp. 185-297. [c]B. S. Luh, *Rice: production and utilization;* AVI Publishing Co., Westport, Conn. Consumption estimates by U.S. Department of Agriculture. [d]Excluding Taiwan Province.

second most important food crop (Table 1). Consumption also exceeds 100 kilograms in Liberia, Malagasy, Sierra Leone, and Guyana. In contrast, per capita rice consumption is generally less than 10 kilograms a year in most of the developed world.

Of the 36 countries that grow more than 100,000 hectares of rice, half have annual incomes of less than US$300/per capita, which places them in the World Bank's lowest income group. In many of these countries, rice is the primary source of carbohydrate and also the primary source of protein. Those who eat more than 100 kilograms of rice annually may obtain more than 40 percent of their protein from rice alone.

FAO and the Trilateral Commission both project that until the end of the century, the rice supply in Asia must increase by more than 3.5 percent a year to prevent increases in its real price. Increases in the demand for rice will result from changes in population and in consumer incomes. In Asia, many consumers are poor and have unsatisfied demand for calories. The World Bank, for example, estimates that more than 600 million persons in South and Southeast Asia suffer from malnutrition due to poverty. Therefore, increasing incomes (or falling real rice prices) would lead to substantial increases in the demand for rice among the poor. This expansion in demand by poor consumers will far outweigh any reduction in demand among affluent consumers who substitute foods such as wheat for rice.

The demand for rice in Africa and Latin America is growing more rapidly than it is in Asia as rice is preferred to coarse grains and most root crops in those regions. Much of the rising demand for rice in Africa has been met through increased imports. For example, in 1961-63 the imports of sub-Saharan Africa accounted for 8 percent of world trade in rice but by 1978-80, they had grown to 18 percent of world rice trade. Nevertheless, in absolute terms the increases in rice production and consumption will continue to be dominated by Asian requirements.

Rice and wheat, the two most important food crops globally, present a distinct contrast in terms of where and how they are grown, and how they are used. Two-thirds of global wheat production is from developed countries, but virtually all global rice production is from the developing world. China and India alone, with a combined population of more than 1.75 billion, produce and consume more than half the world's rice production.

Wheat tends to be grown on large, mechanized farms, even in such developing countries as China and India and utilizes relatively little labor. Rice, by contrast, is predominantly produced on small farms, using labor-intensive cultivation practices and its production and processing absorb nearly half of the labor force in many South and Southeast Asian countries.

Over 20 percent of the wheat crop is traded internationally, compared with 5 percent of the rice crop, and nonfood uses, mainly animal feed, account for one quarter of wheat production compared with only about 7 percent of rice production. Thus, unlike wheat, rice is grown almost exclusively for human consumption in the regions of the world where it is produced.

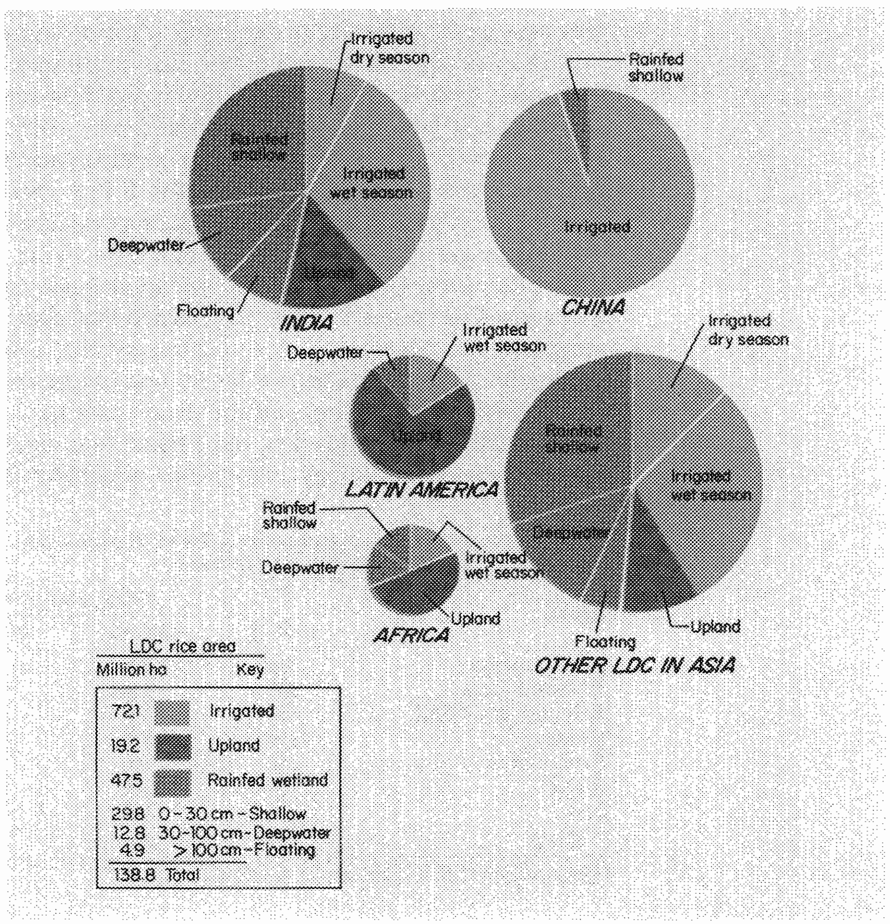
Nationally, average rice yields vary from a high of 5 to 6 t/ha in Australia, Egypt, Japan, North Korea, South Korea, and the United States to a low of less than 2 t/ha in many countries of sub-Saharan Africa, South and Southeast Asia, and parts of Latin America, notably Brazil. High yields are associated with productive environments for rice — good water control (irrigation and drainage) and high levels of solar radiation — plus the widespread planting of high yielding varieties bred for those locations, and the heavy use of complementary inputs such as fertilizer. Countries with high yields also tend to adopt price policies and have levels of infrastructural development and rice research that make it economically attractive to farmers to produce rice intensively.

Types of rice

Rice is an annual grass belonging to the genus *Oryza*. The two cultivated rices are Asian rice (*O. sativa*) and African rice (*O. glaberrima*). Asian rice originated in the foothills of the border regions dividing South and Southeast Asia. The domestication of *O. sativa* — probably by women who collected seeds from wild species and selected from them — began in Asia over 7,000 years ago. *O. glaberrima* was domesticated in West Africa 3,000 to 4,000 years ago; its importance is decreasing as it is being replaced by modern varieties of *O. sativa.*

O. sativa has three ecogeographic races: indica, sinica, and bulu types. Their origin appears to be the result of selection by man in the process of domestication and the emergence of different races of wild rices adapted to specific environments. Indica types were originally confined to the humid tropics, and sinica types (originally known as japonica and also called keng rices) to the subtropical and temperate regions. The bulu (also called javanica) rices flourished alongside indica rices in Indonesia.

Classification of rice in terms of water regimes and soil conditions is preferred because they are important determinants of varietal requirements and crop production practices. Five water regimes are generally distinguished: irrigated, rainfed shallow, deepwater, upland, and tidal wetland. About 56 percent of the rice area in developing Asia is irrigated while upland rice is dominant in Africa and Latin America (Fig. 2). If China is excluded, the portion of irrigated rice in Asia falls to 40 percent. The proportions of rice culture types vary considerably country by country. For example, while almost all rice in Pakistan is irrigated, over 85 percent of the Bangladesh rice crop is rainfed.



2. Area of rice in developing countries by type of rice culture drawn proportional to the estimated 1978-80 hectarage. LDC = less developed countries.

In the early 1940s, the world became aware that hunger and malnutrition affected more than half of the world's population, and that failure to deal with the human suffering posed a serious threat to global peace and orderly progress. For example, while per capita grain production was increasing globally, it was declining in Asia and Latin America and was quite low in Africa (Table 2). To promote agricultural development the international response included the establishment of the Food and Agriculture Organization in 1943, followed shortly thereafter by the United Nations (whose charter stresses freedom from hunger as a basic human right) and the International Bank for Reconstruction and Development (the World Bank).

The food situation was particularly critical in heavily populated Asia where farming techniques had remained virtually unchanged for decades. Yields per hectare, per day, and per worker were low and stagnant, accounting in part for food shortages and the poverty of its rural people. Populations, however, continued to grow at up to 3 percent a year because of modern medicine and sanitation, which led to declining death rates while birth rates remained at high levels. As a result, per capita food production and cultivated area per capita in Asia were declining at alarming rates.

Historically, Asian countries had expanded rice area to meet the increasing demand of growing populations. However, in post-war Asia, the supply of new land suitable for rice was nearly exhausted, and there was little opportunity for increasing yields with existing varieties and traditional inputs and management. It was accepted that future increases in rice production would have to be generated by raising crop yields on land already devoted to rice and by growing more than one rice crop a year.

Although several South and Southeast Asian nations had rice programs dating back to the early 1900s, they lacked the capacity to carry out sustained programs for developing rice technology that would facilitate increased productivity. The high cost of developing irrigation, markets, and extension services has also been beyond the means of these poor countries. Governments, international agencies, and private foundations thus emphasized the development of technology, institutions, and infrastructure as part of their aid

Table 2. Annual per capita grain output for total population, by region, averages 1934-38, 1948-52, 1957-58 to 1959-60 and annual 1960-61.[a]

Region	Grain production (kg/person)			
	1934-38	1948-52	1957-58 to 1959-60	1960-61
North America	768	1,006	1,042	1,107
Western Europe	247	234	284	293
E. Europe and USSR	533	453	535	558
Oceania	455	538	467	688
Latin America	254	190	213	214
Africa	158	161	167	170
Asia	231	197	221	226
World	307	284	316	328

[a]Derived from U.S. Department of Agriculture data.

programs, most of which were bilateral. One exception was the International Rice Commission established by FAO in 1949 as an intergovernmental organization to facilitate rice research in the developing world. It is probably best known in Asia through its Japonica-Indica Hybridization Scheme, which led to the breeding of several varieties including the widely grown Mahsuri, which was named and first released in Malaysia in 1965.

The primary emphasis in technical assistance in the 1950s was the introduction and testing of varieties and systems of crop management from agriculturally advanced countries. The impression was that food crop production had stagnated because farmers did not have access to the technology that had generated productivity gains in the developed world. For example, rice yields in Japan and Australia were two to three times those in South and Southeast Asia. Nevertheless little progress was made.

The lack of success of these agricultural development programs showed that the direct introduction of materials and farming methods from wealthy countries had limited potential for increasing rice yields in the tropics. Thus, the constraints limiting rice yields in the developing world had to be tackled through research on the problems where they existed.

Development agencies shifted their emphasis to helping poor countries to develop their own agricultural research capabilities and to train their own scientists. The forerunner was a cooperative project sponsored by the Rockefeller Foundation and the Goverment of Mexico in the 1940s. Its goal was to increase the production of the basic food crops of Mexico, and the effort to improve wheat was singularly successful. The breeding of rust-resistant varieties made Mexico self-sufficient in wheat in 1956. A decade later the first of the dwarf, stiff-strawed "modern" varieties were released to Mexican farmers, and Mexico now has one of the world's highest average wheat yields.

The foregoing examples demonstrated that highly productive agricultural research programs could be established in developing countries. They also showed that poor farmers would rapidly adopt new technology if they felt it was to their advantage. Indeed, these low-resource farmers proved to be as innovative as any in the developed world. The notion that poor farmers were slow to change and stubbornly resistant to progress was shown to be false.

The international community realized it would be slow and difficult to generate the urgently needed agricultural technology through national agricultural research programs alone. Financial impracticality and manpower constraints of the country-by-country approach would limit the number of countries that could be assisted.

The Ford Foundation and Rockefeller Foundation, influenced by the arguments of such visionaries as Forest F. Hill, J. George Harrar, and Warren Weaver, and buoyed by the success of the Mexican wheat program, suggested an alternative way of increasing investment in food crop research, and for supporting and complementing national agricultural research in developing Asia. They proposed establishing an international research center for rice. Rice was chosen as the target group because of its importance as the primary or secondary food crop for 90 percent of the world's poor.

The International Rice Research Institute was incorporated as a non-profit philanthropic organization governed by an autonomous Board of Trustees in April 1960. It had the encouragement of Asian nations, the full support of the Philippine Government, and the generosity of the University of the Philippines at Los Baños, on whose land it stands. The Ford Foundation agreed to provide funds for the physical plant and the Rockefeller Foundation, for operating costs. Rice research began at IRRI in 1962 when the physical plant was completed.

Subsequently, in 1966, the International Maize and Wheat Improvement Center (CIMMYT) was established in Mexico when the Rockefeller Foundation's Latin American maize and wheat research was restructured. Initial IRRI and CIMMYT successes — which became popularly known as the "green revolution" — encouraged expansion in international agricultural research.

There are now 13 centers in the international agricultural network. Four of them — IRRI, CIAT, IITA, and WARDA — include rice within their mandate crops (Table 3). Among the centers, IRRI has global responsibility for rice research. Its main focus is Asia, where more than 90 percent of the world's rice is produced and consumed. CIAT is primarily responsible for rice research in Latin America, while IITA and WARDA accept similar joint regional responsibility for rice research in sub-Saharan Africa.

Funding international agricultural research

The Ford and Rockefeller Foundations funded the first four centers — IRRI, CIMMYT, CIAT, and IITA — but recognized it was beyond their capacity to adequately support sustained growth in international agricultural research. Consequently, in 1971, at the initiation of the two foundations and the World Bank, the Consultative Group for International Agricultural Research (CGIAR) was established. The World Bank, FAO, and the United Nations Development Programme were named cosponsors of the CGIAR. The World Bank provides the chairman and an executive secretariat. A Technical Advisory Committee (TAC), consisting of 13 eminent scientists from throughout the world, was created to provide scientific advice to the CGIAR. TAC's secretariat is provided by FAO.

The CGIAR is an informal association of countries, multilateral agencies, and private foundations which support collaborative research to help developing nations increase agricultural production and improve its quality. The CGIAR is a means for mobilizing funds for the existing centers, as well as for seeking new opportunities to strengthen international agricultural research. Membership includes donors, or continuing members, and fixed-term members elected by FAO to represent the interests of countries in the five development regions (Asia, Africa, Latin America, Southern and Eastern Europe, and the Near East and South Asia). Between 1971 and 1984, the number of donors (governments, international agencies, and private foundations) pledging funds rose from 17 to 32. Total CGIAR expenditure in 1972 was $19 million; by 1984 pledges amounted to $180 million. While these

Table 3. Name, location, and main programs of 13 centers sponsored by the Consultative Group for International Agricultural Research.

Center and headquarters	Year established	Programs
IRRI International Rice Research Institute, Los Baños, Philippines	1960	Rice, multiple cropping
CIMMYT Centro Internacional de Mejoramiento de Maiz y Trigo (International Maize and Wheat Improvement Center), El Batan, Mexico	1966	Wheat, maize, barley, triticale
CIAT Centro Internacional de Agricultura Tropical (International Center for Tropical Agriculture), Cali, Colombia	1967	Beans, cassava, beef and forages, maize, rice, and swine
IITA International Institute of Tropical Agriculture, Ibadan, Nigeria	1968	Maize, rice, cowpea, soybean, lima bean, cassava, yam, sweet potato, and farming systems
CIP Centro Internacional de la Papa (International Potato Center), Lima, Peru	1971	Potato
ICRISAT International Crops Research Institute for the Semi-Arid Tropics, Hyderabad, India	1972	Sorghum, millet, peanut, pigeonpea
ILRAD International Laboratory for Research on Animal Diseases, Nairobi, Kenya	1973	Blood diseases of cattle
ILCA International Livestock Center for Africa, Addis Ababa, Ethiopia	1974	Cattle and small ruminant production
WARDA West Africa Rice Development Association, Monrovia, Liberia	1974	Rice in West Africa
IBPGR International Board for Plant Genetic Resources, Rome, Italy	1974	Coordinate collection and exchange of plant genetic materials
IFPRI International Food Policy Research Institute, Washington, DC, USA	1975	Food policy research
ICARDA International Center for Agricultural Research in the Dry Areas, Beirut, Lebanon	1976	Wheat, barley, lentils, broad bean, oilseeds, cotton, and sheep farming
ISNAR International Service for National Agricultural Research, The Hague, Netherlands	1980	Management of agricultural research

figures seem very high, they represent less than 2 percent of official global assistance for agricultural development. Over the past 10 years, IRRI's share of the CGIAR budget has grown from nearly $9 million to over $22 million, representing an annual average growth rate of about 7 percent in real terms.

IRRI's MANDATE

The tasks of IRRI, as set by its Board of Trustees and endorsed by the Consultative Group for International Agricultural Research, are:

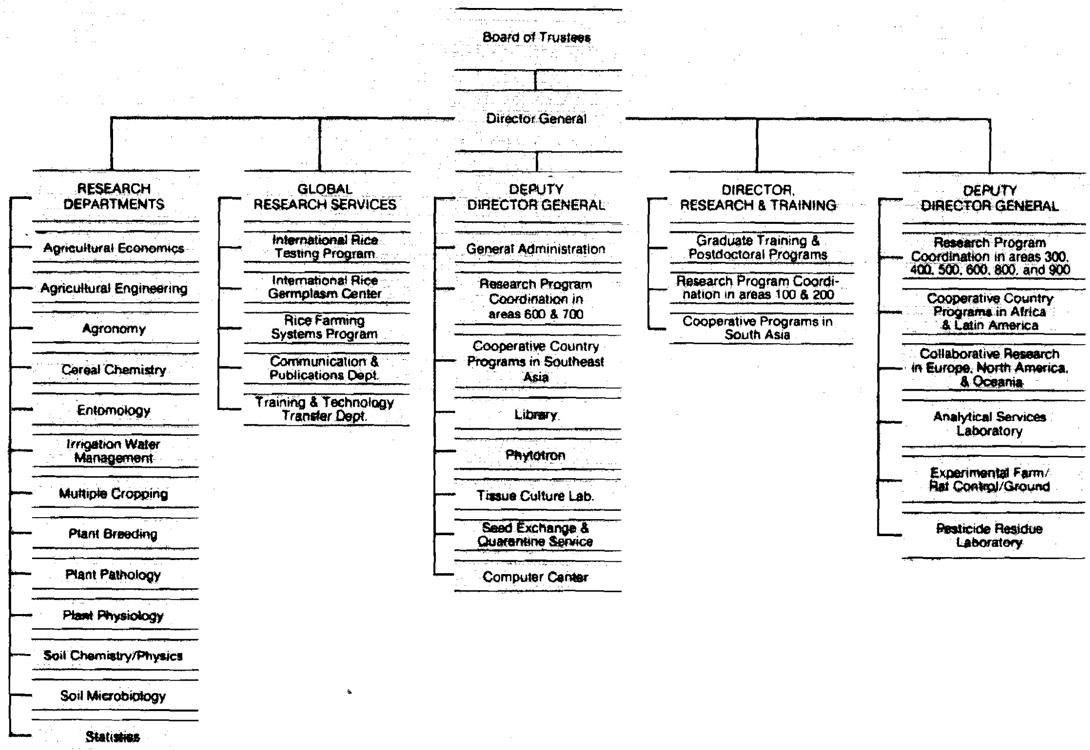
1. to conduct research on the rice plant, and on all phases of rice production, management, distribution, and utilization with the objective of improving the nutritional and economic advantage or benefit for the people of Asia and other major rice-growing areas of the world through improvement in quality and quantity of rice;
2. to publish and disseminate research findings and recommendations of the institute;
3. to distribute improved plant materials to national, regional, and international research centers where they might be of significant use in breeding or improvement programs;
4. to develop and educate promising young scientists from Asia and other major rice-growing areas of the world along lines connected with or relating to rice production, distribution, and utilization, through resident and joint training programs under the guidance of well-trained and distinguished scientists;
5. to establish, maintain, and operate an information center and library that will provide a collection of the world's literature on rice for interested scientists and scholars everywhere;
6. to maintain and operate a rice genetic resources laboratory that will make available to scientists and institutions all over the world a global collection of rice germplasm;
7. to organize or hold periodic conferences, forums, and seminars, whether international, regional, national, or otherwise, for the purpose of discussing current problems.

IRRI does not pursue this mandate in isolation. The institute is designed to work as a partner of national programs in tackling problems of increasing rice production. Problems differ markedly not only between physical environments, but also between countries, where very different levels of support are available for national rice production programs. Different countries may also have different objectives and pursue different policies with respect to their rice sector. Therefore, as developed in Chapter 2, IRRI seeks to work with national programs on a one-to-one basis, as well as by facilitating international collaboration. The areas of collaboration include research, training, information dissemination, and the development of methods to facilitate farmer adoption of new technology.

SCIENTIFIC ORGANIZATION

IRRI is organized around three basic functions: rice research, training, and international collaboration. The director general, with the assistance of three scientist directors, provides guidance on research priorities and direction, under the general direction of the Board of Trustees.

Research activities are administered through 13 disciplinary-oriented



3. Scientific organization of IRRI (see Table 4 for description of research problem areas identified by numbers in this figure).

research departments (Fig. 3). These departments work together and conduct research within interdisciplinary research areas. Each area focuses on a particular problem area of rice science, in addition to training and international collaboration (Table 4). Research coordination and reporting first occurs at the research problem area level. Higher level coordination and integration between these research problem areas is accomplished through director-led umbrella groups which focus on a) rice varietal improvement, b) rice crop management and farming systems, and c) training.

Five Global Research Services are the principal instruments whereby IRRI serves rice research and training on a worldwide basis. They are designed to facilitate coordinated, international collaboration between IRRI and national rice programs in rice varietal improvement (International Rice Testing Program and International Rice Germplasm Center), rice crop management and rice-based farming systems (Rice Farming Systems Program), publication and information dissemination (Communication and Publications Department), and training (Training and Technology Transfer Department). The responsibilities of the Global Research Services are described later in this monograph.

Table 4. Research and training program areas at IRRI.

Research problem area	Description
100	Genetic Evaluation and Utilization of Rice
200	Control and Management of Rice Pests
300	Irrigation Water Management
400	Soil and Crop Management for Rice
500	Climatic Environment and its Influence
600	Constraints on Rice Yields
700	Consequences of the New Technology
800	Rice-Based Cropping Systems
900	Machinery Development and Testing
1000	Associated Formal Training
1100	International Activities

In late 1984, there were 121 scientists from 16 nations working with IRRI. Sixty-three were IRRI core staff and 58 were employed by collaborating international agencies (such as IFPRI and IITA) or were on secondment as visiting researchers from national rice programs, universities, and development agencies. Two-thirds of the IRRI core staff are located at IRRI's headquarters in the Philippines, the rest are stationed in national rice programs. At any one time there are also about 100 rice scientists undertaking nondegree training at IRRI and over 100 scholars conducting research work for MS and PhD degrees.

Scientists are provided independence and an environment conducive to creativity and output within the bounds set by the research goals and priorities assigned to them. Evaluation of scientists and research program areas by the Board of Trustees and the institute occurs at annual program reviews as well as by peer review through seminars and scientific publication. Every 5 years TAC reviews the entire institute program on behalf of the CGIAR, which also commissions across-center reviews on specific topics such as genetic resources conservation or farming systems research.

IRRI research programs are developed in consultation with national rice programs to ensure that its research remains responsive to the needs of rice-producing countries. This consultation and joint research planning is formally accomplished through annual work planning meetings with the countries with which IRRI cooperates most closely. As a result, IRRI's outputs are largely intermediate in nature because they become inputs to national rice programs. The products of rice science are shared through the exchange and international testing of rice germplasm; the training of rice scientists; the sharing of advances in rice science and research procedures through annual reports, publications, workshops, and conferences; and collaborative research between national and IRRI rice scientists.

IMPACT OF MODERN VARIETIES IN ASIA

IR8, the first of the modern rices developed by IRRI, was released in 1965. In the past 20 years, 27 IRRI varieties and more than 100 IRRI-parented varieties have been released by national rice programs. These varieties are now grown on over 40 percent or nearly 50 million hectares of Asian rice lands. During this same period, Asian rice production increased by 66 percent, while population increased by 47 percent (Table 5). As a result, per capita rice availability in general and the real price of rice have fallen in Asia. This has directly benefited Asia's poor rice consumers.

The growth in rice production in Asia was dominated by a yield effect as opposed to an area effect (Table 5). From 1966 to 1983, average yields in the 12 leading rice nations increased by 1 t/ha, or from 2.1 to 3.1 t/ha. With rice being planted to 122 million hectares, the increase in yield is about 80 million tons of milled rice over the 12 nation area. At the 1984 mean price this yield increase represented a value of about US$24 billion. The yield increase resulted from the complementary relationship of modern varieties, added fertilizer, increased irrigation, and other modern agronomic practices. It is difficult to factor out the influence of each contributor to the increased yield. The one thing that is clear is that genetic improvement of rice seed and the development of modern varieties was the driving force behind the agricultural revolution in rice. Without the development of IRRI varieties and their numerous derivatives there is little reason to believe that rice yields would have increased any more rapidly than they did in the decade or so before 1965. The difference between the rates of growth before 1965 and after 1965 represents an increment of 23 million tons of milled rice per year, which may be largely attributed to genetic improvement. Such a volume had a value of US$6.25 billion in 1984.

ABOUT THIS BOOK: AN OVERVIEW

This book reviews IRRI's achievements in its 25th year. The chapters that follow examine the increasingly close collaboration between national rice programs and IRRI, the gains in collecting, maintaining, and using the

Table 5. Twelve leading Asian rice producers: change in 17-year period 1965-66, 1966-67 (mean of 2 years) to 1982-83, 1983-84 (mean of 2 years).

	Change in rice area		Change in rice production		Change in rice yield		Net population change 1965-82 (%)
	million ha	%	million t	%	t/ha	%	
China	3.1	10	67.9	73	1.76	57	42
India	4.0	11	31.5	69	0.66	51	46
Indonesia	1.6	21	18.8	122	1.72	83	42
Bangladesh	1.4	15	7.0	46	0.44	27	58
Thailand	2.8	43	5.2	42	−0.02	−1	56
Burma	0.1	2	7.0	97	1.45	94	50
Vietnam	0.9	19	5.3	60	0.66	75	43
Japan	−1.0	−30	−3.8	−24	0.87	18	20
Philippines	0.3	10	3.8	93	0.99	75	65
S. Korea	<0.1	0	2.3	45	1.96	47	41
Pakistan	0.6	43	3.2	160	1.20	83	61
N. Korea	0.2	33	2.7	117	2.47	66	58
Total	14.0	13	150.9	66	1.00	47	45
Total less China + Japan	11.9	16	86.8	73	0.80	50	47

world's rice germplasm, advances in varietal improvement, significant developments in production technology, improvement of the farming systems in which rice is cultivated, the impact of modern rice technology, the training and information activities of the institute, and, finally, the future course of IRRI.

IRRI and national programs

The success of IRRI is dependent on the dedication and purpose of the national rice programs with which it works. Thus, IRRI's association with national rice programs is highlighted in Chapter 2. The nature of this relationship has changed as national programs have gained in expertise, confidence, and success, and in resources.

Germplasm and information exchange among scientists through workshops, symposia, publications, and training have always been key components of national program-IRRI collaboration. The stress on technical assistance in the 1960s shifted more toward cooperative programs in the 1970s. The emerging scenario in the 1980s is one of collaborative research wherein national programs and IRRI jointly design and accept responsibility for conducting those facets of rice research where each has a comparative advantage.

Currently IRRI has cooperative programs with 18 countries that account for over 85 percent of the world's rice production and hectarage. The institute, in collaboration with CIAT, IITA, and WARDA, has regional programs in Latin America and the Caribbean, and in Africa. IRRI-national program linkages are facilitated through liaison scientists located in national programs and at CIAT and IITA. The global research services identified in Figure 3 provide a mechanism for collaboration in rice research and information transfer between countries, as well as between IRRI and countries. Collaboration with other CGIAR centers such as IFPRI for rice policy research and CIMMYT, IITA, and ICRISAT for dryland crops, as well as with other research and development agencies, provides research complementarity in those areas where IRRI lacks comparative advantage.

Genetic resources

The preservation of unimproved, special purpose, and wild rice strains is critical for retaining the broadest possible genetic diversity for rice breeding programs. Commercial varieties were well represented in national germplasm collections when IRRI was founded. Few minor and primitive varieties had been collected, however, and maintenance of germplasm was difficult for national agencies. As described in Chapter 3, IRRI established a rice germplasm center to service its own breeding program, to provide a source of breeding materials to national programs, and to ensure secure long-term storage of rice germplasm.

The introduction of IR8 and other new varieties in the late 1960s led many farmers to abandon traditional varieties, a situation threatening to lead to the extinction of varieties that had not been collected or conserved. Rice scientists internationally recognized the need for systematic collection, conservation, and classification of unimproved varieties to maintain a genetic heritage for future rice improvement programs. To this end IRRI, in collaboration with national rice programs and other international centers, established an International Rice Germplasm Center (IRGC). Since 1971 this bank has been the central repository for the base collection of the world's rices. In 1984 the bank held over 75,000 of the estimated 100,000 to 120,000 rice varieties now grown in the world. Thousands of breeding lines with desirable traits are also preserved. A computer-generated varietal log of over 45 standardized descriptors allows ready reference and identification of seed required by breeders. In the past 25 years, IRRI has provided over 500,000 seed packages to national rice breeders. And the IRGC has returned to many countries rice varieties that are no longer grown or are no longer available in their original homes.

A duplicate set of seeds is deposited at the U.S. National Seed Storage Laboratory to provide added security. The National Institute of Agricultural Sciences of Japan, the U.S. Department of Agriculture, and IRRI work together to consolidate their collections.

Work is now under way to collect and conserve most of the remaining 30,000 to 40,000 varieties. When the task is completed by 1987, rice may be the first important food crop to be preserved for the 21st century and beyond in as complete a collection of naturally occurring genetic variability as can be achieved.

Varietal improvement

Twenty-seven IRRI varieties have been released by national rice programs in the past 20 years, as shown in Chapter 4. IRRI germplasm is also widely used as parents by national rice improvement programs, which have selected and released more than 100 varieties of these IRRI-parented materials. Such modern varieties, which are capable of yielding two to three times as much as traditional varieties, are now planted on more than 30 million hectares of rice land in Asia, Africa, and Latin America.

Four distinct technological innovations have occurred in the varieties developed by IRRI since 1965. The first, typified by IR8, is the capacity to utilize fertilizer effectively and to flower and set seed during any season of the year regardless of daylength. These characteristics conferred the potential for high yields on areas throughout Asia that have irrigation or reliable rainfall. The second innovation, heralded by IR20 and now integral to all new varieties, is broad-spectrum insect and disease resistance, which improved yield stability on Asian rice farms. The third innovation was the development of fast-growing varieties that also have multiple resistance to diseases and insects, high yield potential, and excellent grain quality. IR8 for example, had a fixed 130-day growth duration; the first really short-duration tropical rice, IR36, matures in 110 days; more recent varieties, such as IR58, mature in 100 days. This means that recently developed modern varieties use less water, are exposed to field hazards for less time, and perhaps most important of all, can be harvested early enough to allow farmers to plant and harvest another crop during the same rainy season.

IRRI's multidisciplinary Genetic Evaluation and Utilization (GEU) program is working to make a fourth breakthrough: to develop improved varieties adapted to unfavorable rice environments. Thus, the focus is shifting to these areas where current varieties are less suited. As a result, greater emphasis is being placed on breeding for tolerance to various physical factors (drought, floods, low temperature) and physio-chemical factors (e.g. acid sulfate soils, saline soils), mineral deficiencies and toxicities.

GEU cooperates with national rice programs in germplasm exchange, in development and refinement of breeding techniques, in the rapid generation advance of photoperiod-sensitive varieties, and in shuttle breeding to reduce the period between the initial cross and varietal release. The international testing, exchange, and distribution of rice germplasm is facilitated through the International Rice Testing Program (IRTP). IRTP now distributes and reports on 23 nurseries (focused on specific water regimes, growth durations, and stress conditions), which are grown in over 60 countries. In 1983, 1195 sets of these nurseries were sent to more than 700 collaborating scientists in 61 countries.

Advances in rice production technology

Improved growing methods have enabled Asian farmers to take advantage of the high yield potential of modern rice varieties. Chapter 5 explores the problem-focused, multidisciplinary production research and training at IRRI, which targets four primary areas: soil fertility, pest management, water management, and rice mechanization. Research strategies combine modification of the crop to fit the environment through rice breeding with modifying the environment to fit the crop through cultural practices.

Research at IRRI has provided basic understanding of the nutrition of the rice plant and the chemistry of flooded soils. These insights have contributed to the identification of causes of adverse soil conditions, which limit the use of about 100 million hectares of land in Asia otherwise suitable for rice. For environments where nutritional disorders are severe, soil amendments have been identified, or management systems devised, to ameliorate the constraints. Varietal tolerance to adverse soils is feasible, however, on marginally nutrient-deficient or marginally toxic soils. The broad soil-stress tolerance possessed by IR36 and IR42 is one reason for their popularity among small farmers.

Low soil fertility, particularly nitrogen deficiency, is an important constraint to rice grown in South and Southeast Asia. IRRI rice scientists have developed efficient, nutrient management methods for wetland rice. The strategy involves selecting varieties that are efficient users of soil and fertilizer nitrogen and managing inorganic and organic fertilizers to maintain soil fertility and productivity.

Elaboration of the dynamics of rice nutrient requirements and the total nitrogen balance of flooded soils has revealed the causes of nitrogen losses. Fertilizer incorporation into the reduced layers of the soil or use of controlled release fertilizers decreases these losses by half. IRRI scientists also seek to increase the productivity, and usefulness to farmers, of biological nitrogen-fixing organisms that are present in the floodwater of most rice paddies. Nitrogen-fixing bacteria, free-living blue-green algae, and the association of azolla and blue-green algae may fix as much 40 to 50 kg N/ha per rice crop. Recycling of organic residues such as rice straw increases nutrient use efficiency and reduces the need for chemical fertilizers in rice culture.

Research on soil fertility management in rice is orchestrated through the International Network on Soil Fertility and Fertilizer Evaluation for Rice, a collaboration among national rice programs, IRRI, and the International Fertilizer Development Center. Seventeen national programs and 59 research groups participated in the network in 1983.

IRRI seeks to develop methods of insect management that will increase both yields and profits of rice-based systems. This includes research into the bionomics of brown planthopper, green leafhopper, stem borers, and other insects that cause economic damage to rice, the development of sampling methods, and the establishment of economic injury levels. A range of approaches, notably breeding of resistant varieties, the application of synthetic and botanical insecticides, and biological and cultural practices, are included in the institute's pest-management strategies. The results provide the basis for integrated pest management in rice. Promotion of this approach, in collaboration with FAO, has led to adoption by national rice programs across Asia.

Varietal resistance is the primary strategy for disease control in rice at IRRI. Studies of the epidemiology of, and surveillance methods for, diseases such as rice tungro virus — possibly the most important virus disease of rice in tropical Asia — yellow dwarf and grassy stunt viruses, bacterial diseases such as bacterial blight and bacterial leaf streak, and fungus diseases such as rice blast complement this research. National rice programs in Asia are gaining increased capacity in disease surveillance, making feasible such disease management strategies as gene rotation for blast control, use of fungicides, and biological control. Thus, resistance breeding and disease management are complementary aspects of disease research at IRRI.

Over the past 20 years, IRRI has studied the ecology of the dominant rice weed species and screened herbicides for effectiveness in rice and upland crops in rice-based systems. Thirty-seven countries in Africa, Asia, and Latin America now collaborate in the testing of herbicide samples for transplanted rice, direct-seeded flooded rice, and upland rice. Cost-efficient weed control technology for irrigated and rainfed environments have been developed. These technologies are now used on millions of hectares of transplanted rice and provided a key technological component in the widespread adoption of direct seeding by rice farmers in South and Southeast Asia.

The purpose of IRRI's research in irrigation management is to identify how the use of irrigation water for rice may be made more efficient and equitable. The research focuses are on technical aspects of water resource management and socio-institutional aspects of irrigation-system management. In the pursuit of these objectives, IRRI works closely with irrigation agencies in Bangladesh, Indonesia, the Philippines, and, more recently, India.

The mechanization program at IRRI endeavors to increase the income and reduce the drudgery of the small rice farmer, and to foster farm equipment manufacturing in developing countries. Machinery design priorities are guided by farmer demand, the commercial viability and capacity of local industry to manufacture and service the machine, and opportunities emerging from IRRI's rice technology research. IRRI works closely with manufacturers to facilitate local fabrication and maintenance of rice machinery through its Industrial Extension Programs in Burma, India, Indonesia, the Philippines, Thailand, and Pakistan. Machines that have achieved considerable commercial success include an axial-flow thresher that will handle wet paddy, a power tiller, a power weeder, and a five-row manual paddy transplanter. Deep-placement fertilizer applicators, machines for direct seeding of upland crops after rice, and low-cost water pumps are under development.

Integrating rice technology in farmers production systems

Chapter 6 examines IRRI's rice-based farming systems program, which develops procedures and technical innovations that facilitate the integration of improved rice technology into farmers' production systems. This research recognizes that how farmers grow rice is influenced by other farm activities, farm resources, markets, and the benefits sought from farming. Therefore, IRRI's farming systems research is multidisciplinary, conducted on farms, and focused on multi-enterprise technology. This latter feature distinguishes it from other research at IRRI.

In principle, the profitability of food crop production may be expanded by increasing the productivity of component crops, by intensifying cropping (i.e., growing more rice crops within a production cycle), by diversifying production (i.e., introducing and increasing the productivity of nonrice crops), or by some combination of them. Technological components leading to increased productivity and intensity of rice production are largely based on research findings from IRRI and from national rice programs. Short-duration varieties made rice intensification more practicable. Close liaison with various IRRI efforts is maintained to ensure feedback of field-identified problems to the research station; similar forward linkages are maintained to provide an array of technological options for on-farm adaptation and verification.

Promising innovations for nonrice components of rice farming systems are identified through collaboration with the Institute of Plant Breeding at the University of the Philippines at Los Baños, which selects varieties of crops other than rice for use in rice-based systems. IRRI, CIMMYT, IITA, and ICRISAT and national programs collaborate in research on rice-wheat and rice-grain legume production systems.

Operationally, farming systems research is carried out in a seven-stage process based on the general hypothesis that the number of crops or enterprises can be productively increased in a given environment. The research methodology first involves site selection, site description, cropping pattern design and testing. These stages lead to the identification of promising technology, which in turn leads to multilocation testing, production programs, and, finally, impact evaluation.

The main technical areas investigated by IRRI through on-farm research are a) rainfed rice-based multiple cropping, b) introduction of grain legumes into rice-based systems, c) increase and stabilization of food crop production in flood- and drought-prone areas, d) crop diversification on irrigated rice lands, e) enhancement of the interrelations between rice systems and livestock production, and f) the role of social organization in intensifying farming systems. Innovations that support intensification of rice-based systems include varietal improvement of rice and other crops; techniques of soil, water, and crop management; and pest management.

The Asian Rice Farming Systems Network is the principal mechanism whereby procedures and technology developed by IRRI and national rice programs are shared. It is a two-way interaction, national programs contribute to IRRI research and also gain from it. In 1984, 11 Asian rice-producing countries, with 188 farming-systems research sites, participated in this network.

Impact of modern rice technology

Chapter 7 examines the reasons rice production has increased at a faster rate than population in South and Southeast Asia since the 1960s. Modern varieties, fertilizer, and irrigation made equal contributions to higher yields, effectively substituting for land, a limiting factor in Asian agriculture. Per capita rice production grew faster in traditional rice importing countries in Asia (such as Indonesia, India, and the Philippines) than it did in traditional exporting countries. The former had a larger proportion of irrigated land, which facilitated rapid adoption of modern varieties. Consequently as Asian importers approached self-sufficiency in the late 1970s, the level and pattern of international trade in rice changed. In the 1960s, South and Southeast Asia was basically self-sufficient regionally; by the 1980s, net rice exports of the region as a whole had become substantial, particularly to the Middle East and Africa.

Consumers have tended to benefit more than producers from improved rice technology, which led to higher per-capita rice supplies. In countries where rice exports have historically been limited — Philippines, Indonesia, and India — real rice prices are 20 to 30 percent below those prevailing in the early 1960s. At the same time, self-sufficiency has been achieved and per capita rice consumption has increased. The real price of rice, however, has not declined in Thailand or Bangladesh where the adoption of modern varieties has remained low because of high proportion of rainfed rice environments, which are unfavorable to wide-scale adoption of present modern varieties.

Environmental determinants, especially water availability and drainage, are major constraints to the wider diffusion of modern rice technology when compared with such social and institutional factors as farm size and tenure. Modern rice technology has increased the demand for hired labor, in particular. However, even though technology may be scale neutral, those with greater access to the most limiting resources, land and capital, benefited more from technological change than did the suppliers of labor, the more plentiful factor of production. Thus increasing rice productivity alone is unlikely to overcome the pervasive negative effects of unequally distributed assets typically found in Asian agriculture and of the urban and capital-using bias of many government policies.

Training and communications

Communication with and between national rice programs is facilitated through scientist exchange and site visits, workshops and conferences, publications, access to IRRI's library and a substantial training program, which are described in Chapter 8.

The training and professional advancement program provides training and research opportunities for national rice scientists and production specialists. This program has three major aspects: research, instruction, and special training. The research program includes postdoctoral fellowships, a graduate degree program, and special nondegree research programs. Since 1962, 241 researchers have participated in the postdoctoral fellowship program, while 387 scholars conducted research toward master's degrees and 145 toward doctoral degrees. IRRI scholars have received degrees from 53 universities, 13 of them in developing countries.

Some 3,000 national rice scientists have attended IRRI's instruction courses, which are oriented to training in research methodology and rice production techniques. Courses in agricultural engineering, agroeconomics, cropping systems, fertilizer and fertility research, integrated pest management, irrigation water management, plant breeding, rice production, and upland rice form the core of IRRI's nondegree training program.

A professional advancement program has provided the opportunity for 288 members of IRRI's junior research staff to gain master's degrees and 8 to complete doctoral degrees. Specialized, nondegree training courses are also offered to IRRI research technicians to better equip them for their responsibilities at the institute.

National and international agencies spend heavily on research and production training, yet less has been invested to develop strong communications systems to interpret these findings and target them to national research and extension workers, and to farmers. The institute seeks to reduce this constraint through training in agricultural communication, and through publication.

IRRI publishes four periodicals (*IRRI reporter, International rice research newsletter, IRRI research paper series,* and the *International upland rice newsletter*) and releases about 20 new books each year. In 1983 some 70,000 copies of major books were distributed. The institute seeks to cooperate with national programs in the copublication of IRRI books in various languages. Nearly 90 editions of 19 IRRI books have been copublished, or were in press, in 31 languages other than English in 14 countries in 1983.

IRRI has possibly assembled the most complete collection of the world rice literature. The rice literature collection exceeds 85,600 items, and the library receives over 2,800 journal titles. A sub-library maintained in Japan provides a translation service and access to the Japanese rice literature. Access by national program scientists to the libraries' resources is facilitated through a computerized, annual publication of the *International Bibliography of Rice Research*.

LOOKING AHEAD

As discussed in Chapter 9, IRRI will continue to work toward the improvement of the productivity, profitability, and stability of rice farming systems in countries where rice is a staple.

The lessons learned since the release of the first modern rice and wheat varieties in the mid-sixties guide us in assessing future priorities. The major benefit of the Green Revolution was increased agricultural productivity from scarce arable land. A second benefit was the demonstration that science-based innovations could be developed in and for the tropics, a development that gave policy makers, researchers, extension workers, and farmers confidence in their ability to bring about a rapid increase in food production and frequently in rural income. A related benefit was the promotion of rural development, and greater social prestige and political importance for the farm sector.

Although the benefits of modern agriculture have been substantial, there are legitimate concerns about the sustainability and social impacts of this pathway of agricultural advance.

In its third decade IRRI's work will continue to address the concerns that have arisen from the past success of modern rices. In particular, IRRI will address the issues of 1) increasing rice yields, particularly in rainfed environments, 2) ensuring stability and sustainability of rice yields and farm profits, and 3) providing more equitable distribution of the benefits of the new rice technology.

Rising real costs of irrigation investment mean that a part of future production increase must come from rainfed areas. Another reason to increase yields in rainfed environments is to spread the benefits of new technology to ecologically handicapped areas and poor farmers. The first and third concerns reinforce each other.

Within irrigated environments, where modern varieties have been widely adopted, IRRI will continue work to increase the stability and sustainability of yields and efficiency in crop production. Yield stability will be enhanced through further incorporation of pest and disease resistance. Efficiency will be increased through the dual strategy of breeding for input-efficient varieties and improving management. Research on soil health and reduced reliance on purchased agrochemicals address ecological concerns about the long run viability of new technology. The conservation of rice cultivars also ensures that the diversity of rice germplasm will be maintained for future generations of rice scientists.

Where increased rice supply has reduced real rice prices, farmers face a cost-prize squeeze. Research to increase input use efficiency, to substitute nonpurchased inputs for purchased inputs, and to make better use of the entire rice biomass will help sustain farmer income.

Equity concerns arise if new technology decreases the income earning opportunities for poor farmers and landless households. IRRI works to develop appropriate technology for these groups as demonstrated by the Prosperity Through Rice Project and through recent initiatives to foster research in alternative income-generating opportunities for rural women.

IRRI will combine maintenance research, to defend the production and productivity gains already made, with like emphasis on downstream research to solve immediate problems, and upstream research to solve downstream problems and to further raise the yield ceiling. Indeed, IRRI's success in extending the frontiers of high technology to ecologically handicapped areas and to poor farmers and farm laborers will depend on its ability to integrate upstream and downstream research.

Most of IRRI's work is undertaken jointly with national rice programs and universities. This collaboration is facilitated through the International Rice Germplasm Center and the three major rice networks: the International Rice Testing Program (IRTP), the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), and the Asian Rice Farming Systems Network (ARFSN). The needs of national programs vary, depending on their ability to sustain a dynamic rice research system capable of generating location specific technology, and to bridge the gap between potential and actual yields in farmers' fields with existing technology. The nature of IRRI's collaborative research will be shaped largely by the circumstances of individual countries and national rice programs in the next 25 years. The aim is to pool the best available knowledge and material for the common benefit of rice farmers everywhere.

CHAPTER 2

IRRI AND NATIONAL PROGRAMS

Over the past 25 years, major rice growing countries with which IRRI has been closely associated have changed dramatically. They have developed a cadre of well trained scientists, though the numbers may be limited. For the most part, their governments have committed themselves to a better agriculture. Hence, the time has arrived when IRRI must carefully reassess how it is meeting its fundamental mandate to help the rice farmer.

An international research and training center, however, cannot be directly involved with the farmer. It must work with the national mechanisms set up for that purpose. Yet if the international center is not in touch with the changing needs of the national programs, there is a strong possibility that its research, no matter how sound, will not be relevant to the current or future needs of the national programs. IRRI is taking deliberate steps to be responsive to the "signals" being raised by national programs.

THE FIRST STEPS

When IRRI was established, it struck out to provide solutions to some of the most pertinent challenges in tropical rice production. Wisely, the primary effort was to develop a "plant type" that would permit the rice plant to produce more grain per unit area, to withstand the rigors of unfavorable weather during the growing season, and to respond to good management. That research led to the development of IR8. More significant than the variety itself was the concept — a powerful wedge that exposed many areas where research was needed to improve the rice plant's capacity to feed human beings.

IRRI recognized that much could be learned from those who were currently working with rice as well as from the farmers who had, by tradition, passed knowledge from generation to generation for millennia. Therefore, one of the first endeavors was to invite scientists from national programs to conferences where they might describe what they were doing and where they needed help. This approach was supplemented by visits made by scientists to various rice growing nations where they learned, firsthand, methods of production and the challenges farmers face in different environments.

IRRI's first annual report (1961-62) records that IRRI scientists visited Sri Lanka, India, Indonesia, Malaysia, Bangladesh, Thailand, Japan, Taiwan, and of course the various rice growing regions of the Philippines. There were discussions with the national leaders about cooperative work. IRRI scientists assumed the responsibility for managing the International Blast Testing Nursery, which had been previously a function of the International Rice Commission of FAO. (In IRRI's second decade, that activity would become a function of the International Rice Testing Program.)

By 1964, just 2 years after IRRI was formally inaugurated, the annual report indicated that specific arrangements had been made to carry out cooperative work with several national programs. The travel of IRRI scientists to rice producing countries was an important phase in internationalizing the IRRI program. By 1965, IRRI was engaged in comprehensive rice research and development programs in several major rice producing countries.

Among the first efforts was assistance in collecting germplasm that was peculiar to certain countries or regions of the world. This activity soon became an important program of IRRI. The IRRI collection has now expanded to many thousands of accessions. It is important not only to preserve this germplasm under conditions that maintain seed germination, but also to have it readily available for breeders who are searching for special genetic characteristics.

IRRI is a research institution. Before it could be of help to the rice-growing world, it had to develop a fund of knowledge. This would take time. A biological entity such as rice cannot be studied in a comprehensive manner at just one location. Different environments cause different responses from the plant. Hence, it was necessary to seek environments that would complement the ones in the Philippines, IRRI's base of operations. Over the years, several such sites have been identified and play a useful role in the overall research effort.

Perhaps the greatest contribution of IRRI to future generations will be those it has trained. IRRI training falls into two major categories. One is the short-term training or updating on current technology. The other is the postgraduate study, which provides the students with formal theoretical training for their chosen professional field. The number of alumni of these professional improvement programs in most of the major rice growing countries is substantial. Many of them, by training and by research experience, are now the professional peers of their colleagues at IRRI. It is important for IRRI to recognize the change in stature and composition of the scientific communities in the national programs with which it works.

Twenty-five years ago, scientists came to conferences and related their problems, but for the most part they were inadequately prepared or equipped to find solutions. Today, they can interact around the conference table with the IRRI scientists and tackle problems in concert with their IRRI colleagues. As a result, IRRI has transcended the technical assistance phase, passed through a cooperative phase, and is today in a collaborative relationship. The national scientist as a collaborator takes the responsibility for certain studies and IRRI complements them by carrying out other studies. Together, they achieve more than if they worked independently. In this way, the national scientists are very much a part of the program and are able to bring appropriate scientific expertise to bear on problems which are of prime significance to them. This element of maturity is important.

ADVENT OF THE LIAISON SCIENTIST

IRRI in its early development decided against establishing substations outside the Philippines. Nevertheless, "field laboratories" were established in special environments. Examples are the Deep Water Laboratory in Thailand and the Cold Tolerance Testing Laboratory in South Korea. But those stations were developed as collaborative efforts between the countries concerned and IRRI. In IRRI's core budget, an allocation is made to fund its share in the operation of the laboratories. Thus, these satellite operations have been recognized as ongoing functions of IRRI.

In the 1970s, the Board of Trustees established a position known as liaison scientist. It was realized that a greater visibility should be developed outside the Philippines for good public relations and communication on an international basis. Such persons are supported by the core budget and serve as IRRI's representatives in a country or a region. They are separate from the cooperative national programs, which have been an ongoing type of working relationship since 1965. The first liaison scientist was based in Indonesia in 1977, but was responsible for appropriate activities and working relationships in Malaysia and Brunei. Subsequently, liaison scientists were located at CIAT in Colombia and IITA in Nigeria. Initially their primary responsibility was coordination of the International Rice Testing Program in their regions. This was a positive step toward closer relations with the national programs.

The rising volume and increasing quality of the research from those national agencies with which IRRI was cooperating made the role of liaison scientist vital. Liaison scientists must be in the right place at the right time to assist with "on the spot" decisions. They must be diplomatic and astute. They are in a position to render a service that could not otherwise be performed. If national scientists and administrators were expected to contact IRRI for certain information, particularly in emergencies, it would never be done. Also, the liaison scientist's accessibility to the national scientists for discussing research programming and establishing the agenda for annual collaborative work planning meetings has been invaluable. Such contacts improved preparation for important meetings and at the same time constituted informal "in-service" training in research management. Liaison scientists act in an extremely important role: giving the total IRRI system a low-profile international visibility. It is important to draw on their expertise and experience as well as that of the national scientist when IRRI is projecting its future research and training programs.

Direct involvement with the national programs is vital. A generation or so ago, a great philanthropist who had spent a lifetime and large amounts of funds to help the poor, once was asked why he took time from his busy schedule to visit small farmers. He replied that "you must not only *care*, but, more important, you must appear to *sincerely care*." This sums up the basic philosophy behind the liaison scientist and his or her assignment. There is great merit in having the humility to learn from others. It is important to have someone who regularly interacts with those whom IRRI has set as its prime target audience. Thus, IRRI can play the role of an impartial analyst, identifying policy options for rice production programs in any situation and analyzing the consequences of these options in relation to national development objectives and regional and international development strategies.

IRRI's MANDATE AND NATIONAL COLLABORATION

It is impossible for IRRI, whose mandate is to work on the rice crop, to be able to do all the research that would be necessary in order to fully understand this crop and to provide answers to the many challenges in maintaining stable production of the crop. However, it is possible for IRRI to become a repository for a wide spectrum of knowledge on the nature of rice. Hence, it must have a direct working relationship with research centers in developed countries that do fundamental research, which may eventually have practical consequences for better and more efficient production.

As the institution evolves, it becomes more important for the senior scientists to devote a reasonable portion of their time to travelling in various parts of the world to improve their knowledge and to share their expertise. Administrators must recognize this as an essential function of scientists' jobs. But it is equally important for them to share their knowledge with workers in different situations on a one-to-one basis or through workshops, conferences, and symposia. The impact of senior scientists through such contacts may be far greater than that of the research that they might do in their home laboratory. So this will become a greater part of the resident scientists' responsibilities in the future. Research assistants, too, will have an increasingly important role to play in helping developing programs. This activity has already begun. In their chosen areas of work, IRRI's technicians are probably the most knowledgeable in the world. Hence, it is important that they share their expertise with their colleagues in the developing countries. It is their counterparts who will be directly responsible for helping the farmer to adapt the new technology and produce rice more efficiently.

Since some national programs are initially doubtful about the value of having a person identified with IRRI located in their country, the liaison scientist must establish rapport, gain credibility and earn confidence in his judgments before significant assistance can be rendered. Thus when the right person is found, it is important to continue his services for a reasonable length of time. The position must be in the core budget to give it permanency as well as flexibility. The person must be carefully selected. He or she must serve as a scientist, as a public relations person, and as communication link with "home base." It is essential for the home base to communicate frequently with the liaison scientist to facilitate exchange of information relative to the development of future programs. Home base senior scientists must recognize liaison scientists as peers and key links to national programs.

International assistance efforts and even those of national organizations are often plagued with rapid turnover of personnel assigned to research and development programs. This results in lack of continuity of effort, frequent change of goals, and loss of expertise as individuals are moved from assignment to assignment. National organizations must feel able to turn to an **institute** like IRRI with their problems, whenever necessary, with confidence that they will receive reliable and up-to-date information or materials and that the quality of the services or materials will be high. Emphasis must be placed on the kind of service that IRRI can render to developing nations. National progress defines the success of an institute like IRRI. IRRI cannot be a substitute for national effort.

IRRI's staff is convinced that a science-based technology is a prime element of a stable and economically sound food production system. To the best of its ability, IRRI hopes to be able to transfer this concept to the national program scientists and leaders. When he was IRRI's director general, N. C. Brady once observed that there was a need to shift the thrust of research "from the world of IRRI" to "the world of a rice farmer." This is what is taking place. And probably appropriately so at this time.

There are different phases through which an institution such as IRRI must pass as it matures. In a recent outside review of IRRI, the panel observed that disseminating rice technology and strengthening national rice programs are major responsibilities of IRRI. The Board of Trustees welcomed the panel's recommendation to strengthen and expand collaborative country programs. It also favored the idea of assuring a degree of permanence to the staff of these programs.

IRRI takes care to avoid imposing on a national program. It provides materials, ideas, and advice upon request, but at no time does it expect a national program to carry out IRRI's research. When IRRI seeks a location for research in a special environment, it covers all costs of conducting such research. But in the case of the International Rice Testing Program, it invites all national programs to utilize the materials provided. Those that accept, assume the responsibility of carrying out the experiment or observations, as the case may be. If they return the data collected, it will be incorporated into a regional or international analysis and the information will be provided to all participating scientists. A national program that wishes to use any of the genetic materials for its breeding program or to release materials as varieties, may do so. IRRI asks only to be advised of how the materials are used so that its scientists have an opportunity to chart the geographical and environmental adaptation of the germplasm being evaluated.

For the national programs that have moved into a collaborative working relationship with IRRI, joint annual planning sessions are routine. At these meetings, representatives from the national program (scientists and administrators) and from IRRI sit down to review progress during the past year and to project the kind of collaborative program that they think most useful for the national needs during the coming year. The plans cover genetic materials and technical assistance that IRRI might provide, and what the collaborating national program will contribute. Once these plans are agreed upon, a formal note of agreement to proceed is signed by senior administrators of both collaborating agencies.

A CATALYST FOR INTERNATIONAL COOPERATION

Ralph W.Cummings, Sr., in a paper presented on the occasion of IRRI's twentieth anniversary, observed that a significant proportion of IRRI's applied research in the future would be done in collaboration with scientists in national programs. He observed that this type of collaboration was essential since IRRI must broaden its focus from the relatively controlled environment of the highly productive irrigated farms to the less controlled but more extensive environment of rainfed agriculture. He went on to indicate that IRRI would 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), Rice-Agroeconomic Network, etc. In 1983, to give greater visibility to these important dimensions of IRRI's program, the Board of Trustees approved the designation of certain activities as Global Research Services. This identification provided a more accurate description of the nature of these important activities.

Cummings further indicated that IRRI would need to continue its effort to raise the capabilities of national research programs. He said greater emphasis should be placed upon training, both formal and informal. Eventually, IRRI would need to become involved in assisting and expediting training within countries with which it was collaborating. Thus, the challenge of the next 25 years will be to maintain the research quality and the spirit of inquiry which characterized IRRI's first and second decades, while simultaneously forging links between its scientists and the scientists of the national programs. IRRI's strategy must be based on the assumption that its ultimate success will be determined only by the success of national programs with which it is directly or indirectly associated.

Greater integration of effort between IRRI and rice growing countries will take several routes.

Location-specific research

Although plant breeders have devised ways to shorten the period between the making of a cross and the production of a relatively stable line that can be tested, evaluation still is slow. One way to accelerate the evaluation process is to test simultaneously in many different locations. When IRTP was conceived, this was the primary aim. Also, many national programs were establishing sound but relatively small breeding programs. It was difficult for them to evaluate their material under a wide variety of conditions. The IRTP allowed a national program to contribute some of its key selections for evaluation throughout the rice growing world. This program is now a decade old. Today, approximately 70 percent of the germplasm being distributed by IRTP comes from the national programs and about 30 percent from IRRI. Its results are invaluable for plant breeders in monitoring the performance of the different "genetic pools" under a wide range of conditions. IRTP helps plant breeders to predict the performance of crosses from certain parents, speeding the process of improving rice varieties.

Special regional problems are another reason for location-specific research. An example is improvement of rice under deep water conditions, a characteristic of one of the main rice growing areas in Thailand. Through a collaborative effort with the Thai Rice Department, it was possible to set up the Deep Water Rice Research Laboratory at Huntra, Thailand. Gradually, the laboratory is becoming a regional center for studies on the deep water environment for rice production.

Cold tolerance is another factor important in rice production in some areas. At Chuncheon in South Korea, the natural supply of irrigation water is very cold, which makes it an excellent screening mechanism for cold tolerance. This location not only serves as a field laboratory for IRRI and Korean scientists, but also for scientists from other parts of the world who wish to evaluate their germplasm for this characteristic.

Collaborative research

IRRI's collaborative research is carried out with both developing countries and developed countries. In developing countries, collaborative research puts IRRI and the national scientist to work on problems of mutual interest. Their solutions will not only be of value to the country in which the research is being done, but may also be used or extrapolated for similar situations in other countries. IRRI can convey the information to others who have similar interests. There are now 14 national programs carrying on collaborative research or training with IRRI.

Advantage can be taken of specialized facilities in developed countries for conducting the fundamental studies that are needed to support the research program of IRRI. Examples of this type of research are studies on sex pheromones with the Tropical Products Institute, U.K.; ecology of the brown planthopper with the Center for Overseas Pest Research, U.K.; microbial control in insects and nitrogen fixation with the Boyce Thompson Institute, USA.; organic matter studies with the University of Hamburg, West Germany; spore formation of azolla with the University of Manchester, U.K.; studies on bacterial leaf blight with Kyushu University, Japan; and monoclonal studies with the American Type Culture Collection, USA.

Cooperative country projects

There are many forms of cooperative country projects. In some instances, grants from donors support a particular research project. In other cases, a host country that has a loan from an assistance agency retains IRRI to carry out, on contractual basis, certain phases of research involving rice or rice-based farming systems. Such cooperative country projects probably will decline in importance for IRRI as they are replaced by collaborative programs. IRRI's major cooperative country projects have been with Bangladesh, Burma, and Indonesia.

Germplasm collection

As modern varieties of rice began to be widely adopted in the late 1960s, the collection and preservation of traditional varieties and wild and exotic types of germplasm became urgent to prevent such strains from being lost forever. The preservation of germplasm was an important part of the international effort from the very beginning of IRRI. This activity has been aided by the International Board for Plant Genetic Resources.

The IRRI Seed Bank for rice germplasm now contains some 70,000 accessions. Many characteristics of the accessions are classified and the information is held in a computer. A national breeder can request germplasm that has certain characteristics and, through the use of the computer, appropriate accessions can be identified. Small samples of the germplasm are then sent to the scientist. The collection must be rejuvenated from time to time and the various characteristics of the germplasm carefully checked and, if necessary, reclassified. Persons knowledgeable in this field believe that another 30,000 accessions are yet to be collected. This task is critical. Certainly by the turn of the century, it could be too late. Thus, this collection, its cataloging, and its preservation are of the utmost importance to national programs.

Training

The productive working relationship between IRRI and national programs is enhanced by the many persons who have participated in IRRI training in the past quarter century. The manner in which they have been trained and the ideals which they have gained strongly influence the kind of improvement programs that are developing. Many alumni are already in positions of leadership in national research programs.

Changes in the capabilities of national programs and their requirements for training will require IRRI to develop new approaches to training. One result of these changes is the emergence of special short courses that IRRI takes abroad and puts on with national programs. We can also expect the computer to play an increasing role in training programs. Already, audiovisual modules concerning certain areas of rice improvement have been developed to enable the student to study on an individual and repetitive basis. Another future change relates to the difficulty that English, the working language of IRRI, poses for the participation of the trainees from some countries. However, if instruction can be presented in each trainee's own language, more individuals could take part.

Consultation

IRRI scientists and administrators act as consultants to national programs in many ways but primarily through visits in response to requests for assistance. In some instances, a panel of scientists may be assembled for a special purpose. For example, when the Peoples' Republic of China wished to explore the feasibility of establishing a national rice research institute, an IRRI panel spent a month with Chinese counterparts, studying various communities and situations to find a site for such a research center. Another panel returned in the next year. The China National Rice Research Institute is now 5 years old and becoming well established in temporary headquarters. Construction of the permanent physical plant has started.

In Sri Lanka, frequent visits have been made by individual IRRI scientists to help with various facets of the program. Bangladesh, while preparing for an external review in 1984, invited several senior scientists from IRRI to assist in evaluating national rice research work and advise on future programs. These kinds of consultancies are extremely valuable to national programs. At the same time, it gives the IRRI staff involved in the consultancies a firsthand view of national program needs.

Study-leave programs undertaken by IRRI senior scientists have consultancy aspects, too. Study leaves usually are taken at a university or a major research institution in a developed country. Through discussions, seminars, etc, people with whom IRRI scientists come in contact gain a better understanding of the nature of an international institution like IRRI.

Senior scientists are also encouraged to participate in international scientific meetings. They usually afford an opportunity for the scientists to present their current research findings, but there is also a useful public relations and consultancy function that takes place when matters of mutual interest are discussed with professional colleagues. Often these meetings lead to the establishment of collaborative research with laboratories that have specialized facilities not available at IRRI.

Publications

An information service responsible for disseminating the results of IRRI's research and conferences has always been an essential part of the total institute organization. Initially it was strictly a service to the institute. It has gradually evolved over the last 25 years and is now called Communication and Publications Department, a Global Research Service.

The speed with which it can process and publish material, produce photographs, and create graphics pertaining to the activities of the institute is important to the work of IRRI. During this quarter of a century, there have been great advances made in audio-visual presentation capabilities. One invaluable public relations development has been a brief (22 minutes) slide show entitled "Rices of IRRI," which uses five projectors simultaneously. This presentation gives a concise overall picture of the activities of IRRI and has received many favorable comments from visitors.

The written word is an efficient means for widely disseminating knowledge. It was soon appreciated however that there was a need to have some publications in languages other than English. To translate technical information is both time-consuming and expensive. Successful designs of some publications have been evolved which permit easy publication in translation. By 1984, more than 80 non-English editions of IRRI books had been printed in 31 languages. These have been of inestimable value to national programs. National agencies can usually distribute local language publications more easily than IRRI can. Hence, copublication has been encouraged, that is, a national agency will assume the responsibility of publishing in the indigenous language.

Every possible measure is taken to place IRRI publications in libraries of the rice growing world. Special discounts are also given to buyers who live in developing countries.

IRRI has a most comprehensive library of rice literature. The library regularly prepares bibliographies, which are provided to national programs as a key to the literature available on rice.

In a modest way, IRRI has now begun to train national scientists on communication methods. This will enable national programs to improve their dissemination of research information.

Conferences, symposia, and workshops

A scientist gains much by meeting with fellow scientists to exchange ideas, philosophies, concepts, and news of advances. Conferences were at first primarily for the IRRI scientific community to learn from the national scientists what they were doing and what their challenges were. Gradually, these conferences became a vehicle for exchange of ideas for the evolution of new types of programs.

Global research services such as IRTP, INSFFER, and ARFSN evolved from a series of conferences held at IRRI to develop networks that would channel information more quickly to national programs. Also they encouraged more cooperative work by national programs.

As IRRI has grown in prestige, it has come to be considered an important focal point for sponsoring or cosponsoring symposia, conferences, and workshops. These events provide an excellent opportunity for scientists to share their ideas with one another and to gain peer recognition.

Younger scientists rarely get sufficient opportunity to participate in international meetings. Yet the leaders of the next generation will emerge from this group. One step toward overcoming that problem was taken in 1984 by holding the International Rice Research Conference away from IRRI for the first time. Locating this type of conference in a national setting from time to time should enable junior scientists in the host country to participate in a way in which they otherwise would have difficulty in doing.

EVOLVING RELATIONSHIPS WITH NATIONAL PROGRAMS

Year by year IRRI has become more closely integrated with national programs through collaborative research activities and the travels of senior scientists to review aspects of the national programs and to consult with colleagues.

Some countries that have strong scientific staffs are interested in contributing to IRRI's research planning process. An important means for doing so is the annual collaborative research meeting. At such meetings, senior scientists and administrators from IRRI and from the national program can discuss IRRI's future programs as well as those that are under way on a collaborative basis. While it would be impossible to satisfy all wishes, it nevertheless is a way IRRI can keep abreast of the issues that are of prime concern to the national program leaders.

Many of IRRI's original working relationships with national programs were established when their concerns were focused on developing a strong research program to support increased rice production. More and more nations, however, have broadened the scope of their agriculture research and education programs to embrace the complete spectrum of agriculture. Within the context of the rice-based cropping systems, IRRI can offer help with the culture of crops other than rice. Moreover, IRRI works with other international centers such as CIMMYT to assist national programs. As national needs have grown, the contracts for agriculture improvement have become more comprehensive and include several crops, livestock, and construction of facilities in some cases. Thus, IRRI's involvement in cooperative contracting arrangements is increasingly as a subcontractor to do those things about which IRRI is best qualified to provide counsel, leadership, guidance, and assistance.

In the early days of IRRI, many if not all of the cooperative contractual arrangements involved grant money. This gave IRRI the flexibility to do many things that expedited the total effort, be it research, extension, or training, without bureaucratic delay. The trend on the part of many donors to move from grants to loans or host country contracts has lessened the flexibility of IRRI and dramatically reduced its usefulness to national programs. Change should not be made for the sake of change. However, it was natural that there should be an evolution from the cooperative contractual arrangements to the collaborative approach which predominates today.

Host country contracts impose great constraints to effective and efficient implementation of cooperation with national research systems by making the salaries and amenities of consultants and support staff subject to the rules and regulations of the host country. Certainly, there is no desire to place the IRRI staff member in a category that makes it difficult for them to relate to their counterparts. IRRI's philosophy has been that its staff must operate with a "low profile." Staff members function as part of the national program and are not set apart in an "expert" type of relationship. As their responsibilities can be assumed by a national scientist who has returned from a period of graduate study or special training, the IRRI scientists fade into the background to play an assistance role. In this way, strong rapport can develop, enhancing credibility and confidence in the counsel offered.

Productive involvement in a national program is heavily dependent on the backup support given by the core staff at the "home base." It is essential that administrators and senior scientists on the core staff understand the nature and needs of the program being conducted. They and staff in the field must complement and supplement each other's efforts. The person in the field must not only be highly skilled in his or her professional discipline, but be able to translate it into useful technology and to help national scientists in implementing the technology.

When developing countries began organizing their research and educational efforts as new nations, many had no choice but to adapt technology from other parts of the world, though it did not always suit the needs of the tropics.

The creation of international institutions like IRRI permitted the sustained generation of research knowledge specific to the tropics. But as the national programs grow in scientific strength, it becomes important that they gain a greater say in the kinds of research that will best meet their needs. Thus we are on the threshold of what could be stated as the need for a *tropical agriculture body of knowledge*. This will be the result of a comprehensive effort of the international agricultural centers that circle the globe embracing the national programs. All have something to offer. The trend toward collaborative research will hasten this synchronization and integration at a greater pace.

As IRRI matures, the danger is that senior scientists, unless they are appropriately motivated and oriented by their administration, will become "IRRI scientists" rather than "international scientists," and there is a difference! The real challenge is how to shift attitudes while maintaining the climate of scientific integrity that will permit them to evolve ideas that can be most useful and pertinent to national programs. The question then arises: what constitutes a truly international institute? Is it simply the presence of an international staff and support from international donors? Perhaps in the future, a carefully orchestrated collaborative effort will be the hallmark of a successful international effort in agricultural research.

To move in the direction of greater collaborative effort, a rebudgeting of both human and financial resources will be necessary to permit more liaison scientists to be placed at strategic locations throughout the rice growing world. At the same time, the national programs that wish to be true partners in this collaborative effort must be willing to commit staff and funds for their support. A collaborative effort is not merely an annual gathering of scientists and administrators who prepare a list of needed activities to be mostly forgotten until the next year when substantially the same list is prepared again. Collaborative efforts must be carefully assessed and screened, and priorities must be set and agreed upon with the understanding that both parties will benefit only if both carry out what they have agreed to do.

New technology from developed countries can be introduced too abruptly into a developing country. Despite the element of prestige sophisticated facilities may give a national program, they may be much too advanced, overwhelming those who would endeavor to adapt them to urgent national needs. It is the responsibility of IRRI scientists working with national programs to encourage the adoption of useful new techniques and technology, but at the same time to make sure that there is a reasonable chance of success.

Traditionally, IRRI's senior scientists have taken their study leaves in developed countries. In the future, some study leaves should be taken in national programs to give scientists firsthand exposure to the nature of the challenges which exist in the "real world" of their concern. Subsequently, they will be in a better position to tailor their programs to meet these challenges. National scientists, too, need an opportunity for sabbatical study. Since it is much more difficult for them to get approval for this kind of "training," exchanges should be encouraged between a senior scientist from a national program and a senior scientist from IRRI for periods up to 1 year.

This type of collaboration could be invaluable for integrating the efforts of national and international scientists.

The success of any endeavor, regardless of how well it may be planned, will be directly related to how it is led. Hence, the selection of persons to serve in a liaison role is one of the utmost importance. National administrators generally wish to have a person with long professional experience. These persons undoubtedly can make an extremely valuable contribution. For the most part, they probably will be more flexible in adjusting to certain difficult circumstances. (On the other hand, they may be more subject to health hazards than a younger person.)

But there is an important educational job to do. Politicians and administrators of national programs must be persuaded that a mix of young scientists and senior scientists is desirable. A generation of professional international scientists are rapidly reaching retirement age. Will there be persons who have the interest, the inclination, and the training available to fill the many posts that will be vacant? Young scientists need to serve as apprentices under some of the more senior people so that they can develop the credibility and rapport that are so important in being a successful liaison scientist.

The person selected to lead need not be a specialist in the particular field in which the leadership is needed. More important, the person must be sensitive to the rights of others and the fact that at all times he or she is a guest in the country. The leader must operate with a low profile but be visible, positive, and constructive.

RELATIONSHIPS WITH INTERNATIONAL CENTERS

Since IRRI works with national programs, it cannot ignore aspects of agriculture outside rice production. It can offer a wide range of valuable guidance, particularly in the area of farming systems. But collaborating with other international centers may often be the best way to serve broad national needs. Programs of this type are already under way.

Joint programs

IRRI, IBPGR, and a number of countries in tropical Asia, plus the Malagasy Republic, collaborate in collecting germplasm. Plans for the collaboration were developed during the IRRI-IBPGR rice germplasm conservation workshop in 1983. The IBPGR has been providing

- the assistance of an adviser in field collection;
- transportation costs within the countries for the collected materials;
- per diem for field collectors if not locally available;
- funds to ship collected seed samples to IRRI for preservation, disposition, evaluation, and use; and
- training courses for field collectors.

The national rice research centers in the cooperating countries provide vehicles, drivers, local guides, and other logistical support for the field collection phase. IRRI directly participates in the field collection or provides technical assistance, depending on the desires of the national programs. The collected samples are preserved in IRRI's International Rice Germplasm Center.

IRRI and Centro Internacional de Agricultura Tropical (CIAT) collaborate in helping national programs increase rice production and improve the well-being of rice producers and consumers in Latin America and the Caribbean. The collaboration includes mutual consultation on all activities between the CIAT rice program and all activities of IRRI related to Latin America and the Caribbean. To keep lines of communication open, CIAT invites IRRI representatives to the CIAT rice program internal review and IRRI invites appropriate CIAT scientists to its annual internal program reviews.

As part of the collaborative effort, IRRI has posted one full-time liaison scientist at CIAT. The IRRI liaison scientist for Latin America participates as a full member of the rice program in the annual internal reviews of CIAT and coordinates the International Rice Testing Program (IRTP) for the Latin American region. The annual work plan for the Latin American IRTP is developed jointly by IRRI and CIAT in consultation with representatives of the national rice research programs in the region. In addition, the IRRI liaison scientist at CIAT maintains communication between the rice programs of IRRI and CIAT and with national programs in the region.

In the Latin American and Caribbean regions, CIAT takes responsibility for all nondegree training activities in rice production and research. IRRI relays to CIAT any request received for this type of training from institutions or individuals in these regions. IRRI holds major responsibility for providing training opportunities for MS or PhD candidates from the region following consultations with CIAT.

Collaboration on trials and studies

IRRI and CIMMYT are collaborating with national programs to increase the production and income of farmers using rice-wheat cropping systems. The objectives are

- to identify rice-wheat cropping systems technology suitable for small farmers,
- to identify better combinations of rice-wheat varieties, and
- to encourage wheat and rice scientists to work together in component technologies to increase production of rice-wheat systems.

Two projects are being implemented in the collaborative network — the international rice-wheat integrated trials and cropping pattern testing involving rice and wheat. Variety trials of rice and wheat are timed to fit the rice-wheat cropping patterns. Rice varieties come from IRRI and its collaborators, while CIMMYT provides wheat varieties with different maturities. The countries involved are Bangladesh, Bhutan, Burma, China, Egypt, India, Indonesia, South Korea, Nepal, Pakistan, Philippines, Sri Lanka, and Thailand.

Collaboration between IRRI and the International Institute of Tropical

Agriculture (IITA) emphasizes the screening of cowpea varieties developed by IITA for planting before and after rice. An IITA senior scientist posted to IRRI acts as a grain legume specialist with special reference to breeding and identification of cowpea varieties suitable for rice cropping systems. He also works with the members of the Asian Rice Farming Systems Network in promoting the cultivation of grain legumes, particularly cowpea in cropping rotations. And he participates in training and technology transfer programs related to the cultivation of grain legumes.

The International Food Policy Research Institute, IRRI, and the International Fertilizer Development Center collaborate on rice policy studies in Southeast Asia. The countries involved are Indonesia, Malaysia, Philippines, and Thailand. The project addresses trade and buffer stock policies, centralized policies, irrigation policies, and consumption and nutrition policies.

The specific objectives of the collaborative project are

- to estimate the cost to the various governments of alternative means of influencing rice supplies and prices;
- to determine the interrelationships among different policy actions for the rice sector through the development of a country-level integrated rice economy model;
- to assess the comparative costs and benefits and alternative policies affecting rice trade and buffer stocks, fertilizer, irrigation, and consumption; and
- to create a network of researchers with experience in the study of rice policy issues relevant to the region.

An IFPRI scientist coordinates the project and is seconded to IRRI's agricultural economics department.

IFPRI and IRRI are also collaborating on a study for the Asian Development Bank (ADB). With technical assistance from the ADB, projections of demand, production, and supply policies on food in the developing-country members of the ADB are being made and rice production and irrigation development strategies are being assessed using the Philippines as a case study. An IFPRI scientist is located at IRRI for certain periods of the year to work on the project with IRRI scientists in agricultural economics and irrigation water management.

Collaboration with centers outside the CGIAR system

Scientists of IRRI and the International Fertilizer Development Center are investigating the transformation taking place in the soil following application of nitrogen fertilizers in flooded rice as well as the development and evaluation of synthetic and natural components that reduce nitrogen losses and are suitable and economical as additives to urea fertilizers.

IFDC has assigned a scientist to IRRI. IRRI makes available data from laboratory, greenhouse, and field research. IRRI plays an active role in the development of the collaborative research program and evaluation of the intermediate and final products at its research farm and in farmers' fields. IFDC makes available data obtained from its basic research program and promotes the planning and implementation as well as the evaluation and utilization of the results of the collaborative studies.

Among the specific studies involved are

- evaluation of the effectiveness of nitrogen source and water depth during fertilizer application on total floodwater nitrogen in unplanted plots;
- evaluation of the efficiency of nitrogen sources and of application needs in calcareous soils;
- evaluation of the effect of urea or ammonium sulfate on the rate of ammonia volatilization, using micrometeorological techniques; and
- evaluation of the use of urease as an inhibitor to control nitrogen losses.

IFDC has a program in Indonesia. IRRI's farming systems scientist located in Indonesia collaborates with these scientists and their Indonesian counterparts.

The International Centre for Insect Physiology and Ecology (ICIPE) and IRRI collaborate on the development of pest management strategies requiring minimum inputs by the farmers. IRRI plays a major role in identifying sources of genetic resistance to insect pests in rice varieties and in investigating insect-host plant relationships using resistant and susceptible varieties. IRRI's involvement includes examining the general nature of varietal resistance and the development of biotypes capable of multiplying on resistant plants. ICIPE concentrates on the identification and characterization of biological, biochemical, morphological, and physical nature of varietal resistance to insect pests and the mechanism of the development of insect biotypes. ICIPE stations one of its scientists at IRRI to work in the collaborative program.

The worsening problem of the attacks of the brown planthopper in the cultivation of high yielding varieties in the tropics made it a focus of the current collaborative effort between IRRI and ICIPE. In addition, scientists in the collaborative program are evaluating the use of simple solutions of plant materials to identify new botanical pest control agents for commercial extraction.

International Rice Testing Program

The IRTP seeks to make the world's best rice germplasm available to any rice scientist. The global IRTP network has established working contacts with more than 700 scientists at over 300 research stations in 75 countries. The IRTP has proven very useful for identifying varieties with broad-spectrum resistance to major diseases and tolerance to environmental stresses. The overall IRTP program is coordinated by IRRI. Rice program leaders of each participating country serve as national IRTP coordinators and contact scientists. The national coordinators consolidate the number and types of nurseries for their country and coordinate their distribution.

CIAT, IITA, IRRI, and the West Africa Rice Development Association recently agreed to modify the organizational structure of the IRTP by establishing regional advisory committees in order to enhance the regional focus of the program.

The regional advisory committee for Africa is chaired by the director general of IITA, with the executive secretary of WARDA and representatives of east, central, and southern Africa serving as vice chairmen. The committee is composed of IRTP coordinators of national rice programs in Africa as well as representatives of regional and international organizations. The IRRI liaison scientist located at IITA is member-secretary of the regional advisory committee. This committee will meet annually to plan and implement an African rice testing network (IRTP Africa).

The IRTP for Latin America and the Caribbean is jointly implemented by CIAT and IRRI. To plan the Latin America/Caribbean IRTP, a regional advisory committee for Latin America and the Caribbean will be proposed in the next IRTP regional meeting. The IRRI liaison scientist located at CIAT will serve as member-secretary of the regional advisory committee for Latin America and the Caribbean.

The IRTP program in Asia will be developed by IRRI in consultation with the leaders of the national rice research systems during the annual rice research conference. Details of the IRTP nurseries will be discussed when IRRI and national scientists meet to develop work plans.

A global advisory committee chaired by the director general of IRRI has also been agreed upon. The committee will consist of a UNDP representative; nominees from CIAT, IITA, IRAT, FAO, WARDA, and other international and regional institutions and programs; some members from regional advisory committees; and some international rice experts drawn both from developing and developed countries. The global advisory committee will have the Global IRTP Coordinator from IRRI as member-secretary. The committee will meet every 2 to 3 years to review the IRTP programs in Asia, Africa, Latin America, and the Caribbean.

WHAT LIES AHEAD

IRRI is involved in a dynamic process. It must be flexible in its approach and sensitive to the rising maturity of the national research systems. As national programs advance, they will be increasingly involved with other international institutions. IRRI must operate in a way that facilitates communication with scientists in national programs without overwhelming them with an endless stream of visitors. This is not to say that IRRI scientists should not spend time with national programs, but that the visits should be planned to minimize inconvenience to the national scientists and be based on their desire for assistance. Liaison scientists will play a significant role in improving the efficiency of communication by acting as a conduit for information on the needs of national scientists.

More conferences should be scheduled on a regional basis to provide collaborating countries with the opportunity to conduct international meetings. In addition, junior scientists in the country holding the meeting will gain exposure. This experience will help prepare the next generation of leaders.

During the next 25 years, IRRI will become much more involved with national programs, both directly and indirectly. It must make certain that it is not perceived as being aloof or overbearing. This perception can easily arise if the institution becomes very specialized and works only on items of a sophisticated nature. Providing research that will help solve the problems of the rice growing world, then, is a logical responsibility of an international institution such as IRRI. On the other hand, it is critical that IRRI in no way seem competitive or threatening to national scientists in their rightful roles. Finding the correct path is not easy, but it can be done. Much thought will need to be given to efficient communication, liaison, and a greater understanding of the sociology involved.

CHAPTER 3

GENETIC RESOURCES

Crop germplasm is one of the important heritages of mankind. Plant cultivation began when food gatherers brought wild-growing plants near to their homesteads. A series of minute changes occurred in every cycle of plant reproduction. Subsequent cultivators of crop plants bequeathed to their descendants the products of evolution, domestication, cultivation, and selection. The human impact on the genetic constitution of crop germplasm transcended political and geographic boundaries as seeds or plant parts were moved through trade or migration. The new environments stimulated the development of different ecotypes. And, in this century, the science of plant breeding has further added dimensions to the molding process and has led to even richer diversity within crops.

Rice cultivation was practiced in north-central India and east China at least 7,000 years ago. Archaeological findings in China show that the rice cultivators on the east coast enjoyed a higher level of culture than their contemporaries in north-central China who subsisted mainly on the millets. These findings place Asian rice ahead of bread wheat in the order of antiquity.

A multidisciplinary analysis of the origin of the two rice cultigens (*Oryza sativa* and *O. glaberrima*) and their 20 wild relatives traced the original habitat of the *Oryza* to the Gondwanaland supercontinent before its fracture and drift, which began about 130 million years ago. The two cultigens underwent a parallel evolutionary pathway: perennial wild → annual wild → cultivated annual in widely separated geographic areas: the African plate and the south Asian plate. Intercrossing among the perennial wild strains, annual wild strains, and the cultivars in more recent times has led to a wide array of intermediate types, collectively called the weed race.

The 20 wild species in the genus are widely distributed in a disjunct pattern in the humid tropics of Africa, South and Southeast Asia, Central and South America, and Oceania. Both diploid and tetraploid forms exist in the wild taxa.

Ecological diversification in *O. sativa*, which involved a hybridization-differentiation-selection cycle was enhanced when ancestral forms of the cultigen were carried by farmers and traders to higher latitudes, higher elevations, dryland sites, seasonably deepwater areas, and tidal swamps. Within broad geographic regions, three major ecogeographic races were differentiated as a result of isolation and selection: indica, sinica (formerly known as japonica), and javanica.

The combined forces of natural and human inputs and diverse climates, seasons, and soils, and varied cultural practices (e.g., dryland preparation and direct seeding vs puddling of the soil and transplanting) led to the enormous ecologic diversity now found in the Asian cultivars. Selections made to suit cultivators' preferences and socioreligious traditions added diversity to morphological features, especially the glume colors, grain size and shape, and endosperm properties.

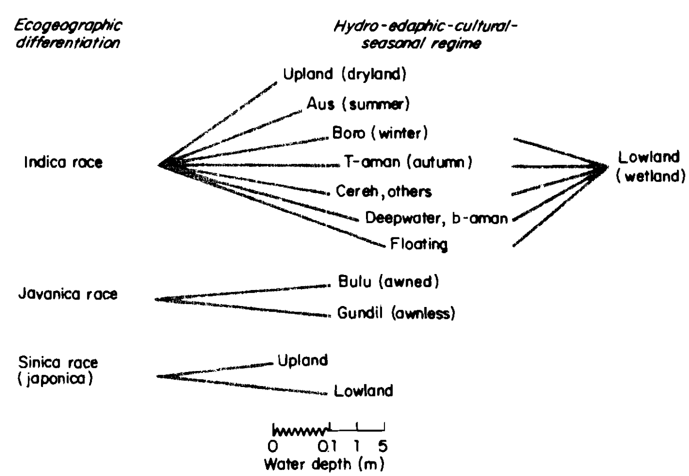
The complex array of cultivars now known in rice literature is categorized in Figure 1 on the basis of hydrologic-edaphic-cultural-seasonal regimes as well as genetic differentiation.

Within the last 2 millennia, dispersal and cultivation of the cultivars in new habitats have further accelerated the diversification process. There are probably 100,000 cultivars of Asian rice now being grown by farmers in more than 100 countries.

The enormous diversity of Asian rices has given rice researchers a wealth of genetic materials to draw on for improving varieties. At the same time, however, the amount of the materials strains the capacity of most national rice research centers to preserve and maintain indigenous rice germplasm.

CONSERVATION EFFORTS

It was fortunate that agricultural research centers in most Asian countries began to collect indigenous commercial varieties of rice shortly before or after World War II. The size of the national holdings ranged from several thousand



1. Conventional classification of *O. sativa* cultivars by genetic and ecocultural criteria. The enormous diversity of the species is a result of broad geographic distribution followed by isolation and selection under diverse environmental-cultural regimes.

to perhaps 12,000 accessions. However, most national collections had similar shortcomings. Although leading commercial varieties in major production areas were well represented, unimproved varieties (land races) and special purpose varieties from remote areas were inadequately collected, and few wild rices were conserved. National centers that lacked refrigerated storage rooms were obliged to grow the seedstocks every year or two in order to maintain seed viability, a task that overburdens small staffs and leads to errors, mixtures, and loss. At several centers, the total holdings dwindled while the laborious process of growing the entire collection was being repeated every year.

The idea of creating a rice germplasm bank at IRRI mainly to serve the rice breeders was conceived early during the planning of the institute and it was endorsed by leaders of many Asian rice research organizations. With the enthusiastic cooperation of the national centers and the FAO Regional Office for Asia and the Pacific, the holdings of the bank have grown from 260 in 1961 to 75,000 in 1984. Donations from various countries helped IRRI to serve as a seed clearinghouse for countries that face constraints in directly exchanging seeds. The medium-term storeroom established at the beginning of IRRI's operations enabled the staff to receive, conserve, and distribute new accessions without having to grow the whole collection every year. IRRI pathologists, entomologists, physiologists, and cereal chemists drew on seedstocks in the bank to begin evaluations and research.

With the release of IR8 in 1966, a wave of new varieties swept across South and Southeast Asia. The rapid adoption of the modern varieties by farmers meant the abandonment of many traditional varieties and, potentially, the extinction of ones that had not been collected and conserved. Several plant scientists predicted that the large-scale planting of the high yielding varieties would wipe out the germplasm represented by traditional rices in irrigated areas. On the other hand, rice breeders themselves were conscious of the importance of preserving the traditional types, which are the building blocks of breeding programs. Meetings of a small group of rice scientists at Los Baños and at Hyderabad culminated in a resolution prepared for the 1971 Rice Breeding Symposium held at IRRI. It urged IRRI to initiate and coordinate field collection activities in parts of Asia where extinction of certain varieties loomed; the 100 rice scientists present adopted the resolution.

With a modest input from the Rockefeller Foundation, IRRI launched collection activities in Bangladesh, Burma, Indonesia, Kampuchea, Sri Lanka, and Vietnam. Funds from the Ford Foundation, USAID and the U.S. Department of Agriculture enabled workers in Pakistan, Indonesia, Nepal, and Laos to start collection campaigns by their rice researchers and extension workers. Service volunteers, missionary workers, and anthropologists also helped canvass remote areas for little known varieties. Whenever IRRI staff participated in field collection, the focus was special types in unusual ecological niches where adverse environmental (both biotic and physiologic) factors prevailed and where resistant or tolerant varieties may be found. About 11,000 seed samples were collected with the direct participation of IRRI staff from 1971 to 1984. Another 27,000 seed samples were collected by workers of national and local governments as well as volunteers.

The International Board for Plant Genetic Resources (IBPGR) joined IRRI in developing two consecutive 5-year plans (1977-82 and 1983-87) for field collection. The IBPGR also channelled funds to expand the efforts of the national workers from 1978 to 1984. This IBPGR grant accounted for about 11,000 seed samples. The inputs of IRRI and IBPGR were both catalytic and synergistic to the massive efforts of the local counterparts. Among the collected samples, about 9,000 were reputed to have resistance or tolerance to one or more adverse production factors. IRRI was also provided duplicate sets of rices collected by regional and national centers in West Africa. Thus, the joint efforts of the national workers, volunteers, and international agricultural research centers have not only averted the genetic cataclysm that threatened, but also greatly enriched the stock of germplasm available to rice researchers.

Efforts are being continued to systematically explore the uncollected areas, mostly along the northern edge of the Himalayas and associated mountain ranges. Coordinated collection plans were developed in consultation with national workers and implemented on a staggered schedule. The target is to assemble more than 98 percent of the available germplasm. However, many pockets in these areas will remain untouched by field collectors due to extreme physical inaccessibility or strife. Increased attention will be paid to the collection of the wild species that have not been adequately covered.

While IRRI has systematically approached every national and local rice research institution for the acquisition of varietal collections, there are still tens of thousands of rice varieties not represented in the IRRI germplasm center. Some of those collections are held under conditions that jeopardize seed viability. To ensure the security of such accessions, it is imperative for the national centers to channel samples into IRRI's medium- and long-term storage rooms and for IRRI to help the centers improve their storage facilities.

For added security, IRRI stores a duplicate set of freshly harvested seeds at the U.S. National Seed Storage Laboratory. IRRI also is working with the U.S. Department of Agriculture and Japan's National Institute of Agrobiological Resources to compare and consolidate holdings so that security is provided to every distinct accession, while redundancy is minimized.

IRRI was able to acquire 7,800 samples from recent collections made in West Africa. The International Institute of Tropical Agriculture in Nigeria is serving as the base collection center for the rice germplasm of Africa, both cultivated and wild. Similarly, the U.S. Department of Agriculture and the National Institute of Agrobiological Resources share responsibilities in preserving the temperate zone varieties.

At the end of 1984 the International Rice Germplasm Center (IRGC) at IRRI held

69,500 accessions of *O. sativa*
1,900 populations of the wild rices
2,900 strains of *O. glaberrima*
700 genetic testers and mutants.

This collection makes IRGC the world's largest repository for a single crop.

IRRI's seed preservation facilities were vastly improved in late 1977 when the Rice Genetic Resources Laboratory was completed with the assistance of the government of Japan, the Asian Development Bank, and the government of Australia. A long-term seed storeroom was added. There stored seeds are dried to 6 percent moisture content and packed under partial vacuum in aluminum cans. The process can preserve seeds for more than 70 years.

Medium-term storage was also improved by switching from glass bottles to aluminum cans. The conversion process however requires massive plantings of old seedstocks in the field for rejuvenation, re-identification, selection, and canning. These operations have taxed the IRGC staff.

DOCUMENTATION AND DISSEMINATION OF SEED AND INFORMATION

The foundation for the computerized management of the voluminous data in the germplasm bank was laid in the early 1960s when standardized descriptors (traits) and descriptor states (values) were initiated. A computer-generated varietal catalog was published in 1970. Information on the 7,600 accessions in the catalog prompted many foreign requests in which accessions were specified by name.

The data management system was improved in 1976 following the establishment of the Germplasm Evaluation and Utilization (GEU) program. IRRI statisticians interlinked the germplasm bank basic (morpho-agronomic) file with the GEU-traits (evaluation data) file for simultaneous retrieval of data from the two sets of files. Computerized files were also set up for seed storage and distribution, and the seed storage file was designed to facilitate periodic monitoring of seed viability and scheduling of rejuvenation cycles.

With these data bases, any request from a rice scientist (at IRRI or in national programs) for a search of accessions in the germplasm center that possess prescribed traits can be readily satisfied through the application of the generalized information retrieval program. The rice scientist may also receive a printout of the data related to the requested accessions. Occasionally when a requesting party submits broad requirements and the retrieval lists hundreds of accessions, the printout is sent to the requester, who is asked to make a judicious selection of the necessary materials: This process has worked to mutual convenience and satisfaction.

Seed distribution continues to be a major service of the IRGC. The number of seed requests — each one being equivalent to one experiment — and the number of seed packages provided to rice scientists are shown in Table 1. The GEU scientists of IRRI have remained the chief clientele of the germplasm bank. But requests by foreign scientists rose to about 260 per year and remained at this level for the past 10 years. IRRI has provided more than 500,000 seed packages to rice scientists throughout the world. When the International Rice Testing Program began in 1976, accessions from the germplasm bank constituted a major source of resistant and tolerant entries.

The exchange of rice germplasm in the past decade, followed by evaluation and use, is unprecedented in the history of agriculture. Being a

Table 1. Progress of the International Rice Germplasm Center (IRGC) in the preservation and distribution of seed of *Oryza* cultigens and wild species, 1973 to 1984.[a]

Year	Distinct accessions of *O. sativa* in IRGC	No. of *O. sativa* samples distributed (no. of requests)		No. of *O. glaberrima*/ genetic testers/wild rices distributed (no. of requests)	
		Inside IRRI	National programs	Inside IRRI	National programs
1973	24,162	8,275 (66)	9,777 (95)	109 (7)	341 (17)
1974	26,818	20,498 (108)	2,603 (83)	189 (1)	160 (10)
1975	30,332	22,155 (151)	4,043 (150)	535 (10)	162 (9)
1976	34,229	40,200 (194)	4,819 (137)	127 (3)	123 (8)
1977	36,956	50,354 (196)	4,126 (148)	74 (8)	597 (14)
1978	40,768	31,941 (182)	7,316 (142)	942 (17)	343 (22)
1979	47,743	26,694 (268)	3,260 (157)	352 (17)	722 (29)
1980	53,431	29,743 (337)	3,659 (156)	733 (23)	483 (51)
1981	57,027	29,053 (319)	4,376 (206)	569 (16)	552 (28)
1982	60,181	33,975 (279)	11,075 (154)	378 (26)	438 (20)
1983	63,490	28,443 (287)	3,756 (150)	342 (20)	972 (38)
1984	64,744[b]	28,170 (277)	6,619 (146)	83 (17)	448 (29)

[a]Numbers in parentheses indicate the number of seed requests processed. [b]About 5,386 recently received seed samples are yet to be grown and registered; 9,831 duplicate accessions and 4,950 nonviable seed samples were removed from the registry during 1973-84.

component of the GEU program and the IRTP, the IRGC has fully exercised its role as an international crop genetic resources center — not just as a gene bank.

USE OF GERMPLASM

Seeds supplied by IRRI have been extensively evaluated and used by rice breeders and others for varietal development or related research. Direct adoption led to varietal releases and large-scale planting of such varieties as Taichung Native 1 and Tainan 3 in India, Chianung 242 in Nepal, Taipei 309 in Bangladesh, and Mahsuri in several Asian countries. Many more accessions were used in breeding programs of national and international centers.

While the long list of resistances and tolerances identified from the IRGC accessions prohibits a full enumeration, the most significant contributions of the useful rice germplasm are in the areas of increasing crop yield, stabilizing production by incorporating the necessary resistances and tolerances, and facilitating intensive multiple cropping.

The Chinese semidwarf gene (sd_1) carried by Dee-geo-woo-gen and Taichung Native 1 has been the most widely used source for short stature, nitrogen response, and high yield. TKM6 of India has provided resistance to stem borers, bacterial blight, and tungro virus. Other Indian varieties have served as donors for resistance to biotypes 2 and 3 of the brown planthopper, the whitebacked planthopper, and the gall midge. Gampai 15 of Thailand was a major source of resistance to the tungro virus. A strain of *O. nivara* originating from north India has remained the sole source of resistance to the destructive grassy stunt virus. Other wild relatives collected from Taiwan, India, and Sri Lanka are the only strong sources of resistance to the ragged stunt virus. Two such resistant wild rices are now extinct in Taiwan. The distribution and use of rice germplasm was further stimulated and expanded in recent years by the worldwide planting of international nurseries coordinated by the IRTP. In essence, the IRGC has provided the bulk of the building blocks not only for IRRI researchers, but also for rice researchers in nearly 100 countries. The enormous genetic diversity preserved by IRRI will ensure a broad genetic base for future rice improvement.

The high returns from increased production and reduced loss due to pest damage has paid for the IRRI germplasm program many times over. For the future, the rice collection preserved at IRRI offers diverse germplasm, which is necessary to cope with rising genetic vulnerability as cultivated varieties become more uniform. In addition, the expansion of rice production into new or marginal areas will require new inputs from the germplasm base.

OTHER INPUTS IN CROP GERMPLASM CONSERVATION

The IRGC has pioneered standardized descriptors (characters) and descriptor states (values or codes), and published a computerized varietal catalog, a manual for field collectors, and a manual on the management of crop genetic resources. During the past decade, 31 young scientists were trained in seedbank management at IRRI. The IRGC staff has also trained hundreds of field collectors through courses held in Bangladesh, Burma, Indonesia, Kampuchea, Madagascar, and Thailand. IRGC has provided consultation on the construction and improvement of seed storage facilities to national centers in Bangladesh, China, Fiji, India, Indonesia, and Thailand and to international centers such as AVRDC, IITA, and WARDA.

The myriad contributions of the IRGC have earned worldwide recognition as a model gene bank for other centers.

CHAPTER 4

VARIETAL IMPROVEMENT

Rice in the tropics is grown in five major ecological situations — irrigated, rainfed lowland, upland, deep water, and tidal wetlands — and a broad array of natural enemies combine to reduce yield.

Varietal improvement at IRRI has focused on developing germplasm possessing high yield, photoperiod insensitivity, disease and insect resistance, improved grain and nutritional quality, early maturity, and tolerance to drought, low temperature, and mineral deficiencies and toxicities.

During the initial years, varietal improvement work at IRRI focused on germplasm for the irrigated conditions, which prevail on half the world's riceland and produce three-fourths of the output. Since 1975, however, IRRI has taken a two-pronged approach. For the favored irrigated and rainfed environments, breeders develop materials with higher yield potential, greater yield stability, shorter growth duration, and superior grain quality. At the same time they prepare to face new disease and insect problems. For the unfavorable environments (drought- or submergence-prone rainfed lowland areas, upland areas, deep water areas, and tidal wetlands), breeders develop rice varieties with higher yield potential, while retaining those traits responsible for their adaptability to specific ecosystems.

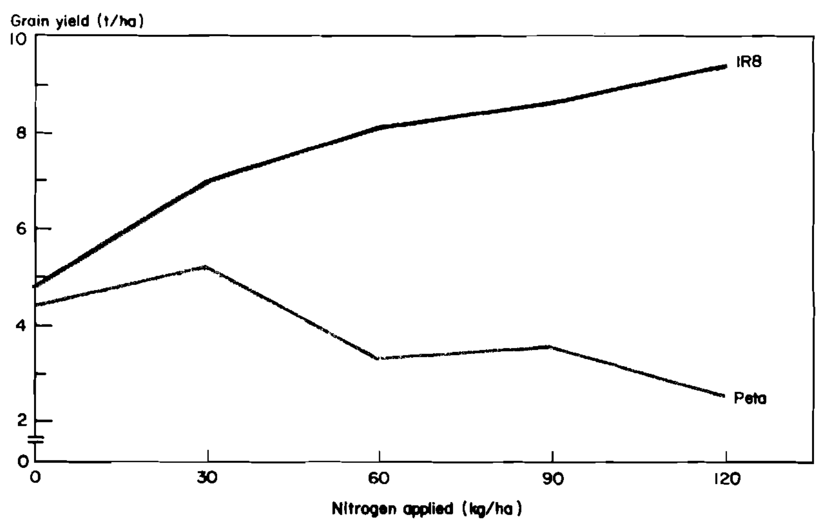
IRRI has one of the biggest crop improvement programs in the world; it endeavors to develop and help develop improved germplasm for varied rice growing conditions.

BREEDING STRATEGIES

To meet the challenge of developing improved rice germplasm for diverse ecological conditions, various breeding strategies have been employed at IRRI. Improvement of yield potential — a most important agronomic trait — received the major attention in the early years. Soon afterwards, IRRI recognized the significance of resistance to diseases and insects for combining high yield potential with stability. Subsequently, development of early-maturing rice varieties possessing high yield and multiple resistance to diseases and insects was undertaken to enable the rice farmers to increase their cropping intensity. While breeding for high yield potential and stability, researchers also emphasized improved grain and nutritional quality to meet the consumers' requirements. With the start of breeding for unfavorable environments, tolerance to drought, low temperature, mineral deficiencies, and toxicities were also included as important breeding objectives. With the increase in the number of traits to be incorporated for various ecosystems, the concept of multidisciplinary breeding emerged in the 1970s to further increase the efficiency of IRRI's breeding program.

High yielding plant type

Before the establishment of IRRI, rice varieties cultivated by farmers in South and Southeast Asia were tall, leafy with weak culms and possessed a harvest index (ratio of the dry grain weight to total dry matter) of 0.3. When fertilizer nitrogen was applied at rates exceeding 40 kg/ha, many traditional varieties tillered profusely, grew excessively tall, lodged early, and yielded less than they would with lower fertilizer rates. To reduce lodging susceptibility, IRRI plant breeders in 1962 crossed Dee-geo-woo-gen, a short-statured variety from China, and Peta, a tall Indonesian variety then popular with Filipino farmers. A selection made from this cross was named IR8 and released in 1966. IR8 was semidwarf (100 cm), erect leaved, high tillering, photoperiod insensitive, had stiff culms, and responded to application of nitrogen fertilizer much better than traditional varieties such as Peta (Fig. 1). The IR8 plant type was a breakthrough: it doubled the yield potential of tropical rice. This advance convinced national rice improvement programs to initiate crossing programs to develop varieties with short stature. Since then most high yielding rice varieties recommended for irrigated and favorable rainfed lowland conditions in the tropics and subtropics have had the semidwarf, nitrogen-responsive plant type.



1. Nitrogen response of Peta and IR8. IRRI, 1966 dry season.

Early maturity

Development of improved germplasm with shorter growth duration has been an important objective. Most traditional varieties in tropical and subtropical Asia mature in 160 to 170 days and many are photoperiod sensitive. IR8 and subsequent improved varieties such as IR20, IR24, and IR26 are photoperiod insensitive and mature in 130 to 135 days. Growth duration was reduced to 105 to 100 days in such varieties as IR28, IR30, and IR36 (Table 1). Because of shorter growth duration, high yield, and high yield stability, IR36 has been widely accepted in rice growing countries of Asia. With IR36, many farmers have increased their cropping intensity. They can grow two crops of rice where only one was possible before or they can follow IR36 with an upland crop. Materials with even shorter growth duration are being developed. The recently released variety IR58 matures in only 100 days. Under optimum conditions the maximum yield potential of the short-duration varieties is comparable to, or only slightly lower than, that of varieties with medium growth duration (130-135 days), but as shown in Table 2, their per-day productivity is much higher.

Grain quality

Grain quality determines, to a large extent, the market price of rice and its consumer acceptability. Preferences for grain size, shape, and eating quality

Table 1. Main characteristics of IR varieties.

Variety	Recommended for	Growth duration (days)	Height (cm)	Amylose content	Gelatinization temperature	Grain size and appearance
IR5	Rainfed	140	130	High	Intermediate	Medium long, bold
IR8	Irrigated	130	100	High	Low	Long, bold
IR20	Irrigated	125	110	High	Intermediate	Medium long, slender
IR22	Irrigated	125	90	High	Low	Long, slender
IR24	Irrigated	120	90	Low	Low	Long, slender
IR26	Irrigated	130	100	High	Low	Medium long, slender
IR28	Irrigated	105	100	High	Low	Long, slender
IR29	Irrigated	115	100	Glutinous	Low	Long, slender
IR30	Irrigated	110	100	High	Intermediate	Medium long, slender
IR32	Irrigated	140	105	High	Intermediate	Long, slender
IR34	Irrigated	130	125	High	Low	Long, slender
IR36	Irrigated	110	85	High	Intermediate	Long, slender
IR38	Irrigated	125	100	High	Intermediate	Long, slender
IR40	Irrigated	120	100	High	Intermediate	Medium long, slender
IR42	Irrigated	135	110	High	Low	Medium long, slender
IR43	Upland	125	110	Low	Low	Long, slender
IR44	Irrigated	130	110	High	Low	Long, slender
IR45	Upland	125	100	High	Intermediate	Long, slender
IR46	Rainfed	130	110	High	Intermediate	Long, slender
IR48	Irrigated	140	120	Intermediate	Low	Long, slender
IR50	Irrigated	105	90	High	Intermediate	Long, slender
IR52	Rainfed	115	95	High	Low	Long, slender
IR54	Irrigated	120	95	High	Low	Long, slender
IR56	Irrigated	110	90	High	Low	Long, slender
IR58	Irrigated	100	80	High	Low	Medium long, slender
IR60	Irrigated	108	95	High	Low	Long, slender
IR62	Irrigated	115	110	High	Intermediate	Medium long, slender

Table 2. Yield of promising early-maturing lines evaluated at IRRI, 1981 dry and wet seasons.

Selection	Growth duration (days)	Dry season Total yield (t/ha)	Dry season Yield per day (kg)	Wet season Total yield (t/ha)	Wet season Yield per day (kg)
IR8455-78-1-3-3	100	6.2	80	4.6	60
IR9729-67-3	100	7.2	92	5.1	65
IR15429-268-1-2-1	97	6.8	91	5.1	68
IR19729-5-1-1-3-2	97	6.1	81	4.3	57
IR19729-5-2-3-2-1	100	6.5	83	4.9	63
IR19743-25-2-2-3-1	96	6.4	86	4.6	62
IR19743-40-3-3-2-3	97	5.8	77	4.6	61
IR19746-28-2-2-3	97	6.0	80	4.5	60
IR9752-71-3-2 (IR58)	98	7.5	99	4.7	62
IR36 (check)	108	6.9	80	4.7	55
IR42 (check)	135	5.9	52	4.7	42

often vary from country to country. Physical properties (size, shape, and translucency of grain) influence the milling recovery. Cooking quality is determined by the physicochemical properties of the starch. The starch fraction, which constitutes 90 percent of the grain, is a polymer of glucose and the proportions of its linear fraction (amylose) and the branched fraction (amylopectin) along with its gelatinization temperature determine, in part, the eating quality of rice.

The grains of most rice varieties grown in tropical Asia have a high amylose content (>25%) and cook dry and fluffy. However, the preferred rice varieties have an intermediate level of amylose (20-23%); they cook moist and remain soft when cool. Varieties with an intermediate amylose content should have broad acceptance in areas where indica rices are grown. All the japonica varieties have a low amylose content and consumers in temperate areas where japonicas are grown overwhelmingly prefer low amylose varieties, which are soft cooking.

A great majority of IR varieties have high amylose (Table 1). Only IR24 and IR43 have low amylose, IR29 is glutinous, and IR48 is the only IR variety that has intermediate amylose content (however, because IR48 is late maturing, it has not been adopted widely). As a result of new emphasis on improved germplasm with intermediate amylose, more than half of the entries in IRRI's replicated yield trials during 1983 had intermediate amylose content. In the near future many improved varieties with intermediate amylose content are likely to become available to the rice farmers of the world.

Disease and insect resistance

The rice plant is subject to the attack by numerous diseases and insects. The most common diseases are blast, sheath blight, bacterial blight tungro, grassy stunt, and ragged stunt. The most important insects are brown planthopper, green leafhopper, stem borers, and gall midge. Varietal resistance is essential for yield stability. Therefore, major resources have been allocated for incorporating genes for disease and insect resistance. IRRI has developed improved lines that possess resistance to as many as five diseases and four insects. For example, IR36 is resistant to blast, bacterial blight, tungro, brown planthopper, green leafhopper, stem borers, and gall midge. Several other IR varieties (Table 3) and numerous breeding lines with multiple resistance to major diseases and insects have been developed and IRRI continues to emphasize the incorporation of diverse genes for resistance into improved germplasm. Good sources of resistance to sheath blight have not been found, but the search continues. The value of multiple resistance to diseases and insects for yield stability is indicated in Figure 2. The yields of IR8, a susceptible variety, fluctuate greatly due to pressure of diseases and insects, whereas the yields of IR36 and IR42, which have multiple resistance, show little variation from year to year.

Drought tolerance

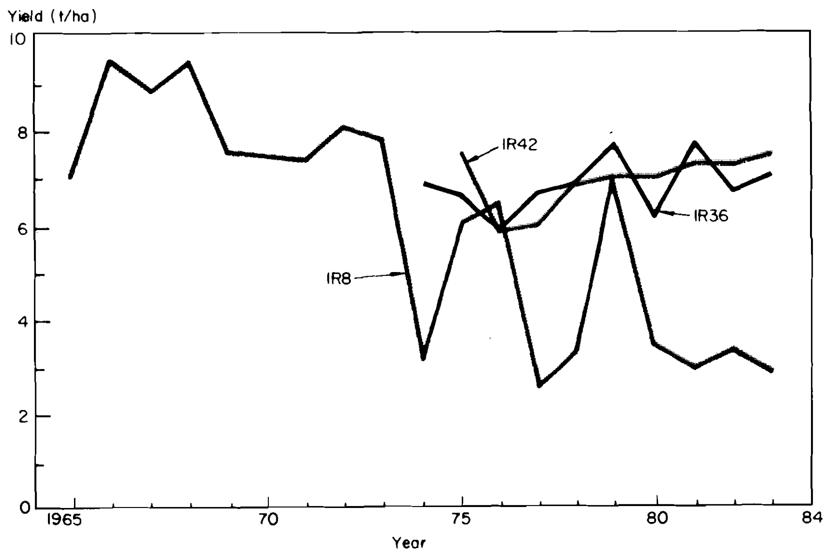
The need to improve the drought tolerance of modern varieties became clear when IRRI began an upland rice breeding program in 1970. The mass screening technique developed in 1973 enabled breeders to evaluate the rice germplasm collection for sources of drought tolerance. Upland rices such as Moroberekan and 63-83, lowland varieties such as Khao Dawk Mali 105 and Nam Sagui 19, and deep water rices such as Leb Mue Nahng 111 were identified as useful donors of drought tolerance.

Table 3. Disease and insect reactions[a] of IR varieties in the Philippines.

Variety	Blast	Bacterial blight	Grassy stunt	Tungro	BPH[b] biotypes 1	2	3	Green leaf-hopper	Stem borer	Gall midge
IR5	MR	S	S	S	S	S	S	R	MS	S
IR8	S	S	S	S	S	S	S	MR	M	S
IR20	MR	R	S	MR	S	S	S	R	MR	S
IR22	S	R	S	S	S	S	S	S	S	S
IR24	S	S	S	S	S	S	S	R	S	S
IR26	MR	R	S	MR	R	S	R	R	MR	S
IR28	R	R	R	R	R	S	R	R	MR	S
IR29	R	R	R	R	R	S	R	R	MR	S
IR30	MS	R	R	R	R	S	R	R	MR	S
IR32	MR	R	R	R	R	S	R	RT	MR	S
IR34	R	R	R	R	R	S	R	R	MR	S
IR36	R	R	R	R	R	R	S	R	MR	R
IR38	R	R	R	R	R	R	S	R	MR	R
IR40	R	R	R	R	R	R	S	R	MR	R
IR42	R	R	R	R	R	R	S	R	MR	R
IR44	MR	R	S	R	R	R	S	R	MR	S
IR46	R	R	S	R	R	S	R	R	MR	S
IR48	MR	R	R	R	R	R	S	R	MR	S
IR50	MS	R	R	R	R	R	S	R	MR	S
IR52	MR	R	R	R	R	R	S	R	MR	—
IR54	R	R	R	R	R	R	S	R	MR	—
IR56	R	R	R	R	R	R	R	R	MR	—
IR58	R	R	R	R	R	R	S	R	MR	—
IR60	R	R	R	R	R	R	R	R	MR	—
IR62	R	R	R	R	R	R	R	R	MR	—

[a]R = resistant, MR = moderately resistant, S = susceptible. [b]BPH = brown planthopper.

2. Yields of IR8, IR36, and IR42 in dry season replicated yield trials at IRRI.



Many of IRRI's breeding lines combine drought tolerance and improved plant type. Two varieties released by the Philippines, IR43 for upland and IR52 for rainfed lowland, have shown good drought tolerance at the vegetative stage over several seasons of testing. These varieties also have excellent yield potential. Several upland breeding lines, such as IR5931-110-1, IR6115-1-1-1, and IR6023-10-1-1, show very good recovery from drought. IR3794-9-2-3 and IR10025-16-2 have been rated outstanding for both drought tolerance and recovery in international trials. Several rainfed lowland breeding lines, such as IR29341-85-3-1-3 and IR33353-64-1-2-1, are drought tolerant under both transplanted and direct-seeded conditions.

Tolerance to problem soils

Work at IRRI leading to varietal improvement for adaptation or resistance to soil-related (chemical) stresses was initiated in the Soil Chemistry Department by simple pot experiments in the early 1970s, using such traditional varieties and breeding lines as could be obtained. The collaboration between soil chemists and plant breeders now involves

- monitoring adaptation to soil stresses in advanced lines and varieties (whether or not specifically bred for tolerance to such stresses) and at the same time identifying potential soil-related constraints on yield;
- singling out varieties with superior tolerance to serve as donors in crosses with improved types; and
- integrating soil-related constraints into the overall breeding objectives for key areas, including disease and insect resistance and tolerance to more than one soil stress, as needed.

Constraints and appropriate resistant donors have been identified for salinity, alkalinity, acid sulfate soils, peat soils, iron toxicity, zinc deficiency, phosphorus deficiency, iron deficiency, aluminum toxicity, manganese toxicity, and boron toxicity.

The breeding program emphasizes tolerance to salinity, which is relevant to coastal rice culture as well as to irrigated arid rice lands, as in Pakistan and Egypt. Salinity tolerance from donor varieties like Pokkali, Nona Bokra, Cheriviruppu, and SR26B has been successfully transferred to improved breeding lines that are now being used to make crosses specifically directed at selected saline rice areas, in collaboration with breeders in those areas.

Cold tolerance

In 1970 IRRI began making crosses with donors of cold tolerance for areas where low temperature is a constraint to rice production. The resulting populations were grown in cooperative programs. Since 1973, IRRI has grown cold tolerance nurseries in the mountainous area of Northern Philippines in cooperation with the Philippine Bureau of Plant Industry. Through an extensive search of the rice germplasm bank for indica varieties with short duration and tolerance to low water and air temperatures, several promising donors, such as Pratao, HR33, C21, Leng Kwang, Azucena, and Do Do, were identified.

Studies of data from low temperature rice-growing areas have revealed several characteristic temperature regimes, and varieties adapted to one regime may not be adapted to others. The International Rice Cold Tolerance Nursery (IRCTN) grown at tropical and temperate sites allows cold-tolerant varieties and breeding lines to be tested under diverse conditions. Entries from the IRCTN have already been released as varieties in India, Nepal, and several African and Latin American countries. The IRRI breeding lines IR19743-46-2-3, IR19746-26-2-3, and IR9202-5-2-2 have given excellent performance in the IRCTN.

Breeding lines from the crosses IR9202 (IR2053-521-1-1/K116//KN1B-361-8-6-9-1), IR13155 (BG90-2/KN-1B-214-1-4-3//IR28), and IR7167 (China 1039 Dwf/KN-1B-361-1-8-6-10) have performed well in Banawe, Philippines, and South Korea. The Rapid Generation Advance facility has been used in combination with screening for tolerance to leaf discoloration in cold water. The RGA-derived line IR20654-R-R-R-1-2 has good cold tolerance and has been used extensively as a parent in the Korea-IRRI Collaborative Project on cold tolerance.

RICE IMPROVEMENT FOR DIFFERENT CULTURAL TYPES

Because rice is grown under diverse ecological conditions, cultural and production practices vary considerably and adapted varieties have distinct characteristics. Rice growing environments have been classified into five major categories: irrigated, rainfed lowland, upland, deepwater, and tidal wetlands. These major categories have been divided into several subcategories as shown in Table 4. Although IRRI's varietal improvement work at first was focused on development of improved germplasm for irrigated conditions, now, more than 70 percent of varietal improvement resources are allocated for unfavorable environments.

Irrigated

Improvement of the yield potential was the primary objective at the inception of the breeding program in early 1960s. The development of short-statured varieties with improved harvest index and consequently higher yield potential was a momentous achievement. However, early dwarfs were susceptible to many of the major diseases and insects. Incorporation of disease and insect resistance into improved varieties was emphasized in the early 1970s and several varieties with multiple resistance were developed.

Concurrently, efforts were made to shorten the growth duration to enable farmers to increase the number of crops they could grow each year. Thus rice improvement for irrigated conditions has had three stages:

1. Development of photoperiod-insensitive, nitrogen-responsive, short-statured varieties, such as IR8, with sturdy stems, high tillering ability, and dark green leaves. IR8 matures in 130 days, has high dry matter production, and high harvest index (0.50 vs 0.30 to 0.35 for the old varieties), and is capable of yielding 8 to 9 t/ha under ideal conditions.
2. Incorporation of genes for multiple resistance to diseases and insects into materials with improved plant type, which led to varieties such as IR26 and IR42 that have great yield stability.

Table 4. Classification of rice growing environments (area of each major capacity indicated in parentheses).

Irrigated (77 million ha)
Irrigated, with favorable temperature
Irrigated, low temperature, tropical zone
Rainfed lowland (33 million ha)
Rainfed shallow, favorable
Rainfed shallow, drought-prone
Rainfed shallow, drought- and submergence-prone
Rainfed shallow, submergence-prone
Rainfed medium-deep, waterlogged
Deepwater (12 million ha)
Deepwater (50 cm to 100 cm water depth)
Very deepwater (100 cm water depth)
Upland (19 million ha)
Upland, long growing season, favorable soil factors
Upland, long growing season, unfavorable soil factors
Upland, short growing season, favorable soil factors
Upland, short growing season, unfavorable soil factors
Tidal wetlands (5 million ha)
Tidal wetlands with perennially fresh water
Tidal wetlands with seasonally or perennially saline water
Tidal wetlands with acid sulfate soils
Tidal wetlands with peat soils

3. Stepwise improvement in rice varieties. Right to left: Leb Mue Nahng, a tall traditional variety, is photoperiod sensitive, susceptible to diseases and insects and has a harvest index of 0.3. Peta, a semi-improved variety, is tall, photoperiod insensitive, matures in 155 days, is susceptible to diseases and insects, and has a harvest index of 0.35. IR8, an improved short-statured variety, matures in 135 days, is susceptible to diseases and insects, and has a harvest index of 0.5. IR36, an improved short-statured variety, matures in 110 days, is resistant to diseases and insects, and has a harvest index of 0.5.

3. Development of earlier maturing varieties with short stature and multiple resistance to diseases and insects, such as IR36 and IR50. These shorter duration varieties also have very rapid growth rates and improved harvest index so that they are capable of producing high yields. This stepwise improvement is shown in Figure 3.

To date more than 100 breeding lines from IRRI's irrigated rice improvement program have been named varieties by the national programs all over the world. Twenty-three IR varieties have been recommended for the irrigated conditions in the Philippines. Materials developed for irrigated environments are also evaluated under rainfed lowland and upland conditions. Two varieties (IR43 and IR45) have been recommended for upland and two (IR46 and IR52) for rainfed lowland (Table 1). Most of the irrigated rice lands in the tropics are now planted to modern varieties developed by IRRI and national rice improvement programs.

As shown in Table 1, most IR varieties have high amylose content and thus cook dry and fluffy. In recent years, emphasis has been placed on developing improved germplasm with intermediate amylose content, which Asians tend to prefer. Many multiple disease- and insect-resistant breeding lines with intermediate amylose content are now in the final stages of evaluation. Thus more and more future IR varieties will have better palatability.

Two major challenges face the irrigated rice breeders:

1. Since the advent of the first improved variety, IR8, only marginal improvements have occurred in yield potential. Concerted efforts must now be made to overcome the yield barrier. Some innovative approaches for achieving this objective are described later.
2. The natural enemies of rice continue to change and develop new races and biotypes that threaten the resistance of improved varieties. Breeders therefore must incorporate diverse genes for resistance to major diseases and insects to ensure yield stability.

Rainfed lowland

The rainfed lowland breeding effort, which began in 1976, has focused on combining drought and submergence tolerance with improved plant type and disease and insect resistance. With the division of rainfed lowland cultural types into five categories (Table 4), specific breeding objectives have been formulated for the four unfavorable classifications in order to combine tolerance to the various stresses with the appropriate plant type and maturity for each cultural type.

Three types of shallow rainfed lowland situations exist: drought-prone, drought- and submergence-prone, and submergence-prone. Drought-prone areas include areas with well-drained soils and a short rainy season where very early varieties are direct seeded, as well as areas with erratic or bimodal rainfall where later maturing, photoperiod-insensitive or sensitive varieties are grown. Strong drought tolerance and vegetative vigor are essential in varieties for these areas. In the two types of areas where submergence is a danger, tall varieties are grown to escape injury from floods. Intermediate-height varieties with strong submergence tolerance are needed for these areas. In medium-deep rainfed lowland areas, late duration or photoperiod-sensitive varieties that can tiller well under stagnant flooding and are lodging resistant are required. Resistance to prevalent diseases and insects is necessary for all rainfed lowland situations.

The rainfed lowland pedigree nurseries are screened at IRRI for drought and submergence tolerance and advanced lines are evaluated at representative Philippine sites. One example is the Drought-Prone Areas project conducted by the Agronomy Department. This consists of a yield trial and observation nursery grown at several drought-prone sites. Promising lines are entered in the International Rainfed Rice Shallow Water Yield Nursery (IRRSWYN) for evaluation by national programs.

International collaboration has become more important in the breeding effort. Breeders in the national programs request F_2 or later generation seed from crosses made at IRRI. In Northeast Thailand, the varieties farmers grow have excellent grain quality and adaptation to poor soils, but they lack insect and disease resistance and are relatively low yielding. A shuttle breeding project is under way to develop lodging-resistant, photoperiod-sensitive varieties from the Thai recommended varieties.

IR5 was the first IRRI variety widely grown under rainfed lowland conditions. Its intermediate plant stature and relatively good lodging resistance made it very suitable for rainfed lowland conditions. A sister line of IR5 was selected in India and named Pankaj. IR5 is still very popular, particularly in medium-deep areas, and has been a widely used parent in rainfed breeding programs.

More recently the Philippines released two IRRI varieties, IR46 and IR52, for rainfed lowland conditions. IR46 has given high and stable yields in international trials and is an excellent parent in crosses. IR52 combines high yielding ability with drought tolerance at the vegetative stage, although it is somewhat susceptible to blast. The breeding lines listed in Table 5 have

Table 5. Promising breeding lines for rainfed lowland conditions.

Designation	Maturity (days)	Height (cm)	Resistance to[a]					Tolerance to	
			BB	BPH			GLH	Drought	Submergence
				1	2	3			
IR4819-77-3-2	120	110	M	R	S	R	R		+
IR4829-89-2	140	110	M	R	S	R	R	+	+
IR8129-166-2-2-3	130	120	R	R	R	R	M	+	
IR10781-75-3-2-2	130	115	R	R	R	S	R	+	+
IR13146-45-2-3	125	105	R	R	S	R	R	+	+
IR13365-253-3-2	135	110	R	R	R	S	S		
IR14632-2-3	125	115	R	R	R	R	M	+	
IR14753-49-2	120	115	R	R	S	R	R	+	

[a]BB = bacterial blight, BPH = brown planthopper (and its biotypes), GLH = green leafhopper.

performed well over several years in international trials, and have been noted for drought or submergence tolerance.

Upland

About 19 million hectares are planted to upland rice, which is about 15 percent of the world's rice area. In tropical Asia alone, 11.5 million hectares of varying topo-hydrologic-edaphic regimes are planted to upland rice. In Latin America, 6 million hectares, or 72 percent of the total rice area are planted to upland rice. Most of the rice area is in Brazil. West Africa has another 2 million hectares of upland rice.

To raise the yield potential of upland rice, IRRI is developing intermediate-stature varieties (±120 cm) with moderate and plastic tillering ability to replace the tall, low tillering, and weak-strawed traditional types. Yield stability is one of the most important requirements in the improved varieties. It can be achieved through incorporation of tolerance to drought and resistance to blast. Tolerance mechanisms related to drought are 1) avoidance imparted by deep and thick roots, plasticity in leaf rolling and unrolling, and cuticular resistance; and 2) the ability to recover after water stress.

The growth duration should be from 90 to 130 days to suit various ecological niches. Breeding efforts at IRRI aim to retain the agronomic and grain quality traits preferred by farmers, such as long and well-exserted panicles, high panicle fertility, nonshattering spikelets, and grain with intermediate amylose content, intermediate gelatinization temperature, and soft gel consistency.

Emphasis is given to incorporation of high levels of disease and insect resistance. Blast is the major disease limiting production under upland situations. Other disorders such as panicle discoloration, sheath blight, helminthosporium leaf spot, and leaf scald and insects such as stem borers and whitebacked planthoppers also are of considerable concern.

Incorporation of tolerance to adverse soil conditions such as nitrogen and phosphorus deficiency, aluminum and manganese toxicity in acid soils, and iron and zinc deficiency in alkaline soils are receiving top priority in the breeding program.

Deep water

Excess water is as important as insufficient water in limiting the adoption of improved rice varieties. There are about 8 million hectares of rice land where water depth reaches 50 to 100 centimeters. Modern dwarf varieties do not survive in such water regimes. In another 4 million hectares, water depth reaches more than 100 centimeters.

IRRI has developed prototype varieties for the deepwater conditions. RD19, a product of collaboration between IRRI and the rice improvement program of Thailand, combines the stem elongation ability of traditional floating rices with the short stature of improved varieties. It is well adapted to water depths of up to 100 centimeters and has outyielded the traditional varieties by 20 to 30 percent in replicated yield trials. However, it has poor grain quality and is susceptible to many diseases and insects. Efforts are being made to improve the grain quality of RD19 and incorporate genes for disease and insect resistance. For the severe deepwater situations — water depths greater than 100 centimeters — IRRI is developing improved varieties without dwarfing genes, but with high levels of disease and insect resistance. Incorporation of resistance to tungro, bacterial blight, and stem borer is receiving priority along with tolerance to drought at seedling stage and tolerance to submergence. Appropriate levels of photoperiod sensitivity must be retained as changes in the growth duration for specific deepwater areas are not desirable.

The harvest index of the deepwater rices is very low, between 0.15 to 0.25. That is, a great proportion of biomass goes into production of straw. Thus to improve the yield potential of deepwater rice, harvest index must be raised. IRRI is looking into the ways to do so.

Tidal wetlands

In tidal wetlands, three types of floods are superimposed on each other in ratios that depend on the relative distance of the site from the sources of the flooding: 1) diurnal flooding, resulting in mixing of salt water with fresh water, 2) fortnightly tides from the interaction of fresh water supplied by rivers with moon tides from the sea, and 3) monsoon-derived fresh water floods from rivers.

At some distance from the coast, diurnal movements are no longer important, and progressively farther from the coast, moon tides are also dampened, so the flooding becomes purely monsoonal, turning into deep or very deep stagnant floods, suitable for deepwater or for floating rices.

A significant feature of coastal floods is that the diurnal and moon tides can be accurately predicted for every site every year. Therefore, agronomic practices are highly important. Farmers have developed techniques for using seedlings at least 30 days old that have been once or twice retransplanted to increase their height and hardiness. In combined diurnal and moon-tide flooding, these seedlings are transplanted just as one early-season peak flood recedes, thus leaving them almost 14 days to become established before the next moon tide arrives.

The culture in coastal wetlands depends also on a highly specific adaptation to prevailing soil characteristics, which range from salty to peaty or acid sulfate.

Breeding strategies are centered on improving submergence tolerance and straw stiffness, while retaining the tolerance to specific problem soils.

BREEDING METHODOLOGY

Generally speaking, breeding methods include the procedures to create genotypic variability or to evaluate such variability in order to select among genotypes. The efficiency of a breeding program depends on choice of suitable breeding methods and selection procedures.

Screening and evaluation techniques

Scientists in various IRRI departments have developed a broad range of techniques for screening and evaluation of important traits (Table 6) that have contributed significantly to the progress of varietal improvement at IRRI. These techniques are employed in several national programs as well as at IRRI. Each year 30,000 to 35,000 seed samples from the germplasm bank are screened to identify donor parents for the traits to be incorporated into the breeding materials. In addition, all the entries in the hybridization block (300-400), pedigree nurseries (60,000-120,000), observational yield trials (1,000-1,500), and replicated yield trials (500) are screened every year for one or more traits using these screening techniques.

Breeding operations and procedures

The rice breeding program at IRRI started in 1961 with a plant breeder and a geneticist. Another plant breeder was added in 1963. It now involves six plant breeders. In addition two scientists handle the international nurseries. Of the six rice breeders, one handles the breeding program for irrigated rice, one works on upland rice, one is assigned to rainfed lowland rice, one is in charge of the breeding work for deep water, and one handles the breeding program for tidal wetlands and for adverse soil conditions. The sixth rice breeder is responsible for hybrid rice breeding. The geneticist is in charge of operations related to germplasm collection, conservation, and distribution. He also devotes time to upland rice improvement.

Over the years, the organization of the breeding program has been modified to meet the growing challenges and increase the efficiency of the varietal improvement work. Currently, the hybridization block contains entries nominated by all the plant breeders and other scientists and its composition is changed every season. All the crosses are made at one place and all the F_1 hybrids are grown in one common F_1 nursery. The F_2 and later generation nurseries are grown under appropriate environments. For example, breeding nurseries for irrigated conditions, particularly the segregating materials are managed to expose them to maximum disease and insect pressures. Nurseries for upland and rainfed lowland drought-prone areas are

Table 6. Techniques developed at IRRI to screen and evaluate rice breeding materials.

Resistance/tolerance to	Screening condition	Department	Year developed
Blast	seedbed	Plant pathology	1962
Yellow stem borer	field	Entomology	1962
Striped stem borer	field	Entomology	1962
Whorl maggot	greenhouse	Entomology	1965
Stem rot	greenhouse	Plant pathology	1966
Brown planthopper	greenhouse	Entomology	1967
Green leafhopper	greenhouse	Soil chemistry	1969
Aluminum toxicity	greenhouse	Soil chemistry	1969
Manganese toxicity	greenhouse	Soil chemistry	1969
Iron deficiency	greenhouse	Soil chemistry	1969
Whitebacked planthopper	greenhouse	Entomology	1970
Iron toxicity	greenhouse	Soil chemistry	1970
Salinity	greenhouse	Soil chemistry	1970
Phosphorus deficiency	greenhouse	Soil chemistry	1970
Bacterial blight (needle inoculation)	field	Plant pathology	1971
Sheath blight	field	Plant pathology	1972
Alkalinity	greenhouse	Soil chemistry	1972
Cold at seedling stage	greenhouse	Plant physiology	1972
Drought in upland	field	Plant breeding/Agronomy	1974
Drought in upland	greenhouse	Agronomy	1973
Bacterial blight (clipping)	field	Plant pathology	1973
Zigzag leafhopper	greenhouse	Entomology	1973
Submergence	greenhouse	Plant physiology	1974
Cold at panicle initiation	greenhouse	Plant physiology	1975
Cold at anthesis	greenhouse	Plant physiology	1976
Drought in rainfed lowland	field	Plant breeding	1976
Acid sulfate soil	field/greenhouse	Soil chemistry	1976
Peat soil	field	Soil chemistry	1976
Leaf scald	greenhouse	Plant pathology	1977
Bakanae	greenhouse	Plant pathology	1978
Submergence	field	Thailand/IRRI project	1978
Sheath rot	greenhouse	Plant pathology	1979
Cercospora leaf spot	greenhouse	Plant pathology	1979
Leaffolder	greenhouse	Entomology	1979
Boron toxicity	greenhouse	Soil chemistry	1979
Brown spot	greenhouse	Plant pathology	1981
Caseworm	greenhouse	Entomology	1982
Thrips	greenhouse	Entomology	1983
Rice bug	field	Entomology	1983
Bacterial leaf streak	greenhouse	Plant pathology	1983

grown under moisture stress. The yield trials are also conducted under appropriate environmental conditions. However, seed increase and production of breeder seed of named varieties and growth of elite breeding lines is done under favorable conditions.

In addition to field evaluation for various stresses, breeding materials are screened in the greenhouse by plant pathologists and entomologists for disease and insect resistance. Agronomists and soil scientists evaluate the materials for tolerance to drought and problem soils and plant physiologists handle the screening work for cold tolerance. Thus a close liaison is maintained between breeders and problem-area scientists.

During the first decade, IRRI plant breeders made 200 to 300 crosses per year. In the early years of the second decade, the number of crosses increased to 1,000 to 2,000 per year. In the mid-1970s, the vacuum emasculator was developed and two additional plant breeders were added to the IRRI staff. The number of crosses made per year increased to over 4,000.

A number of these crosses are made at the request of scientists collaborating with IRRI; they are sent F_2 seed. Many topcrosses and multiple crosses are made to combine traits from more than two parents. Subsequent generations are handled mostly by employing pedigree method of selection. The number of pedigree nursery rows grown has increased from 3,600 in 1964 to 120,000 in 1983.

The backcross method of breeding has also been used at IRRI in specific situations such as to transfer the gene imparting resistance to grassy stunt virus disease from *Oryza nivara* to *Oryza sativa* varieties.

Yield improvements in rice so far have been brought about primarily through improvement of plant type. Further gains in yield potential may be possible by increasing the physiological efficiency of varieties that have improved plant type. Physiological characteristics that bear on yield are related to 'source' (amount of carbohydrate produced) and 'sink' size (number and size of florets) and harvest index. The inheritance of these traits is not well understood and genes controlling them and other desirable plant characteristics are likely to have some undesirable linkage relationships. Breeding approaches that will help retain desirable genetic linkages but break or overcome the effects of the undesirable (repulsion phase) linkages and improve efficiency in discriminating between high and low yielding genotypes would lead to development of higher yielding rice varieties. During the past 5 years IRRI has adopted some nonconventional breeding methods and procedures, such as heterosis breeding, mutation breeding, tissue culture, and Rapid Generation Advance (RGA) aided by modified selection and evaluation procedures that accelerate the achievement of these goals.

Heterosis breeding

Heterosis breeding aims to exploit the phenomenon of hybrid vigor to increase yield potential and yield stability. During the 1970s, Chinese scientists successfully developed and used F_1 rice hybrids which now cover 7 million hectares in China. In farmers' fields these hybrids yield 15 to 20 percent more than the best available pureline varieties.

IRRI revived research on hybrid rice in 1979 as a means to increase varietal productivity in tropical rices. Results obtained to date indicate that the hybrid breeding approach can help raise the yield potential in rice varieties by as much as 1 t/ha over the yield of best tropical pureline rice varieties. The yield advantage is due to increase in dry matter or harvest index. Increase in dry matter results primarily from increased leaf area: the leaves tend to emerge from the main culm in hybrids faster than they do in their parents. Increased harvest index is due to higher spikelet number per unit area and higher 1,000-grain weight. Hybrids also show higher productivity per day and appear to be more efficient physiologically.

The genetic tools — cytoplasmic male sterile (CMS) lines, maintainer lines, and restorer lines — used in China to develop F_1 hybrids were tested at

IRRI, but were found to be unadapted to tropical conditions. IRRI has since developed some CMS lines that are better adapted than the Chinese lines under tropical conditions; however, their disease and insect resistance level is not yet adequate. CMS lines possessing high yield potential and good disease and insect resistance are in the pipeline. A large number of restorer lines have also been identified among the elite breeding lines. By crossing the elite CMS and restorer lines, rice hybrids for the tropics may be available before 1990.

Techniques developed in China to produce hybrid seeds have been found adaptable to the tropics. Depending on the weather and management, hybrid seed production plots can yield 0.6 to 1.6 t/ha. Since the seed production techniques are labor intensive and skill oriented, their adoption would depend on the availability and cost of labor, which under the Asian conditions may not be a serious constraint.

These developments at IRRI and in China have encouraged rice scientists of Indonesia, India, South Korea, and several other countries to initiate hybrid rice research in collaboration with IRRI.

Tissue culture

Tissue culture research in relation to rice varietal improvement work at IRRI was initiated in 1979. The focus has been on anther culture, somaclonal variation and selection of mutants at the cellular level for salinity tolerance and disease resistance, and embryo rescue.

Considerable advances have been made in plant regeneration through anther culture. Among 100 rice varieties screened for androgenetic ability, 35 produced callus and 22 regenerated into plants. The objectives of anther culture research at IRRI are to

- reduce the time needed to produce cold-tolerant rice varieties from sexual crosses of japonica × japonica, indica × indica, and indica × japonica;
- increase the protein and lysine content of rice by stressing rice calli with amino acid analogs and regenerating plants from surviving cells;
- derive high yielding lines from F_1 plants of sexual crosses and segregating materials; and
- examine gametoclonal variation for tolerance for adverse soils and environmental stresses.

Several doubled haploid lines have been produced that have a higher level of cold tolerance and superiority in other agronomic characteristics. They are being evaluated in South Korea.

In work on somaclonal variation, a salt-tolerant variant of Taichung 65 showed a much greater survival rate at high levels of salt concentration than the parent. Also some interesting variants with compact tiller arrangement have been isolated from the somaclones of Nona Bokra, a traditional salt-tolerant rice variety. Recently, IRRI initiated research on the use of phytotoxin of *Helminthosporium oryzae* to develop rice germplasm resistant to brown spot disease.

In attempts to transfer brown planthopper resistance from *Oryza australiensis* and *O. officinalis* to high yielding *O. sativa* varieties, breeders have produced several hybrids through the embryo rescue technique. Conventional techniques have not succeeded in producing F_1 hybrid seeds from crosses of these species.

Mutation breeding

Because there is ample variability in the rice germplasm, IRRI has made limited use of mutation breeding; however, it has been employed in two instances. First, to produce a genetic male sterile mutant for population improvement programs, a mutant was induced in the rice variety IR36 with ethyleneamine treatment. This mutant is a pollen-free type, stable, and monogenic recessive. Currently, it is being maintained in a population derived from IR36 that segregates in a ratio of 1 male sterile: 1 male fertile. Second, breeders have used the induced mutation method to improve tall traditional varieties that are well adapted to adverse soils and tidal wetlands. With ethyleneamine treatments, intermediate-statured mutants of Siyam Halus, a tall variety adapted to tidal wetlands, have been developed.

Breeders are now using this technique to reduce the height of well-adapted tall leafy upland varieties. Moderate reduction in height should improve harvest index and yield potential without sacrificing adaptability.

Population improvement

Combining a large number of desirable genes into a single genotype is hindered by linkage with undesirable genes, small population size, and the low number of parents included in conventional crosses. Population improvement is designed to overcome such obstacles. The male-sterile mutant of IR36, described above, has formed the basis of several random-mating populations composed for specific objectives. Recurrent selection is now being practiced in populations designed for such objectives as tolerance to drought, salinity, submergence; resistance to blast or stem borer; and high grain quality and yield.

Rapid Generation Advance

The Rapid Generation Advance (RGA) method is one way to advance hybrid populations to homozygosity without selection. It complements breeding programs where photoperiod sensitivity or cultivation in the temperate zones is the objective. The advantage of the method is that it is fast but requires no selection at IRRI. Such selection would be irrelevant, or even prejudicial, to the breeding objectives elsewhere.

Generally, two or three generations are completed in the greenhouse, after which the F_4 or F_5 generation is sent back to the breeder who originated the population and to others interested in that population.

The method was first tried at IRRI in 1976 and a greenhouse with a darkroom was later built as a permanent facility. By 1984, more than 1,000 populations had been processed through RGA on requests from breeders in many parts of the world. One-third were contributed by rice breeders for temperate zones and the rest by breeders of rainfed and deepwater rices.

The chief objective of the IRRI varietal improvement program is to help national program scientists develop improved varieties of rice for varied growing conditions. Toward this end, rice germplasm at various stages of development is supplied at the request of rice scientists all over the world.

IRRI freely shares germplasm at all stages of development with scientists anywhere in the world. In the early years, IRRI named varieties, but that was discontinued in 1975 because of IRRI's partnership in varietal development with national rice improvement programs. Evaluation of elite IRRI germplasm is the responsibility of the national programs, which can release any IRRI breeding line under any name by acknowledging its source.

Exchange of germplasm

Since 1962 the germplasm bank has provided more than 91,000 seed packets of rice accessions to researchers in more than 100 countries of the world. More than 179,000 seed packets of IRRI breeding lines have been supplied upon request from 87 countries since 1963. These include seeds of early generation segregating lines, fixed breeding lines, and named varieties. Breeders in developing countries frequently ask IRRI to make crosses with specific objectives for them. IRRI makes the crosses and sends them either F_1 or F_2 seeds. In addition, many breeders ask for F_2 seeds of IRRI crosses, which are supplied freely. Many visitors and trainees request the seeds of promising lines or early generation materials and take the samples with them.

Seeds of breeding materials are also exchanged through collaborative research projects. For example, a collaborative project aimed at determining the biotypes of brown planthopper involves the exchange of differential varieties and selected resistant entries between IRRI and several national rice improvement programs.

International Rice Testing Program

International nurseries provide an excellent mechanism for exchange and distribution of germplasm. The International Rice Blast Nursery was started in 1965, followed by the International Rice Yield Nursery (1972) and the International Rice Observational Nursery (1973). The nursery program was expanded and reorganized into the International Rice Testing Program (IRTP) in 1975. IRTP now assembles, distributes, and reports on 23 nurseries (Table 7), which are grown in over 60 countries. In 1983, 1,195 sets of these nurseries were sent to more than 700 collaborating scientists in 61 countries. More than 60,000 seed packets of IRRI breeding materials are distributed annually through these nurseries. The international nurseries also facilitate the exchange of germplasm from one national program to another. For example, a good line developed in India can be nominated to a specific nursery and distributed to other countries. In this way, Indonesian breeders have the opportunity to receive improved breeding materials from India and vice versa.

Some high yielding varieties developed by one national program and introduced in other countries through IRTP have been found promising and

Table 7. International Rice Testing Program nurseries for 1983.

Nurseries for		
Target environments		
Irrigated		
Yield	• IRYN-VE	International Rice Yield Nursery-Very Early
	IRYN-E	International Rice Yield Nursery-Early
	IRYN-M	International Rice Yield Nursery-Medium
Observational	• IRON	International Rice Observational Nursery
Rainfed upland		
Yield	• IURYN-E	International Upland Rice Yield Nursery-Early
	IURYN-M	International Upland Rice Yield Nursery-Medium
Observational	• IURON	International Upland Rice Observational Nursery
Rainfed lowland		
Yield	• IRRSWYN	International Rainfed Rice Shallow Water Yield Nursery (50 cm water depth)
Observational	• IRRSWON	International Rainfed Rice Shallow Water Observational Nursery
	• IRDWON	International Rice Deep Water Observational Nursery (50-100 cm water depth)
	• IFRON	International Floating Rice Observational Nursery (100 cm water depth)
	• ITPRON	International Tide-Prone Rice Observational Nursery
Specific stresses		
Temperature	• IRCTN	International Rice Cold Tolerance Nursery
Soil	IRSATON	International Rice Salinity and Alkalinity Tolerance Observational Nursery
	Acid Upland	Acid Upland Screening Set
	Acid Lowland	Acid Lowland Screening Set
Diseases	• IRBN	International Rice Blast Nursery
	IRBBN	International Rice Bacterial Blight Nursery
	IRTN	International Rice Tungro Nursery
Insects	• IRBPHN	International Rice Brown Planthopper Nursery
	IRWBPHN	International Rice Whitebacked Planthopper Nursery
	IRSBN	International Rice Stem Borer Nursery
	Rice Thrips	Rice Thrips Screening Set

recommended as commercial varieties. Thus BG90-2, developed in Sri Lanka, has been approved for general cultivation in Burma, India, Nepal, and Tanzania. Similarly, Jaya, developed in India, has been recommended in Ivory Coast, Mali, and Senegal.

Varieties with broad spectrum resistance to diseases and insects are identified through IRTP, and variation in the races of diseases and biotypes of insects can also be detected.

IRTP nurseries are also plant breeders' main source of introduced genetic materials for use in hybridizations. In a 1984 study of the diffusion of germplasm among Asian rice improvement programs, IRTP trials were found to be the source of 67 percent of all introduced cultivars used in hybridizations.

Shuttle breeding

Recently IRRI adopted the shuttle-breeding approach to collaboratively develop improved varieties for certain locations. Some of the pressures to which rice varieties may be exposed do not occur in the Philippines so segregating populations if grown at IRRI cannot be exposed to them. Shuttle breeding overcomes this difficulty. Crosses between high yielding disease-and insect-resistant IRRI varieties and breeding lines and locally adapted varieties are made at IRRI. The F_1 progenies are grown at IRRI and the F_2 populations are grown under appropriate environments in the collaborating country, exposing the populations to suitable selection pressures. By shuttling seed back and forth, subsequent generations are grown alternately at IRRI and the collaborating country. Evaluation and selection takes place in each generation. By the F_6 generation, selected progenies are advanced to yield trials in the collaborating country and are distributed for wide evaluation in the IRTP nurseries.

IRRI has a shuttle breeding project with China for developing early-maturing and cold-tolerant varieties with multiple disease and insect resistance and one with Thailand for developing improved varieties for rainfed lowland situations.

IRRI and Philippine rice improvement

The improved germplasm developed at IRRI is highly adapted to Philippine growing conditions. Varietal identification is made on the basis of multi-location trials conducted by the Philippine Seed Board. Uniform variety trials composed of entries developed by IRRI, University of the Philippines, and the Bureau of Plant Industry are tested at 12 cooperating institutions under irrigated, rainfed lowland, and upland conditions. Varietal recommendations are made on the basis of comparative performance during at least three seasons of testing. So far 27 IRRI breeding lines have been approved by the Philippine Seed Board and released as IR varieties: the first was IR8 and the most recent, IR62. Twenty-three were recommended for irrigated lowland conditions, two for rainfed lowland conditions, and two for upland conditions. The IR varieties are widely accepted by Filipino farmers. In 1984, about 80 percent of the rice area in the country was planted to IR varieties. IR36 and IR42 were the most widely planted varieties in 1984.

Training

The training program familiarizes rice breeders with the latest methodologies and techniques of crop improvement. It was initiated in 1962 and since then 547 individuals from 38 countries have participated. At present IRRI has four types of training programs related to varietal improvement.

In the nondegree training program, rice breeders come to IRRI for periods varying from 3 to 18 months and work with rice breeders in the ongoing breeding programs. They may participate in all the breeding operations or work in specialized activities such as germplasm conservation or grain quality evaluation. To date, 113 individuals have participated in the nondegree training program.

The GEU training program was initiated in 1975. Trainees are given formal lectures on techniques of crop improvement, they participate in all the field operations and laboratory work related to genetic evaluation and utilization (GEU) of rice germplasm and make crosses for their own programs. About 25 to 30 young rice scientists participate in this 4-1/2 month training course, generally held from February to June to coincide with a rice cropping season. To date, 360 trainees from 28 countries have participated.

The degree training program, which leads to MS or Ph D degrees, was initiated in cooperation with the University of the Philippines at Los Baños. Subsequently, agreements for cooperative training were made with several other universities in developing and developed countries. The students take their coursework at one of the collaborating universities and conduct their thesis research at IRRI under the supervision of an IRRI plant breeder. To date 32 students have studied for master's degrees and 19 for Ph D degrees at IRRI.

The postdoctoral and senior research fellowships program allows young Ph Ds and experienced rice breeders from the national rice improvement programs to spend 1 or 2 years at IRRI working on specific projects related to rice improvement and to participate in the ongoing rice breeding operations. To date, 23 rice breeders have worked as postdoctoral or senior research fellows in rice breeding.

Use of IRRI genetic materials in plant breeding

The adoption of IRRI varieties by plant breeders who use them as parents — genetic building blocks — in their hybridizations to develop a "second generation" of improved varieties better suited to local conditions is a more subtle type of diffusion than their spread onto farmers' fields, but equally significant.

In the early 1970s, new semidwarf varieties developed by national rice improvement programs began to replace IR8 and other early semidwarfs. Examples are RD 17, 19, and 25 released in Thailand; improved Sabarmati and Sabari in India; Tong-il and Milyang 30 in Korea; Pelita and Bogowanto in Indonesia.

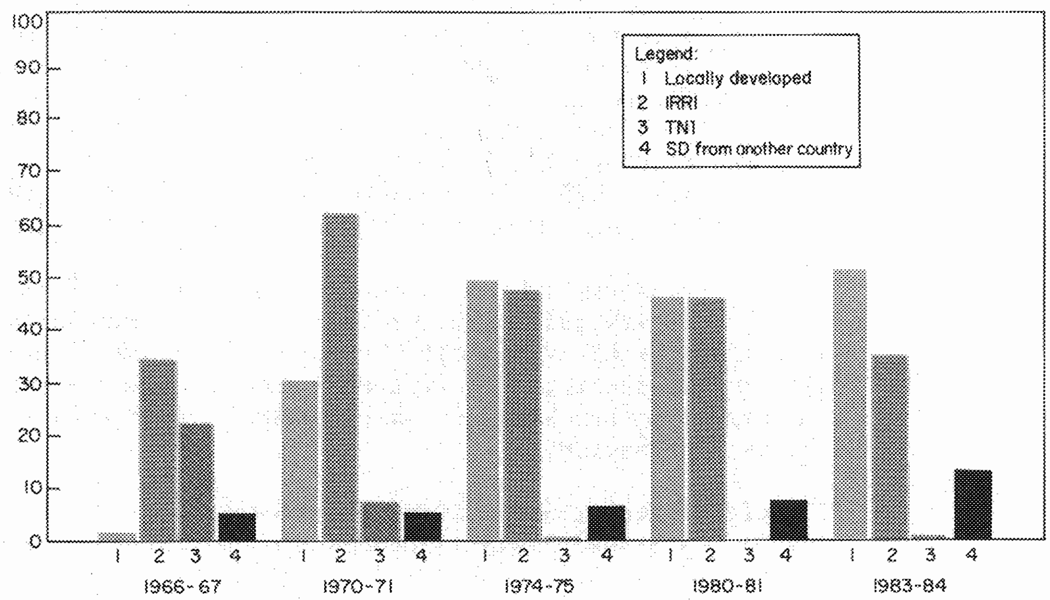
Studies by IRRI have documented the diffusion of improved rice varieties into crossbreeding programs between 1965 and 1984 at over 20 agricultural research centers in 10 Asian nations.

When IRRI demonstrated the value of short plant height, Asian plant breeders rapidly adopted the early semidwarf lines as parents to develop their own semidwarfs. In 1965-67, 61 percent of all crosses analyzed involved a semidwarf parent. By 1971, semidwarfs were used in over 80 percent of the crosses, a level that continued through 1984. Crosses involving a tall variety dropped from 74 percent in 1965 to 45 percent in 1975, then increased to 49 percent by 1984.

Breeders have increasingly crossed semidwarfs with other semidwarfs. In 1965, 28 percent of all parents in the total genetic pool were semidwarfs and 40 percent were tall. By 1975, the intensity of semidwarf use in crosses had increased to 58 percent and remained at about that level through 1984.

The direct use of IRRI varieties peaked in 1970 when 62 percent of the Asian crosses involved an IRRI parent (Fig. 4). Use of IRRI materials declined as the use of locally developed semidwarfs became more common. About half of the crosses made from 1975 to 1984 involved at least one local semidwarf.

In the mid-1960s, Taichung Native 1 was the most popular parent. It was



4. Sources of 1,308 rice cultivars used in 578 hybridizations from 1965 to 1984 at 14 research stations in 7 Asian nations.

used in 22 percent of the crosses at that time. But the adoption of IR8 as a parent was surprisingly rapid. IR8 was used in 20 percent of the 1965-67 crosses, although IRRI officially released IR8 only in 1966. Breeders apparently acquired seeds of the experimental line that became IR8 and started crossing it with local varieties even before it was widely available to farmers.

By 1970, IR8 and other IRRI varieties had largely replaced TN1 as a parent. By 1975, however, IR8, like its predecessor, had virtually disappeared from the Asian breeding scene. In 1984, IR50 was the most popular IRRI parent, used in 10 percent of the crosses; IR36 was used in 9 percent. The local semidwarfs most intensively used as parents in 1984 were OR59-6 and IET 1444 (Rasi) from India.

The pedigrees of all local semidwarfs used in the 1983-84 crosses have been traced back four generations. An IRRI variety or experimental line was a *direct* parent of 58 percent. But 45 percent were progeny of still earlier crosses involving a local semidwarf. Tracing the ancestry of those local semidwarfs back a second generation showed that 81 percent were progeny of IRRI varieties.

Achievements of IRRI's rice improvement program

IRRI's breeding program has been a pacesetter for other rice breeding programs, particularly those in the developing world. When IR8 was released by IRRI in 1966, most national programs started developing materials with similar plant type. When IRRI released disease- and insect-resistant varieties, national programs organized the host-resistance programs. There is hardly any rice breeding station in the developing world where one cannot find an IRRI-trained rice breeder. They employ IRRI-developed methodology and use IRRI-developed materials for testing or as parents in their hybridization programs.

Twenty-seven IR varieties are now planted on vast areas of Asia, Africa, and Latin America. In addition, national programs have released more than 100 varieties from the IRRI-bred lines. The IR varieties and the national varieties developed from IRRI-bred materials are now planted on over 30 million hectares. These varieties generate an additional income of $6.25 billion a year for the rice farmers. IR36 alone is planted on about 11 million hectares of rice land every year. No variety of any crop has been planted that widely before. An outside review team that evaluated the research and training programs of IRRI in 1982 said, "The impact of IR36 alone would more than justify the investment in IRRI since its establishment 21 years ago."

A recent survey of the 370 improved rice varieties released by national programs in 36 countries revealed that 74 percent were semidwarfs and a third of these were IRRI-bred lines. In the ancestry of almost 70 percent of 183 locally bred semidwarfs, an IRRI-bred line was the parent. This shows how heavily IRRI-bred materials are utilized either as direct introductions or in the breeding programs as parents all over the world.

In recent years, China developed hybrid rice varieties, which are now planted on 7 million hectares in that country. The restorer parents of almost 90 percent of these hybrids are IRRI-bred varieties or breeding lines. IR26 is the most important restorer used in China.

THE SPREAD OF MODERN VARIETIES: TWO EXAMPLES

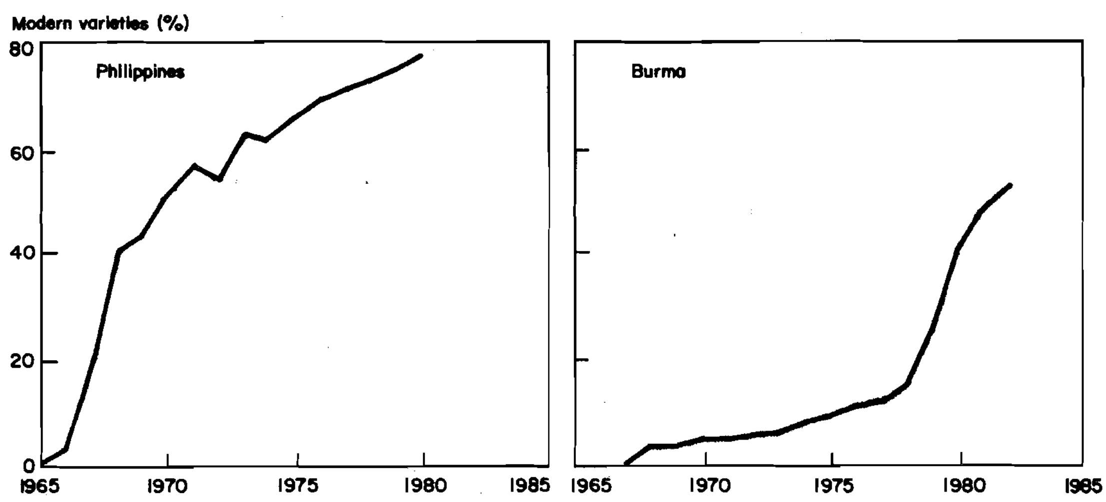
Modern rice varieties and the associated technology of modern farming methods have spread throughout South, Southeast, and East Asia. Since 1965-67, rice yields in the region have increased more rapidly than has population. Yield increases in Burma and Indonesia are especially notable as here the adoption of modern varieties, combined with rising fertilizer use and the extension of irrigation, led to yield increases at almost double the rate of population growth. In 17 years, yields in Burma rose by 94 percent, in Indonesia by 83 percent. Such truly remarkable results on a national scale and for a major food crop have few historic parallels.

Two of the significant changes brought about by the modern varieties were their relative resistance to lodging and their ability to use, profitably, heavier applications of nitrogen fertilizer. Without the modern varieties, there is little likelihood that the use of fertilizer would have increased even at the modest rate achieved. Experimental data suggest that yields of modern rice varieties can be maximized at input levels of close to 100 kg N/ha, yet in most countries the actual levels used by farmers are far below this. That suggests that yields have great potential for continued upward movement and that the potential of modern varieties is only beginning to be realized.

The Philippines and Burma present rather contrasting patterns of adoption of modern varieties. The Philippines, the home of IRRI, had access to IR8 even before it was named a variety. In 1966, IRRI had planted 13 hectares of IR8-288-3, a line that had performed exceptionally well in yield trials. Fifty tons of seed were made available to Philippine government agencies for multiplication and distribution to farmers. An additional 5 tons of seed was packed in 2-kilogram bags and made available to any farmer willing to travel to IRRI to get it. Within a few weeks, over 2,300 farmers representing 48 of the nation's 56 provinces responded.

The adoption process for modern varieties of rices in the Philippines and Burma is shown in Figure 5. The first year that seeds were available, they were widely distributed, but in limited volume. Not only did both the Philippine government program and the IRRI distribution result in seeds moving to all portions of the nation, but even within individual municipalities the seed was frequently used in central and highly visible locations to assure the widest possible audience for the demonstration plots (R. E. Huke and J. Duncan, 1969, unpublished IRRI seminar paper). The combination of broad exposure and a series of government policies, ranging from significant extension effort through programs designed for encouraging fertilizer use and the support of farm-gate price of rough rice, led to rapid early adoption. By the third year of seed availability, over 40 percent of Philippine riceland was planted to modern varieties. Of this, roughly 80 percent was in IR8 or IR5 while the remaining 20 percent was shared by varieties from the College of Agriculture and from the Bureau of Plant Industry. During the next 12 years, increases continued, but at a much slower rate. An "S" curve, steep in the early years and tapering in the later years, is clearly evident. Such a curve is typical of early adopters.

Burma shows a markedly different pattern of adoption (Fig. 5). A small



5. Proportion of rice land planted to modern varieties in the Philippines (Herdt and Capule 1983) and Burma (Agric. Corp. data).

quantity of IR8 seed was made available to Burma in 1966, but it was not made widely available to farmers. Rather it was limited to experimentation and testing on agricultural stations. In 1969 Burma introduced IR5 followed the next year by IR20.

Over the subsequent 8-year period, IR5, IR20, IR22, IR24, C4-63, and Ngwetow, an improved local variety, all found their way in limited volume to farmers' fields, but adoption was slow for several reasons: Burma already had a rice surplus, prices received at the farm gate did not encourage intensification of production, IRRI varieties were not readily accepted by consumers, and the semidwarf stature was not well suited to areas subject to water more than 30 centimeters deep. By the 1977-78 crop year, only 10 percent of Burma's rice area was planted to modern varieties, primarily IR5 and C4-63.

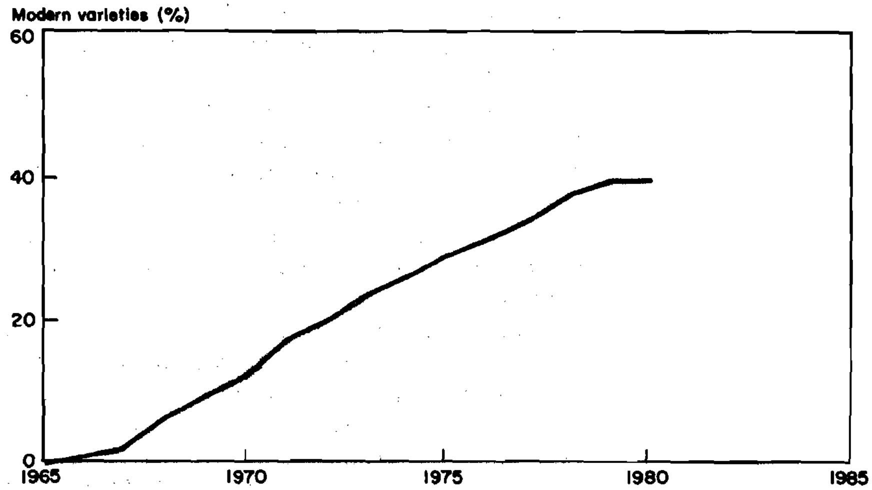
Then the government embarked on the *Whole Township Rice Production Program* as a way of increasing national rice production and hastening the adoption of modern varieties. By that time two intermediate-statured varieties with improved grain quality — Shwe-War-Tun, a mutant of IR5, and Seintalay — became available. In 1977-78 two townships were chosen as initial sites for the program. An intensive extension effort was made, seeds of the abovementioned varieties were provided, fertilizer was made available at subsidized prices, and all of this was accompanied by a government agreement to purchase the output at a guaranteed price. The impact of the policy change represented by the institution of this program has been impressive. By 1980-81, the area under modern varieties had quadrupled to slightly over 40 percent of the total rice land. By 1982-83, the program had expanded to include 84 townships of the nation's 586 townships and modern varieties covered 52 percent of the rice land.

But 84 townships are not sufficient to account for the 52 percent of Burma's rice area. Clearly the program had an influence well beyond the townships directly involved. Many farmers in settlements near demonstration sites obtained new seed, were able to acquire some fertilizer, and followed farming guidelines similar to those issued under the township program. Thus in 5 years of intensive effort, Burma had increased the area under modern varieties by five times and had increased the mean yield of rice by 50 percent.

Burma's curve of adoption is typical of a late adopter with a long slow increase to the takeoff point, followed by a steep rise and the beginning of a tapering off (Fig. 5). Without another major shift in government policy it appears that the Burmese curve of adoption will flatten at roughly the 70 percent level.

Modern varieties of rice have been available only since 1966. During the early years their impact, though often dramatic in individual countries, was hardly significant on a world scale (Fig. 6). By 1980 only 40 percent, or about one-half, of the potential conversion area had been realized and even in the converted area only about half of the potential increase in yield had been accomplished. From the mid-1960s to the early 1980s, area planted to rice had increased only slightly in the 11 nations and most of the increase in production had resulted from higher yields due to modern varieties and improved farming

6. Proportion of rice area planted to modern varieties in 11 nations (Indonesia, Philippines, India, Bangladesh, Pakistan, Sri Lanka, Nepal, Burma, Thailand, W. Malaysia, S. Korea) (Herdt and Capule 1983).



practices. As a consequence, in Asia's dozen leading rice producers, the ratio of population to net rice output has declined from 8.7 persons per ton in the early 1950s to 6.6 persons per ton currently. Until 1965, the decline was due chiefly to the expansion of area planted to rice. Since then the improvement has been a result chiefly of the impact of modern varieties.

CHAPTER 5

ADVANCES IN RICE PRODUCTION TECHNOLOGY

In the past 25 years, significant improvements in production technology have helped farmers take advantage of the high yield potential of modern rice varieties. Progress in technology for irrigated transplanted rice, which dominates Asian rice production, has been substantial and many advances have been made in broadcast-seeded flooded rice. Shallow rainfed rice culture has benefited by the applicability of many irrigated rice technologies. Other types of rainfed rice — deepwater and upland — have been less influenced by new production technologies.

UNDERSTANDING OF RICE ENVIRONMENTS

The chemistry of flooded soils

Although about 90 percent of the world's rice is grown on flooded soils, at IRRI's inception there was little integrated information on the chemical and electrochemical changes that take place when tropical soils are submerged. This gap was partially closed by work done at IRRI in the early 1960s. The scope of the initial study was then extended by including hundreds of soils from Asia, Africa, and Latin America. We now have a clear idea of the effects of flooding on chemical changes in soils.

The pH values of acid soils increase when flooded, whereas those of alkaline soils decrease. The convergence of pH values toward 7 increases the availability of nutrients and depresses the toxicity of aluminum, manganese, and iron.

When an aerobic soil is flooded, its redox potential decreases. This change increases the availability of most nutrients, but may cause toxicities of iron, hydrogen sulfide, and organic substances.

The main chemical changes caused by flooding include depletion of oxygen, accumulation of carbon dioxide and ammonia, denitrification, sulfate reduction, and increased availability of iron, manganese, phosphorus, and silicon. On balance, these changes benefit the rice plant.

The descriptive phase was followed by an interpretative phase, which consisted of applying physical chemistry to explain the chemical and electrochemical changes that take place in flooded soils. IRRI's pioneering research was a milestone in the study of the chemistry of rice soils and of submerged soils as a whole.

The nutrition of the rice plant

The new knowledge of the chemistry of flooded rice soils proved invaluable in understanding the behavior of the rice plant in its peculiar habitat and in curing nutritional disorders.

Soil pH and redox potential were shown to be important master variables controlling the availability of nutrients and the generation of toxins. Iron and aluminum toxicities were identified as growth-limiting factors in acid wetland soils, whereas in alkaline soils the problems were zinc and iron deficiencies. In cold soils, the adverse factors were low nutrient availability and toxicities of organic acids and carbon dioxide. Zinc deficiency was diagnosed as a widespread nutritional disorder of rice on alkaline, poorly drained, and peat soils. Sulfur deficiency was identified on sandy soils low in organic matter. The main chemical growth-limiting factors in upland rice soils were identified as aluminum and manganese toxicities in acid soils and iron deficiency in neutral and alkaline soils. Soil and plant tests were developed to identify nutrient deficiencies and soil toxicities.

Improving the productivity of rice lands

About 100 million hectares in South and Southeast Asia that are climatically and physiographically suited to rice culture lie idle or are cultivated with poor results largely because of adverse soil conditions. The problems have been identified as salinity, alkalinity, acid sulfate conditions, iron toxicity, and excess organic matter. The affected areas have been roughly delineated, and amendments worked out. In addition, about 100 million hectares that are in rice suffer from the same problems or deficiencies of nitrogen, phosphorus, or zinc. On soils that are marginally nutrient deficient or marginally toxic, use of varietal tolerance to adverse soils has been shown to be a substitute for soil amendments. In adverse soils, varieties that have tolerance to a soil stress yield 2 t/ha more than varieties lacking the trait (Table 1). The wide range of soil-stress tolerance possessed by IR36 and IR42 (Table 2) is one reason for their popularity among small farmers.

Another important finding for small farmers throughout Asia stemmed from the discovery of widespread zinc deficiency in the Philippines. Nationwide tests revealed that applying a small quantity of zinc would give a response of 0.7 t/ha with a benefit/cost ratio of 32 to 1. Zinc fertilizers are now

Table 1. Yield advantage due to soil stress tolerance in modern rices as shown by tests in farmers' fields in the Philippines, 1977-81.

Stress	Total number			Mean yield (t/ha)		
	Tests	Sites	Rices	Susceptible	Tolerant	Advantage
Salinity	23	14	63	1.5	3.6	2.1
Alkalinity	3	2	47	0.9	3.6	2.1
Iron toxicity	12	4	55	2.2	4.8	2.6
Peatiness	13	5	39	1.4	3.1	1.7
Al/Mn toxicity	3	1	32	2.0	3.8	1.8
P deficiency	13	2	110	1.9	4.4	2.5
Zn deficiency	25	10	91	0.8	2.9	2.1

Table 2. Reactions of four IR varieties to adverse soil conditions on the scale 1-9.[a]

	Wetland soils							Dryland soils	
	Toxicities					Deficiencies		Fe deficiency	Al or Mn toxicity
	Salt	Alkali	Peat	Fe	B	P	Zn		
IR8	3	6	5	7	4	4	4	4	4
IR26	5	6	6	6	4	1	5	4	3
IR36	3	3	3	3	3	7	2	2	4
IR42	3	4	3	3	4	3	4	5	5

[a]1 = almost normal plant, 9 = almost dead or dead plant.

recommended for all neutral and alkaline irrigated rice soils. Zinc deficiency is perhaps the most important nutritional factor limiting rice yields on peat soils.

BIOLOGICAL NITROGEN FIXATION

In many rice growing areas in the Third World, farmers use little commercial nitrogen fertilizer because it is too expensive. Low-cost sources of nitrogen are urgently required to allow farmers to more fully benefit from the fertilizer responsiveness bred into modern rice varieties.

Biological nitrogen fixation is the chief natural means by which nitrogen removed by crops is replenished in soil. It is especially active in submerged soils, which explains why a lowland rice field can produce higher and more stable rice yields year after year than an upland field, without application of nitrogen fertilizer. Long-term fertility experiments have shown that nitrogen-fixing bacteria and blue-green algae fix as much as 40 to 50 kg N/ha in fields that receive no nitrogen fertilizer.

Recent research on biological nitrogen fixation has helped explain the role of nitrogen-fixing microorganisms in rice soils and has shown that free-living heterotrophic bacteria, free-living blue-green algae, and *Anabaena azollae* associated with azolla have promise as sources of nitrogen for rice production.

The objectives of the biological nitrogen fixation program are

- to identify nitrogen-fixing organisms in rice soils and to determine the quantity of nitrogen they fix and the factors that influence their activity,
- to develop methods and cultural practices to enhance biological nitrogen fixation in rice fields,
- to collect and maintain major nitrogen-fixing organisms that are active in rice fields,
- to establish a cooperative research network on biological nitrogen fixation in rice fields, and
- to train scientists who will strengthen national capabilities for research on biological nitrogen fixation.

Heterotrophic nitrogen fixation

Early studies of the total nitrogen balance in flooded soils after several rice crops showed that lowland rice stimulated agronomically significant increases in soil nitrogen content. Experiments with tagged nitrogen (^{15}N) confirmed that heterotrophic nitrogen fixation takes place in the soil near the root, on and in the root, and on the basal portion of the shoot; and that the rice plant utilizes part of the fixed nitrogen.

Considerable microbiological work has been done with immunological techniques, as well as with conventional methods, to identify the major bacteria responsible for associative nitrogen fixation in the rice root zone. The most abundant nitrogen-fixing bacteria associated with the rice plant have been found to grow autotrophically while utilizing hydrogen gas. Because hydrogen gas is evolved from rice soils, nitrogen fixation associated with rice may be stimulated by this process.

Rice varieties differ in their capacities to stimulate nitrogen gain. For example, over three rice crops, the nitrogen increase in potted soils was 858 mg/pot for Raminad #3, 776 mg for Oking Seroni, 240 mg for Cigalon, and 188 mg for Pokkali. These values correspond to 57, 52, 16, and 12 kg N/ha for one rice crop. Varieties high in biomass production tend to be better stimulators of nitrogen fixation. IR42 ranks among the best.

These results indicate that screening and breeding rice varieties that encourage nitrogen fixation is possible. However, measurement of nitrogen balance by Kjeldahl analysis requires too much time and labor to be suitable for large-scale screening. Use of improved acetylene reduction assay or ^{15}N dilution techniques allow researchers to detect significant differences in the abilities of varieties to stimulate nitrogen fixation, with and without straw amendment. In addition nitrogen fixation associated with the rice plant is significantly correlated with tiller number, total dry weight, shoot weight, root weight, and nitrogen uptake of the plant. For large-scale varietal screening, plant acetylene reduction activity at the heading stage with characterization of phenotypic traits may be the most useful parameters to measure.

Free-living blue-green algae

An extensive review of the literature has shown adequate evidence to establish that blue-green algae (BGA) can be utilized as an alternative or supplementary source of nitrogen for rice. However, their practical utilization is limited by a lack of knowledge of the factors permitting the establishment of blooms of inoculated or indigenous strains.

Ecology in rice fields. A set of standardized methods for field studies of BGA has been developed. It comprises methods for sampling, evaluating BGA populations, and estimating nitrogen-fixing activity (acetylene-reducing activity). A large-scale survey of the occurrence of BGA in soils, started in 1982, has revealed nitrogen-fixing strains in all the rice soils tested in the Philippines, a presence that is greater than expected. An extensive study of epiphytic BGA (BGA that grow attached to the rice plant) showed that they contribute significantly to the nitrogen nutrition of deepwater rice. Although surface application of mineral nitrogen inhibits nitrogen fixation by BGA, deep placement does not disturb the natural algal nitrogen-fixing system and it decreases the losses of nitrogen by volatilization.

Availability of BGA nitrogen. Estimates of nitrogen contained in BGA blooms in submerged soils range from 10 to 20 kg N/ha. Studies with ^{15}N

have shown that, depending on the strain of BGA and the mode of application, 15 to 36 percent of applied algal nitrogen is available to the two crops following application.

A major limiting factor under environmental conditions in the Philippines are grazer populations, e.g. microcrustaceans, snails, chironomid larvae — that feed on BGA. Control of grazer populations with conventional insecticides or inexpensive insecticides of plant origin has been successful in increasing growth of BGA, their nitrogen fixation, and the nitrogen content of the rice grain. Control of grazers by cultural practices (wetting/drying) is also promising.

Azolla

Azolla is a water fern associated with the nitrogen-fixing, endosymbiotic blue-green alga *Anabaena azollae*. Azolla has long been grown in subtropical China and Vietnam as a green manure for rice. In the tropics, azolla has not been used by rice farmers though it is widespread. IRRI is attempting to identify strains best adapted to the tropics and to establish economic procedures for their use as a nitrogen source for rice.

IRRI maintains 132 strains of azolla representing six genera and acts as a germplasm center for azolla conservation and distribution. In 1983-84 more than 250 samples ranging from a few grams to half a kilogram were given to laboratories or individuals from 15 countries. *A. filiculoides, A. microphylla,* and *A. caroliniana* from IRRI's collections are now used in Vietnam and China.

Azolla physiology. Physiological studies at IRRI have shown that the productivity and average nitrogen-fixing rates of azolla decrease at temperatures above 22° C. This explains why azolla is more productive during the cooler weather of the wet season than during the sunny and hotter weather of the dry season. The most promising strains for heat tolerance are *A. pinnata* var. *pinnata* #701, which gave consistently high yields, and *A. microphylla* #418, which performed well during both the wet and dry seasons.

A bioassay to test the ability of a soil to support azolla growth without phosphorus application has been developed. Tests with 26 soils showed that an available phosphorus (Olsen P) content greater than 25 ppm permits good azolla growth — a doubling time of 3 days or less.

The contribution of nitrogen fixation to the nitrogen nutrition of azolla was assessed by ^{15}N dilution technique using *Lemna* as the non-nitrogen fixing control. The results showed that about 80 percent of nitrogen in azolla comes from biological nitrogen fixation.

Azolla as a source of nitrogen. A study with ^{15}N-labeled azolla plants demonstrated that about 30 percent of azolla nitrogen was absorbed by the first rice crop. A comparison of azolla and chemical fertilizer for six successive rice crops has shown that incorporation of one azolla crop before transplanting and three to four successive crops of azolla grown together with rice after transplanting is equivalent to the application of 60 kg N/ha for a wet season rice crop and 100 kg N/ha for a dry season rice crop.

Collaborative trials. Tests of azolla by the International Network on Soil

Fertility and Fertilizer Efficiency for Rice started in 1979. There are now trials at 35 sites in 10 countries. New procedures were introduced in 1983 to compare azolla with chemical nitrogen fertilizer, and to gather data from azolla applied before transplanting and azolla grown together with rice. The results show that incorporation of one crop of azolla is equivalent to the application of 30 kg N/ha as urea, while incorporation of two crops, one before and one after transplanting, has the same effect as 60 kg N/ha of urea.

Possible adoption

Research at IRRI has shown that biological nitrogen fixation has potential in low-input rice farming as an alternative source of nitrogen as well as in high-input farming as an additional source of nitrogen in integrated fertilizer management. Among the technologies studied, the use of azolla is ready for adoption by farmers whose fields have good water control. The use of free-living BGA is at the stage of large-scale field testing, while heterotrophic biological nitrogen fixation associated with rice is still at the experimental level.

ORGANIC MATTER AND RICE SOILS

The recycling of organic residues can significantly increase nutrient use efficiency in all rice cultures and reduce the need for chemical fertilizer. Organic amendments of rice soils can serve as substitute for, or supplement to, inorganic fertilizer.

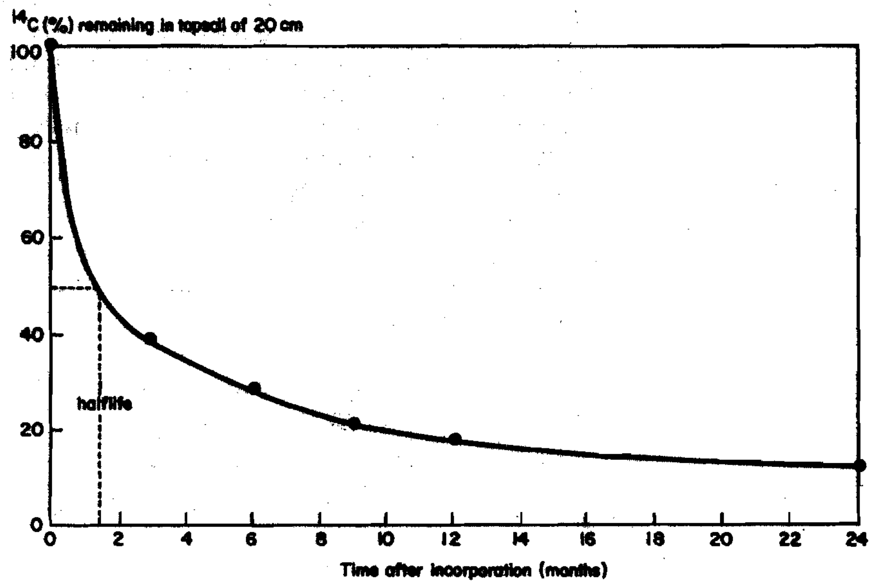
Decomposition of rice straw in wetland rice soils

It is generally believed that the decomposition of organic materials is retarded in flooded anaerobic soils because of lack of oxygen. But field experiments with ^{14}C-labelled mature rice straw in a soil with a pH of 6 revealed that in the tropics the decomposition pattern in permanently flooded rice soils is comparable to that in upland soils. After only 43 days, half of the incorporated carbon is mineralized and lost, mainly as carbon dioxide and methane; after 1 year, about 20 percent is left; and after 2 years, only 10 percent remains (Fig. 1). The fastest degradation of rice straw takes place in the puddled layer. Deeper incorporation slows decomposition — by about 20 percent for each 5 cm of soil depth.

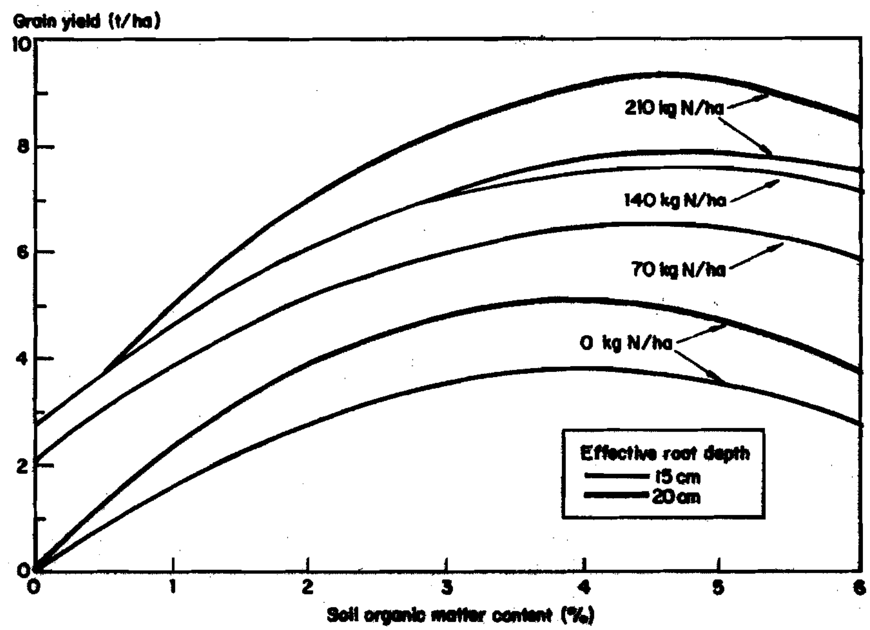
The established decomposition pattern in lowland soils suggests that incorporation of rice straw can play a prominent role in replenishing nutrients for plant growth and in the cycling of nutrient elements on a seasonal basis. To gain the benefits of straw amendments without making puddling and harrowing more laborious, the rice straw should be chopped and then incorporated shallowly.

Optimal organic matter for rice growth in wetland soils

Fifteen years of data from trials with nitrogen fertilizer rates ranging from 0 to 210 kg N/ha at six sites in the Philippines have established a significant relationship between grain yield of modern rice varieties, fertilizer rate, and



1. Decomposition of ^{14}C-labelled rice straw in top 20 cm of a continuously submerged Andaqueptic Haplaquoll, IRRI farm, Los Baños, Philippines.



2. Relationship between soil organic matter content, N-fertilizer rate, and grain yield of rice in puddled and submerged soil.

soil organic matter content. That is, data on the effective rooting depth (for rice mostly 15 cm), soil organic matter content, and nitrogen-fertilizer rate are sufficient to predict maximum grain yield of rice (Fig. 2). The model identifies an optimum soil organic matter content for rice, which for wetland soils is about 4 percent.

The reason for the existence of an optimum soil organic matter content is that, although in wetland rice soils the carbon-nitrogen ratio remains fairly constant, increases in soil organic matter cause a decrease in soil bulk density. The effect of this relationship is that the uptake of nitrogen reaches a maximum and then levels off as soil organic matter increases.

When nitrogen fertilizer is applied, the optimum organic matter content is higher than without fertilizer nitrogen because there is an interaction between fertilizer nitrogen and soil nitrogen that increases uptake of soil nitrogen. Nevertheless, even with high rates of nitrogen fertilizer, the optimum soil organic matter is about 5 percent. Further increases in soil organic matter do not seem to produce higher yields.

SOIL FERTILITY AND FERTILIZER MANAGEMENT

The broad aim of IRRI's soil fertility and fertilizer management research is to generate knowledge and technology related to efficient nutrient use. The focus, however, has been developing technology for maximizing nitrogen use efficiency in lowland rice.

Historically, the most significant finding was the identification, in 1966, of the high yield potential and fertilizer responsiveness of IR8-288-3, subsequently named IR8, the first modern rice variety. Noteworthy also was the identification of a genetic source of high protein, IR480-5-9, which has been used for many crosses.

Efficient soil nitrogen utilization

Varieties differ in ability to utilize soil and fertilizer nitrogen, and by exploiting those differences, new practices can be developed that will increase fertilizer use efficiency in lowland rice. Eight years of experiments at four experiment stations in the Philippines have clearly demonstrated varietal differences. The results show that IR42 is a more efficient utilizer of soil and fertilizer nitrogen than IR36, the most widely grown variety in the world (Fig. 3). IR8, which is susceptible to insects and diseases, performed poorly at all nitrogen levels.

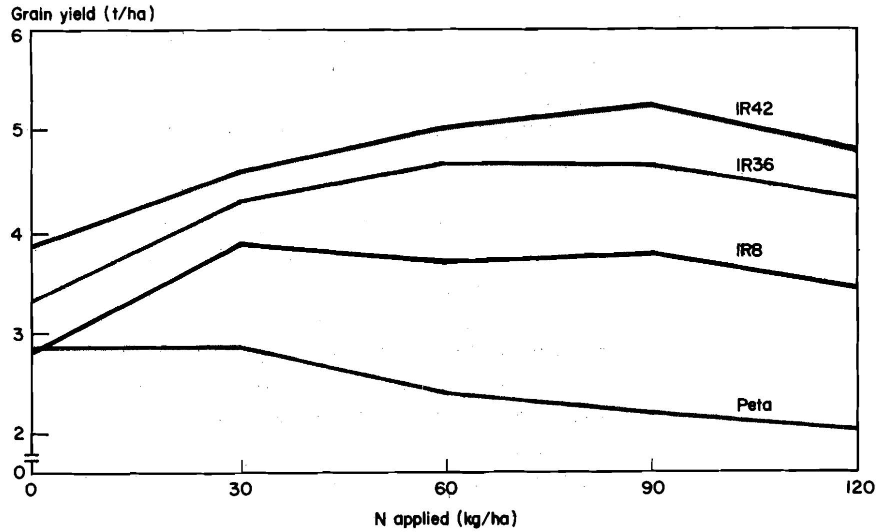
Other studies (with ^{15}N-depleted ammonium sulfate, IRRI-University of California Cooperative Project) suggest that some varieties depend primarily on soil nitrogen and others use fertilizer nitrogen more efficiently. Those differences are clearer in the dry season than in the wet season (Fig. 4). In order to detect significant differences among varieties in their ability to utilize soil and fertilizer nitrogen, the following criteria must be met:

- plant behavior with respect to fertilizer utilization efficiency must be consistent in repeated experiments, and
- plant characteristics associated with nitrogen utilization efficiency must be identified.

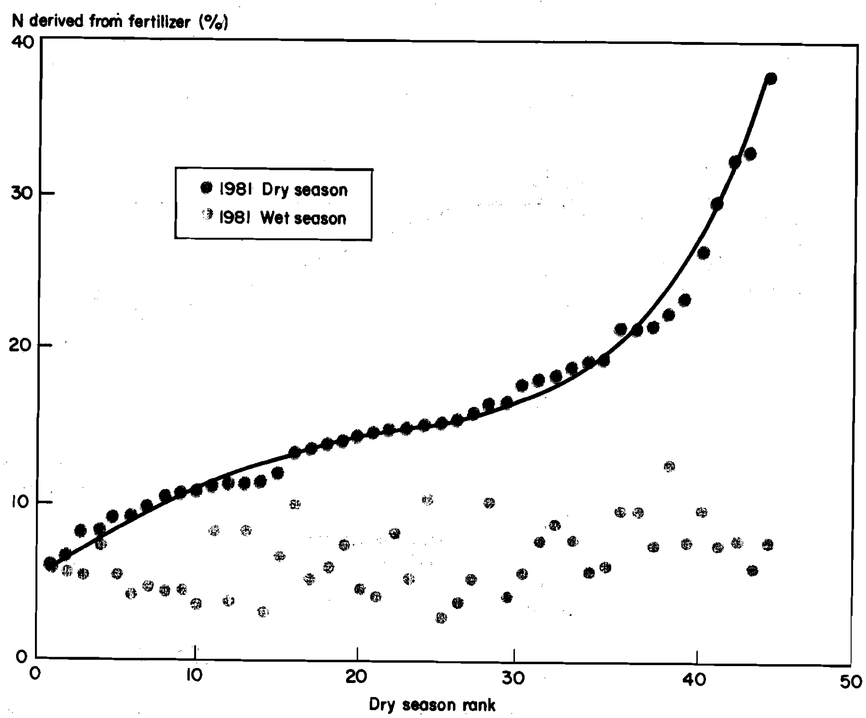
Basic studies on nitrogen transformation

Research on nitrogen losses is conducted to develop management practices that maximize the utilization of fertilizer nitrogen in various soil, climate, and water regimes.

3. Grain yield response of four rices to different levels of nitrogen. Data are averages for IRRI and three experiment stations of the Philippine Bureau of Plant Industry, 1976-83 wet seasons.



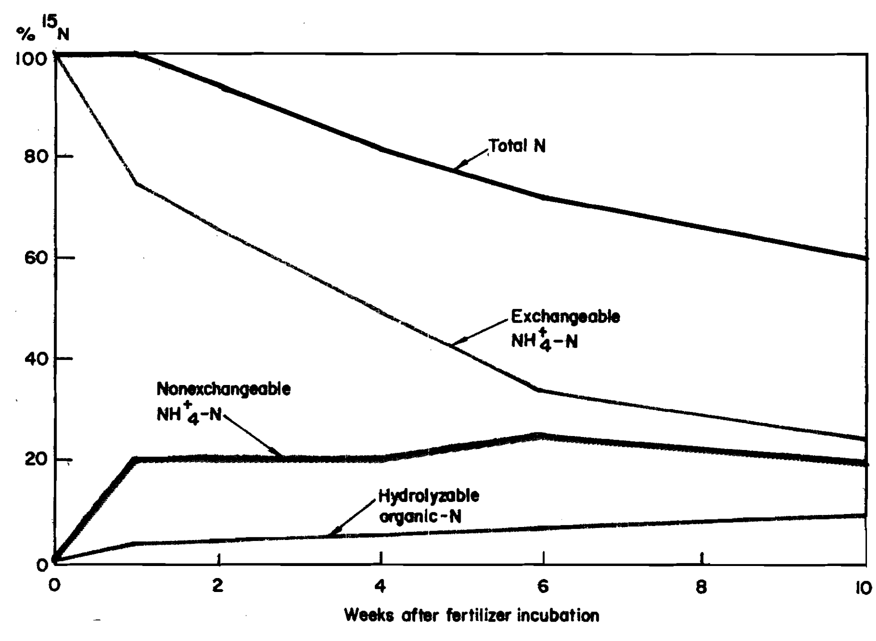
4. Percentage of nitrogen derived from fertilizer in 1981 dry and wet seasons with varieties or lines sorted according to dry season rank.



Basic studies on the ammonium dynamics of lowland rice soils have been made using ^{15}N tracer technique (IRRI-Justus Liebig University Cooperative Project). In a laboratory experiment, the total amount of ^{15}N recovery from Maligaya silty clay loam (Entic Pellusterts) from Central Luzon was 60 percent (Fig. 5). In that soil, nitrogen fixed by the nonexchangeable (clay-fixed) fraction exceeded that of the organic nitrogen fraction because the vermicullite in the soil fixes considerable amounts of ammonium ions in wet conditions. The initial fixation of ammonium nitrogen and subsequent release of nitrogen during crop growth help supply nitrogen steadily for high rice yields in lowland soils.

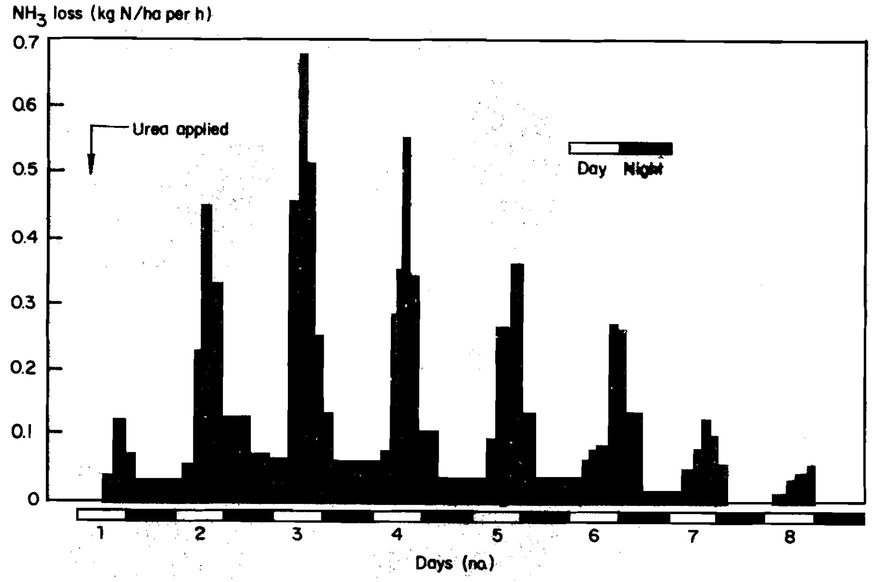
The agronomic significance of the high pH that develops in rice floodwater has largely been neglected as a factor in the direct volatilization loss of ammonia. In a study during the 1983 wet season, when prilled urea was broadcast on bare soil (which was subsequently flooded) and into various depths of floodwater (2.5, 5, and 10 cm) and incorporated lightly, more than half of the applied nitrogen was recovered in the floodwater irrespective of the water depth. But the smallest amount of total nitrogen (urea + ammonium nitrogen) was recovered in the floodwater where urea was broadcast onto mud and then incorporated into soil. (The measurements were made daily for 7 days after the fertilizer application.) The results demonstrate that broadcasting and incorporating nitrogen fertilizers prior to transplanting when there is standing water in the field leads to high nitrogen losses and lowers nitrogen use efficiency, which is costly for farmers.

Loss of ammonia through volatilization ranges up to 60 percent of applied nitrogen. Recently, micrometeorological techniques were used to measure



5. Recovery of ^{15}N-fertilizer from three soil nitrogen fractions and in total nitrogen at various sampling times in Maligaya silty clay loam. Laboratory experiment.

6. Ammonia fluxes in urea-amended field in Maligaya silty clay loam (Entic Pellusterts) at the Maligaya Rice Research and Training Center, Philippines.



ammonia loss directly in the field at IRRI and at the Maligaya Rice Research and Training Center (IRRI-IFDC-CSIRO Cooperative Project). The ammonia fluxes from urea-amended floodwater peaked on the third day after urea application (Fig. 6). The total measured ammonia loss was 36 percent of the nitrogen applied. The magnitude of losses is influenced by the ammonium concentration in floodwater; the biochemical activity of the aquatic biota and their effects on pH of the floodwater; nitrogen sources; and time and method of application. These studies underscore the need to thoroughly incorporate ammonium-form fertilizers into the soil to minimize ammonia losses.

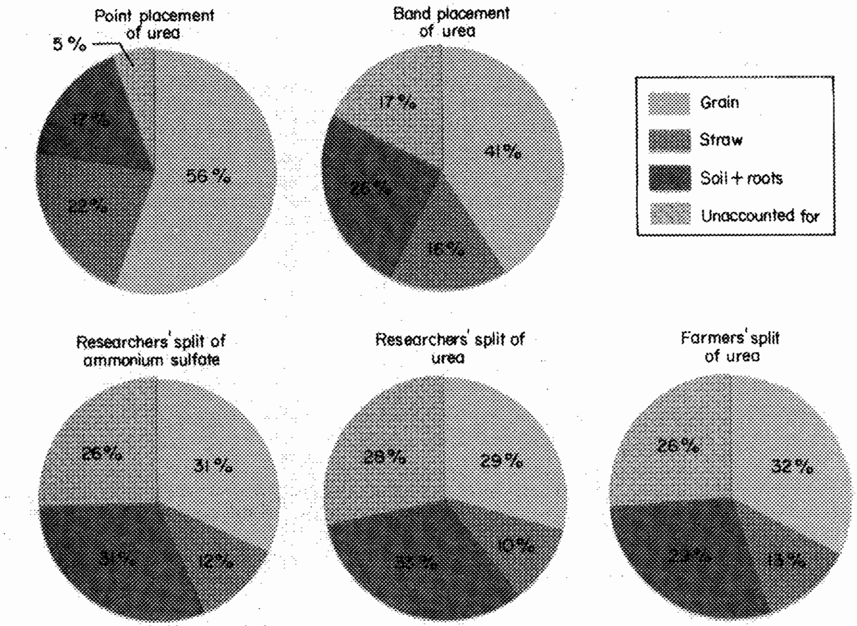
^{15}N-balance studies were conducted during the 1984 dry season in Nueva Ecija, Philippines, on a Vertisol using water depths and nitrogen management practices as variables. A simple technique to measure ammonia volatilization loss was used to evaluate the effect of water depth on floodwater chemistry and nitrogen loss from lowland rice. Applying nitrogen fertilizer into water 5 centimeters or more deep led to higher ammonia loss and significantly lower grain yield than applying fertilizer without standing water.

^{15}N-balance studies on a calcareous soil suggest that deep point placement of nitrogen fertilizer results in minimum nitrogen loss and maximum nitrogen use efficiency (Fig. 7).

Fertilizer nitrogen management for efficient use

Low soil fertility, particularly nitrogen deficiency, is an important constraint in rice-growing countries in South and Southeast Asia. For several years, IRRI has investigated a number of concepts that could increase nitrogen use efficiency in lowland rice:

- varietal differences in nitrogen utilization efficiency
- improved timing of nitrogen application



7. Balance of [15]N-labelled fertilizer at harvest with various methods of application. Pangasinan, Philippines, 1983 dry season.

- deep placement of nitrogen fertilizer
- controlled-release nitrogen fertilizers
- use of nitrification and urease inhibitors

The primary purpose of improved nitrogen management practices should be to maximize nitrogen uptake at critical growth stages. It is also important to ensure that nitrogen absorbed by the plant is utilized for grain production (referred to as "efficiency of absorption"). Varietal differences in nitrogen utilization efficiency have been evaluated for a number of years and the results suggest that the quantity of nitrogen used by the rice plant is related to growth duration. Another consideration is the consistency of performance of a rice variety or line from one season to another. Results obtained thus far suggest that the varietal selection for nitrogen utilization efficiency has some promise.

The common farmers' practice of making basal fertilizer applications in standing water leads to high nitrogen losses. In IRRI studies, application and incorporation of basal fertilizer in the mud without standing water resulted in only 13 percent of the applied fertilizer nitrogen being detected in the subsequently applied floodwater, but when fertilizer was applied in standing water 59 percent of the fertilizer nitrogen was found in the floodwater. Similarly, yields from application of nitrogen fertilizer without standing water were significantly higher — by 0.9 t/ha in the dry season and 0.5 t/ha in the wet season — than yields from fertilizer application in standing water (Table 3). The benefits of this technology can easily be reflected in farmers' fields without changing nitrogen application rates. New practices stemming from these findings are now part of the 16-step recommendations of the Masagana-99 Program of the Philippines.

An increasing amount of research is being done on deep placement of fertilizers by machine both at the IRRI farm and in farmers' fields. The effect of deep placement of urea by machines on rice yield was compared with that of deep point-placement of urea supergranules by hand in 1984 dry season trials in Maligaya silty clay loam. The yields with point placement by deep plunger were comparable to yields with point placement by hand. Similar promising results were obtained with band placement with a spring auger or point placement with a press wedge in the Maligaya soil. In Maahas clay, no machine produced yields comparable to those achieved with point placement by hand.

Sulfur-coated urea (SCU) is a controlled release fertilizer that has been widely tested on rice. SCU appears to be efficient in increasing grain yield in various soils and environments. In most trials, application of SCU gave yields comparable to those from deep point-placed urea supergranules.

The potential of nitrification and urease inhibitors has been evaluated over the past 3 years. Dicyandiamide, a nitrification inhibitor, was not found to increase grain yield. Field trials at IRRI with phenylphosphorodiamidate (PPO) showed that it retarded urea hydrolysis and delayed the appearance of aqueous ammonia in the floodwater. It did not, however, increase grain yield or total nitrogen uptake when compared with the control without urease inhibitors.

Soil fertility and fertilizer network

The organization of the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) was prompted by the global oil crisis in 1973-74, which led to a dramatic increase in fertilizer prices. INSFFER is a collaborative undertaking of national programs, IRRI, and the International Fertilizer Development Center. In 1983, there were 17 national programs

Table 3. Effects of water depth, application method, and urea source on the grain yield of IR58. IRRI, 1984.

Urea[a] source	Application method[b]	Water depth during basal fertilizer application (cm)	Grain yield[c] (t/ha) Dry season[d]	Grain yield[c] (t/ha) Wet season[e]
SCU	All basal, broadcast and incorporated	0	6.6 a	4.6 a
USG	All basal, hand point-placement	5	6.6 a 6.4 a	4.5 a 4.4 ab
PU	Researchers' split	0		
PU	Researchers' split	5	5.5 b	3.9 bcd
PU	Farmers' split	0	5.4 b	4.1 abc
PU	Farmers' split	5	5.2 b	3.8 cd
PU	Farmers' split	10	4.7 b	3.4 d
PU	Farmers' split	15	5.1 b	3.4 d
—	No fertilizer nitrogen	—	2.9 c	2.7 e

[a]SCU = ordinary sulfur-coated urea, PU = prilled urea, USG = urea supergranules. [b]Researchers' split = two-thirds broadcast and incorporated before transplanting and rest topdressed in 5 cm standing water 5-7 days before panicle initiation. Farmers' split = half topdressed 10 days after transplanting and half 10 days after panicle initiation. [c]Average of 4 replications. In a column, means followed by a common letter are not significantly different at the 5% level by DMRT. [d]87 kg N/ha applied. [e]58 kg N/ha applied.

participating with 59 collaborators and 99 sites.The objectives are to find ways to increase fertilizer use efficiency and to improve and maintain soil fertility through collaborative research trials, training, and site visits.

Initially, INSFFER focused on fertilizer, but in 1979 its scope was expanded to include biological nitrogen fixation and use of alternative materials such as biofertilizers. Currently, there are 12 collaborative trials being undertaken, including three trials on upland rice, which were started in 1984. Every year, results from collaborators are compiled and analyzed statistically, economic analyses are made, and a report for each trial is prepared with brief interpretive discussions. These reports are distributed to collaborators and others.

One trial, the acid lowland rice nursery, is a joint activity of INSFFER and the International Rice Testing Program. A trial on the management of acid upland soils for rice will be a joint activity of INSFFER and Asian Rice Farming Systems Network.

Some important findings from the INSFFER trials:

- At about half the wetland rice sites, deep placement of urea and sulfur-coated urea was more effective than split application of prilled urea. Identification of site parameters responsible for the similarity in the effectiveness between the deep placement, slow release, and split broadcast application still needs to be done.
- Rock phosphate was as effective as superphosphate fertilizer for irrigated wetland rice especially during the wet season.
- Azolla could provide a rice crop the equivalent of 30 kg N/ha from urea.
- Nitrogen response was observed in all long-term fertility trials during the first crop and phosphorus response occurred after a few years. Potassium, however, remained adequate in most of the sites even after several cropping seasons.

Based on INSFFER results, on-farm testing of deep placement with urea supergranules is being carried out in Indonesia, Philippines, India, and Bangladesh. In Karnataka, India, the use of supergranules is planned for 300,000 hectares of wetland rice in 1985. Several countries have made plans to produce granular urea for rice.

Cooperative nitrogen research

Alternative fertilizer management practices such as deep placement and optimum timing are evaluated in farmers' fields in a cooperative program under way in Thailand, Indonesia, Bangladesh, and the Philippines. Through farm-level testing of technology developed at IRRI and through the INSFFER, research results are fine tuned for rapid adoption in national programs.

Integrated nutrient management

Integrated nutrient management combines organic sources, such as azolla, rice straw, and straw compost, with inorganic fertilizers to maintain soil fertility and productivity. Studies of the long-term effects of integrated nutrient management on soil fertility and yields in intensive cropping are under way. Basic transformation processes are being examined: applied management research on phosphorus, zinc, and sulfur is being carried out to integrate balanced nutrition in rice and rice-based cropping systems.

Soil physics

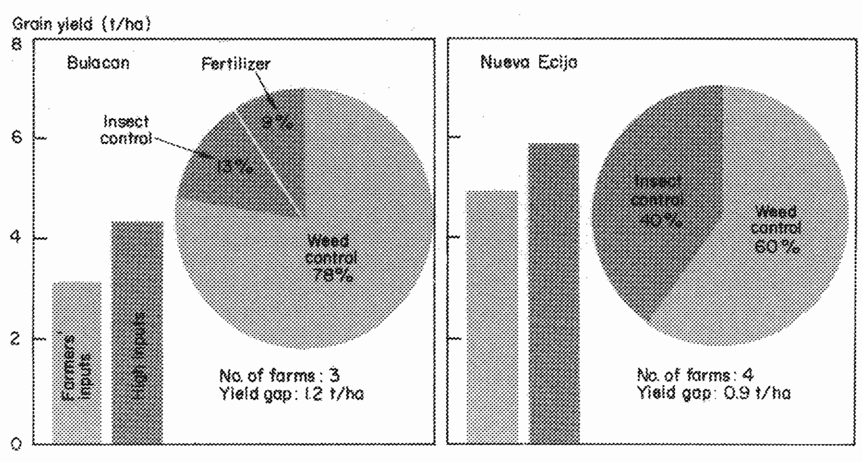
Soil physics research addresses the effects of puddling on rice soils. In a field experiment, puddling was found to decrease bulk density, soil strength, saturated hydraulic conductivity, percolation rate, maximum and minimum soil temperature to a depth of 15 centimeters, oxidation reduction potential, and losses of nitrogen, phosphorus, potassium, and zinc through leaching. Puddling significantly increased grain yield.

DIRECT SEEDING ON PUDDLED SOIL

Varietal adaptation, fertilizer management, and weed control technology developed at IRRI and elsewhere have led to massive shifts to direct seeding with pregerminated rice. Large areas in the Philippines are employing direct-seeded flooded rice culture. In some provinces, such as Bulacan and Nueva Ecija, the adoption of direct seeding reaches from 80 to 95 percent in the dry season. In Thailand, 500,000 hectares are direct seeded and in Malaysia about 50 percent of total rice area is direct seeded. Nevertheless, constraints research in farmers' fields in the Philippines suggests that weed control technology is not used properly by farmers practicing direct seeding (Fig. 8).

MAXIMIZING RICE YIELDS

To determine maximum rice yields using the best available rices and production technology and to delineate problems, a multidisciplinary experiment was initiated at IRRI. The high yields achieved, 8.9 t/ha in the 1983 dry season and 5.3 t/ha in the wet season, suggest that yield levels can be raised



8. Average yields with farmers' and high inputs and contributions of fertilizer, weed control, and insect control to the yield gap. Yield-constraints experiments on broadcast-seeded irrigated farms in Nueva Ecija, and Bulacan, Philippines, 1984 dry season.

significantly with varieties that have more lodging resistance and with improved insect control.

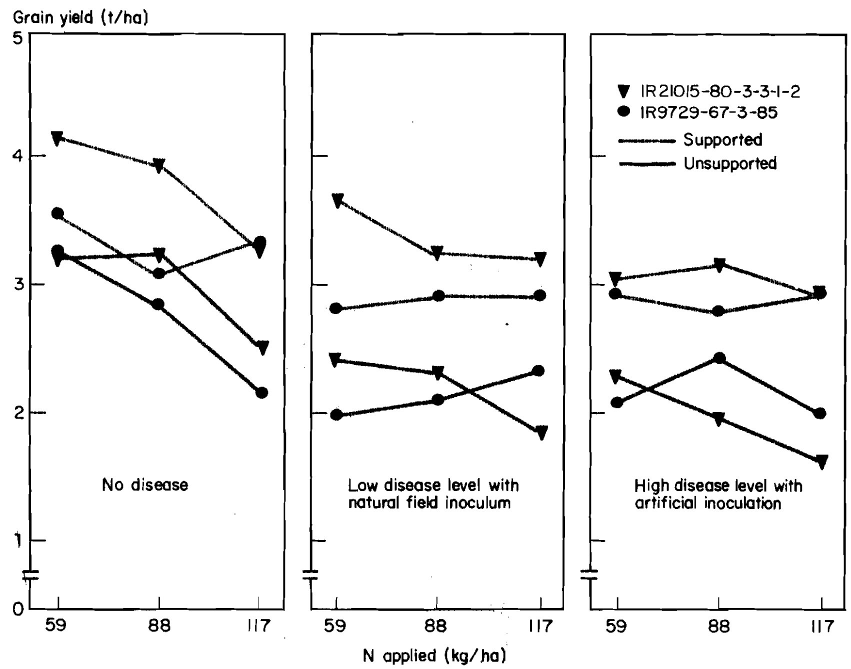
The effect of lodging, one of the major causes of low grain yield and low quality of rice, was assessed by comparing plots grown with and without plant support. For IR21015-80-3-3-1-2, the supported plot yielded 1.0 t/ha more than the unsupported plot, while for IR9729-67-3-85 the gain was 0.7 t/ha. These results indicate an additional 1 t/ha in grain yield is possible with greater lodging resistance in some modern rices (Fig. 9).

INSECT CONTROL

The objective of the IRRI insect management research and training program is to develop means to control insects that will increase both yields and profits in rice-based cropping systems. The objective is achieved by the development of control tactics that can directly be adopted by farmers, by the development of research techniques that national programs can use to create locally suitable control tactics, and by training national program scientists. Chemical control, biological control, and cultural control are utilized in combination with varietal resistance in an integrated approach to the management of rice pests.

Monitoring of insect pests

Control tactics have to be based on the proper identification of the pest and on the knowledge of pest populations that cause economic damage. IRRI



9. Grain yield in supported and unsupported plots at three disease and N application levels. 1983 wet season.

provides an insect identification service to national programs and advises on insect sampling methods and means of establishing economic injury levels.

Insecticide evaluation

Methods have been developed to test various formulations of insecticides against the brown planthopper, whitebacked planthopper, green leafhopper, zigzag leafhopper, stem borers, leaffolder, whorl maggot, armyworms, and rice bug and to determine the toxicity of the insecticides to natural enemies of insect pests. The evaluation methods have been published and are being used in many national programs. Since 1960, more than a thousand chemicals have been evaluated in the laboratory or field. The efficacy data have led to many national recommendations useful to farmers in tropical Asia.

Indiscriminate insecticide use and planthopper outbreaks

IRRI research has established the role of insecticides in triggering brown planthopper outbreaks. The studies indicate that of the various environmental factors influencing the expansion of brown planthopper populations, insecticides have the greatest effect. Insecticides that induce resurgence have been identified and national programs now consider the potential for resurgence before recommending new insecticides. At sublethal dosages, these insecticides cause pest resurgence by killing natural enemies of the pest and by increasing the oviposition rate of the pest. In the Philippines, methyl parathion has been delisted from the Masagana 99 recommendations because it caused hopper resurgence and is toxic to humans. IRRI research has shown that the proper use of insecticides by farmers will do more than any other management practice to prevent outbreaks of brown planthoppers on susceptible varieties.

Insecticide application methods

More efficient insecticide application methods reduce farmers' expenditures on inputs and increase the profitability of rice production. Broadcasting of granular insecticide into the paddy water, injection of insecticide into the root zone, and soil incorporation of insecticides have been compared with foliar spraying, the common practice. Soil incorporation of a granular systemic insecticide prior to transplanting was found to give much longer residual activity than foliar sprays or broadcast granules. The protection from soil incorporation equalled that from several foliar sprays or paddy water broadcast applications, providing control of the numerous pests that attack during the vegetative stage, when insect damage has a severe impact on rice yields.

Selective insecticides.

Because natural enemies — predators and parasites — have a significant role in the control of insect pests, IRRI evaluates commercial insecticides to identify those that are least toxic to natural enemies but highly toxic to the target insect pests. Most commercial organic insecticides are highly toxic to natural enemies, but a new class of insecticides known as growth regulators are being developed by the chemical industry. In extensive testing by IRRI, buprofezin, a molting inhibitor, has been shown to be highly effective against the brown planthopper at low rates and safe for the natural enemies of rice pests.

Botanical insecticides

Because of the high cost of commercial insecticides, there is a need to identify plants that might be grown by farmers to provide compounds for rice insect control. Seed oils of neem (*Azadirachta indica*), chinaberry (*Melia azedarach*, *Melia toosendan*), and custard apple (*Annona squamosa*) have been shown to have activity against leafhoppers and planthoppers in IRRI laboratory tests and are now being evaluated under field conditions.

Biological control

Parasites, predators, and pathogens are extremely important for holding populations of insect pests below levels where they cause economic injury. Studies are under way to identify the factors that affect the level of natural enemy activity and to determine how that activity can be enhanced. Fungal pathogens of the brown planthopper, whitebacked planthopper, and green leafhopper have been collected in surveys conducted in the major rice growing regions of Asia in an attempt to obtain highly virulent strains for use as foliar sprays.

Integrated pest management for rice

Because of its broad research on numerous control tactics, IRRI has been a proponent of the integrated pest management concept, which has been accepted to various degrees by most national programs. IRRI's interdisciplinary research, involving entomologists, plant pathologists, and weed scientists, serves as an example for national programs. IRRI has pioneered development of sampling methods and establishment of economic injury levels, which are basic to integrated pest management. Half the technology used in the German-sponsored surveillance and early warning system in the Philippines and Thailand was supplied by IRRI. IRRI has also collaborated closely with the FAO in the development and utilization of suitable pest management technology, training, and publications.

The importance of biocontrol agents against major insect pests has been determined at IRRI. The breeding of resistant varieties is a major control tactic and these varieties are primarily responsible for the success of integrated pest management in rice. With IRRI's help, national programs are developing technology for decision making (methods for sampling and determining economic injury levels) and formulating control tactics, screening resistant varieties, and testing insecticides. IRRI has developed techniques for implementing integrated pest management: farmer surveys to determine pest perception, determination of key pests, and teaching farmers integrated pest management. A field trial has been designed to adapt integrated pest management to the multitude of environments in which rice is grown. A book, *Illustrated guide to the management of rice pests in tropical Asia*, has been published which provides field technicians with the knowledge to teach farmers how to manage insects, rodents, diseases, and weeds.

DISEASE CONTROL

For much of the past 25 years, plant pathology research at IRRI has focused on varietal resistance as the primary means of disease control. The rationale for this approach was that poor rice farmers could little afford purchased inputs, such as fungicides, and that extension programs in developing countries might have difficulty collecting the extensive surveillance data required for disease management schemes such as gene rotation. However, as agricultural development has progressed in a number of countries, the use of fungicides is now a practical option for some farmers. Similarly, some strong national agricultural research and extension organizations have emerged in Asia. Consequently, IRRI's research has turned more toward disease management in recent years, with varietal resistance remaining as a foundation.

Gene rotation

The concept of gene rotation was developed as a means of managing monogenic resistance of blast disease, but a similar scheme has been applied for management of brown planthopper in Indonesia. For rice blast, the concept has been partly implemented in South Korea. The strategy depends upon predicting what resistance genes will be effective against new blast races through international testing of released varieties and resistance sources. If a released variety shows susceptibility at a location, other varieties at that location that show resistance can be used as gene sources. Thus, a breeding program would quickly be able to replace varieties whose resistance genes have become ineffective with varieties that have effective genes. It is assumed the original variety, or the resistance genes from that variety, could be eventually re-deployed when virulence to these genes disappears from the fungus population.

Fungicides

Through the screening of promising compounds for control of rice fungus diseases, benomyl was found to control bakanae, a seedborne disease that can be serious on susceptible varieties. Another systemic compound, CGA49104, was found to be highly effective as a seed treatment against leaf blast, and should become a useful tool for blast management.

Use of zinc to lower kresek incidence

The recommendation to dip rice seedlings in zinc compounds before transplanting has been widely adopted by farmers in the Philippines to compensate for zinc-deficient soil. Research at IRRI has shown that this practice also reduces kresek incidence. Kresek is a severe systemic form of bacterial blight that is transmitted to seedlings through the paddywater. IRRI studies found that kresek growth on agar plates was inhibited by all three concentrations of zinc sulfate tested. Thus the practice of dipping seedlings in zinc compounds could be used not only to amend zinc-deficient soil but to reduce kresek incidence as well.

Bacterization of rice plants for sheath blight control

Bacterization, a form of biological control, involves establishing a biological barrier to the target pathogen by inoculating antagonistic microorganisms in the host. Screening and evaluation of possible antagonists to sheath blight have been done at IRRI. Seed treatments with several isolates of fluorescent *Pseudomonas* and other nonfluorescent bacteria have been effective in reducing disease incidence and severity. These bacteria are widely distributed in rice fields in the tropics and consequently are a potential tool for sheath blight management.

Straw decomposition for disease control in crops following rice

The concept of using cellulolytic fungi to accelerate the decomposition of infected rice straw was developed as a means of reducing the severity of diseases in crops grown after rice at IRRI. *Trichoderma* spp. have been tested as a biocontrol agent of soilborne pathogens like *Rhizoctonia solani* and *Sclerotium rolfsii*, which attack legumes and other crops. *Trichoderma* spp. were highly competitive, reduced the survival of pathogens, and decomposed rice straw. Thus, they can be used in the management of crop stubble in a cropping system where rice is a base crop.

Monitoring and prediction of tungro

Tungro is the most important virus disease of rice in tropical Asia. It is found sporadically but occasional outbreaks damage vast tracts of rice. Spraying insecticide against the vector is effective for tungro control if done at the appropriate time. But once the disease is epidemic, application of insecticide is seldom sufficient to stop it. Hence, monitoring and prediction of the disease are critical for control of tungro.

Epidemiological studies conducted by IRRI from 1972 to 1980 demonstrated that tungro incidence in the wet season crop is correlated with the number of tungro virus vectors in the early season and the proportion that are transmitting tungro. This finding indicated that tungro outbreaks might be predicted by monitoring the disease and the vector insects at early stages of growth or before seedbeds are prepared.

To support the development of a tungro monitoring system and to accumulate information on tungro epidemiology in the Philippines, IRRI organized a training program in collaboration with the Ministry of Agriculture. Eighty persons from the Regional Crop Protection Center (RCPC) and surveillance and early warning systems were trained during 1981-83. To follow up the training, IRRI has also helped RCPC officers in each region do the monitoring.

IRRI has developed a simple method for identifying tungro with tincture of iodine. This technique is economical because it uses widely available materials. The iodine test is applied in monitoring and can be used by individual farmers. FAO has introduced the test and the monitoring concept in Malaysia.

WEED CONTROL

In the past 20 years, IRRI has developed cost-efficient weed control technology now being used in millions of hectares of transplanted and direct-seeded rice areas in South and Southeast Asia.

Identification of cost-efficient herbicides

In 1967, the finding that all commonly marketed phenoxy herbicides, such as 2,4-D and MCPA, are effective grass killers if applied before weed emergence in transplanted rice led to the introduction of a low-cost weed control technology in tropical Asia. Since then, several herbicides have been identified that are selective to annual and perennial weeds in rice, notably butachlor and thiobencarb. The use of herbicides as a component of total weed control in rice has been widely adopted. In 1983 farmers applied herbicide to more than 70 percent of the rice land in the Philippines. Just 15 years earlier, herbicides were used on barely 1 percent of the rice land. Spectacular rates of adoption have also occurred in South Korea; Sulawesi, Indonesia; and Punjab and Haryana, India.

In 1968 IRRI began herbicide testing with national programs. Thirty-seven countries in Africa, Asia, and Latin America have tested 1,221 sets of herbicide samples for transplanted, direct-seeded flooded, and upland rice.

The results from research at IRRI and in cooperating countries have encouraged broad usage of butachlor (22 countries) selected at IRRI in 1968 and thiobencarb (56 countries) selected in 1969.

Weed control technology developed at IRRI greatly helped in the recent switch from transplanting to direct seeding of rice, which is now widely practiced in Malaysia, Thailand, and the Philippines.

Control of *S. maritimus*

Scirpus maritimus, a perennial sedge that is a common weed in lowland rice in some countries, can be controlled by applying low-cost 2,4-D at the appropriate time. During 1983-84 IRRI also identified a coded compound, DPX 5384 (from Du Pont), that controls both *S. maritimus* and barnyardgrass (Table 4). This herbicide would be a valuable addition to integrated practices developed at IRRI to minimize competition from *S. maritimus* and other weeds in lowland rice.

Weed control in upland rice

Progress has been made in the control of several important weeds of upland rice. In recent tests, IRRI found that pendimethalin mixed with fluazifop-butyl (1.0 + 0.08 kg ai/ha) in the sprayer tank and applied 12 days after rice emergence provided far better control of grasses such as *Rottboellia exaltata* than hand weeding or a single application of either herbicide (Table 5).

Table 4. Effect of DPX 5384 on the control of weeds and yield of direct-seeded, flooded IR42. IRRI, 1982 wet season.

Treatment	Application: Rate[a] (kg/ha)	Application: Days after seeding	Weed wt[b,c] (g/m²): *Scirpus maritimus*	Weed wt[b,c] (g/m²): Grasses	Weed wt[b,c] (g/m²): Broadleaf weeds	Grain yield[b]
DPX 5384	0.05	6	4 a	0 a	0 a	5.0 a
DPX 5384	0.05	8	4 a	0 a	0 a	4.7 a
Butachlor	1.0	6	128 b	0 a	1 a	2.1 b
Untreated check	—	—	36 b	11 b	17 b	2.2 b

[a]Active ingredient. [b]Av of 3 replications. In a column, means followed by a common letter are not significantly different at the 5% level by DMRT. [c]Sampled at heading of the grassy weeds.

Table 5. Effects of herbicides on weeds and grain yield of IR36 grown under upland conditions. IRRI, 1983 wet season.

Treatment	Application[a]: Rate[b] (kg/ha)	Application[a]: Time[c]	Dry weed wt[d,e] (g/m²): Broadleaf	Dry weed wt[d,e] (g/m²): Grasses	Dry weed wt[d,e] (g/m²): Sedges	Grain yield[d] (t/ha)
Pendimethalin + fluazifop-butyl[f]	1.0 + 0.08	12 DE	12 a	10 c	36 ab	2.0 a
Pendimethalin	1.5	PE	8 a	110 b	16 ab	0.2 b
Fluazifop-butyl	0.05	12 DE	4 a	238 b	6 bc	0 b
Untreated check	—	—	8 a	946 a	0 c	0 b

[a]All herbicide treatments were followed by 2,4-D amine at 0.05 kg ai/ha 14 days after the rice emerged. [b]Active ingredient. [c]DE = days after rice emergence; PE = preemergence, 4 days after seeding. [d]In a column, means followed by a common letter are not significantly different at the 5% level by DMRT. [e]45 days after seeding. [f]Tank-mixed.

Basic research on control of *R. exaltata* suggests that for highly effective weed control with herbicides or hand weeding, the amount of rainfall through the season should be higher than pan evaporation. In other words, despite hand weeding or use of herbicides, high grain yields of upland rice will not result if available moisture is below the critical level (Fig. 10). On one hand, moisture stress, particularly at the reproductive stage, will decrease growth and grain yield of rice and on the other hand, herbicides are totally ineffective in soils with high soil moisture tension.

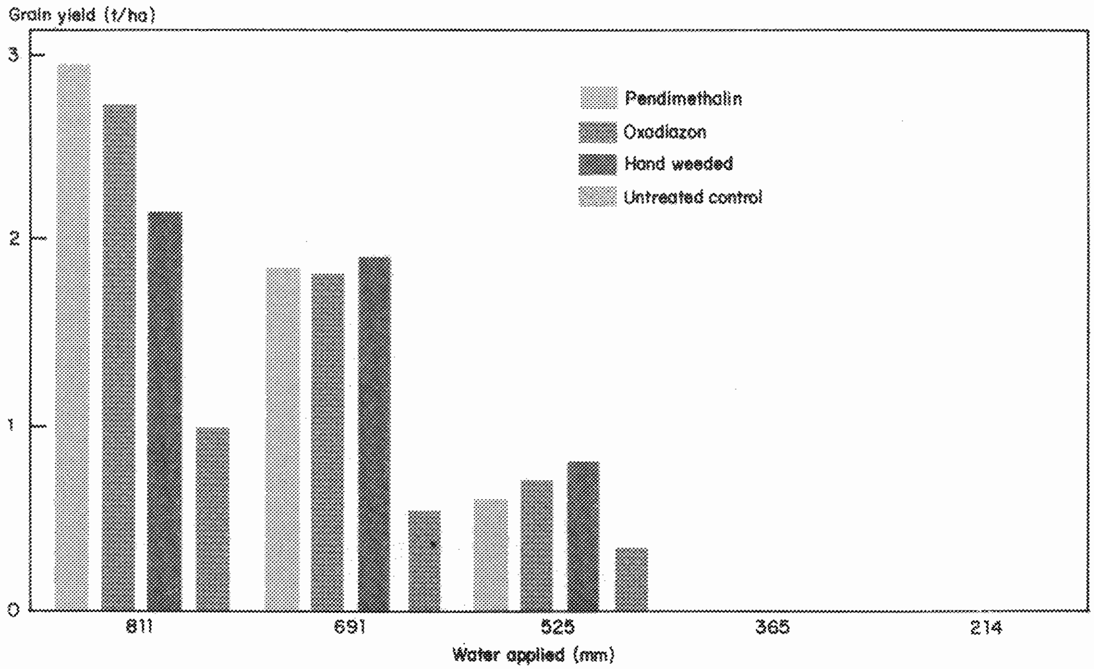
For control of *Cyperus rotundus*, an application of either glyphosate or the coded compound SC-0224 at 2 kg/ha before planting gives complete control. These findings are highly important for developing a total upland rice technology for farmers.

Herbicide application techniques

IRRI has intensified research on herbicide application techniques which affect herbicide efficiency. The birky, a new low-volume pneumatic sprayer, performed significantly better than the conventional sprayer. It has the additional advantage of reducing the amount of water the operator has to carry while spraying.

Weed control in dry-seeded wetland rice

Dry-seeded wetland rice refers to rice that is seeded dry and begins its growth as a dryland crop, but as the rainy season progresses and water accumulates in



10. Effect of herbicides on grain yield of upland rice (IR36) at different soil moisture regimes.

the field, part or all of its subsequent growth is as a wetland crop. In such situations, the onset of flooding is unpredictable, but the cumulative duration of flooding is long enough to prevent the growing of upland crops in most seasons. At present, dry seeding of wetland rice is a minor practice in tropical Asia, but the area involved is likely to increase as farmers move to double cropping using early maturing varieties to take full advantage of the rainfall during the wet season.

Weed problems in dry-seeded rice are far more severe than in rice sown on puddled soil because of differences in land preparation, because of the lack of water early in crop growth, and because the dry-seeded crop emerges at the same time as the weeds. Applications of single herbicides have generally given poor results because of lack of herbicide persistence, a narrow spectrum of weed control, and intense weed pressure. Usually herbicide application has to be followed with hand weeding to prevent substantial yield losses.

Use of more than one herbicide gives more effective and longer lasting weed control. The herbicides may be applied simultaneously or sequentially. Any follow-up hand weeding that may be required will be less laborious and the critical period for weeding will occur later in crop growth when there is less conflict with other farm operations. A herbicide combination of thiobencarb plus propanil applied at the two- to three-leaf stage of the grassy weeds has given good weed control and high crop yields in trials at IRRI over the past 5 years. In most cases, there was no need for hand weeding after this herbicide combination was applied.

The impact of IRRI's irrigation water management research and program activities can be best seen in the context of cooperation with national agencies. Cooperative agreements are in force with the Philippines, Bangladesh, and Indonesia, while a fourth agreement is being initiated in India.

The Philippines

IRRI works closely with the Philippine National Irrigation Administration (NIA). A formal agreement provides blanket approval for joint research and training activities. In 1975 NIA established the Water Management Training Center at Muñoz, Nueva Ecija, following submission of an IRRI-sponsored study that concluded that farmers would employ improved irrigation practices only if the tertiary-level facilities were adequate and if field personnel of NIA had proper skills in water management and understood farmer requirements. The Muñoz center trains field technicians for the entire country, using a curriculum that draws heavily on research findings of joint IRRI-NIA programs.

Subsequent work by IRRI indicated that field-level water management activities are heavily dependent on how the main channel system is managed. Without reliable and adequate water supplies, farmers cannot implement many of the techniques being taught at Muñoz. Consequently NIA created a systems management department that monitors and evaluates water management at system level and helps field engineers develop alternative methods of water distribution. This program has implemented many of the innovative research activities undertaken by IRRI in the Central Luzon area.

IRRI's research within the Philippines is being done jointly with personnel from the systems management department to explore ways to allocate and distribute water more equitably among all users in irrigation systems.

Recently a joint study with NIA evaluated how designs of structures and layout of irrigation channels affect farmer behavior. This study revealed a close relationship between design criteria and creation of additional and illegal turnouts by farmers. The preliminary recommendations of the study have influenced the selection of design criteria by NIA in new schemes and in rehabilitation programs.

The joint NIA-IRRI research projects, as well as the annual IRRI water management training program, have exposed a significant number of senior NIA staff to IRRI's activities. Over the past decade, many have moved into policy making positions in NIA. As a result, NIA has become recognized as one of the most progressive irrigation agencies in Asia, and certainly the most innovative in sponsoring and implementing research activities.

Bangladesh

In 1981 IRRI entered into an agreement with the Bangladesh Rice Research Institute (BRRI) and the Bangladesh Water Development Board (BWDB) to assist a research project in two areas of Bangladesh. In northwestern

Bangladesh, work has been oriented to improving the performance of deep tubewells through a combination of training, research, and extension. As a result, the area irrigated by tubewells has grown substantially and yields have risen because modern rice varieties have been widely adopted. Similar results have been obtained in southwestern Bangladesh in a major gravity irrigation system.

This program has emphasized the development of internal research and training capabilities within both BRRI and BWDB, so that they will both be able to undertake long-term collaborative programs. The IRRI-BRRI-BWDB program is regarded as the most successful water management program in Bangladesh.

Indonesia

The collaborative program in Indonesia, through the Agency for Agricultural Research and Development (AARD), has just begun, but it is significant that the national water management program is headed by a former IRRI scholar.

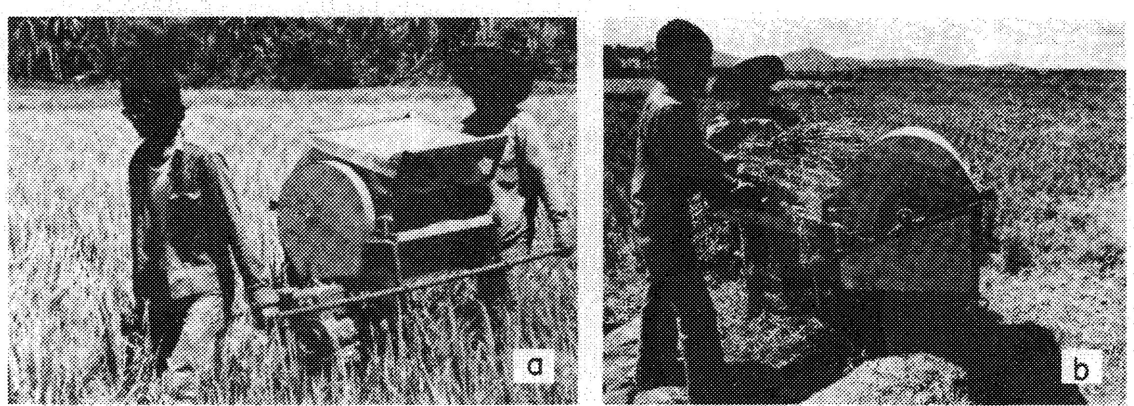
MACHINE DESIGN AND DEVELOPMENT

IRRI has focused on providing appropriate farm machines to small rice farmers through local manufacturers. IRRI machinery design is guided by farmer demand. To get new machines into production, IRRI works closely with local manufacturers. The following machines have achieved the greatest commercial success.

Axial-flow threshers

In 1973, IRRI released the design of an axial-flow thresher that could handle wet paddy (Fig. 11a and b). It was powered by a 7-to 10-hp engine and had an output of 1 t/h with less than 1 percent threshing loss. This machine quickly became popular in the Philippines for contract threshing.

11. IRRI axial-flow thresher: a) original prototype units, and b) latest version.



12. IRRI portable paddy thresher.

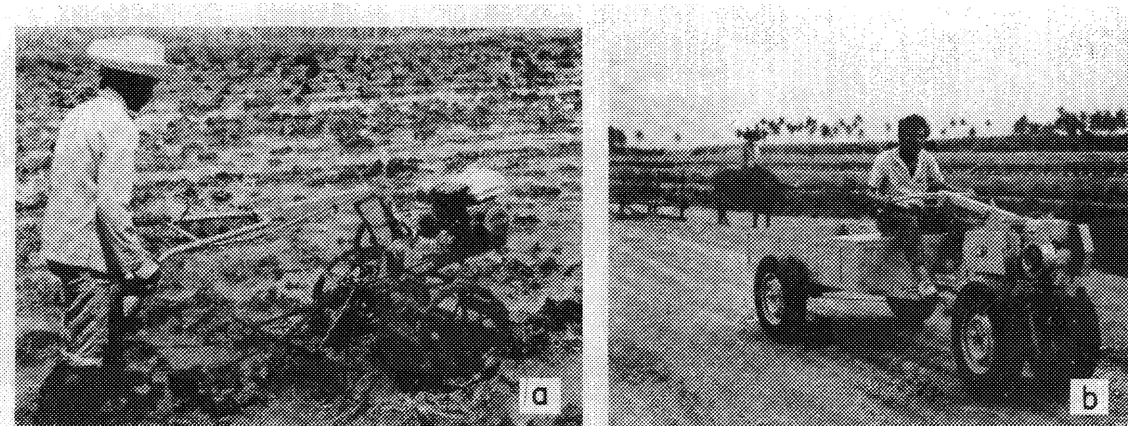
In 1977, IRRI released the design of a portable thresher, which was designed for individual farm ownership. This machine was powered by a 4- to 5-hp engine with a threshing output of 300 to 600 kg/h (Fig. 12a and b). Since the machine weighed only 105 kilograms, it could be conveniently carried into the field by the operators, thus minimizing the handling of harvested paddy. Because of the axial-flow principle, which was pioneered by IRRI, these machines readily threshed wet paddy, a feature that was well liked by farmers in tropical Asia.

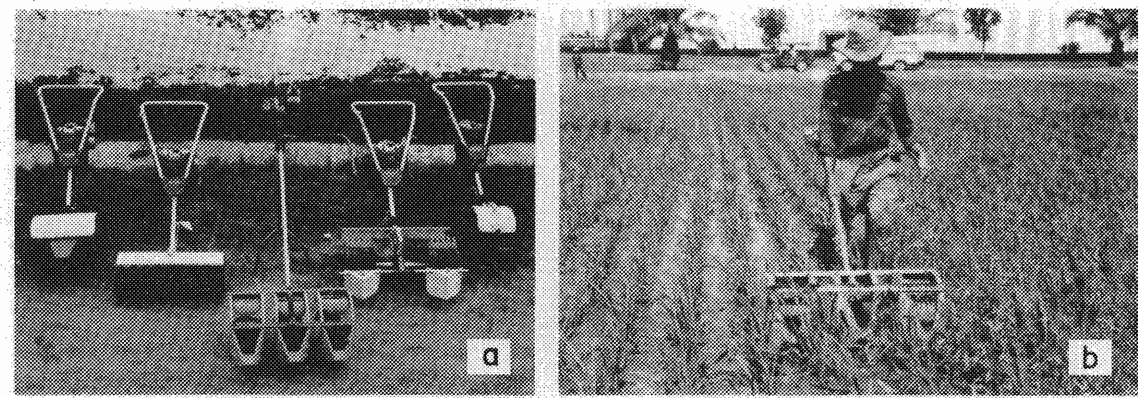
Efforts were also made by IRRI to introduce the threshers in other rice producing countries. They are now the most popular threshers for paddy in the tropics; an estimated 50,000 threshers have been commercially produced in Asia, 20,000 of them in the Philippines and 18,000 in Thailand. Adapted versions of the thresher are also produced in India, Egypt, and Pakistan.

IRRI power tiller

13. IRRI power tiller with a) comb harrow, and b) trailer.

The IRRI power tiller design was released to manufacturers in the Philippines in 1971 (Fig. 13a and b). By 1973 over 2,500 power tillers had been





14. a) IRRI 3-row portable power weeder prototype with commercially produced Japanese weeder by Ohtake & Co. b) IRRI 5-row portable power weeder prototype.

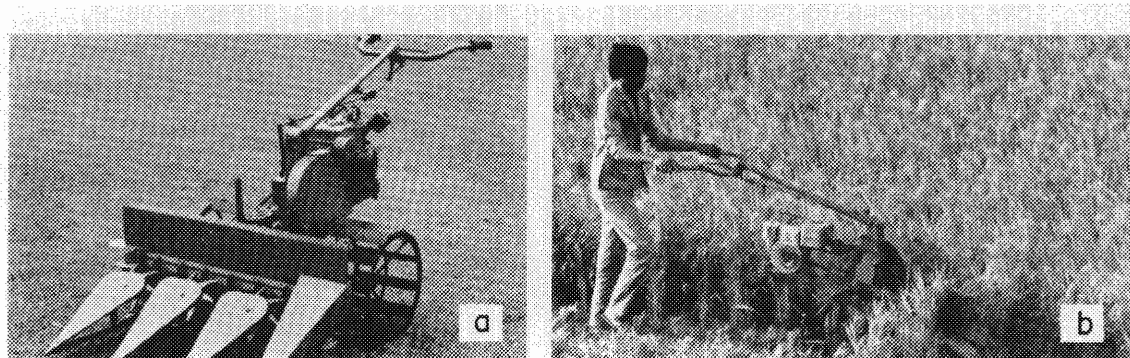
manufactured in the Philippines. After the release of the IRRI power tiller, many local manufacturers started to develop their own improved power tillers. About 1975, a simple locally developed power tiller gained popularity. This machine is now produced by most manufacturers in the Philippines. The IRRI power tiller played a catalytic role by demonstrating that there is a market for indigenously manufactured power tillers in the Philippines.

Power weeder

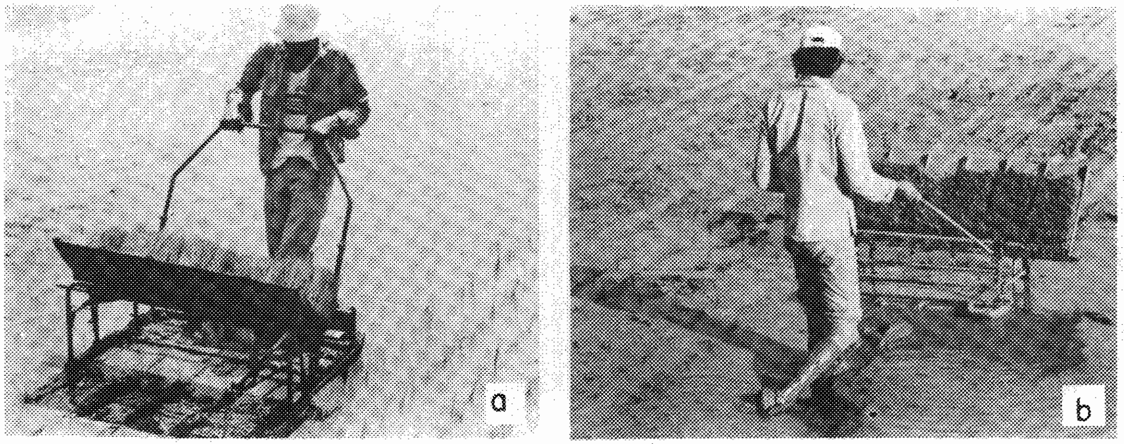
In 1970 the three-row IRRI power weeder (Fig. 14a and b) was released to a Japanese manufacturer. Concern in Japan about the adverse effects of herbicides helped in popularizing the IRRI weeders. As the market grew, other Japanese companies developed power weeders, which were based on the original IRRI design. Eleven companies are now manufacturing the IRRI-type power weeders in Japan and over 280,000 have been produced.

IRRI-CAAMS reaper

A reaper developed by IRRI and the Chinese Academy of Agricultural Mechanization Sciences has received very good response from farmers and manufacturers in the Philippines (Fig. 15a and b) since it was introduced in



15a and b. CAAMS/IRRI one-meter-wide reaper.



16. a) Manually-operated 5-row IRRI transplanter (original design). b) Improved 6-row transplanter.

1982. Fifteen manufacturers in the Philippines now sell this machine. In Pakistan, a 2.2-m-wide tractor-mounted reaper adapted from the IRRI design is now in commercial production. Over 2,000 machines were manufactured during 1983-84.

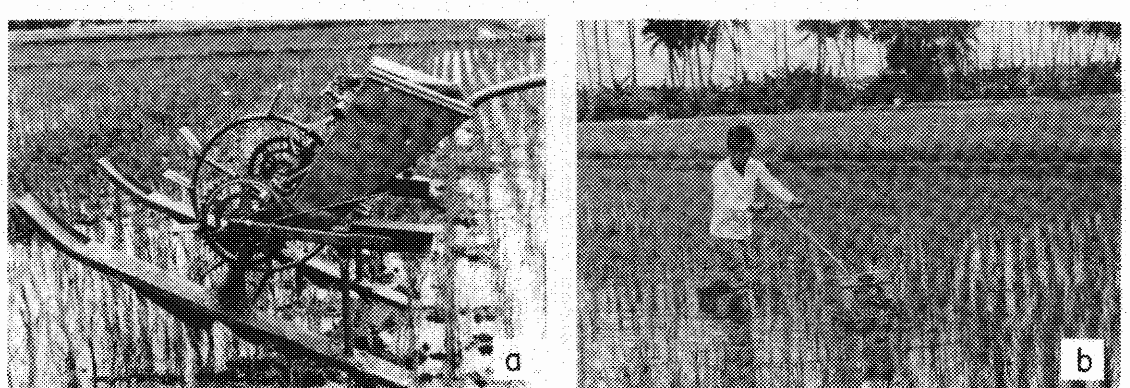
Transplanter

A five-row manually operated paddy transplanter was released to manufacturers in 1978 (Fig. 16a). The machine has become popular in Burma, where 7,000 units have been manufactured. An improved IRRI transplanter (Fig. 16b) design is now being introduced in the Philippines, which will be made available to manufacturers in other rice growing countries.

Deep-placement fertilizer applicator

Many agronomic studies have demonstrated that fertilizer use efficiency can be substantially raised in rice production through deep placement. However, deep placement applicators for lowland rice have never been very successful.

17. Spring auger applicator for prilled urea.



Experiments conducted at IRRI have recently demonstrated that applicators developed in the past do not perform well because most of the fertilizer is transferred to the floodwater during placement. Based on these findings, new deep placement injectors have been developed at IRRI that place fertilizer in the soil under flooded field conditions without permitting any nitrogen transfer to the floodwater. In farm trials, these machines have raised fertilizer use efficiency as much as 50 percent. Over 100 injectors are undergoing field testing and evaluation in the Philippines and other Asian countries before their release for commercial production. Figure 17a and b show one such machine for applying prilled urea in lowland rice fields.

CHAPTER 6

INTEGRATING RICE TECHNOLOGY INTO FARMERS' PRODUCTION SYSTEMS

CONCEPT AND POTENTIAL FOR INTENSIFICATION AND DIVERSIFICATION

Improved rice technology will support yet further increases in food supplies if the scope of research is expanded to include the production systems in which rice is grown. How farmers grow rice is influenced by other farm activities, farm resources, and the benefits sought from farming. By understanding the relationships of rice to farmers' resources, goals, and other activities, rice technology can be designed to better suit farmers' systems. Also, other farm components that fit with new rice technology can be identified or developed.

Farming systems research uses rice technology to expand food-producing farm enterprises by generating rice-based multi-enterprise technologies (to be used by farmers), developing and disseminating research methodology (to be used by farming systems researchers), and specifying attributes of rice and other technologies that will facilitate the creation of more productive combinations of farm enterprises (for scientists and research directors).

An approach to rice-based farming systems research

Farming systems research is multidisciplinary, conducted on farms, and focused on multi-enterprise technology — three features that together distinguish it from other research at IRRI. A multidisciplinary approach is employed because the phenomena examined — more productive farming systems — cannot be fully understood in a unidisciplinary context. While scientists in individual disciplines engage in farming systems research, the main hypotheses are jointly formulated, jointly tested, and jointly interpreted with farmer involvement.

Since new technologies ultimately must be adopted by farmers, an early test of the acceptability of experimental technology is useful. Farmers' comments and actions in response to trials on their farms may indicate whether or not an experimental technology is likely to be adopted. Precise interpretations of farmers' opinions, however, are clouded by the researchers' presence, the provision of some inputs, the size of experimental plots, and other factors. These factors influence economic stimuli and possibly also farmers' responses to the stimuli. Neither farmers' likes nor dislikes regarding experimental technology nor their decision to perform or not perform their role in an experiment are wholly reliable indications of a technology's ultimate acceptability. Until farmers try technology with researchers completely absent, tests for acceptability must be conducted synthetically (e.g., through cost and returns analysis), based upon assumptions about farmer behavior.

The focus of IRRI's farming systems research is on the development of multiple cropping technology (or multiple-enterprise technology, when research on feed production and its utilization by animals is included). Technical multiple cropping research is undertaken as part of the farming systems program at IRRI because it is needed to fully exploit new advances in rice technology.

Operationally the research is carried out in a seven-stage process beginning with the general hypothesis that the number of crops (or number of enterprises) can be increased in a given environment. Choice of the target environment is so fundamental that this first research stage is called *site selection*, although it also involves, usually explicitly, the hypothesis that a new multi-enterprise technology for that regime will be successful. Target regimes, which are chosen in consultation with national programs, are those where food production lags due to problems that prospectively can be overcome through technology which is or has recently become available, and farming systems research. Sites are subsequently described in the second research stage, *site description*.

Specific hypotheses of new technology to expand the number of enterprises at a site are formulated in the third research stage, *cropping pattern design* (or multi-enterprise technology design, as the case may be). The design is based on detailed information about such environmental features as soil chemical properties, hydrology, labor supply, markets, seasonal pest incidence, cultural factors, and so on, which have been obtained during site description. Designed technology is then tested.

The *testing* stage of research comprises replicated trials on farms, usually involving a number of different enterprise combinations in different strata of the environment. The relation of the human and institutional environment to the acceptability of new technology is examined and the economic performance of the experimental technologies is compared with that of farmers' present practices. This research is carried out with several different, sometimes purposely overlapping, samples of farms. Field researchers may include government officers from research and extension agencies and a few IRRI personnel with experience from previous farming systems research projects, but usually they are persons from the locality who have been hired and trained for the project.

The fifth and subsequent stages of research are undertaken primarily by government agencies. Technology that appears promising is tested over a much wider, often discontinuous, area where the environment is similar to that for which the technology was developed. This *multilocation testing* stage then leads to a sixth stage, *production programs*, in which recommended new technologies are disseminated to farmers, often through special extension programs. Together, stages five and six could also be regarded as a single technology-introduction, or extension, stage.

The final stage in research occurs some years after farmers have been introduced to a new technology. The effects of the new technology are evaluated to indicate needed additional research. *Impact evaluation* addresses such things as changes in production, the biological and physical environment, farmer incomes and income distribution, labor employment and wages, family work roles, migration, and education.

RELATIONSHIP OF ENVIRONMENT TO INCREASING FARM ENTERPRISES

Environment sets the limits within which technical innovation can reasonably be expected to increase the number of enterprises on a farm. How this is answered with respect to the climatic environment is discussed below, followed by a discussion of the economic and sociocultural environment.

Climate and rice-based farming systems

Three elements of the climatic environment play a dominant role: temperature, rainfall, and radiation. While temperature and radiation are a determining factor for potential yields, rainfall and temperature set the geographic limits for a farming system.

The length of the growing season is in the first instance determined by the temperature regime. For each crop, threshold temperatures can be found. Furthermore, within these thresholds, temperature determines the length of the phenological stages, particularly the vegetative stage. A decrease of 1° C in the mean temperature over the growing period increases the total growth duration of many modern rice varieties by approximately 5 to 7 days. Similar relationships are known for upland crops. This effect has to be taken into consideration particularly in areas where the length of the rainy season is limited.

Rainfall is often the dominant environmental parameter determining the particular cropping sequence in an area. At the same time, rainfall is the most variable parameter of the environment. Monthly means of total rainfall can only be used to indicate certain trends of the rainfall regime. If other parameters of the environment such as soil physical and geomorphological characteristics are known, it is possible to use simplified dynamic water balance models to determine how long during the year adequate moisture is generally available for a crop. This will indicate various degrees of environmental suitability for rice-based farming systems.

While spatial variability of rainfall regimes is large, its interannual variability is an even greater problem for the integration of rice-based farming systems. Mean monthly values do not indicate this interannual variability and rainfall totals should be expressed as probabilities over shorter cumulative periods such as weekly or 10-day totals. For the Philippines, long-term weekly rainfall totals for about 50 locations are available and 75 percent probabilities have been established for the totals. Knowing the potential evapotranspiration on a weekly basis, researchers can now estimate in which weeks there is a 75 percent probability that rainfall will exceed potential evapotranspiration. The long-term records can also be used to calculate the probability of dry spells during the growing period using the Markov chain approach. Analyzing rainfall data in this manner allows the possibility of tailoring rice-based farming systems to suit the needs of specific environments to be better assessed. When integrated with information on soils and landscapes, the potential for the introduction of a more intensive or diversified system can be more accurately assessed.

Environment and the economics of multiple enterprises

Adding activities on a farm affects the economics of farming in a quite different way from increasing the output per activity. To increase output, there must be added investment in inputs, but the degree of response declines as investment increases. Spreading a given level of investment in variable inputs over a number of enterprises offers a higher rate of return than investing in a single enterprise (assuming declining marginal returns in each activity). Adding enterprises can forestall the necessity of accepting lower marginal returns in order to increase profit. Hence there is incentive to rice farmers to add more enterprises, including additional rice crops, in rice-based systems.

While spreading investment in variable inputs across enterprises, farmers invest in a way that makes the marginal return per unit of additional cost about the same in each enterprise. This is known as the principle of equi-marginal returns. IRRI researchers found that when average rates of return to variable costs are computed for several years, they are about equal within a site, but different across sites. Return rates are lower in unfavorable environments than in favorable regimes. The site-specific average return rates are a guide for evaluating the acceptability of new technology. In the Philippines, average return rates on variable costs appear to be about 2:1.

Credit is often regarded as a key to improving farm production and incomes. Production may stagnate in some localities because farmers cannot afford to purchase extra fertilizer, pesticides, etc. in order to apply higher rates. Credit programs may indeed be the only choice in regions where there are no new farm enterprises into which farmers may spread investment and earn high rates of return. However it also is clear that if more productive alternatives are made available through multiple cropping, farmers are inclined to reinvest some of their gains in more intensive input use. For example, in Iloilo, Philippines, average fertilizer rates per rice crop increased from about 20 kg N/ha to 60 kg N/ha, following farmers' adoption of multiple cropping techniques. Analyses showed that farmers, particularly the relatively smaller farmers, tended to increase the proportion of their income spent on agricultural inputs as their incomes increased.

Even small farms in the monsoon tropics have quite diverse land resources. Irrigation tends to homogenize land resources, but rainfed lowland areas and upland areas are highly diverse. Temperature and rainfall afford many different choices in crops and other enterprises at any given time.

Together these features mean that operating an optimum set of activities requires many decisions, so that farmers can continue to earn incremental returns at ever higher rates of inputs. Diversification and intensification occur as farmers seek greater returns to their management.

In lowland rice-based systems, diversification entails switching land back and forth between the upland (dry, or oxidized) state, and the lowland (wet, or reduced) state. That change in the mode of production entails a fixed production cost, i.e., a cost that is independent of the variable inputs that are applied. Remaining in either an upland or lowland mode does not entail this between-crop fixed cost. Hence adding more crops of the same kind is usually more profitable than diversification between upland and lowland crops.

Sociocultural domains of rice-based farming systems

Next to ascertaining the biological and technical feasibility of alternative cropping patterns, their acceptability to several categories of farmers has to be assessed and tested. Social research is often necessary to determine under which conditions small-scale cultivators in a certain region are willing to accept all or elements of specific alternative cropping patterns. Consequently, ways to identify the farmers' agricultural decision criteria, which are related to rejection, acceptance, or partial acceptance of newly designed cropping patterns, are tested at several research sites. Starting from a simplified payoff matrix, alternative courses of action that are recognized by farmers are determined, along with the factors (physical, socioeconomic, and cultural) that farmers perceive as influencing their choice of an action. A proper mix of fieldwork techniques is essential to discover farmers' motivations for selecting or rejecting specific options, or their elements.

During the testing of alternative cropping patterns, researchers carry out case studies on a restricted number of households differing in farm size, land tenure status, family composition, off-farm employment, and cooperation in on-farm cropping systems trials. Following several months of case studies, a brief questionnaire is drawn up for a survey of a much larger number of households. This second component of data collection, usually completed in 3 to 5 days, serves to establish the degree of representativeness, for larger areas, of the facts and figures collected through the case studies.

Another field of research concerns the socioeconomic impact of alternative cropping patterns. It focuses on developing ways to assess the likely impact of specific alternative cropping patterns on several categories of rural households and individuals and to determine under which conditions any negative effects can be minimized. Special attention is paid to agricultural laborers, women, and very poor farmers to insulate them from potential adverse impact on employment of some innovations. Villages that have widely adopted alternative cropping patterns are compared with adjacent communities in which such changes have occurred to a smaller extent. Again, case studies on a restricted number of differing households in the two areas are followed by a survey with a short questionnaire.

This approach has the following advantages:

- Detailed and reliable facts and figures can be collected on the situation and on the reactions of several categories of households and of different members of these households in several categories.

- It can be combined with the study of the conditions under which several categories of farmers are able to accept specific innovations. This investigation, too, can be done by comparing several categories of households in two neighboring villages that differ in degree of acceptance of new technology.

TECHNICAL ACHIEVEMENTS

The six principal technical issues about which hypotheses have been formulated in the course of farming systems research at IRRI are:

1. Rainfed rice-based multiple cropping
2. Grain legumes in rice-based systems
3. Production stabilization in flood- and drought-prone environments
4. Diversification under irrigation
5. Association of rice-based systems with livestock production
6. Role of social organization changes in intensifying farming systems

Substantial work toward testing hypotheses related to the first three technical issues has been completed. Tests of hypotheses related to the other issues are under way.

Rainfed rice-based multiple cropping

Innovations that are regarded as having potential for increasing cropping frequency are identified and tested. Testing must be conducted under the management that the innovations are likely to receive, but in a way that permits sound conclusions to be drawn from the results. Although a technical innovation may be the ultimate source of improved systems performance, the incorporation of that innovation invariably has ramifications for other cropping activities. For example, substitution of a short-maturity, high yielding photoperiod-insensitive rice variety for a late maturing, low yielding traditional variety will create slack field time. But to exploit that field time by growing a second crop, it will be necessary to harvest, thresh, and store the first crop before the field can be prepared for the second crop. Practical techniques to secure the first crop and to plant the second crop must be identified. If the second crop is an upland crop, the hazard of excess water has to be examined. Furthermore, a newly introduced crop may attract pests and develop diseases and therefore crop protection specialists must normally be involved. If the crop is to have real value, it must be possible to sell, consume, or feed it — matters that are of concern to marketing specialists and development officials. Since no single discipline has the tools to address all problems that will be encountered, cropping systems research projects need to be multidisciplinary.

When synthesizing new cropping patterns for rainfed rice environments (physical and socioeconomic), the common approach has been to increase harvest frequency by replacing late maturing traditional varieties with crops that have shorter maturities and that raise per day yield. Crops are harvested earlier, thereby reducing the hazard of drought damage.

Rice - rice patterns. In the mid-1970s, several rice varieties and lines that mature in less than 120 days became available. Examination of rainfall patterns or a combination of rainfall and terrain features at several locations in the Philippines suggested that it should be possible to grow two rice crops a year. Thus the creation of varieties of short duration triggered research on double rice cropping in rainfed environments. Constraints of the hydrologic growing year and farm resources were found, however. That in turn forced scientists to examine alternative planting techniques, notably direct seeding for establishing the first rice crop early, and to study ways to overcome the labor bottleneck between crops which delays the planting of the second crop.

Rice - upland crop patterns. Where the rainfall-soil-terrain complexes do not produce hydrologic years of sufficient duration and intensity to grow double crop rice, early planted rice crops can be followed by upland crops. If the onset of the wet season is abrupt, so that fields become saturated quickly, rice is the logical crop with which to start a sequence. At such sites, the research objectives have been to find combinations of rice varieties and establishment techniques that produce high and stable yields, but which leave adequate time for an upland crop. Furthermore, a balance must be struck between early and late upland crop establishment. Flooding is a hazard when upland crops are established early. On the other hand, late planting to avoid the flooding hazard exposes the crop to drought stress, including inadequate plow-layer moisture for germination and early growth. Furthermore, an important criterion for choice of upland species is that the species must be marketable.

Upland crop - rice patterns. For environments in which the wet season onset is gradual or the soils are permeable, harvest frequency can be increased by planting upland crops before rice. For reliable yields, the expected period between the date of earliest effective rains and the date of damaging soil saturation should be 75 to 90 days. The prerice crop should be able to cope with occasional short periods of excess moisture.

Grain legumes in rice-based cropping systems

Development of early maturing and high yielding rices increased the scope for crop intensification in rainfed areas. Their shorter growth duration added 30 to 60 days to the period during which there is enough water in the soil to grow another crop. Grain legumes such as mungbean, soybean, cowpea, and peanut are obvious choices for this period. These crops not only are popular foods, their high quality protein is a valuable supplement to the diet of rice farmers. This plant protein can be produced with minimum resources and therefore is less costly than animal protein. Grain legumes also improve soil productivity.

Traditionally, farmers who took advantage of the drought resistance of grain legumes by growing them after rice used little or no inputs. Consequently yield remained very low. The lack of improved seed, poor management, little or no use of inputs, and inefficient markets and low economic return are the major constraints.

For fast establishment of grain legumes after flooded rice, farmers use various minimum tillage systems, such as broadcasting or dibbling seed in the rice stubble. These traditional methods give natural control of early season insect pests. New crop establishment methods must combine the advantages of such systems. Better varieties of mungbean, cowpea, and soybean are now available. The best establishment methods are no tillage and dibbling of seeds immediately after rice harvest and row drilling of seeds after a single rototillage. The addition of a rice straw mulch immediately after planting increased soybean yields. Where soybean has not been extensively grown, inoculation of seeds with rhizobium culture can increase yield significantly.

Dual-purpose (grain + fodder) legumes are of interest to small farmers who produce animals in addition to crops. After harvest of grain of mungbean or cowpea, biomass can be returned to soil to contribute nitrogen or to feed animals.

Association of rice-based systems with livestock production

Most small rice farms have livestock, but because attention is given to crops, livestock traditionally are fed crop residues and weeds and are allowed to graze. In some cases, pigs and poultry are also semiscavengers, finding part of their feed around the farm. Such low level of inputs and haphazard management naturally result in poor growth and reproductive rates, compounded by diseases and parasites.

In order to help rice farmers with livestock management, current technologies in rice-based farming systems need to be reviewed to identify cropping systems and crop varieties that could provide more legume herbage for animals, especially during the dry season when feeds are scarce, without unduly sacrificing grain yields. In addition, there are benefits of using animal manure and compost to replace part of the needed inorganic.

Advances in animal breeding and health also must be made to facilitate development of more productive crop/livestock systems for small farms. Draft animals that are also used for meat production or triple-purpose (meat-milk-draft) animals are better suited to small farm conditions than single-purpose breeds.

Collaborative research on livestock in rice farming systems started between staff of the University of the Philippines at Los Baños and IRRI in 1984. On-farm crop-livestock research is now under way at sites in the Philippines, Thailand, Nepal, Indonesia, and Sri Lanka through collaboration with the Ministries of Agriculture in those countries. On-station research concentrates on forage crops that can be grown as either monocrops or intercrops on small farms, on dual-purpose crops for food and fodder, on feed quality evaluation of crop residues and by-products, and on pesticide levels in crop residues.

PLANT BREEDING FOR NEW RICE-BASED FARMING SYSTEMS

Rice

Plant breeding for rice to fit into multicrop sequences means making certain adjustments. The rice crop has to be squeezed into a shorter growth period in order to accommodate additional crops (rice or other), or improved rices have to be developed for more adverse conditions, meaning deeply flooded and waterlogged fields, and drought-prone conditions at the start and end of the monsoon. IR36, which was released in 1976, together with improved weed management practices and direct seeding techniques, has made the introduction of an extra crop possible in many areas. Varieties with shorter duration and high yield capacity now include IR58 (100 days), which should help to stimulate farmers to move to a more intensive system. New improved varieties with drought and flood tolerance will help efforts to intensify cropping in adverse environments.

Other cereals

Maize and sorghum are commonly used for crop intensification in rice-based cropping systems. Maize varieties must be early maturing and have stable yield, drought and waterlogging tolerance, and resistance to maize borer and, in many areas of Asia, resistance to downy mildew. For sorghum the desirable characteristics are high, stable yield, good ratooning ability, drought and waterlogging tolerance, good seedling vigor, spreading head, and in Asia resistance to headworm and rhizoctonia.

For 3 years, the Philippine Institute of Plant Breeding (IPB) evaluated several hundred varieties of maize and sorghum grown before and after rice. Sorghum evaluation before rice was discontinued because yield levels were low and the harvest tended to occur in the wet season. The most promising varieties from the screening and from national programs were submitted to IRRI and subsequently evaluated at sites of the Asian Rice Farming Systems Network and at Philippine cropping systems sites. The top eight field maize entries had an average yield of 2.3 t/ha. The best two green maize varieties had a marketable ear yield of 5 to 7 t/ha. The most promising sorghum entries with 100-day maturities in IRRI trials yielded 3.2 to 3.7 t/ha. One variety produced a yield of 3.6 t/ha in 82 days.

In 1983-84, a total of 127 sorghum genotypes from ICRISAT and IPB were tested. Screening was conducted directly in a postrice environment under zero tillage. There was a wide variability among the different genotypes in all the plant characters observed. Forty-nine entries were selected for further testing based on grain and fodder yields, growth duration, and plant height. Eight yielded more than 4 t/ha.

Grain legumes

Grain legumes commonly grown in the tropics after rainfed lowland rice or upland rice are mungbean, cowpea, and soybean. Peanut is also common after upland rice.

IRRI fosters grain legume improvement through international and national collaboration. IRRI collaborates with many national programs and with IITA on cowpea and soybean improvement in rice-based cropping systems. Through IPB of the University of the Philippines at Los Baños, collaborative work is carried out with several other centers for development of mungbean, peanut, and soybean varieties for rice-based systems.

Cowpea. Cowpea is grown for dry seed, green pods, animal fodder, and green manure in rice-based cropping systems in Bangladesh, India, Philippines, Indonesia, Thailand, and Sri Lanka. The IRRI and IITA grain legume collaborative program develops and identifies varieties that are early maturing, resistant to insects and diseases, high yielding, and tolerant of drought and excessive moisture. Varieties identified for dry seeding in prerice environments produce 1.0 to 1.3 t/ha in 55 to 67 days or 1.5 to 2.0 t/ha in 70 to 75 days. These varieties are being evaluated in national programs through the Asian Rice Farming Systems Network.

Soybean. Soybean is cultivated for protein and oil in rainfed as well as partially irrigated areas. IPB developed UPLSY-2, which has been released in the Philippines. Several new varieties have been found to be promising after rice at IRRI. Recently, IITA, AVRDC, International Soybean Program (INTSOY), and IPB agreed to collaborate in developing and identifying tropically adapted varieties — for planting after rice — that have better seed longevity, insect and disease resistance, and drought tolerance. Promising varieties from these centers and national programs will be tested in tropical Asia.

Mungbean. Mungbean, being a short-duration crop, is often grown before and after rice in the Philippines, Indonesia, Thailand, Sri Lanka, and Bangladesh. The major breeding objectives at IPB are to develop varieties that are early maturing, high yielding, resistant to diseases (Cercospora leaf spot and powdery mildew), and drought tolerant. Through hybridization and selection, IPB has developed several varieties for intensive cropping systems that mature in 60 to 65 days and have a yield potential of 1.2 to 1.5 t/ha.

Peanut. Peanut is an important source of protein and oil for many rice farmers and is commonly grown after upland rice in South and Southeast Asia, but the yields are held down by disease and drought stress. IPB has been involved in identifying early maturing varieties that are resistant to diseases and drought tolerance. These peanut varieties along with breeding lines from ICRISAT are being tested after rice in several Asian countries.

Pigeonpea. Pigeonpea has promise as an upland crop after rice. IRRI collaborates with ICRISAT in identifying early maturing, high yielding, and disease-resistant varieties. Several early maturing varieties that have a seed yield of over 2 t/ha have been identified. These varieties now are being tested at various cropping systems sites in the Philippines.

Testing and Evaluation in National Programs. Improved mungbean and cowpea varieties for dry seed or green pods have been tested in the Philippines, Thailand, Malaysia, Bangladesh, and Sri Lanka. The best yielding varieties are also used in cropping pattern testing at several locations in these countries. Several national programs have released high yielding and early maturing varieties for cultivation.

Root crops

Sweet potato varieties were screened for intensive cropping under rainfed lowland conditions before and after rice cultivation by the IPB of the University of the Philippines at Los Baños in collaboration with IRRI. Varieties were evaluated for earliness, high tuber and vine yields, and resistance to pests, particularly weevil. For the prerice environment, more than 100 varieties were screened under shade to simulate intercropping conditions in the field. Tuber yields were very low (5 t/ha), although in some varieties, vine yields were observed to be encouraged by shading. In the postrice screening, more than 300 varieties were evaluated. Varieties that had yields comparable to a local variety that can yield 25 t/ha in 120 days were considered promising. Fifteen promising varieties were then turned over to IRRI for multiplication, distribution, and testing at the Philippines' cropping systems sites.

SOIL AND CROP MANAGEMENT

Research on soil and crop management in multicrop systems is basic to advances on rice-based farming systems. There are formidable soil and water management problems in moving from a lowland rice monoculture to a mixed cropping system involving three or four upland crops.

Research and training at IRRI in the late 1960s showed that well-controlled irrigation and drainage crops could be relay planted between the rows of the preceding crop, enabling land and time to be used efficiently for photosynthesis. Although the cropping sequences required high levels of labor use for crop establishment, care, and harvesting, labor needs were spread over the year.

This research demonstrated that the agricultural production potential of rice-based cropping systems was high. As the objective was to demonstrate the production potential, many constraints (physical, farm resource, marketing, and management) were either overcome by technical means or ignored.

Following the successful demonstration of cropping potential, the next step was to increase multiple cropping under conditions that confront farmers. For this purpose on-farm trials were initiated at selected sites.

On heavy-textured rainfed lowland rice fields, it was found that crops grown in sequence with rice had erratic yields. A major cause was the timing of sowings in relation to rainfall, which may be too high or too low. Because simple solutions to the problem could not be found, research was initiated to examine soil and crop relations more critically. Important to crop emergence and root development are factors that influence water and oxygen status, mechanical impedance, nutrient uptake, and toxicities.

After a rice field is drained and harvested, moisture in the surface soil layer decreases rapidly. For seeding the following crop, moisture is in the optimum range for only a few days. Mechanization allows sowing to be completed rapidly and more reliably. Field studies also suggested that modification of mechanical placement techniques could widen the moisture range from which a high emergence percentage will be obtained.

Once the crop emerges, root development may be detrimentally influenced by the presence of a perched water table. Although mechanical impedance may hamper root penetration if the lower part of the plow layer dries before roots pass through it, mechanical impedance would not be critical if the crops were planted within a week. Low levels of oxygen and presence of toxic compounds appear to be more harmful than mechanical impedance. For example, a study in which radioactive ^{32}P was used to locate the positions of active roots showed that deep fertilizer placement increased root proliferation and that absence of phosphorus fertilizer reduced proliferation. These results suggest that the availabilities of nutrients, particularly phosphorus, are low following the harvest of a rice crop from a puddled soil.

A survey of lowland rice fields at 34 locations in 5 countries found that shear strengths — measured by a cone penetrometer — often exceed the 2 MPa (or 20 bars), which is sufficient to seriously limit extension of roots of maize and other crops.

Nonetheless, after the harvest of lowland rice from puddled soils, water may well be plentiful in the soil below the compacted layer, and this water would be available to a postrice maize or legume crop provided that the roots — and also oxygen — could penetrate the layer. Such penetration can be made possible by disrupting the compacted layer with a subsoiler tine, for example, or by ensuring that the turnaround time (the interval between rice harvest and planting of the follow-on crop) is short enough that the roots of the new seedlings encounter the compacted layer when it is still moist and therefore weak. At IRRI, experiments with both maize and mungbean have shown that disruption of the compacted layer, with disturbance of the soil to 35 centimeters deep, does result in a rapid root penetration when seeds are planted along the tilled strip as soon as possible after the tillage is done.

Grain yields for mungbean planted promptly after field draining were as high as 2 t/ha. When planting was delayed by only 2 days, grain yields decreased by about 20 percent. Grain yields of 1.5 to 2.1 t/ha were achieved with no fertilizer or irrigation, though there was rigorous weed and pest control. The crops essentially grew on the water stored in the soil since there was little rainfall.

The high yields achievable by these techniques derive in part from precision manual seeding, so that the uniformly planted crop makes effective use of sunlight. The advantage of quick turnaround is that the roots can penetrate quickly when the soil shear strength is low, and hence fully exploit the soil's water reserve.

INSECT PESTS IN MULTI-ENTERPRISE SYSTEMS

The role of the entomologist in cropping systems programs is to develop appropriate insect control technology that farmers can utilize. A methodology was developed, based on yield loss assessment, for safe, economic insect control recommendations.

Treatments established at on-farm research sites and replicated over farms measure yield losses by growth stage. Analysis of yield loss data from the research sites has provided several surprising findings, which have allowed control efforts to be focused on the growth stages during which yield losses are greatest. This permits farmers to use their scarce resources more efficiently.

For example trials have shown that the rice in double rice-crop patterns in rainfed sites had minimal insect damage. Low losses in the first crop in the early rainy season are attributed to the earlier planting date and subsequent slow buildup of insect pests after a 3- to 4-month fallow period. This explanation is corroborated by light trap catches, which show a slow rise in insect numbers after the dry season.

Yield loss studies on the second rice crop revealed that by far the most significant insect damage occurs during the vegetative stage. This finding led to the realization that whorl maggot (*Hydrellia philippina*), caseworm (*Nymphula depunctalis*), green semilooper (*Naranga aenescens*), and hairy caterpillar (*Rivula atimeta*), which are considered insignificant when they occur alone, can cause economic damage when they occur in combination. Consequently if farmers carefully monitor the vegetative stage for these pests, insecticide applications, which had been thought necessary at all growth stages, can be substantially reduced.

Insect control recommendations often are made on a nationwide basis, but the on-farm cropping systems trials show that this approach can be extremely wasteful, and they suggest the need for more regional testing using the yield loss method. In 5 years of trials in Pangasinan, Philippines, for example, untreated mungbean grown after rice averaged 75 percent yield loss, which could have been prevented with four insecticide sprays. But mungbean grown before rice in Cagayan suffered only 18 percent loss (average of 2 years of trials), which was uneconomical to prevent with insecticide. Most damage was done by pod borers, principally *Heliothis armigera*, in the postflowering stage. The farmers' method of sowing mungbean in rice stubble depresses populations of several preflowering insect pests — beanfly, thrips, and leafhopper. As a result minimum tillage methods that leave some rice stubble in the field are desirable.

RICE-BASED FARMING SYSTEMS AND TECHNOLOGY DISSEMINATION

The integration of new rice technology into more productive farming systems requires innovation in crop varieties and their management. That search has given rise to both new farming techniques and a methodology that other researchers may follow to identify and solve problems of agricultural production in a systems context. Involvement of national program staff in farming systems research ensures that both technology and research methodology are widely brought to bear on rice farming systems.

Multilocation testing

Farming systems research sites are chosen to represent much larger areas that are targeted for development. Promising technology is identified at sites through an iterative process of design and testing and specified in a set of recommended practices that researchers expect to be acceptable to farmers and more productive than their present practices.

Following technology development at a few sites, multilocation testing is undertaken to verify the suitability of new technology over a larger area. The results of multilocation testing permit technical advice to be formulated for farmers and the establishment of the conditions under which the technology can be recommended. The conditions for which a technology is recommended, referred to as the *domain of adaptation* or the *recommendation domain*, denote the biophysical and socioeconomic features of the environment needed to support the technology. If successful, they form the basis for a production program such as the successful Kabsaka program of the Philippine Ministry of Agriculture and Food in Iloilo Province.

Production programs

A production program is a plan that provides support services to facilitate adoption of new technology. The plan may only give information to farmers through extension channels or it may include credit, marketing assistance, and other infrastructural services as well.

Alternatives to farmers' present practices often require additional resources such as seeds (of a new variety), fertilizers, chemicals, equipment (such as sprayers), and additional labor. Agricultural suppliers may need to be established, expanded, or reorganized to meet new input requirements. If farmers lack cash to purchase inputs, credit facilities may be needed. To communicate the recommended cropping practices, the extension service may need to be expanded, reorganized, and strengthened through training. The increased output resulting from adoption of recommended technology may require improved transport facilities, expanded storage, or government support to stabilize prices. To oversee and coordinate these activities, a public or private management institution may need to be created.

As in the case of multilocation testing, IRRI has developed and disseminated procedures to implement production programs. Again, IRRI's contributions have been through methodology development, training, and country visits by IRRI scientists. Training includes monitoring tours, which expose national production specialists to the approaches used in other network countries.

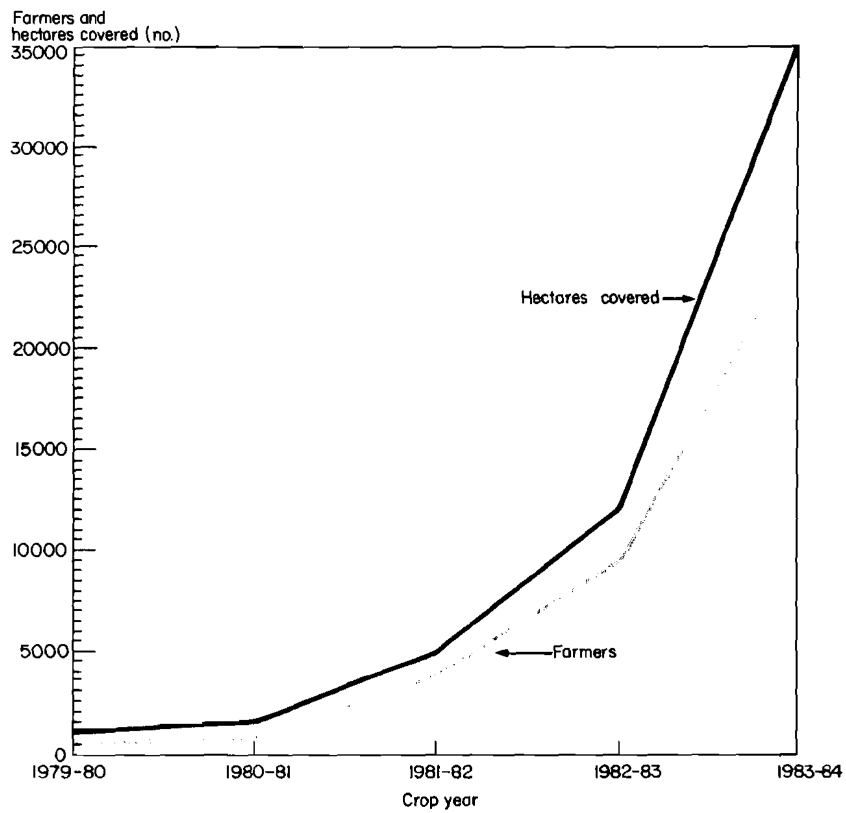
After 3 or more years of site research, several national programs have implemented pilot production programs. Small production programs covering several hundred hectares are in operation in Nepal, Indonesia, Bangladesh, Philippines, and Sri Lanka. The programs cover the original research sites and other areas with the same environment as the original sites. The Philippines and Nepal are also implementing large production programs.

In the Philippines, IRRI's cooperation with the Ministry of Agriculture and Food (MAF) in cropping systems site research in rainfed areas has led to a successful production program under the Rainfed Agricultural Development Project, Iloilo, Region 6. The program is locally known as KABSAKA or *Bounty on the Farm*, and is financed by a World Bank loan.

The program aims to increase the intensity of land utilization in rainfed rice lands by introducing cropping patterns that allow farmers to harvest up to three crops annually. KABSAKA technology attempts to attune crop management to the environmental and agroclimatic conditions of the area. The basic technology involves an early first crop of dry-seeded or wet-seeded rice, immediately followed by a second rice crop (usually transplanted), and finally an upland third crop such as mungbean.

The area devoted to KABSAKA technology has rapidly expanded since its introduction in 1977. In 1977-78, the first year of the pilot extension phase, 169 farmers adopted the technology on 382 hectares. In the third year 600 farmers had adopted the KABSAKA program on 1,000 hectares. By 1983-84 the number of farmers in the program had increased to 25,624 and the area covered to 34,694 hectares (Fig. 1). It is estimated that 60,000 hectares will be covered by KABSAKA in 1986. Rice production of farmer-adopters have more than doubled from the 2.5 tons per hectare yield under traditional culture (Table 1). Net returns of adopters increased by about 108 percent in the first year of the expanded project and have been maintained in real terms in subsequent years.

There are still constraints that prevent farmers from attaining higher yields and higher net returns. Although in 1981-82 all farmer cooperators grew IR36, only a few used certified seed so yields were considerably lower than would have been expected from the variety planted. Also the lack of money resulted in long turnaround time between crops, lower than recommended fertilization rates, and underdosages of insecticides and herbicides. Although KABSAKA yields are higher than yields under traditional culture, they are



1. Number of farmers and area using KABSAKA technology, Iloilo, Philippines, 1979-80 to 1983-84 crop years.

Table 1. Rice yield of two-crop systems in rainfed lowland rice areas in Iloilo, Philippines, 1977-1983.

Year	Farmers (no.)	Yield (t/ha)		
		First crop	Second crop	Total
Pilot extension phase				
1977-78	88	4.9	1.5	6.4
1978-79	276	4.4	4.6	9.0
Expanded KABSAKA Project				
1981-82	4562	3.6	3.0	6.6
1982-83	9750	3.1	1.9	5.0

still low compared to the potential. Cropping intensities were still significantly below the potentially attainable level of 3.0, averaging only about 1.8 from 1981 to 1983.

Nepal has implemented production programs in two cropping systems research sites in the Terai (plains) and four sites in the hills. A total of 643 hectares of wheat were covered during winter; 1,274 hectares of rice and 35 hectares of maize during summer crop; and 12 hectares of *dhaincha* (a green manure) and 2.5 hectares of mungbean during spring. The programs in the Terai were expanded and in 1983-84, 17,000 hectares of winter crop were covered in five districts of the Central Development Region. The government plans further expansion.

ASIAN RICE FARMING SYSTEMS NETWORK

The Asian Rice Farming Systems Network was organized in 1975. In it, IRRI scientists and national program scientists work together to develop rice-based cropping systems technology in major rice environments in Asia. The network focuses on cropping pattern testing in farmers' fields. With the rapid expansion of some national programs to farming systems studies including livestock, aquaculture, and forestry, collaboration has expanded to other major problems in intensification.

National programs

One activity of the network is to help member nations organize a national coordinated farming systems or on-farm research program. The farming systems research methodology is applicable to systems involving only upland crops as well as to rice-based farming systems. The Philippines, Indonesia, Thailand, Sri Lanka, China, South Korea, Nepal, Malaysia, and Burma have organized national coordinated cropping or farming systems programs utilizing the organizational structure IRRI is promoting in the network.

The network in the future will help strengthen research activities at each site and encourage the multidisciplinary approach to cropping systems research both in experiment stations and farmers' fields. It will organize more collaborative research in research stations on major problems common in the region.

Cropping pattern testing

Cropping pattern testing is under way at 42 sites in 11 Asian countries. The sites were carefully selected to represent the major rice-growing environments in Asia. The aim at most sites is to find ways to increase production, net income, and cropping intensity. The experimental cropping patterns are always compared with the dominant cropping patterns used by farmers at each site.

Rice - wheat system

National programs involved in the Asian Rice Farming Systems Network, CIMMYT, and IRRI have agreed to jointly develop technology for rice - wheat systems in various environments. The first two projects are cropping pattern testing and integrated rice - wheat trials. Collaboration on rice - wheat cropping pattern testing is under way in Nepal, Bangladesh, Sri Lanka, and South Korea.

In Nepal, trials at four cropping systems sites are showing substantial increases in yields and incomes from introducing improved varieties and management methods into rice - wheat patterns. Use of earlier maturing varieties has made it possible to change from a rice - wheat pattern to a rice - wheat - upland crop pattern in some areas. In other areas where a single rice crop is traditionally grown, earlier varieties have made possible a rice - wheat pattern.

At one site in Bangladesh where deepwater rice is grown and where the traditional patterns are rice - wheat and rice - potato, researchers have found rice - potato - sesame and rice - mustard - mungbean to be promising. At an irrigated site, researchers are finding that the net income from rice - rice - wheat is slightly better than that from either rice - rice or rice - rice - rice.

In the southern part of South Korea, rice - wheat, a common pattern, gives high output, but cropping systems trials indicate that the net income it produces is only somewhat higher than that of a single crop of rice.

In the other project, International Rice-Wheat Integrated Trials, the objective is to identify better varieties of rice and wheat with multiple resistance to pests and diseases that fit the rice - wheat system. Philippines, Thailand, Indonesia, Burma, Sri Lanka, Bhutan, Nepal, Pakistan, Bangladesh, China, and South Korea participated in 1982-83 trials. CIMMYT provided 14 varieties of wheat. Wheat yields in 16 trials conducted in eight countries ranged from 0.2 to 5.4 t/ha. Yield levels tended to be higher at sites at higher latitudes.

The first rice trial, which started in 1983, contained one set of eight early maturing varieties and another set of eight early and medium maturing varieties from the International Rice Testing Program yield nurseries. Cooperators added two local checks. IRRI distributed early maturing sets to China, Egypt, Bangladesh, Nepal, South Korea, Bhutan, and Pakistan and 26 early and medium maturing sets to Malaysia, Bangladesh, Thailand, Philippines, Burma, Nepal, Indonesia, and Sri Lanka.

For the wheat trial in 1983-84, CIMMYT provided five varieties and each national program could add five varieties. However, in most tropical countries, four to five varieties from the Philippines Institute of Plant

Breeding were provided plus the five from CIMMYT. There were two sets of trials: one for optimum time of planting (around 15 Nov) and the other for late planting (around 15 Dec). IRRI distributed 22 sets for optimum planting and 20 for late planting.

Long-term cropping pattern and fertilizer studies

There is concern in the network that more intensive crop production may result in a rapid loss of soil fertility and productivity. As a result, network scientists have launched long-term cropping pattern and fertilizer studies to determine the effects of continuous cropping, using different crop rotations, on the soil and crop performance and to determine the residual effects of fertilization and other soil amendments on cropping pattern performance. South Korea, Nepal, Indonesia, Burma, Thailand, and China conduct studies in irrigated rice; Indonesia and Nepal in upland rice; and Bangladesh, Burma, and Indonesia in rainfed lowland rice.

Farming systems working group

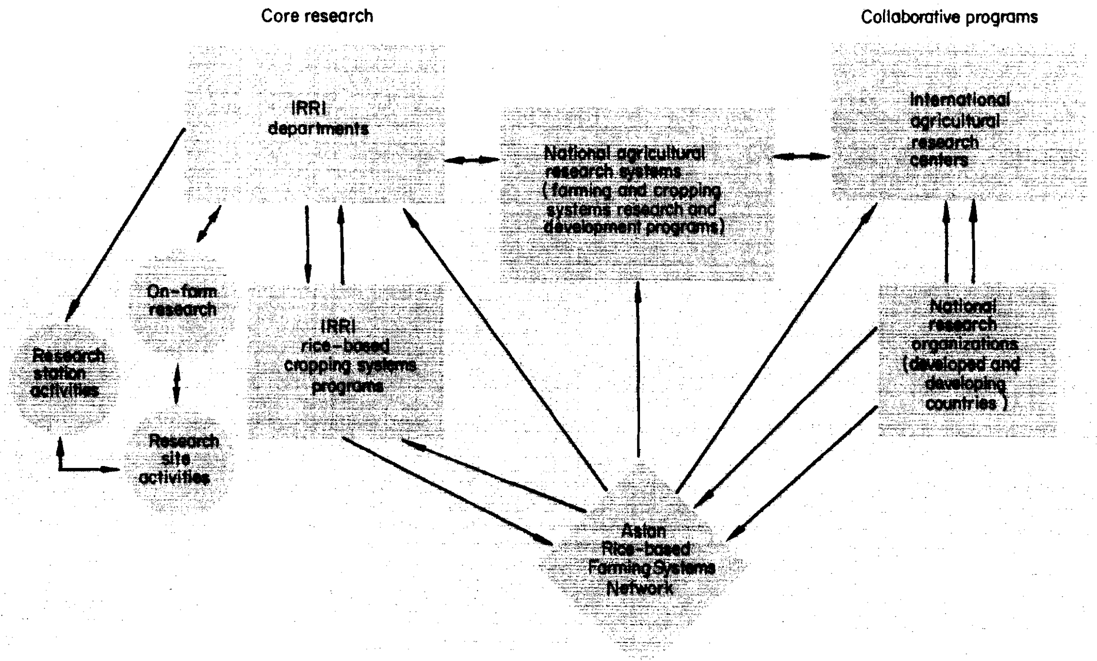
Since the network is a collaborative effort between IRRI and national programs, a working group has been created to review the progress of research, prepare plans for collaborative research, discuss issues to facilitate the implementation of farming systems research and development, and exchange research information. The members of the working group are program leaders from national programs, the farming systems network coordinator, and the network economist. Other key scientists in the region and IRRI serve as resource persons during the meetings. Meetings are held once a year with the location rotated among member countries. The manner in which the entire farming system program is organized, pooling the best available material and know-how from among international centers including IRRI and national research systems, is indicated in Figure 2.

Sharing of research information

The major role of the network is to facilitate exchange of research information among scientists in Asia and other continents involved in farming systems research. The Asian Rice Farming Systems Network has held 15 meetings since 1975. The network also organized a workshop on cropping systems in 1975, a symposium on cropping systems in 1980, a workshop on varietal improvement of upland crops in 1982, and a workshop on crop-livestock in 1983. Cropping systems topics were on the agenda of the 1982 and 1983 international rice research conferences. In addition, monitoring tours on farming systems, varietal improvement of upland crops, and rice - wheat systems have been organized by the network. Publications on cropping systems from IRRI and other sources are distributed to the collaborators. The collaborators also send papers to IRRI for multiplication and distribution in the network.

Training

An essential component of the network is training provided to national



2. Organization of Asian Rice Farming Systems Network.

program staff to develop the relevant disciplinary skills and interdisciplinary understanding for farming systems research. More than 429 program scientists have participated in IRRI's cropping systems training course since 1969.

SUMMARY

Advances in production through farming systems research depend upon both the development of technical linkages among farm enterprises as well as the integration of promising new technology into the system. The principal technical areas where significant advances have been made include: (a) intensification of rainfed rice-based multiple cropping through introduction of short-duration high yielding varieties, and direct seeding of the early rice crop, and (b) introduction of grain legumes into rice-based systems. Current research aims to increase and stabilize food production in flood- and drought-prone areas, diversify and improve crops used before and after rice on irrigated ricelands, enhance the linkage between rice systems and livestock production, and clarify the role of social organizations in intensifying farming systems..

The range of innovations that support the intensification of rice-based systems includes varietal improvement of rice and other crops, soil and crop management, pest management, and others. A structure for international collaboration has been established through the Asian Rice-based Farming Systems Network. Technical advances, including improved varieties of rice and other crops, are distributed and shared among the participants.

CHAPTER 7

IMPACT OF MODERN RICE TECHNOLOGY

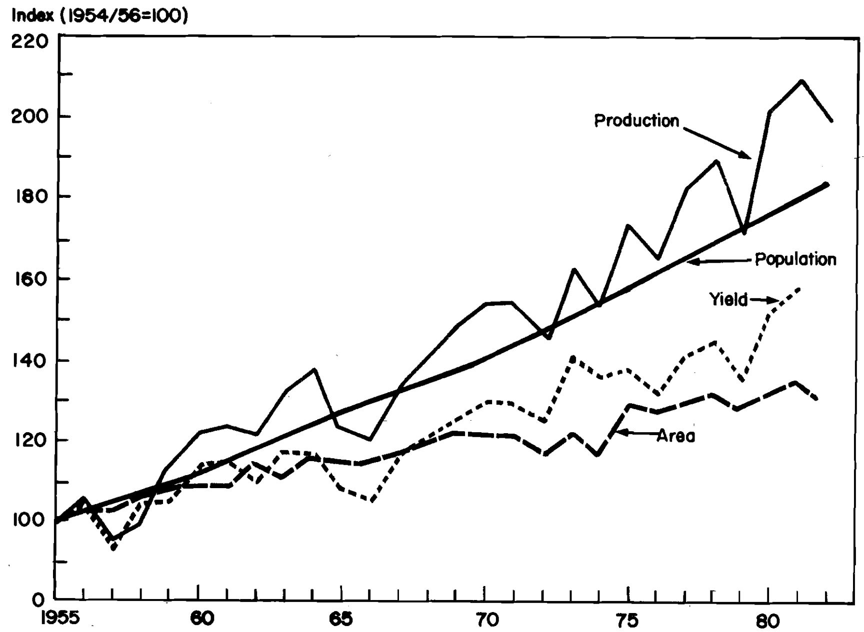
IRRI's goal is to increase food production to alleviate hunger among the Asian poor. The initial strategy adopted by biological scientists was to develop rice varieties with high fertilizer response in the tropical conditions under which most Asian rice is grown. Fertilizer is a reproducible factor and as technological advances have occurred, its price relative to the value of land and agricultural output has declined. It is therefore an economical substitute for land, which is an increasingly severe limitation to agricultural development as populations expand in most Asian countries.

The first generation of modern varieties was developed in experiment stations of Asia favored by well-controlled water, fertile soils, and other factors suitable for high production. While this narrow research focus made possible a major breakthrough within a short period of time, it did mean that the early modern varieties were environment specific, performing best under irrigated conditions.

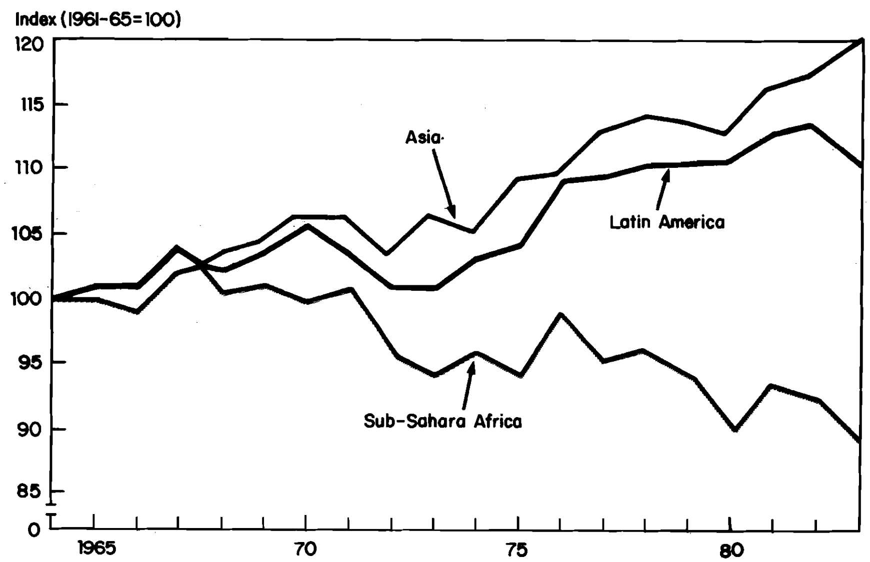
As the new seed-fertilizer technology spread, it became increasingly clear that more attention should be given to the complexity and diversity of the physical as well as the economic and social environment in rural South and Southeast Asia. Less than 40 percent of Asian rice area is irrigated while the greater part is characterized by rainfed and deepwater conditions. The higher cash inputs required to obtain the yield advantage of modern varieties further means that distribution of asset ownership, imperfect capital markets, and other social and institutional factors affect the adoption pattern and impact of the new rice technology at the farm level.

This chapter deals with the overall consequences of the modern varieties on production, yields, input use, and trade patterns and then examines the distributional implications of technical change in rice. Though rice variety is the focus of this analysis, it is recognized that fertilizer, irrigation, farm chemicals, and sometimes machinery are either components of the new technology or their use has accompanied the adoption of the new rice varieties.

The annual growth of rice production in South and Southeast Asia accelerated from 2.4 percent between 1955 and 1965 to 2.9 percent between 1965 and 1980, outpacing population growth (Fig. 1). In general, gains in per capita food production in Asia have been impressive compared with trends in other regions (Fig. 2). In sub-Saharan Africa, per capita food production actually declined throughout the 1970s.



1. Trends in population, paddy production, area and yield in South and Southeast Asia, 1955-82.



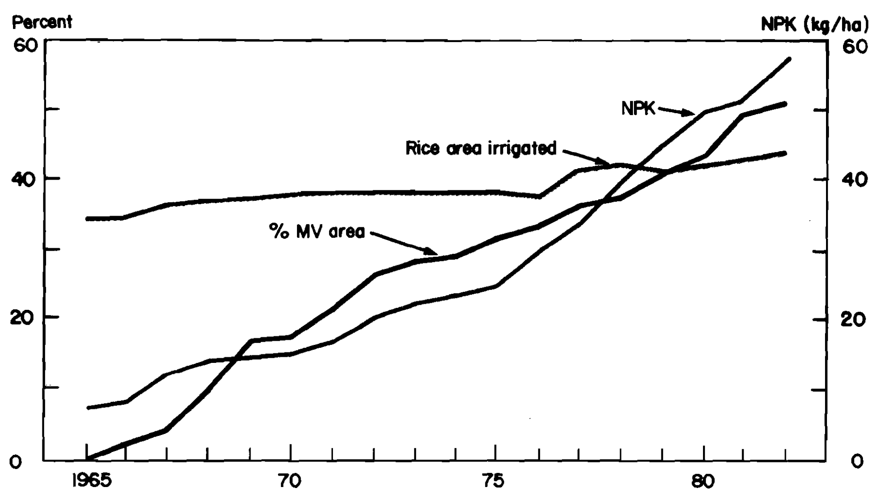
2. Trends in per capita food production in Asia, Latin America, and sub-Sahara Africa, 1961-65 average and 1965-83.

Table 1. Growth rates in rice production, area, yield and their contribution to output gains before and after introduction of modern varieties in South and Southeast Asia.

	1954-56 to 1964-66	1964-66 to 1979-81
Annual growth rate (%)		
Production	2.4	2.9
Area	1.4	0.9
Yield	1.0	2.0
Contribution (%) to output growth		
Area	58	32
Yield	42	68
Modern varieties		21
Fertilizer		22
Irrigation		25
Total	100	100

The primary basis of production growth in Asian rice shifted from crop area expansion in the decade before 1965 to increases in yield through more intensive cultivation in the decade after 1965. As annual yield increases doubled from 1.0 percent to 2.0 percent, about three-fourths of the growth in rice production was caused by yield improvements compared with only about 40 percent in the previous period (Table 1). Growth in crop area planted to rice slowed from 1.4 percent to 0.9 percent a year as its contribution to rice production declined from almost 60 percent to only about 30 percent.

IRRI research has shown that modern varieties have contributed 21 percent of the increase in rice output between 1965 and 1980, or, in absolute terms, more than 27 million tons of paddy annually in the 11 major rice producing countries. Modern varieties have also indirectly contributed to higher rice production because fertilizer-responsive varieties raise the profitability of investing in fertilizer and irrigation. By 1980, 40 percent of rice area in Asia was planted to modern varieties, and fertilizer use per hectare was eight times higher than in 1965 (Fig. 3). Despite the slow rise in the proportion of



3. Trends in rice area irrigated, area planted to modern varieties (MV), and fertilizer (NPK) use per hectare, South and Southeast Asia.

irrigated land, irrigation has contributed slightly more to production growth than fertilizer or modern varieties because of improvements in the quality of irrigation (Table 1).

The production impact of the faster maturing varieties introduced in the 1970s is ignored in the above analysis because of the problem of quantification. Nevertheless, by making it possible to escape drought in the areas with short water supply and to crop more intensively in areas with ample water, shorter growth duration may be as important a factor as high yield in the contribution of varietal improvement to increased rice production over the past two decades.

Modern varieties and production

The diffusion of modern varieties has not been uniform across countries (Fig. 4). In Thailand and Bangladesh, where adoption rates are relatively low, production growth continues to depend mainly on area expansion (Table 2). Growth rates in yields in fact decelerated over time as production spread to marginal areas. In Burma, though use of modern varieties is still comparatively low, adoption sharply accelerated in the late 1970s because of a special production program and an increase in farm prices.

Adoption rates of modern varieties in the Philippines, Indonesia, India, Pakistan, Sri Lanka, and Malaysia are from 50 to 80 percent of rice area. Growth rates in rice yields in those countries, except for Malaysia, have risen sharply since 1965 and modern varieties have contributed about a quarter or more to the growth of rice output.

4. Rate of adoption of modern varieties in nine Asian countries.

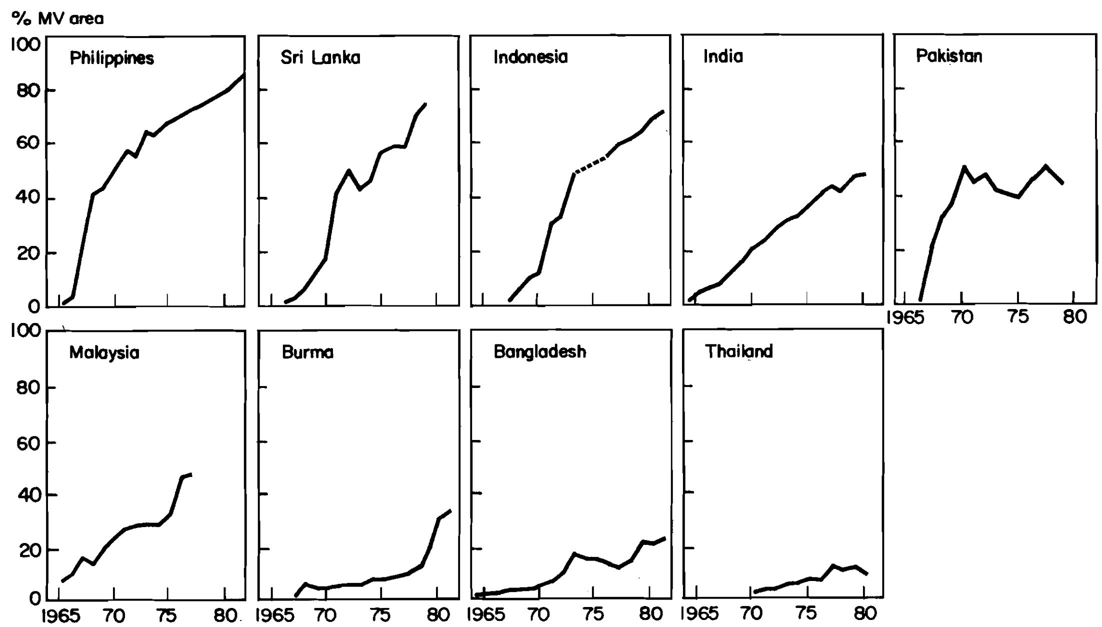


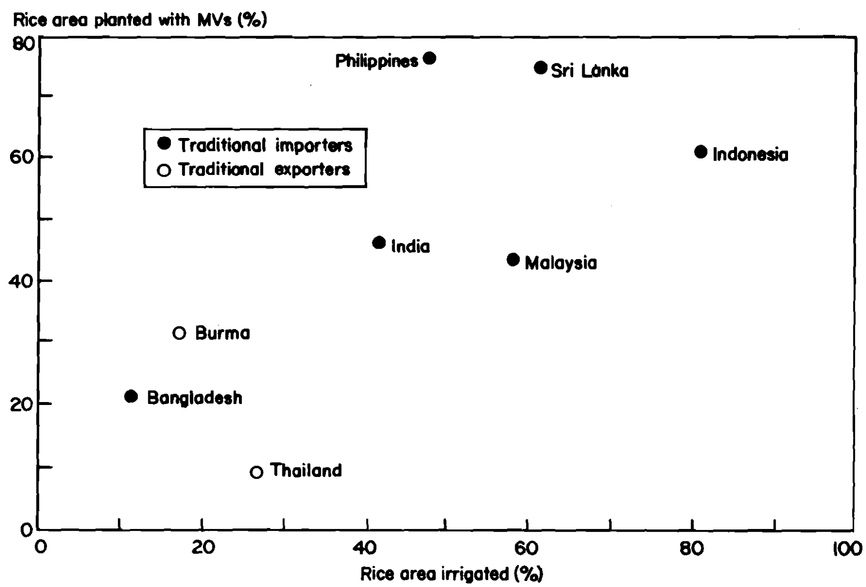
Table 2. Trends in rice yields and contribution of area and yield-increasing factors to rice production growth in selected countries of South and Southeast Asia.

	Annual growth of yields (%)		Contribution (%) to output growth					
			1954-56 to 1964-66		1964-66 to 1979-81			
						Yield		
	1954-56 to 1964-66	1964-66 to 1979-81	Area	Yield	Area	MV[a]	Fertilized	Irrigated
Bangladesh	1.9	1.1	39	61	50	7	23	20
India	0.3	1.9	81	19	14	23	31	32
Indonesia	1.9	3.2	34	66	37	23	20	20
Malaysia	2.2	2.0	58	42	47	na	na	na
Pakistan	1.1	3.6	77	23	40	na	na	na
Philippines	0.7	3.8	68	32	19	26	31	24
Sri Lanka	1.6	3.2	56	44	31	23	21	25
Burma	1.0	3.3	63	37	9	35	19	37
Thailand	0.9	0.4	68	32	63	13	10	14

[a]Modern varieties.

Modern varieties and irrigation

Because modern rice varieties developed so far have been more suited to irrigated and favorable rainfed lowland conditions, intercountry differences in adoption rate are clearly related to the proportion of area irrigated and inadvertently to the historical trade position of Asian countries (Fig. 5). Countries with low adoption rates are those where less than 30 percent of rice area is irrigated — Thailand, Burma, and Bangladesh. In these countries, rice is cultivated in large deltaic areas where the cost of developing an effective water control system (to apply and remove water, as needed) is high. Except for Bangladesh, these countries have traditionally exported rice because of a



5. Proportion of rice area irrigated and planted with modern varieties, 1980.

relatively high land-man ratio and a natural comparative advantage in producing rice relative to other crops.

Countries with high adoption rates are also those where cost of irrigation is relatively cheaper and therefore the ratio of irrigated area higher. Yet, the Philippines, where the proportion of irrigated area is comparable to that of India, has a much higher rate of modern variety adoption. The reason is that a large part of the Philippines' rainfed land is characterized by favorable lowland conditions where the short-statured modern varieties also have a yield advantage. In India there is relatively more rainfed rice area that either has deep water conditions or is drought prone. Under such conditions, modern varieties show little advantage over traditional varieties. The countries with high adoption rates have traditionally imported rice mainly because the supply of land is low relative to the population. Malaysia, which continues to import rice, has abundant land, but it is more suited to tree crops than to rice.

Because the early modern varieties have been best suited to irrigated conditions (which the importing countries had developed to a greater extent than exporters) and because of the strong political desire for self-sufficiency in importing countries, the regional impact of the adoption of modern varieties has been to lower the cost per kilo of producing rice in traditional importers more than in traditional exporters of rice (Siamwalla and Haykin 1983). As traditional importers moved closer to rice self-sufficiency by the late 1970s, the level and pattern of international trade in rice changed. In the mid-1960s, South and Southeast Asia was basically self-sufficient in rice at a regional level with exports about 3 percent above imports (Table 3). By the early 1980s, as several importing countries reached self-sufficiency, net exports of the region as a whole became very substantial. Rice imports remained fairly constant, while exports particularly to the Middle East and Africa rose sharply.

The changing pattern of trade and self-sufficiency ratios of individual countries is influenced not only by production growth but also by demand and trade policy factors. Substantial gains in self-sufficiency ratios were achieved in Malaysia, Sri Lanka, and the Philippines but not in India, Indonesia, and Bangladesh (Table 4). Export surpluses declined in Burma, but increased in Thailand. Per capita rice availability, however, rose in all countries except Bangladesh, where modern varieties have had the least impact.

IMPACT ON INCOME DISTRIBUTION

The broad benefits of the new rice technology on rice production and yields are clear. It is the distribution of the benefits that stirs disagreement. In the

Table 3. Trends in Asian rice imports and exports and share in world rice trade.

	Imports		Exports		Net exports (million tons)
	Million tons	% of world	Million tons	% of world	
1964-66	5227	67	5382	68	155
1980-82	6015	48	7707	61	1692

Table 4. Adoption of modern varieties, extent of irrigation, and trends in self-sufficiency among traditional Asian rice importers and exporters.

	Self-sufficiency ratio[a]		Annual growth in per capita consumption (%)
	1964-66	1979-81	1964-66 to 1979-81
Traditional importers			
Bangladesh	97	98	–0.1
India	98	101	0.7
Indonesia	95	93	3.4
Malaysia	66	86	2.2
Philippines	89	103	1.1
Sri Lanka	49	88	0.7
Traditional exporters			
Burma	126	110	2.8
Thailand	128	138	1.2

[a]Production divided by production plus net imports.

early literature on the Green Revolution, scholars studying the same events and sometimes the same data sets, drew opposite conclusions in part due to methodological and definitional issues. At one extreme were those who believed the technology was widening the gap between the rich and the poor (Frankel 1971, Griffin 1974). At the other extreme were those who saw technological change as a necessary component of development and who separated the issue of economic growth from the issue of distribution (Hayami and Kikuchi 1981). It is generally accepted, however, that distributive effects of technical change depend on the nature of the technology, the nature of the demand for the commodity, the pattern of ownership of resources, and the overall social and institutional context in which it occurs.

Producers vs consumers

The distribution of benefit from technical change between producers and consumers depends essentially on what happens to market price. Technical change shifts the supply curve downward or lowers the per unit cost of production. In closed economies, where demand for rice will typically be inelastic with respect to price, technical change will lead to a price decline that will be more rapid than the increase in quantity demanded that results from the lower prices. Therefore, consumers will gain more than producers as domestic rice production increases.

In open economies, demand elasticities will be quite high because expanded production can be sold in the world market with much less impact on world prices, enabling producers to capture part if not all the benefits from modern varieties. In this case, price will fall only to the extent that technological change occurs in many countries and then has an effect on the world supply curve. Producers rather than consumers will likely receive relatively more of the benefits of productivity change. Government trade and marketing policies, however, influence the ultimate effect of technological change on prices.

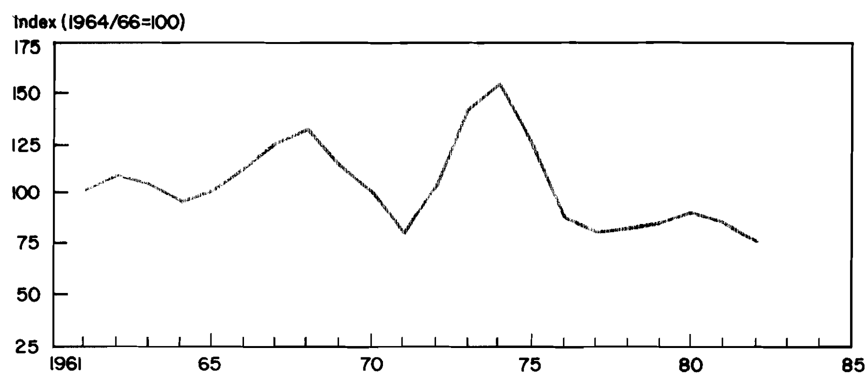
Increased rice availability has contributed to the 11 percent decline in average real world price of rice between the 1960s and the 1970s (Fig. 6). If the unusually high world prices of 1973-75 are excluded, the decline in average real world price is 27 percent. Price increases in the early 1970s reflected bad weather and a global shortfall in grain production, as well as reduced productivity of early modern varieties due to disease susceptibility. The second generation modern varieties, released in the mid-1970s, have led to steady production growth and contributed substantially to the current situation of stable to declining prices.

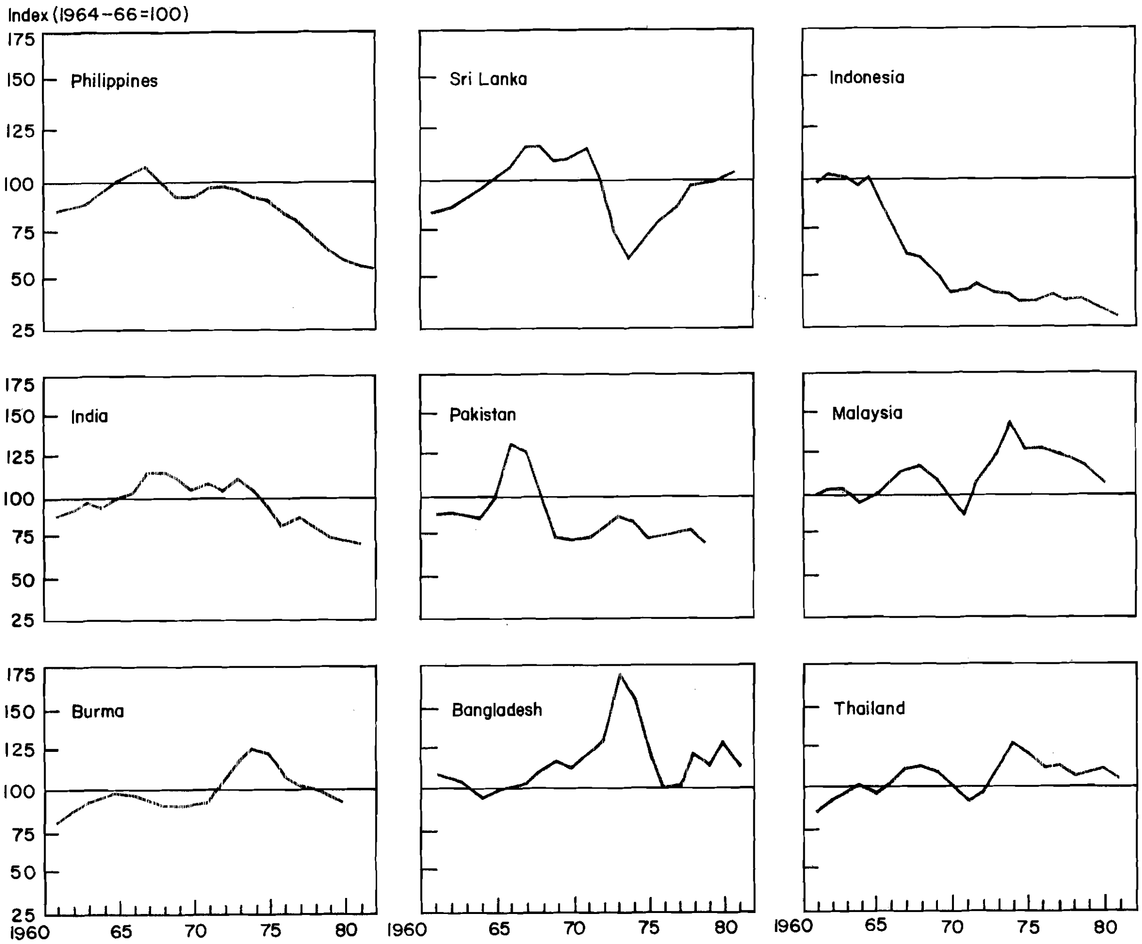
Changes in productivity and government price policies influence movements in real rice prices. In countries with high adoption of modern varieties, real rice prices generally fell, but they remained about the same or even rose in countries with relatively low adoption rates (Fig. 7). As self-sufficiency was approached in traditional importing countries — Philippines, India, Indonesia — the real price of rice steadily decreased. In contrast to Pakistan, where rice is also a major export, domestic real price of rice in Thailand did not follow the decline in real world price because export-related taxes were adjusted to protect farmer incentives. In Burma and Bangladesh, the limited technical progress as well as government trade and market policies explain the relatively constant levels of the real rice price. In Malaysia where income per capita has already reached high levels, the government has maintained the real price of rice to protect farm incomes.

Lower real prices of rice clearly benefit both urban and rural consumers by raising real income and indirectly by improving nutritional intake. The budget share of rice in the total expenditures of the poorest quartile of the population is typically at least double that of the upper quartile. The demand for rice among poorer households is 75 to 100 percent more responsive to rice price than the demand of the higher income group of households. Consequently, a fall in real rice price will raise real income of the low income household relatively more than the rest of the population.

Between 1975 and 1980 when the real rice price declined by 20 percent in Indonesia and 30 percent in the Philippines, there should have been a 20 percent increase in rice consumption by the poor in Indonesia and a 21

6. Trends in real world price of rice, 1961-82.





7. Trends in real price of rice in selected Asian countries.

percent increase in the Philippines. Regalado (unpublished MS thesis, University of the Philippines at Los Baños, 1984) showed that an 18 percent decline in rice price would allow members of the lowest income group in the Philippines to satisfy their minimum calorie intake. Thus, the declining real prices caused by production growth should have had a substantial impact on the calorie intake of the poor.

Whether rice producers as a whole gain as much as consumers from technical change is unclear. Evenson and Flores (1978) estimated total benefits from rice research in Asia from 1950 to 1975 (Table 5). The impact of national research and IRRI-type new varieties was estimated using a range of yield effects and demand elasticity of -0.3 and supply elasticity of 0.4. The calculations showed that rice research increased yields enough to provide benefits valued at $268 million to $310 million per year. Consumers gained at the expense of producers in that analysis because a closed economy model was assumed. In Colombia, where rice exporting was prohibited, high rates of

Table 5. Estimated annual benefits from rice research (million US$).[a]

Years	Producer's gain High	Producer's gain Low	Consumer's gain High	Consumer's gain Low	Social gains High	Social gains Low
			National research institutions			
1950-60	−25.9	—	52.0	—	26.1	—
1961-65	−53.1	—	107.0	—	53.9	—
1966-71	−211.4	−186.6	431.7	374.1	220.3	190.4
1972-75	−403.2	−190.1	414.3	387.0	211.0	196.9
			IRRI			
1966-71	−133.4	−70.4	270.2	141.7	136.8	71.3
1972-75	−87.3	−60.7	176.0	141.6	88.7	71.9

[a]Source: Evenson, R. E. and P. Flores. 1978. Social returns to rice research. In *Economic Consequences of the New Rice Technology*. International Rice Research Institute, Los Baños, Philippines.

return on rice research showed a similar pattern of gains to consumers and losses to producers (Scobie and Posadas 1978).

IRRI studies indicate that such a pattern of distribution of benefits will not occur in many Asian countries where rice is still grown as a subsistence crop. Even if demand is inelastic, when part of production is retained by the farm household, rice farmers also gain as consumers from a technology-induced fall in rice price. Given inelastic demand, the distribution of benefits will be directly related to the proportion of output retained and eaten by farm households. For the Philippines, the benefits from the introduction of modern rice varieties are evenly shared between producers and consumers (Table 6). Among producers, small farmers (who consume a greater proportion of their output) gain while larger farmers tend to lose. Technical change in rice then transfers income from large commercial farms and landlords to the urban poor, rural landless, and small farmers.

These results only hold, however, if the technological change is adopted by small and large farmers alike and is pervasive enough to shift the aggregate

Table 6. Estimates of the changes in consumers' surplus and producers' income due to technical progress in rice production for two assumptions on producers' home consumption.[a]

	Estimated changes[b] in: Fixed home consumption	Estimated changes[b] in: Variable home consumption	Difference[c]
Price	−14.3	−13.6	1.7
Quantity	4.3	5.0	0.7
Consumers' surplus	5.7	5.0	−0.7
Producers' cash revenue	−1.4	−1.1	0.3
Production cost	−2.8	−2.3	0.5
Producers' cash income	1.4	1.2	−0.2
Producers' home consumption	0	2.0	2.0

[a]Source: Hayami, Y. and R. W. Herdt. 1977. Market price effects of technological change on income distribution in semi-subsistence agriculture. *American Journal of Agricultural Economics* 59:2. [b]Assuming η (price elasticity of demand) = 0.3, β = 0.4, k (shift in supply schedule) = 10%, r (ratio of marketable surplus to total output) = 0.4, δ (elasticity of home consumption) = 0.4. [c]Fixed home consumption − variable home consumption.

supply function and lower prices. If the technological change is monopolized by a very few large farmers, or if prices are not permitted to respond to the new technology, then large farmers could indeed capture the major part of the gains from technical change, denying them to both small farm and consumer. If small farmers do not adopt the new technology, then again they do not receive the benefits. Thus an important issue is whether certain groups of farmers are systematically excluded from participating in the new technology.

In analyzing the impact of technical change on distribution of benefits among rice producers, there are three central concerns: distribution among landlords, tenants, and landless households through employment effects, distribution between small and large farms, and distribution between favorable and unfavorable environments.

Modern varieties and employment

One way adoption of modern varieties can affect income distribution is through its impact on labor. Poor households derive income mostly from selling their labor, while richer households typically own land and other forms of capital as well. If adoption of modern varieties reduces labor use, the income of tenants and landless workers relative to landowners will deteriorate even if the new technology is neutral to the scale of operation.

Adoption of modern varieties has had direct and indirect effects on employment. Table 7 summarizes several studies that analyzed direct employment effects in Asia by comparing labor use between farms using modern and local varieties. Most of these studies use cross-section data at a single point of time, except for the Philippine studies where changes in the same farms over time have been monitored.

Table 7. Amount of labor used by farmers at 13 locations in Asia to grow modern or local rice varieties.[a]

	Labor use (man-days/ha)		Labor productivity (kg/man-day)		
Location	Modern variety	Local variety	Modern variety	Local variety	Study years
Suphan Buri, Thailand	117	81	29.3	25.6	1971-72
Central Luzon, Philippines[b]	82	60	35.6	27.3	1966-74
Laguna, Philippines[c]	106	88	33.1	28.4	1966-75
Indonesia[d]	25	18	—	—	1972-75
Hwaseong-gun, South Korea	139	126	51.8	44.4	1974
Mymensingh, Bangladesh	194	137	17.5	16.1	1969-70
West Godavari, India	90	98	—	—	1969-70
Ferozepur, India	92	92	—	—	1969-70
Punjab, Pakistan	43	45	66.6	39.4	1972
Sind, Pakistan	35	20	57.8	68.0	1972
Kanpur, India	105	91	—	—	1966-71
Palamau, India	279	143	—	—	1970-71
Dry zone, Sri Lanka	169	127	21.6	17.8	1970-71

[a]Source: Baker, R., and R. W. Herdt. In press. *The Asian Rice Economy.* Resources for the Future, Washington, D.C. [b]Compares 63 farms, of which none grew modern varieties in 1966, with the same farms in 1974 when 64 percent grew modern varieties. [c]Compares 62 farms, of which none grew modern varieties in 1966, with the same farms in 1975 when 95 percent grew modern varieties. [d]Nationwide; preharvest labor only.

In 10 of the 13 cases, labor input per hectare was higher with modern varieties than with traditional varieties; for three others there was no difference. In seven of the eight cases for which yield data were available, labor productivity improved despite the rise in labor input. The increased labor demanded by the new seed-fertilizer technology for weeding, other crop care activities, and harvesting typically exceeded the labor reduction that occurred in instances where land preparation was mechanized.

There is some evidence also that the demand for hired labor rises even more rapidly than that for family labor. In 16 out of the 19 studies on labor use shown in Table 8, more hired labor was used for modern varieties than for traditional varieties and in all but one of those 16 cases, yields of modern varieties were also higher. When the proportion of hired labor increases with total labor use, landless laborers will receive relatively more of the labor's share in output than farm operators' households.

Econometric analyses of factors affecting labor use at the farm level tend to confirm the labor-using bias of the modern variety technology (Table 9). A cross-section study in Punjab (Rao 1975) clearly showed the positive and highly significant contribution of modern variety adoption to employment. Labor demand function estimates based on time-series and cross section data

Table 8. Hired labor used by farmers growing modern rice varieties compared with hired labor used by farmers growing local rice varieties at various locations in Asia.[a]

Location	Labor units	Hired labor (labor day/ha) Modern variety	Local variety	Yields (t/ha) Modern variety	Local variety	Study years
		India				
Cuttack, Orissa	Rs	260	110	4.3	2.1	1966-67
Varanasi, Uttar Pradesh	Rs	230	225	1.5	1.6	1966-67
Saharanpur, Uttar Pradesh	Rs	94	50	3.5	2.0	1966-67
Raipur, Madhya Pradesh	Rs	99	115	0.8	1.9	1966-67
Kolaba, Maharashtra	Rs	94	77	1.2	1.4	1966-67
Amritsar, Punjab	Rs	199	178	2.6	2.9	1967-68
Krishna, Andhra Pradesh	Rs	178	133	4.2	4.0	1966-67
East Godavari, Andhra Pradesh	Rs	390	316	5.8	2.2	1968-69
West Godavari, Andhra Pradesh	Rs	373	328	5.7	3.2	1967-68
West Godavari, Andhra Pradesh	Rs	659	588	5.5	2.8	1968-69
Ernakulam, Kerala	Rs	354	294	3.3	2.2	1966-67
Thanjavur, Tamil Nadu	Rs	98	116	3.0	1.9	1966-67
Thanjavur, Tamil Nadu	Rs	195	186	3.5	2.7	1967-68
Birbhum, West Bengal	Rs	221	144	3.5	2.5	1968-69
		Indonesia[b]				
West Java	Days	274	107	6.3	5.5	1968-69
West Java	Days	241	172	5.2	2.9	1969-70
Central Java[c]	Days	221	239	3.7	4.8	1968-73
Central Java	Days	171	168	4.5	3.4	1968-69
		Philippines				
Laguna[d]	Days	85	51	3.5	2.5	1966-75

[a]Source: Barker, R., and R. W. Herdt. In press. *The Asian Rice Economy. Resources for the Future,* Washington, D.C. [b]Preharvest labor only. [c]Compares 30 farms, of which 2 grew modern varieties in 1968-69 and 28 did in 1973-74. [d]Compares 62 farms, of which none grew modern varieties in 1966 and 95 percent did in 1975.

Table 9. Two econometric analyses of the impact of modern variety adoption on labor use, India and the Philippines.[a]

	India[b]		Philippines[c]	
	1968-69	1969-70	Central Luzon	Laguna
Modern variety adoption	0.12	0.13	0.07	0.05
	(6.00)	(4.33)	(2.59)	(1.45)
Wage	—	—	−0.35	−0.18
			(−5.44)	(−2.59)
Fertilizer and insecticide cost	—	—	0.09	0.03
			(3.51)	(0.97)
Herbicide cost	—	—	(3.51)	(0.97)
			(0.66)	(0.21)
Tubewell expenses	0.09	0.04	—	—
	(4.50)	(4.00)		
Tractor dummy (1)	−0.01	0.01	−0.08	−0.07
	(−0.50)	(0.50)	(−2.00)	(−1.82)
(2)	—	—	−0.03	−0.05
			(−0.69)	(−1.76)
Gama institution dummy	—	—	−0.09	0.07
			(−1.73)	(2.26)
% irrigated area	0.24	−0.06	—	—
	(2.40)	(−0.55)		
Crop area	0.73	0.68	0.77	0.94
	(18.25)	(13.60)	(15.34)	(13.51)
R^2	0.80	0.75	0.75	0.60

[a]Figures in parentheses are t-values. [b]Based on log-linear regression of farm level data from Ferozepur, Punjab, as reported in Rao, H., 1975, *Technological Change and Distribution of Gains in Indian Agriculture,* Institute of Economic Growth, India. [c]Based on log-linear regression on farm level data from Central Luzon (1966-74) and Laguna (1966-75) as reported in IRRI, 1978, *Changes in Rice Farming in Selected Areas of Asia.*

in the Philippines from 1966 to 1975 also indicate that modern varieties tend to significantly raise labor use per hectare.

The empirical evidence presented above pertain only to the direct employment effect of the new technology. It should be remembered that the modern variety technology and the higher agricultural income resulting from its adoption have had important indirect effects of creating nonagricultural employment opportunities through increased demand for industrial goods and services from the agricultural sector (Krishna 1975, Mellor and Lele 1973). Several studies have indicated that increased employment generated by higher consumer expenditures from higher farm income dominate the indirect employment due to greater demand for nonfarm inputs (Bell and Hazel 1980; A. Gibb, unpublished PhD dissertation, University of Michigan, 1974).

Factor share of labor

Estimates of changes in income share of labor have also been used to infer the impact of modern variety adoption on employment and income distribution. Assuming wages do not change, income share of labor will rise if the new technology increases labor use. Overall increase in labor demand will also tend to increase wages, further increasing labor's share in gross income from rice production. Empirical studies of factor shares, however, often have not distinguished the effect of increases in labor supply that tend to lower wages, such as population growth and slow growth in labor demand in the nonagricultural sector, from the effect of increase in labor demand from modern variety adoption.

Several studies in India indicate that labor's share in gross revenue declined as land's share increased over the period of modern variety diffusion in the 1960s (Jha 1974, Mellor and Lele 1973). This can occur when labor supply increased faster than labor demand, as Jha (1974) found, so that the income share of land rises even if technical change itself is neutral in scale.

Early adoptors may capture large profits before the rice price is bid down or wages are bid up, *ceteris paribus*. As technology diffuses more widely, prices will adjust to the new equilibrium and the relative share of labor will return to the original level or will increase if modern varieties have a labor-using, land-saving bias rather than being a neutral technology. In a 1970 study in North India, no significant change in labor use was observed (Bardhan 1970). A few years later, as modern varieties diffused more widely, increases in labor demand in this region led to a significant rise in real wages (Lal 1976). Real wage rates were constant or declining in other parts of India where diffusion of modern varieties was limited.

Farm-level studies in Indonesia and the Philippines (Table 10) have found changes in income shares of labor to be related to technical change in rice production. In Indonesia, the studies were made in North and South Subang, two villages in a rice-dominated area that differ markedly in adoption. In South Subang where farmers generally found the modern varieties unsuited to their production conditions, yields increased only 300 kg/ha and labor's share in the gross value of output declined. In North Subang, with 100 percent modern variety adoption, yield gains were almost three times those in the other village and labor received more than its proportionate share.

In the Philippines, the studies were made in Laguna and Central Luzon, both areas of progressive rice farms. Adoption of modern varieties was virtually complete by 1970 in Laguna and by the mid-1970s in Central Luzon. Rice yields about doubled in both areas between 1965 and 1982. But average paddy income per hectare received by labor rose much more in Central Luzon because total labor use per hectare increased by more than 40 percent. Although mechanization of land preparation spread widely in both areas, increases in labor demand for other tasks more than offset the labor displaced by tractors. In Laguna, however, threshing had historically been manual and the rapid adoption of mechanical threshers in the late 1970s reduced labor use per hectare. Consequently, the share of labor in gross value of output increased in Central Luzon and declined in Laguna. The benefits from the successful introduction of new technology seem to be greater for hired labor than for other claimants involved in rice production.

The belief that the new seed-fertilizer technology promotes mechanization is based on the erroneous assumption that the degree of technical complementarity between modern varieties and machines is similar to the

Table 10. Trends in modern variety adoption, yields, labor use, income, and factor share in areas of Indonesia and the Philippines, wet season.[a]

Location	Area under modern varieties (%)	Yield (t/ha)	Labor use		Labor income (t/ha)		Factor share (%)	
			Total (labor-days/ ha)	% hired	Total	Hired	Total labor	Hired labor
			Indonesia					
North Subang								
1968-71	7	2.3			0.9	0.8	43	38
1978-79	100	3.2			1.3	1.1	46	37
South Subang			119[b]	78[b]				
1968-71	n.a.	2.6			1.3	0.8	56	37
1978-79	14	2.9	157[c]	66[c]	1.3	0.8	49	33
			Philippines					
Central Luzon								
1966	0	1.9	59	58	0.5	0.3	26	16
1970	70	2.6	64	55	0.8	0.4	30	17
1974	76	2.0	90	69	0.6	0.4	32	21
1979	97	3.9	80	63	1.2	0.8	31	22
1982	98	4.2	84	62	1.3	0.8	31	20
Laguna								
1965	0	2.3	91	53	0.8	0.5	35	20
1970	90	3.4	89	71	1.1	0.8	31	23
1975	99	3.7	106	80	1.0	0.8	27	21
1978	97	4.0	95	72	1.3	1.8	33	25
1981	100	4.4	93	69	1.3	0.9	30	21

[a]Sources: 1. Hayami, Y., and M. Kikuchi. 1981. *Asian Village Economy at the Crossroads.* Tokyo University Press, Tokyo. 2. IRRI *Annual Report,* 1983. [b]Average of 1978-79 wet season and 1979 dry season. [c]1978 dry season.

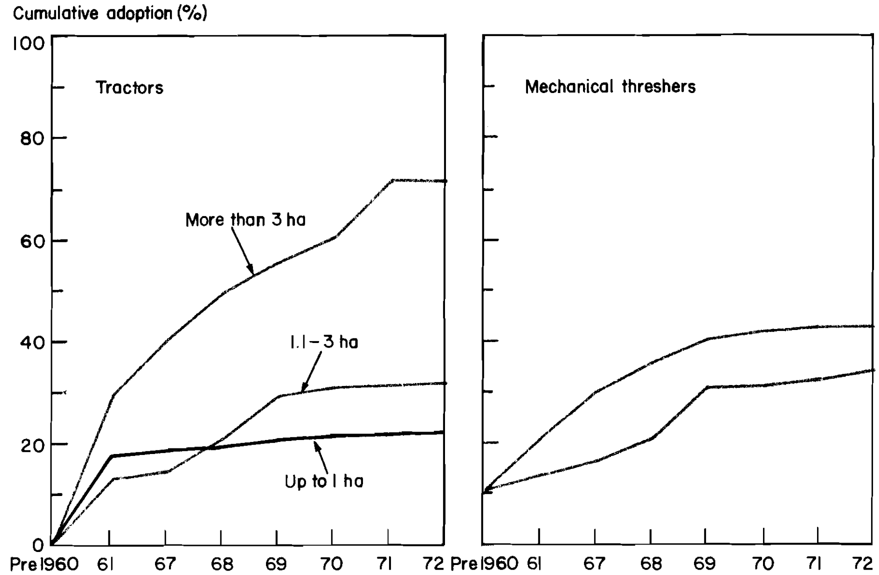
complementarity between variety and fertilizer or between variety and irrigation. However, little evidence has been found for a strong causal relationship between adoption of the modern varieties and mechanization, particularly the use of tractors. Technical complementarity exists between modern varieties and some types of machines such as water pumps but they do not displace labor. In an IRRI study of 30 Asian villages, increases in the adoption of tractors by large farmers was well advanced before the introduction of modern varieties, and there was no sign that tractor adoption was accelerated by the dramatic spread of modern varieties since the late 1960s (Fig. 8).

Several IRRI studies have shown that a better explanation of popularity of tractors in South and Southeast Asia is artificially cheap machine use resulting from overvalued exchange rates and concessional loans. The lower supervision cost for land preparation with tractors compared with bullock teams may have also induced mechanization especially among large farms in South Asia (Binswanger 1978).

Farm size and modern varieties

To achieve the potential yield advantage of modern varieties, farmers must spend more on inputs such as fertilizer and chemicals. Because ownership of capital and land is unequally distributed and rural financial markets are not

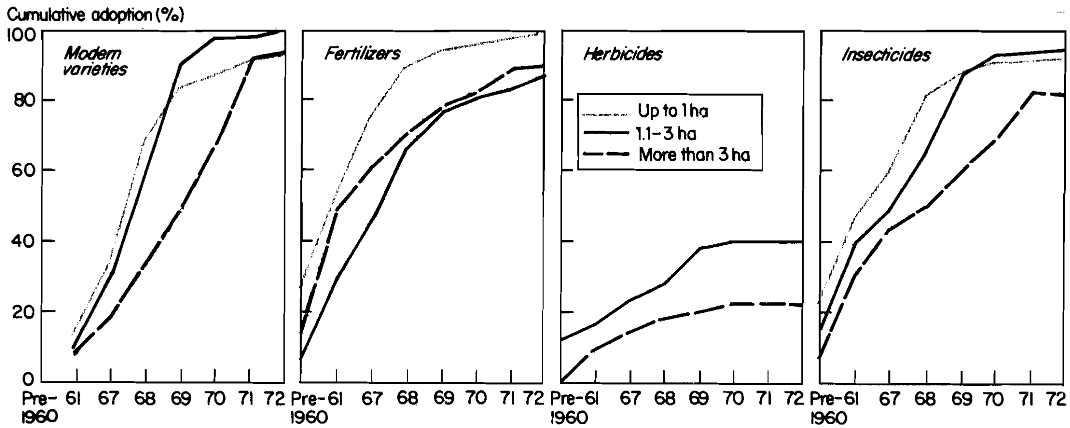
8. Cumulative percentage of farms in 3 size classes adopting mechanical innovations in 30 villages in Asia, 1971-72.



fully developed, opportunities for adoption of the new rice seed fertilizer technology may not be equally available. Large commercial farmers who have better access to information and better financial capacity may have an advantage in adoption over small farmers. It is further hypothesized that profits derived by large farmers may be used to enlarge landholdings, displacing small nonadoptors through land purchases or eviction of tenants. Large farms may also have a greater tendency to mechanize due to labor-management problems, thereby reducing employment opportunities and wage rates for the landless population. Though the seed-fertilizer technology is inherently neutral to scale, in practice this may not necessarily be the case. What has been the empirical evidence?

The 1971 IRRI study of adoption in 30 villages in six countries of Asia showed that the use of modern varieties is not limited to large farms. Pooling all sample farms and classifying them by size revealed that on the average, small farms appear to adopt modern varieties even faster than large farms (Fig. 9). The adoption of associated inputs (fertilizer and chemicals) follows a similar pattern.

To minimize the effect of intercountry and intervillage variations in environmental factors associated with adoption rates, villages were first classified according to degree of dispersion in farm size (Gini coefficient) within the village and then the relation between farm size and adoption rate was examined. Still, there was no significant difference in the rate of adoption of new varieties between small and large farms in almost all villages that had Gini coefficients ranging from 0.2 to 0.4. The only exception was a village in India, Pedapulleru, which had the most concentrated land distribution.



9. Cumulative percentage of farms in 3 size classes adopting specific innovations in 30 villages in Asia, 1971-72.

There, small farms definitely lagged behind large farms in adopting the new varieties.

Early adoption studies in India based on nationwide farm surveys conducted during late 1960s found a statistically positive relationship between the proportion of farmers adopting modern varieties and the size of the farm (Lockwood et al 1971, Schluter 1971). The data, however, showed a clear upward shift in adoption in all size groups over time. Small farmers who adopted new varieties had a higher proportion of rice area planted to modern varieties. They also used as much fertilizer and other cash inputs as large farmers and obtained similar yields.

In later studies in India and Bangladesh, farm size itself ceased to be a limiting factor in modern variety adoption. A survey of 25,000 farmers in all 16 states of India in 1975-76 showed no clear relationship between farm size and percentage of rice area in modern varieties in 14 of the states (Table 11). The variability in rate of adoption is among states rather than across size within a state.

A 1979-80 nationwide farm survey in Bangladesh has also indicated that small farmers plant as large a proportion of their rice area to modern varieties as large farmers, and sometimes more (Table 12). The difference between seasons is more striking, because much of the aus crop is grown as dryland crop, the aman crop is deepwater, and the boro crop is largely irrigated. In the boro season, over 70 percent of the two smallest farm size groups planted modern varieties compared with about 50 percent of the larger farm size group. In the aus and aman season, only 20 to 30 percent of all farmers grew the modern varieties, and there was no difference by farm size. Thus, environment is a key determinant of adoption.

Favorable vs unfavorable areas

While farm size, land tenure, and other related institutional factors such as credit and marketing institutions influence adoption of modern varieties only in a relatively minor way, accumulated evidence indicates that environmental

Table 11. Rice area and proportion in modern varieties by farm size in states of India, 1975-76.[a]

	Rice area (thousand ha)	Area in modern varieties (%)				
		Farms below 1 ha	Farms 1-2 ha	Farms 2-4 ha	Farms 4-10 ha	Farms over 10 ha
West Bengal	5426	18	13	17	15	50
Bihar	5257	34	33	38	24	16
Orissa	4684	28	30	33	35	38
Uttar Pradesh	4622	34	34	24	31	21
Madhya Pradesh	4588	0	0	0	0	1
Andhra Pradesh	3894	34	42	54	54	49
Tamil Nadu	2564	70	60	50	67	19
Assam	2241	1	1	2	0	0
Maharashtra	1417	4	6	7	12	0
Karnataka	1194	39	46	37	52	23
Kerala	885	48	39	51	100	100
Punjab	567	99	100	100	100	100
Gujarat	459	5	2	3	4	2
Haryana	304	71	91	92	86	93
Jammu and Kashmir	252	88	75	74	80	0
Rajasthan	155	0	0	2	12	56

[a]Sources: 1. National Council of Applied Economic Research. 1978. *Fertilizer Demand Study: Interim Report,* Vol 2-6, New Delhi. 2. Directorate of Economics and Statistics. 1977. *All India Estimates of Rice.* New Delhi, Ministry of Agriculture.

Table 12. Proportion of rice area planted to modern varieties on farms of various sizes, by season, Bangladesh, 1979-80.[a]

Season	Area in modern varieties (%)					Sample farms (no.)
	Farms below 0.4 ha	Farms 0.4-1.0 ha	Farms 1.0-2.0 ha	Farms 2.0-3.0 ha	Farms over 3.0 ha	
Boro 1979-80	86	71	47	47	52	1812
Aus 1980	24	21	19	20	31	1897
Aman 1980	31	27	27	27	23	1872

[a]Source: Unpublished data from Bangladesh Agricultural Research Council and International Fertilizer Development Center.

factors, particularly degree of water control (ability to apply and remove water, as needed), represent the major constraint to the wider diffusion of modern rice technology. The yield potential of the improved rice plant can be most fully realized in irrigated areas and hence it is there that adoption would be most rapid. This clearly explains differences in modern variety adoption rate across countries. Within countries, the variability in rate of adoption across areas, as in India (Table 11), and across seasons, as in Bangladesh (Table 12), indicates the importance of environmental factors.

Table 13 shows the regional differences in the progress of technical change in India. In North India and South India, which have a high proportion of irrigated area, adoption rates, fertilizer use, and yields are also much higher. In contrast, East India, which has heavy rains during the growing season and poorly developed water control, has the lowest rate of adoption, and consequently low fertilizer use and yields.

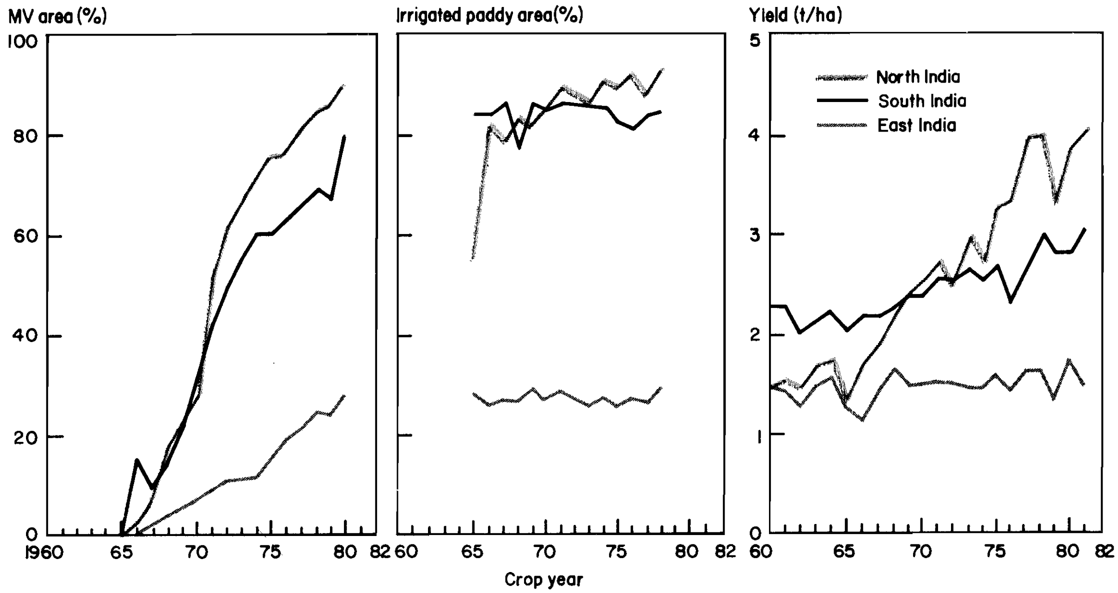
Table 13. Percent of area under modern varieties, percent of area irrigated, fertilizer use in rice, and rice yields, by major states in India, 1978-80.[a]

	Area under modern varieties (%)	Area irrigated (%)	NPK use (kg/ha)	Yield (t/ha)
North India				
Punjab	93	97	112	4.1
Haryana	82	93	41	3.6
Jammu and Kashmir	76	91	22	3.0
South India				
Andhra Pradesh	70	95	44	2.8
Karnataka	62	61	32	3.0
Tamil Nadu	83	92	66	2.9
Kerala	39	33	35	2.4
West India				
Maharashtra	63	25	21	2.0
Gujarat	55	32	36	1.6
East India				
Assam	23	28	2	1.5
Bihar	23	35	17	1.4
Orissa	23	26	9	1.4
West Bengal	34	26	33	2.0
Central India				
Uttar Pradesh	44	22	46	1.4
Madhya Pradesh	27	16	8	1.0
Rajasthan	26	35	8	1.3
All India	43	40	21	1.9

[a]Sources: 1. Directorate of Economics and Statistics, various years, *All India Estimate of Rice,* New Delhi, Ministry of Agriculture. 2. The Fertilizer Association of India, various years, *Fertilizer Statistics,* New Delhi.

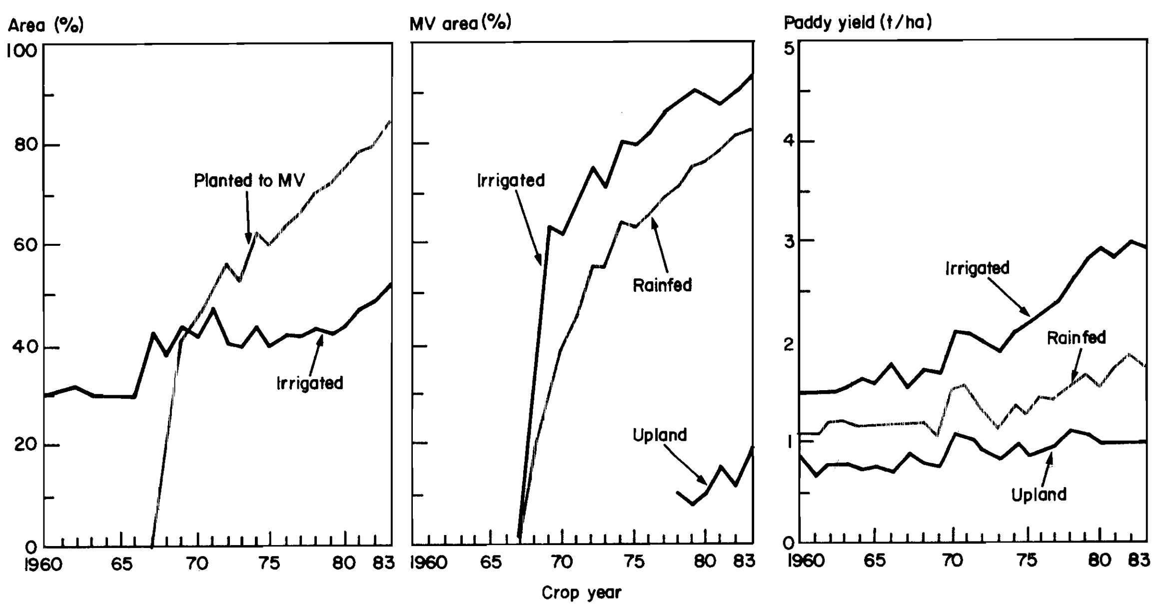
The gap in yields across regions in India has also widened over time as East India lagged far behind North and South India in developing irrigation and adopting modern varieties (Fig. 10). The proportion of irrigated area in East India has remained under 30 percent. In North India, the proportion of irrigated area has expanded and though it did not significantly change in South India, it was already very high. Technological change and productivity growth therefore proceeded at a faster rate in North and South India than in East India where yields remained low.

In the Philippines where modern varieties were adopted more rapidly than in any other country, the difference in adoption rate and yields by type of environment is probably least marked. In the very early years of introduction of modern varieties, the diffusion of modern varieties in irrigated areas was almost as rapid as in the rainfed lowland areas (Fig. 11). These are in the favorable rainfed lowlands where the degree of water control is not greatly different from that in irrigated areas during the wet season. By 1970, however, more than 60 percent of irrigated areas were already planted to modern varieties compared with less than 40 percent of the rainfed lowland areas, as the possibilities of further expansion on favorable rainfed areas were exhausted. Meanwhile continued investment in irrigation extended the dry



10. Trends in adoption of modern varieties, percent of area irrigated, and yields of rice in three major rice growing regions in India.

11. Trends in adoption of modern varieties. percent of rice area irrigated, and yields of rice by environmental conditions in the Philippines.



season crop area where productivity advantage of the new seed-fertilizer technology is even greater.

The introduction of short-duration and more drought-resistant varieties in the mid-1970s pushed adoption rates of modern varieties in rainfed lowlands closer to those in irrigated areas by the early 1980s. Upland rice areas also began to be planted with modern varieties in the 1980s.

Yields have risen in the three categories and as expected from the pattern of modern variety adoption across environments, yields rose fastest in irrigated areas. The small increase in upland yields is explained partly by the reduction of marginal upland areas as the proportion of upland rice area to total rice area declined from 20 percent in 1965 to less than 10 percent in the 1980s. The yield gap among irrigated, rainfed lowland, and upland rice farms has widened over time.

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CHAPTER 8

TRAINING AND COMMUNICATION

IRRI works with national programs to improve the production of rice and rice-based farming systems. It maintains communication with the various national programs through the exchange of visits by scientists and policy makers, workshops and conferences, publications, and a substantial training and professional advancement for the national scientists. In addition, leading scientists and administrators from various national programs who serve on the Board of Trustees of IRRI help guide IRRI's activities. All of these are major avenues for exchange of information and technology between IRRI and national programs.

Training Programs

The objective of IRRI's training and professional advancement programs is to provide relevant training to national scientists and production specialists in order to strengthen research on rice and rice-based farming systems. Training at IRRI covers a broad range of topics. They can be categorized as research-oriented programs, instruction-oriented programs, or special training programs.

RESEARCH-ORIENTED PROGRAMS

The research-oriented training programs comprise the postdoctoral fellowship program, the MS and PhD degree programs, and the special nondegree research programs.

Postdoctoral fellowship program

Postdoctoral fellowships are generally full-time research programs. They allow scientists from national rice programs and rice-based farming systems programs to work at IRRI using appropriate facilities to explore their research interests. They improve their research competence and at the same time contribute to the endeavors of IRRI.

A few scientists from developed countries who have special scientific skills may also be accepted as postdoctoral fellows to supplement the expertise available at IRRI, but they are expected to find their own support, as funds available to IRRI are intended for scientists from developing countries.

There are three categories of postdoctoral fellows:

Postdoctoral Fellow 1. Up to 5 years of postdoctoral experience.

Postdoctoral Fellow 2. Between 5 to 9 years of postdoctoral experience.

Senior Research Fellow. At least 10 years of postdoctoral experience.

The senior research fellows are considered equivalent to visiting scientists, except that the latter are generally professors from developed countries who come to IRRI on sabbatical leave to work on problems of mutual interest. Senior research fellows are provided accommodations, research support, a monthly stipend, and living allowances for the duration of their stay at IRRI. IRRI gives visiting scientists accommodations, research and logistical support, but no salary.

Senior scientists from countries that do not have the academic equivalent of the PhD degree are called special research fellows and they receive the same benefits given to postdoctoral and senior research fellows. Similarly, young scientists from organizations in the developed countries with which IRRI has collaborative research projects are called collaborative research fellows. Their salaries are paid directly by the collaborating institutions, and they make their own arrangements for housing. Senior scientists from those organizations, as well as university professors on sabbatical leave, are called visiting scientists.

Degree programs

Degree training programs were initiated in 1962 when the first batch of scholars arrived at IRRI. In this program, students take their coursework at a university, but they conduct their thesis research at IRRI under the guidance of IRRI scientists. In the early years, the coursework was done primarily with the University of the Philippines at Los Baños. However, arrangements have been made for students requiring a broader selection of courses to study at universities throughout the world. From 1963 to 1984, scholars in IRRI's cooperative degree programs received 387 master's degrees and 154 doctoral degrees. The degrees were awarded by 53 universities, 13 of them in developing countries.

These cooperative arrangements have several advantages. They encourage collaboration between IRRI and universities; they are less expensive and enable IRRI to accept almost double the number of students that could be handled if they came to IRRI for both coursework and thesis research; and, for the scholars enrolled at universities in their home countries, there is less difficulty in adjusting to student life, especially for those who have already been employed for several years.

In addition, students from certain universities in Japan, West Germany, Belgium, and the Netherlands, with which IRRI has agreements for collaborative research, come to IRRI to work on collaborative projects. They use their research findings to fulfill the degree requirements at their universities.

Nondegree programs

Scientists associated with national organizations who are interested in coming to IRRI to do experimental work or to learn new techniques, without pursuing a degree, are accepted as full-time research fellows, usually for 6 months to 1 year. The duration of such a fellowship should be long enough to enable the research fellow to conduct at least one experiment, analyze the data, and write a scientific report under the supervision of an IRRI scientist.

INSTRUCTION-ORIENTED PROGRAMS

Scheduled courses

Short-term courses are highly oriented to research methodology and production. Participants spend about half of their time in classrooms, learning the basic aspects of the problem, and the other half in the field or laboratory. They plan and conduct experiments with minimum supervision from instructors. Such programs emphasize the integration of formal and nonformal methods of curricula organization, giving equal importance to learning through classroom lectures and learning through work experience.

Agricultural Engineering Training Course: This 3-week course, offered to cooperators in IRRI's farm machinery program, includes all aspects of design, manufacture, and field evaluation of IRRI-designed machines. It consists of classroom lectures, practical shop work, such as the assembly of IRRI farm machines, and field work to develop competence in the operation and maintenance of appropriate machines.

Agroeconomic Research Methodology Training Course: In this 2-month course participants learn to handle the economic component of multidisciplinary research in rice and rice-based cropping systems. The role of economists working with biological scientists in the development of technology is emphasized. In the first 2 weeks, the participants attend a rice production course; then in the following 6 weeks, there are lectures, discussions, and field and classroom exercises on the methodology and procedures of economic research.

Cropping Systems Training Program: In this 5-month course, participants are trained to design and conduct applied and adaptive research for rice-based cropping systems in their own regions, identify and solve production constraints in various crops and cropping systems, and apply important crop science concepts to improve the use of farmers' resources. They study site description and selection, design of cropping systems, testing of cropping patterns, appropriate techniques for crop production and protection, and profitability analysis of introduced cropping patterns. Every scholar participates in the design and operation of two rice-based cropping systems trials.

Genetic Evaluation and Utilization: This 4-month training program is built around IRRI's genetic evaluation and utilization (GEU) program. The participants study the various types of rice culture, and the GEU pest and agroecologic problem areas. They learn techniques of screening for varietal resistance or tolerance, as well as hybridization methods and evaluation of progenies. They are encouraged to produce F_1 seed using the most promising varieties from their countries, and to take the seed, along with other selected breeding materials, to their home countries for evaluation and use. Thus, the scholars become important agents in accelerating the pace of plant breeding work in their countries. They work under the direction of a GEU scientist and present a seminar on their accomplishments at IRRI and on problems and progress in their varietal improvement programs at home.

Integrated Pest Management Training Course: In a 3-1/2 month course, plant protection staff are trained to design and implement integrated pest management programs that reduce crop damage, maximize profits, and protect the environment. The course covers basic rice production; principles, economics, and ecology of rice pest management; identification, biology, and integrated control of rice pests; monitoring techniques and economic thresholds to be used in decision making and development; and implementation of pest management programs. It emphasizes practical field training.

Irrigation Water Management Training Course: This 6-week course emphasizes means of improving the performance of irrigation systems, through better understanding of irrigation water management and related soil, agronomic, socioeconomic, and communication factors. A 10-day field exercise in a Philippine irrigation project provides firsthand experience in the application of improved management concepts.

INSFFER Training: This is a 4-month course that complements the applied aspect of the International Network on Soil Fertility and Fertilizer Evaluation in Rice — a collaborative project among national programs, IRRI, and the International Fertilizer Development Center. The objective of the course is to strengthen the scholars' capabilities in theoretical and practical aspects of fertilizer use, biological nitrogen fixation, and experimental techniques. The participants train in soil fertility and fertilizer experiments for rice and in the factors that affect crop responses. They also take an intensive short course on azolla and soil microbiology. Total soil health care and integrated nutrient supply are emphasized.

Rice Production Training Program: Rice production and extension specialists learn applied research techniques and methods of disseminating new rice technology in a 5-month course that covers soil and water management, pest management, and socioeconomic factors; statistical procedures for research analysis; and communication skills — factors that affect rice production. This course has undergone a continuous change in its composition and updating of the topics covered since its inception in 1966. Participants help design and conduct at least two applied research trials and take part in a field day. They organize a 2-week rice production course to gain practical experience in training others. Participants in this training program have played key roles in the extension of the rice production programs throughout the developing world.

A 2-week Rice Production Training Program is a condensed version of the 5-month course. It is designed primarily for junior researchers and extension workers. Foreign scientists working in developing countries and a few farmers are also accepted for training, depending on the availability of classroom space and other facilities.

Upland Rice Training Course: This course lasts 4 months and provides training on the principles of rice production in rainfed upland conditions. It deals with the ecology and physiology of dryland rice, understanding and management of problem soils, crop management, soil and water conservation, pest management, and varietal improvement, with emphasis on resistance to the blast disease of rice, drought, and problem soils.

Special training courses

Special short courses are offered on an *ad hoc* basis to meet the requests of national programs. Several courses have been held at IRRI or at national research training centers in collaboration with national scientists or to assist the national scientists offering these courses.

A 3-week farm managers' course has been conducted for several years. It deals with the practical aspects of experiment station management — seedbed and land preparation, fertilizer application, planting, weed control, insect and rat control, rice crop production, seed processing and storage, water management, installation of underground irrigation systems, labor distribution and management, care and maintenance of the experimental farm, and record keeping.

A special course covering experimental sampling and analytical techniques involved in field research on ^{15}N in rice has been conducted for five Indonesians in collaboration with the International Fertilizer Development Center.

With the increasing importance of research on rice-based cropping systems, IRRI offers special courses on breeding techniques and procedures for developing improved varieties of upland crops, with emphasis on the grain legumes commonly grown after rice throughout Asia. The participants are national scientists who actively collaborate in these studies.

IRRI offers a special course on pest control systems relevant to cropping systems environments. The course includes field and laboratory training on entomological theory and field practices and visits to outreach sites in the Philippines where entomological studies are conducted by IRRI scientists.

Courses on disease control in cropping systems environments include lectures on theories of disease control, field practice, and a visit to Philippine sites where disease control studies are conducted.

In response to requests from national organizations, IRRI occasionally accepts one or two staff members for on-the-job training in library and documentation work for a 1-month period. Because of staff constraints, however, only a limited number of candidates can be accepted.

IRRI is often asked to offer special courses on statistical analysis of research data. Because the statistics department is fully occupied throughout the year, only a limited number of candidates can be accommodated. Courses last up to 3 months.

Courses offered abroad

Sometimes, in collaboration with the national rice research programs, IRRI offers short courses outside the Philippines in order to help national organizations start their own training programs. They usually address problems involving biological or physical constraints that do not occur in the Philippines, such as deepwater rice, or areas of research, such as hybrid rice, for which national programs have more expertise and facilities than IRRI. Occasionally, IRRI scientists help organize and offer a series of lectures, generally on research methodology in some countries.

New courses

An agricultural communication training course is being offered for the first time in 1985. The course will provide intensive training in writing, editing, production management, and audiovisual production to information officers in agricultural improvement programs in the Third World to help them interpret, simplify, and popularize research findings and disseminate improved agricultural technology to extension agents and farmers. The course will provide instruction in principles of editing, editing research publications, copy marking and proofreading, graphics and design, typesetting, printing, photography, printing production management, and audiovisuals.

The proposed course on statistical procedures and computer applications in agricultural research will be offered to statisticians in national agricultural research organizations. The 2-month course will cover practical aspects of statistics and computing as related to crop research. Participants will learn new statistical procedures and research techniques and become familiar with the use of microcomputers for the management of agricultural research data. They will take the 2-week rice production course followed by 6 weeks of lectures, group discussions, case studies, and computing exercises.

The first training course on rice germplasm conservation and management will start in 1985. The 1-year course will include a 3-month expedition to collect germplasm, participation in the 4-month genetic evaluation and utilization training program at IRRI, concentrated instruction in the academic and operational aspects of genetic conservation, and field and laboratory work in characterizing the collected rices. The participants will be awarded a certificate, "Associate, IRRI."

SPECIAL ORIENTATION PROGRAMS FOR POLICY MAKERS AND RESEARCH MANAGERS

From time to time, special orientation programs are organized for senior officials of ministries of agriculture and national and international agricultural organizations. The typical program is composed of a 1-month study tour on agricultural research and management at IRRI and a few other organizations. Participants spend 1 week at IRRI getting acquainted with recent innovations and facilities in agricultural research and training. They visit some of IRRI's outreach stations and offices and certain stations of the participating ministry of agriculture to become acquainted with national food production programs. Visits to other countries to observe the national research and training system can be arranged on request of the organization.

To date, senior officials of the Agency for Agricultural Research and

Development, Indonesia; U.S. Agency for International Development; Indian Ministry of Agriculture; and the West Africa Rice Development Association have participated in this program.

ELIGIBILITY FOR PARTICIPATION IN IRRI'S TRAINING PROGRAMS

Criteria for selection

IRRI receives a large number of applications for its training and educational programs every year. In the research-oriented programs, priority in selection is given to the following:

1. Candidates from research or educational institutions engaged in rice and rice-based farming systems in the developing countries, particularly those that have collaborative research and training programs with IRRI and for which funds to cover training are made available by special grants. IRRI endeavors to locate support for candidates who lack funding.
2. Candidates from other research or educational institutions engaged in rice and rice-based farming systems whose training is sponsored by national or other organizations.
3. Candidates from countries or localities that have unfavorable production environments that IRRI believes to have received insufficient research attention. IRRI will endeavor to locate funds for their training if special grants are not available.
4. Candidates from developed countries nominated to IRRI under existing agreements that include funds for their research training at IRRI.
5. Candidates from developed countries whose applications are not sponsored by funding agencies, but whose research work would complement the work at IRRI. Such candidates, when accepted, do not receive accommodations or living allowances from IRRI.
6. Candidates who lack affiliation with a national organization, but possess expertise of direct interest to IRRI.

In the nondegree training programs, the candidate selection process reflects two guidelines — to help national systems improve expertise in the area of research methodology and to select candidates that give IRRI's training endeavors the greatest impact.

Acceptability for a nondegree training program is based on

- the number of openings available for the candidate's country,
- the candidate's eligibility for admission, and
- the importance of the training to the national program that employs the candidate.

To enhance group homogeneity and facilitate communication, IRRI sets minimum requirements for acceptance: candidates must have at least a BS degree in agriculture or related subjects; be 25 to 45 years of age; be junior researchers, scientists, or professionals from a national organization or other agencies working on rice or rice-based cropping systems; be proficient in English; and be physically fit.

Nomination and selection of candidates

As a general procedure, candidates are nominated to IRRI by the national systems that employ them, with the assurance that the candidates will return to work on rice or rice-based cropping systems. In countries where there are IRRI representatives, liaison scientists, or national coordinators, they interview the candidates to ascertain their eligibility for admission. In countries where IRRI does not have outreach staff, the candidate may be interviewed by IRRI scientists visiting those countries or the applications may be sent directly to IRRI. All applicants for IRRI's training and educational programs are evaluated by the standing committees of the IRRI Academic Council.

Terms and conditions of IRRI fellowships

For candidates selected for IRRI funding, IRRI covers travel and shipping expenses, board and lodging, a stipend for incidental expenses, insurance, local travel in connection with the research, research support, book allowance, and university fees of degree scholars. The money comes from IRRI's core-training funds, collaborative country program funds, or other special project funds. IRRI also administers the fellowships or scholarships of other candidates and bills their sponsoring organizations for the fellowship costs.

THE IRRI ALUMNI: THEIR PROFILE AND CONTRIBUTION TO THE NATIONAL PROGRAMS

From 1962 to 1984, there were 3,700 scholars and fellows in the various training and professional advancement programs at IRRI (Table 1). About a third were in research-oriented programs, the rest were in short nondegree courses. Eight out of 10 scholars and fellows came from Asia where 90 percent of the world's rice is grown (Table 2). Most trainees came from countries that have large

Table 1. Training programs at IRRI, 1962-84.

Training program	Total participants
Research-oriented	
Postdoctoral fellowships	241
Degree programs (MS and Ph D)	679
Nondegree training	511
Short-term courses	
Agricultural engineering	261
Agroeconomics	42
Cropping systems training program	470
Genetic evaluation and utilization	348
Integrated pest management	93
Irrigation water management	162
Soil fertility and fertilizer evaluation	133
Rice production (5 months)	601
Upland rice	46
Special purpose	113
Total	3700

Table 2. Total number[a] of IRRI trainees, 1962-84 (October).

Country	Postdoctoral fellows	Degree programs MS	Degree programs Ph D	Nondegree programs	Short-term and special courses	Total
		Asia and Oceania				
Philippines	25	109	55	62	351	602
Indonesia	2	32	21	46	345	446
India	90	8	24	31	236	389
Thailand	5	54	16	42	254	371
Bangladesh	9	64	28	20	189	310
Sri Lanka	5	25	9	33	197	269
China (Mainland)	23	23	3	23	106	178
Burma	1	14	—	13	115	143
Pakistan	8	14	7	18	84	131
Malaysia	3	2	1	14	89	109
Korea	13	11	14	43	23	104
Vietnam	3	4	4	16	53	80
Japan	23	3	8	38	4	76
Nepal	2	15	2	2	45	66
China (Taiwan)	—	28	1	12	—	41
Laos	—	—	—	7	18	25
Iran	—	—	—	6	6	12
Fiji	—	—	—	1	6	7
Kampuchea	—	—	—	1	5	6
Bhutan	—	—	—	1	4	5
Australia	—	1	1	1	—	3
British Solomon Is.	—	—	—	—	—	3
Iraq	—	—	—	1	2	3
Turkey	—	—	—	—	2	2
New Guinea	—	—	—	—	1	1
Israel	—	—	—	—	1	1
Afghanistan	—	—	—	—	1	1
Subtotal	212	407	194	432	2140	3385
		Africa				
Nigeria	2	5	1	3	20	31
Egypt	1	—	2	7	12	22
Tanzania	—	3	—	1	14	18
Sierra Leone	—	—	—	3	11	14
Senegal	—	1	—	7	5	13
Mali	—	—	—	3	5	8
Ghana	1	1	—	2	4	8
Sudan	—	—	—	1	7	8
Liberia	—	1	—	—	6	7
Kenya	—	—	—	2	5	7
Madagascar	—	—	—	1	2	3
Upper Volta	—	—	—	—	2	2
Ethiopia	—	—	—	—	2	2
Somalia	—	—	—	1	1	2
Uganda	—	—	—	—	1	1
Ivory Coast	—	—	—	1	—	1
Morocco	—	—	—	1	—	1
Gambia	—	1	—	—	—	1
Cameroon	—	—	—	—	1	1
Subtotal	4	12	3	33	98	150

Continued on next page

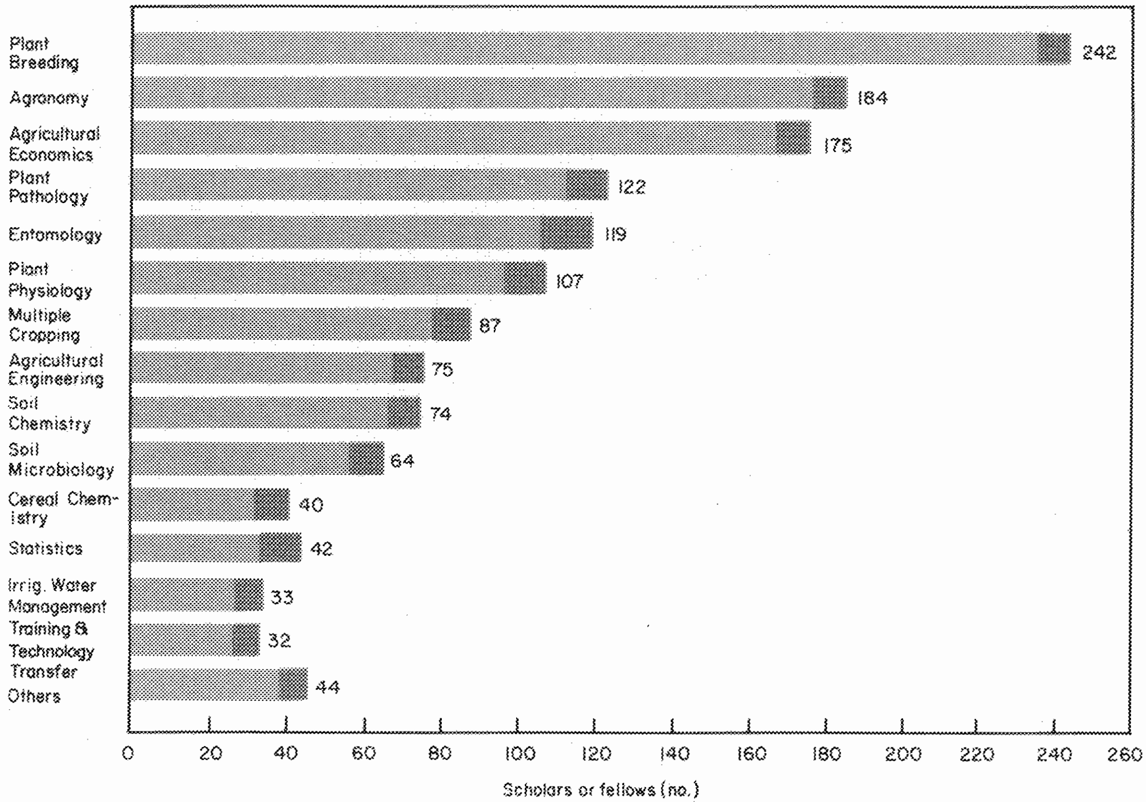
Table 2 continued

Country	Postdoctoral fellows	Degree programs MS	Degree programs Ph D	Nondegree programs	Short-term and special courses	Total
		Latin America and Caribbean				
Colombia	3	6	1	3	3	16
Cuba	—	—	—	9	4	13
Mexico	—	4	1	2	3	10
Brazil	—	1	—	—	3	4
Guyana	—	2	—	—	1	3
Peru	1	1	1	—	—	3
Ecuador	—	1	—	—	2	3
Dominican Republic	—	—	1	—	1	2
Panama	—	—	1	1	—	2
Venezuela	—	—	—	2	—	2
Trinidad	—	—	—	—	2	2
Costa Rica	—	—	—	1	—	1
Chile	—	1	—	—	—	1
Jamaica	—	—	—	—	1	1
Paraguay	—	—	—	—	1	1
Subtotal	4	16	5	18	21	64
		Other				
United States	7	7	13	9	10	46
Germany	8	—	10	4	—	22
United Kingdom	3	1	3	7	—	14
Netherlands	1	3	2	5	—	11
France	1	—	—	1	—	2
Belgium	—	—	1	1	—	2
Canada	—	—	2	—	—	2
Switzerland	—	—	—	1	—	1
Italy	1	—	—	—	—	1
Subtotal	21	11	31	28	10	101
Total	241	446	233	511	2269	3700

[a]Excludes the 2-week rice production training course and other special short-term programs.

areas of rice, though the small numbers from Burma and Vietnam is a reflection that IRRI collaborative programs with these countries were initiated only recently. The nationality of the scholars/fellows in different training programs is also related to the number and nature of educational institutions in those countries. For example, most postdoctoral and senior research fellows were from India, which has many universities with PhD programs. For the same reason, the number of MS and PhD students from India was one of the lowest. There have been a relatively small number of students from Africa and Latin America because IRRI coordinates training with international agriculture centers such as IITA, WARDA, and CIAT. They accept in their own training programs most of the candidates from the continents in which they are located, but those requiring more specialized training are referred to IRRI.

Most research scholars and fellows were in the production-oriented programs of the plant breeding, agronomy, agricultural economics, plant pathology, and entomology departments (Fig. 1). The largest number of



1. Distribution of IRRI scholars and fellows by field of specialization, 1962-84.

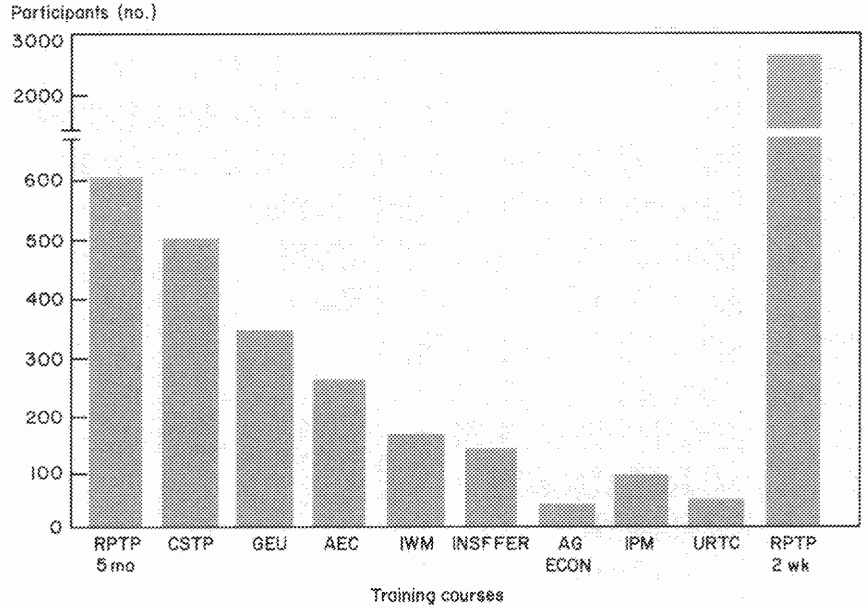
trainees were in the rice production, cropping system, and genetic evaluation and utilization training programs (Fig. 2).

In 1980-81, a mail survey of all IRRI alumni was conducted to obtain information on the role they play in the national programs, the relevance and effect of their training at IRRI, and their contribution to food production in their countries. The initial response to the survey was about 36 percent, but increased to more than 50 percent after two reminders. The responses from the Philippines, Thailand, Bangladesh, and Indonesia ranged from 60 to 80 percent and they were selected for more thorough analysis about the relevance and impact of IRRI training programs.

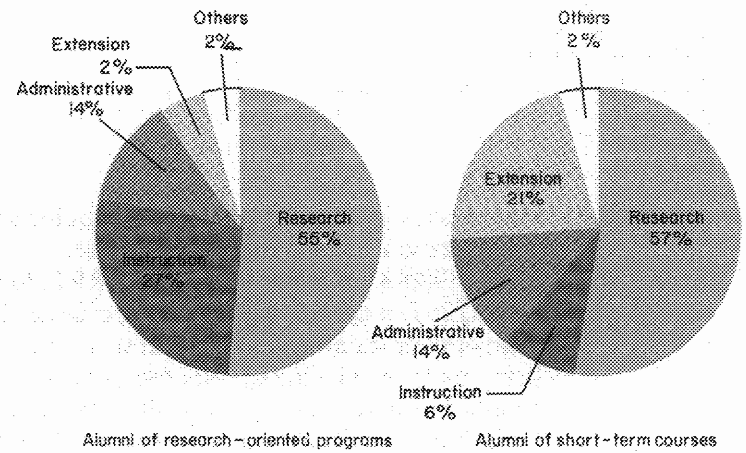
The survey showed that 72 percent of all trainees and scholars came to IRRI from government agricultural agencies, 17 percent were from agricultural universities, 5 percent were from private corporations engaged in rice research and production, and 6 percent were from other organizations. Nearly 98 percent returned home after completion of the training programs at IRRI.

At the time of survey, about 90 percent were employed by government research institutions or agricultural universities. About half the alumni of both the research-oriented programs and the short courses are engaged in research and one in seven is in administration (Fig. 3). The sharp contrasts were the proportion in instruction — 27 percent of alumni of research-oriented

2. Distribution of participants in formal training courses, 1962-83.



3. Current assignments of IRRI-trained Asian scientists in their respective countries, December 1962.



programs compared with 6 percent for alumni of short courses — and the proportion in extension — 21 percent of alumni of short courses compared with 2 percent of alumni of research- oriented programs. Quite a large number of alumni are the heads of research institutes and, at the time of survey, 98 of the participants from Asian countries had received national recognition awards for a wide variety of contributions such as development of high-yielding varieties, appropriate crop production practices, design of agricultural implements, etc.

Most of the trainees and fellows had bachelor's degrees prior to their training at IRRI. However, the alumni of the research-oriented programs tended to pursue higher education and, at the time of the survey, the majority had PhD degrees. There was, however, little change in the academic attainment of alumni of the short-term training courses. This suggests that the alumni of research-related programs had greater opportunity and drive for academic advancement than those in training courses.

The nature of the employment of IRRI alumni before and after their training at IRRI is shown in Table 3. This information is grouped in 5-year cohorts to show their changing work responsibilities. Most trainees at the time they arrived at IRRI had research assignments, but within a few years (cohorts of 1962-66, 1967-71, and 1972-76), many had been assigned to administrative positions. Obviously, this reflected their promotions to positions with broader responsibilities.

Most trainees in the research-related programs indicated that they found the research aspects of the training programs most useful, while participants in the nonresearch courses emphasized the training in research as well as in practical fieldwork (Table 4).

Table 3. Occupations of Asian alumni, by cohort.

	Cohorts (%)			
	1962-66	1967-71	1972-76	1977-80
At time of training	(N-59)	(N-173)	(N-166)	(N-437)
Administrative	2	2	4	5
Research	56	45	69	70
Extension	10	29	14	14
Instruction	32	23	13	11
	100	99	100	100
At time of survey[a]	(N-62)	(N-175)	(N-168)	(N-440)
Administrative	31	22	17	8
Research	34	45	55	68
Extension	8	15	14	13
Instruction	27	18	15	11
	100	100	100	100

[a]N includes those who were studying and were out of work at pretraining.

Table 4. Aspects of training most useful to job of alumni respondents from Asia, by training program.

	Alumni (%)	
Useful aspect	Research-oriented (N-230)	Short-term courses (N-409)
Research experience	46	30
Lectures and discussions including seminars and coursework	21	32
Practicum including fieldwork and special projects	10	15
Training in production of rice and other crops	4	11
Others, including acquaintance with peers and senior scientists	7	1
All aspects	9	10
No useful aspect	2	0.5
Total	99	99.5

The research trainees indicated that the major constraints that they found on their return home were inadequate facilities and funds (Table 5). However, most of them felt that the training at IRRI was applicable to the conditions existing in their countries. The inadequacy of budget and research facilities was also reflected in the survey of the immediate supervisors of the IRRI alumni in their respective countries (Table 6). Moreover, none of the national program leaders surveyed found IRRI's training unsatisfactory; the ratings were extremely satisfactory, 35 percent; moderately satisfactory, 62 percent; and slightly satisfactory, 3 percent.

PROFESSIONAL ADVANCEMENT OF IRRI JUNIOR RESEARCHERS

IRRI assistant scientists, senior research assistants, research assistants, and research aides, known as junior scientists, have been the backbone of its research and training programs. IRRI has aided their professional advancement on a case-by-case basis since its first years.

In 1974, a formal professional advancement program was set up to improve the efficiency, competence, productivity, and motivation of employees in their present jobs, and to create a reservoir of qualified personnel from which workers can be selected to fill more responsible positions.

Over 250 junior staff members have taken advantage of IRRI's various professional advancement programs. Master's degrees have been completed by 288 staff members under the program and 8 have received doctoral degrees.

In the degree programs, candidates pursue their coursework at a local university, usually the University of the Philippines at Los Baños, either on a three-unit-per-semester basis or full-time for up to 1 year. They use their on-going research at IRRI in the preparation of their theses.

Table 5. Constraints reported by IRRI alumni in the application of their training upon their return home.

Constraint	Research alumni (%)			
	Philippines	Bangladesh	Indonesia	Thailand
None	21	19	33	69
Inadequate budget and skilled manpower	32	4	19	15
Inadequate facilities	26	54	38	8
Inadequate support of agency or superior	10	15	0	0
Training not appropriate to subsequent job	8	8	5	4
Concepts learned were difficult to adapt	3	0	5	4
Total	100	100	100	100

Table 6. Assessments of national program leaders of constraints the IRRI alumni face.

Constraint	Responses (no.)	Program leaders' responses (%)			
		Highly serious	Moderately serious	Not serious	Total
Inadequate budget	136	17	41	42	100
Inadequate facilities	132	8	42	50	100
Inadequate manpower support	127	11	43	46	100
Inapplicability to subsequent job	125	4	14	82	100
Difficulty in adapting concepts learned	116	5	29	66	100

Junior researchers may also receive nondegree training in research laboratories. Selected candidates are sent by IRRI to undertake specialized training abroad. Such training includes short courses, training in special methodology, or implementation of certain aspects of collaborative research programs with expert scientists in specialized laboratories both in developed and developing countries.

Sometimes, on-the-job training is offered at IRRI by scientists from developed countries. In these cases, IRRI invites scientists from research laboratories in developed countries to train junior researchers at IRRI. These programs usually last 2 to 3 weeks and consist of a series of lectures and practical demonstrations.

IRRI also encourages junior researchers to participate and deliver papers in conferences and workshops to sharpen their research and communication skills. For each junior researcher, IRRI covers the expenses of attending one scientific meeting per year in the Philippines. For a small number of junior researchers, participation in scientific meetings abroad is supported.

Communication and Publications

The first IRRI publication was the 55-page 1962 IRRI Annual Report, although IRRI's formal program of publishing and communication began only in 1963 with the establishment of the Office of Communication. According to the 1963 Annual Report, "the principal means of communication at present are scientific articles written by senior staff members and submitted to established scientific and technical journals."

In 1963, IRRI scientists published 23 journal articles. The first IRRI symposium proceedings, *Rice genetics and cytogenetics,* was edited and work began on another, *Rice blast disease.* A rice research translation series was proposed but did not materialize.

In 1968 the Office of Communication was divided into the Office of Information Services (OIS) and the Department of Rice Production Training and Research. OIS was later called the Information Services Department and, in 1983, was redesignated as the Communication and Publications Department (CPD) and classified as a Global Research Service.

Publishing and distribution at IRRI

Today, CPD has sections for editorial, typesetting, graphics/design, photography, printing, audiovisual, distribution, and research, and employs a staff of about 50. Four of the staff members are senior editors; a double degree in both agricultural science and journalism is a prerequisite for IRRI editors. CPD also employs, on a part-time basis, about 30 student assistants from the University of the Philippines at Los Baños; first priority is given to journalism students.

IRRI releases about 20 new books per year and in 1983 distributed about 70,000 copies of major books. Three-fifths were sold (individuals in developing countries get a 60 percent discount) and the remainder were given to key agricultural science libraries in the Third World.

Book publishing is self-sustaining at IRRI. New titles are funded by sales. The system allows wider distribution than would be possible through free distribution. It also means the promotion of IRRI publications cannot be ignored. Eighty percent of sales are in Asia, but IRRI is systematically trying to open new distribution channels in Africa and Latin America, as well as in developed countries.

IRRI publishes four periodicals. The *IRRI reporter* is published four times a year and distributed to 15,000 rice workers. Six issues of the *International rice research newsletter* and 1 issue of its subject index, 15 issues of the *IRRI research paper series,* and 2 issues of the *International upland rice newsletter* are published annually.

A series of 63 rice production training modules (sets of slides, cassette tapes, booklets) was completed in 1983, and work began on a multiple cropping series. These modules are part of training support at IRRI.

Training and education

Each year one to four graduate students from national programs take coursework for MS or PhD degrees in development communication at the University of the Philippines at Los Baños and conduct their thesis research at IRRI. The students have been from Bangladesh, India, Indonesia, and the Philippines.

IRRI has also provided on-the-job training internships for nine information specialists from Bangladesh, China, Kenya, the Philippines, Indonesia, Sri Lanka, and the USA. The internships usually last 4 months. The trainees are put into the IRRI production line (editorial, graphics, printing, photography, etc.) and become, essentially, CPD staff. Trainees work mostly on IRRI projects, but are also free to work on projects for their home organizations during free time. Both graduate students and trainees work with (and sometimes establish) communication and publications units when they return to their national programs.

Copublication

IRRI publishes almost exclusively in English. Copublication — cooperation with national agricultural improvement programs and private publishers — is used to move information into the multitude of languages that IRRI's clientele read. IRRI does not ask for royalties or payment for non-English editions of its books that are published in developing nations.

IRRI's most successful copublication efforts have been with simple, extension-level publications that were designed to facilitate easy and inexpensive translation. *A farmer's primer on growing rice* and *Field problems of tropical rice* account for about 85 percent of the 600,000 copies of IRRI books published in languages other than English (Table 7).

A farmer's primer is a highly illustrated 221-page book for extension agents and progressive farmers. It explains how and why to use improved production techniques such as proper timing of transplanting or fertilizer application.

Table 7. Quantity of translated IRRI books in print (71 translated editions of 17 IRRI books) through 1984.

Title	IRRI books (no.)	
	In languages other than English	In English
Farmer's primer	178,600	10,000
Field problems (1st ed.)	191,000	100,000
Field problems (2d ed.)	172,500	20,000
Major weeds	10,000	5,000
Other translated IRRI books	81,500	53,100
Total	633,600	188,100

To facilitate copublication, IRRI has prepared sets of the black and white illustrations with the English text masked out. Sets of the prints are given to copublishers, who then translate the text, assemble the translated material together with the illustrations, and print it locally. Nineteen editions of *A farmer's primer* had been published in 16 languages by 1984, and at least 17 other editions were in preparation.

Field problems of tropical rice uses numerous color photos to help rice workers identify common insects, diseases, weeds, and problem soils. The color photos appear on one page and the text on the facing pages. No text is printed on the pages with color photos. Cooperators translate the text, typeset it locally, then paste the translated text over the English text. IRRI then arranges inexpensive printing, using IRRI's color plates.

The first edition of *Field problems* (1970) was copublished in 10 languages. IRRI released a revised edition of *Field problems* in 1983, and had printed 50,000 copies in Vietnamese, 10,000 copies in Pilipino, and 4,000 in Spanish by mid-1984. Editions in about 25 languages are in progress.

By the end of 1984, nearly 90 editions of 19 IRRI books had been copublished, or were in press, in 24 languages other than English in 14 countries (Table 8).

In 1983 IRRI and UPLB initiated an MS research project to survey the translators and publishers of non-English editions of IRRI materials. National agencies were obviously interested in copublication, yet IRRI really knew little about the process. Primary data for the study were gathered from 40 translators and publishers belonging to 28 agencies in 12 countries through interviews and mailed questionnaires. Secondary data for 40 agencies in 24 countries were taken from IRRI records and correspondence and from content analysis of translated editions.

Translators were found to have played the key role in the copublication of IRRI books. Three-fourths of the translated editions are the result of the initiatives of translators who contacted publishers to propose publication of translation. Most translators of IRRI books have been cooperating scientists in national programs. More than half are crop scientists and 77 percent have MS or PhD degrees. More than 90 percent work for national research, extension, or teaching agencies. Most respondents regard being translator of a

Table 8. Languages into which IRRI books have been translated, through December 1984.

Language	Copies printed or in press
Arabic	17,000
Bahasa Indonesian	28,000
Bahasa Malaysian	15,000
Bengali	186,000
Burmese	20,000
Cebuano	10,000
Chinese	71,200
French	5,500
Gujarati	4,000
Gujarati-Hindi combined	2,000
Hiligaynon	5,000
Hindi	16,000
Ilocano	5,000
Kannada	4,000
Marathi	1,100
Nepalese	15,000
Oriya	16,000
Pampango	3,000
Parsi	12,000
Pilipino	35,000
Portuguese	5,000
Spanish	9,800
Swahili	6,000
Tamil	8,000
Telegu	6,000
Thai	11,000
Urdu	30,000
Vietnamese	85,000
Warai	2,000
Total	633,600

respected book as a form of scientific recognition. Only half of the translators received any financial remuneration; those who were paid received an average of $115.

Multilanguage poster

IRRI and FAO have cooperated to prepare a poster, *Natural enemies of insect pests of rice,* which contains color photographs to help farmers and technicians recognize and preserve predators and parasites of rice pests. Fifty thousand copies of the poster have been published in 14 languages at a cost only slightly higher than that of printing 50,000 copies in English.

Cooperators in national programs translated the English text and had the translations typeset locally to specifications set by IRRI. Printing negatives were prepared from each of the 14 translations to be printed as part of the "black press run" (color photographs are printed in yellow, magenta, blue, and black ink). Three of the four colors necessary were printed in a press run of 50,000 copies. Only the black plates that carried the translated text went through the press in 14 individual runs.

If the 14 posters had been done individually, with the same specifications and printed at the same plant, the cost would have been $186,000. By "ganging" the press runs, the job was done for $18,500, or $0.37 per poster. This project demonstrates how cooperative manufacture can conserve scarce resources for information materials.

The posters are being distributed to IRRI and FAO cooperators to post in villages throughout Asia. IRRI has purchased 10,000 additional copies at cost for distribution to other agencies. IRRI is arranging other language editions of the poster.

The color plates for the poster were also designed uniformly — so that that they can be re-used for a booklet, similar to *Field problems,* on beneficial insects.

Effectiveness of publications in local languages

Despite the enthusiasm of many agencies for rice publications in local languages, little is known about the effectiveness of translated materials. To determine if providing agricultural materials in local languages has an effect on knowledge transfer, IRRI and Araneta University, Manila, are initiating a research project to compare *A farmer's primer* and the *Natural enemies* poster in Cebuano (a language of the central Philippines) and English. Two groups of 40 technicians each in a Cebuano-speaking area of Leyte and Southern Leyte have been selected. One group will receive the poster and the primer in English and the other group will receive the Cebuano editions. The Ministry of Agriculture has instructed all of the technicians to study the materials. Researchers are pretesting the technicians' knowledge of the topics covered by the publications. Two months later, they will conduct a post-test. In the pretest and post-test, interviewers speak only English to the group receiving the English editions and Cebuano to the group receiving the Cebuano editions, and the questionnaires will be in the corresponding language.

International Workshop on Copublication

A copublication workshop, perhaps the first to focus on strategies to alleviate the language barrier in agricultural development, was held at IRRI in 1983. Cosponsors were IRRI and Canada's International Development Research Centre. The meeting attracted 62 publishers, communicators, and administrators from national programs, international centers, extension agencies, private publishing houses, and development groups in Asia, Africa, and Latin America. Sessions focused on design techniques, policies, and strategies to encourage copublication. Participants recommended the establishment of an international network to encourage copublication of materials from international agricultural research centers and other organizations. IRRI is organizing a meeting of a steering group appointed at the workshop to plan and seek funds for the network.

Joint publishing in English

IRRI also has joint publishing arrangements with publishers such as John Wiley and Gower Publishing Companies in developed countries. In these arrangements, IRRI takes a minimum of 3,000 paperback copies at a low cost for sale in the Third World. The commercial publisher produces a hard-cover edition and has exclusive sales rights in developed countries.

This arrangement benefits IRRI, its cooperators, and the publisher. IRRI gets a lower price on the paperback volumes because the publishing company does not pay royalties on the paperback copies and because the economies of scale from longer press run allow it to set a lower unit price. The publishing company benefits by being assured of the sale of the 3,000 copies that IRRI purchases, and it realizes a lower unit cost for the hardbound copies that it sells.

Coordination of book exhibitions

Educational materials must go into many channels of dissemination to gain truly wide exposure. One such channel is commercial book distributors and stores. Book publishers and dealers in every country regularly meet at book fairs, where they examine new materials, arrange translation or joint publishing rights, and negotiate bulk sales or distribution agreements.

IRRI's first participation in fairs was in the 1981 Philippine Book Exhibit in China. Chinese interest in publications on agricultural science was high, and the China National Publications Import and Export Corporation invited IRRI to organize an exhibit of publications from all CGIAR system centers. The first International Agricultural Research Centers Book Exhibit was held in Beijing, Sian, and Ch'angsha in 1982, and featured 500 titles.

Also in 1982, IRRI exhibited at the Frankfurt Book Fair — the world's largest publication display and marketplace for developing and developed nations. About 5,500 publishers, distributors, and others associated with the book trade annually meet at Frankfurt. IRRI and the German Agency for Technical Cooperation organized the International Agricultural Research Center Exhibition at the 1983 and 1984 Frankfurt book fairs. About 600 titles were exhibited by 17 centers.

IRRI has also exhibited at book fairs in Indonesia, Malaysia, Mexico, India, Philippines, Singapore, Thailand, USA, and Zimbabwe.

In 1984, IRRI compiled *Publications on international agricultural research and development,* a 539-page catalog of 1,100 books and educational materials published by the centers. The catalog is probably the largest compilation of titles on Third World agricultural science in existence. IRRI is handling its world distribution.

Training program in agricultural communication

Most developing countries have fairly well-established agricultural research and educational institutions. Millions of dollars have gone into education and training of scientists such as plant breeders, agronomists, and entomologists. As a result, national programs are developing a backlog of improved agricultural technology. Much of that technology, however, does not reach the farmer because few national programs have information units that can adapt and package the technical information in a form that can be used by extension agents and farmers. Professionals with background in both agriculture and communication are essential to the success of such information units.

In recent years, IRRI has received an increasing number of requests from national rice improvement programs to take trainees and interns in agricultural communication. In 1983, IRRI and UPLB initiated a PhD research project to assess the training and educational needs of Asian agricultural institutions by surveying administrators and information officers of 73 teaching, 108 research, and 65 extension organizations in nine South and Southeast Asian countries.

Respondents ranked technical writing, publication editing, and audiovisual production as their most urgent needs for both short-term training and undergraduate education. For MS and PhD education, respondents felt the strongest need for development communication theory and research and management of information systems. Most respondents indicated that they would like to send one to four of their professional personnel for graduate and undergraduate studies in agricultural communication and six or more persons for short-term training in information skills.

With this study as background, IRRI presented a funding proposal to the International Development Research Centre to support a 3-year pilot project of training in agricultural communication. The proposal was approved and the first course will start in 1985. Two 4-month training courses per year will be offered for information specialists from national agricultural improvement programs.

Future responsibilities

CPD's designation as an IRRI Global Research Service reflects an increasing mandate not only in publishing and providing information resources for world rice scientists, but also in institution-building and developing agricultural communication as a profession in the Third World.

IRRI is one of the largest nongovernmental book publishers in the Philippines and is one of the largest publishers of agricultural science in English in Asia. Thus, CPD has no less a responsibility to help strengthen national communication systems than, for example, IRRI plant breeders have to build strong breeding programs.

There is much concern about the need to increase transfer of improved agricultural technology in the developing nations. International agencies have spent millions to build strong breeding, pest management, agronomic, and related programs. Yet relatively little consideration has been given to strong communication systems that would give national institutions the capacity to interpret research findings and target them to extension workers and farmers. IRRI plays a catalytic role in communication development, but there is a far greater potential that is still virtually untapped. IRRI global projects include increasing cooperation with national information programs and publishers in translation, copublication, and distribution of IRRI materials in non-English languages, and providing opportunities for training and graduate-level research and education. The groundwork for new initiatives in agricultural communication has been laid during the past few years.

Conferences, Workshops, and Symposia

IRRI held 124 workshops, conferences, and symposia involving over 7,000 participants between 1963 and 1984.

Topic	*Conferences*
Genetic evaluation and utilization	20
International rice research conference	17
Collaborative planning workshop	13
Constraints and consequences	13
Pest management	9
Soil and crop management	9
Cropping systems	8
Agricultural engineering	7
Irrigation water management	3
Others	25

Generally, the participants in conferences are scientists who are actively involved in research on the subjects of these conferences and a small number of administrators who are closely associated with the management of these projects. Besides serving as a forum for discussing the current knowledge and developing plans for future research on these topics, the conferences provide an important mechanism for transferring information to scientists associated with these projects. The proceedings of conferences are published to serve the scientific community at large.

Library and Documentation Center

One of IRRI's objectives as set forth in the Memorandum of Agreement with the Government of the Philippines is the "establishment and operation of an information center and library, which will give interested scientists and scholars everywhere, access to a collection of the world's literature on rice."

In fulfilling this objective, the first measure the library undertook was the identification of all rice publications and the subsequent publication of the *International bibliography of rice research,* covering the years 1951-60. This was followed by yearly supplements, which until recently were all manually keysorted. With the cooperation of the IRRI Department of Statistics, the library has published computerized supplements starting with the 1980 supplement. The 1983 supplement had 6,081 entries. The computerized system has speeded the publication of the bibliography, as well as providing the information required for the computerized literature-search system being developed. To date, in addition to the continuous entry of current rice information, we have stored retrospective information from 1971 to 1983, and have readied supplements for 1961 to 1970 for entry into the system. When the retrieval system becomes operational, the stored information may be manipulated in several ways — for journal publications, current awareness, and retrospective searching.

Obviously the publication of the *International bibliography of rice research* and its supplements is a major service of the library. Prior to the establishment of IRRI, there was no bibliographic control of rice publications. There were short, specific listings, but no comprehensive and systematic compilation existed that covered what the whole world publishes on rice. The bibliography also gave the outside world exposure to the wealth of rice literature emanating from Japan.

There are at least 24 languages used in reporting scientific investigations of rice. Because the Japanese alone produce 40 percent of the rice literature, IRRI has a branch of its library in Japan. All requests for translations of Japanese literature into English are channeled through this office, which is manned by a Japanese rice expert and two librarians. The office also does nearly all the indexing of Japanese periodicals, especially those in Japanese characters, and procures out-of-the-way Japanese publications.

Translations from other languages into English are also being done by special arrangement in Thailand and Taiwan and with commercial services. A section in the bibliography annually lists the translations that the library acquires.

The bibliography is a major service for the rice workers. However, the backup service is even more vital. Every item indexed and picked for inclusion in the compilation is acquired in whatever form it is available — printed or microform, mimeographed or typewritten — thus providing the rice workers worldwide a place to turn to for information and procurement of literature.

Scientists from at least 32 countries, excluding those at IRRI, request photocopies of information from the library. The greatest number of requests come from India, Bangladesh, Malaysia, and the United States. Many requests are also received from Latin America and Africa.

Copies of the bibliography and its supplements are sent to agricultural libraries, documentation centers, research stations, and institutions where they can be used by those actively engaged in rice research or disseminating information about the crop. Wherever scientists have access to the bibliography, the IRRI library is available.

The bibliographies and other listing that have been published:

International bibliography of rice research 1951-1960
Annual supplements, 1961-1983
Cumulative indexes, 1961-65, 1966-70, 1971-75, 1976-80

International bibliography on cropping systems 1973-74
Annual supplements, 1975-1979

A bibliography of rice literature translations available in the International Rice Research Institute library and documentation center

Theses and dissertations on rice available in the library of the International Rice Research Institute 1974
Annual supplements 1975-1983

International directory of rice workers

Every month the library issues a new acquisitions list of monographs, new serial titles, and translations.

The library also has a current awareness service. It involves reviewing publications immediately upon receipt, selecting information from periodicals, books, pamphlets, patents, and reports, that is pertinent to the work of IRRI. The information is then brought to the attention of the scientists concerned by duplicating and distributing the tables of contents. In cases of microfilm, the first page of the text is copied complete with bibliographic citation. The notification always indicates the language in which the publication is written if other than English and if English summaries or abstracts are present. The service has resulted in requests for loans and photocopies of articles appearing in journals in over 90 percent of the cases. The table-of-contents duplication has been extended to the research stations in Bangladesh, Indonesia, and Africa.

Among the other services the library provides are compilation of short selective bibliographies on specific topics; answering requests from outside IRRI for assistance in solving problems of library administration, organization, selection and acquisition, information retrieval, and technical processing; and purchasing of books for fellows and trainees. Occasionally the library also accepts library trainees/scholars as part of the institute's training program.

The library has an overall monographic collection of 66,528 and now receives 2,821 journal titles. The overall rice literature collection numbers 85,687 items.

The IRRI library is a special library because of its special collection. However, it is a special public library because its doors are open to the public. For its immediate clientele, that is, the IRRI staff and trainees, the rule is: Lend everything to anybody in any desired quantity for any length of time, but subject to immediate recall.

CHAPTER 9

LOOKING AHEAD

"The tragedies of the potato famine and the Bengal famine, and the great epidemics of the cereal rust, rice blast, bacterial blight and virus diseases of rice that have threatened crop production for decades, will not have their counterparts in the future."

J. G. Harrar (1968)

IRRI owes its origin to the visionaries such as Drs. J. G. Harrar and F. F. Hill. Harrar expressed in 1968 the hope that the tragedies caused by pest and disease epidemics in rice and other crops would not recur, thanks to modern science and technology. It was in March 1968 that William S. Gaud, Director of the U.S. Agency for International Development, first used the phrase *Green Revolution* to denote the potential for increasing the yield of rice, wheat, maize, and other crops through the use of high yielding varieties. Yields of rice and wheat, which had remained stagnant for centuries in many of the densely populated countries of Asia, were beginning to rise in 1968. It was in this context that optimistic views such as those of Dr. Harrar were expressed. We know now that while impressive progress has been achieved in yield increase and pest containment, we are still far from the goal set by Harrar. Also, the famines of today are caused not solely by devastation of crops by pests, but by poverty, lack of purchasing power, and unemployment as well. There is no room for complacency and this is no time to relax.

An analysis of the lessons learned since 1968, when the forward march of agriculture began in many developing countries of Asia and Latin America, will help us to develop priorities for the future. With that in mind, we can construct a Green Revolution balance sheet in rice and other crops.

Before discussing the positive and negative aspects of Green Revolution technology, a few basic facts have to be emphasized. First, the technology involving the application of water, fertilizer, and good management practices to genetic strains capable of responding to such inputs is not in any way different from the yield-increasing techniques adopted in Europe and North America after Leibig's discovery of using chemical fertilizers in agriculture in the last century. In other words, there has been only one pathway to yield improvement available to all countries whether developing or developed. This pathway involves the cultivation of a variety with a potential for high yield and management practices that will help the plant express its full yield potential.

Second, terminologies such as low-input technology are misleading. Inputs are needed for output. What can be done is to replace to some extent purchased inputs with home-produced inputs; for example, supplying nitrogen through biofertilizers rather than entirely through mineral fertilizers. Also, by cultivating varieties possessing built-in resistance to pests and diseases and to adverse soil factors, the need to purchase pesticides and soil amendments can be eliminated or substantially reduced. In fact, this has been one of the major contributions of IRRI. Hence, low-input technology implies only low cash-input technology and *not* the supply of smaller quantities of nutrients and other inputs.

Keeping the above scientific facts in mind, we can proceed with an analysis of the benefits conferred by the Green Revolution technology as well as the concerns aroused by them.

GREEN REVOLUTION BALANCE SHEET

Benefits

The first important benefit of the Green Revolution, particularly in rice and wheat, has been the generation of self-confidence among farmers, extension workers, scientists, and political leaders in their ability to bring about rapid increases in food production. Because self-confidence is a basic requisite for success in any area of human endeavor, this is a great gain.

Second, the spread of new technologies in the countryside leads to such a demand for inputs and infrastructure such as rural roads, power supply, marketing arrangements, and assured irrigation that political priority for the farm sector gets increased.

Third, farmers and farming gain greater social prestige and recognition. Before the advent of new technologies, agriculture, particularly the cultivation of food crops, was regarded as a profession that required only brawn and no brain. Therefore, the educated and intellectual classes did not consider farming as a profession but sought jobs in urban areas. Similarly, agricultural colleges and universities did not attract the brighter students, who tended to prefer other fields of studies such as medicine, engineering, commerce, etc. This position began to change in many developing countries in the 1970s as many young students began to find scientific agriculture not only remunerative but intellectually satisfying. The art and science of farm management are gaining in importance.

Fourth, agrarian reform started attracting serious attention. New technologies made land-based occupations attractive and increased the pressure on political leaders for equitable land rights and laws.

Fifth, rural development started receiving serious attention, because when agriculture moves from a subsistence level to a market-oriented one, rural communication, rural electrification, and other areas of rural infrastructure development become an economic and social necessity.

Sixth, in the countries of South and Southeast Asia where the Green Revolution technology took roots and started making an impact, production increased largely through increased productivity. The pathways of productivity improvement in rice are described in Chapter 4. In many rice growing developing countries, land and not labor is the most serious constraint. Land is also constantly required for nonagricultural uses and hence is a shrinking resource for agriculture. Therefore, the only pathway open to many developing countries for improving food production is higher productivity and cropping intensity. Before the introduction of high yield technology, production gains in many countries came largely through area expansion.

Seventh, the Malthusian prediction on famines arising from an adverse relationship between population growth and food production has so far not come true in most parts of Asia and Latin America. The situation is different, however, in countries of Sub-Saharan Africa. The Green Revolution technology has provided the breathing spell necessary for national policies to have an impact on adjusting population growth rates to the resource potential of each country.

Finally, an important outcome of the rate of increase in food production keeping above population growth rates has been a relative stability and even decline in the price of rice. This has enabled the economically handicapped sections of the population to increase their calorie intake, thereby preventing a further growth in the number of undernourished people.

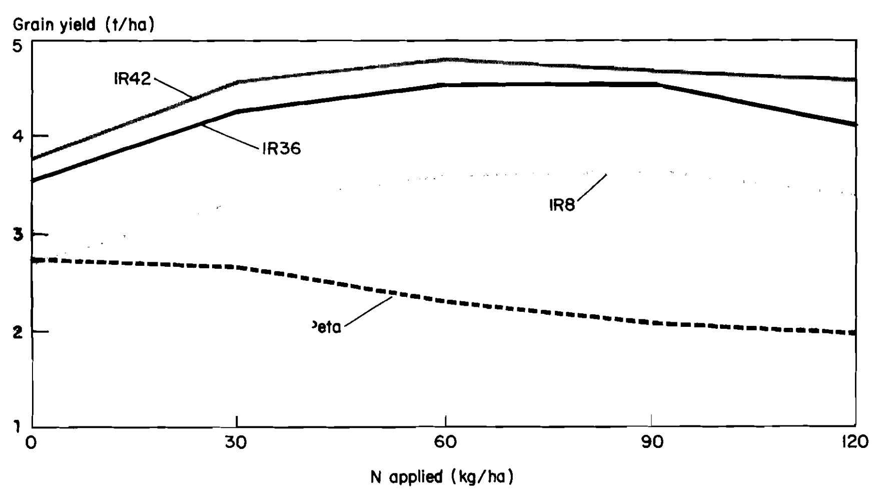
Concerns

While the above represent some of the important benefits from the high yield rice technology developed and introduced jointly by IRRI and national research systems since 1960, we cannot overlook the fact that some serious doubts and concerns have been expressed about the sustainability of this pathway of agricultural advance. IRRI's major goal is to work for improving the productivity, profitability, stability, and sustainability of rice farming systems in all countries where rice is a staple. Therefore, the concerns expressed since the early seventies on the sustainability of the production techniques associated with the Green Revolution need careful consideration. These concerns can be grouped into five major categories: economics, equity, employment, energy, and ecology.

Economics. The cost, risk, and return structure of agriculture greatly influences land and water use planning, varietal choice, and input application levels for small farmers. In most developing countries, effective crop insurance schemes do not exist. If crops are damaged by natural calamities such as typhoons, floods, drought, and pest epidemics, financial institutions and governments may agree to the rescheduling of debts and waiving of interest. They are not in a position to write off the debt. Therefore in disaster-prone areas, farmers will choose not to apply purchased inputs as far as possible. Following the escalation in the cost of fossil fuels in the early 1970s, petroleum-based fertilizers and pesticides became more expensive. While input prices went up, the output prices did not register a commensurate rise. The terms of trade became adverse in many countries; farmers paid more for goods they bought and got less for products they sold.

Although it is true that high yielding rice varieties can express their full yield potential only under conditions of adequate nutrient supply and soil and plant health care, the view that they can perform better than the earlier tall varieties *only* if they are given large quantities of fertilizer is not correct. In fact, the new high yielding strains yield more than the earlier tall rice varieties at all levels of nutrient supply (Fig. 1). The reason for this is their ability to partition more of the dry matter to grain and less to straw and other parts of the plant. In other words, if a tall variety and a semidwarf variety both make 10 tons of dry matter under similar soil fertility conditions, the tall strain may yield only 2 to 3 tons of grain while the other 7-8 tons of dry matter go to the remaining plant parts. On the other hand, semidwarf high yielding varieties may yield 4-5 tons of grain with only 5-6 tons of dry matter going to other plant parts. The other reason why carefully tested and selected high yielding varieties perform better than traditional varieties under many situations is the broad spectrum of resistance to pests, diseases, and soil stresses possessed by the new strains. Therefore, under resource-scarce conditions, what is important is the identification and popularization of varieties that can give maximum yields with the available resources. Before the advent of high yielding varieties, land and water use patterns were largely based on the needs of the farmer's family and the immediate neighborhood. However, when production and productivity increased, farmers had surplus rice for the market. Under such conditions, farmers' decisions on investment in inputs are influenced by the market. Government policies in input and output pricing then become crucial to sustaining the interest of farmers in improved technologies. Farmers' decisions on technology choice and adoption will always be based on the net return per hectare as well as security of that return, not on gross yield per hectare.

Equity issues. Equity issues are those involving the relative benefits derived by small and large farmers, the fate of landless labor, and the impact of new technologies on the income and well-being of women. It is now widely recognized that new technologies by themselves tend to be *scale neutral,* i.e. all



1. Grain yield response of four rices to different levels of nitrogen. Data represent the average for IRRI and three experiment stations of the Philippine Bureau of Plant Industry (Maligaya, Bicol, and Visayas), 1976-84 wet seasons.

farmers, irrespective of the size of their holding, can derive economic benefit from them provided they have access to the needed inputs. However, high yield technologies are not *resource neutral.* In other words, more inputs are required for higher output. A certain degree of resource neutrality can be introduced by substituting nonmonetary inputs for purchased inputs. As mentioned earlier, there is a limit to which such a substitution is possible, particularly when a vertical growth in productivity is the only available method for increasing production. Government policies rather than scientific work will have to provide the tools for enabling all farmers (irrespective of the size of their holding, input purchasing and risk-taking capacity, and social status) to derive economic benefit from new technologies. Similarly, the adverse impact of modern technology on rural women can be avoided through a careful study of the potential consequences of new technologies for women and men before they are widely popularized.

Employment. Developing countries with large rural populations already have serious problems of unemployment and underemployment. Technologies that reduce labor use will have to be accompanied by the creation of alternative avenues of employment. Unless job destruction and job creation are concurrent events, considerable human hardship can result from the adoption of technologies, which substitute capital and machines for human labor. In several countries of Asia, undernutrition or calorie inadequacy is the major nutritional problem. This tends to be more related to inadequate purchasing power than to the lack of an adequate supply of food in the market. Hence, an employment revolution is important for families without assets, in the form of either land or livestock, to derive nutrition benefit from the Green Revolution. New technologies should be subjected to an employment impact analysis before they are recommended for large-scale adoption.

Energy requirements. If the pathway of productivity advance chosen requires increasing consumption of nonrenewable forms of energy, the technology will become self-defeating in the long run, because a finite source of energy cannot be exploited in an exponential manner. The question arises as to how far renewable sources of energy can provide substitutes for fossil fuel-based energy.

Dependence on fossil fuels in rice production has already been reduced through the concurrent development of modern varieties and crop management methods. For example, today's modern varieties are more fertilizer efficient and more resistant to insects and diseases than earlier modern varieties or traditional varieties. Integrated pest and nutrient management have further reduced the energy requirements for growing a rice crop, which are more fully discussed in Chapter 5.

Ecology. Ecological impact of new technology covers areas such as the erosion and loss of plant genetic resources, pollution caused by the use of chemicals and high doses of fertilizers, vulnerability to pests and disease epidemics arising from genetic homogeneity, and destruction of soil fertility and soil erosion.

These issues are recognized and addressed in current IRRI programs. Germplasm collection and preservation has been an integral part of IRRI's program since its inception. Technologies that tend to reduce energy requirements also reduce the potential for insult to the environment. Issues of soil health are addressed through soil and land management research described in Chapters 5 and 6.

LOOKING AHEAD

On the basis of the foregoing analysis of the positive and negative features of the pathway of productivity improvement generally associated with the Green Revolution, it will be useful to consider the steps necessary to maximize its benefits and to avoid potential adverse impact. The previous chapters describe the scientific methods adopted by IRRI and national research systems to achieve a positive balance sheet. These are summarized in Table 1. The question arises, "Where should IRRI go from here? Should we continue on a *more of the same* approach, or do we need an infusion of new ideas, techniques, and strategies in the design of the core research activities in the Philippines and cooperative research programs with national research systems, universities, institutions, and scientists?" The answer is "We need a blend of both."

The research programs of IRRI can be broadly grouped under three categories:

1. *maintenance research* designed to defend the production and productivity gains already made,
2. *downstream research* to solve the immediate field problems through appropriate applied and adaptive research programs, and
3. *upstream research* to harness the latest advances in science and technology to solve downstream problems and to further raise the yield ceiling.

How can IRRI maintain a balance among these three groups of research strategies in its core and cooperative programs to achieve an effective match between the needs of national programs and IRRI's research and training capability? Obviously, the situation regarding the new opportunities opened by scientific progress as well as by the changing needs of national rice development programs is a dynamic one. There has to be a continuous assessment and realignment of priorities and a redeployment of resources. A brief indication of current approaches in maintenance, downstream, and upstream research is given below.

Maintenance research

Maintenance research is exceedingly important, because it is only by defending the gains already made in irrigated and favorable rainfed areas that the immediate requirements for rice can be met. According to FAO, if past trends in demand and production continue, the annual gross import requirement of the developing countries would rise from the 8.3 million tons of paddy required in 1975-76 to 33 million tons in the year 2000. To balance rice supply and demand, the annual rate of production increase should be 2.8 percent for the period 1980 to 2000, compared to the growth rate of 2.4 percent achieved during 1960-80. FAO's calculations on global rice needs by 2000 are

Table 1. Steps taken by IRRI and national programs to balance the positive and negative features of the pathway of productivity increase associated with improved rice production technology.

Concern	Response
Economics	
High cost	Substitution of noncash inputs and improved management
High risk	Maturity adjustment Tolerance of adverse soil factors Pest resistance
Low return	Constraints analysis Input-output pricing Farming systems research
Equity	
More benefits to larger farmers	Scale neutrality and noncash inputs
Increased social tension	Public policy package
Adverse impact on women	Women in Rice Farming Network
Employment	
Labor displacement	Consequences analysis
Famine of jobs	Labor diversification Drudgery reduction Better human energy input-output relation Asian Rice Farming Systems Network
Energy	
Increased dependence on fossil fuels	Biological nitrogen fixation (BNF) Integrated pest management (IPM) Appropriate farm machinery
Ecology	
Gene erosion	International Rice Germplasm Center (IRGC)
Genetic homogeneity	Genetic evaluation and utilization (GEU) and International Rice Testing Program (IRTP)
Pesticide residues	Integrated pest management (IPM)
Soil degradation	International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER) Irrigation water management (IWM) Soil physics

given in Table 2. Total paddy production in the world during 1984 was predicted at 465.7 million tons. The global stocks of milled rice are expected to be 45 million tons by the close of 1984-85. The world import of rice during 1984-85 is expected to be about 12 million tons, the same as that during 1983.

Irrigated and favorable rainfed areas provide more than 80 percent of the world's rice. A priority area of research should be the intensification of the GEU, IRTP, and INSFFER programs, so that the care of the soil and the health of the plant receive the attention they need for sustained productivity. Research on the containment of the damage caused by the triple alliance of pests, pathogens, and weeds will have to be strengthened.

Table 2. FAO projections of global rice demand in 1990 and 2000.

Region	Consumption (million tons)			Annual change (%)	
	1974-76	1990	2000	1980-90	1990-2000
Far East	170.4	265.0	323.0	3.0	2.0
China	121.6	183.8	220.1	3.0	1.8
Latin America	14.0	21.4	28.6	2.8	3.0
Africa	6.4	13.2	20.8	4.1	4.6
Near East	5.5	10.3	15.3	4.1	4.0
Developed countries	24.1	24.5	26.9	0.9	0.8
World	342.0	518.4	634.7	2.1	2.5

As countries become self-reliant in their rice needs, grain quality considerations will gain in importance both in the home market and export trade. Countries such as Thailand, Burma, Pakistan, etc., which export rice, will have to pay greater attention to grain quality preferences of importing countries and to postharvest technology. Therefore, maintenance research will have to be structured to assist in consolidating and expanding the production gains already made in favorable environments.

Upstream and downstream research

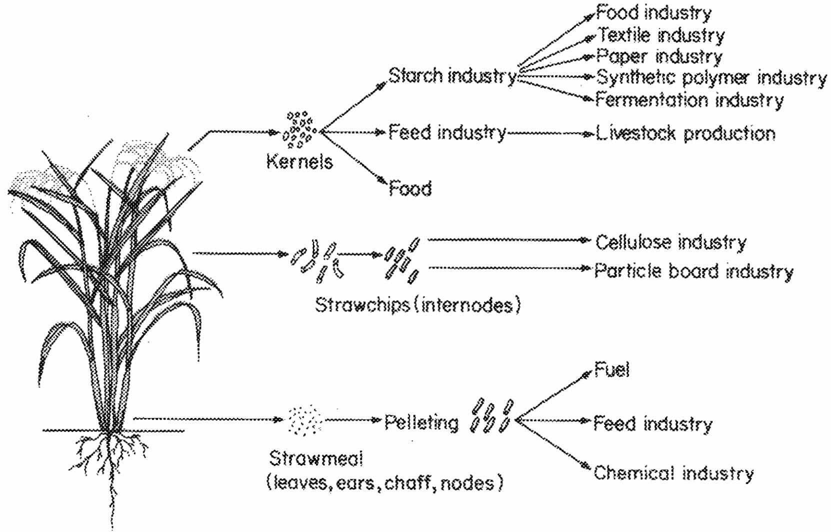
New tools and techniques must be harnessed in the development of varieties with more stable resistance to pests and diseases, improved nutritive quality of grain, and higher yield in drought and flood-prone areas, and in adding a dimension of resource neutrality to scale neutrality in technology development. Similarly, in programs designed to diversify employment opportunities, there is a need to look at the entire rice plant and not at grain alone. In 1983, IRRI and the University of the Philippines at Los Baños initiated a joint demonstration project on the theme *Prosperity through Rice,* with financial support from the Asian Development Bank. This project has three major components:

1. increasing yield at minimum cost both through the substitution of home-grown inputs for purchased inputs and by increasing the efficiency of use of purchased inputs;
2. increasing the income and employment potential of rice farming systems through scientific multiple cropping, mixed farming, and integrated rice and fish culture techniques; and
3. preparing value-added products from the straw, bran, and husk (Fig. 2).

Scientific multiple cropping methods will emphasize the cultivation of crops with nonoverlapping pest sensitivity and the ability to extract nutrients and water from different depths of the soil profile. Also, nutritional and marketing considerations will be introduced in the design of cropping sequence.

Biomass utilization in particular offers an opportunity for creating new jobs in villages. In fact, women, who tend to get displaced from occupations involving drudgery such as weeding and transplanting, can be trained and provided with gainful employment in the postharvest sector. Jobs lost in the production phase of rice cultivation will have to be compensated for by the

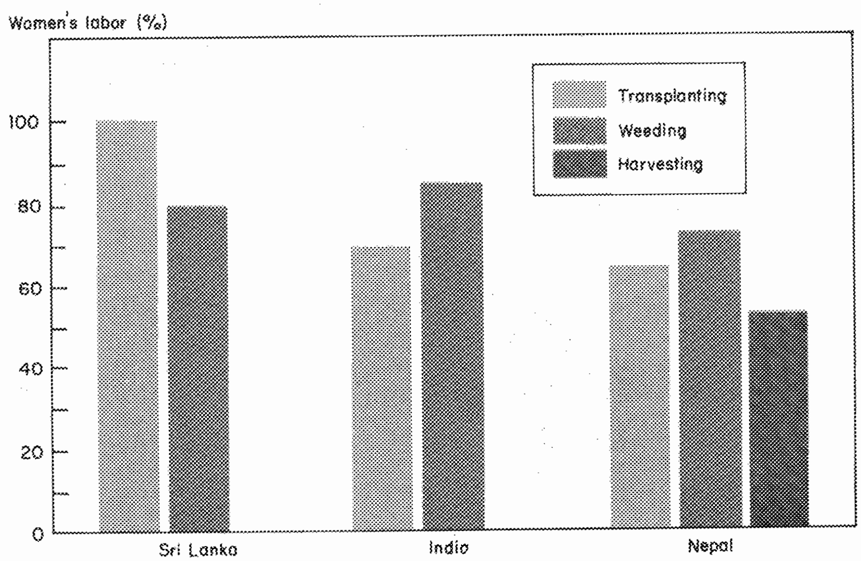
2. Potential utilization of rice by-products leading to increased income and employment potential in agriculture.



creation of new jobs in the postharvest phase. This problem deserves attention as women provide more than half of the labor inputs in rice farming (Fig. 3).

Progress in molecular biology and genetic engineering has been spectacular in recent years. This again is an area where IRRI will have to take serious interest if it is to continue to be relevant to the needs of national research systems. Already IRRI is working on the application of tissue culture and anther culture techniques. It is now necessary to develop, through collaboration with advanced institutions, a whole series of new approaches to pest and

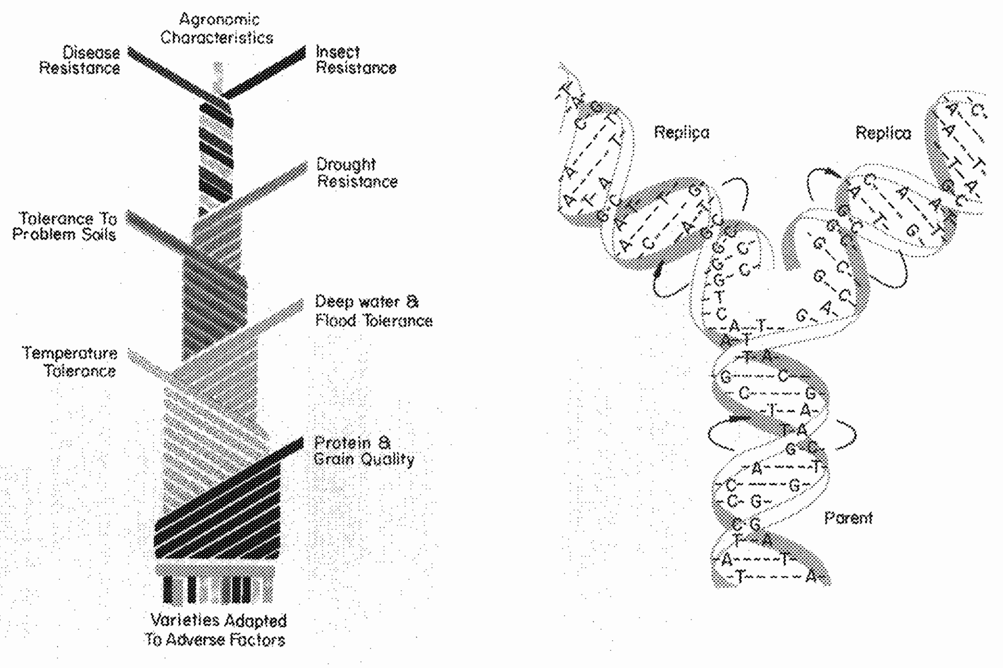
3. Contribution of women to transplanting, weeding, and harvesting on Asian rice farms.



disease control and to yield increase and improvement of quality. IRRI, through both core and cooperative research, will integrate the GEU work with the new opportunities now available for gene transfer across sexual barriers through the techniques of molecular genetics (Fig.4).

The modifications in varietal traits needed for further increase in rice yield include

1. Increasing biomass production
   a. Fast leaf area development
   b. Low maintenance respiration
   c. Low photorespiration
2. Increasing crop sink size
   a. Large spikelet number per shoot
   b. Large grain size
   c. Greater partitioning of assimilates into spikelet formation
   d. Increase in harvest index (up to 0.6)
3. Assuring better grain filling
   a. Slow senescence
   b. Maintenance of healthy root system
4. Increasing lodging resistance
   a. Stiff culm
   b. Slow senescence
   c. Maintenance of healthy root system

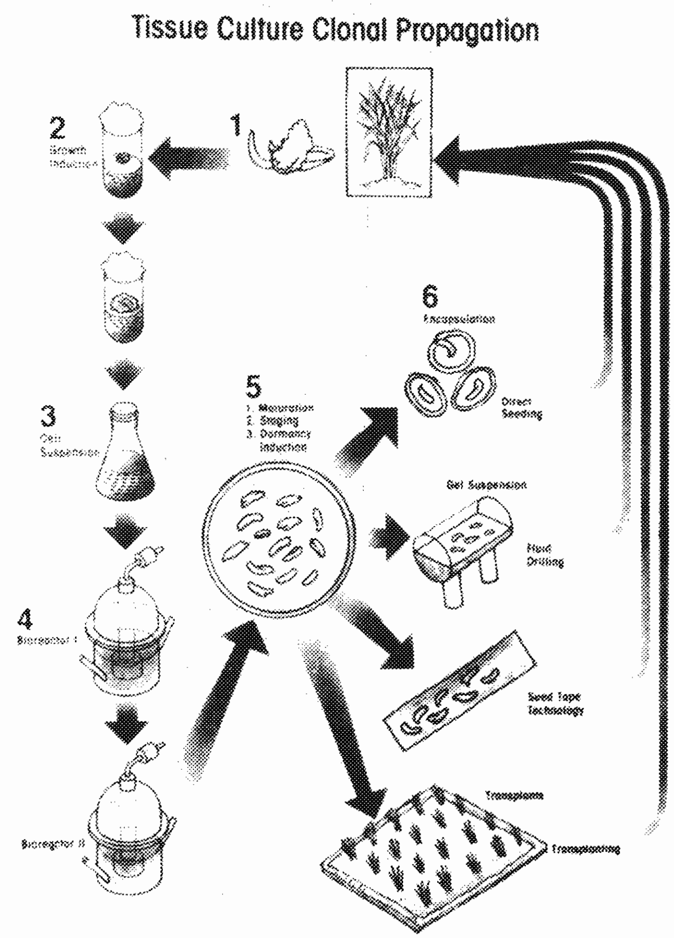


4. The integration of GEU and biotechnology will produce rice varieties with required agronomic characteristics.

The identification of the precise factors involved in the loss of fertilizer nitrogen through radiotracer and micrometeorological techniques is another example of an upstream approach helping to solve a downstream problem. Two other examples can be cited.

As mentioned in Chapter 4, hybrid rice is already grown widely in China. A major impediment to the commercial cultivation of hybrid rice is the high cost of F_1 seed. Recent research on the induction of somatic embryogenesis in some rice varieties may pave the way toward the standardization of economic and rapid methods of hybrid seed production. If synchronized somatic embryos could be mass produced through tissue culture techniques, planting material that retains the heterosis of F_1 hybrids can be made available to farmers in sufficient quantities at a reasonable price (Fig.5).

5. Tissue culture offers the opportunity to develop hybrids with heterosis in the F_1 population.



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Another example of a downstream problem being studied with the help of an upstream technique is the development of blast-resistant high yielding varieties for rainfed upland areas. For example, the variety Denorado from the southern Philippines has enduring blast resistance and excellent grain quality. It is, however, low yielding because of a plant type which is not conducive to its being cultivated with good soil fertility. Somaclonal and gametoclonal variation induced in tissue culture may help in selecting better plant types of Denorado without affecting its ability to tolerate blast.

In addition to such approaches, attention will also have to be given to research on gene transfer across sexual barriers through protoplast culture, somatic hybridization, and genetic engineering; the production of monoclonal antibodies specific for viruses and bacteria; DNA cloning; and the construction of a genomic library. Such basic areas of biotechnology research will need collaborative efforts between appropriate advanced institutions and IRRI.

In other words, mission-oriented basic research and strategic research, often referred to as upstream research, will have to be fostered to solve downstream problems. IRRI's ability to fulfill its mission of extending the frontiers of high yield technology to ecologically handicapped areas and to economically poor farmers depends on the intelligent integration of upstream and downstream research.

COOPERATIVE RESEARCH

IRRI's work during the past 25 years is an outstanding example of the power of purposeful cooperation. In the preceding pages, it has been repeatedly emphasized that much of the work of IRRI is indeed joint work with colleagues in national research systems, universities, and nongovernmental organizations. Because the major accomplishments are the products of multidisciplinary and interinstitutional cooperation that transcend political and geographic frontiers, the methods adopted for promoting symbiotic links among scientists and institutions working with rice are summarized in Table 3 and are briefly described below.

Global research services

The International Rice Germplasm Center (IRGC), which is helping to conserve a representative sample of naturally occurring genetic variability in rice, is a good example of team effort in conquering the threats of genetic erosion and wipe-out. Another example is the germplasm collection of azolla and blue-green algae. The importance of these collections for rice research and development in the 21st century and beyond cannot be overemphasized.

International networks

IRRI coordinates three major networks: the International Rice Testing Program (IRTP), the International Network on Soil Fertility and Fertilizer Evaluation for Rice (INSFFER), and the Asian Rice Farming Systems Network (ARFSN). The activities and impact of these networks have been

Table 3. Pathways of cooperation between IRRI and other scientists and institutions.

Pathway	Examples
Research services	IRGC, azolla germplasm
Networks	IRTP, INSFFER, ARFSN
Country programs	Resident scientists Scientist-scientist
Cooperative research	Hot spot screening Shuttle breeding Farm machinery
Collaboration with advanced institutions	Organizations (USAID, IRAT, GTZ, ODA of U.K., etc) Universities and institutions International centers (IITA, WARDA, ICIPE, etc.) Individual scientists
Training and technology transfer	Los Baños In-country Joint
Knowledge sharing	Seminars, monitoring tours Bibliographic services Publications

described earlier. They provide an excellent framework for cooperation among rice scientists and research institutions in all parts of the world.

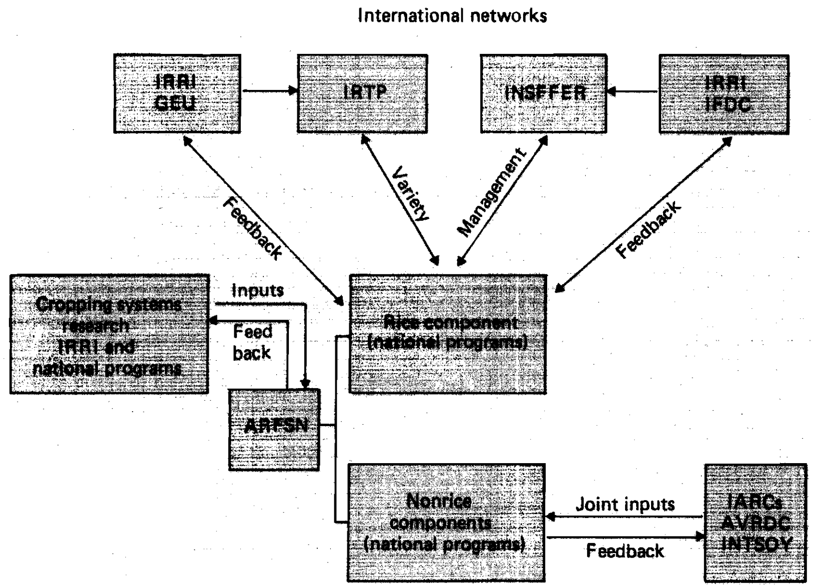
These networks will be improved not only in their coverage of less favorable and adverse growing environments but in their technical components. For example, an *ufra* nematode screening nursery will be started soon under IRTP. INSFFER will increasingly cooperate both in soil health monitoring and in promoting integrated nutrient supply systems involving organic and biological sources of fertilizer in addition to mineral fertilizers. In the farming systems network, nutritional considerations, integrated pest management procedures, sex-related issues, and assessment of marketing opportunities will be integrated.

Also the three networks will be functionally linked so that a purposeful feedback relation as shown in Figure 6 is developed. These networks serve as focal points for bringing together relevant data, material, and techniques from wherever they are available — from other international agricultural centers, universities, and institutions in both developing and developed countries, national research institutions, and individual scientists. Thus, they serve as global pools of the best available material and knowledge on rice. They help all research systems to benefit from each other's work and thereby often help purchase time in efforts to increase and stabilize rice production.

Collaboration with national research systems

Collaborative programs with national research systems have to be tailored to specific requirements so that the complementary strengths of national research systems and IRRI can be fused meaningfully. To illustrate the need for a multiple choice approach in research and development strategies,

6. Functional linkage of IRTP, INSFFER, and ARFSN networks to achieve feedback.



countries with more than 100,000 hectares under rice have been broadly grouped under 4 categories, based on their current average national rice yield in relation to the potential average yield of 6 tons per hectare, which is considered feasible using the best available technologies under favorable environments (Table 4). In the case of Group I countries, what will be of great interest is research designed to raise the yield ceiling itself. In the case of Group II countries, there is need for concurrent efforts to increase maximum yields by removing the constraints to achieving the ceiling possible with the already available technologies.

Group III countries may require more research to increase yield under unfavorable ecological and economic policy environments. There could be many reasons why they are not able to increase the average yield to about 6 tons per hectare. Large areas may be rainfed. There could be soil constraints, both deficiencies and toxicities. There could be serious pest and disease problems. Inadequacies in input delivery systems and capital availability for the modernization of agriculture could also play an important role.

Finally, there are the Group IV countries that have at present rather low national average yields. Here again the reasons may vary. The entire area in some countries may fall under the category of rainfed upland. A careful study will have to be made of research areas that need attention based upon the identification of potential impact points.

In large countries such as India, there may be areas such as the northwestern region where Group I or II conditions prevail. There may be other areas belonging to the Group III or the Group IV category. The greatest need in such countries will be location-specific research coupled with

Table 4. Classification of rice-growing countries according to the gap between their average and potential 6 tons per hectare rice yield.

	Group I (yield gap almost 0%)	
Australia	Egypt	Italy
Japan	Korea	USA
	Group II (yield gap < 25%)	
China	Colombia	Iran
Peru		
	Group III (yield gap > 50%)	
Afghanistan	Bangladesh	Burma
Cuba	Dominican Republic	Ecuador
India	Indonesia	Malaysia
Mexico	Nigeria	Pakistan
Philippines	Sri Lanka	Thailand
USSR	Venezuela	Vietnam
	Group IV (yield gap > 75%)	
Brazil	Guinea	Ivory Coast
Kampuchea	Laos	Liberia
Madagascar	Mali	Nepal
Sierra Leone	Tanzania	Zaire

appropriate public policy measures. In countries that export rice, grain quality considerations and better postharvest technology are extremely important.

For IRRI's research to be meaningful to such wide diversity of national needs, it will have to be based upon achieving a proper match between development goals and research strategies. For example, in irrigated and favorable and rainfed lowland areas, research on increasing the yield ceiling further by techniques such as the commercial use of hybrid vigor will have to be intensified. At the same time, work on multiple resistance or tolerance to pests and adverse soil factors will have to be carried out using the GEU approach.

There are several approaches to collaboration with countries:

- IRRI resident scientists working with national research systems,
- annual work plan meetings between scientists of the national research system and IRRI, and
- scientist-to-scientist collaboration.

All of these methods will have to be used to their full potential.

Cooperative research

In addition to the work undertaken under the networks and through collaborative research, we should take advantage of the wide variability in growing and socioeconomic environments in rice improvement work in different countries. Examples of such cooperative research include

- testing segregating material at suitable hot spot locations with regard to pest incidence and adverse soil factors,
- shuttle breeding to get more rigorous screening for pest resistance and adaptation to adverse environments, and
- developing farm machinery to increase productivity and efficiency, and to promote opportunities for labor diversification.

Collaboration with advanced institutions

Science and technology, particularly in fields such as microelectronics, computer science, genetic engineering, biomass utilization, satellite imagery, and informatics, are making explosive progress. It will be neither necessary nor possible for IRRI to initiate research in every frontier of science. What IRRI can do is to help in marrying problems to techniques. For this purpose, IRRI develops collaborative research programs with advanced institutions and universities as well as with individual scientists in both developed and developing countries. In this way, IRRI can tap the expertise and equipment available in such institutions for solving complex problems encountered in rice farming. Such cooperative research is already under way with several institutions all over the world, but there is immense scope for a planned expansion of such purposeful collaboration. In particular, research on the effective utilization of the total rice plant and rice ecosystem to increase income and employment can be carried out with speed and efficiency only by tapping the time and talent of advanced laboratories.

Training and technology transfer

Human resource development is the key to converting the resource endowments of each country into wealth meaningful to its people. The highest priority, then, should continue to be given to knowledge and skill transfer through both nondegree and degree training programs. In the future there will have to be increasing emphasis on organizing joint training programs within countries and between agricultural universities of different countries and IRRI. A great impediment in knowledge and skill transfer is communication. Although IRRI uses English in its research and training programs, an increasing number of scholars in different countries lack the necessary grasp of this language to master the subject. Therefore IRRI will have to continue to explore and intensify methods of introducing an element of language neutrality in information dissemination. The major approaches are

- learning by doing,
- multilanguage copublication,
- autotutorial modules with the explanation in different languages,
- computer-aided instruction, and
- in-country training programs in which the local language is the medium of instruction.

IRRI will also have to identify gaps in existing training efforts. For example, in most countries of South and Southeast Asia, land holdings are small (usually less than one hectare) and are getting smaller as population increases. Hence the organizational aspects of technology transfer need attention. Obviously, most of the cited techniques are beyond the technical and financial means of individual small farmers. The package of technologies listed earlier can be divided into three major groups on the basis of their feasibility of adoption on individually owned small farms:

1. Some aspects of technology such as choice of variety, time of planting, and several cultural practices, exclusive of purchased inputs, are under the control of the individual farm family.

2. Several other aspects of the technological package will need government support and action for their spread. For example, the timely supply of inputs, input-output pricing policies that determine the cost and return structure of farm operations, land ownership and tenancy policies, etc. depend upon what governments do or do not do.
3. Technologies such as scientific water management, integrated nutrient supply, and improved biomass utilization need, for profitable and effective adoption, coordinated action by a group of farm families living in a watershed or village. To generate the necessary cooperation among such farm families, they must be taught to recognize the economic benefits of group endeavor.

For prosperity through rice to become a reality, we need a combination of individual initiative, government support, and group action. Current extension efforts by and large tend to concentrate on only one aspect of the triad of such interactions — the initiative of the individual farm family. We need demonstration and training programs to convince farmers with small holdings of the economic advantages of group activity. Economic incentive by way of reduction of production cost as well as of risk, and increase in net returns have to be the major motivating factors for cooperative action among farmers in the village. Also, appropriate government policies in the form of group insurance and group incentive schemes will help. Therefore the social engineering and public policy aspects of technology transfer and diffusion require as much attention as the bioengineering and chemical engineering aspects.

Breathing spell

Population growth is continuing at more than 2% annually in many developing rice growing countries. To feed this growing population, the growth rate in rice production needs further acceleration. Time is a precious factor in programs designed to accelerate the pace of agricultural progress. This is where IRRI can play a pivotal role in the development and dissemination of material and techniques through research and testing networks, training programs, seminars, monitoring tours, bibliographic services, and multilanguage copublication. By serving as a bridge in a two-way flow of knowledge and appropriate technologies among nations and institutions, IRRI hopes to serve diverse needs and respond to diverse challenges.

BEYOND THE GREEN REVOLUTION IN RICE

A review of the progress made in rice research and development during the past 25 years indicates that several countries in South and Southeast Asia have increased their annual rice production by a factor greater than that achieved during the preceding 5,000 years. For example, from 1960 to 1984, Indonesia's annual rice production tripled from 8 million tons to 25 million tons. While such remarkable accomplishments make us proud and confident, the path ahead is not an easy one. Stability and sustainability of production demand greater attention. Replenishing soil fertility and avoiding genetic vulnerability to pests arising from genetic homogeneity in cultivated varieties need urgent action.

Eternal vigilance is the price of stable and successful agriculture. In such a scenario, IRRI's major and most meaningful contribution will continue to be the conservation of genetic variability in rice and its conversion into a wide range of valuable breeding material for selection and further breeding in different rice growing countries. The individual strengths of national research systems may vary, but their collective strength is considerable. On the occasion of its 25th anniversary, IRRI rededicates itself to the cause of nurturing and harnessing this collective strength for the welfare of rice farmers and consumers everywhere.